VARIABILITY OF RAINFALL AND SOIL WATER IN THE DRY TROPICS: A CASE STUDY FOR SELECTED LOCATIONS OF INDIA, NIGER AND BOTSWANA

S. M. VIRMANI AND A. K. S. HUDA

ICRISAT

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

ICRISAT PATANCHERU P.O.

ANDHRA PRADESH 502 324, INDIA

DRAFT

VARIABILITY OF RAINFALL AND SOIL WATER IN THE DRY TROPICS: A CASE STUDY FOR SELECTED LOCATIONS OF INDIA, NIGER AND BOTSWANA*

S.M. Virmani and A.K.S. Huda**

Abstract

The objectives of the study were to examine the variability of rainfall and soil moisture availability of three diverse locations in dry tropics i.e. Hyderabad in India, Niamey in Niger, and Lobatse in Botswana. The normal rainfall based on rainfall data from 1941-70 were 792 mm, 592 mm and 553 mm for Hyderabad, Niamey and Lobatse respectively. The coefficients of variation in rainfall were 31% for Lobatse and 20% for both Hyderabad and Niamey. We examined the mean weekly rainfall distribution and the probability of receiving atleast 10 mm and 20 mm rainfall (which approximately satisfying 0.33 and 0.66 of potential evaporative demand) in each week for the selected three locations. The probability exceeding 70% of receiving atleast 20 mm rainfall in each week occured only for two weeks in Hyderabad, for 8 weeks in Niamey, and for not a single week in Lobatse. Cumulative probabilities of available soil water (ASW) stored in the profile at the end of rainy season were also simulated. Results showed that at Hyderabad, after rainy sorghum, another crop in the postrainy season can be raised in 70% of the years under residual soil moisture conditions. For Niamey, and Lobatse growing a crop in the postrainy season without irrigation involves high risk. Cumulative probabilities of runoff were also simulated for these locations assuming a rainy season sorghum. In 70% of the years the simulated runoff was 120 mm, 75 mm, and 115 mm respectively for Hyderabad, Niamey and Lobatse.

*Submitted as Conference Paper No.   by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for the Task Force Meeting on Assessment of Climate Impacts on Agriculture, organized by the International Institute for Applied Systems Analysis (IIASA) and United Nations Environmental Program (UNEP), 1-5 April 1985, Laxenburg, Austria.

**Principal Agroclimatologist and Agroclimatologist, Farming Systems Research Program, ICRISAT, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, Ind[illegible]

Introduction

The semi-arid tropics (SAT) are characterized by a short and intense rainy season followed by a relatively long dry season. Generally the rainy season lasts from two to about 4 months; the amount of rainfall received ranges between 400 to 1200 mm; the rainy season may have one peak when it is called as unimodal or two peak periods of rainfall when it is called as bimodal. In the semi-arid tropics areas lying between 5° to 12° latitude, the rainy season is distinctly bimodal, while in those located above 20° it is generally unimodal. The areas lying between 12° and 20° latitude show some tendency towards bimodality. The SAT region is also characterised by warm thermal regimes throughout the year. The annual potential evaporation for most of the SAT ranges between 1500 and 2500 mm. The potential evaporation is quite intense in the hot dry season preceding the rainy season. The U.S. class 'A' open pan evaporation rates during this period range between 10 to 15 mm/day.

The SAT areas show considerable variability of rainfall from year to year. In statistical term the coefficients of variation is generally observed to range between 20 and 30 percent. The distribution of rainfall during the rainy season is quite erratic. Therefore for developing alternate crop production strategies, it is important to consider the rainfall distribution pattern and its reliability. We, at ICRISAT, found that the rainfall can be characterized, in agronomic terms, most usefully by estimating the probabilities of rainfall and soil water in a stochastic process.

The use of Markov chain procedures for estimating initial and conditional probabilities of rainfall (Robertson 1976, Virmani et al. 1982) could be used effectively for defining the dependability of precipitation during the rainy season. The risks associated with the survival of crops on receipt of sowing rains and the dependability of rainfall at critical stages of crop development could be assessed through such analyses.

Water-balance studies are also very important for characterising the variations in availability of water for crop production. A knowledge of these values is important for evaluating risks to dependable crop production in dryland areas and for developing strategies to overcome them; however, few empirical data are available. The water-holding capacity of the soil has a considerable influence on the availability of soil moisture during the growing season. Such information based on water-balance research is useful to agricultural scientists in devising cropping strategies for optimizing crop production in different types of soils, for evaluating risks, and for optimizing inputs.

The objectives of the study were to examine the variability of rainfall and soil moisture availability of three diverse locations in dry tropics i.e. Hyderabad (17° 27' N Lat, 78° 28' E Long) in India, a site chosen to represent Asian SAT environment, Niamey (13° 29' N Lat, 2° 10' E Long) in Niger in Western Africa, selected to represent the sub Sahelian SAT environment in the Sudan bioclimatic region; and Lobatse (25° 13' S Lat, 25° 14' E Long) in Botswana, a location representing the Southern African dry climatic environment (Figure 1). The following climatic characteristics for these locations were studied.

(a) annual rainfall variability

(b) annual rainfall probability

(c) weekly rainfall distribution

(d) weekly rainfall probability

(e) soil water at the end of rainy season

(f) runoff in the rainy season

Annual Rainfall Variability

The annual rainfall variability for 1941-70 are shown in figures 2, 3, and 4 for three locations i.e. Hyderabad, Niamey, and Lobatse. The normal rainfall based on rainfall data from 1941-70 are 792 mm, 592 mm and 553 mm for Hyderabad, Niamey and Lobatse respectively. The coefficients of variation in rainfall were 31% for Lobatse and 20% for both Hyderabad and Niamey. Figures 2 to 4 also depict the ± 1 standard deviation from the normal rainfall. A normal rainfall year for a location was defined if the annual rainfall was within ± 1 standard deviation of the normal rainfall. Figures 2-4 show that atleast 70% of the years were normal in these three locations. The number of years which received above normal rainfall are 4 in Hyderabad, 2 in Niamey, and 5 in Lobatse. Similarly the number of years which received below normal rainfall are 3 in Hyderabad, 4 in Niamey, and 4 in Lobatse. The lowest rainfall in Hyderabad was 457 mm in 1941, and the highest rainfall was 1192 mm in 1962. In Niamey, the lowest rainfall was 313 mm in 1944 and the highest rainfall was 900 mm in 1952. In Lobatse, the lowest rainfall was 250 mm in 1962 and the highest rainfall was 980 mm in 1967.

There were some extreme years which occurred outside the 30 year period of 1941-70 selected for this study. For example, in 1984 the total annual rainfall in Niamey was only 260 mm. In Hyderabad the extremely poor rainfall year was 1913 when 487 mm was received. The annual rainfall for Hyderabad in 1915 and 1916 were 1431 mm and 1425 mm respectively.

Variability of Total Annual Rainfall

The probability of occurrence of below normal and above normal rainfall years is important to develop alternative cropping systems for any region. In 70% of the years the rainfall received in Hyderabad, Niamey, and Lobatse was 700 mm, 560 mm, and 450 mm respectively (Figure 5). This shows that rain water availability is relatively less in Lobatse followed by Niamey, and Hyderabad. The Farming Systems Research at ICRISAT has amply demonstrated that in Hyderabad region a double crop system (eg. Intercrop, sequential, relay) is feasible if the water-holding capacity exceeds 150 mm such that it could store sufficient available water at the end of rainy season. This is important for postrainy season crop which is usually a rain free period.

The determination of probability of annual rainfall can be useful in many other ways. For example, it is seen from figure 5 that the probability of receiving 800 mm rainfall was 50% in Hyderabad, 4% in Niamey, and 10% in Lobatse. This shows that again for Hyderabad region high valued crops having more water requirements could be grown in 50% of the years. But in Niamey and Lobatse. the risk of growing such crops without irrigation is very high.

Weekly Rainfall Distribution

It is well known that the information on annual rainfall can often be misleading for developing cropping systems. Thus we further examined the mean weekly rainfall distribution and the probability of receiving atleast 10 mm and 20 mm rainfall (which approximately satisfying 0.33 or 0.66 of potential evaporative demand) in each week for the selected three locations (Figures 6, 7, and 8).

The period receiving more than 20 mm weekly mean rainfall extends from 25th week (18 June) to 42nd week (21 October) except the two week periods of 40th and 41st week in Hyderabad. The periods receiving more than 20 mm weekly mean rainfall extends from 24th week (11 June) to 37th week (16 September) except for 26th week (25 June - 1 July) in Niamey. The rainy season in Lobatse starts from mid October and continues upto mid March. There are only 9 weeks which receive more than 20 mm rainfall but these are not consecutive weeks.

The probability exceeding 70% of receiving atleast 20 mm rainfall in each week occurs only for two weeks in Hyderabad (26th and 38th weeks i.e. 25 June - 1 July, 17-23 September) and for a 8 week period in Niamey (29th to 36th week i.e. 11 July to 9 September). The probability of receiving atleast 10 mm rainfall exceeding 70% in each week extends from 26th week (25 June) to 38th week (23 September) except for 33, 34 and 36th week in Hyderabad. In Niamey the probability of receiving atleast 10 mm rainfall exceeding 70% in each week extends from 27th week (2 July) to 37th week (16 September). In Lobatse, there was no single week which received atleast 10 mm rainfall in 70% of the years.

Soil Water

Cumulative probabilities of available soil water (ASW) stored in the profile at the end of rainy season were also simulated using the Ritchie (1972) soil water model. The data base was 1941-70. Soil water was simulated assuming rainy season sorghum (Figure 9). The available soil water-holding capacity was assumed 150 mm for Hyderabad, and 50 mm for both Niamey and Lobatse. In 70% of the years, the simulated ASW was 100 mm, 5 mm and 18 mm respectively for Hyderabad, Niamey and Lobatse.

Results show that at Hyderabad, after rain- sorghum, another crop in the postrainy season can be raised in 70% of the years under residual soil moisture conditions. Using the crop simulation models, Huda and Virmani (1985) discussed in these proceedings the probability of simulated crop yields at some selected locations in India and Niger. For Niamey, and Lobatse growing a crop in the postrainy season without irrigation involves a high risk. The reasons are not only the unt and distribution of rainfall, but the poor water holding capacity of soils. In the rainy season, much of rainfall water goes as runoff and conservation of such water could be used for supplemental irrigations either during the intermittant drought in the rainy season or for a postrainy season crop. Thus a quantification of the probability of runoff water is useful for developing watershed based cropping strategies.

Runoff

Cumulative probabilities of runoff were also simulated for these locations assuming a rainy season sorghum (Figure 10). Data base used was 1941-70. Daily available soil water was first simulated using Ritchie (1972) method. Daily runoff was simulated when the rainfall became excess to the capacity of the profile. Accumulated runoff was simulated at the end of each rainy season. Figure 10 shows that in 70% of the years the simulated runoff was 120 mm, 75 mm, and 115 mm respectively for Hyderabad, Niamey and Lobatse. Figure 11 shows the seasonal variability of runoff for Hyderabad from 1941-70 assuming both rainy season sorghum and rainy season fallow.

Conclusions

The dry tropics are noted for their variable rainfall and high evaporation. The generalized agroclimatic analyses based on monthly mean rainfall provide insufficient agroclimatic divisions within the ecological region for planning strategies to increase and stabilize crop production. Probability estimates of weekly rainfall, soil water at critical growth stages, and seasonal runoff are much more sensitive parameters. A knowledge of these values is important for evaluating risks to dependable crop production in dryland areas and for developing strategies to overcome them.

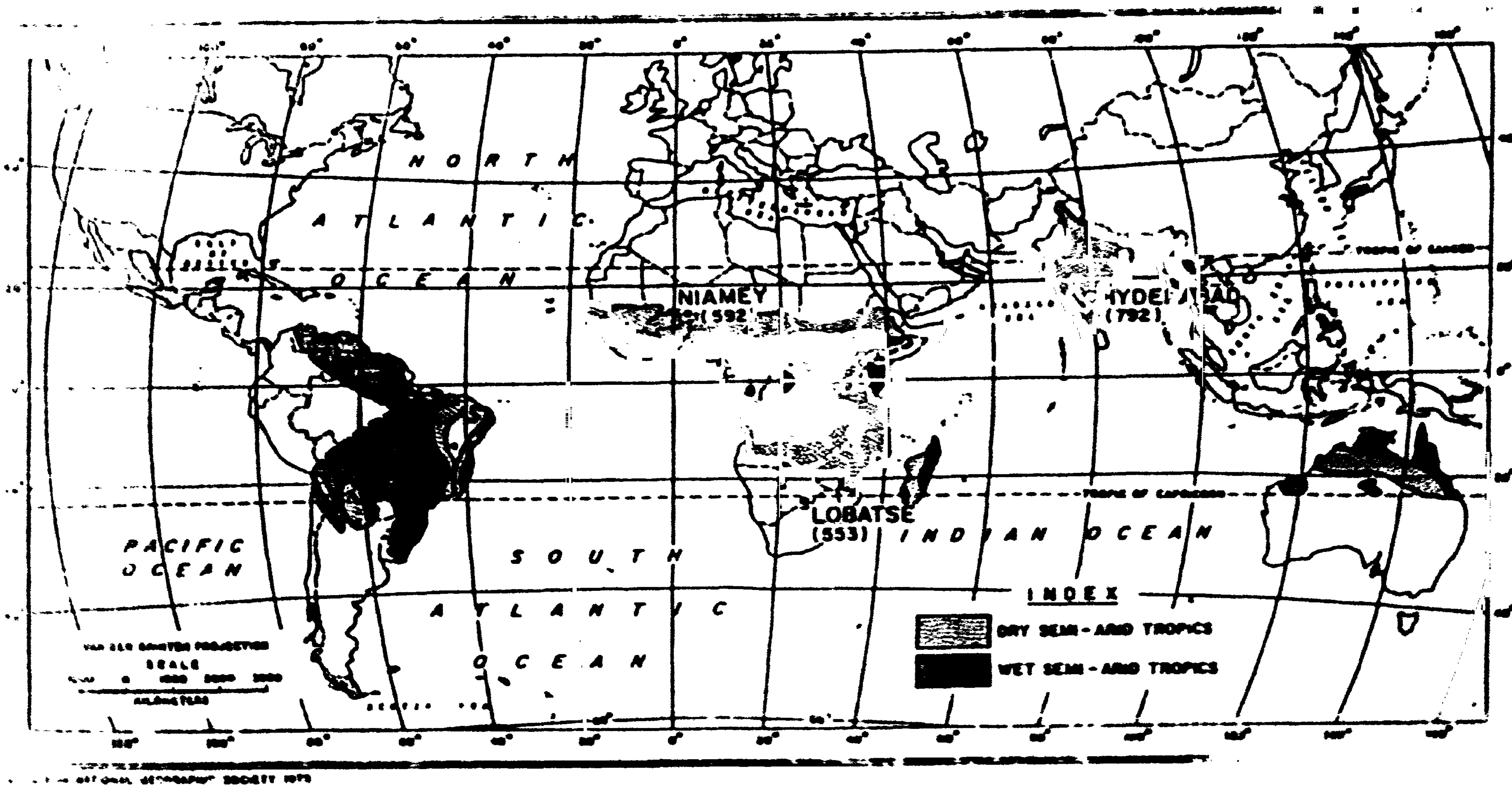
References

Huda, A.K.S., and S.M. Virmani: 1985, 'Simulated Changes in Sorghum Yield in the Semi-Arid Tropics for Altered Climate Scenarios', These proceedings.

Ritchie, J.T.: 1972, 'Model for Predicting Evaporation from a Row Crop with Incomplete Cover', Water Resources Research 8, 1204-1213.

Robertson, G.W.: 1976, 'Dry and Wet Spells', UNDP/FAO, Tun Razak Agriculture Research Center, Sungh: Tekam, Malaysia, Project Field Report, Agrometeorology; A-6, pp. 15.

Virmani, S.M., M.V.K. Sivakumar, S.J. Reddy: 1982, 'Rainfall Probability Estimates for Selected Locations in Semi-Arid India', Research Bulletin No.1 (2nd Enlarged Edition), ICRISAT, Patancheru P.O., Andhra Pradesh 502324, India.



qui

Selected locations in India, Niger, and Botswana.

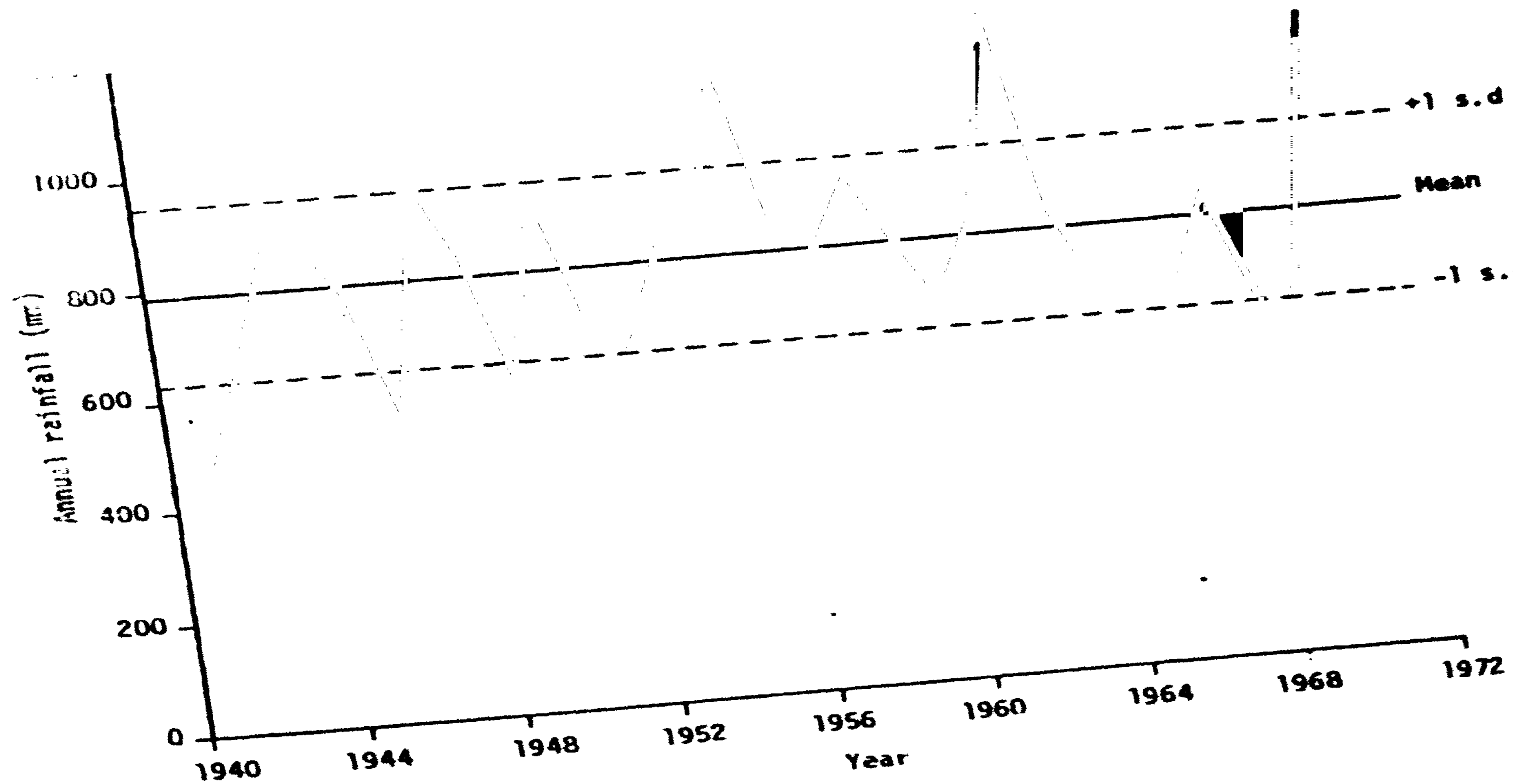


Figure 2.

Annual rainfall at Hyderabad, India, 1941-70.

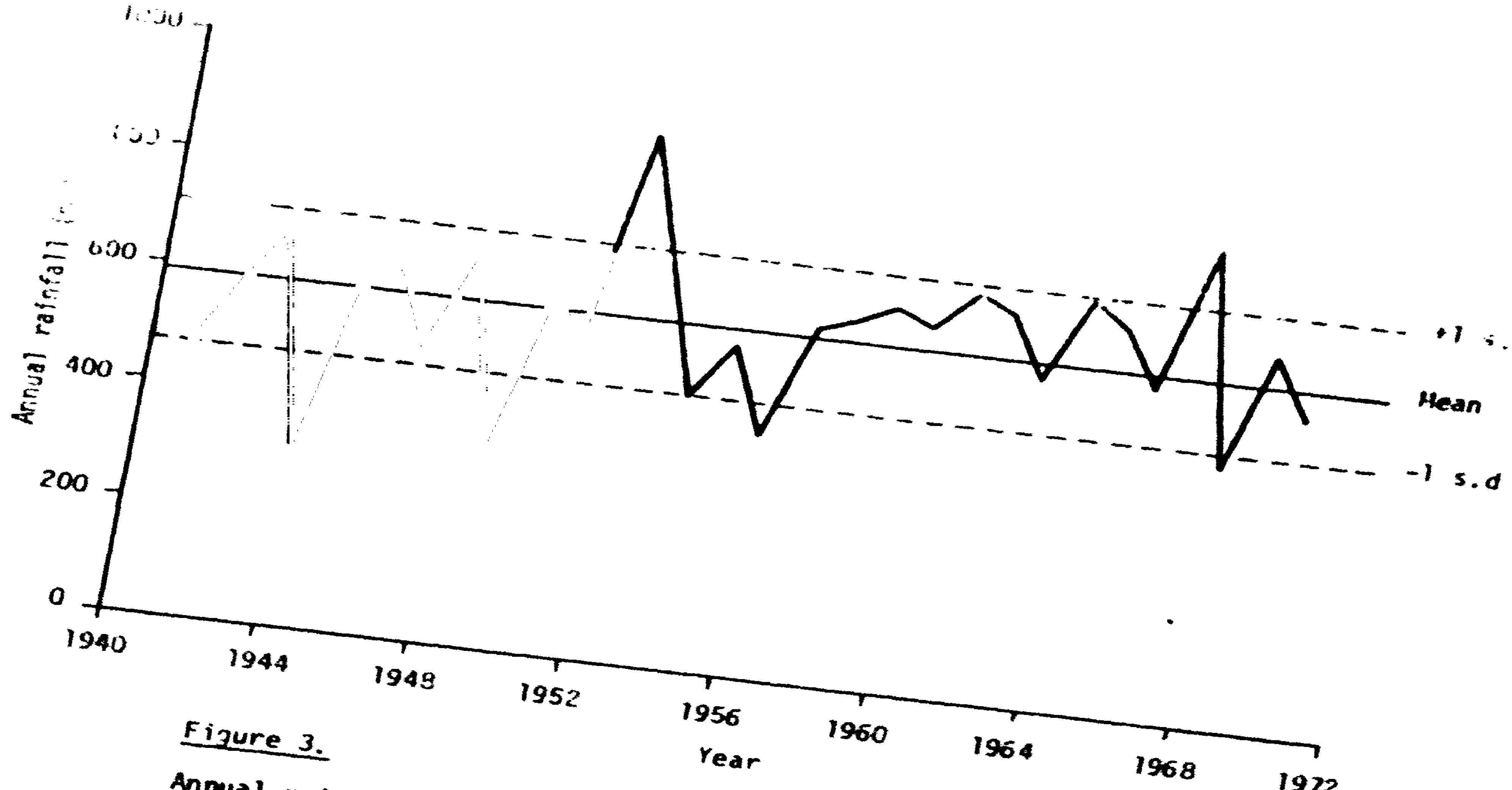


Figure 3.

Annual rainfall at Niamey, Niger, 1941-70.

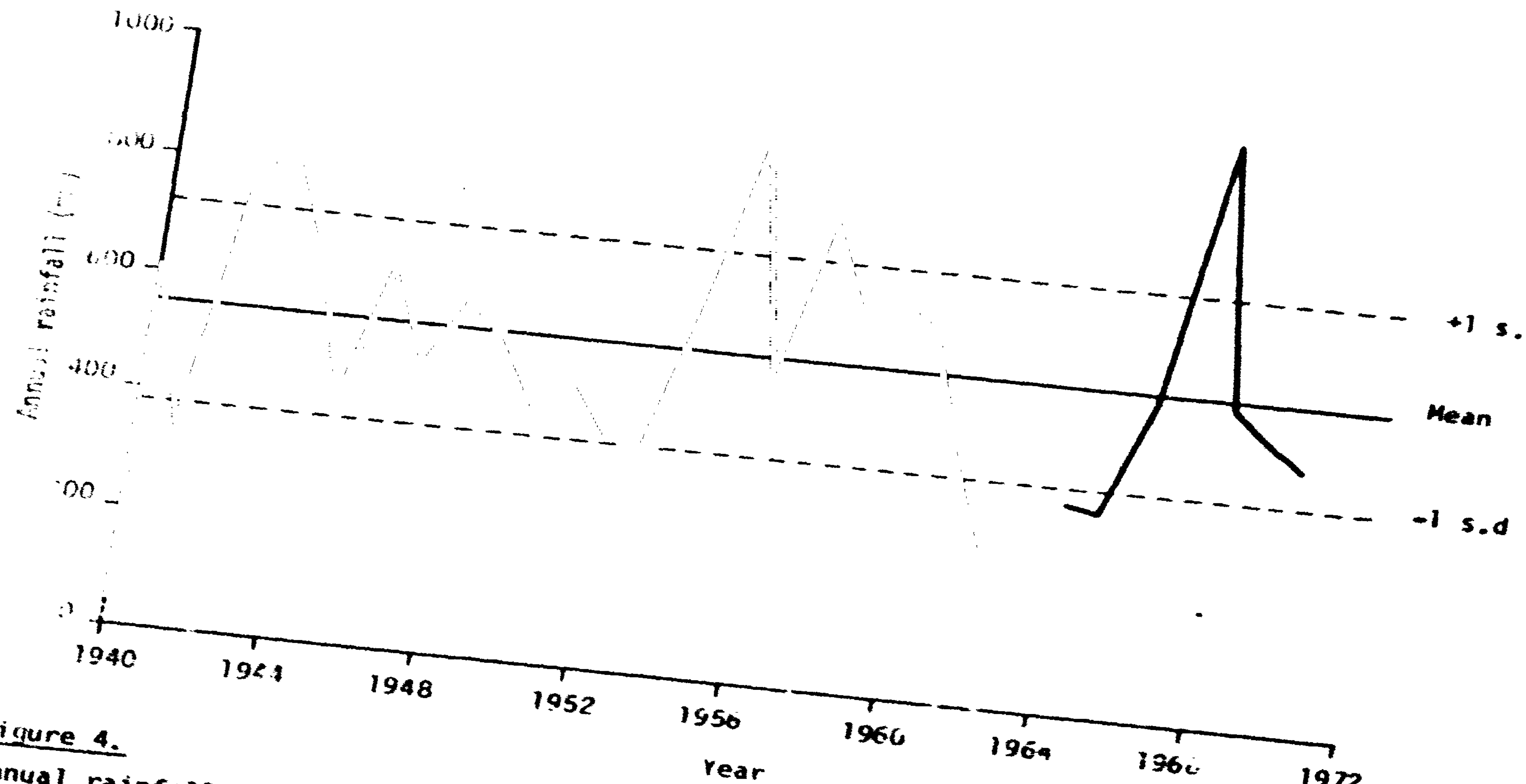


Figure 4.
Annual rainfall at Lobatse, Botswana, 1941-71. Data for 1963 are not available.

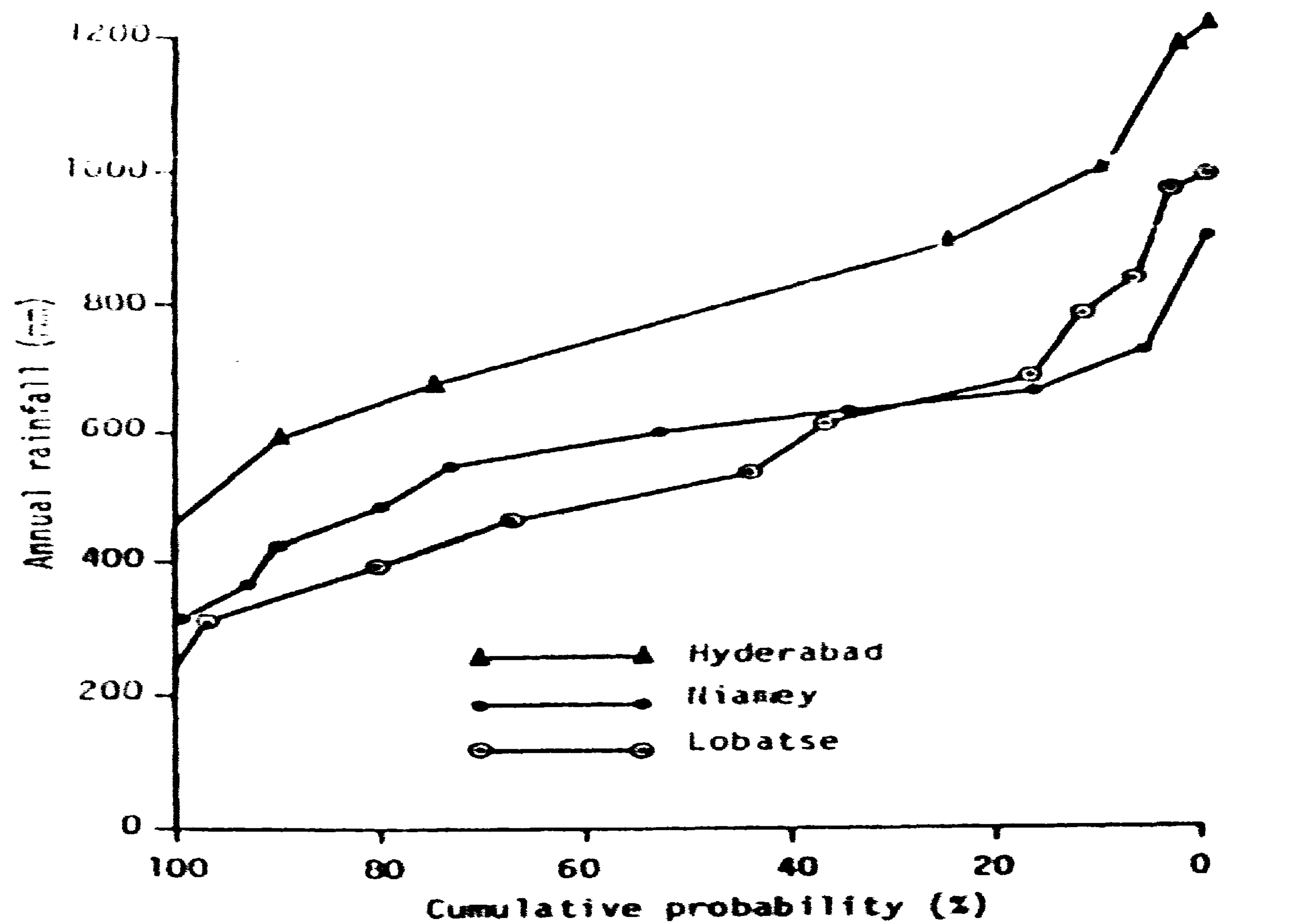


Figure 5.

Cumulative probability (%) of annual rainfall (mm) for Hyderabad (India), Niamey (Niger), and Lobatse (Botswana). Rainfall data from 1941-70 were used.

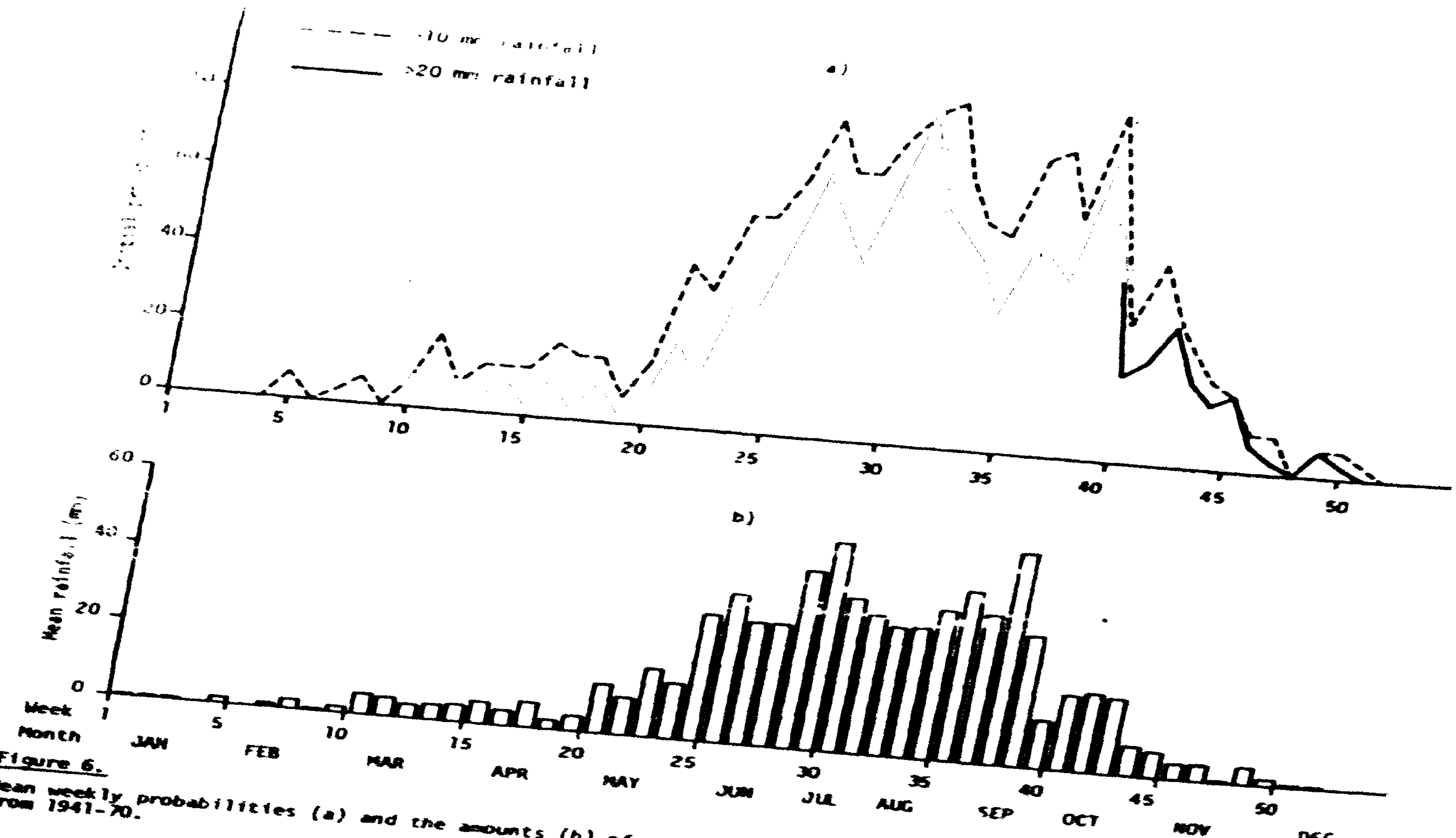


Figure 6.

Mean weekly probabilities (a) and the amounts (b) of rainfall at Hyderabad, India, based on rainfall data from 1941-70.

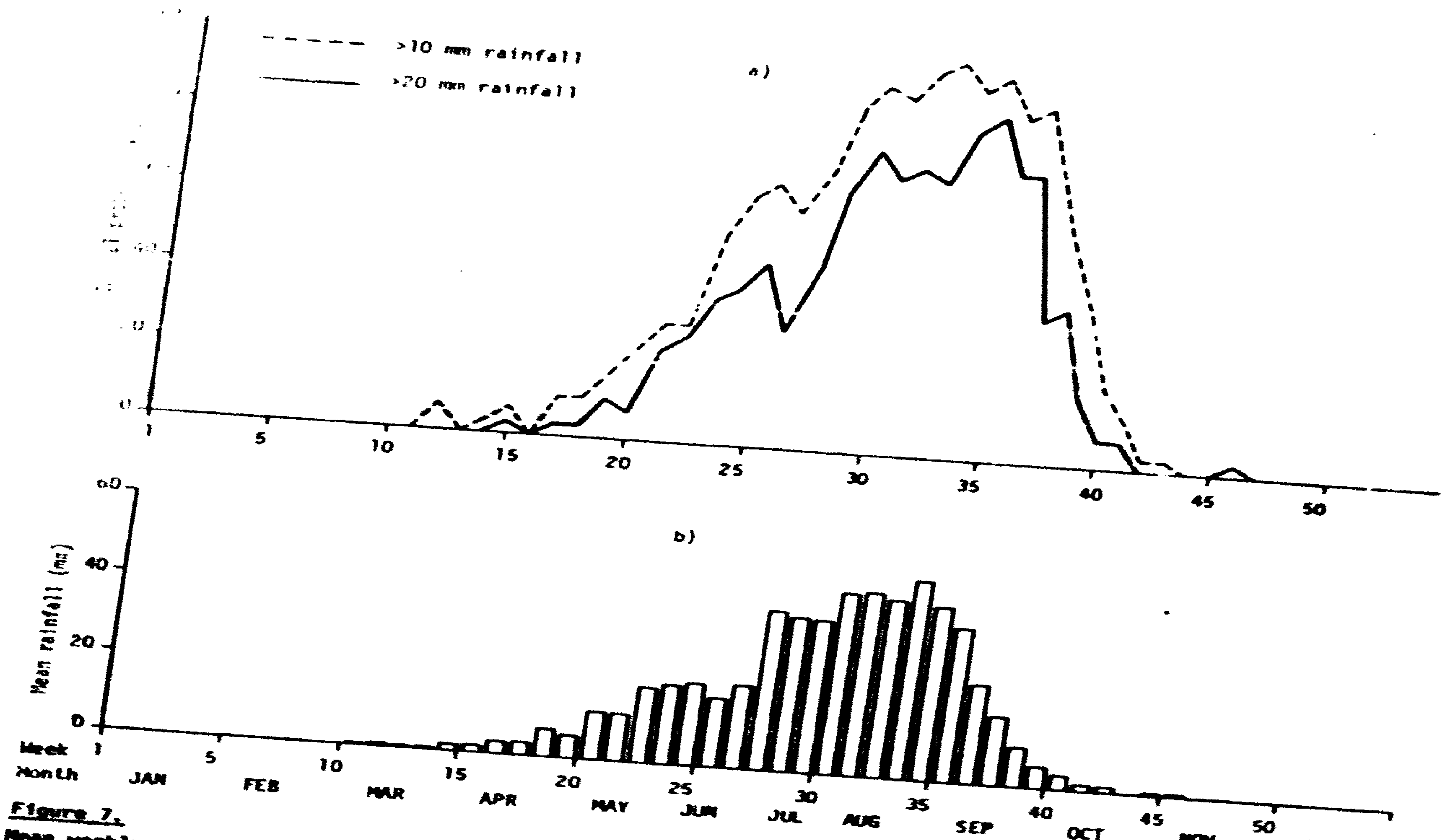
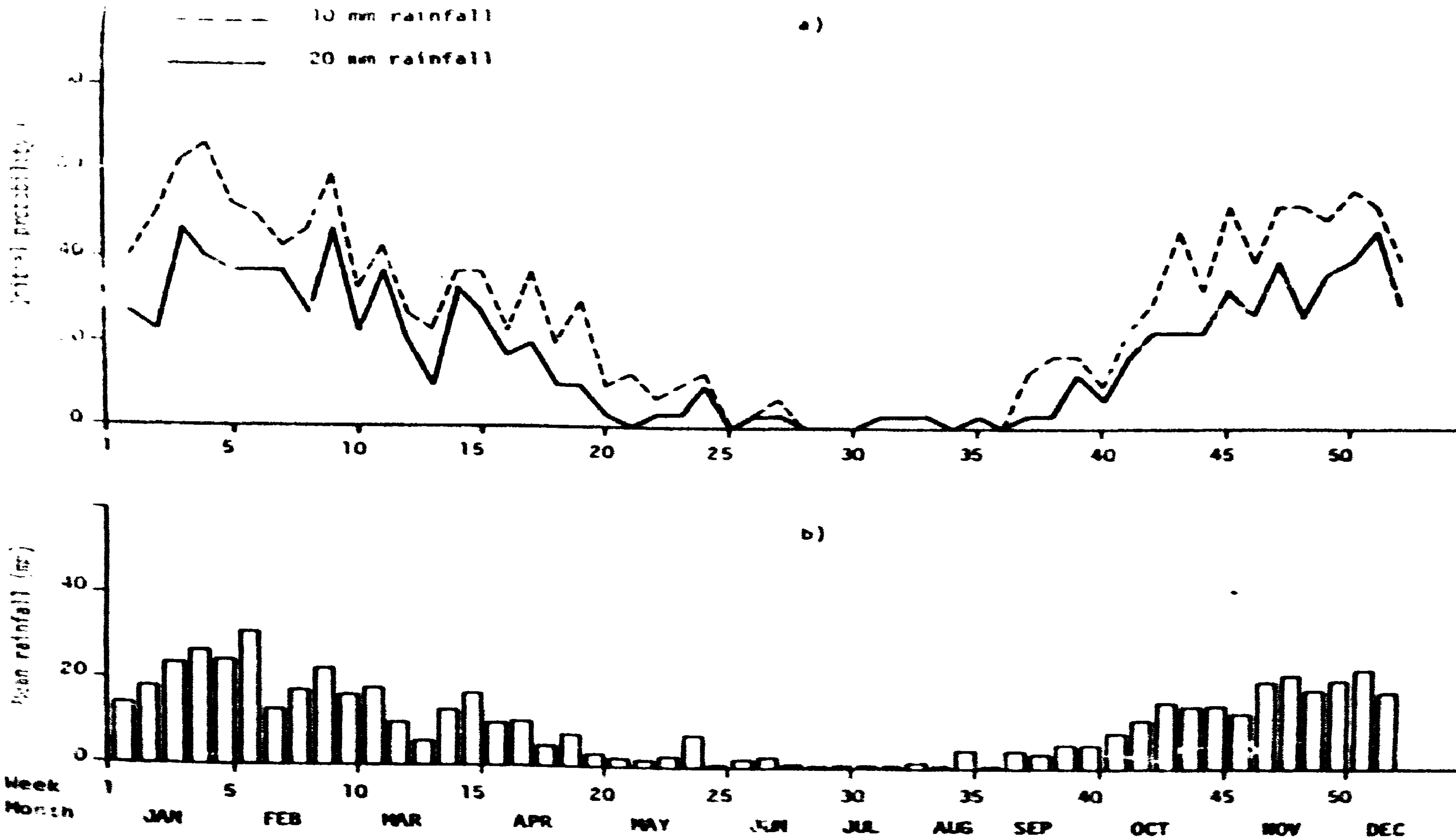


Figure 7.

Mean weekly probabilities (a) and the amounts (b) of rainfall at Niamey, Niger based on rainfall data from 1941-70.



<u>**Figure 8.**</u>

Mean weekly probabilities (a) and the amounts (b) of rainfall at Lobatse, Botswana based on rainfall data from 1941-71.

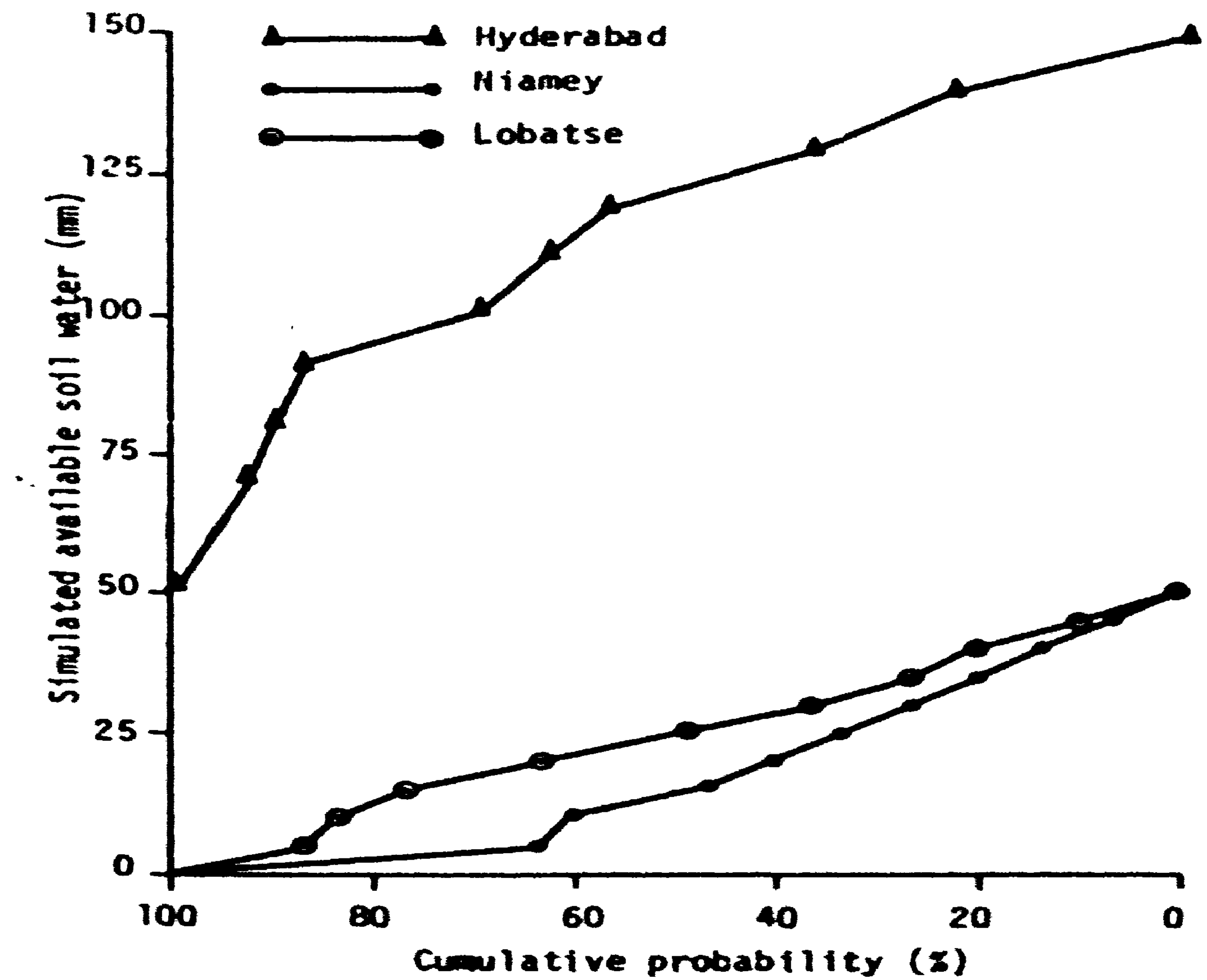


Figure 9.

Cumulative probability (%) of simulated available soil water at the beginning of the postrainy season after sorghum in the rainy season for three selected locations.

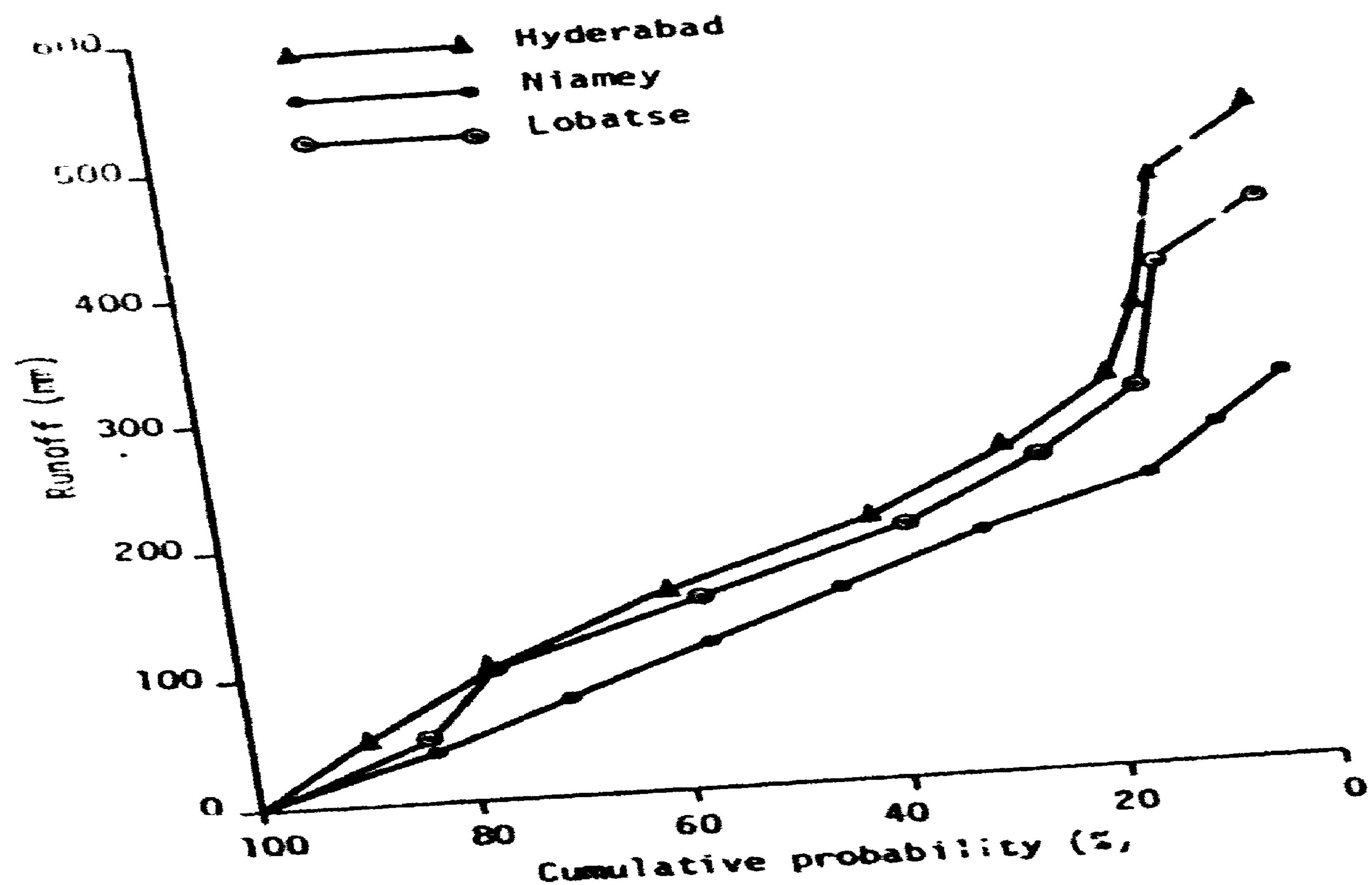


Figure 10.
Cumulative probability (%) of runoff at three selected locations.

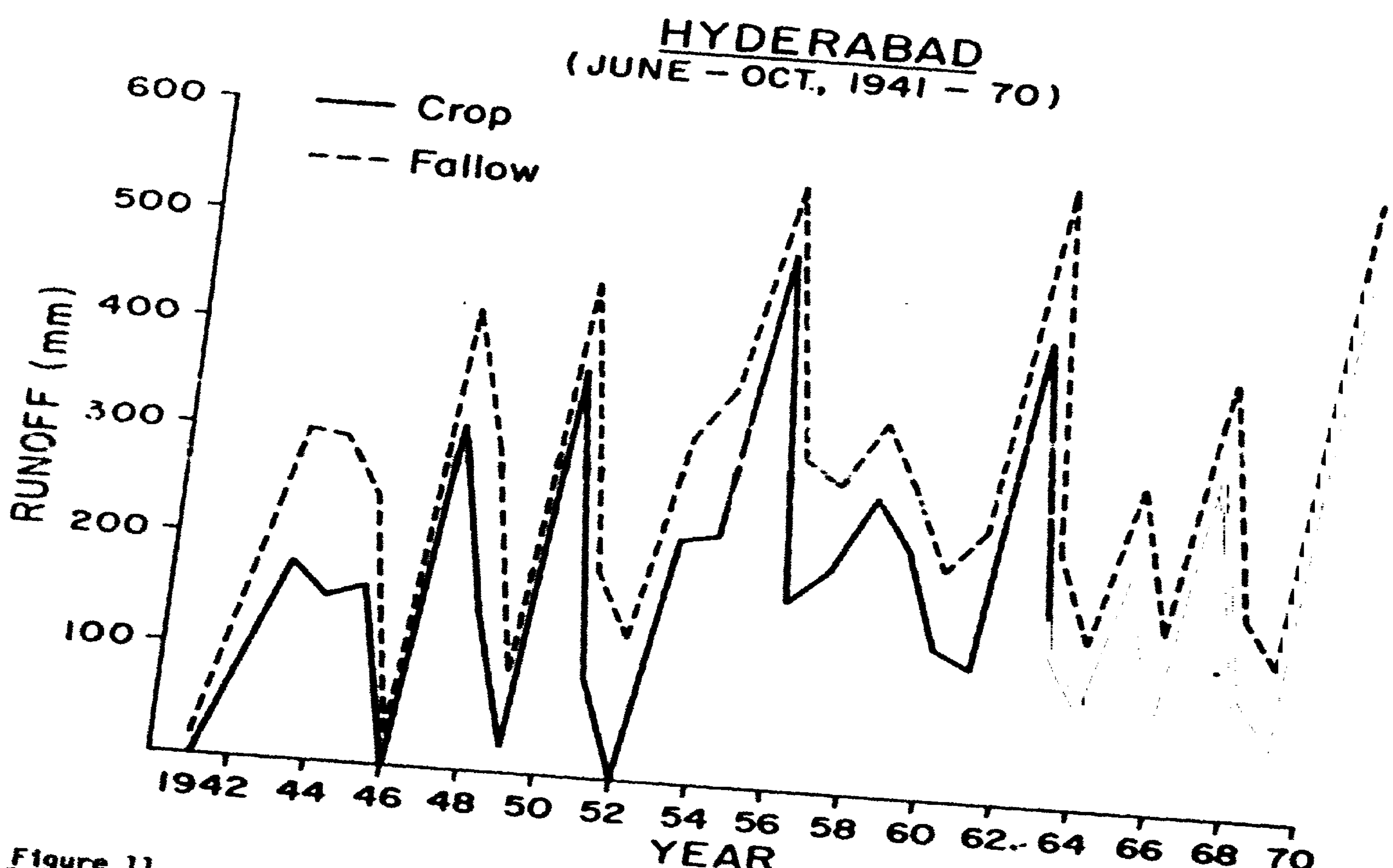


Figure 11.

Seasonal variability of runoff for Hyderabad, assuming both sorghum and fallow in the rainy season.