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551.577.54 (547.1)

# Behaviour of rainfall over lakes around Bombay

SURENDER KUMAR and S. C. BHAN
*Regional Meteorological Centre, Bombay*
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**सार** — मासिक वर्षा के विश्लेषण से दो सर्वथा भिन्न-भिन्न वर्षा-प्रचुर क्षेत्रों का स्पष्ट तौर से पता चला है। पहले क्षेत्र में ग्रेटर बंबई में स्थित झीलें शामिल हैं और दूसरा क्षेत्र ठाणे जिले में है। यह ज्ञात हुआ कि विभिन्न उप-अवधियों/महीनों की वर्षा पूर्ववर्ती उप-अवधियों/महीनों की वर्षा पर निर्भर नहीं करती। विभिन्न महीनों के अंत में झील के स्तरों का पूर्वानुमान ज्ञात करने के लिए झील के स्तरों और मासिक वर्षा के मध्य बहु-समाश्रयण समीकरणों का विकास किया गया है।

**ABSTRACT.** Analysis of monthly rainfall brings out two distinctly different areas of rainfall affinity-one comprising of the lakes situated in Greater Bombay and the other in Thane districts. Rainfall of different sub-periods/months was found to be independent of the rainfall of preceding sub-periods/months. Multiple regression equations between lake levels and monthly rainfall have been computed to predict the anticipated lake levels at the end of different months.

**Key words** — Rainfall, Lake, Regression.

## 1. Introduction

Bombay city, for its water supply, depends on the lakes situated in the northern suburbs of the city and in Thane district to the north of it. These lakes get almost all of their water from southwest monsoon rains. Any significant shortfall in the rains leads to disruption of normal water supply to the city as happened during the initial six weeks of 1992 monsoon season when the failure of rains led the municipal authorities to impose major cuts on water supply and at one stage considered evacuation of the people from some parts of the city. The present study was, therefore, initiated to understand the behaviour and spatial distribution of rainfall over the lakes and its effect on the water level of the lakes.

Some characteristics of rainfall around the lakes have been reported by Mukherjee and Shyamala (1984), but they did not include all the lakes in the study and also the data used was for the period 1901-1950. In this study recent data (1961 onwards) have been used for all the lakes. Geographic location of all the lakes is shown in Fig. 1.

## 2. Data

Monthly rainfall data of the lakes upper Vaitarna and Bhatsa, for the period from 1967 to 1991, were obtained from Irrigation Department of Maharashtra and the daily data of rainfall and lake levels in respect of lakes Tansa, Modak Sagar, Tulsi, Vihar and Powai, for the period 1961 to 1992, were obtained from the Municipal Corporation of Greater Bombay. Rainfall data of Colaba and Santacruz were obtained from the records of Regional Meteorological Centre, Bombay. Lake Powai has not been included in any of the analysis as its water is not utilised for drinking purpose.

## 3. Analysis and results

### 3.1. *Monthly rainfall*

Mean monthly rainfall and the corresponding coefficients of variation (CV) for monsoon months of all the lakes are presented in Table 1. Rainfall of Colaba and Santacruz is also included for the purpose of comparison. The monthly CV are the least in July followed by August indicating a stability of rainfall during the two months. June rainfall shows a gradient from south to north. This is because the southern parts of the city get more rainfall during onset phase of monsoon rains. This gradient is reversed during the months of July and August.

The correlation coefficients (CCs) between monthly and seasonal rainfall of different stations and lakes were derived and have been presented in Table 2. It is seen from the table that the rainfall of all the lakes has got a higher correlation with the rainfall of Santacruz than with that of Colaba.

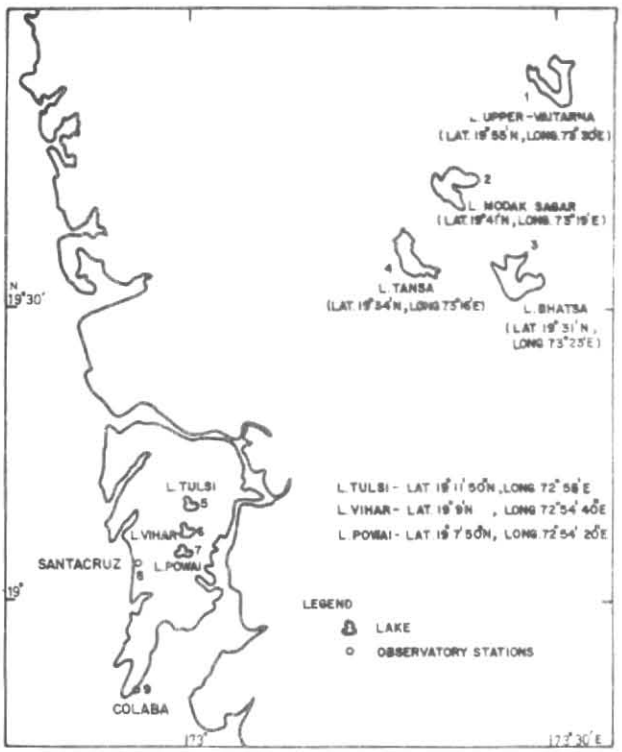



Fig. 1. Geographic location of different lakes

Table 2 brings out that the correlation between the rainfall of stations and lakes situated within one district (between rainfall of these in Greater Bombay — Colaba, Santacruz, Lake Tulsi and Vihar, or between rainfall of Modak Sagar) are very high ($r \geq 0.75$) than with those situated in the other district. This type of spatial distribution may be due to the orographic effects as the lakes in Thane district are situated in the vicinity of western ghats whereas those in Greater Bombay are situated in plains. Presence of mesoscale systems may also be contributing towards this type of differential distribution.

This information on differential rainfall over time and space can be of much help to the forecasters for issuing the day-to-day weather foecast for the area.

### 3.2. *Sub-period rainfall*

Interrelation between rainfall of different sub-periods and months have been investigated to find out whether there are any links in the rainfall of different months. The CC between various series with no month in common have been presented in Table 3. For most of the sub-periods/months the CCs are not significant. Even the statistically significant CCs, wherever obtained, do not explain the variability of rainfall by more than 25% and are, therefore, hardly of any predictive value. This brings out that if the rainfall over the lakes is less in the beginning of the seasons, it does not indicate that it will continue to be less during the later part of the season and thus unnecessary panic can be avoided.

TABLE 1

**Mean monthly rainfall (mm)**
**(Based upon data of 1961-1991)**

| Lake/Station | Months | | | |
|---|---|---|---|---|
| | June | July | August | September |
| Colaba | 618 | 697 | 453 | 288 |
| | (50)* | (46) | (60) | (69) |
| Santacruz | 569 | 772 | 516 | 306 |
| | (44) | (35) | (53) | (70) |
| Vihar | 549 | 815 | 543 | 285 |
| | (54) | (35) | (49) | (65) |
| Tulsi | 597 | 962 | 638 | 378 |
| | (48) | (30) | (53) | (101) |
| Bhatsa** | 455 | 970 | 694 | 347 |
| | (46) | (36) | (26) | (61) |
| Tansa | 412 | 891 | 655 | 343 |
| | (41) | (34) | (35) | (72) |
| Modak Sagar | 400 | 931 | 737 | 344 |
| | (52) | (34) | (32) | (67) |
| Upper Vaitarna | 360 | 958 | 690 | 282 |
| | (43) | (34) | (26) | (65) |

* Figures in parenthesis indicate the coefficient of variation (per cent).
** Based upon data of 1967-1991.

### 3.3. *Rainfall and lake levels*

The effect of monthly rainfall on rise of lake levels has been discussed in this section. Multiple regression equations between the monthly rainfall and lake levels at the end of month have been developed based on stepwise regression method. These analysis have been carried out for the lakes Tansa, Vihar and Tulsi only because for the lakes upper Vaitarna and Bhatsa, the data on lake levels were available only for a period of 10 years. Also this analysis was not carried out for the lake Modak Sagar, since this lake gets some water from the lake upper Vaitarna.

Two regression equations have been developed for each lake — one for lake level on 1 July based on June rainfall and lake level on 1 June; and the other for the level on 1 August based on July rainfall and lake levels as on 1 July. The equations were not developed for other periods as it was observed that during many of the years the lakes started overflowing during the month of August/September.

TABLE 2

**Correlation coefficients between the rainfall of different lakes**

| Lake/Station | Colaba | Tulsi | Vihar | Upper Vaitarna | Bhatsa | Tansa | Modak Sagar |
|---|---|---|---|---|---|---|---|
| | | | **June** | | | | |
| Colaba | 1.0000* | | | | | | |
| Tulsi | 0.6485 | 1.0000 | | | | | |
| Vihar | 0.7957 | 0.4964 | 1.0000 | | | | |
| Upper Vaitarna | 0.2890 | 0.3412 | 0.3531 | 1.0000 | | | |
| Bhatsa | 0.1772 | 0.3605 | 0.2366 | 0.7508 | 1.0000 | | |
| Tansa | 0.4387 | 0.5348 | 0.3900 | 0.8619 | 0.8174 | 1.0000 | |
| Modak Sagar | 0.2451 | 0.3602 | 0.2302 | 0.8629 | 0.8623 | 0.9154 | 1.0000 |
| Santacruz | 0.9035 | 0.8331 | 0.7625 | 0.3804 | 0.3225 | 0.5409 | 0.3461 |
| | | | **July** | | | | |
| Colaba | 1.000 | | | | | | |
| Tulsi | 0.5637 | 1.0000 | | | | | |
| Vihar | 0.5891 | 0.8481 | 1.0000 | | | | |
| Upper Vaitarna | —0.1083 | 0.0391 | —0.0683 | 1.0000 | | | |
| Bhatsa | 0.3376 | 0.5496 | 0.3789 | 0.6581 | 1.0000 | | |
| Tansa | 0.2546 | 0.5007 | 0.2938 | 0.6316 | 0.9536 | 1.0000 | |
| Modak Sagar | 0.3369 | 0.4419 | 0.2748 | 0.5701 | 0.9381 | 0.8994 | 1.0000 |
| Santacruz | 0.8118 | 0.7668 | 0.7495 | —0.0262 | 0.4369 | 0.3450 | 0.3920 |
| | | | **August** | | | | |
| Colaba | 1.0000 | | | | | | |
| Tulsi | 0.7727 | 1.0000 | | | | | |
| Vihar | 0.8144 | 0.9140 | 1.0000 | | | | |
| Upper Vaitarna | 0.3060 | 0.2204 | 0.3090 | 1.0000 | | | |
| Bhatsa | 0.6899 | 0.7398 | 0.7509 | 0.4626 | 1.0000 | | |
| Tansa | 0.7015 | 0.6526 | 0.7549 | 0.5587 | 0.8213 | 1.0000 | |
| Modak Sagar | 0.6625 | 0.5455 | 0.5959 | 0.6446 | 0.7533 | 0.8473 | 1.0000 |
| Santacruz | 0.9417 | 0.8558 | 0.8980 | 0.3158 | 0.7150 | 0.7380 | 0.6601 |
| | | | **September** | | | | |
| Colaba | 1.0000 | | | | | | |
| Tulsi | 0.2084 | 1.0000 | | | | | |
| Vihar | 0.8706 | 0.4191 | 1.0000 | | | | |
| Upper Vaitarna | 0.6038 | 0.1892 | 0.6234 | 1.0000 | | | |
| Bhatsa | 0.5788 | 0.1509 | 0.6012 | 0.8539 | 1.0000 | | |
| Tansa | 0.5520 | 0.1414 | 0.5673 | 0.8478 | 0.9304 | 1.0000 | |
| Modak Sagar | 0.5860 | 0.1231 | 0.5704 | 0.9057 | 0.9387 | 0.9569 | 1.0000 |
| Santacruz | 0.8981 | 0.2930 | 0.8984 | 0.6454 | 0.6369 | 0.5943 | 0.6016 |

The regression equations are listed below:

*Lake Tansa*

$$Y_1 = 4.87 + 0.967\ X_1 + 0.023\ X_2 \quad (R^2 = 0.88) \qquad (1)$$

$$Y_2 = 201.5 + 0.442\ X_3 + 0.0064\ X4 - 0.00002\ X_4 \quad (R^2 = 0.81) \qquad (2)$$

*Lake Tulsi*

$$Y_1 = -55.30 + 1.115\ X_1 + 0.012\ X_2 \quad (R^2 = 0.87) \qquad (3)$$

$$Y_2 = 75.15 + 0.833\ X_3 + 0.011\ X_4 \quad (R^2 = 0.80) \qquad (4)$$

*Lake Vihar*

$$Y_1 = 15.17 + 0.926\ X_1 + 0.008\ X_2 \quad (R^2 = 0.085) \qquad (5)$$

$$Y_2 = 9.96 + 0.967\ X_3 + 0.008\ X_4 \quad (R^2 = 0.86) \qquad (6)$$

where,

$Y_1$ — Water level in the lake as on 1 July (feet)

$Y_2$ — Water level in the lake as on 1 August (feet)

$X_1$ — Water level in the lake as on 1 June (feet)

TABLE 3

**Correlation coefficients between rainfall of disjoint sub-periods/months**

| Months | June | July | August | September | June-July |
|---|---|---|---|---|---|
| | | **Lake Tansa** | | | |
| July | 0.02 | | | | |
| August | 0.15 | —0.12 | | | |
| September | 0.11 | 0.29 | 0.20 | | |
| June-July | | | —0.05 | 0.30 | |
| August-September | 0.17 | 0.10 | | | 0.16 |
| | | **Lake Tulsi** | | | |
| July | —0.28 | | | | |
| August | 0.24 | —0.04 | | | |
| September | —0.08 | 0.12 | —0.20 | | |
| June-July | | | 0.15 | 0.05 | |
| August-September | 0.09 | 0.10 | | | 0.15 |
| | | **Lake Modak Sagar** | | | |
| July | 0.38 | | | | |
| August | 0.30 | 0.47* | | | |
| September | 0.19 | 0.37 | 0.38 | | |
| June-July | | | 0.49* | 0.36 | |
| August-September | 0.31 | 0.50* | | | 0.42* |
| | | **Lake Vihar** | | | |
| July | —0.41 | | | | |
| August | —0.22 | 0.13 | | | |
| September | —0.26 | 0.15 | 0.11 | | |
| June-July | | | —0.15 | —0.16 | |
| August-September | —0.18 | 0.10 | | | —0.18 |
| | | **Lake U. Vaitarna** | | | |
| July | 0.15 | | | | |
| August | 0.21 | 0.11 | | | |
| September | 0.26 | 0.17 | 0.05 | | |
| June-July | | | 0.18 | 0.25 | |
| August-September | 0.32 | 0.19 | | | 0.30 |
| | | **Lake Bhatsa** | | | |
| July | 0.30 | | | | |
| August | 0.41 | 0.04 | | | |
| September | 0.20 | 0.28 | 0.26 | | |
| June-July | | | 0.22 | 0.31 | |
| August-September | 0.37 | 0.21 | | | 0.33 |

* Significant at 5% level

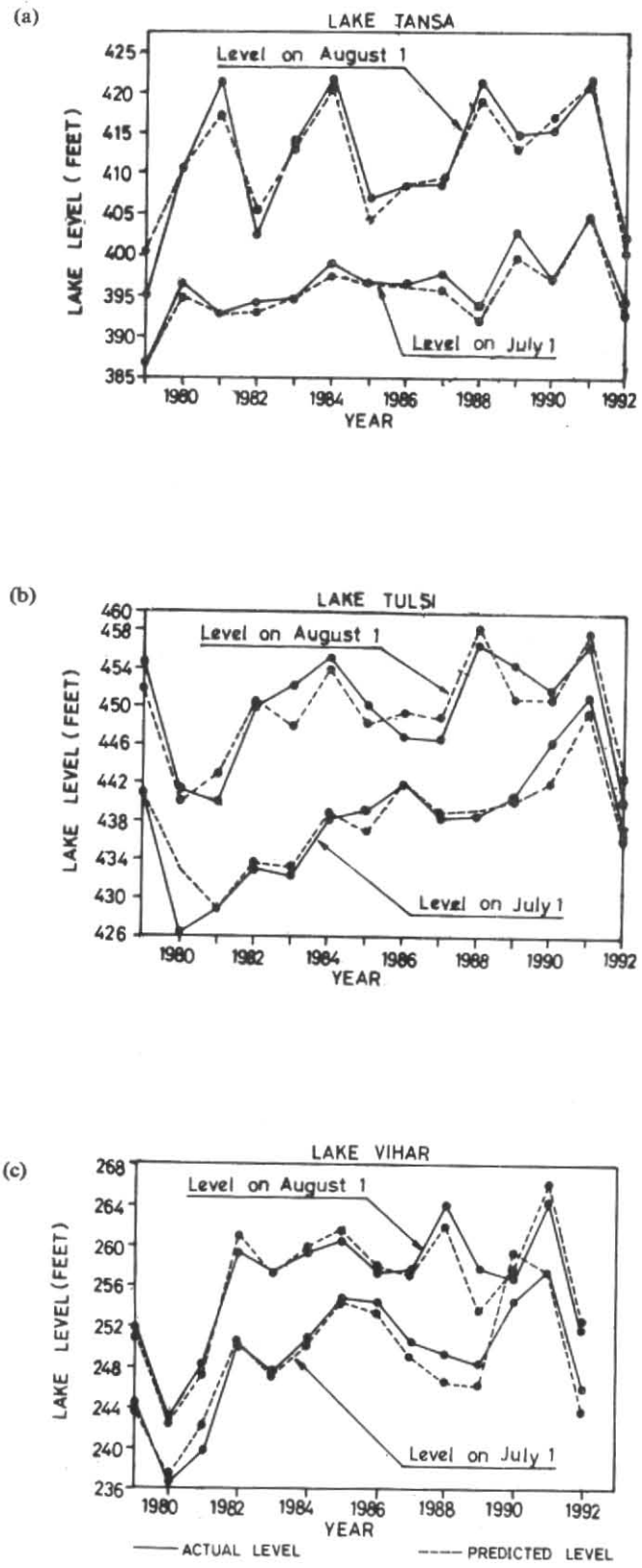
$X_2$ — Rainfall over the lake for the month of June (mm)

$X_3$ — Water level in the lake as on 1 July (feet)

$X_4$ — Rainfall over the lake for the month of July (mm)

Though these equations cannot be directly used for predicting lake levels since they require rainfall of a particular month in the beginning of that month, yet they can be very useful in predicting different scenario based on various probabilities of rainfall, say, 60% or 70% of normal rainfall. This may help in projecting minimum expected water level in the lakes and thus can be a useful aid in water management.

30 years' data, from 1961 to 1990, were used to develop these equations and the data for 1991 and




**Figs. 2 (a-c). Actual and predicted lake levels**

1992 were used to test the results. Actual and predicted lake levels for part sample and test data have been presented in Figs. 2 (a-c). It is seen from these figures that these equations give good estimates of lake levels.

## 4. Conclusions

The following salient features of rainfall over lakes around Bombay emerge from the study :

(*i*) Monthly total rainfall for June shows a gradient from south to north. This gradient is reversed during the months of July and August.

(*ii*) Monthly total rainfall of July and August months is less variable compared to that of June and September.

(*iii*) Spatial distribution of rainfall shows two distinct areas of rainfall affinity — first comprising Colaba, Santacruz, Lake Tulsi and Lake Vihar; and the other comprising lakes Upper Vaitarna, Tansa, Bhatsa and Modak Sagar. The rainfall over the lakes shows a higher correlation with rainfall of Santacruz compared to that of Colaba.

(*iv*) Less rainfall during the first half or initial months of the season does not indicate that it will continue to be less during rest of the season.

(*v*) Different water scenario can be projected using the regression equations based on different probabilistic rainfalls during June and July; and lake levels at the beginning of these months.

*Acknowledgement*

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### Reference

Mukherjee, A. K. and Shyamala, B., 1984, *Mausam*, **35**, pp. 165-170.