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Rainfall over lakes around Bombay

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सार — इस शोधपत्र में झीलों पर वर्षा की जलवायु विज्ञान के विकास के लिए बम्बई के इर्दगिर्द की झीलों पर वर्षा के विभिन्न अभिलक्षणों का अध्ययन करने का प्रयास किया गया है। इस अध्ययन के लिए दक्षिणपश्चिम में मानसन की अवधि के लिए चार झीलों याने तंसा, तुलसी, पवाई एवं विहार झीलों के पचास वर्षों के आंकड़े और वैतरण के 1956 से 22 वर्ष के आंकड़े लिए गए हैं। फिर उनकी कोलाबा में प्राप्त आंकड़ों से तुलना की गई है। मासिक, सीजनल, पंचदिवसीय एवं दैनिक वर्षा के सामान्य मानों का विश्लेषण करके सांख्यिकीय अध्ययनों के आधार पर अनेक निष्कर्ष निकाले गए हैं। झीलों में भारी वर्षा के अवसरों की प्रतिशतता ज्ञात करने की दृष्टि से उक्त झीलों एवं कोलाबा में हुई दैनिक वास्तविक वर्षा का भी विश्लेषण किया गया है।

ABSTRACT. An attempt is made in this paper to study the various rainfall characteristics of the lakes around Bombay so as to develop a climatology for the lake rainfall. The study covers fifty years data for the four lakes, *viz.*, Tansa, Tulsi, Powai and Vehar and 22 years data for Vaitarna from 1956 for southwest monsoon period in comparison with Colaba. Many conclusions based on statistical studies have been arrived at by analysing monthly, seasonal, pentad and daily rainfall normals. Analysis of the daily actual rainfall for lakes and Colaba has also been considered with a view to find out the percentage occasions of heavy rainfall over lakes.

1. Introduction

Bombay city and suburbs get their water supply chiefly from the five lakes, *viz.*, Tulsi, Tansa, Powai, Vehar and Vaitarna. June, July, August and September are the chief rainy months for the country as a whole. Though monsoon is a natural phenomenon which is still beyond human control, any scientific information such as onset, duration, intensity etc will be of great use in proper water management and budgeting.

2. Physical features

Powai, Vehar and Tulsi lakes are situated in the northern suburbs of Bombay, whereas Tansa and Vaitarna lakes are situated to the north in Thane district. Fig. 1 gives the geographical map of the lakes and Table 1 gives the general information regarding the lakes, like distance from Bombay, the year in which the lake was put into commission and the like.

3. Data utilised

The daily rainfall data for the four lakes, *viz.*, Tansa, Vehar, Tulsi and Powai for the period 1901 to 1950 have been collected from the Municipal Corporation, Bombay. The data for Vaitarna were available only from 1956, when the lake was commissioned. Since the period for which data are available is different, Vaitarna has not been included in the study for comparative purpose with Colaba. However, a separate note is added at the end covering the rainfall features for Vaitarna lake.

4. Analysis and results

Lake rainfall climatology has been developed in three parts :

(*i*) Monthly and seasonal rainfall with number of rainy days,

(*ii*) Pentad rainfall and

(*iii*) Daily rainfall.

Normal date of onset of monsoon over lakes has been taken as 10 June which is also the normal date for Colaba.

4.1. *Normal monthly rainfall*

Mean monthly rainfall for the four lakes for the period 1901-1950, along with the seasonal totals have been calculated for the months June to September and season as a whole and are given in Table 2. Many important conclusions can be drawn from the table. The rainfall during the month of June is generally of the order of 40-50 cm; the contribution to the seasonal

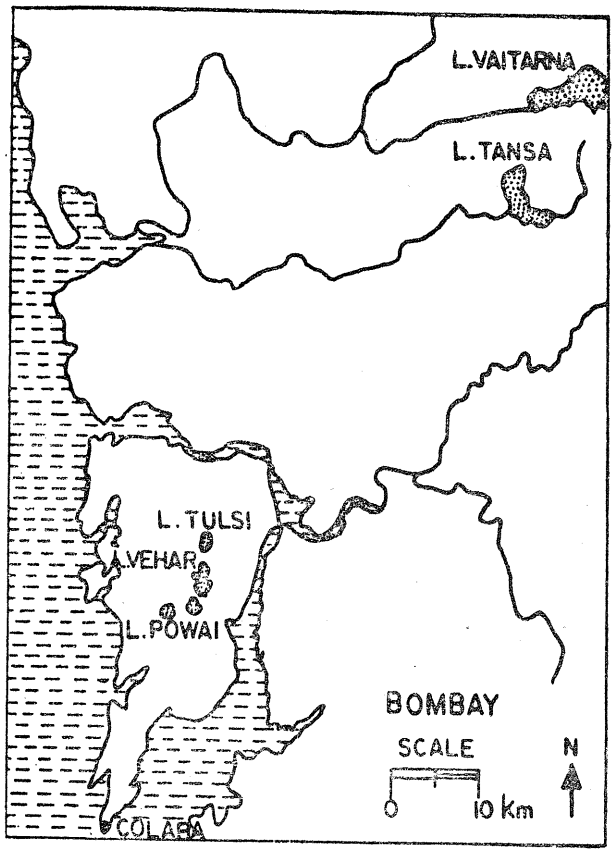


Fig. 1. Geographical map of lakes

TABLE 1

General information about the lakes

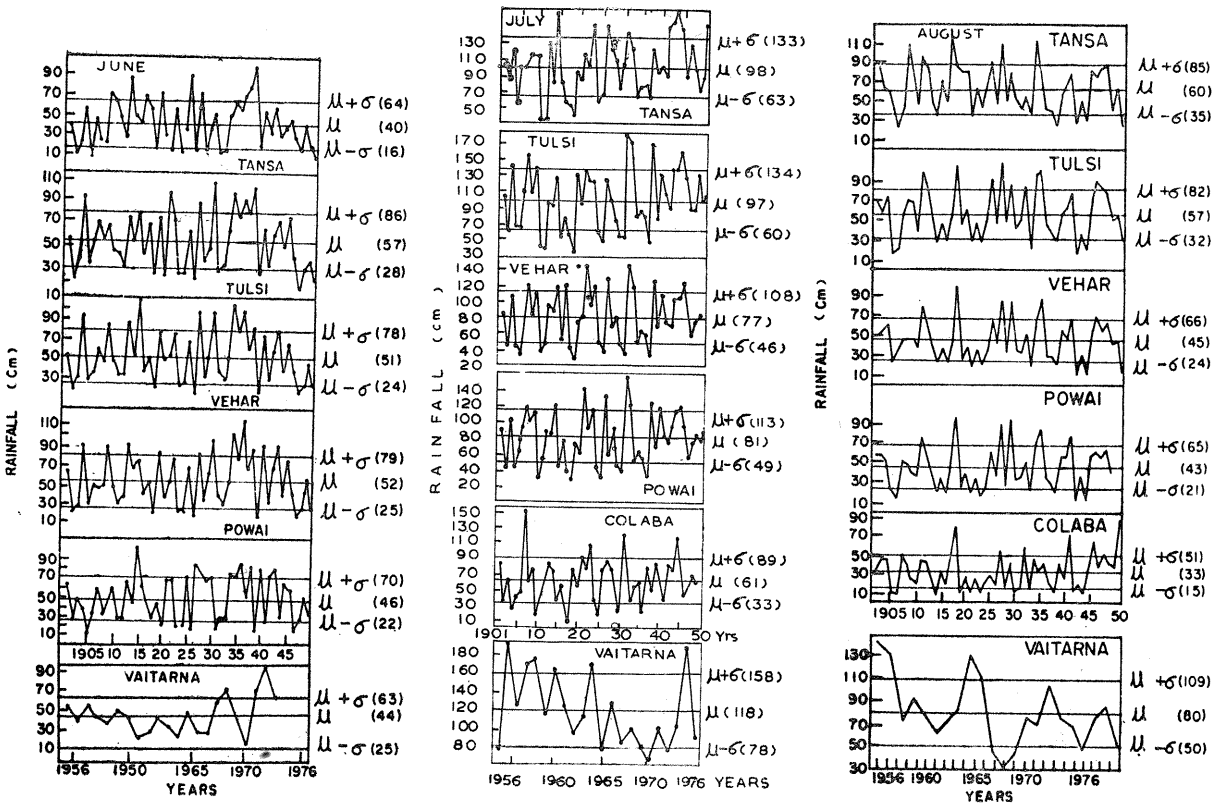
Particulars	Tansa	Tulsi	Vehar	Powai
Distance from Bombay (in km)	106.21	35.4	28.96	27.35
Year in which the lake was put into commission	1892	1879	1859	1890
Catchment area (in sq. km)	135.38	6.76	18.96	6.61
Quantity of water supplied to Bombay (in M.L. per day)	418	14	91	Not used for potable purpose

TABLE 2

Mean monthly rainfall in (mm)

Lake	Months				Seasonal
	Jun	Jul	Aug	Sep	
Tansa	400.1 (17)	984.2 (43)	600.7 (26)	327.4 (14)	2312.4
Tulsi	573.1 (23)	967.4 (39)	567.4 (23).	352.7 (14)	2460.6
Vehar	515.6 (25)	774.4 (38)	452.3 (22)	310.9 (15)	2053.2
Powai	519.1 (25)	809.8 (39)	447.2 (21)	315.5 (15)	2091.6
Colaba	464.9 (27)	613.5 (36)	329.0 (19)	285.9 (17)	1693.3

Figures within bracket indicate percentage contribution to the seasonal total



Figs. 2-4. Yearly variations of rainfall for June, July & August respectively

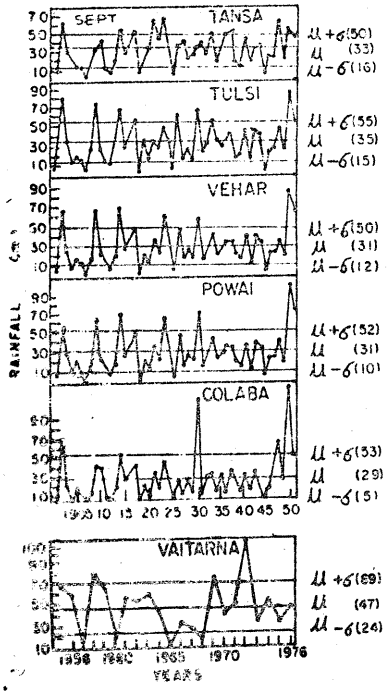


Fig. 5. Yearly variation of rainfall for September

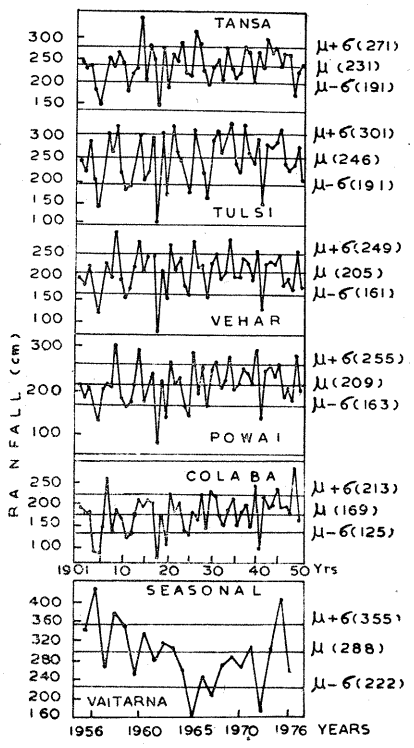


Fig. 6. Yearly variation of seasonal rainfall

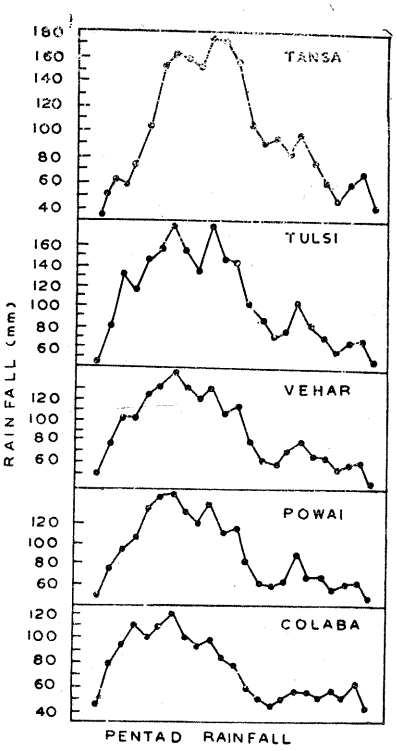


Fig. 7. Normal pentad rainfall

rainfall decreasing as we go northwards, and the lakes Tansa and Vaitarna receiving lesser rainfall as compared to the other lakes in this month. July is the rainiest month for the lakes and Colaba, and the rainfall is higher over lakes to the north. During August rainfall decreases and the rainfall amounts are less than in June except Tansa and Vaitarna lakes where it exceeds the June monthly rainfall. The rainfall decreases in September.

4.2. *Actual monthly rainfall for the period 1901-1950*

Figs. 2-6 show the year to year variation of rainfall for June, July, August, September and season as a whole.

In June coefficient of variation is generally of the order of 55% being maximum at Tansa (60%) and minimum at Colaba and Powai (51%). In July, the standard deviation values are higher than in the month of June, but the coefficient of variation is less in July indicating that the rainfall in July is less variable. The mean coefficient of variation is 39% for lakes and 46% for Colaba. In August the values for standard deviation are generally less as compared to June and July, the average coefficient of variation being 45% for lakes and 54% for Colaba. In September mean standard deviation is less than the standard deviation in August. The average value of coefficient of variation is 59%. Thus in general, rainfall is more variable in September as compared to other months.

4.3. *Seasonal rainfall*

More than 70% of the occasions the seasonal rainfall value lies between $\mu+\sigma$ and $\mu-\sigma$ and on 86% of occasions the value is above $\mu-\sigma$ limit. Mean coefficient of variation is 22% which is lower as compared to monthly rainfall. But mean standard deviation for seasonal rainfall is higher as compared to any individual month.

The year to year variation of rainfall trend for fifty years is generally identical for Colaba and lakes, the maximum and minimum of rainfall for different lakes and Colaba occurring in the same years indicating a definite correlation between the rainfall pattern. This is true for June, July, August, September and seasonal rainfall also. Table 3 gives number of rainy days, rainfall per rainy day, and rainfall per day for June, July, August and September for all lakes and Colaba.

4.4. *Pentad rainfall*

Fig. 7 gives the normal pentad rainfall.

The maximum in pentad rainfall values are observed during 32nd , 41st, 48th and 53rd pentads, the maxima during 32nd and 41st pentad being very prominent.

4.5. *Daily rainfall*

After examining the monthly, seasonal and pentad rainfall we shall now examine daily rainfall at these places for both normal and actual rainfall values.

TABLE 3

Mean number of rainy days and rainfall per rainy day and per day

Lake	June			July			August			September		
	A	B	C	A	B	C	A	B	C	A	B	C
Tansa	14.1	28.4	13.3	26.6	37.0	32.0	24.0	24.2	19.4	15.6	21.0	10.9
Tulsi	16.2	35.4	19.1	27.2	35.6	32.2	25.0	22.7	18.3	15.8	22.3	11.7
Vehar	15.8	32.6	17.2	25.6	30.3	26.0	23.4	19.3	14.6	15.2	20.4	10.4
Powai	15.7	33.1	17.3	25.7	31.5	27.0	23.2	19.3	14.4	14.9	21.2	10.5
Colaba	14.2	32.7	15.5	22.2	27.6	20.5	18.2	18.1	10.6	12.6	22.7	9.5

A=Mean number of rainy days, B=Rainfall per rainy day in mm, C=Rainfall per day in mm

4.5.1. *Normal rainfall*

From the actual daily rainfall, the daily normals have been calculated for four lakes and Colaba. Five day moving averages of the normals have been computed.

In June rainfall is generally light during the first week and during the rest of the month the rainfall is moderate. The five day moving averages of these daily normals show significant positive correlations with Colaba at 1% level (Table 4).

In July the rainfall is generally moderate at lakes and Colaba. It is seen that there is a positive significant correlation between Colaba, Powai, Vehar and Tulsi, correlations being significant at 1% level, while Tansa is not correlated with Colaba and other lakes. This information may be useful in day to day forecasting.

In August rainfall continues to be moderate, though the daily normal rainfall values are less as compared to those of the month of July. It is seen that all the lakes and Colaba are found to be correlated with each other and are significant at 1% level.

In September, it is seen, that during the first three weeks rainfall continues to be moderate but less in amount as compared to August. During the last week of the month rainfall is light. It is also seen that all lakes and Colaba are highly correlated at 1% level.

4.5.2. *Actual rainfall*

The actual daily rainfall that occurred over the lakes and Colaba during the period 1901-1950 has been grouped in the various classes: rather heavy (35.0-64.9 mm), heavy (65.0 to 124.9 mm) and very heavy > 125.0 mm) of rainfall. Table 5 gives the cumulative percentage occasion in the different intensity groups for monthly and seasonal rainfall. Highest recorded rainfall figures in the lakes and Colaba are also included in the table. Considering 50 years data from 1901-1950 for the lakes, it is seen

TABLE 4

Correlation coefficients between the lakes and Colaba

	Colaba	Powai	Vehar	Tulsi	Tansa
			June		
Colaba	1				
Powai	0.93	1			
Vehar	0.95	0.99	1		
Tulsi	0.95	0.97	0.99	1	
Tansa	0.84	0.95	0.91	0.88	1
			July		
Colaba	1				
Powai	0.67	1			
Vehar	0.89	0.97	1		
Tulsi	0.69	0.85	0.04	1	
Tansa	—0.20	—0.00	—0.06	0.34	1
			August		
Colaba	1				
Powai	0.94	1			
Vehar	0.92	0.95	1		
Tulsi	0.96	0.94	0.91	1	
Tansa	0.98	0.89	0.82	0.87	1
			September		
Colaba	1				
Powai	0.83	1			
Vehar	0.86	0.99	1		
Tulsi	0.82	0.99	0.99	1	
Tansa	0.71	0.78	0.83	0.84	1

r=0.5 is significant at 1% level

TABLE 5

Intensity analysis of actual daily rainfall data (1901-1950)

Lakes	Jun			Jul			Aug			Sep			Seasonal			Highest recorded rainfall (mm)	
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C		
Tansa	3.0	1.2	0.3	7.3	3.6	1.0	4.1	1.7	0.3	2.1	0.7	0.1	16.5	7.2	1.8	420	(1 Jul 1941)
Tulsi	4.1	2.0	0.7	6.9	4.1	1.4	3.4	1.6	0.4	2.1	1.0	0.3	16.5	8.8	2.7	373	(19 Jun 1921)
Vehar	5.8	1.9	0.6	5.7	3.0	0.7	2.6	1.0	0.3	1.7	0.8	0.2	13.8	6.7	1.7	458	(20 Sep 1923)
Powai	3.7	1.9	0.6	6.2	3.2	0.6	2.5	1.1	0.3	1.8	0.8	0.3	14.2	7.0	1.7	486	(20 Sep 1923)
Colaba	3.2	1.6	0.5	4.2	2.0	0.6	1.9	0.9	0.2	1.6	0.7	0.2	11.0	5.2	1.5	684	(22 Sep 1949)

Percentage occasions when rainfall per day > 34.9 mm =A; >64.9 mm=B and >124.9 mm=C

TABLE 6

General information for Vaitarna lake

Distance from Bombay = 119.09 km

Catchment area = 450.66 sq. km

Year in which the lake was put into commission = 1956

Quantity of water supplied to Bombay = 545 ML/day

Parameters	Jun	Jul	Aug	Sep	Seasonal
Mean monthly total in cm	44.1	118.0	79.6	46.5	288.3
Percentage of monthly total to the seasonal total	15	41	28	16	—
Standard deviation	19	40	29	23	67
Coefficient of variation	44	34	37	49	23
Mean number of rainy days	18.6	26.8	26.9	16.6	—
Monthly maximum in cm	95.1	192.7	141.5	104.2	421.2
Monthly minimum in cm	12.3	65.2	31.4	11.3	163.4
Correlation coefficient with Colaba (for the same period)	0.9	0.7	0.7	0.7	0.7
Rainfall per rainy day in mm	30.2	44.0	29.6	28.0	—
Rainfall per day in mm	14.7	38.1	25.7	15.5	—
Percentage occasions of seasonal rainfall between	72	59	64	68	72
Percentage occasions of seasonal rainfall above	14	27	18	14	14
Percentage occasions of seasonal rainfall below	14	14	18	18	14

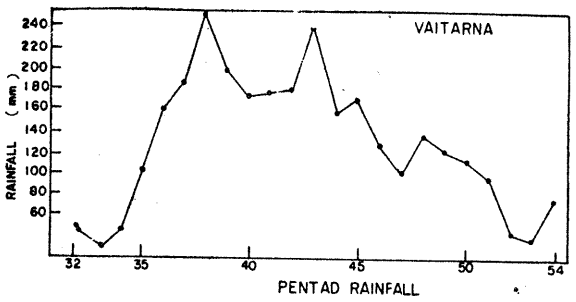


Fig. 8. Pentad rainfall characteristics

that on an average only 15% of the occasions the rainfall exceeds 34.9 mm.

Monthly distribution of heavy and very heavy occasions also shows that the heavy/very heavy occasions are very less, of the order of not more than 2%, during June, August and September while in July it is about 3%.

5. Vaitarna

The general information regarding the rainfall characteristics for Vaitarna lake is given in Table 6. Figs. 2 to 6 show the yearly variation for June, July, August, September and season as a whole. Fig. 8 shows the pentad rainfall characteristics.

6. Conclusions

(1) Average seasonal rainfall is maximum at Tulsi.

(2) Year to year variation of seasonal and monthly rainfall is generally similar for all lakes and Colaba.

(3) Average monthly rainfall is less variable in July as compared to other months. During June rainfall is less variable in Colaba, Vehar, Powai, but during August and September it is so in lakes Tansa and Vaitarna. Coefficients of variation for the seasonal rainfall is low, of the order of about 22% for the lakes and Colaba.

(4) During the four months and the season the percentage occasions when the rainfall exceeds $\mu-\sigma$ limit is 82%.

(5) Number of rainy days are nearly the same during June over the lakes and Colaba (50%). But during the other three months, it is more (by 20%) over the lakes as compared to Colaba. For the entire season lakes have about 66% rainy days while Colaba has 56%.

(6) Pentad rainfall characteristics of the lakes and Colaba are generally similar showing first maximum in 38th pentad and second maximum at 41st pentad.

(7) Daily normal rainfall is light during the first week of June and during last week of September. It is moderate during 2nd week of June to 3rd week of September, the values increasing and reaching maximum in July.

(8) The daily rainfall normals of Colaba, Powai, Vehar and Tulsi are highly correlated (positive correlation) with each other in all the months. Tansa lake has high positive correlation with the other lakes and Colaba only during June, August and September.

(9) From analysis of actual daily rainfall data for 50 years, it is seen that the number of occasions with heavy/very heavy rainfall are about 2.0% only.