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Correlation structure of daily rainfall over Teesta catchment

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सार – कई वैज्ञानिक अध्ययनों में मौसम की विभिन्न स्थितियों में दैनिक वर्षा के स्थानिक वितरण का पता लगाने के लिए पुनः आकलित किए गए आंकड़ों का व्यापक रूप से उपयोग किया गया है। इस शोध पत्र में तीस्ता जलग्रहण क्षेत्र में मानसून के महीनों के दौरान दैनिक वर्षा की भिन्नताओं का पता लगाने के लिए व्यति सहसंबंध विश्लेषण किए गए हैं। इस अध्ययन के लिए 1995–2000 की अवधि के दस स्टेशनों के दैनिक वर्षा के आंकड़ों का उपयोग किया गया है। सम्पूर्णतः मानसून के चार महीनों के लिए किए गए अनुमानित व्यति सहसंबंध क्षेत्र के विश्लेषण से यह पता चला है कि मानूसन के महीनों के दौरान उत्तर–दक्षिण, उत्तर उत्तरपूर्वी – दक्षिण दक्षिणपश्चिमी क्षेत्र में 60–80 कि. मी. तक और शेष दिशाओं में 50 कि.मी. तक वर्षा हुई। दैनिक वर्षा के पैटर्न को दो दीर्घवृत्तों के परिच्छेदों में बेहतर रूप से बताया जा सकता है :– एक उत्तर उत्तरपूर्वी दक्षिण दक्षिणपश्चिमी क्षेत्र (75° उ. – 80° उ. /115° द. – 100° द.) की दिशा में प्रमुख अक्ष सहित और दूसरा उत्तर उत्तरपश्चिमी – दक्षिण दक्षिणपूर्वी (110° उ. – 120° उ / 70° द. – 60° द.) दिशा में प्रमुख अक्ष सहित इन्हें अधिकांश उच्चभूमियों की दिशाओं में घूमते हुए देखा जा सकता है। यह भी देखा गया है कि सहसंबंध गुणांकों के स्थानिक वितरण के दीर्घवृत्तीय पैटर्नों के प्रमुख अक्षों की दिशा को छोड़कर सभी दिशाओं में दूरी सहित अनुमानित सहसंबंध गुणांकों में कमी आई है और ये 50 कि.मी. के पार लुप्त हो गए। यह भी देखा गया है कि जलग्रहण क्षेत्र के पहाड़ी इलाकों में इसके दक्षिण दक्षिणपश्चिम की ओर उच्चभूमियों के कारण उत्तर उत्तरपूर्वी दिशा (65° उ.) में जल पहुँचानें अवरोध आ जाता है।

ABSTRACT. In many scientific studies, the r-estimates were widely used to know the spatial distribution of daily rainfall in various weather situations. In this present paper, the cross - correlation analysis has been performed to understand the variability of daily rainfall during monsoon months over Teesta catchment. For the purpose of study, ten station's daily rainfall data for the period 1995-2000 has been utilized. The analysis of estimated cross-correlation field entirely for four months of monsoon suggested that the rainfall area during the monsoon months extends up to 60-80 km distance in north-south, northnortheast-southsouthwest and 50 km in the remaining directions. The pattern of daily rainfall can best be represented as intersection of two ellipses, one with major axis in the direction of northnortheast-southsouthwest (75° N-80° N/115° S-100° S) and another with major axis in northnorthwest-southsoutheast (110° N-120° N/70° S-60° S) direction and are seen traversing in the directions of major uplands. It is also found that the estimated correlation coefficients decreased with distance in all the directions other than in the directions major axes of elliptical patterns of spatial distribution of correlation coefficients and became insignificant beyond 50 km. It is also seen that in hilly regions of the catchment, the moisture feed is blocked further in northnortheast direction (65° N) due to presence of uplands southsouthwest of it.

Key words –Cross correlation, Catchment, Major axis.

1. Introduction

The river Teesta, meaning Maiden, is often considered as a distorted form of Nepali word Tristora which means 'Three currents'. Till Yumthang, in the state of Sikkim, the river is a small stream often covered with snow and ice during the winter months. The origin of the river is a result of three river streams from Himalayan Glaciers joining at Chungthang, in the state of Sikkim. The river Teesta flows approximately 400 km from its origin to join the Great river Brahmaputra at Fulchery Ghat before finally falling into Bay of Bengal. The approximate length of the Teesta river up to Indo-Bangla Border is 250 km and of this approximately 140 km lies in the hilly terrain with remaining 110 km in the plains. The river Teesta catchment extends from Indo-China Border to Indo-Bangla Border with a total catchment area of 12,500 sq.km of which 9350 sq.km lies in the hilly region which is 75 percent of the total catchment area. The river Teesta Catchment has been divided into three parts (*i*) Upper Catchment above Yoksum (*ii*) Middle Catchment upto Teesta Bridge below Yoksum (*iii*) the Lower Catchment upto Indo-Bangla Border from Teesta Bridge. The Upper catchment is an upland which lies approximately between 4000-8000 m above sea level, the Middle Catchment lies approximately between 1000 - 4000 m above sea level and the Lower Catchment lies approximately between 10-1000 m above sea level.

It is seen that, over Teesta Catchment the monsoon normally sets in the first week of June and maintains itself till withdrawal in the second week of October with July month being the wettest month, followed by August and June during four months of monsoon. The river catchment of Teesta generally gets heavy rainfall whenever the monsoon trough shifts close to the foot hills of Himalayas from its normal position with maximum rainfall occurring to the south of the axis of monsoon trough. Moreover, the synoptic scale transient systems moving in northwesterly direction after originating in north Bay of Bengal on interaction with uplands of Catchment produce copious amounts of rainfall through enhanced convective activity. Studies also indicated the upper air cyclonic circulations over the catchment or to the west of the catchment also give good amounts of rainfall. The mountain barrier extends in the basin from northwest to northeast directions and is open for southerly and southeasterly or Southwesterly moisture currents to flow into the basin.

2. Data

To study, variability of daily rainfall over Teesta Catchment ten stations namely, Champasari, Chungthang, Damthang, Domohani, Gangtok, Jalpaiguri, Khanitar, Neora, Sevoke, Singla Bazar were selected and six years continuous daily rainfall data for the period 1995-2000 has been collected from the records of Flood Meteorological Office, India Meteorological Department, Jalpaiguri and Meteorological Office, Gangtok. In this study, the rainguage network density is only one rainguage per 1250 sq.km and is not equal to the optimum rainguage network suggested for hilly regions (WMO, 1965). For operational purpose, the no. of stations should be kept minimum required to give acceptable estimate of average areal precipitation over the catchment which is numerically equal to arithmetic mean of 'N' values from 'N' stations situated within the catchment. However, determining the optimum density of rainguage network is a difficult problem in applied hydrology. In this connection, it is worth to mention that the purpose of study is to investigate variability of rainfall based on spatial correlation of daily rainfall totals. The estimates so obtained by way of cross-correlations can be utilized to obtain average areal precipitation, probable maximum precipitations at each of the stations and to obtain rainfall gradients to know the distribution of rainfall over various elevation zones. Here, in this paper, the cross correlation pattern is investigated for two different cases in the frame work of topographical features and overall relationship between correlation coefficient and distances are investigated. Hence, for the purpose of analysis limited numbers of rainguages which are sufficiently apart are only considered. For the purpose of analysis, a total of 732 data points, for entire June to September period, of each of the stations selected are considered. Again, to study the correlation structure of daily rainfall over Teesta Catchment for heavy rainfall situations, in total, 72 occasions on which the observed average areal precipitation greater than or equal to 15 mm were selected and daily rainfall of each of the stations (72 data points) corresponding to above occasions were correlated. The geographical locations of the selected stations are given in Table 1 and are depicted along with Teesta Catchment boundary in Fig 1. Of the stations selected, Damthang is at a higher altitude of 1981 m, followed by Gangtok 1756 m and Chungthang 1631 m. The station Jalpaiguri is at a lowest altitude of 80.2 m.

TABLE 1

Showing geographical locations of selected stations

S. No.	Name of station	Lat./Long.	State	Altitude (amsl)
1.	Damthang	27°14'/88°28'	Sikkim	1981 m
2.	Gangtok	27°19'/88°37'	Sikkim	1756 m
3.	Chungthang	27°36'/88°39'	Sikkim	1631 m
4.	Singla Bazar	27°07'/88°14'	W.Bengal	320 m
5.	Khanitar	27°11'/88°30'	Sikkim	302 m
6.	Neora	26°52'/88°46'	W.Bengal	164 m
7.	Sevoke	26°50'/88°28'	W.Bengal	152 m
8.	Champasari	26°43'/88°25'	W.Bengal	123 m
9.	Domohani	26°33'/88°45'	W.Bengal	84.5 m
10.	Jalpaiguri	26°32'/88°43'	W.Bengal	80.2 m

3. Methodology

The composite (Cross) correlation technique employed by Sharon (1979) is used in this study which involves estimation of correlation coefficients of one of the key stations with the remaining stations and a total of $n(n-1)$ cross correlations estimated on presumption that

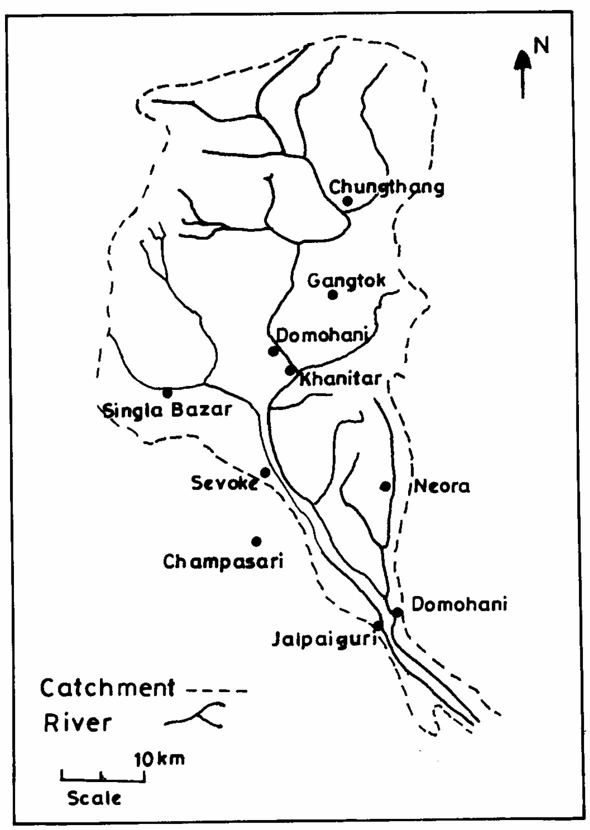

Fig. 1. Basin map of Teesta

each of the *n* stations acts as a key station to the other neighbouring stations. Thus, only distance and direction of other neighbouring stations from the key station are preserved for each correlation coefficient independent of the identity of the particular station. The maps prepared and on which iso correlation lines were drawn for the purpose of analysis, thus have n (n–1) correlation coefficients each at appropriate direction and distance from key station with the location of key stations identically at the centre of the map. Each estimate is included twice in the map at diametrically opposite points in relation to the centre of the map. This method eliminates draw backs present in the methods adopted by Huff and Shipp (1969) in which iso-correlation lines were drawn around key stations taking only neighbouring *n* stations without the knowledge of inter dependence of among *n* stations. The final maps prepared are representative of general spatial distribution of daily rainfall over the catchment area chosen. Olaniran (1988) used the technique employed by Sharon(1979) to study daily rainfall variability in southwestern Nigeria and showed from the spatial distribution of correlation coefficients that it resembles elliptical pattern with major axis in the direction of major upland and also found the

TABLE 2

Showing mean daily rainfall (mm) and standard deviation, coefficient of variation of selected stations during southwest monsoon season (June-September, Period 1995-2000)

Name of the station	Mean	Std	CV%
Damthang	17.9	20.1	112
Gangtok	21.0	22.1	105
Chungthang	11.8	11.3	96
Singla Bazar	11.3	18.1	160
Khanitar	10.7	16.7	156
Neora	25.6	42.1	164
Sevoke	28.2	40.8	145
Champasari	27.0	41.4	153
Domohani	21.9	40.2	183
Jalpaiguri	24.8	41.9	170

spacing between rainfall areas is 50 km in case of monsoon month of August. The main purpose of this study is to identify the extent of rainfall areas and the distances between them during the southwest monsoon season which is a synoptic scale weather situation. In this paper, the rainfall area is defined as the area receiving daily rainfall ≥2.4mm. The ten stations were chosen as to cover the entire basin and are evenly distributed within the basin. One pair of stations close to one another (approx.10 km) in hilly region and second pair of stations close to one another (approx.10 km) were selected to see the variability of rainfall between them at the same time.

4. Results and discussion

The mean daily rainfall and corresponding standard deviations are calculated for all the stations considered are presented in Table 2. The Table.2 show high mean daily rainfall in respect of stations with less altitude than the stations at higher altitude. The figures of coefficient of variation are also high for low altitude stations than high altitude stations. The percentage coefficient of variation lies between 145 to 183 for low altitude stations within the catchment and 96 to 112 for high altitude stations within the catchment. From the figures of Table 2 in can be concluded that the temporal variability of the rainfall is small in respect of hilly regions, in comparison, with the regions in plains. The correlations between ten stations chosen, were estimated using the standard formula for the correlation coefficient. The significance of the estimated correlation was tested for probability point 0.02 of Gaussian distribution. The significant correlation is found

TABLE 3

Showing cross correlation coefficients between selected stations for southwest monsoon season (Period 1995-2000) when one of the stations reporting rainy day (≥2.4mm)

	Chungthang	Damthang	Khanitar	Singla Bazar	Neora	Champasari	Domohani	Jalpaiguri	Sevoke	Gangtok
Chungthang	1.00	0.00	0.06	- 0.01	0.01	0.01	-0.01	0.00	0.07	-0.01
Damthang	0.00	1.00	0.32	0.34	0.12	0.24	0.08	0.04	0.23	0.31
Khanitar	0.06	0.32	1.00	0.26	0.06	0.10	0.00	-0.01	0.14	0.14
Singla Bazar	-0.01	0.34	0.26	1.00	0.07	0.07	0.04	0.03	0.19	0.17
Neora	0.01	0.12	0.06	0.07	1.00	0.40	0.36	0.33	0.44	0.17
Champasari	0.01	0.24	0.10	0.07	0.40	1.00	0.38	0.36	0.53	0.10
Domohani	-0.01	0.08	0.00	0.04	0.36	0.38	1.00	0.84	0.27	-0.02
Jalpaiguri	0.00	0.04	-0.01	0.03	0.33	0.36	0.84	1.00	0.25	-0.03
Sevoke	0.07	0.23	0.14	0.19	0.44	0.53	0.27	0.25	1.00	0.20
Gangtok	-0.01	0.31	0.14	0.17	0.17	0.10	-0.02	-0.03	0.20	1.00

TABLE 4

Showing cross correlation coefficients between selected stations for the southwest monsoon season when average areal precipitation ≥15 mm (Period 1995-2000)

	Chungthang	Damthang	Khanitar	Singla Bazar	Neora	Champasari	Domohani	Jalpaiguri	Sevoke	Gangtok
Chungthang	1.00	–0.04	–0.03	–0.04	–0.03	–0.13	–0.09	–0.11	–0.03	–0.01
Damthang	–0.04	1.00	0.52	0.16	0.15	0.20	0.06	0.14	0.13	0.31
Khanitar	–0.03	0.52	1.00	0.25	0.14	0.02	0.17	0.13	–0.02	0.25
Singla Bazar	–0.04	0.16	0.25	1.00	0.14	0.08	0.08	0.04	0.00	0.01
Neora	–0.03	0.15	0.14	0.14	1.00	0.37	0.13	0.10	0.62	0.11
Champasari	–0.13	0.20	0.02	0.08	1.37	1.00	0.69	0.62	0.46	–0.03
Domohani	0.09	0.06	0.17	0.08	0.13	0.69	1.00	0.89	0.08	–0.11
Jalpaiguri	–0.11	0.14	0.13	0.04	0.10	0.62	0.89	1.00	0.16	–0.11
Sevoke	–0.03	0.13	–0.02	0.00	0.62	0.46	0.08	0.16	1.00	0.18
Gangtok	–0.01	0.31	0.25	0.01	0.11	0.03	–0.11	–0.11	0.18	1.00

to be 0.07. The estimated cross correlation coefficients are presented in Table 3 when at least one of the stations reported ≥2.4 mm rainfall. The estimated cross correlation coefficients are presented in Table 4 when the observed average areal precipitation obtained by isohyetal method using 25 rainguage stations situated in and around the Teesta Catchment was greater than or equal to 15 mm. The stations selected all lie within a distance of 130 km. That means, the estimated correlations give the pattern of rainfall within 130 km and not more than 130 km. It is seen that significant correlation coefficients found between stations separated by 60-80 km during southwest monsoon. It can be said that the rain yielding cloud or rainfall area in southwest monsoon, generally, extends up to a distance a 60-80 km. The estimated cross-correlation coefficients can be utilized for generating missing daily rainfall at these stations based on empirical linear regression equations of the form $S_1 - Sm_1 = r\, S_{d1}/S_{d2}\ (S_2 - S_{m2})$ where S_{d1},S_{d2} are the standard deviations, S_{m1},S_{m2} are the mean daily rainfalls. It is based on the presumption that the distribution is Gaussian. The pattern of cross correlation coefficients is mapped in Fig. 2 estimated when one of the stations reported rainfall greater than or equal to 2.4 mm. It is seen from the map that the pattern resembles two intersecting ellipses with their major axes oriented in the directions southsouthwest-northnortheast and northnorthwest-southsoutheast when the field of significant correlation line (0.07) is considered. Numerically high significant cross-correlations are also found in the directions of

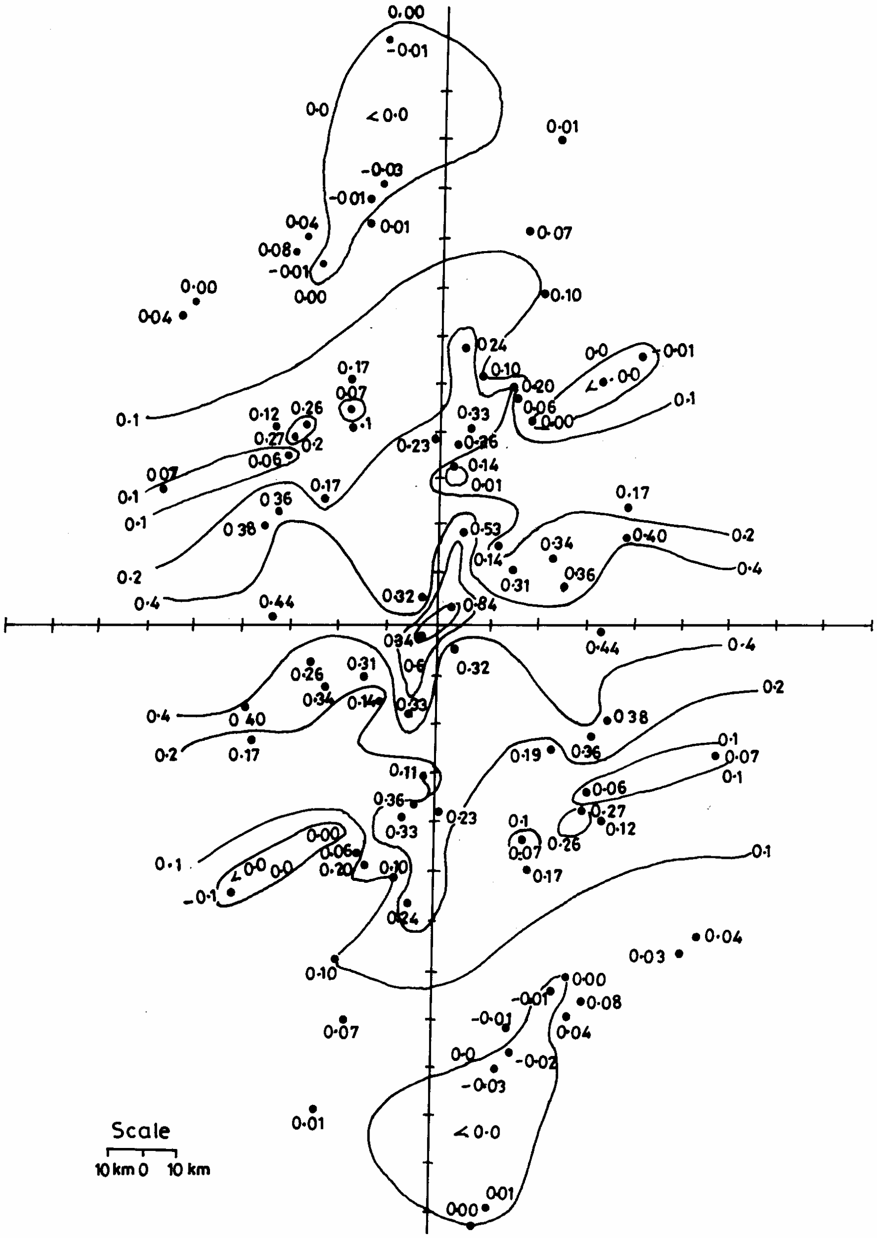

Fig. 2. Spatial distribution of correlation coefficient estimated from daily rainfall data of southwest monsoon (June-September) when one of the station reporting rainfall ≥2.4 mm

north-south, northeast-southwest, northwest-southeast directions up to 50-60 km. It is also found that significant correlation 0.84 found within a radius of 10 km from the particular station in the plain areas. However, it decreased 0.32 in the hilly terrain within the same distance of 10 km.

5. Conclusions

For the southwest monsoon season, as suggested by the cross-correlation analysis, the rainfall area extends to 60-80 km distance with highly significant correlation between stations within 10 km in plain areas with significant correlation showing less value within 10 km in hilly areas. The decrease in the correlation coefficient may be attributed to the presence of ridge line between them. The observed pattern of correlation coefficients is of two intersecting ellipses with their major axes traversing in the directions of major uplands of catchment. The uplands present in the middle and upper catchments block moisture feed further in northnortheast direction. The convective activity is enhanced in the south of the uplands giving good amounts of rainfall at least up to 50 km distance. High mean daily rainfall and high variability in daily rainfall are observed in the stations situated in plains rather than at stations in upland areas. The observed pattern of correlation coefficients is a result of movement of the storms over the catchment. There is a sufficient evidence to conclude (Huff and Shipp, 1969) that the storm tracks are primarily responsible for observed patterns of the spatial correlation. The quasi-linear relationship observed in case of correlation coefficients and distance is an indication of the homogeneity of the cloud. However, it is mentioned that the estimate of average areal precipitation based on the above ten stations is truly representative of area-wide rainfall or not need some supporting documentation based on research. Hence, the estimates may not be considered as strict analytical solution but as an approximate method of calculation based on empirical relations and particular magnitude of error always persists. Substantiating the extent of rainfall area obtained in this paper with satellite imageries is beyond the scope of this paper.

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