ANALYSIS OF DROUGHT CHARACTERISTICS IN WATER RESOURCES PLANNING -A CASE STUDY

A DISSERTATION

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BY

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CERTIFICATE

Certified that the dissertation entitled 'ANALYSIS OF DROUGHT CHARACTERISTICS IN WATER RESOURCES PLANNING - A CASE STUDY' which is being submitted by Er.Mithilesh Kumar Jha in partial fulfilment for the award of the Degree of Master of Engineering in Water Use Management of University of Roorkee, is a record of student's own work carried out by him under our guidance and supervision. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked at this University for a period of four months from July 16,1986 for preparation of this dissertation.

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SYNOPSIS

Droughts and floods are natural phenomena and have considerable adverse effects on the developmental activities, particularly in case of water resource development. Planners have given much emphasis on floods due to their immediate devastating effects while droughts still remain to be recognised as important parameters in water resources planning. The existing definitions of droughts and the criteria to identify them are not very comprehensive and they do not reflect effectively their partinent features or impacts. These criteria/definitions are inadequate as they do not take into consideration some important factors.

An attempt has been made in this dissertation to analyse drought characteristics and to evaluate suitable criteria which may properly account for the impacts of droughts. The study very clearly indicates the limitations of existing criteria and highlights the fact that additional drought characteristics, such as, the deficiency of water alongwith its time distribution, the capacity of the people to bear the deficit conditions etc., help in identification of drought situation in better way. Two parameters 'effective deficiency (ED)' and 'effective deficiency with extreme conditions duly represented (ED_e)' have been evaluated and suggested for the purpose.

The methodology for evaluation of the suggested parameters have been illustrated with the help of a case study in respect of Palamu district of Bihar which is a typical drought prone area. The efficiency of the model suggested for identifying the drought has also been tested and the result has been found to be satisfactory.

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CHAPTER - I

INTRODUCTION

Right from the very beginning, the human race had to fight against nature for its survival. Natural calamities which are to be very frequently confronted include drought, floods, cyclones, volcano, landslides, avlanches and earthquakes etc. All these calamities have their special characteristics and the human race has adapted itself to face them.

1.1 DROUGHT - A NATURAL CALAMITY

Since the beginning of the existence of mankind, drought has affected the human activity throughout the world. Historical records of the drought confirm the fact that it has occurred in almost every part of the world at sometime or other. Despite developments in almost all the fields the drought continues to pose considerable problems for the human race. A recent example is the drought of Euthopia which exposes as to how hollow is the claim of development of human race.

Droughts together with floods, cyclone and earthquakes account for more than 90% damages caused to man's vital environment by natural calamities. The remaining other natural hazards are not of much significance (although they may have considerable importance for some areas in local situations).

Drought is, however, considerably different from other natural disasters. While the disasters like earthquake, cyclone, floods etc. have some degree of suddenness, the drought is of creeping and pervasive nature which starts slowly and has slow but lasting effect. The calamities like earthquakes, cyclones, floods etc. because of their flashy nature, cause considerable loss of properties and lives in a relatively very short period. As a result these have created a sense of panic and fear among the masses and perhaps that is one reason why these calamities have attracted more attention. On the other hand the human society gets sufficient time to adapt itself to face the consequences of drought which may be equally disastrous. However, when the duration of the drought becomes considerably long the miseries become unbearable and drought has long term effects.

1.2 DROUGHT - A RECURRING PHENOMENON

Whatever be the scientific reasons of drought and theories behind it, there is no denying the fact that drought is an unavoidable aspect of the arid and semi-arid environment and a constant natural enemy of humanity. Man has lived and struggled with drought throughout the history. Even such areas which have normally sufficient precipitation to meet various needs of the area, are confronted with the occurrences of drought of shorter or longer duration at sometime or other. Climatological and statistical analyses done so far have indicated the fact that drought is a recurrent phenomenon, an integral though irregular, part of the climate. It will occur in the future with absolute certaininty although the specific time cannot be predicted on the basis of present knowhow. However, it has been discovered that average frequency of drought is more or less stable over time. The analysis based on the rainfall deficiency equal to/greater or than 25% of the normal has revealed that the periodicity of drought varies from once in 2½ years in Western Rajasthan to once in 5 years in West Bengal, Madhya Pradesh, Konkan, coastal Andhra Pradesh, Orissa, Bihar and Maharashtra. The recurrent characteristics of drought is reflected in the folklare and religion of all the early people. A rain God and a drought goddess may be found in the pictographs and sculptures of the mayas which signifies the importance of the water problem in their culture. Chapter 41 of Genesis in the Bible gives the same indication. The dream of the Pharah of fat cattle and full ears of grain compared with lean animals and withered ears of grain, were interpreted by Joseph with a meteorological reference to the temporary prevalace of the dry east wind. The reference to seven good years and seven years of drought may be inferred as cycle but the passage is a definitive indication of impressive rainfall fluctuations in Egypt or the source of the Nile river.

It is internationally accepted fact that the major cause of drought is deficiency in rainfall and the occurrence of rain is a random phenomenon. A look at the rainfall data indicates the presence of cyclicity in rain deficiencies. The average annual rainfall data of a region (Palamu district of Bihar) have been plotted in Figure 1.1 which amply demonstrates the recurring nature of deficient rain and hence the drought. For a region where schemes for water resources

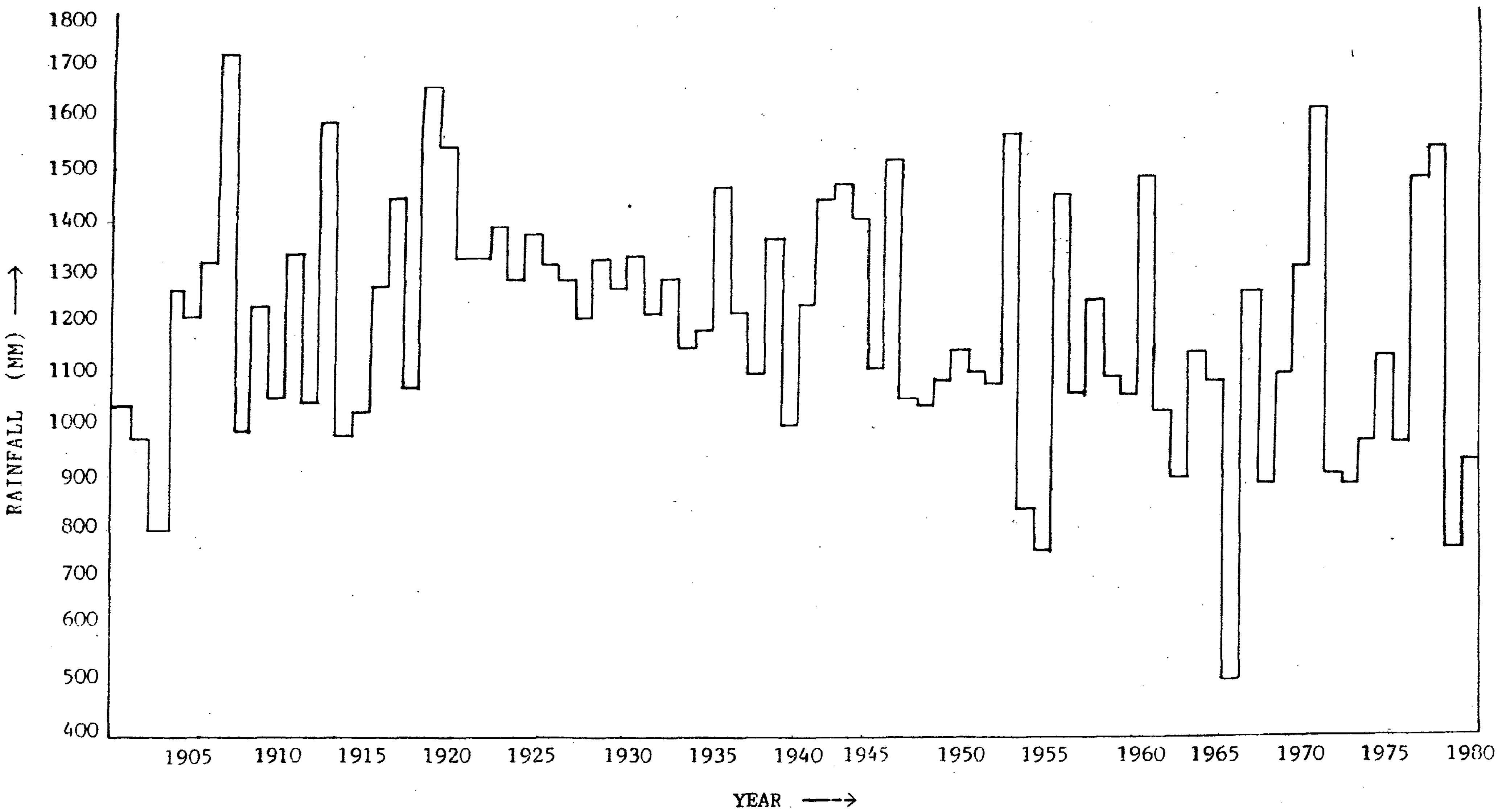

FIG. 1.1 YEARLY RAINFALL PATTERN IN PALAMU DISTRICT.

development have been implemented, the annual river flow and its time distribution may provide a good guide for drought conditions. The occurrence of low flows in succession is bound to have adverse effects and will create drought situation despite the optimum utilisation of available resources. The annual flow data of a river are plotted in Figure 1.2 which clearly demonstrates the recurring features of drought.

1.3 A LOOK AT WORLDWIDE DROUGHT SITUATION

More than a fourth of the population of the world lives in lands of famine and nearly half of the remainder lives under the constant threat of deficient rainfall (Tannehill, 1947). Examples are galore in the history to show that drought is the chief cause of most of the famines throughout the world. Many civilisations have been perished due to abnormally long persistent deficiency of rainfall. Syrian Desert is one such example. Presently, Syrian Desert is a vast area between the coast range of the eastern mediterranean and the Euphrates. It is said that at one time it was more populated than any area of the same size in England and the rainfall was more than at present during the olden times. The overthrow of the Roman Empire has also been attributed to drought (famine).

In recent times, the worldwide drought occurred in the year 1979, 1981 and 1983. However, the year 1983 witnessed one of the worst worldwide drought ever recorded. The number of people affected for exceeded that in any other single drought - year.

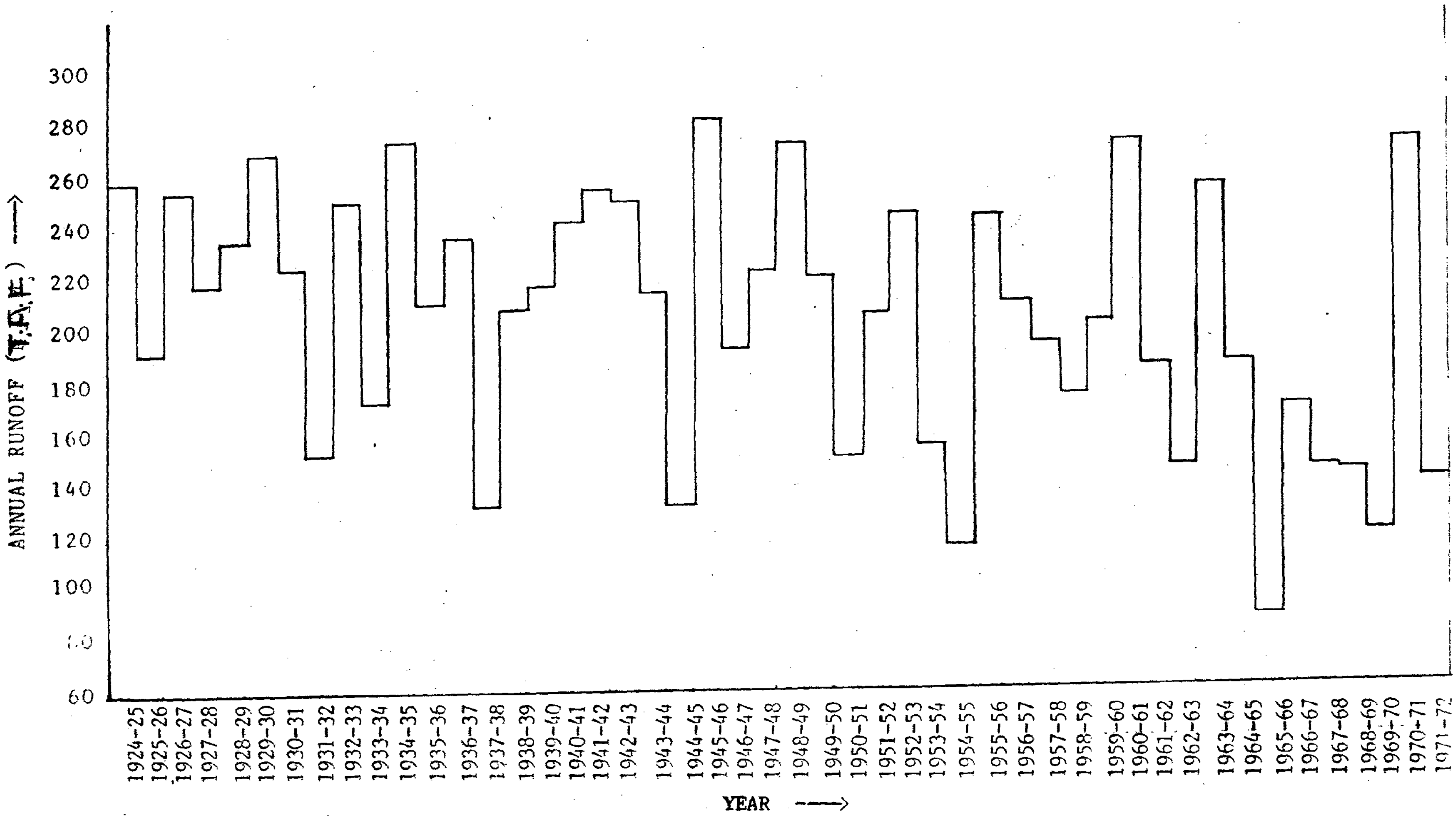

FIG. 1.2 **YEARLY RUNOFF PATTERN OF A TRIBUTARY OF NORTH KOEL IN PLAMU DISTRICT.**

Africa was the worst affected continent where as many as 34 countries involving more than 150 million people suffered from the drought. In Asia, India and Philippines were affected by drought with the result that India had to import 600 million rupees worth of foodgrains. While in North America midwest U.S.states were hit by widespread drought, in central America,it was the Mexico which suffered from this natural hazard. Likewise, in South America, Peru, Bolivia and Brazil were the suffering countries - with Brazil recording its worst ever drought in its past 300 years history which culminated in the deaths of thousand of people. In Europe, Romania, Czechoslovakia, Yugoslavia, Hungery, Danube River Basin experienced the driest spell of this century. Spain and Southern Itlay were the two other Europian countries along with three North African countries namely Morocco, Tunisia and Algeria which were affected by Mediterranian drought. The drought in Australia was the worst in its 200 years history. In China more than 16 million ha of farm land were affected. Other recent droughts which affected several parts of the world may be cited as those of 1972-73 drought in U.S.S.R., the 1977-79 drought in U.S.A., the 1976 drought in U.K., the early seventies drought in Sahel and East Africa etc. The 1973 and 1974 drought in East Africa claimed more than 1 lakh people and thousands of animals.

In China, where the written records of drought date back to as much earlier as 206 B.C., most of the famines were caused as a result of severe droughts. The principal cause of drought in China and India may, undoubtedly be attributed to failure of rains and its erratic behaviour. In China during the period between 206 B.C. and 1949, there was on an average one major flood or drought every year. As many as 1056 major droughts were recorded during the said period.

1.4 DROUGHT IN INDIA

In India, as elsewhere in the world, drought is a frequent natural calamity which finds its place in all the great epics of the country. One of the earliest droughts in India has been referred in 'Vayu Purana'. In Ramayana also, there is description of drought during the period of King Dashratha the father of Lord Rama. In Mahabharata (3000 B.C.) which is the second great epic of India, there is mention of serious drought during the reign of Emperor Mandhata of the race of Iksvakus. Written records also give the evidence of occurrence of several famines like the one which occurred about 160 years before the Mahabharatha war during the reign of king Shantanu, the ruler of Hastinapur. During the reign of king Trisanku, father of the famous king Harishchandra, a famine is said to have occurred. It has also been recorded that a severe famine occurred during the period of king Chandragupta Maurya's reign.

In pre-independence period, the large catestrophic effect of frequent droughts and famine caught the attention of the then British rulers in the 19th century when a series of famine and irrigation commission were set up to go into the various aspects of the problem and to suggest suitable measures to mitigate the distress of the people. The Indian Finance Commission, 1880 has mentioned the occurrences of severe famine and drought conditions in the then North-West province and the Punjab. Subsequently, in 1896, the National congress urged the then Government to adopt more realistic and 'people's welfare oriented' approach towards this problem. Inspite of all these, the drought continued unabated in its devastating form taking heavy fall of lives and properties at frequent intervals. The Great Bengal famine of 1942 is one such example in recent times in which innumerable lives were lost.

According to an estimate, about 107 million ha. which works out to be about one-third of the total geographical area of 329 million ha. of the country and 29 percent of the population are affected by drought. The drought affected area includes 39 percent of the total gross cultivable area of 185 million ha. Likewise, nearly one-eighth of the total area of the country is subjected to be vagaries of the flood and it has been further revealed that the flood prone areas are increasing inspite of flood protection measures being taken up on priority basis. Hence, India is affected by the drought-flood- drought syndrome. The statewise percentage of population affected by drought has been given in Annexure-I.

In India, the failure of monsoon rains is the principal cause of drought. The monsoon rain is irregular both in space and time which results in serious economic imbalances. The rainfall in the country is highly variable from mean annual rainfall of as much low as 15 cms in extreme western Rajasthan to as high as 1000 cms. in the Khasi and Jaintia hills. Some of the highest rainfall in the world has been recorded in this country which is 1142 cms in a year and 104 cms in a single day. About 85 percent of the total rainfall occurs in the four monsoon months. Further, the number of rainy days is also highly variable with about 10 days per year in the extreme Rajasthan area to about 150 days in a year in north-eastern part of the country (K.L.Rao, 1979). A study conducted by Central Water Commission indicates that about 54.5% of the geographical area of the country receives less than the mean annual rainfall of 105 cm for the entire country (C.W.C. Brochure on drought, 1982). The Irrigation Commission, 1972 has indicated 67 districts as drought - prone areas which spans over eight states of Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil-Nadu. Later, National Commission on Agriculture (1976) identified some more districts as drought-prone areas. Subsequently, the Ministry of Agriculture finally identified a total of 99 districts (in 13 states) as drought-prone areas. The Figure 1.3 shows the drought-prone districts in the entire country. The statewise geographical area as affected by drought is given in Table 1.1.

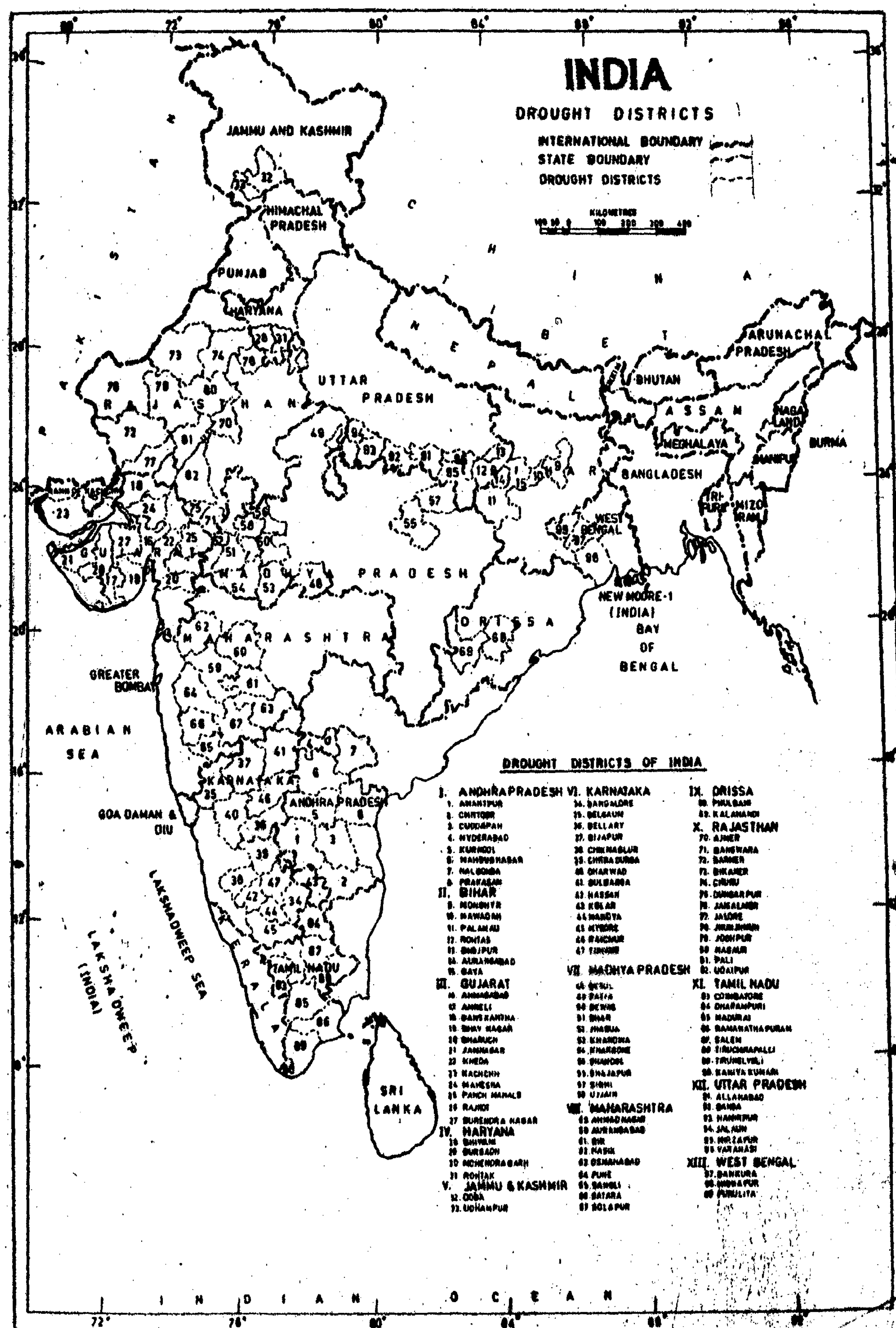

FIG. 1.3 DROUGHT PRONE DISTRICTS IN INDIA

Table 1.1: Statement Showing the Percentage of Geographical Area affected by Drought (Statewise)

S.N.	Name of the State	Total Geographical area(M.ha)	Geographical area affected by drought(M.ha)	Percentage
1.	Andhra Pradesh	27.7	12.6	45.0
2.	Bihar	17.4	4.3	25.0
3.	Gujarat	19.6	12.1	15.0
4.	Haryana	4.4	1.7	20.0
5.	Jammu & Kashmir	22.2	0.84	3.0
6.	Karnataka	19.2	15.2	79.0
7.	Maharashtra	30.8	12.4	40.0
8.	Madhya Pradesh	44.3	8.65	20.0
9.	Orissa	15.6	2.29	15.0
10.	Rajasthan	34.2	21.41	63.0
11.	Tamil Nadu	13.0	8.33	64.0
12.	Uttar Pradesh	29.4	4.38	15.0
13.	West Bengal	8.8	2.67	30
	Total	286.6	106.84	37
	other states union territories	42.2		
	All India	328.8	106.84	32.5%

The north-western parts of the country (like Rajasthan, Gujarat, Punjab) are particularly more drought-prone areas where the mean annual rainfall is lower than 70 cm (Beran & Rodier, 1985). The country was severely hit by droughts in the year 1907, 1911, 1918, 1920, 1939, 1951, 1965-67,1972-73 and 1979. The 1919 drought was widespread and destructive engulting 12 states viz. Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Himachal Pradesh, Rajasthan, Orissa, J & K, Punjab, Haryana, Uttar Pradesh and West Bengal where crops over nearly 35 million hectares were affected (Shrivastava, 1979). The severity and devastations of the 1965-67 droughts are born out by the fact that a huge amount of Rs.722 crores were spent in drought-relief measures in 156 affected districts of the country. The two consecutive droughts during the period 1971-72 and 1972-73 were no less destructive and widespread as nearly Rs.790 crores were spent in 227 affected districts (Jaiswal, 1981). Hence, the recurrent drought has considerably affected our national economy.

1.4.1 Level of Foodgrain Production in India:

The trend of foodgrain production in India during the period 1960-61 to 1979-80 has been shown in Table 1.2. It is seen from the Table 1.2 that the foodgrain production of India has considerably increased from 79.3 million tons in 1960-61 to 131 million-tons in 1978-79 (a year of very favourable rain). However, the agricultural production were badly affected during the period of severe droughts and erratic monsoon rains as is evident from the sharp declines in the level of foodgrain

Table 1.2: Trends in Food Production in India, (1960-61 to 1979-80)

Year	Food Production in million tons	Increase(+) or Decrease(-) over preceding year, percent
1960-61	79.3	-
1961-62	82.7	+ 4.28
1962-63	80.2	- 3.02
1963-64	80.7	+ 0.01
1964-65	89.0	+10.28
1965-66	72.3	-18.76*
1966-67	74.2	+ 2.63
1967-68	95.1	+28.17
1968-69	94.0	- 1.15
1969-70	99.5	+ 5.85
1970-71	108.4	+ 8.94
1971-72	105.2	- 2.95
1972-73	97.0	- 7.79*
1973-74	104.7	+ 7.94
1974-75	99.8	- 4.68*
1975-76	121.0	+21.24
1976-77	111.2	- 8.09*
1977-78	126.4	+13.67
1978-79	131.9	+ 4.35
1979-80	108.9	-17.43*

* Due to severe drought

Source: C.W.C. - Brochure on Drought (March, 1982).

production in some years. The two drought years of 1965-66 and 1966-67 had agricultural production of only 72.3 million tonnes and 74.3 million tons respectively, although in the preceeding year (1964-65) and in the following year (1967-68) the food grain production was 89.0 million tons and 95.1 million tons respectively.

1.5 DROUGHT - A RETARDING FACTOR IN DEVELOPMENTAL ACTIVITIES

The developmental activities are centred around the resources which are available in various forms around the centre of the activity. In other words we can say that the resource cycle plays very important part in the developmental activities and perhaps that is the reason why a resource planning and balancing constitute the most important component of the developmental planning of the region. One need not emphasize the role of water resources in various developmental activities and it is an established fact that the resource cycle gets greatly disturbed with the impact of drought.

Apart from shortages in the resources on short-term basis, the effect of drought on long-term basis is felt in many ways. For example the migrating tendency of the people residing in drought affected areas greatly affects the human resource development whatsoever. Temporary migrations are common features in drought years, though permanent migrations do take place at sometime. As a result, there is radical alterations of the existing social order; the public health gets deteriorated; sense of insecurity develops and and overall exploitation of the local people takes place. These factors on one hand restrict the development of society and on the other hand greatly discourage the planners to make large scale investment in the region. Drought has terrific impact on the human society because the very foundation of the economy is shaken. Obviously, the economic impacts of the drought are most significant of all other drought impacts. Over the years its impact has been felt in agriculture, urban water supply, industry, pollution control, energy production, recreation, navigability of rivers, negative impacts on fish and wild life etc. Reduction of crop production, cattle, industrial goods, hydro-power etc. are some of the major economic losses caused by the drought.

In addition to economic and socio-economic impacts of drought, there are many other impacts of drought which may be termed as'secondary drought impacts'. Some of the important impacts may be listed as soil erosion and resulting dust storms, forest fires, plant diseases, insect plagues, disease of personal and public hygiene, increased concentration of pollutants and consequent degradation of water quality, harmful effects on public health and wildlife, and deterioration in the quality of visual landscape. Yet another feature of chronically affected drought-prone areas is desertification. According to an estimate in the United States, each year about 70,000 sq.km of land in the world undergo desertification. The total area threatened is equal to that of the united states, Soviet Union and Australia combined (Yerjerick, et.al:1983).

The foregoing discussions clearly indicate how the developmental activities are retarded in drought-prone regions and perhaps that is one reason why the socio-economic gap is increasing day by day making the drought-prone areas more and more backward. This phenomenon is more pronounced on global level as majority of economically backward nations are unfortunately those regions which are prone to drought and other natural calamities.

These aspects have been realised by the Government and necessary actions have been taken to evaluate the development plans in drought affected areas with special consideration. For example the criteria of B.C. ratio of 1.5 for irrigation projects has been relaxed to 1.0 for economically backward and drought prone areas. Similarly, Irrigation Commission, 1972 has stressed upon extensive irrigation planning for drought prone regions instead of intensive irrigation.

1.6 DROUGHT - NEED FOR BETTER UNDERSTANDING AND READINESS TO FACE IT

Natural disasters are part and parcel of the human life and nature has in-built system to enable the human to overcome the disasters. No doubt, the shock and temporary losses remain. The drought as one of the nature's calamity is also a recurring phenomena and is bound to affect us in one way or the other. The impact of drought is felt depending upon the intensity of drought and the adaptibility of suffering masses. However, it remains a fact that drought is one of the basic reasons for the nation's backwardness. Further, the drought of ordinary and mild nature have, in general, a slow and long term effect and therefore they remain unnoticed although they have an equally harmful consequences. As compared to drought, other calamities for example a flash flood has short-term but tremendous effect on the human's society and as such they have always got a prominent reference in the history book of social development. Perhaps, this is one reason why drought and its related problem have always been studied and handled with least priority. It is only after a severe or dangerous drought that the society gets alarmed and short-term measures are taken up. And very often these measures never come as anti-drought measures but in the shape of comic relief. The real problem remains as such to torment the people in future.

The drought is a phenomenon whose management is possible only in two ways viz. - (a)better understanding of the phenomeron;and (b)readiness to face it. In the present stage of development, the question of modifying the drought problem like modification of flood by structural measures does not arise and hence one has to adopt the measure so that the impact of consequences of drought could be minimised.

It is, therefore, very reasonable and quite relevant to think that a proper understanding and scientific study of drought is extremely essential in view of its impact on a wide spectrum of social concerns. Under prevailing conditions there is no part of the science of hydrology which is more important than the quantative analysis of drought (Whipple, 1966). Hence, one of the most important factors which must be considered in any water resources system planning is to identify droughts which are likely to occur during the projected life of that system. The extreme values of drought play an important role in the future performance of any water resources system. A proper understanding of the nature and extent of the drought problem may facilitate the preparation of an appropriate and more realistic plan.

Unfortunately, the drought phenomenon is not sufficiently understood in terms of its characteristics and impact. Not only this, even its definition has been a matter of world wide controversy. It is not that the 'drought' has not been defined; but its proper definition taking into account its overall effects on human society is still eluding the world.

1.7 OBJECTIVE OF THE STUDY

Unfortunately, in India the studies related to drought are not in tune with the demand of the society. There are very limited studies and that too are very much restricted to specific disciplines. The need is to identify the drought conditions, its characteristics and impact with reference to the aspirations of the common man.

In this study an attempt has been made to :-

(a) review the available literature on drought and related aspects, and evaluate the findings;

(b) identify the drought characteristics and suggest suitable parameters to define these characteristics; and

(c) develop a suitable model to properly evaluate the intensity of drought and its consequences.

CHAPTER - II

DEFINITION OF DROUGHT AND ITS CRITICAL REVIEW

> "What is drought? If I am not asked I know what it is: if I want to explain it, I do not know how".
>
> - St.Augustine

Drought is essentially a situation in which the water availability is not enough to meet the expectations of the society. However, this description of drought is too simple to reflect the real picture. This is so not only because of the complex process of the hydrologic cycle but also due to factors such as (a)relative usage of the resources; (b)extent of consumption of different form of water; (c)degree of dependence on the output; and also among other things; (d)the socio-economic aspects of the society and its tolerance capacity. That is precisely the reason why the drought has been defined in many ways by different affected sections of the society, each section giving priority to the aspects which concern them most. For example, for a farmer the drought occurs when the crop production is less than a certain level: a meteorologist defines the drought as a situation under which the rain is less than normal: the drought, according to a hydro-geologist, occurs when the water level in the wells goes down a defined mark; and so on. Each of the opinions is true but only in limited sense. However, a proper understanding and a systematic and effective scientific investigation of drought problem requires a precise definition of the problem. Unfortunately, this initial step of defining the drought has proved to be a principal obstacle to the investigation of the problem (Yevjevich, 1967) as there are diversified ways of its definition by authorities of various disciplines. This is because of the fact that the notion of drought is not absolute, but relative to the usage and expectations of the people of a particular region. That is why the definition of drought becomes complex and controversial and an universally accepted definition is yet to be found. "..... We have no good definition of drought. We may say truthfully that we scarcely know a drought when we see one". (Tannehill, 1947)

No doubt attempts have been made by various researchers to study the various aspects of drought in order to evaluate the consequences in proper perspective but so far they have remained confined to a specific field of interest. For a water resources development planner, it is extremely essential to look into the problem in a very very broad perspective giving due weightage to different aspects and keeping in view the overall objective of the social development. An attempt has been made in the following sections to review the various approaches which are directed towards defining the drought.

2.1 DROUGHT FOR A COMMON MAN

In the abridged version of Advanced Learner's Dictionary of current English, drought means "continuous (period of) dry weather causing distress; want of rain". The Chamber's

Dictionary describes drought as "dryness; want of rain or of water; a condition of atmosphere favourable to drying".

Generally, the drought in literary term means scarcity which is taken with respect to water. However, the shortage of water either in the form of rain or riverflow or ground water creates the situation of drought the moment it adversely affects the crop production or becomes insufficient to meet the day-to-day demand such as drinking water requirement, industrial water needs etc. In case the shortage of water of a region can be balanced by transfer from any other region having surplus water then the drought condition may not occur. In other words, for a lay man, it is not the scarcity of water but the adverse effects of the scarcity which matters. That is precisely the reason why the term 'scarcity' gets changed from region to region depending upon the condition of water deficiency which results in hardships and sufferings to the people residing in a region. For example, in U.S.A. a commonly used definition was "a period of atleast 21 consecutive days when rain is less than the normal for the place and time" (Gibbs, 1967). With a slight difference, Hoyt (1936) also says the samething - "In the humid and semi-arid climate droughts do not result until annual precipitation is as low as 80% of the mean". However, a prolonged lack of precipitation less than average is often an objective measure of drought conditions. (Russel et.al.1970). In Bali,"a period of 6 days without rain is drought", whereas in Libya, "droughts are recognised only after 2 years without rain" (Hudson & Hazen, 1964). In Egypt, "any year the Nile river does not flood is drought, regardless of rainfall". The word drought in Australia is used to signify a period of months or years during which little rain falls and the country gets burnt up, grass and water disappear, crops become worthless, sheep and cattle die" (Campbell, 1976). In India, drought is a situation of less rain during the monsoon period leading to failure of crops and fodder. It is partly because of the fact that the Indian farming is still very much dependent upon rain. As a matter of fact certain regions of India are in the grip of flood-drought - flood syndrome. However, the definition of drought in India varies considerably from one part to other. But the fact remains that it is basically the failure of crops due to shortage of rain water (or more appropriately irrigation water) at the critical time.

The foregoing discussions clearly indicate that the drought must be understood in view of its impact and the sufferings which a common man has to face. And, hence the various factors leading to these sufferings are to be properly evaluated and incorporated in the studies which are directed towards drought and its alleviations.

2.2 METEOROLOGICAL DROUGHT

Of the various variables which affect the drought, the rainfall is no doubt the most significant one. And perhaps this is the reason that most of the definitions of drought, particularly of earlier period, do incorporate the amount of rain, its duration and intensity. The earliest definition (Russel, 1896) of drought is "a period of months or years during which little rain falls". In early 20th century, Brounov defined drought as "the conditions as a result of rainfall of less than 5 mm in 10 days". Similarly, "15 days with no rain were considered to be drought in U.S.A."(Cole,1933). However, Bates (1925) feels that annual precipitation/monthly precipitation of 75%/60% of normal may create a situation like drought.

Only a few of the many definitions have been cited in above para with an objective to illustrate how the concept of linking the drought with rainfall emerged. With further studies, other characteristics of rainfall, and also the hydro-meteorological parameters affecting the rainfall were incorporated in defining the drought. Temperature is another meteorological variable which is very frequently used in the definition of drought parameter. This again is perhaps because of the fact that the temperature variation directly affects the human being particularly in increasing or decreasing the level of water consumption in almost all the spheres of life viz. drinking water, irrigation water, municipal water etc. Temperature was used in defining a precipitation factor by Lang (1915) and also in defining index of aridity $I = \frac{P}{t+10}$ by de martonne(1926); where

I = index of aridity;

P = monthly precipitation (mm); and

t = temperature in ^{o}C

Similarly, other hydro-meteorological parameters have been incorporated in the definition of drought from time to time. A comprehensive list of definition of drought or the associated concept of drought as suggested by various authors for different regions has been given in annexure II(W.M.O.1975).

A look at the various hydro-meteorological definitions of drought will indicate that in most of the cases the definitions are based on local conditions and the basic concept is to demarcate the limit of rainfall amount, duration and its intensity, temperature; and other soil moisture conditions etc. beyond which the human sufferints start. In some cases these definitions are very vague and also contradictory to some other definitions. Therefore, it is very difficult to accept any of these definitions as the real indicator of drought conditions in a general way. Further, the definitions are greatly handicapped in taking into account the factors other than hydro-meteorological factors which are equally important so far as the sufferings of common masses are concerned.

Indian meteorological department has defined drought"as a situation occuring in a sub-division in a year when the annual rainfall is less than 75% of the normal". Further, when the deficiency of rainfall is above 50% of the normal it is termed as severe drought. Likewise Ramdas et. al(1950) defined the drought as a week with actual rainfall equal to half the normal rainfall or less (cited from W.M.O.1975). Ramdas (1960) considered a year as drought affected when rainfall is less than normal by twice standard deviation of the series. However, drought as such has no significance until and unless it is viewed in terms of its consequences on various aspects of the human activities. If there is not so good rainfall but reasonably distributed over the monsoon period then there is every likelyhood that drought may not occur at all even though there is no rainfall during the rest period of the year or annual rainfall is less than 75% of normal rain. In India during a crop season (particularly in Kharif season) there may not be any rainfall for weeks altogether and still a drought like situation may not occur. This is because of the fact that it is the period of rainfall suitable for a particular purpose which matters most and not the total amount of rainfall or the number of weeks without rainfall. There are lot of instances when the annual rainfall is well above 75% of normal rainfall and still the year has been declared as 'drought year'. For example in Palamu district (Bihar) during the period 1950-80, the years which have been declared as drought year, are given below along with annual rainfall. The normal annual rainfall of Palamu is 1194.75 mm and 75% of it works out to be 896 mm.

S.N.	Year	Annual Year(mm)
1.	1950	1143.23
2.	1951	1101.40
3.	1952	1078.13
4.	1954	837.53
5.	1955	757.23
6.	1956	1145.67
7.	1957	1057.07

8.	1958	1239.47
9.	1965	1088.00
10.	1966	505.30
11.	1972	903.85
12.	1979	757.30

From above, it may be seen that out of 12 declared drought years the rainfall is less than or equal to 75% of the nromal only in case of four years viz, 1954, 1955, 1966 and 1979. Obviously, the criterion of the annual rainfall being less than or equal to 75% of the normal rainfall for drought fails to project the correct situation. Similarly, according to the definition given by Ramdas (1960) only one year viz.1966 can be considered as drought year as well other years have rainfall more than ($\bar{p}$ - 2 σp) where $\bar{p}$ = average annual rainfall, p = standard deviation.

It is, therefore, evidently clear that meteorological definitions of drought are of little significance for all practical purposes.

Similarly, the definition given by the British Rainfall Organisation, "as a period of atleast 15 consecutive days none of which has created rainfall of 0.01 inch or more" (Heathcote, 1973) also does not appear to be very significant atleast from the point of view of Indian conditions. However, the definition suggested by the U.S.Bureau of weather is more comprehensive though very general in nature. According to this definition the drought is "lack of rainfall so great and long as to affect injuriously the plant and animal life of a place and to deplete water supplies both for domestic purposes and for the operation of power plants, especially in those regions where rainfall is normally sufficient for such purposes" (Haven, 1954).

But even this definition is very very specific without considering the overall factors responsible for and leading to drought. For example, this definition obviously may not hold good for regions where water resources potential(both surface as well as ground water) have been efficiently exploited and managed.

2.3 HYDROLOGICAL DROUGHT

In the recent Glossary of Meteorology drought has been defined as "a period of abnormal dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance i.e. crop damage, water supply shortage etc. in the affected areas". It is further stated therein that the term should be reserved "for periods of moisture deficiency that are relatively extensive in both space and time". V.Yevjevich (1967) defined drought as a "meteorological phenomenon that occurs when precipitation and/or natural runoff in a given period are less than normal, and when this deficiency is sufficiently great and prolonged as to damage human activities". Hence, the droughts are associated with water deficits of prolonged duration and large areal coverage with large impacts on a region.

Obviously the definition of drought remains incomplete unless the scope of utilisation and availability of the potential surface and ground water resources is duly accounted for. Many authors have considered the role of hydrology in drought and have emerged with definitions of drought which are commonly referred to as 'hydrological drought'.

A hydrological drought occurs when there is marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers, cessation of spring flows and fall in ground water levels.

V.Yevjerich (1967) defined hydrological drought as "the deficiency in water supply on earth's surface, or the deficiency in precipitation, effective precipitations, run-off or in accumulated water in various storage capacities".

In hydrological drought the effective rainfall is determined by the portion of rain that escapes through the surface or sub-surface drainage. Hydrological drought may also be reflected in depleted snowmelt due to poor snowfall in an earlier season as a result of which the hydro-power generation may be reduced and industry as well as agriculture may be affected.

Whipple (1966) has described drought as "prolonged periods of stream runoff averaging less than the long term mean". Since he has considered only the flow in rivers, his definition may well be classified as 'hydrological drought'. Quite often, a hydrological drought is defined as a drought when the runoff is less than 75% of the normal runoff. A typical text book definition of drought has been given by Linsley et. al.(1975) as a 'period during which stream flows are inadequate to supply established uses under a given water management system'.

As mentioned earlier it is definitely necessary to incorporate the hydrological conditions in the definition of drought as the river flow or the ground water is very vital to the society. However, the other factors particularly the hydro-meteorological factors which in many cases directly affect the agriculture in India, can not be overlooked. Therefore, the definition of drought based on the shortage of streamflow etc. alone cannot depict the overall conditions which lead to drought. However, it may be very important in case of a region where the developmental activities are centred around a water resources development scheme and agriculture and other activities are, by and large, fully dependent on river flow. Even in such cases a general criterion of annual runoff being less than a specified limit does not appear to be appropriate as the water availability as well as its utilisation are highly variable in time.

Unfortunatly, most of the definitions of hydrological drought are based on the quantum of annual river flow without taking into account its time distribution and its utilisation.

As descussed in earlier sections the drought must be viewed from the point of view of sufferings caused by deficiency of water resources and its erratic nature. For an agriculture based society like ours, a very important factor is the agriculture produce which can not be ignored while evaluating the drought conditions.

2.4 AGRICULTURE DROUGHT

In para 2.2 and 2.3, drought has been defined in terms of rainfall (meteorological drought) and runoff (hydrological drought). These definitions, however, do not take into consideration the 'soil-moisture' which is the most vital for the plant's life. With this aim in view, many investigators have given the definition of drought in terms of soil-moisture which may be termed as 'agricultural drought'. An agricultural drought may be defined 'as a prolonged abnormal moisture deficiency' (Palmer, 1965). Landsberg(1927) stated that 'drought begins when plants can no longer recoup water from the soil as quickly as it is lost by transpiration'. It is, therefore, obvious that an 'agricultural drought' is of prime importance as far as India is concerned where nearly 80% of the population is engaged in agriculture for their livelihood.

"A day on which the available soil-moisture was depleted to some small percentage of available capacity" was considered as drought by Van Bavel & Verlinden (1956), while Thornthwaite (1947) defined drought "as a period of dryness i.e. want of rain or water, specially such dryness of weather or climate as affects the earth and prevents growth of plants". All these definitions point out only the soil-moisture deficiency and not the extent or particular period of soil-moisture deficiency which is more important from the plant's growth point of view. The water requirement of plant is different for different plants and so are the critical growth stages during which lack of water has most adverse effect on the growth of plants. It can, therefore, be said that an agricultural drought is caused by an inadequate amount of soil water available over a critical time period of crop growth. So, a study of agricultural drought should take into account the types of the crop, their rooting depth, the characteristics of the soil and the meteorological factors that affect the moisture supply and demand. Hence an agricultural drought occurs as a result of prolonged shortage of moisture in the root zone of crops (particularly during the critical plant growth stages) due to irregular or erratic rainfall. Obviously, agricultural drought will depend upon the density and distribution of plant, animal and human population, their life-styles, their use of the land as much as on rainfall deficiency. So, an agricultural drought may be distinguished from 'hydrological drought' by a difference in concept of 'effective rainfall'. In agricultural drought the effective rainfall is that portion of the rain which is retained in the root zone, while in hydrological drought it is the portion of rain which appears as surface or sub-surface run-off. Agricultural droughts are common both in humid and semi-humid areas and can be identified during the period when the crops are in greater water needs while the rainfall and soil-moisture are together incapable to sustain the existence and growth of crops to maturity causing extensive soil stress and wilting. United Nations Drought and Relief Organisation (UNDRO) has recognised the agricultural drought as one of the worst disasters. It is difficult to identify its exact start or termination. Its duration may be very long and indefinite but its creeping spread may be very vast in extent with devastating impact over an entire area or over an entire continent.

2.5 DROUGHT AND SOCIO-ECONOMIC FACTORS

In the foregoing sections, the factors which directly affect in creating a drought like situation have been discussed and the various definitions of drought based on these factors have been described. But the impact of drought of same intensity will vary from society to society depending upon the socio-economic conditions of the society, the resisting capacity of the peopleresiding in the region and also on the geographical heterogeneity. Of these, the socio-economic factors are very important and it has been seen that with the economic development the resisting capacity of a nation to fight a drought increases. No doubt the vice-versa also holds good and the economic development of the country is, to a great extent influenced by the degree to which the area is prone to natural calamity like a drought.

It is, therefore, necessary to examine as to how the droughts are looked upon by economist and social reformers.

The economist views the economic drought from entirely a different angle. In an economic sense 'drought may mean a water shortage, which significantly alters or disturbs the established production and water uses'. It may, however, be said that 'economic drought' is a situation when the production falls below expectations. Sociological drought may be defined as 'the meteorological hydrological conditions under which there is less water available than is anticipated and relied on for the normal level of socio-economic activity of the region. Hence, economic and sociological droughts are defined in terms of the effect or impact of various variables characterising a drought on the social well being in general; whereas a physical drought is defined in terms of various hydro-meteorological characteristics.

The above discussions very clearly show that the drought must be looked in totality and not merely in terms of a specific factor causing the droughts.

2.6 NEED FOR DEFINING DROUGHT IN PROPER PERSPECTIVE

If all the definitions of drought proposed by various investigators are compiled, it may well cross the century mark. These definitions at the same time reflect very diverse view points and quite a few may turn out to be contradictory to each other. But basically, all of them are based on lack of water due to prolonged weather conditions and the consequent adverse effects on various water uses. However, for the same water use the concept of drought may change with time, place and specified need. For example, a drought for the grower of sugarcane may not necessarily be a drought for the grower of maize. Similarly, the same percent of shortage may not cause the similar adverse effects for Rajasthan and Assam. So, it can be suggested that drought only occurs to the poeple, their uses and needs. Corrodus (1967) stated that "......a stable eco-system is in equilibrium with the stresses of its environment including restricted water supply. Man endearers to draw out of the system more than was being produced previously and the effects of water shortage become exaggerated under these conditions". It is, therefore, evidently clear that the time and space processes of water supply and water demand are the two basic processes that should be considered for an objective definition of drought (V.Yevjerich, 1967). So, a comprehensive definition must be based on 'supply and demand'(need) concept. In this connection, the definition given by Dracup, Lee and Paulson Jr. incorporating the above concept may be called as a comprehensive one...."Drought is a water shortage with reference to a specified need for water in a conceptual supply and demand relationship". Zekaisen (1980) while modifying the Palmer's (1965) drought definition also reflects the same concept....."The interval of time generally of the order of several days, months or years in duration during which the actual water supply at a given location rather consistently falls short of the demand." Hence, it can be suggested that a single or a general definition of drought is not possible for all water uses and conditions. Even if there were a quantitative definition of drought applicable to all purposes, it would be too generalised to be used for practical purposes. However, even though there may be different drought definitions suiting different purposes, an underlying criterion for their choice can be standardised. Dracup, Lee and Paulson Jr. (1980) have suggested the following set of decisions necessary to develop an accurate, practical and analytical definition for 'drought':

1. Is the primary interest in precipitation(meteorological drought), stream flow (hydrological drought), or soil moisture (agricultural drought) ?

   That is, selection of the nature of water deficit to be studied.

2. What is the fundamental averaging period of the time series to be studied (e.g. month, season or year) ?

   That is, selection of the averaging period used to discretise a continuous time series.

3. How are drought events distinguished analytically from other events in the time series ?

   That is, selection of the truncation level used to separate droughts from the remainder of the time series (mean or median).

4. How are the regional aspects of droughts to be considered in the study ?

   That is selection of the methods of analysis (regionalisation or standardisation).

In addition, it would be also necessary to evaluate the consequences of drought from socio-economic consideration incorporating the factors responsible for these consequences in appropriate manner in the definition of drought. Therefore, it is necessary to analyse the time series of various variables affecting the drought, and the dependent variables which are consequently affected by drought. The major variables are to be selected in view of the socio-economic conditions of the region. The analysis should be used to identify/derive suitable parameters which should be considered in defining the drought in proper perspective. In brief, attempt must be made to identify the drought characteristics and then to identify suitable parameters to depict the characteristics from the socio-economic consideration.

CHAPTER - III

DROUGHT CHARACTERISTICS

It is evident that drought as such should not be viewed from any specific consideration such as meteorology, hydrology, agriculture etc. It has already been discussed that the definitions of terms like hydrological drought, meteorological drought, agricultural drought are incomplete and do not represent the real picture. No doubt, some of the definitions are quite comprehensive and in a general way cover the salient features of drought but these are very general in nature. Obviously, such qualitative descriptions may not be of much help for practical purposes. For a correct evaluation of the situation it is necessary to have quantitative assessment in terms of the characteristics of important variables which would lead to drought-like situation. Hence, it is of utmost importance to carry out the necessary studies in respect of:

(a) Identification of variables which play major role in development of drought-like situation;

(b) Identification of the characteristics of these variables; and

(c) Development of suitable relations duly incorporating the characteristics of identified variables in order to define drought both qualitatively and quantitatively.

For this, it will be equally necessary to evaluate and quantify the consequences of drought so that the objective is properly defined.

3.1 CONSEQUENCES OF DROUGHT

Although drought is essentially a physical phenomenon, an outcome of some hydrological or hydro-meteorological imbalances, it can well be said as a social, economic and environmental phenomenon of great importance due to its ultimate consequences on a wide range of socio-economic activities of a region.

During drought period, due to lack of water agricultural activities are highly distu bed as a result of which the crop production badly suffers. Similarly, due to low water availability, the hydro-power generation is adversely affected. This in turn has impact on many power based industries apart from the industrial units which are directly hit because of shortage of water supply. Further, due to reduce crop production many agriculture based industries are affected. Those industries which are directly dependent upon agricultural production like fertiliser manufacturers, food processors etc. suffer economic losses on account of drought.

Furthermore, the timber production may also suffer due to forest fires, tree diseases, insect infestation, impaired productivity of forest land. Due to insufficient flows in the rivers, streams and ponds, fisheries activities are also affected.

The causes and consequences of drought can be represented in brief as shown in Figure 3.1.

3.1.1 Social Consequences of Drought - Global Impacts:

The drought is, in general, viewed in isolation for a region. No doubt, a number of consequences are restricted to a particular region which is considered to be so-called 'drought-prone' or 'drought-affected' area. And most of the measures to combat drought in the form of relief-measures or otherwise are suggested for local region only. However, it is very much essential to look at the drought not in isolation but in totality and hence the consequences of drought must be viewed in broader perspective that is at state level, nation level and at global level. The range of possible social consequences has been nicely depicted in Figure 3.2 (Yevjerich, 1983).

The various consequences as discussed above should be critically reviewed in view of socio-economic profile of a region and then they must be rated to assign priority in drought alleviation measures. The definition of drought for the specific region must, therefore, incorporate the consequences in terms of their rating.

3.2 FACTORS CAUSING DROUGHT SITUATION

No doubt the lack of water for a prolonged period is the prime factor responsible for the occurrence of a drought situation. But this is not all. The shortage of water in terms of its volume alone may not sufficiently describe the drought

Likewise, economic losses accrue to dairy industries also because of unavailability of water and fodder to the cattle.

From social point of view also, drought has manifold consequences. Due to large scale reduction in the crop yields and consequent impact on other allied agricultural activities, a sense of insecurity grips the general masses particularly the people who depend entirely on agriculture for their livelihood. Hence, the problem of unemployment crops up and in many cases people are forced to migrate to some other places in search of food, job etc. Sometimes due to recurrent phenomenon of drought the people are forced to change their life styles in order to cope with the consequences of drought. Apart from these, the problem of public hazard may also be created due to increase of pollutant concentrations and diminished sewage flows. Because of malnutrition, people may face various disease problems. One of the worst effects of drought is felt in drinking water/municipal water supply which leads to miseries of general people.

Drought has also environmental impacts which may be manifested in damage to animal species, fish species, plant species etc. The quality of water is affected due to increase of salt concentration. Air quality also suffers from dust, pollutants etc. Damage to wild life habitat may be other consequences of a drought. The scenic landscape may also be affected due to loss of vegetative covers etc.

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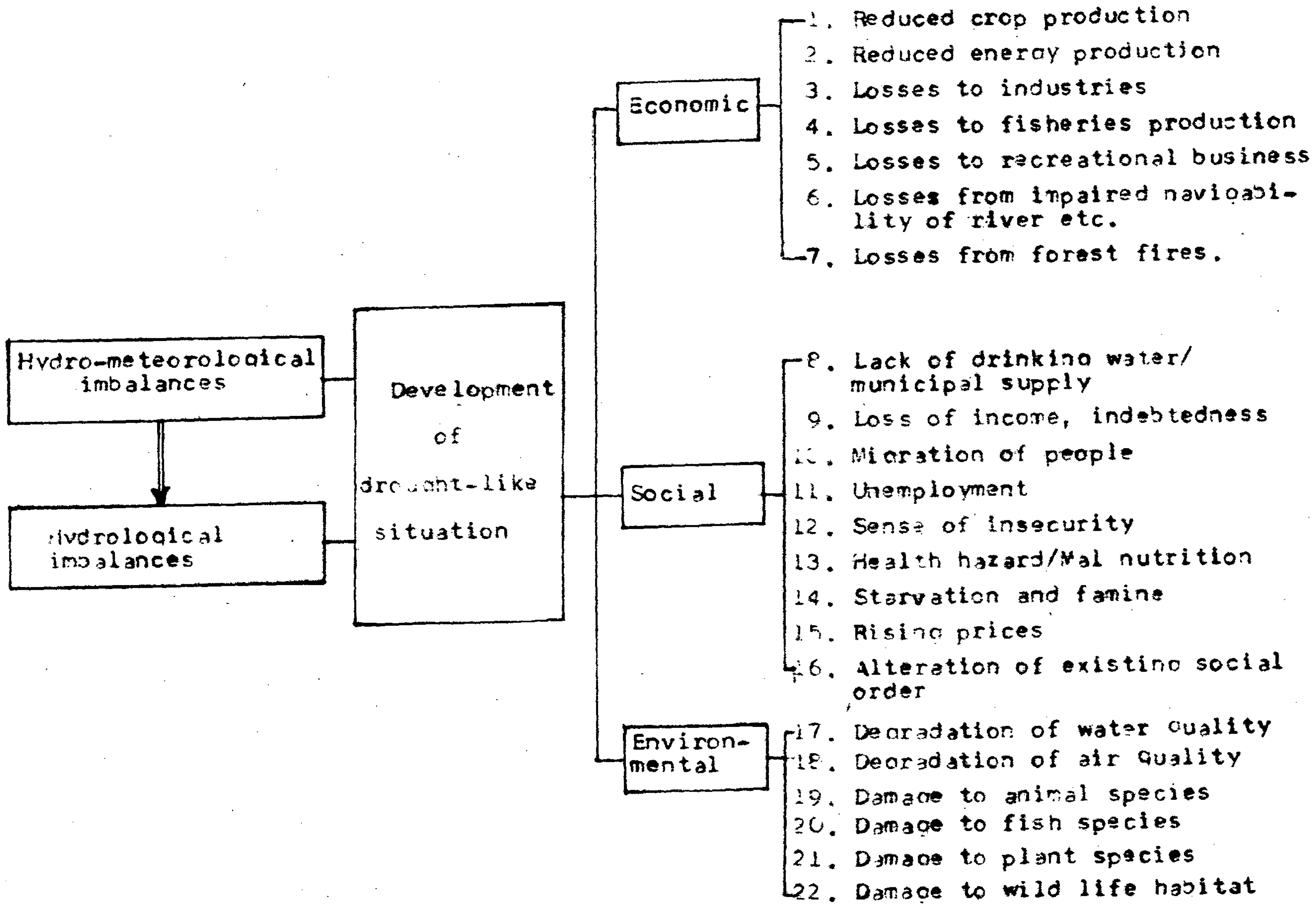

Fig. 3.1 Causes and Consequences of drought

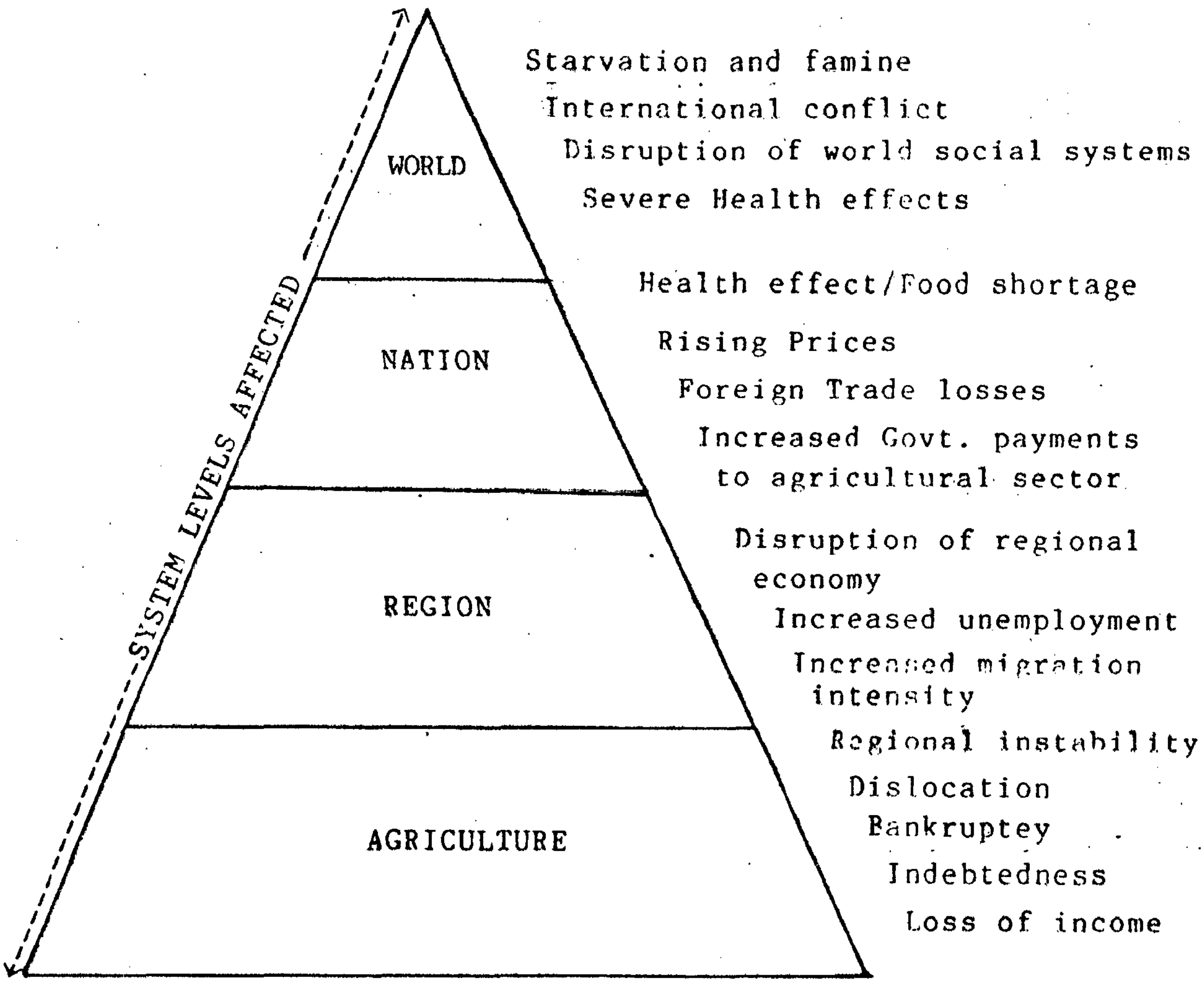

FIG. 3.2 RANGE OF POSSIBLE SOCIAL CONSEQUENCES

situation. The form of utilisable water that is the rain water, the river flow, the canal diversions, the water from wells and other sources vary from place to place and also how developed the region is. Similarly, the degree of dependence of people residing in the region also varies considerably. The shortage of different forms of water along with the degree of dependence of society is, therefore, very important.

Further, the demand of water in its various forms again varies considerably with time. For example, the demand of municipal water is more in morning and evening hours; the industrial water requirements are, generally, restricted in certain hours; and the irrigation water requirements have definite critical period for various crops when the water supply becomes more important. It is, therefore, necessary to give due importance to the time distribution of the demand and availability of water. This will be illustrated from two typical examples:

(a) The rainfall in a region in a year is, say, about 80% of the normal rain but this amount is proportionately distributed over the kharif season with respect of demand in different months.

(b) The rainfall is almost equal to the normal rainfall of the region but majority of rain is concentrated in the month of August and early September with negligible rain in the month of July and early October.

Obviously, for a farmer who fully relies on the rains, the conditions at (a) is more favourable than that at (b).

The critical periods of crop production are the periods when even marginal shortage of water has very adverse effect on crop production. This period, therefore, must be given more weight as compared to other periods. Similarly, the need for municipal water is to be given priority over other usage of water in an urban area, whereas the irrigation water has over-riding priority in an agriculture based area. Yet another factor which is very important, is the condition prevailing in previous years. It is well known that the droughts are mostly a part of the drought cycle. This sort of drought cycle is nothing but the chain effect of previous year's condition.

The drought, therefore, must not be looked only in terms of a single parameter that is quantum of shortage of rain or river flow. Any proper definition of drought should incorporate all the above factors.

3.3 IDENTIFICATION OF PARAMETERS TO DEFINE THE DROUGHT SITUATION

As discussed earlier, the drought conditions of an area must be evaluated in terms of the specific objectives which are to be decided in view of socio-economic conditions of the area. However, these objectives which appear in the form of output viz. shortage of food grains, health hazard problem, shortage of drinking water, closure of industries etc. must be correlated to such parameters which reflect the characteristics of factors leading to such drought conditions. The identification of such parameters becomes necessary to have an advance estimate of the forthcoming drought event and in taking necessary measures such as water management etc. to reduce the adverse effects of drought. This is also equally important to incorporate the features of drought in any water resources planning for the region.

Some of the commonly used parameters to define drought include:

(a) Mean of the annual rainfall
(b) Mean and standard deviation of the annual rainfall.
(c) Mean of the annual river flow
(d) Mean/Mean and S.D. of other hydro-meteorological parameters such as temperature, humidity etc.

In some of the cases the variables such as soil moisture conditions etc. are also used. But in most of the cases only the annual values are taken into account which do not reflect the situation in respect of the following factors:

(a) Time distribution of the input variable that is rain or runoff;
(b) the time distribution of planned/proposed water utilisation;
(c) priority of different uses of water such as irrigation, municipal, industrial etc;
(d) period-wise priority of water use for each of the purposes separately;

However, this parameter primarily reflects the total deficiency in the input sequence(s) which affect the conditions leading to drought. Obviously, this is not sufficient to reflect the overall conditions, as only one out of various factors is reflected by the above parameter. This can be improved to some extent by using the cumulative absolute variation of each period.

Cumulative Absolute Variation, CA_D

$$CA_D = \sum_{i=1}^{n} V_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3.2)$$

Where V_i = Variation in input sequences in period i.

This parameter, no doubt, reflects the total variations as well , but does not differentiate between the drought and the flood situation. Therefore, it is not likely to serve as a good indicator of the drought conditions.

Sum of the Squares of the Monthly Variations:

Yet another parameter which is very commonly used in statistical analysis is the sum of the squares of the variations in different time period, i.e.

$$SE_D = \sum_{i=1}^{n} V_i^2 \qquad \ldots\ldots\ldots\ldots\ldots(3.3)$$

However, this parameter also suffers from the same deficiency as in case of the cumulative absolute variation,

(e) the conditions of previous years.

Further, the commonly used factors are based on a specific variable without any regard to the drought consequences which is very important. This is more so because the drought consequences vary from place to place and the nature of drought gets entirely changed in different socio-economic conditions.

In view of the above, it may be concluded that the existing parameters are insufficient and it may be necessary to identify some additional parameters which reflect the drought in proper perspective.

3.3.1 Commonly Used Statistical Parameters:

In order to reflect the above mentioned drought features some of the commonly used statistical parameters which may be considered are described below:

Annual Deficiency, D_A

$$D_A = \sum_{i=1}^{n} V_i = I_A - R_A \quad \ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, V_i = Variation in the input sequences in period i i.e. the difference between the actual input sequences and the desired input in period i,

I_A = Total of the each ith period's actual input sequences.

R_A = Required or desired input over the whole period, n.

However, this parameter primarily reflects the total deficiency in the input sequence(s) which affect the conditions leading to drought. Obviously, this is not sufficient to reflect the overall conditions, as only one out of various factors is reflected by the above parameter. This can be improved to some extent by using the cumulative absolute variation of each period.

Cumulative Absolute Variation, CA_D

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$$SE_D = \sum_{i=1}^{n} V_i^2 \qquad \ldots\ldots\ldots\ldots\ldots(3.3)$$

However, this parameter also suffers from the same deficiency as in case of the cumulative absolute variation,

CA_D. It has, however, the advantage of assigning more weight to extreme conditions.

3.3.2 Improvements in the Commonly used Statistical Parameters:

The major deficiency in the above parameters which renders them unsuitable in drought analysis is their inability to differentiate in the droughts and the flood conditions. This can be improved by using the following modified parameters:

$$DD_A = \sum_{i=1}^{n} X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where, DD_A = annual deficiency leading to drought

X_i = V_i i.e. variation in the input sequence in p period'i when V_i 0

= 0 when V_i 0

This parameter as a matter of fact, reflects the sum of the deficiencies of input (rainfall, runoff etc.) in different periods i.e. the surpluses are eliminated. However, the following three important factors are not properly accounted for in the above parameter.

(a) Time distribution of the total deficiencies,

(b) the relative importance of various time i.e. the critical period of different uses during which deficit of water has most adverse effects; and

(c) the deviations from the normal conditions prevailing in different periods.

Therefore, the above parameter can be further improved as follows:

$$DD_N = \sum_{i=1}^{n} K_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where DD_N = the deviation leading to drought situation in relation to the normal conditions prevailing in the different periods,

$$K_i = |(V_i - \bar{V}_i)| \quad \text{if } (V_i - \bar{V}_i) < 0$$

$$= 0 \quad \text{if } (V_i - \bar{V}_i) \geq 0$$

V_i = Variation between the input sequence at period i and the required input at period i

$\bar{V}_i$ = the average of the variations in ith period as obtained from the historical data.

This improvement accounts for the normal conditions prevailing in the region and hence it is likely to reflect the resisting capacity of the society to combat drought. However, it is necessary to incorporate further improvements to account for the relative impact of deficiencies in different periods in the same year.

The factors at equation (3.4) and equation (3.5) can be further improved by introducing another term w_i - weight for the ith period in the following way:

$$WDD_A = \sum_{i=1}^{n} W_i * X_i \qquad \text{.........(3.6)}$$

Where WDD_A = weighted annual deficiencies affecting the drought

W_i = weight assigned to the period i

X_i = V_i i.e. variation in the monthly input sequences,

when $V_i < 0$

= 0 when $V_i \geq 0$

and,

$$WDD_N = \sum_{i=1}^{n} W_i * K_i \qquad \text{..............(3.7)}$$

Where WDD_N = weighted annual deviations leading to drought situation in relation to the normal conditions prevailing in the different periods,

$$K_i = |(V_i - \bar{V}_i)| \text{ if } (V_i - \bar{V}_i) < 0$$

$$= 0 \quad \text{if } (V_i - \bar{V}_i) \geq 0$$

V_i = Variation between the input sequence at period i and the required input at period i,

$\bar{V}_i$ = the average of the variations in the ith period as obtained from the historical data.

W_i = Weight to be assigned to ith period.

The weight W_i for different periods can be assigned with reference to the importance of respective periods.

The equation (3.6) suggests a parameter which takes into account most of the important factors leading to drought. However, this can be further improved by including a factor in respect of overall conditions prevailing in the year.

3.3.3 Suggested Parameters:

The overall conditions prevailing in the year can be taken into account by multiplying WDD_N by the ratio of the normal annual conditions of the input sequence to the actual value of the input in the year i.e. R_r. Thus, the 'effective deficiency' which is likely to represent the drought conditions reasonably may be given by:

$$\text{Effective Deficiency, ED} = R_r \sum_{i=1}^{n} W_i * K_i \quad \ldots\ldots(3.8)$$

Where, W_i = weight to be assigned to ith period

$$K_i = |(V_i - \overline{V}_i)| \quad \text{if } (V_i - \overline{V}_i) < 0$$
$$= 0 \quad \text{if } (V_i - \overline{V}_i) \geq 0$$

V_i = variation between the input sequence at period i and the required input at period i.

$\overline{V}_i$ = the average of the variations in the ith period as obtained from the historical data.

$$R_r = \frac{\text{the normal annual conditions of the input sequence}}{\text{the actual input in the same year}}$$

In case, the extreme conditions play vital role in development of conditions like drought then the effective deficiency can be reflected by:

$$ED_e = R_r * \left[\sum_{i=1}^{n} (W_i * K_i)^2 \right]^{\frac{1}{2}} \quad ....(3.9)$$

Where ED_e = effective deficiency with extreme conditions duly represented;

and K_i, W_i, R_r have their meanings as explained in case of equation (3.8).

The above discussions clearly indicate that there is considerable scope for improvement in defining the drought conditions by incorporating the various characteristics of the factors leading to drought in a suitable equation. Equations (3.8) and (3.9) appear to be quite comprehensive and include the important features of drought.

The above parameters have been developed for a selected region and the effectiveness of each of them has been evaluated, the details of which are discussed in Chapter - V.

CHAPTER - IV

Some of the factors which are likely to cause drought have been described in the last chapter. With a view to further explaining the above parameters and to evaluate their suitabilities the data of a drought prone district of Bihar have been collected and analysed. While selecting the area, the following points were kept in view:

a) The area represents a typical drought prone region of India, where drought is always a recurring feature;

b) The necessary data are available for carrying out the proposed studies;

c) The input sequences which are to be considered in evaluating the drought situation are few and simple in nature;

d) The region as a whole is homogeneous both from the hydrological as well as social considerations; and

e) The drought constitutes the major form of natural calamity and hence the major reason for the non-development of the region.

Keeping in view the above factors, Palamu was considered as a case study. It is one of the backward and chronically drought affected districts of Bihar and has considerable percentage of tribal population. The population is agricultural based, the agriculture mainly depending upon rain. The irrigation schemes have been planned but not yet fully implemented. The area was taken up for development under the drought prone Area programme of the Ministry of Agriculture and Irrigation, Government of India.

4.1 DESCRIPTION OF THE STUDY AREA

The district of Palamu is the fourth largest district of the state of Bihar with a total geographical area of 12,019.90 sq.km. It forms the north-west corner of the Chhotanagpur Division and lies between 23°20' and 24°39' N latitudes and 83°22' and 85°00' E longitudes. The district is cut into two approximately equal parts by the river Koel which after flowing from east to west in the south of the district, turns north and eventually joins the river Sone at the northern boundary of the district. The district is drained by the river Sone through its tributaries Koel, Kanhar, Auranga, Amanat and Sadabah. The river Sone forms the northern boundary of the district while the Kanhar river forms part of the south-western boundary (Figure 4.1).

The district has total culturable area of 5,46,785 ha (45.49%) while the grass sown area is 3,28,019 ha. The nature of soil is highly variable from village to village and plot to plot. The important type of soils found are heavy clay, sandy soil and loam soil. The major crops cultivated are rice, wheat, maize, pulses, sugarcane and oilseeds etc.

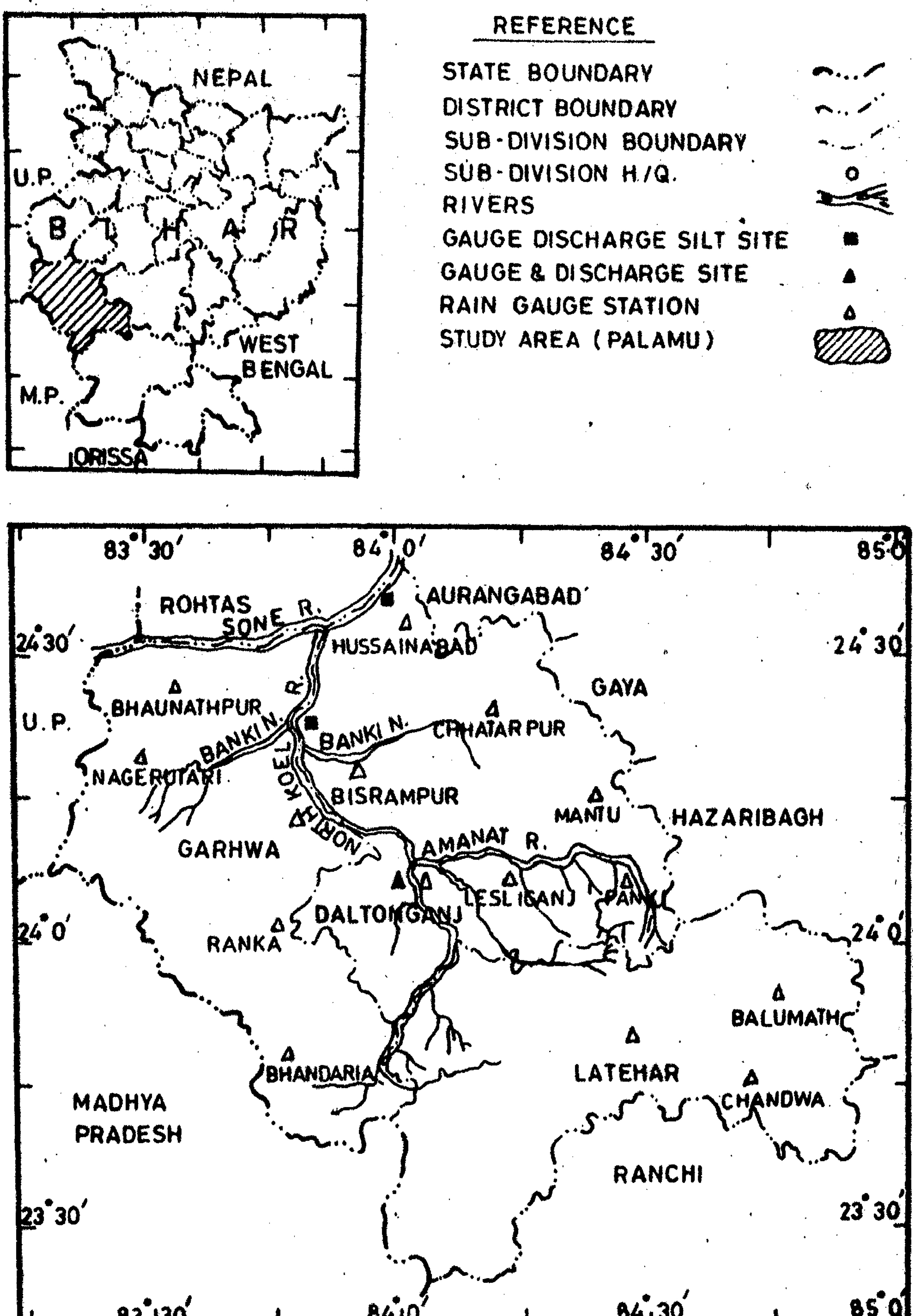


Figure 4·1 - Index Map of Palamu District

4.1.1 Socio-Economic Profile:

Population and Employment: In 1981, the total population of the district was 19.16 lakh (an increase of 27.4% over last 10 years since 1971). Out of this population 18.08 lakhs or 94.36% people lived in villages and 1.08 lakhs or 5.64% lived in cities or towns. However, a steady shift towards urbanisation has been noticed in the last few decades. Figure 4.2 shows the percentage of population living in rural and urban areas. The district comprises 3583 nos. of villages with 5 nos. of towns.

The average density of pupulation in the district has been reported as 159 per sq.km. As per available report only about 32.83% of the population of the district as a whole have some sort of jobs. So, on an average one person has to earn for three. The percentage of non-workers is more or less similar for the rural area also where 67.19% of the rural population has been found as non-workers. The corresponding figures for the urban areas have been reported as 25.15% workers and 74.85% as non-workers. The cultivators and agricultural labourers in the district formed 27.55% of the entire population which works out to be 85.08% of the total workers. It is, therefore, seen that the main occupation of the people is agriculture.

Livestock: Palamu is a rich district in live-stock wealth. According to 1977 live-stock causes, it had a live stock population of about 14.7 lakhs. The district also had 434567nos. of poultry.

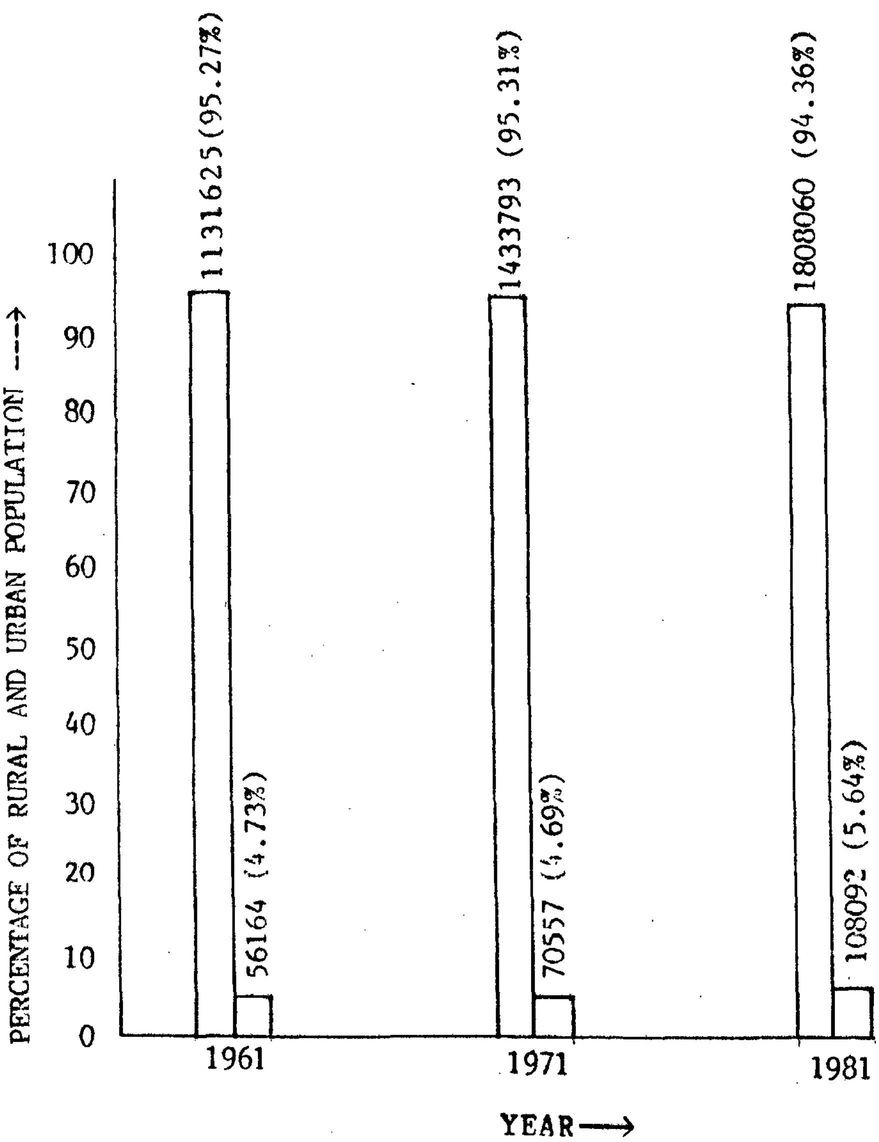


FIG. 4.2 -RURAL AND URBAN POPULATION AND ITS PERCENTAGE IN PALAMU DISTRICT.

Drinking Water Facilities: All the 5 towns of the district viz. Daltonganj, Latehar, Netarhat, Garhwa and Hussainabad are provided with water supply services. However, a vast majority of the rural pupulation has not been provided with drinking water facilities. Out of 3218 nos of inhabitated villages in the district, 1058 nos of villages have been identified as the villages having drinking water problem. By and large, the villagers are dependent, for their drinking water, on open dug wells, ponds, tanks, rivers, springs etc.

Agriculture and Irrigation: There are two cropping seasons viz. Kharif (June to November) and Rabi (December to May). Out of 12.02 lakh ha of reporting area, an average of 2.83 lakh (considering a period of eight years from 1972-73 to 1979-80) is cultivated. Very limited area has irrigation facilities as about 80% of the cropped area is fully dependent upon the monsoon rainfall without any irrigation facility whatsoever. The percentage of the areas having cropped coverage with and without irrigation have been shown in Figure 4.3.

Forest: About 47.00% of total reporting area i.e. 5,64,872 ha area is under forest as per land use record for 1979-80. The optimum area under forest, according to expert opinion, should be atleast 33% and so the district is better placed in this respect.

Mineral Resources: The Palamu district has promising deposit of limestone and dolomite, coal, bauxite, graphite and fire clay. Among the other minerals of economic importance ...

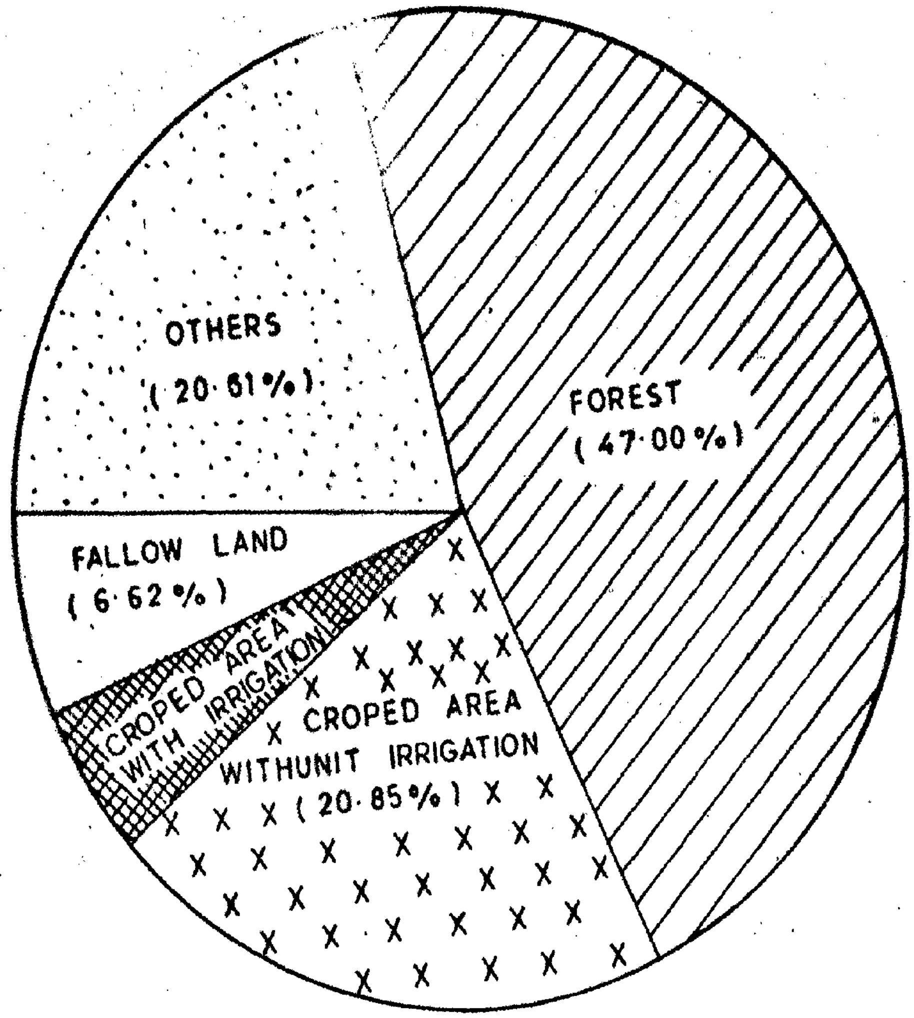


FIG. 4·3 – BROAD LAND USE CLASSIFICATION OF THE STUDY AREA occuring in the district are magnetite, steatile and some lead ores.

Electrification: All the five towns are electrified whereas only 626 villages had electricity supply till 31st March,1981.

Industries: There are many coal bearing areas and some of the important coal fields are located at Daltonganj, Hutar and Auranga. There is only one largescale industry i.e. Portland cement factory at Japla. Small scale industries are also very few and only handloom industry can be said to be in good condition. One more flourishing industry is the shellac industry. The cultivation of lac is widespread and lac industry is a valued subsidiary occupation of the cultivators. Other important cottage industries are weaving, tassar industry, catechu manufacture and ghee making.

Communications: Transport and communication facilities in Palamu district are not satisfactory. Although the towns and sub-divisional headquarters are well connected with metalled roads, many big villages are yet to be connected with district, sub-division and block headquarters and among themselves by good roads. The total length of state highways in the district is about 228 km. There are also 800 km of forest roads. The total length of railway line passing through this district from Japla to Mahuamillan is 184 km.

Water Resources Development:

Existing and Proposed: At present there are no major projects in the district. However, there are as many as 5 nos. of major projects which are under different stages of planning and construction. They are on the rivers Kutku Kanhar, Auranga, Amanat and North-Koel. The proposed irrigation potential of these schemes works out to 3.128 x 10^5 ha.

The existing 7 nos. of medium irrigation schemes have altogether designed irrigation potential of 23,553 ha. In addition, there are 4 nos. of such schemes which are under different stages of construction. The designed potential of these schemes has been estimated as 22,508 ha.

The total irrigation potential of existing minor irrigation projects is 46,739 ha while that of such schemes whic are under construction works out to 22,842 ha.

4.1.2 Hydrological and Hydro-Meteorological Conditions:

Major portion of the district is drained by the Sone basin through its main tributaries North Koel and Kanhar. The river Auranga, Amanat, Tahley etc. are the important sub-tributaries of the North-Koel. The general line of drainage is from south to north towards the river Sone. There are many other smaller streams which are torrents with rock strench beds. The upper reaches of the river Koel, the Auranga and the Amanat are characterised by high banks and only in rainy season these rivers are in high floods, rather flash floods. In summer season these rivers are mostly dry.

The country is drained very rapidly which is borne out by the fact that only the Sone river overflows its banks. Except for a few tracts, almost the entire district is drained by the river Koel which may, therefore be regarded as the most important tributary of the Sone. The catchment areas of important rivers in Palamu district have been shown in Table 4.1.

Table 4.1: Catchment Area of Important Rivers in Palamu

Sl.No.	Name of the river	Approximate length in kms.	Catchment area in sq.km.
1	Sone	72	-
2	Koil	125	-
3	Auranga	112	-
4	Amanat	-	-
5	Sadabah	-	-
6	Kanhar	-	-

Hydrological Network: There is relatively a good network of hydrological station in the district where as many as 7 nos., of gauge and discharge sites/gauge sites are existing on different rivers. The details of these hydrological sites which are being maintained by various agencies are given in Table 4.2.

Table - 4.2: Hydrological Sites in Palamu District

S.N.	Name of the sites	River	Agency
1.	Panduka	Sone	Sone river commission, Govt. of India
2.	Mohammadganj	N.Koel	C.W.C.
3.	Daltonganj	N.Koel	C.W.C.
4.	Auranga Dam Site	Auranga	Govt. of Bihar
5.	Amanat Dam Site	Amanat	Govt. of Bihar
6.	Kutku Dam Site	Kutku	Govt. of Bihar
7.	Tahley Dam Site	Tahley	Govt. of Bihar

The surface water as well as the groundwater comprise the water resources of the district. The normal run-off has been estimated to be 4908.63 m.c.m. The maximum runoff of the district was 10,232.48 m.c.m. in the year 1980 which works out to be 208.46% of the normal while the minimum runoff of the district was 21.44 m.c.m. in the year 1966 which works out to be 0.44% of the normal. The groundwater potential in the district is of the orderof 455.23 m.c.m. The total water resources both from surface and groundwater (excluding water committed for use outside the district i.e. 1278.81 m.c.m.) at 50%

dependability works out to be 3934.68 m.c.m. while the same at 75% dependability works out to 2409.27 m.c.m.

The climate of the district is on the whole dry and bracing. There are mainly three seasons; the winter season (November-March), the summer season (March-May) and the monsoon season (June-September/October). The district falls within the retreating range of the south-west monsoon and as such the rainfall is wholly dependent upon local conditions and local winds which are seldom favourable to the district. The rainfall is, therefore, erratic both in time and quantity. The normal annual rainfall of the district is 1194.75 mm which is lower than that of the state as a whole (271 mm). 86% of the annual rainfall is received during the south-west monsoon season. The maximum rainfall was 1721.10 mm recorded in 1907 while the minimum rainfall recorded was 505.30 mm (1966). The average no. of rainy days is 60.21 which varies from 51 days to 85 days as we proceed from north to south. There are 25 nos. raingauges stations i.e. 1 station per 480.80 km^2. Except for one raingauge station viz. Daltonganj meteorological observatory being maintained by India Meteorological Department, the rest are under the supervision of statistics and Evaluation Directorate, Govt. of Bihar. Table 4.3 shows the details of raingauge stations in Palamu.

The temperature ranges from 46.7°C in May and June to 6°C to 8°C in monsoon months. However, the daily range of temperature is of the order of 16° to 17°C during the winter and summer months.

Table - 4.3 : Raingauge Stations in Palamu

S.N.	Name of sub-division	Area in sq.kms.	No. of raingauge stations	Average area in sq.kms. for each station
1.	Sadar Sub-division	4315.2	10	431.52
2.	Garhwa Sub-division	4044.1	7	577.73
3.	Latehar Sub-division	3660.6	8	457.58
	District	12019.9	25	480.80

The summer months are the driest with humidities as low as 20 to 25% in the afternoons. During the summer and winter months, sky is generally clear or lightly clouded. In April and May cloudiness increases particularly in the afternoons. During the monsoon months sky is heavily clouded to overcast. Winds are light to moderate during the winter and summer months; severe thunderstorms occur during the summer months; even during the monsoon, rainfall is often associated with thunder. Dust storms and occasional hailstorms occur during summer. Fog may also appear on one or two days in the winter season. The salient features of Palamu district have been given in Annexure - III.

4.2 DATA AVAILABILITY

As may be seen from the description of the region the major portion consists of rural areas with its population depending mainly on agriculture and perhaps this is the reason why the impact of drought is felt immediately and very badly in the region. Further, the percentage of the cropped area having irrigation facility is also very low (4.92%) and agriculture is basically dependent upon monsoon rain. There fore, for all practical purposes, the impact of drought can be very safely gauged in terms of the foodgrain production. Further the quantum of foodgrains is also not very large and the produce is generally just sufficient to meet the local requirement. In this background, it does not appear necessary to consider the monetary value of the foodgrains. This is more so in view of the fact that the majority of pupulation of the area is poor and stil the practice of payment of wages to the labourers in terms of quantity of foodgrains is prevalent. Therefore, only the amount of foodgrains produced in different years have been considered as the main output sequence to measure the degree of drought. The data in respect of various foodgrain production has been collected from the statistics and Evaluation Directorate, Government of Bihar for the year 1948-49 to 1980-81. These data are given in Annexure IV. Figure 4.4 shows the annual produce of the different crops from the year 1948-49 to 1980-81.

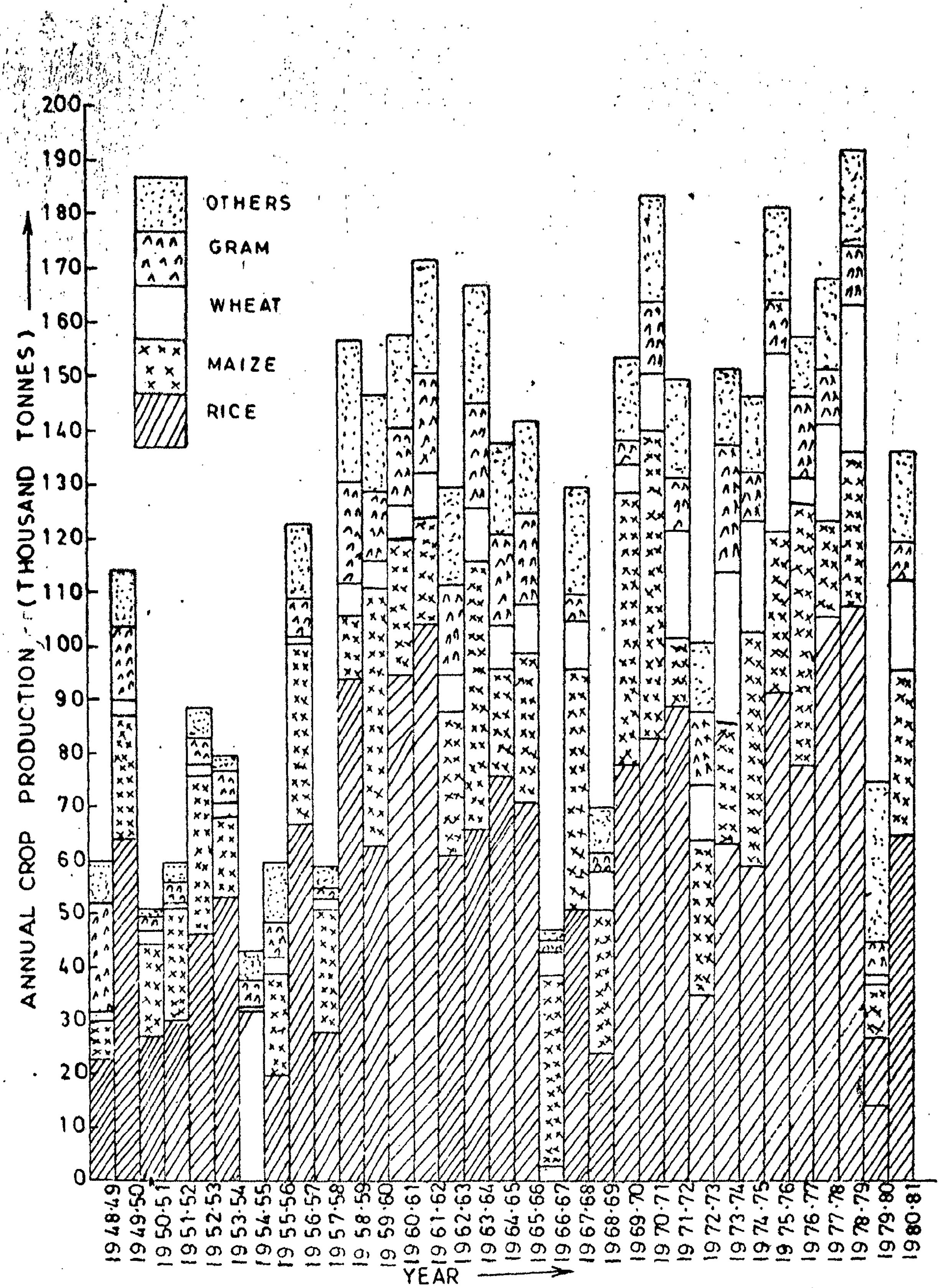


FIG. 4·4 – ANNUAL PRODUCTION OF MAIN CROPS IN PALAMU DISTRICT

As discussed earlier about 81% of the cropped area is wholly dependent upon rain. Therefore, the rainfall can be assumed to be main input sequence. The rainfall data of 3 representative rain-gauge stations of the area for the year 1901 to 1980 have been collected. In view of the practical considerations and also in view of the time constraint for the analysis, the monthly rainfall data have been collected and analysis has been restricted to monthly data. The detailed monthly rainfall data are given in Annexure V. The plot of rainfall data is shown in Figure 1.1.

In order to estimate the overall crop water requirement the data in respect of potential evapotranspiration as worked out for the region by India Meteorological Department have been collected. The monthly evapotranspiration data are shown in Figure 4.5.

Apart from the above mentioned data, other important informations such as those about temperature, humidity, soil-characteristics, cropping pattern existing in the region, cropping pattern proposed in various projects, the salient features of various projects have also been collected and used in the analysis which is presented in the next chapter.

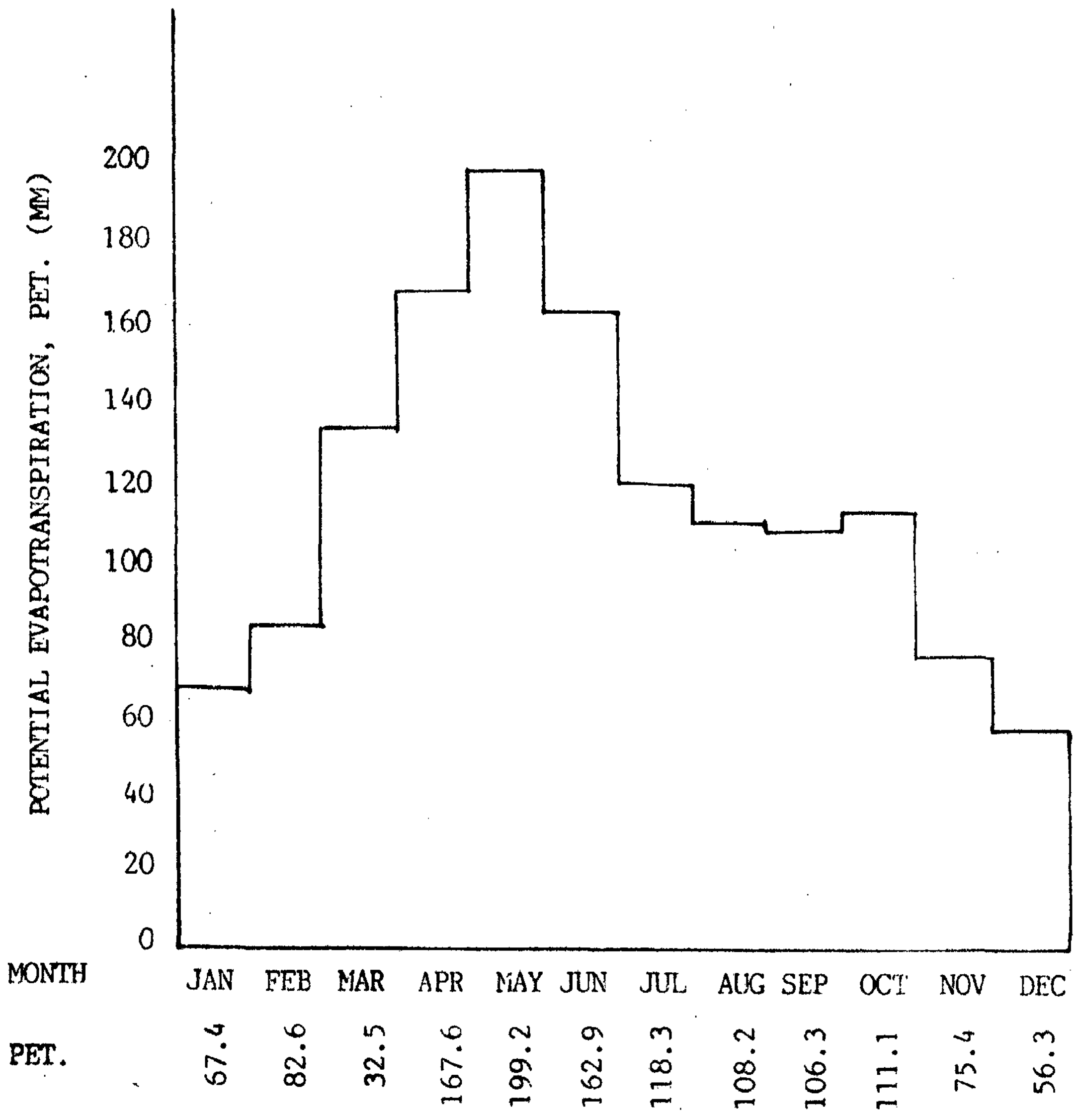


FIG. 4.5. MONTHLY POTENTIAL EVAPOTRANSPIRATION FOR PALAMU DISTRICT.

CHAPTER - V

ANALYSIS AND RESULTS

In order to examine the suitability of various parameters as suggested in Chapter III, the data in respect of the study region have been processed and analysed. As already mentioned, very limited data have been used with an objective to highlight the procedures and to examine the suitability of various parameters. The brief description of the analysis and the results thereof are presented hereunder.

5.1 DATA PROCESSING

Out of the three major data series, the data in respect of potential evapotranspiration are duly processed by India Meteorological Department using the Penman's method of computation of potential evapotranspiration. But the data in respect of the food production and the rainfall are basically raw data as observed/estimated and reported. These data have been processed before their use in the analysis. However, the other data which have been referred to in the analysis have been assumed to be duly processed and adopted as such.

5.1.1 Data in respect of Foodgrain Production:

These data have been processed to incorporate the progressive rise in the production with time as a result of overall development in the field of agriculture and application of modern techniques. It is a fact that the rainfall is the major input but with time there has been steady development in the field of agriculture which obviously are independent of the rainfall input. In the absence of necessary intermations about the other inputs i.e. agricultural development, fertilisers, better variety of seeds etc. the method of 'Moving Average Technique' has been used to separate out the component which may be attributed to the steady development in the fields.

The moving averages of the crop production with different periods have been computed and are shown in Table 5.1. The plot of moving average values with different span of time has been shown in Figures 5.1, 5.2, 5.3, 5.4, 5.5 & 5.6.

From the above figures it would be seen that the moving average with the base period of 17 years gives reasonably a smooth curve suggesting thereby that the random component of the food production sequence (which may be attributed to random input i.e. rainfall) can be assumed to have been evened out with this time base. This time base also appears to be justified as it is likely to cover approximately two cycles of good and bad years from drought considerations.

An attempt has been made to develop suitable equation to represent the moving averages. For this both linear and non-linear equations have been attempted and least-square techniques have been used to estimate the parameter of these equations.

Table 5.1: Moving Averages of Crop Production (in tonnes)

S.N.	Year	Annual food-grain prod. (Tonnes)	Moving averages with the span of					
			5 yrs.	9 yrs.	11 yrs.	13 yrs.	15 yrs.	17 yr
1.	1948-49	59578	-	-	-	-	-	-
2.	1949-50	114778	-	-	-	-	-	-
3.	1950-51	51275	74744.6	-	-	-	-	-
4.	1951-52	59511	78814.4	-	-	-	-	-
5.	1952-53	88581	64487.4	75528.11	-	-	-	-
6.	1953-54	79927	66268.0	75477.89	81476	-	-	-
7.	1954-55	43143	78922.2	80209.67	89450.64	92425	-	-
8.	1955-56	60180	73031.2	90878.2	93380.09	101067	100225	-
9.	1956-57	122780	88518.6	101821.7	104347.45	102232	107422	1064[illegible]
10.	1957-58	59126	109348.4	111081.1	110748.18	111175	109000	1112[illegible]
11.	1958-59	157364	128912.8	116635.8	117925.72	117247	115049	1073[illegible]
12.	1959-60	147292	138740.0	130457.0	123245.72	121357	114231	1119[illegible]
13.	1960-61	158002	152898.6	139153.3	132233.36	118843	116985	1125[illegible]
14.	1961-62	171916	154932.6	141289.7	131057.18	125516	116347	1164[illegible]
15.	1962-63	129919	154163.6	139969.2	131704.09	126299	123766	1225[illegible]
16.	1963-64	167534	149964.6	136917.2	132725.36	128734	132009	1288[illegible]
17.	1964-65	138447	125029.8	128369.2	132458.72	138325	133833	1312[illegible]
18.	1965-66	142007	125025.2	127972.4	135779.18	137769	136646	1329[illegible]
19.	1966-67	47242	105590.4	129294.8	135064.18	134234	136273	1381[illegible]
20.	1967-68	129896	108787.2	131541.2	128647.18	133574	136239	1395[illegible]
21.	1968-69	70360	117149.2	124185.1	130633.72	131821	137846	1402[illegible]
22.	1969-70	154431	137728.2	125665.6	128746.9	135835	136928	14[illegible]
23.	1970-71	183817	132014.8	126195.8	132715.63	135113	139501	1420[illegible]
24.	1971-72	150137	148297.0	141180.33	134182.54	137425	141198	1370[illegible]
25.	1972-73	101329	146766.0	144318.88	145207.09	141348	134968	1352[illegible]
26.	1973-74	151771	146423.8	155224.7	150943.81	141175	134635	-
27.	1974-75	146779	148025.0	159510.1	148638.36	141722	-	-
28.	1975-76	182103	161461.62	159800.6	147053.72	-	-	-
29.	1976-77	158143	169707.4	153765.0	-	-	-	-
30.	1977-78	168512	149351.6	-	-	-	-	-
31.	1978-79	193000	147395.8	-	-	-	-	-
32.	1979-80	45000	-	-	-	-	-	-
33.	1980-81	137000	-	-	-	-	-	-

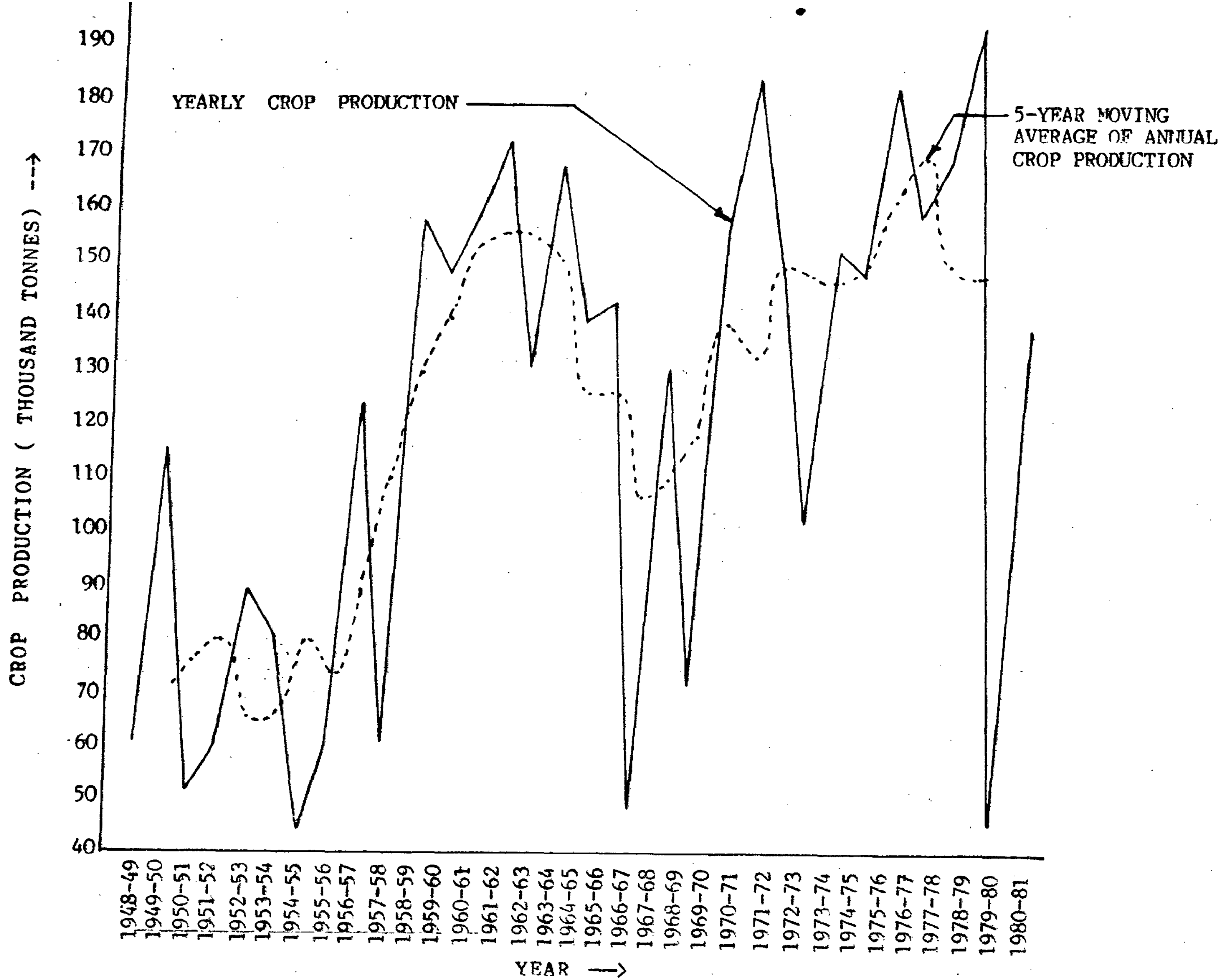
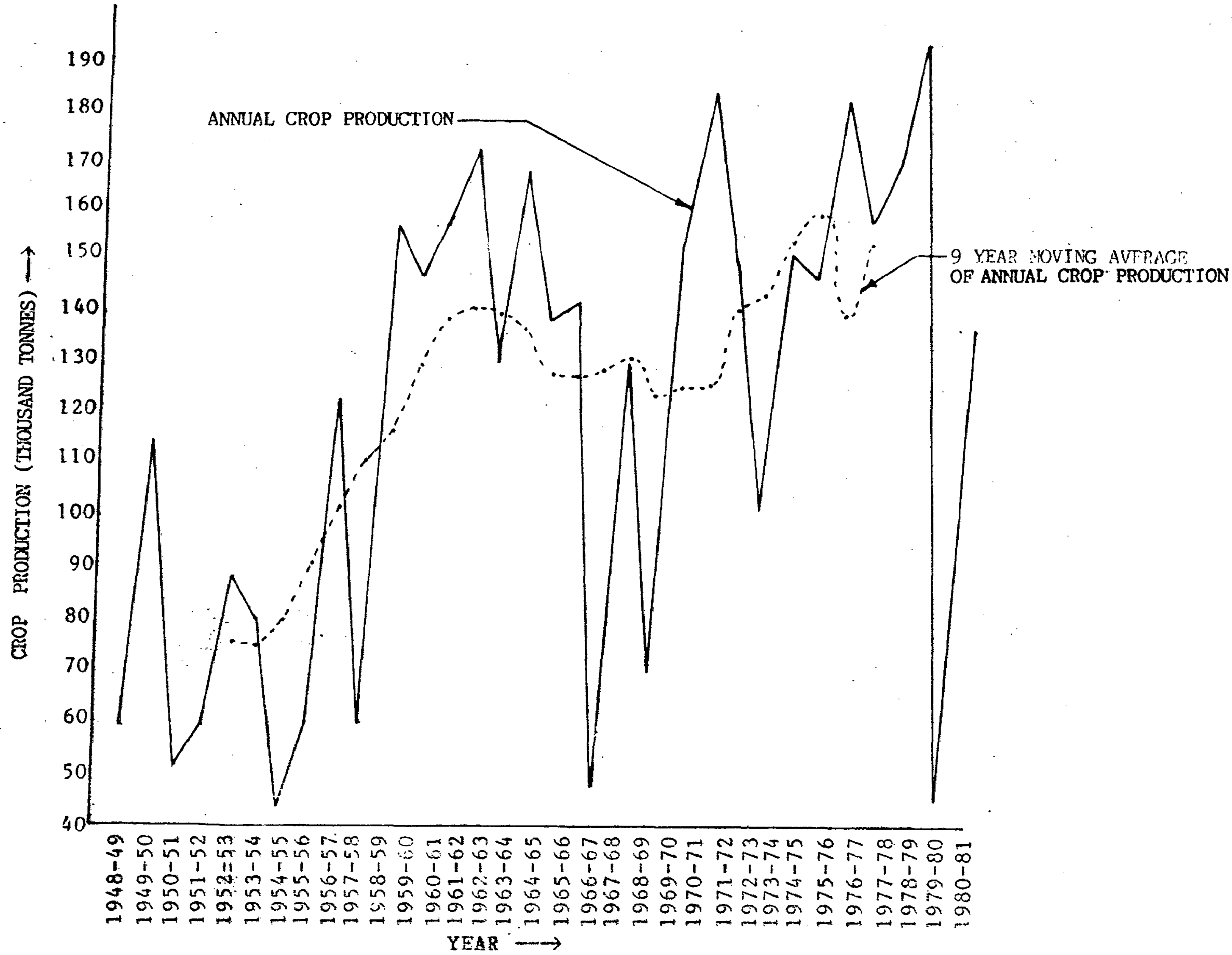


FIG. 5.1 - FIVE YEAR MOVING AVERAGES OF ANNUAL CROP PRODUCTION



190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
CROP PRODUCTION (THOUSAND TONNES) ⟶
ANNUAL CROP PRODUCTION
9 YEAR MOVING AVERAGE
OF ANNUAL CROP PRODUCTION
1948-49
1949-50
1950-51
1951-52
1952-53
1953-54
1954-55
1955-56
1956-57
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1971-72
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1973-74
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1975-76
1976-77
1977-78
1978-79
1979-80
1980-81
YEAR ⟶

FIG. 5.3 [illegible]

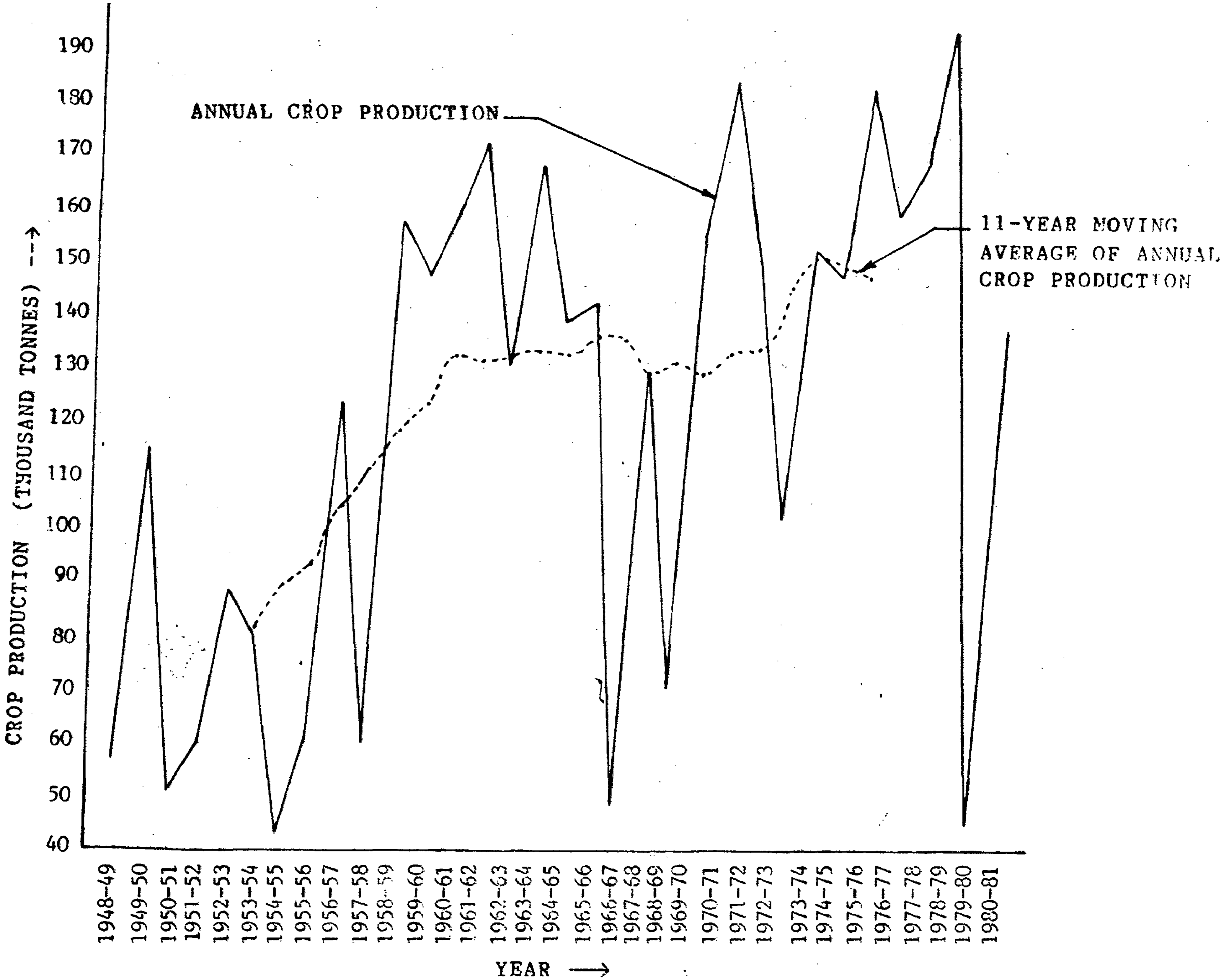


FIG. 5.3 -ELEVEN YEAR MOVING AVERAGES OF ANNUAL CROP PRODUCTION

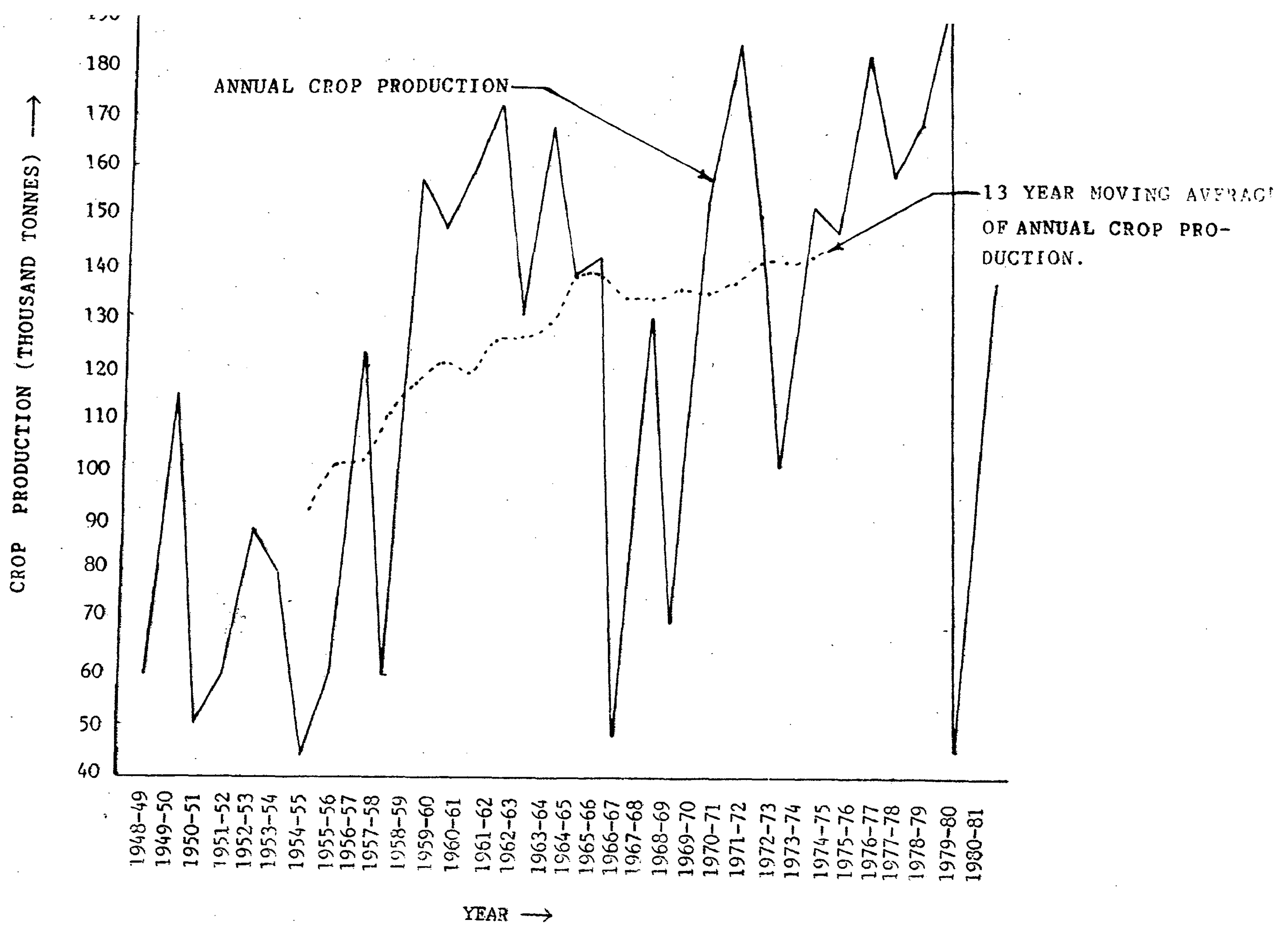


FIG. 5.4 -THIRTEEN YEAR MOVING AVERAGES OF ANNUAL CROP PRODUCTION.

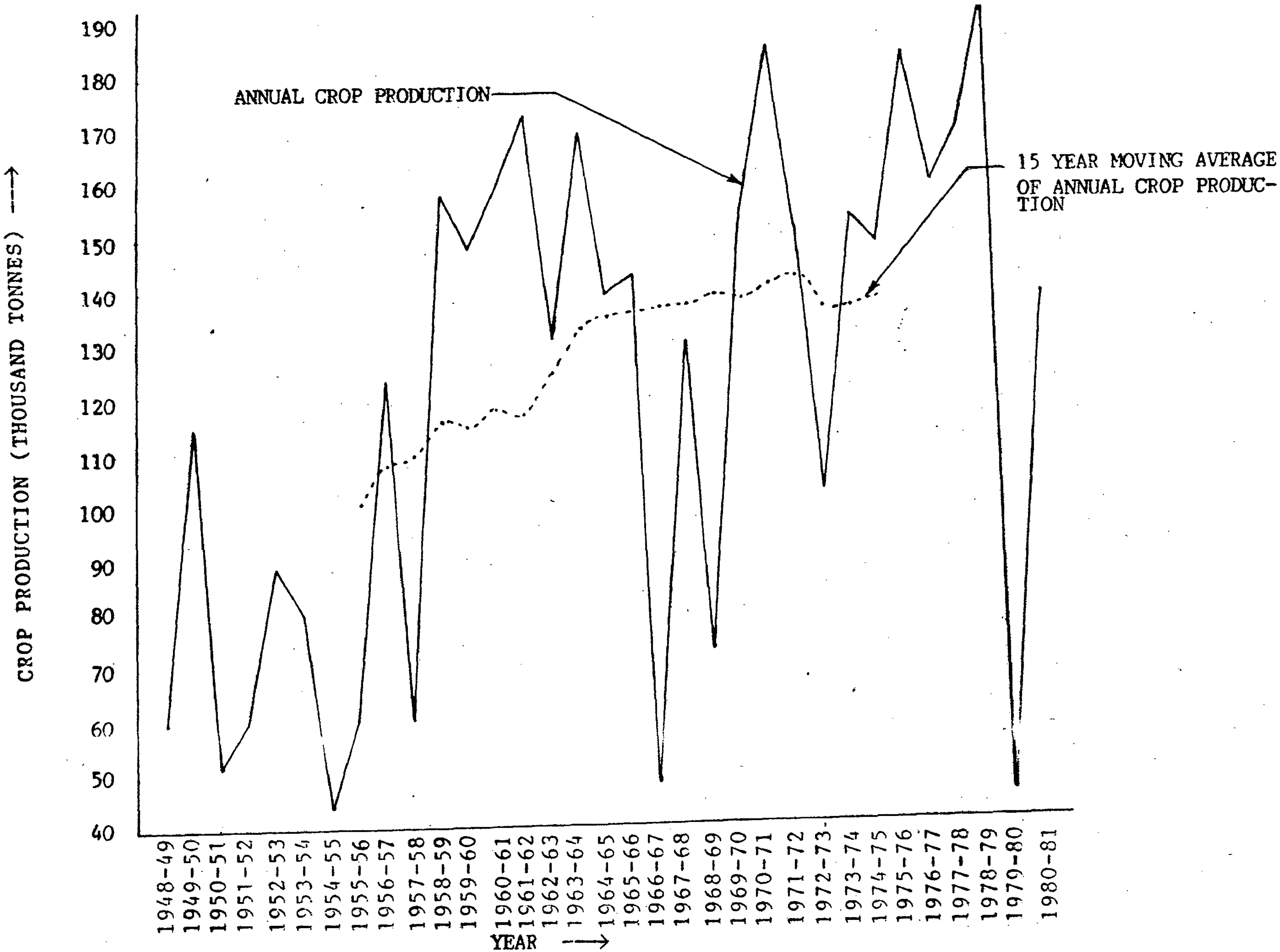


FIG. 5.5. FIFTEEN YEAR MOVING AVERAGES OF ANNUAL CROP PRODUCTION

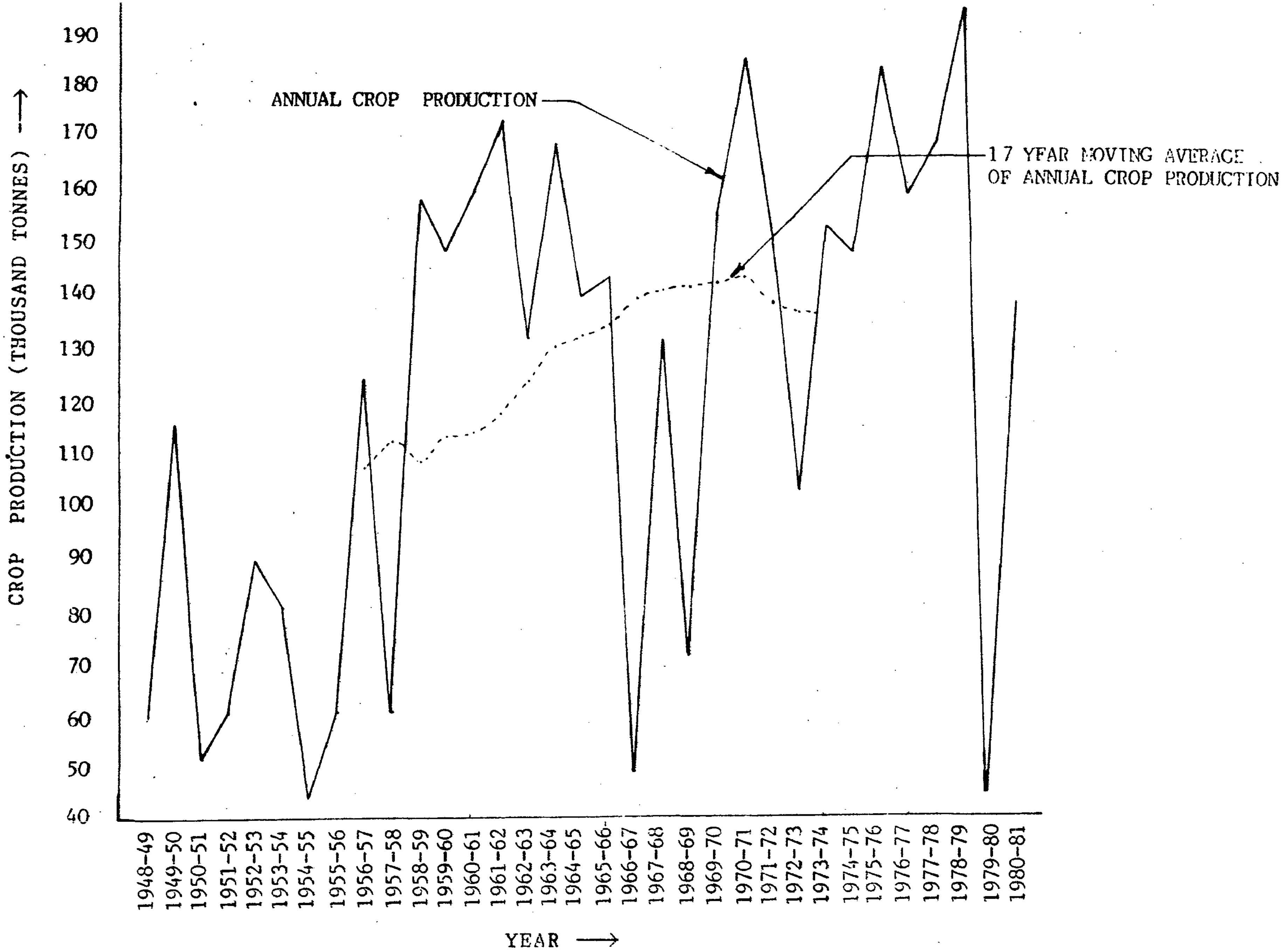


FIG. 5.6 SEVENTEEN YEAR MOVING AVERAGES OF ANNUAL CROP PRODUCTION

The equations which have been attempted and their coefficient of correlations have been given in Table 5.2 and the same are shown in Figure 5.7.

Table 5.2: Relationship of Crop Production and Time

S.No.	Equation	Coefficient of correlation (r)
1.	$Y = 85894.8 + 2402.76x$ where Y = Annual crop production x = year	0.9295
2.	$Y = 121246.26\ e^{0.004354x}$ where Y = Annual crop production x = year	0.9285

The value of coefficient of coefficient of correlation has been higher in case of linear relationship and so the same has been adopted. It has been assumed that the rising trend indicated by the linear relation is as a result of the overall development in agricultural techniques. And hence it appears necessary to account for this development in the raw data of annual crop production before it is analysed further.

Equivalent Crop Production: Using the equation representing the rising trend of annual crop production as given in Table 5.2, the crop production of different years have been suitably brought to the same time base. The crop production of all

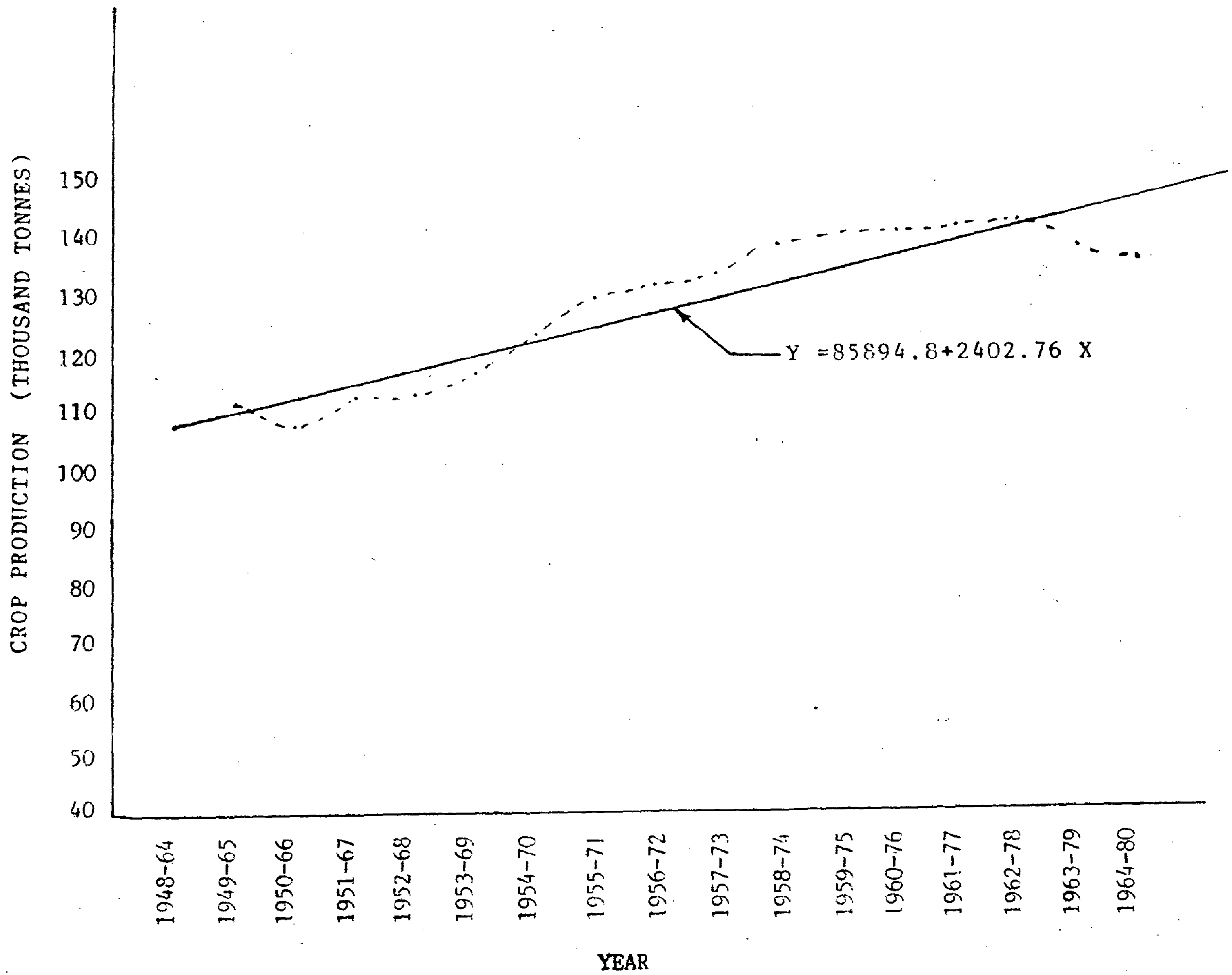


FIG. 5.7 **RELATIONSHIP BETWEEN CROP PRODUCTION AND TIME**

the years have been brought to the year 1980-81 and has been referred to as 'equivalent crop production (CP_e)'.

The annual crop production and annual equivalent crop production in different years are shown in Figure 5.8 and details of computation are given in Annexure VI.

5.1.2 Rainfall Data:

There are about 25 rain-gauge stations in the district but the complete data for considerably long period are not available for all the sites. Therefore, data of only three representative locations have been used in the analysis. The stations whose data have been used are:

a) Daltonganj

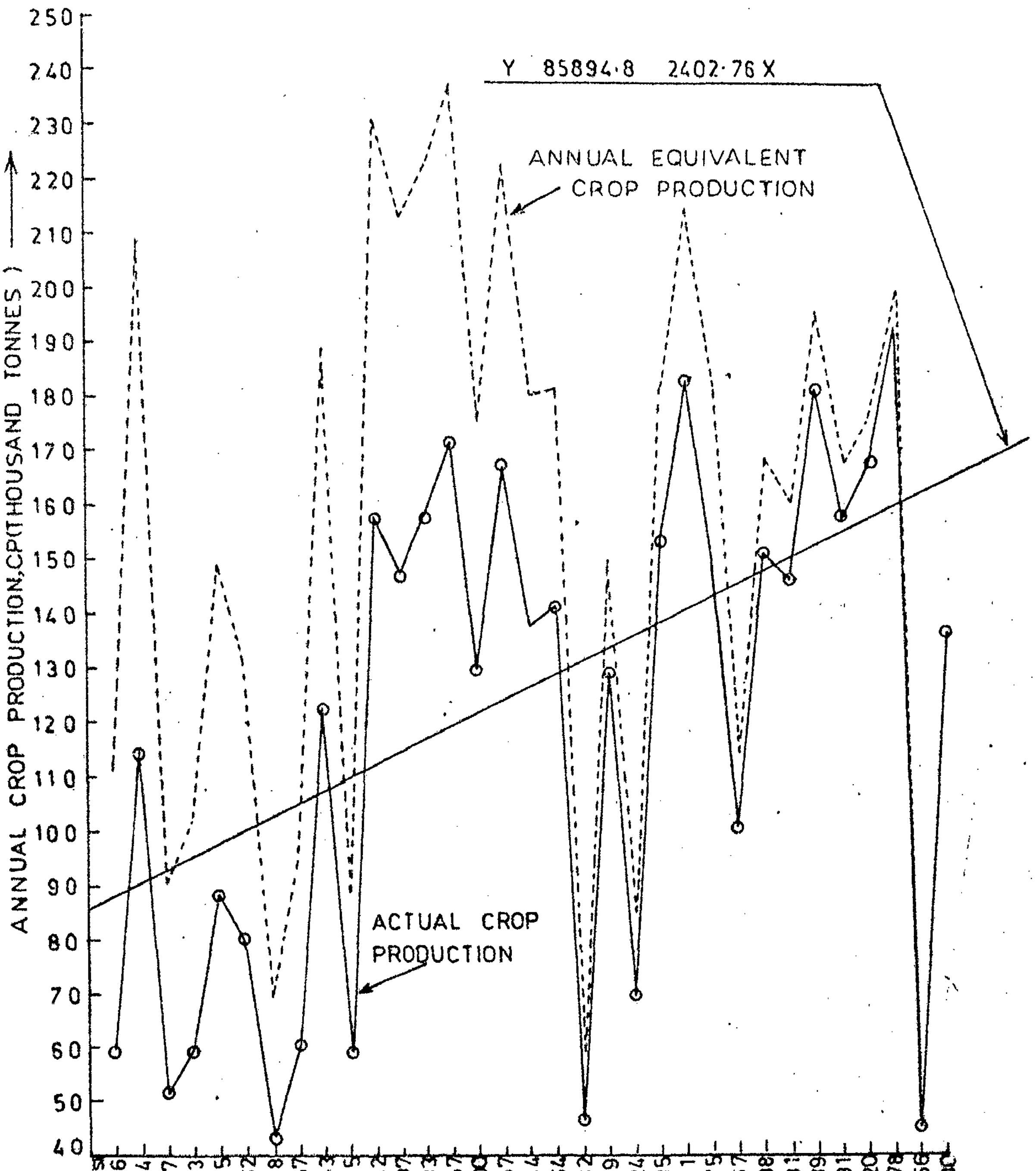
b) Garhwa

c) Latehar

The locations of these stations are shown in Figure 4.1. The average rainfall data have been given in Annexure IV.

5.2 STATISTICAL CHARACTERISTICS

The statistical characteristics of the two major data sequences have been computed to have a first hand idea about the consistency of the data. The mean, standard deviation (S.D.) and coefficient of variation (C.V.) of the data sequences of both rainfall and crop production have been computed and shown in Table 5.3.



YEAR	CP (TH TONNES)	CPe (TH TONNES)
1948-49	59.58	111.46
1949-50	114.78	209.04
1950-51	51.28	90.97
1951-52	59.51	102.93
1952-53	88.58	149.45
1953-54	79.93	131.62
1954-55	43.14	69.38
1955-56	60.18	94.57
1995-57	122.78	188.63
1957-58	59.13	88.85
1958-59	157.36	231.42
1959-60	147.29	212.07
1960-61	158.00	222.83
1961-62	171.92	237.57
1962-63	129.92	176.00
1963-64	167.53	222.57
1964-65	138.45	180.44
1965-66	142.01	181.64
1966-67	47.24	59.32
1967-68	129.90	160.19
1968-69	70.36	85.24
1969-70	154.43	183.85
1970-71	183.82	215.11
1971-72	150.14	172.75
1972-73	101.33	114.67
1973-74	151.77	168.98
1974-75	146.78	160.81
1975-76	182.10	196.39
1976-77	158.14	167.91
1977-78	168.51	176.20
1978-79	193.00	198.78
1979-80	45.00	45.66
1980-81	137.00	137.00

FIG. 5·8 - RELATIONSHIP OF CROP PRODUCTION AND EQUIVALENT CROP PRODUCTION WITH TIME

Table 5.3: Statistical Characteristics of Annual Rainfall and Annual Equivalent Crop Production

S.N.	Statistical characteristics	Rainfall	Equivalent crop production
1.	Mean	1194.75	156.797
2.	Standard Deviation	231.75	51.34
3.	Maximum value	1721.0	237.574
4.	Minimum value	505.30	45.664
5.	Coefficient of variation	0.194	0.327

An attempt has also been made to check the type of distribution which appears to be suitable for these data. Table 5.4 and Table 5.5 suggest that normal distribution appears to be a fairly good distribution for these two sequences.

The rainfall data of each month have also been analysed independently and the mean, standard deviation (S.D.) and coefficient of variation (C_v) of the rainfall data of each month have been given in Table 5.6 and shown in Figure 5.9 which clearly indicates the high degree of variability in time-distribution of the rainfall.

Table 5.4: Type of Rainfall Distribution

Equal Probability Class	Class interval	Theoretical value for normal distribution	Actual Value
I	$P_A \leq 970.88$	5.5	9
II	$970.88 < P_A \leq 1094.87$	5.5	8
III	$1094.87 < P_A \leq 1194.75$	5.5	5
IV	$1194.75 < P_A \leq 1294.63$	5.5	2
V	$1294.63 < P_A \leq 1418.62$	5.5	3
VI	$P_A > 1418.62$	5.5	6

Check for Normal Distribution:

$$\chi^2 = \frac{(O-t)^2}{t} = \frac{37.5}{5.5} = 6.82$$

(Chai square)

There are six class intervals and so the degree of freedom (D.O.F.) = 5

For D.O.F. = 5 and at 5% level

$$\chi^2 = 11.07$$

(Chai square)

Hence, the hypothesis that the sample constitutes the normal distribution is accepted.

Table 5.5: Type of Equivalent Crop Production Distribution

Equal Probability Class	Class interval	Theoretical value for normal distribution	Actual value
I	$CP_e \leq 107.20$	5.5	8
II	$107.20 < CP_e \leq 134.67$	5.5	3
III	$134.67 < CP_e \leq 156.797$	5.5	2
IV	$156.797 < CP_e \leq 178.92$	5.5	7
V	$178.92 < CP_e \leq 206.39$	5.5	6
VI	$CP_e > 206.39$	5.5	7

Check for normal distribution:

$$\chi^2 = \frac{(O-t)^2}{t} = \frac{29.5}{5.5} = 5.36$$

(Chai square)

Where, O = Observed value

t = Expected value

Since, there are six class intervals, the Degree of Freedom (D.O.F.) = 5

For D.O.F. = 5 and for 5% level

$$\chi^2 = 11.07 \text{ (From Table)}$$

(Chai square)

Hence, the hypothesis that the sample constitutes the normal distribution is accepted.

Table 5.6: Statistical Characteristics of Monthly Rainfall for the Period 1901-80

S.N.	Months	Statistical Characteristics		
		Mean	S.D.	C.V.
1.	January	1[illegible].14	21.52	1.12
2.	February	18.16	23.25	1.28
3.	March	15.91	17.39	1.09
4.	April	8.86	11.79	1.33
5.	May	10.6	12.12	1.14
6.	June	145.71	90.24	0.06
7.	July	319.06	131.62	0.41
8.	August	304.37	87.64	0.29
9.	September	198.18	91.65	0.46
10.	October	52.82	40.27	0.76
11.	November	6.67	14.84	2.22
12.	December	4.27	6.40	1.50

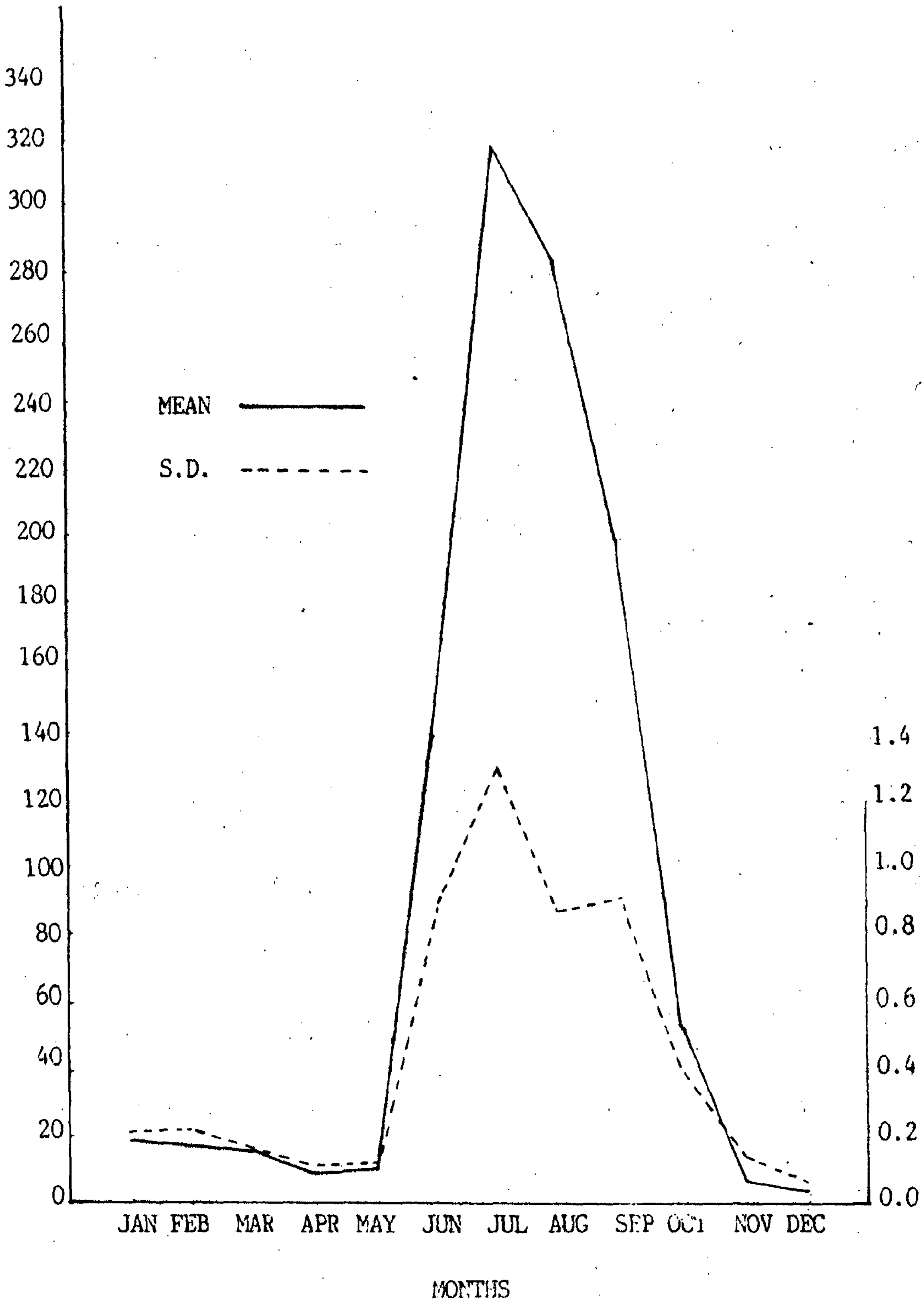


FIG. 5.9: STATISTICAL CHARACTERISTICS OF MONTHLY RAINFALL.

5.3 EQUIVALENT CROP PRODUCTION AS A FUNCTION OF DIFFERENT PARAMETERS

5.3.1 Commonly Used Statistical Parameters:

To begin with, the data in respect of the annual rainfall and the corresponding annual crop production have been plotted to examine if it is possible to develop a direct relation. Figure 5.10 shows highly scattered points suggesting that the direct relation between the annual value of crop production and the annual rainfall does not appear feasible. Almost similar situation is observed in case of the plot of the annual rainfall and annual equivalent crop production, CP_e which is shown in Figure 5.11. Therefore, it may be concluded that the total annual rainfall, as such, cannot be considered to be the indicator of the variability in the crop production, although the rainfall is the most important input. And, hence, it appears necessary to consider the other characteristics of the rainfall along with the total amount over the whole period.

The relation between the annual deficiency, D_A (Eqn.3.1) and the annual equivalent crop production, CP_e will be similar to that presented in Figure 5.11 because the term R_A of equation 3.1 is constant throughout.

The values of the following parameters have also been computed for each year:

a) cumulative absolute variation, CA_D (Equation 3.2),

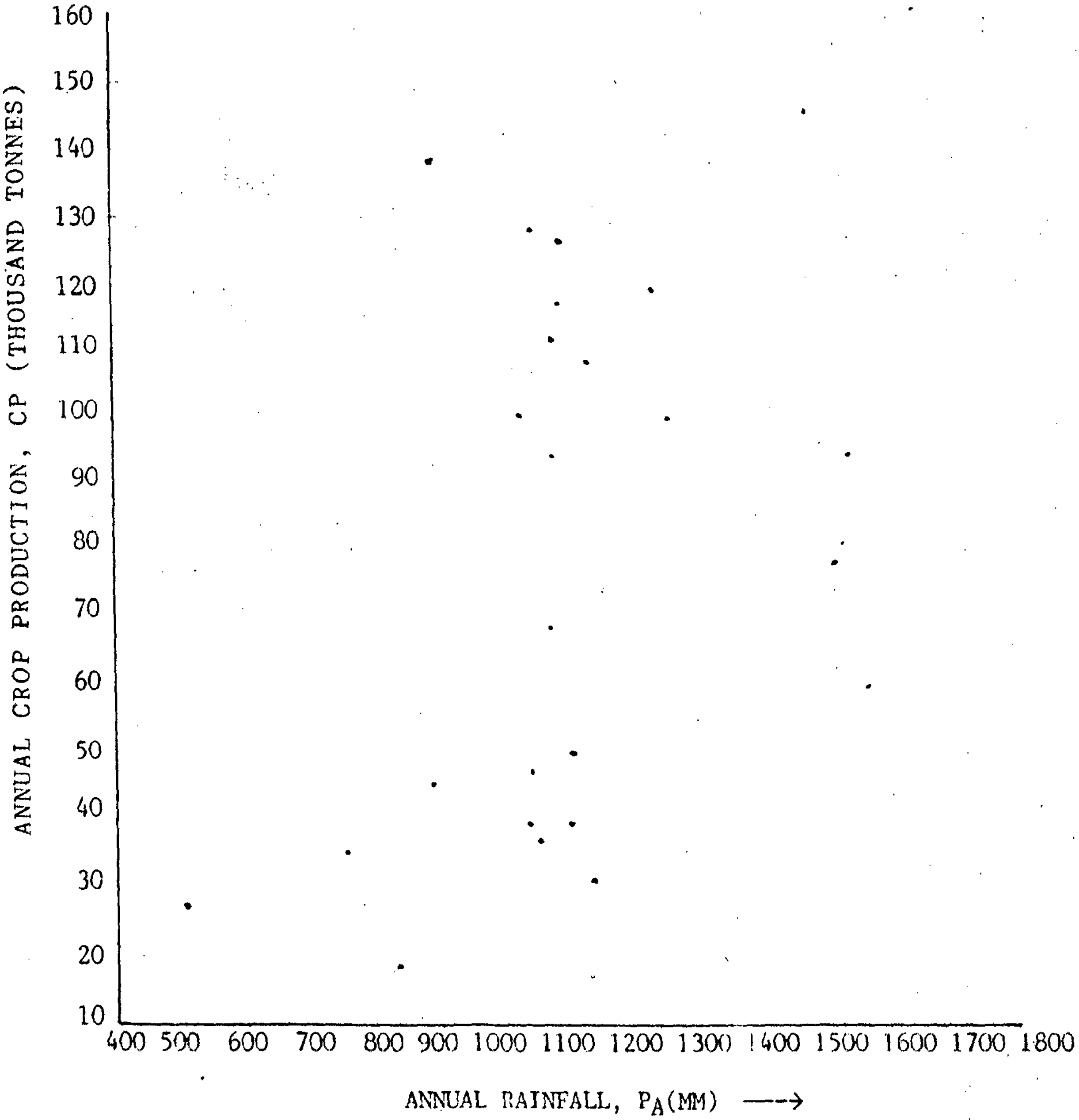


FIG. 5.10 RELATION BETWEEN P_A AND CP

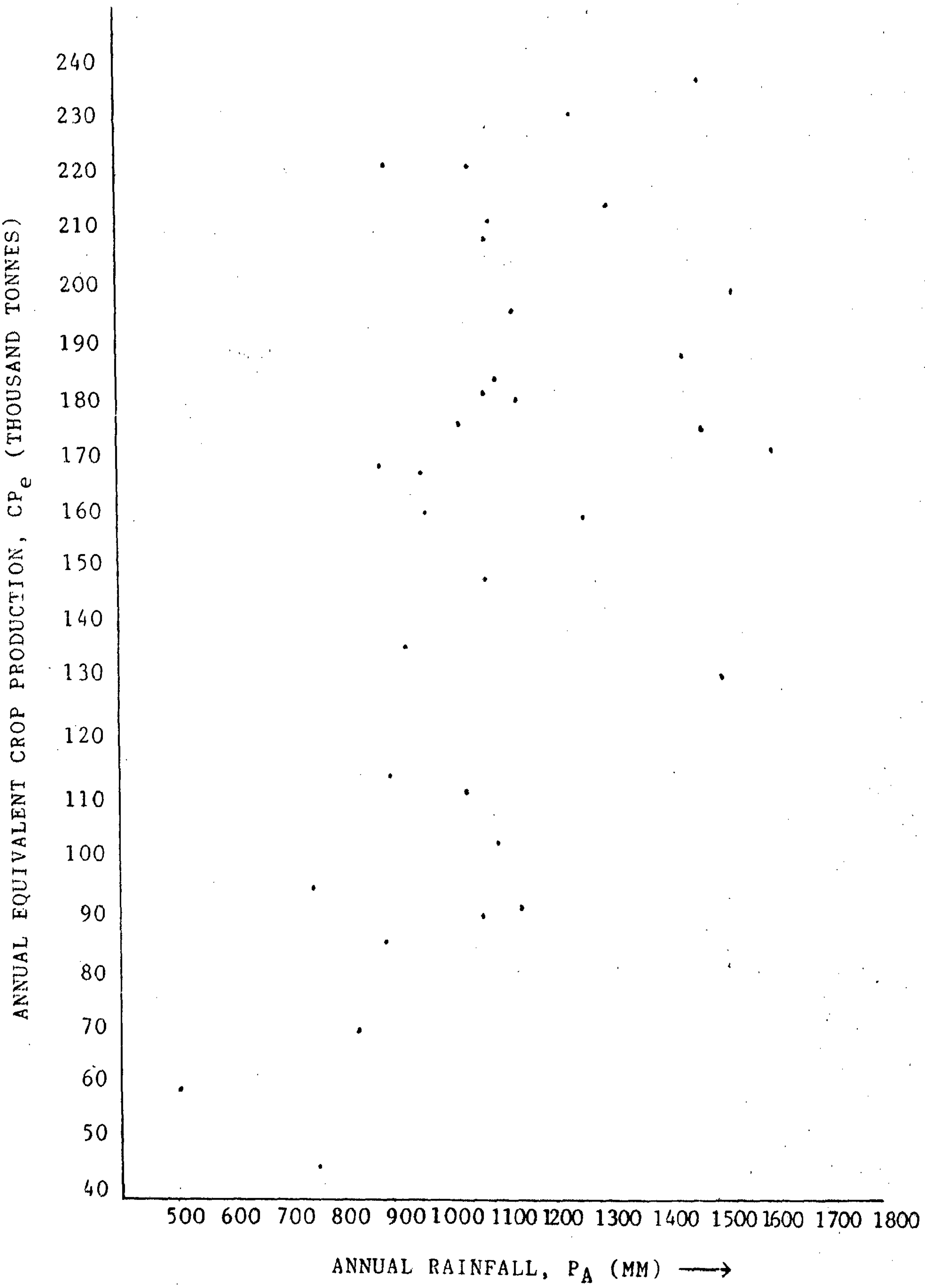


FIG. 5.11 : RELATION BETWEEN P_A AND CP_e

b) sum of the squares of monthly variation, SE_D (Equation 3.3) and,

c) Annual deficiency affecting the drought DD_A (Equation 3.4).

The plot of these parameters versus the annual equivalent crop production is also highly scattered. For example, the plot between the annual deficiency affecting the drought i.e. DD_A and the equivalent crop production is shown in Figure 5.12 which is self explanatory. An attempt has also been made to examine the presence of any dependence and trend; and for this the 'rank correlation' has been computed. But unfortunately, this does not suggest any relationship as such. The value of the rank correlation between the rank of equivalent crop production and the corresponding rank of DA, CA_D, SE_D and DD_A are given in Table 5.7.

Table 5.7: Rank Correlation Coefficient between the rank of CP_E and different parameters

S.N.	Parameters	Rank correlation coefficient
1.	$D_A = \sum_{i=1}^{12} V_i$	0.576
2.	$CA_D = \sum_{i=1}^{12} V_i$	0.421
3.	$SE_D = \sum_{i=1}^{12} V_i^2$	0.469
4.	$DD_A = \sum_{i=1}^{12} X_i$	[illegible].585

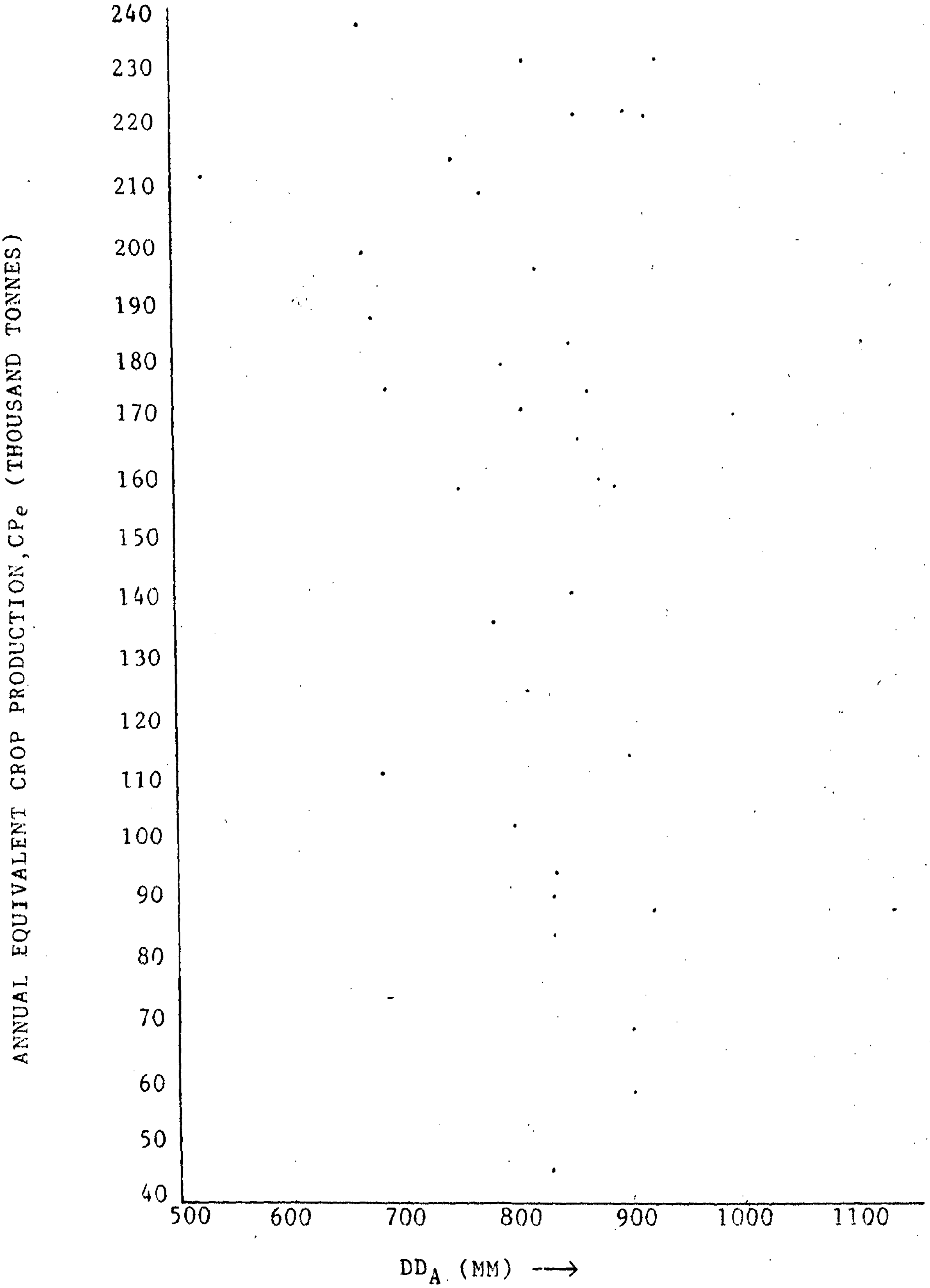


FIG. 5.12 RELATION BETWEEN DD_A AND CP_e

5.3.2 Parameters Representing the Time Distribution along with the Total Amount of Input and Output Sequences:

As may be seen from Figure 5.7 the mean monthly rainfall in the non-monsoon months is very nominal and more than 86% of the annual rainfall is concentrated during the five months of the monsoon season. Further, the farmer in the region, in general, depends upon the rain during the monsoon period only and for rabi and hot weather crops in the region, he hardly relies on the rain. In view of this, it has been considered proper to take into account the distribution of rainfall only during the five months of the monsoon period. In order to account for this distribution, a parameter P_{rd} has been computed as follows:

$$P_{rd} = \sum_{m=1}^{5} \left(\frac{Rm}{REQ_m}\right) * \frac{P_A}{P_N} \quad \text{.........(5.1)}$$

Where P_{rd} = Parameter to account for the percentage distribution of rainfall vis-a-vis percentage distribution of the required amount of water;

R_m = Percentage of the rainfall in the month m of the monsoon period;

REQ_m = Percentage of gross water requirement in the month m of the monsoon period;

P_A = annual rainfall; and

P_N = normal annual rainfall.

It would be observed that the percentage distribution of rainfall and gross water requirement has been used in the analysis. It is so mainly because of the fact that the detailed statistics of existing cropping pattern of the whole district and other related informations were not available and assessment of average monthly water requirement is based on the detailed study of a small portion of the district covered by the proposed Auranga Reservoir Project (Sinha, 1982).
The equation (5.1) can be written as

$$P_{rd} = \sum_{m=1}^{5} K_m * \frac{P_A}{P_N} \quad \ldots\ldots\ldots\ldots(5.2)$$

Where $K_m = \frac{R_m}{REQ_m}$

while analysing, the maximum limit for the value of K_m has been kept as one. This is based on the assumption that the excess water i.e. water more than the requirement does not help in additional production but the shortage of water affects and causes proportionate reduction in the crop production. The above parameter has been computed for different years and an attempt has been made to correlate the annual crop production with this parameter and the plot of the same is shown in Figure 5.13. The details of computations are given in Annexure VII. However, the plot is considerably scattered in this case also and does not help in arriving at any conclusion.

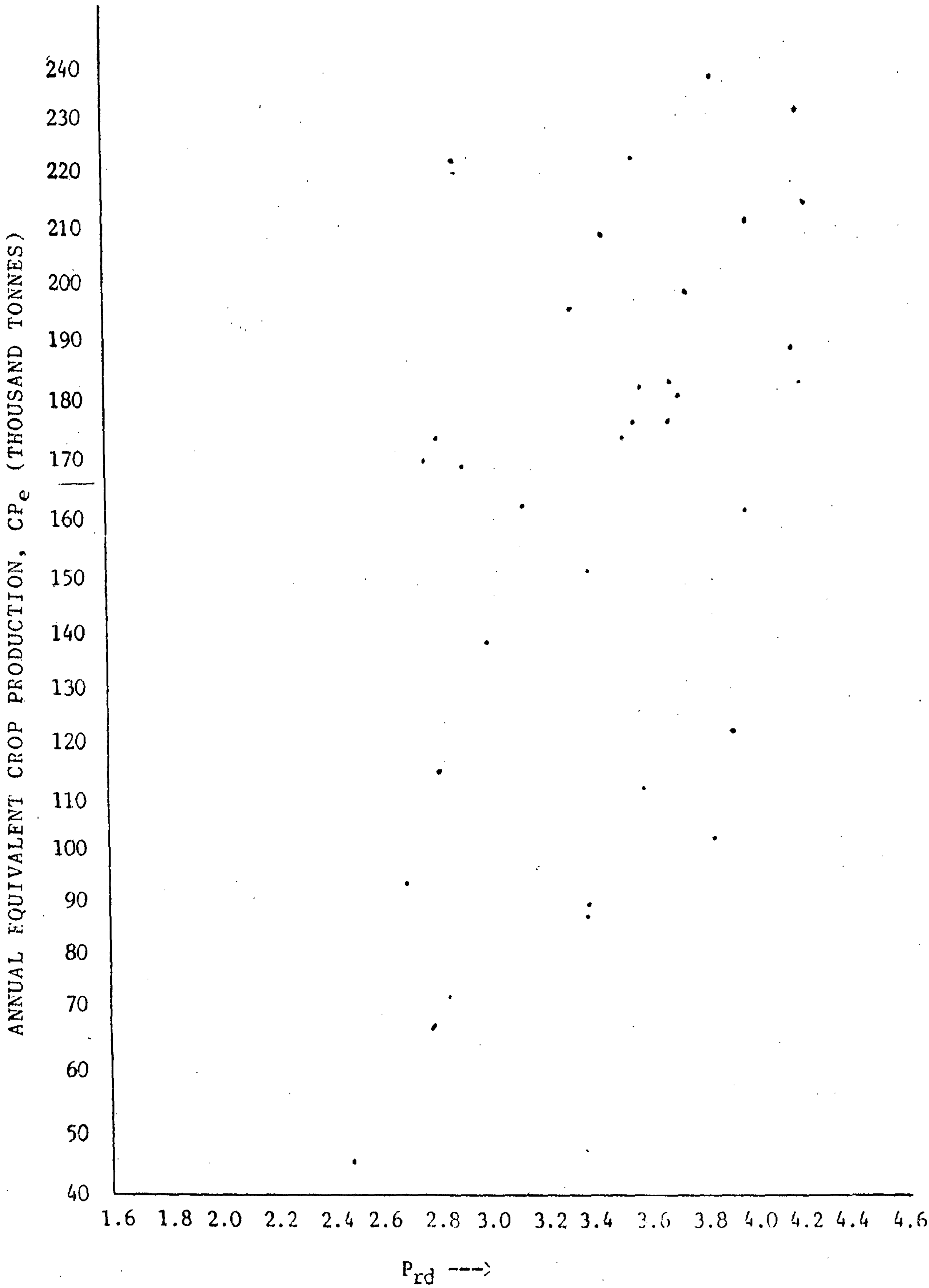


FIG. 5.13 RELATION BETWEEN P_{rd} AND CP_e

Assuming that the monsoon rain occurring in the monsoon period has major role to play, the above parameter has been slightly modified by substituting, $\frac{P_m}{PREQ_m}$ for $\frac{P_A}{P_N}$ where P_m = total rainfall observed in the respective year during monsoon period; and $PREQ_m$ = gross water requirement in the respective year during monsoon period.

Thus, $$P_{rdm} = \sum_{m=1}^{5} K_m * \frac{P_m}{PREQ_m} \qquad ....(5.3)$$

In this case, the gross water requirement has been estimated in millimeter for the Auranga area and the same has been assumed to be applicable for the whole region. However, even this modified parameter does not improve and the scatter remains as such. (Figure 5.14). Details of computation have been given in Annexure VII.

The possible reason for poor performance of above parameters (which consider the total amount of rainfall as well as its time distribution) may be their inability to account for:

(a) the importance of different time periods with respect to different crops; and

(b) the normal conditions of deficiency for which the people residing in the region are accustomed to. .

5.3.3 Deviation from the Normal Conditions:

In order to consider the effect of shortages with respect to the nromal shortages in specific period and to account for farmer's capability to cope with the regular features in the region, the parameter

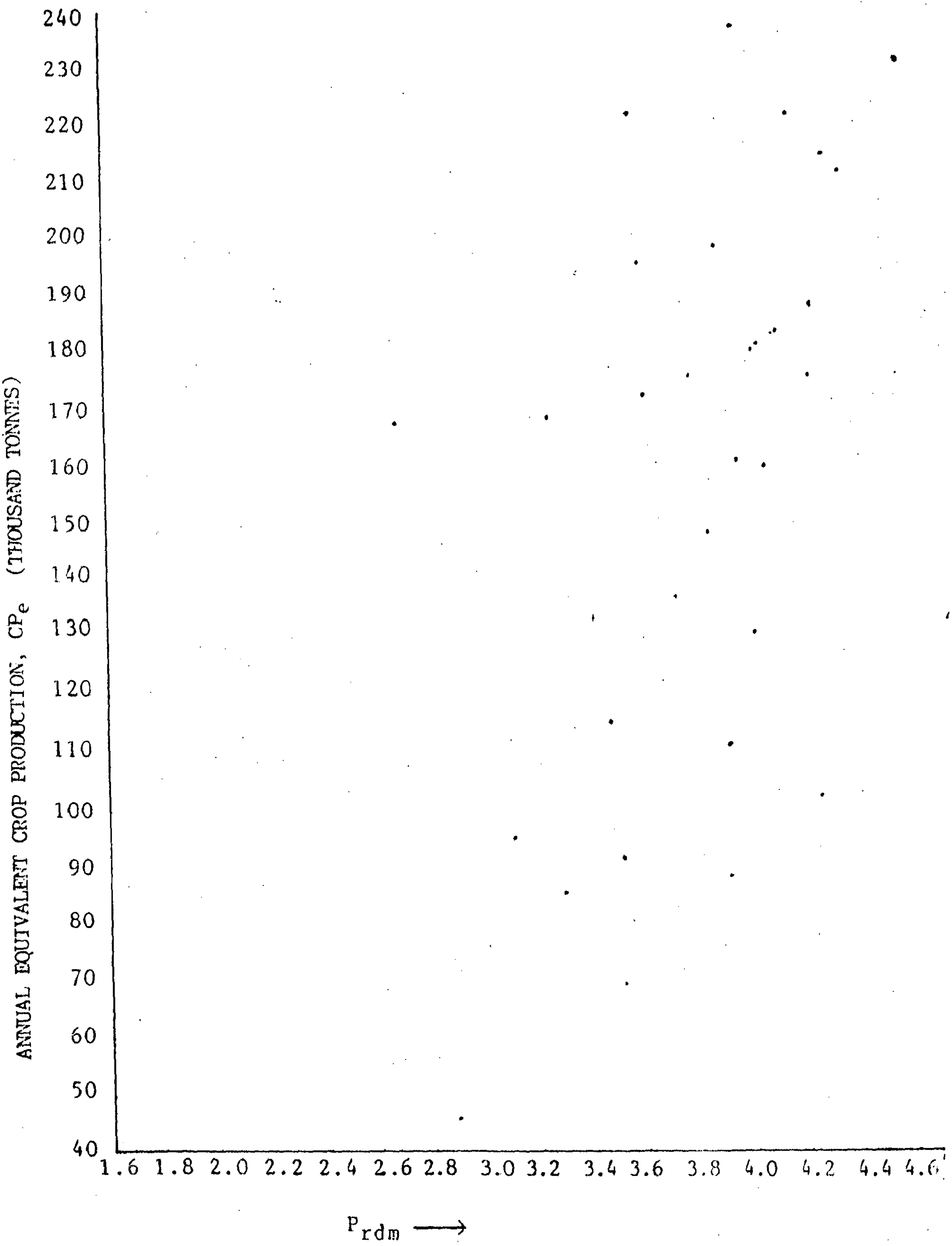


FIG. 5.14: RELATION BETWEEN P_{rdm} AND CP_e

$DD_N = \sum_{i=1}^{n} K_i$ (Equation 3.5) has been computed and the same has been plotted and shown in Figure 5.15 (Details of computation in Annexure VIII). This plot may be considered to be a slightly improved version of the earlier plots but this again does not help in any decision making.

5.3.4 Weightages to Different Periods:

It remains a fact that the crop production is greatly influenced by the availability of water in certain preiod which are considered to be critical from the consideration of crop growth. For example, in case of paddy, there are broadly three important growth stages viz. pannicle initiation, preflowering and flowering covering three monsoon months i.e. July, August and September/October. During these periods of growth stages, the water is required most by the paddy plant to sustain its satisfactory growth. On the other hand, during the maturity stage, the paddy plant can tolerate water deficit to a great extent without causing any significant reduction in the ultimate yield. Hence, the period of maturity stage is not so much important from the point of view of water requirement as those of other three important stages mentioned above. Similarly, the month of June is also not so much important as the shortage of water supply in this period may only delay the sowing period. Likewise other crops have also their own critical period of growth stages. And hence, it is desirable to assign a suitable weight to different periods say different

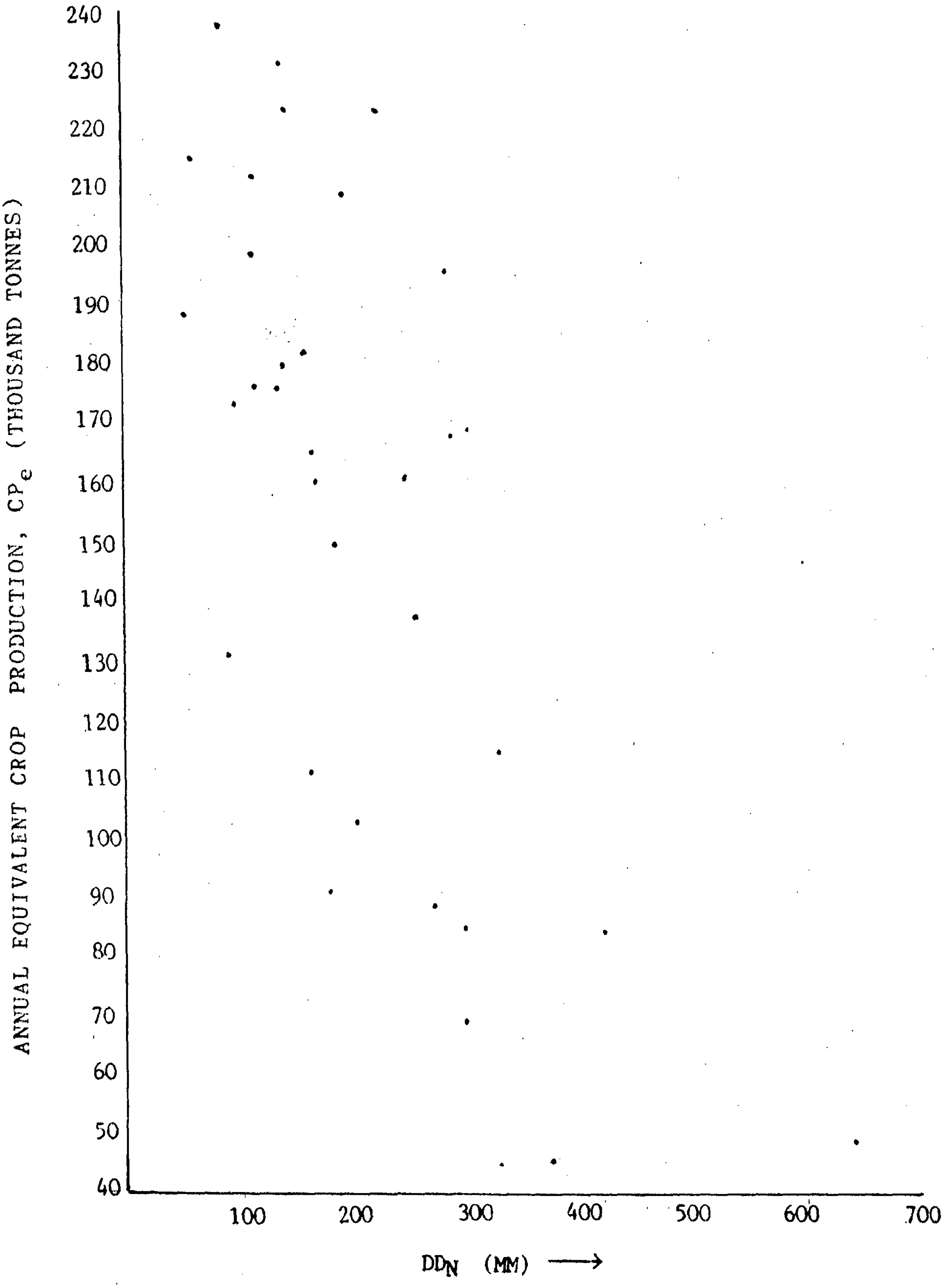


FIG. 5.15 RELATION BETWEEN DD_N AND CP_e

months with respect to different crops and also with respect to relative importance of different periods (months). With the weights thus assessed, the parameter WDD_A (Equation 3.6) and WDD_N (Equation 3.7) can be computed.

Assessment of Weightages to Different Months: The method for the assessment of weightages to different months as proposed in the work of Afshar (1985) has been adopted in the absence of any other comprehensive work reported elsewhere. The method adopted by him is as follows:

Depending upon substantial to marginal condition of crop growth, a weightage of one to zero (one for the worst effect and zero for no effect) was assigned to different stages of individual crops. Then the average weightage for each month has been computed duly incorporating the area under each crop as mentioned below:

$$W_j = \frac{\sum_{i=1}^{n} W_{ij} * A_i}{\sum_{i=1}^{n} A_i} \quad \ldots\ldots\ldots(5.4)$$

where, W_j = Average weightage for the jth month, ($j = 1$ to 12)

W_{ij} = weightage worked out for ith crop in jth month,

A_i = area under ith crop, and

n = number of crops.

Thus, the value of average monthly weightages is computed. However, these values are further modified suitably to account for the relative importance of water requirement of different months, as the above weightages as computed from (5.4) are based on water needs of various crops in different months. Further, the weightages are adjusted so that $\sum_{i=1}^{12} W_j/12 = 1.0$. Figure 5.16 shows the weightages for different months as estimated by the method mentioned above.

Using the above weightages for the different months, the parameter WDD_N (Equation 3.7) has been computed and a plot between WDD_N and CP_e has been made (Figure 5.17). This plot indicates marked improvement and the scatter is considerably reduced.

The parameter WDD_N is further improved by incorporating the annual rainfall. Thus, the suggested parameter i.e. the effective deficiency, ED (Equation 3.8) has been computed for each year. The details of the computations have been given in Annexure VIII. The plot is shown in Figure 5.18 which indicates a definite improvement and suggests that a suitable equation can be developed between this parameter i.e. effective deficiency and the equivalent crop production.

Although the parameter 'effective deficiency' (Eqn.3.8) appears to reflect the drought conditions quite reasonably, the effect of extreme conditions of deficit is not given any differential treatment. Hence, the parameter ED_e i.e.

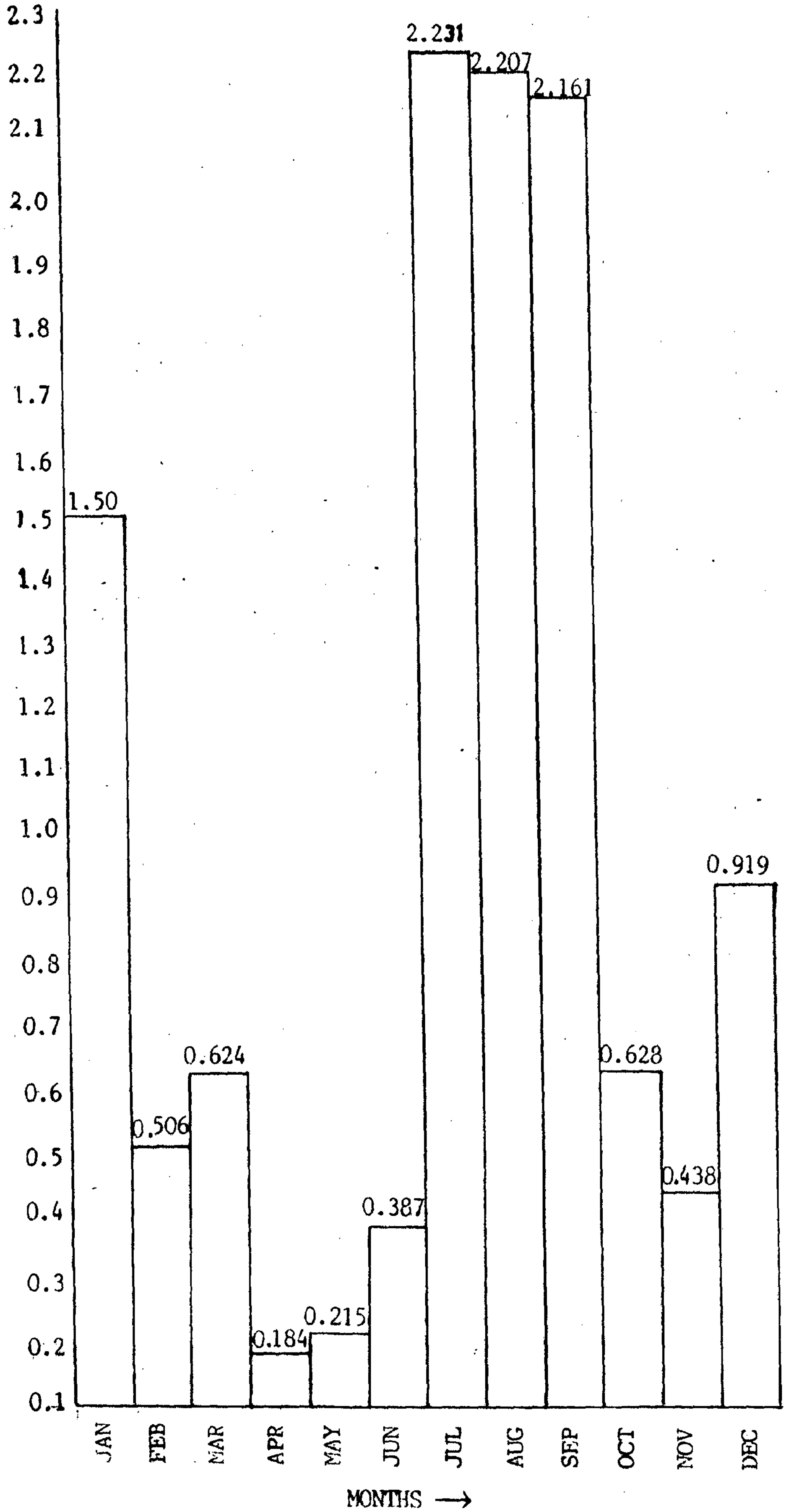


FIG.5.16.-WEIGHTAGES TO DIFFERENT MONTHS

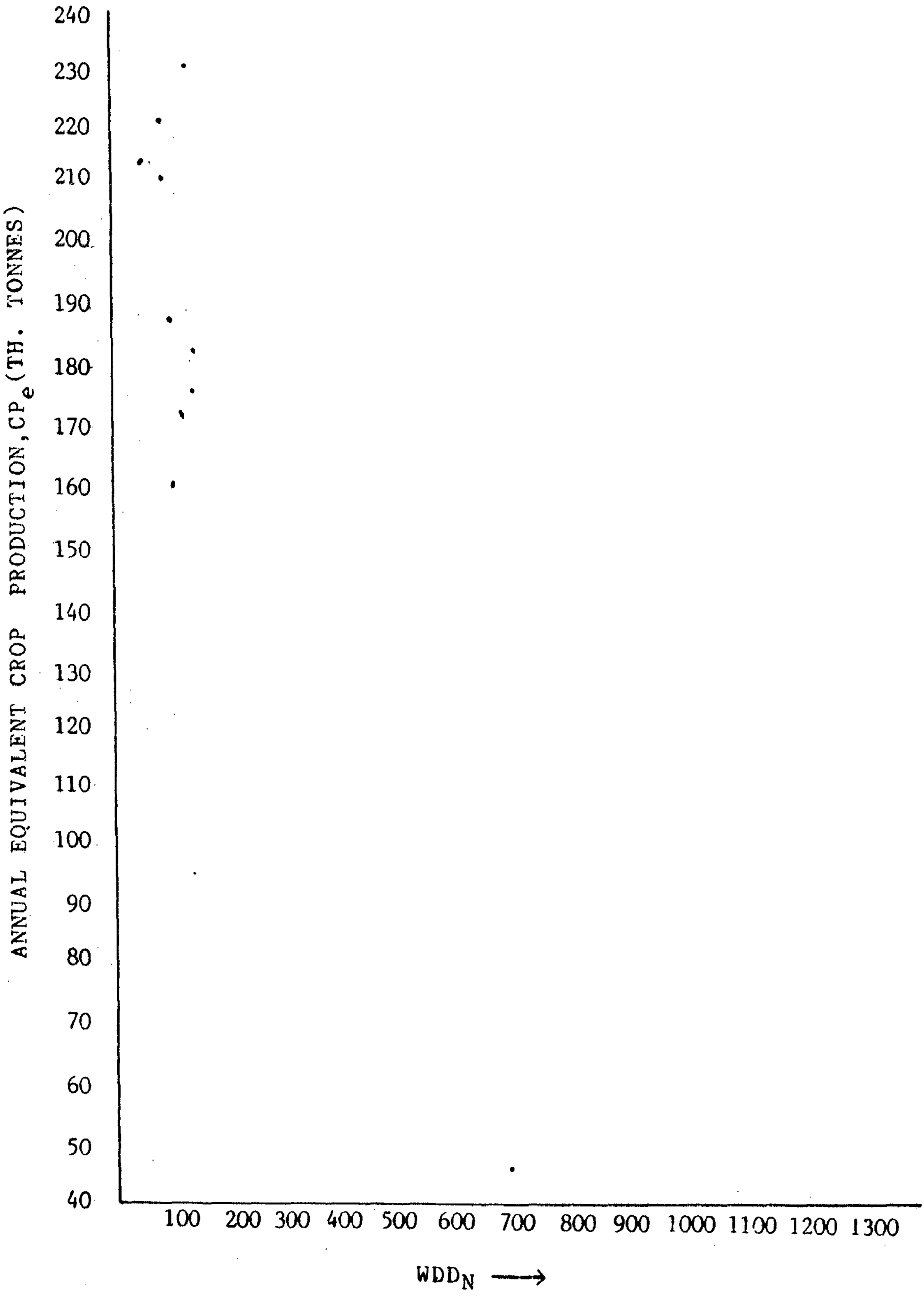


FIG. 5.17 RELATION BETWEEN WDD_N AND CP_e

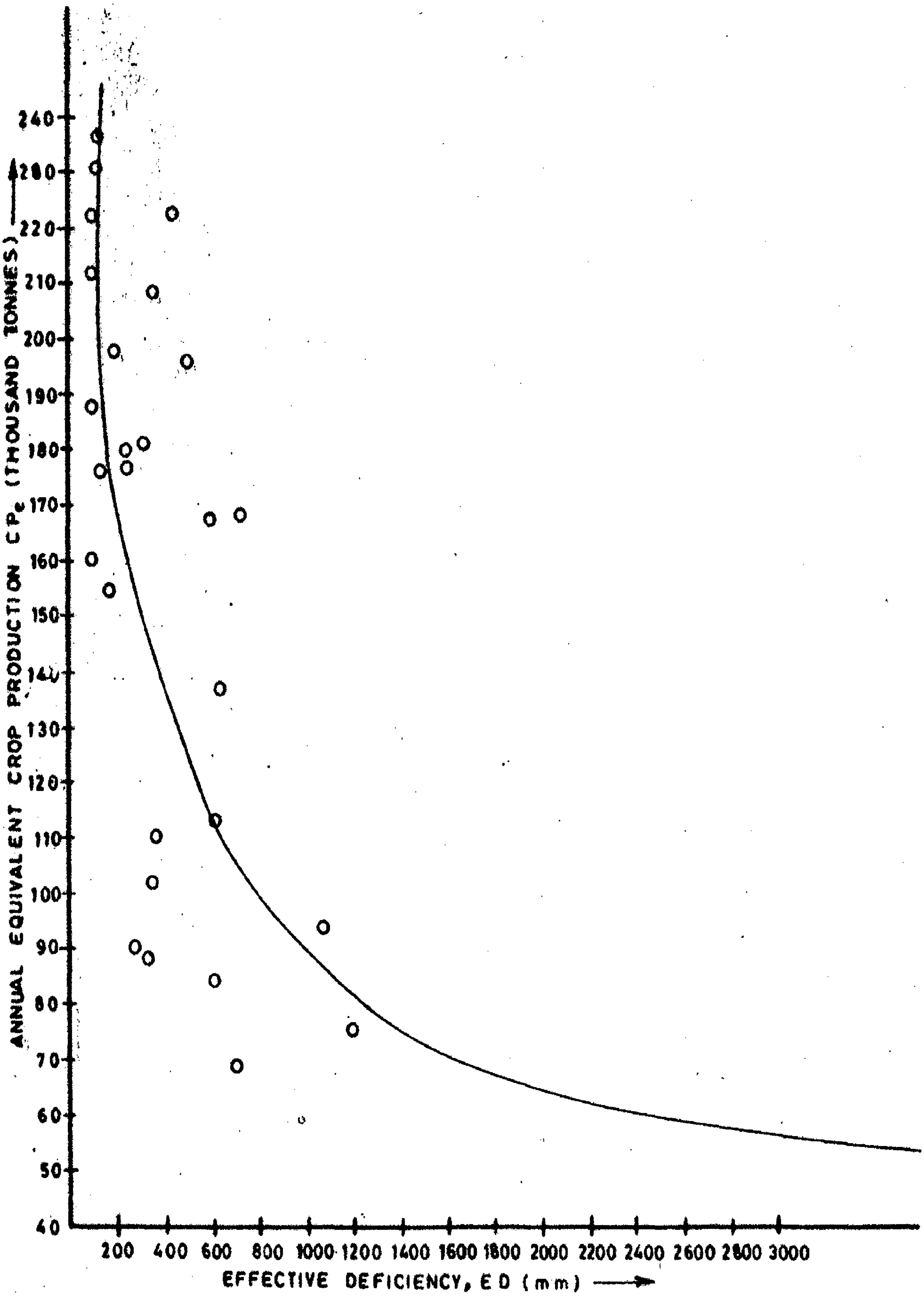


FIG. 5·18 RELATION BETWEEN E.D. AND CPe

'effective deficiency with extreme conditions duly represented' (Equation 3.9) has been computed for each year and plotted against the CP_e of the corresponding year as shown in Figure 5.19 (Details of computations given in Annexure IX). This plot seems to have minimum scatter and is likely to suggest a reasonable model for estimating equivalent crop production, CP_e with the help of the various characteristics of the input sequence i.e. rainfall and other variables affecting the crop production.

A review of the plot of CP_e against the different identified parameters i.e. D_A, CA_D, SE_D, DD_A, DD_N, WDD_A, WDD_N, ED and ED_e suggests that the two parameters viz. 'effective deficiency (ED)' and the 'effective deficiency with extreme conditions duly represented, (ED_e)' are likely to represent the drought conditions in the best manner.

5.4 MATHEMATICAL REPRESENTATION OF THE DROUGHT CONDITIONS IN TERMS OF DIFFERENT PARAMETERS

An attempt has been made to develop a suitable relation between the two identified parameters, i.e. ED and ED_e and CP_e in order to develop a suitable model to identify the drought with the help of observed variables. The following types of equations have been attempted:

a) $Y = A - ax^b$ ....(5.5)

b) $Y = a.e^{-bx}$ ....(5.6)

c) $Y = \dfrac{1}{a + bx^e}$ ....(5.7)

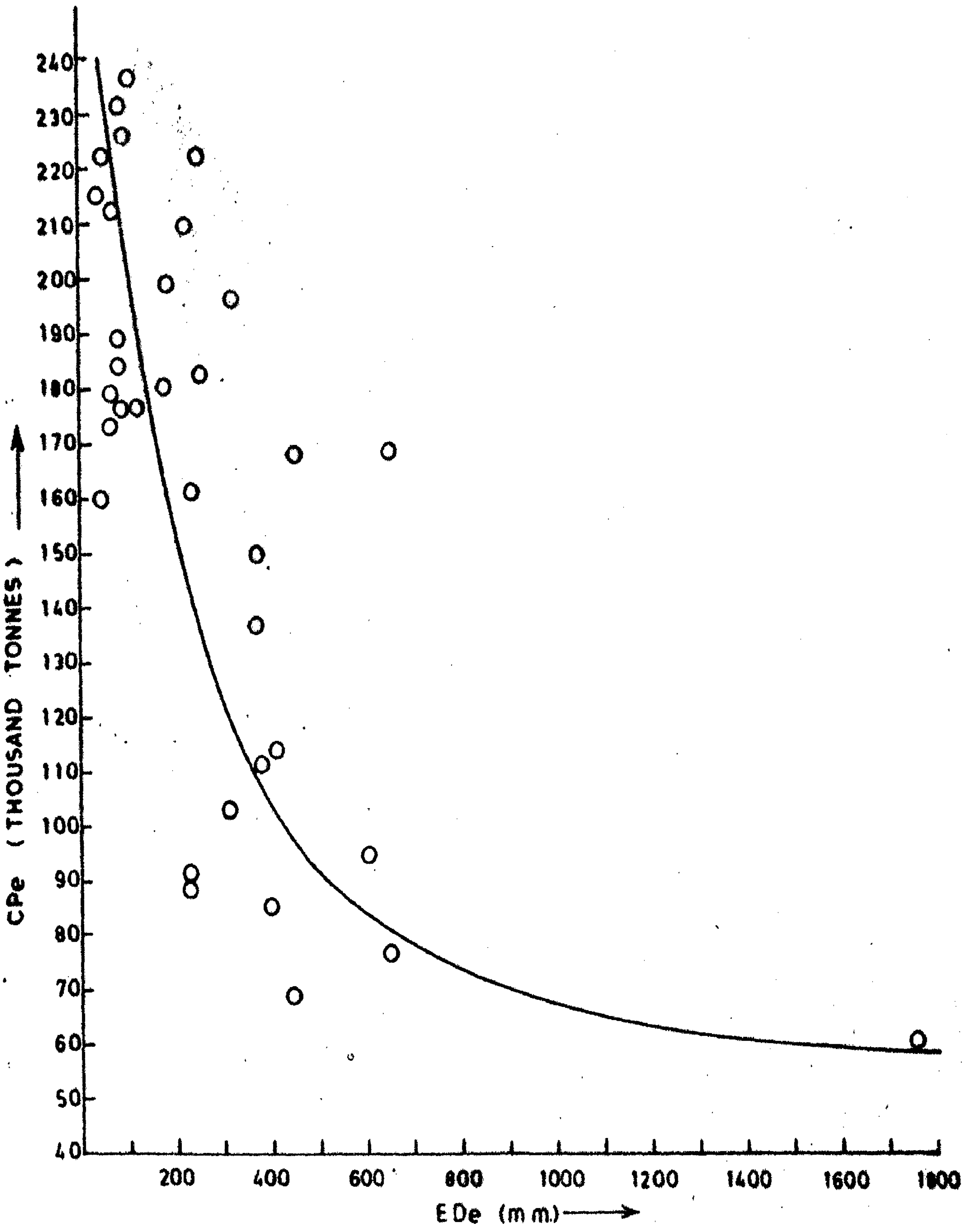


FIG. 5.19 – RELATION BETWEEN EDe AND CPe

where, Y = Dependable variable i.e. annual equivalent crop production CP_e;

x = Independent variable i.e. the parameters ED and ED_e; and

A,a,b,c = Parameters of the model to be evaluated by suitable statistical techniques.

5.4.1 Estimation of the Parameters of the Equation:

The parameters a & b of equation (5.6) have been estimated by least-square technique after converting the equation into linear form by taking the logarithmic i.e.

$$\log Y = \log a - b.x$$

In case of Equation (5.5), the value of A is initially assumed suitably and then the equation is transformed to linear form as follows:

$$\log(Y-A) = (-\log a) + b \log x$$

The value of a & b is then estimated by 'least-square techniques'. The best set is found by trial and error method with different values of A.

In case of equation (5.7), the values of the constants a, b, c are estimated by the method of 'selected points method' after drawing a suitable curve. The curves are suitably modified and the equations re-established. The best equation, out of several trials is selected.

In order to have a comparison, the coefficient of correlation is estimated between the actual value of CP_e and the estimated value of CP_e as found with the suggested criterion.

The final set of equation between CP_e and ED with highest value of coefficient of correlation is given in Table 5.8.

Table 5.8: List of Established Equations

S.N.	Different types of Equations established	Coefficient of correlation (r)
1.	$CP_e = 250,000 - 8517.44\ ED^{0.3919}$	0.6294
2.	$CP_e = 180631.1076\ e^{-0.000476813\ ED}$	0.534
3.	$CP_e = \dfrac{1}{0.003242 + 0.0000858\ ED^{0.659}}$	0.6559

Out of the above three equations, the equation with the highest value of 'r' is recommended for adoption i.e.

$$CP_e = \frac{1}{0.003242 + 0.0000858\ ED^{0.659}} \qquad \text{..........(5.8)}$$

Similar, exercises were carried out to find the relationship between the parameter ED_e and CP_e and the final equation with highest value of 'r' is given below:

$$CP_e = \frac{1}{0.0017988 + 0.000341798\ ED_e^{0.5136076}} \quad .... (5.9)$$

where, CP_e = Equivalent crop production; and

ED_e = 'Effective deficiency with extreme conditions duly represented'.

The Figure 5.20 shows the relationship of CP_e with the parameters ED and ED_e. The details of computation of CP_e for various years with the help of equations (5.8) & (5.9) have been given in Annexure X. The equation (5.9) has coefficient of correlation 'r' as 0.6833 which is higher than that of Equation (5.8) and therefore, the equation may be considered to be the best out of various suggested representation of the drought conditions. However, the parameter ED and ED_e represent more or less similar features and, therefore, both the parameters have been considered for further analysis. These parameters alongwith the other prevalent parameters have been used to examine the effectiveness and hence the suitability of these parameters in representing the drought conditions.

5.5 EVALUATION OF THE IDENTIFIED PARAMETERS

From the above study, two parameters, namely, ED and ED_e, have emerged to be reasonably good parameters which incorporate the different factors enumerated in Chapter III and at the sametime represent reasonably acceptable relationship with equivalent crop production. However, it remains a fact that these parameters represent only few of the numerous factors which eventually are responsible for

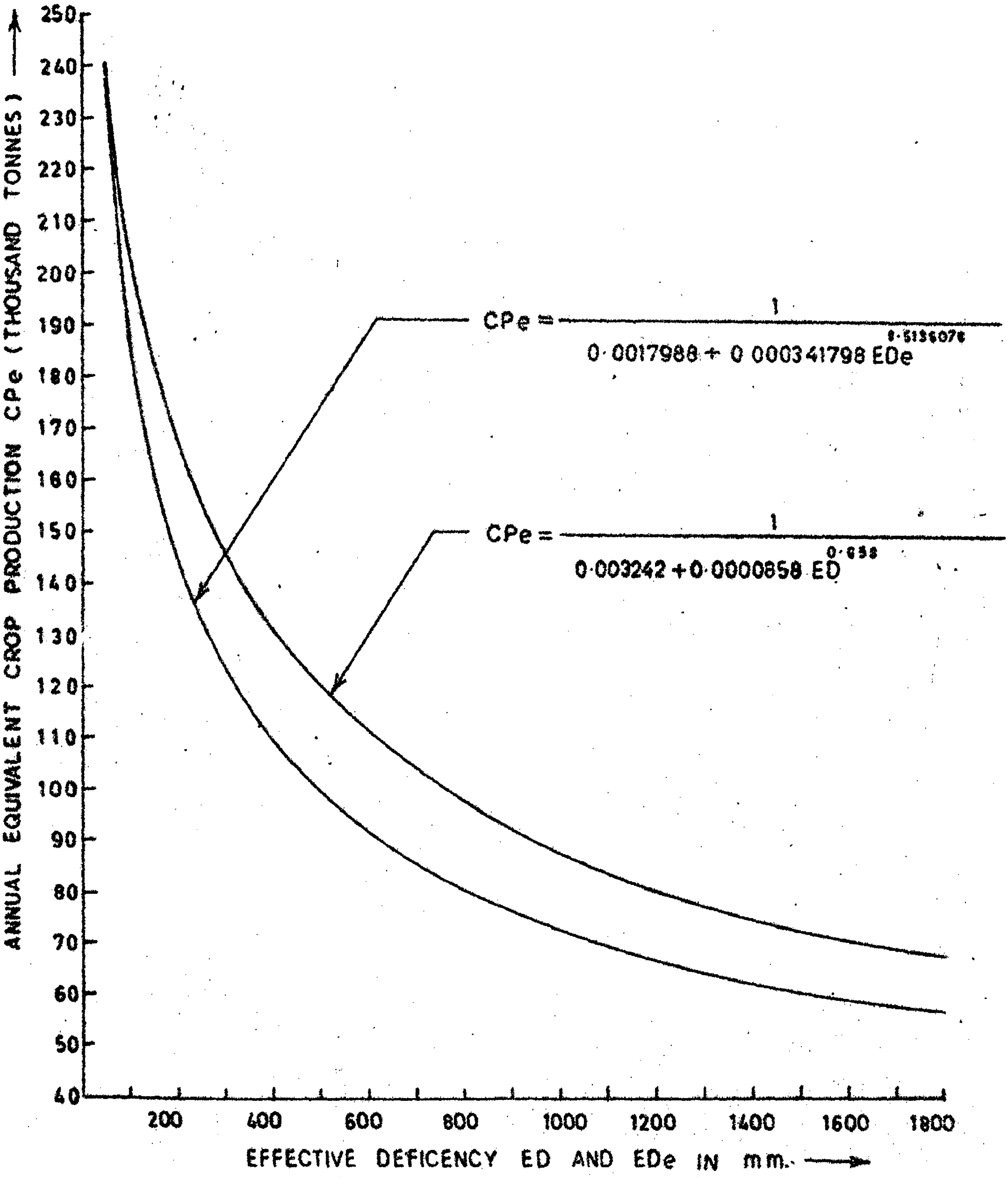


FIG. 5·20 - GRAPHICAL REPRESENTATION OF THE MATHEMATICAL EQUATION CORRELATING CPe with ED/EDe.

food production. Perhaps, that is the reason why coefficient of correlation is not very high but still it is quite reasonable and the coefficients of correlation with the two parameters, namely, ED and ED_e are best among the others. Further, the basic idea is not to find the amount of crop production, but to identify the parameters which are rational and more appropriate to represent drought conditions from overall conditions.

The suitability of these parameters vis-a-vis other prevalent parameters in identification of drought situation has been evaluated and presented below.

5.5.1 Ability of Various Parameters to Identify Drought Years:

The following criteria/parameters have been considered in the study:

a) Annual rainfall less than 75% of normal,

b) Aridity index,

c) Effective deficiency (ED,)

d) Effective deficiency with extreme conditions duly represented, (ED_e) and

e) 75% of average equivalent crop production.

These criteria/parameters have been used to identify the drought years for the period from 1948 to 1980. On the basis of rainfall criteria, a year has been declared as drought year whenever the total annual rainfall becomes less than 75% of the normal rainfall in the region. The aridity index criterion considers a year to be drought whenever the departure of aridity index from normal is between 0 to $1/2\sigma$ (where σ is the standard deviation of aridity index for a time series). Study has already been done earlier to identify drought years with the help of aridity index criterion for the region under study and so the result of the same has been adopted as such. In order to identify the drought year from the parameter ED and ED_e, the limit of these two parameters has been identified to that corresponding to 75% of average CP_e. The average CP_e works out to be 156.797 thousand tonnes and values of ED and ED_e corresponding to 75% of 156.797 thousand tonnes (i.e. equal to 117 thousand tonnes) work out to be 522.0 mm and 333.0 mm respectively. All the years with the value of effective deficiency, ED more than 522.0 mm may be considered to be drought years. Similarly the years having the value of ED_e more than 333.0 mm may be considered to be drought years. Table 5.9 and 5.10 show the drought years which have been identified on the basis of parameters ED and ED_e respectively.

The drought years so identified by different criteria / parameters have been compared with actual droughts as declared by the State Government for Palamu district during the period 1948-80.

Comparison of Drought Years Identified by Various Parameters: Table 5.11 is self-explanatory and clearly indicates the drought years as identified by various parameters. This table also shows as to how many drought years are identified

Table 5.9: Drought Years Identified by the Parameter ED

S.N.	Year	Value of ED (mm)	Limiting value of ED (mm)	Remark
1.	1954	608.0	522.0	Drought
2.	1955	1075.93	522.0	Drought
3.	1966	2941.24	522.0	Drought
4.	1968	616.79	522.0	Drought
5.	1972	614.45	522.0	Drought
6.	1973	723.58	522.0	Drought
7.	1976	594.72	522.0	Drought
8.	1979	1074.79	522.0	Drought
9.	1980	649.30	522.0	Drought

Table 5.10: Drought Year as Identified the Parameter ED_e

S.N.	Year	Value of ED_e (mm)	Limiting value of ED_e (mm)	Remark
1.	1948	376.59	333.0	Drought
2.	1952	372.05	333.0	Drought
3.	1954	447.18	333.0	Drought
4.	1955	602.36	333.0	Drought
5.	1966	1759.57	333.0	Drought
6.	1968	393.07	333.0	Drought
7.	1972	406.24	333.0	Drought
8.	1973	648.05	333.0	Drought
9.	1976	449.0	333.0	Drought
10.	1979	645.32	333.0	Drought
11.	1980	364.17	333.0	Drought

Table 5.11: Drought Years as Identified by Different Parameters/Criteria

S.N.	Year	Name of Parameters/Criteria				
		75% normal annual rain-fall	Aridity index	ED	State Govt. declara-tions	ED_e
1.	1948					●
2.	1949					
3.	1950				⊗	
4.	1951				⊗	
5.	1952				⊗	●
6.	1953		○			
7.	1954	⊙	○	◍	⊗	●
8.	1955	⊙	○	◍	⊗	●
9.	1956				⊗	
10.	1957		○		⊗	
11.	1958		○		⊗	
12.	1959					
13.	1960		○			
14.	1961					
15.	1962		○			
16.	1963		○			
17.	1964		○			
18.	1965				⊗	
19.	1966	⊙	○	◍	⊗	●
20.	1967		○			
21.	1968	⊙	○	◍		●
22.	1969		○			
23.	1970		○			
24.	1971					
25.	1972		○	◍	⊗	●
26.	1973	⊙		◍		●
27.	1974		○		⊗	
28.	1975		○			
29.	1976		○	◍		●
30.	1977					
31.	1978					
32.	1979			◍	⊗	●
33.	1980	⊙	○	◍	⊗	●

by all the parameters/criterion and which of the drought years are identified only by a few parameters/criteria. The ability of various parameters/criteria in identifying the drought years is illustrated by Table 5.12.

Table 5.12: Ability of various Parameters to Identify Drought Years

A. No. of drought years declared by State Govt.during the period 1948-80.	14
B. No. of years out of above 14 years which have been identified by	
i) 75% normal annual rainfall	 4
ii) Aridity indix	 8
iii) Effective deficiency, ED	 6
iv) Effective deficiency with extreme conditions duly represented, ED_e	 7

From Table 5.12 it would be seen that during the period of 1948 to 1980, the State Govt. declared 14 drought years out of which only 4 years satisfy the '75% normal rainfall criterion and 8 years fulfil the 'aridity index criterion'. But as may be seen from Table 5.11, the total no. of drought years during the same period identified on the basis of 'aridity index criterion' are 19. During the same period the parameter ED could identify 9 drought years out of which 6 years were included in 14 'declared drought years' while the parameter ED_e could identify 7 'declared drought years'. The efficiency of various parameters/criteria in identification of drought years is given in Table 5.13.

Table 5.13: Efficiency of various Parameters/Criteria in Identifying Drought Years

S.N. Particulars	Name of Parameters/criteria				No. of drought years declared by State Govt.
	75% normal annual rainfall	Aridity index	ED	ED_e	
1	2	3	4	5	6
1. No. of drought years identified	6	19	9	11	14
2. No. of drought years common with those in (6)	4	8	6	7	
3. Net efficiency as compared to the criterion (6)	19%	24%	28%	32%	

It would be observed that the parameters ED and ED_e have considerably improved result. However, it remains a fact that the decision of the State Govt. to declare drought years is, many a time, influenced by the political and other factors. Also, in majority of the cases the decisions are premature and are taken soon after the initial deficiency of the rain in the monsoon period. A subsequent rain may change the situation altogether.

In order to have a more rational evaluation of various criteria/parameters the drought years have been assumed to be the years when CP_e is less than 75% of the average CP_e. On this basis 10 years have been identified as drought years and the efficiency of various parameters/criteria in identifying the drought situation is given in Table 5.14.

Table 5.14: Efficiency of various Parameters/Criteria in Identifying Drought Years

Particulars	Name of parameters/criteria				
	75% normal annual rainfall	Aridity index	ED	ED_e	75% average CP_e
1	2	3	4	5	6
No.of drought years identified	6	19	9	11	10
No.of drought years common with those in (6)	5	8	6	8	
Net efficiency as compared to the criterion (6)	42%	34%	40%	58%	

5.5.2 Drought Forecasting:

One important aspect is the ability of the planner to forecast the drought conditions as early as possible. Obviously, the criterion of '75% normal annual rainfall' or 'aridity index' or 75% normal crop production can be used for declaring a year to be the drought year only after the rainfall and other data are available. In other words these criteria may not be of any help so far as the decision making and advance action to take remedial or relief measures are concerned.

The parameter 'effective deficiency, ED' and the 'effective deficiency with extreme conditions duly represented, ED_e' have the advantage of declaring a particular year as drought year as soon as the effective deficiency exceeds a specified limit. (In this case, 522.0 mm for ED and 333.0 mm for ED_e). Table 5.15 and 5.16 illustrate procedures as to how a drought forecasting can be done. In case of parameter ED, almost all the years which have been identified as drought year could have been declared as drought year by the end of the month of September. Out of 9 identified drought years, 2 years (1966 & 1973) could have been declared as drought year only at the end of July; 3 years (1954, 1955 & 1979) at the end of August and 3 years (1968, 1972 & 1980) at the end of September.

Similar is the case with the parameter ED_e which is able to forecast a drought by the end of September in respect of all the 11 years identified as drought year on the basis of this criterion. Out of 11 identified drought years, the forecasting was possible in respect of 4 years (viz. 1952, 1954, 1966 & 1973) at the end of July; 2 years (viz. 1955 & 1979) at the end of August and remaining 5 years at the end of September.

Table 5.15 : Forecasting of 'Drought' with the help of Parameter'ED'

Sl. No.	Identified drought year	June (wi=0.387) Ki (mm)	Rr	ED (mm)	July (wi=2.231) Ki (mm)	Rr	ED (mm)	Aug. (wi=2.207) Ki (mm)	Rr	ED (mm)	Sept. (wi=2.161) Ki (mm)	Rr	ED (mm)	Oct. (wi=0.628) Ki (mm)	Rr	ED (mm)
.	1954	37.58	1.54	22.40	133.73	1.64	513.15	39.8	1.42	569.04*	0.0	1.26	504.92	39.98	1.31	557.85
.	1955	101.22	1.53	59.93	71.59	1.38	274.47	135.54	1.51	752.02*	78.47	1.54	1028.10	0.0	1.44	961.34
.	1966	0.0	1.11	0.0	282.76	2.31	1457.23*	97.67	1.92	1625.08	153.6.	2.17	2556.96	50.48	2.28	2746.78
.	1968	46.91	1.13	20.51	105.26	1.32	333.95	0.0	1.17	296.	78.87	1.25	529.28*	14.78	1.26	540.89
.	1972	111.84	2.80	121.90	43.44	1.52	213.10*	0.0	1.16	162.63	131.1	1.33	563.26*	0.0	1.22	520.91
.	1973	16.81	1.59	10.34	214.73	2.23	1068.31	0.0	1.46	708.93	0.0	1.30	631.24	0.0	1.23	597.25
.	1976	0.0	0.96	0.0	0.0	0.98	0.0	19.44	1.01	43.33	165.13	1.08	471.73	50.48	1.14	487.54
.	1979	31.94	1.14	14.09	67.99	1.21	198.5	160.97	1.44	747.8*	60.13	1.44	934.92	36.68	1.49	1001.7
.	1980	0.0	0.81	0.0	43.09	0.99	95.17	94.1	1.12	340.27	75.37	1.19	555.36*	0.0	1.18	550.69

* Time of forecast of drought ; $R_{ri} \frac{P_{Ni}}{P_{Ai}}$ where P_{Ni} = Normal rainfall upto ith Month

P_{Ai} = Total rainfall upto ith month

Table 5.16 : Forcasting of Drought with the help of Parameter ED

Sl. No.	Identified drought year	Monsoon season/Kharif season June (wi=0.387) Ki (mm)	Rri	ED (mm)	July (wi=2.231) Ki (mm)	Rri	ED (mm)	Aug. (wi=2.207) Ki (mm)	Rri	ED (mm)	Sept (wi=2.161) Ki (mm)	Rri	ED (mm)	Oct. (wi=0.628) Ki (mm)	Rri	ED (mm)
1.	1948	[illegible]	0.85	0.0	105.33	1.16	282.94	15.57	1.12	322.55	18.43	1.12	367.15*	1.98	1.13	371.84
2.	1952	0.0	0.64	0.0	130.59	1.05	354.94*	2.14	1.04	353.16	0.0	1.00	353.16	10.11	1.02	352.84
3.	1954	37.58	1.54	22.40	153.75	1.64	489.88*	39.8	1.42	442.12	0.0	1.26	392.31	39.98	1.31	409.18
4.	1955	101.22	1.53	59.73	71.59	1.36	226.94	135.54	1.51	515.45*	76.47	1.54	586.98	0.0	1.44	548.87
5.	1966	0.0	1.11	0.0	282.76	2.31	1457.23*	97.37	1.92	1625.08	153.6	2.17	2556.96	50.48	2.28	27[illegible].96
6.	1968	46.91	1.13	20.51	105.26	1.32	310.91	0.0	1.17	275.58	78.87	1.25	363.42*	14.78	1.26	366.51
7.	1972	111.84	2.8	121.9	43.44	1.52	161.33	0.0	1.16	123.12	131.1	1.33	402.37*	0.0	1.22	369.1
8.	1973	16.81	1.59	10.34	214.73	2.23	1068.41*	0.0	1.46	699.50	0.0	1.30	622.84	0.0	1.23	589.30
9.	1976	0.0	0.96	0.0	0.0	0.98	0.0	15.44	1.01	43.35	161.13	1.08	388.17*	50.48	1.14	411.32
10.	1979	31.94	1.14	14.59	67.99	1.21	184.15	160.97	1.44	556.54*	60.13	1.44	587.15	36.68	1.49	790.61
11.	1980	0.0	0.81	0.0	43.09	0.95	0.0	94.1	1.12	256.31	75.37	1.19	334.26*	0.0	1.18	331.45

* Time of forecast $Rri = \frac{P_{Ni}}{P_{Ai}}$ where, P_{Ni} = Normal rainfall upto ith month

P_{Ai} = Total rainfall upto ith month

5.6 FINDINGS OF THE STUDY

The comparison of various criteria/parameters and their ability in drought forecasting very clearly indicates the relative merits of each. The parameter ED_e is undoubtedly superior to various criteria/parameters which are currently under use and which have been identified during this study.

CHAPTER - VI

CALCULATION AND RECOMMENDATION

This study has been done with an objective of developing a suitable parameter which is rational and is capable of identifying the drought condition in proper perspective with the help of available hydrological and hydro-meteorological data. This study has already indicated the limitations of various existing criteria which result from the fact that they omit the consideration of some pertinent factors which are also responsible for development of drought like situation.

6.1 CONCLUSIONS

On the basis of analysis presented in this study, the following conclusions can be drawn:

a) Existing criteria are inadequate to define the drought situation in proper perspective.

b) The drought has to be considered in totality and should not be related to any specific discipline such as hydrological drought, meteorological drought or agricultural drought.

c) The various consequences of drought must be evaluated and duly incorporated in defining the drought conditions in any region.

d) The following factors should be considered when a drought situation is to be defined for agriculture based society from the view point of water resources planning:

i) Time distribution of the input variables i.e. rain or runoff;

ii) The time distribution of planned/proposed water utilisation;

iii) Priority of different uses of water;

iv) Period-wise priority of water use for each of the purposes separately; and

v) The conditions of previous years.

e) The parameter ED_e is found to represent the drought situation in much better way than any of the existing criteria.

6.2 LIMITATIONS OF THE STUDY

The study was carried out under the constraint of time and this has restricted the scope in the following way:

a) The data of only one district have been analysed.

b) In order to simplify the study only the agricultural produce which, obviously is the most important one, has been considered to be the drought consequence affecting the society.

c) The input sequences which are supposed to affect the crop production and hence the drought conditions are also restricted.

d) The time factor has also affected the possibility of use of other parameters/equations.

6.3 RECOMMENDATIONS

a) More drought-prone areas should be covered under such type of studies to arrive at a more rational and comprehensive decision.

b) As for input sequences, more data in addition to rainfall and river flow should be analysed to incorporate other aspects of drought consequences.

c) The proposed developmental plan which are likely to be taken up in the study area should be taken into consideration while analysing a drought situation.

Statewise Percentage of Population affected by Drought

S.N.	Name of the State	Total Population (1971 census)	Population affected by drought	Percentage
1.	Andhra Pradesh	4,35,03,000	1,45,19,791	33
2.	Bihar	5,63,53,000	1,55,63,502	28
3.	Gujarat	2,66,97,000	1,83,62,603	69
4.	Haryana	1,00,37,000	39,66,358	40
5.	Jammu & Kashmir	46,17,000	6,81,066	15
6.	Karnataka	2,92,99,000	2,40,06,759	82
7.	Maharashtra	5,04,12,000	1,74,81,066	15
8.	Madhya-Pradesh	4,16,54,000	86,07,698	21
9.	Orissa	2,19,45,000	17,85,594	8
10.	Rajasthan	2,57,66,000	1,15,07,729	45
11,	Tamilnadu	4,11,99,000	..	
12.	Uttar-Pradesh	8,83,41,000	10,31,47,45	12
13.	West-Bengal	4,43,12,000	91,43,161	21
	Total	48,41,35,000	16,10,64,026	33
	Other states/ Union Territories	6,40,25,000		
	All India	54,81,60,000	16,10,64,026	29.38

SUMMARY OF VARIOUS DEFINITIONS OF DROUGHT

Author/Year	Definition of Drought or associated concepts	Region
1.Russel,1896	A period of months or years during which little rain falls; "the country gets burnt up, grass and water disappear, crops become worthless and sheep and cattle die".	Australia
2.Brounov (early 20th century)	Ten days with rainfall not exceeding 5 mm.	Ref. Tannehill, 1987
3.Vysotskss (1905)	Established P/E ratio where P is precipitation and E is potential evaporation (both annual values in mm). P/E = 1 1/3 for moist forest = 1 for transitory forested steppe = 2/3 for moderately dry steppe = 1/3 for southern dry steppe	U.S.S.R.
4.Henry(1906)	21 days or more when rainfall is 30% or less of average for the time and place. Extreme drought when rainfall fails to reach 10% of normal for 21 days or more.	U.S.A.
5.Lang(1915)	Precipitation factor = P/T P in mm, T in ^{o}C	Germany developed to aid climatic classification of soils.
6.Koloskov(1925)	Ratio of annual precipitation to accumulated mean daily temperature during vegetation period(divided by 100)	U.S.S.R. Ratio may be used as a comparative agroclimatic index

7. de-Martonne (1926)	Index of aridity, $I = \frac{P}{t+10}$ where P is monthly precipitation (mm) and t is mean monthly temperature (^{o}C). Monthly index of I is approximate indicator of aridity. Index modified to $I = \frac{nxP}{t+10}$ where n is number of days during a certain period from a few days to a year and $\bar{p}$ is daily mean precipitation in the period.	Used to define climatic limits of deserts, prairies and forests. Does not apply well in cool zones where t + 10 approaches zero. Used extensively by geographers & biologists to compute aridity.
8. Selyaninov (1930)	Index given by $K = \frac{\Sigma p}{\Sigma t/10}$ where p is sum of rainfall (mm) during those months when mean temperature is above $10^{o}C$ and t is the sum of the daily mean temperatures above $0^{o}C$ for the same period.	U.S.S.R. Author suggested that a period be considered as a dry spell when K 1 and as a drought when K 0.5.
9. Koppen (1931)	Defines 'dry' climate by: $p < 2t$ for regions of winter rain and $p < 2t + 14$ for regions of summer rain or no rainy season where p is annual precipitation in cm and t is mean temperature in ^{o}C. 'Desert' climate defined by; p t for winter rain; p t + 14 for summer rain; $p < t + 7$ for no rainy season.	Used extensively in classification of the dry climates of the world.
10. Thornthwaite (1931)	Precipitation effectiveness as a function of mean temperature.	U.S.A.
11. Cole (1933)	15 days with no rain	U.S.A.
12. Bates (1935)	When annual precipitation is 75% of normal or when monthly precipitation is 60% of normal.	U.S.A.
13. Hoyt (1936)	Any amount of rainfall less than 85% of normal	U.S.A.

14.British Rainfall Organisation(1936)	Absolute drought: at least 15 consecutive days none of which received as much as 0.25 mm. Partial drought: at least 29 days during which mean rainfall does not exceed 0.25 mm per day. Dry spell: 15 consecutive days none of which has received as much as 1 mm.	Britain; inapl in normally drier regions
15,Knochenbauer (1937)	Daily maximum temperatures and humidity at time of afternoon observation used to define a dry spell.	Germany
16.Bova(1941)	Used a drought index K $K = \frac{10(H + Q)}{\sum t}$ Where H is productive soil moisture in mm in the top 100 cm of soil at beginning of spring; Q is precipitation in mm accumulated daily from beginning of spring; $\sum t$ is the temperature (°C) sum counted from the day of the passage of mean daily temperature through zero.	U.S.S.R. When K 1.5 beginning of drought damage to plants is indicated.
17.Baldwin-Wiseman (1941)	Engineer's drought in Australia is three or more consecutive months with deficit of 50% from mean rainfall.	Australia
18.Blumenstock (1942)	Less than 2.5 mm in 48 hours	Ref. Thornthwaite (1941)
19.Conrad (1944)	A period of 20(or 30) consecutive days or more without 6.4 mm of precipitation in 24 hours during season March to Sept.inclusive.	U.S.A.
20.Condra(1944)	Period of strong wind,low precipitation, high temperature and usually low relative humidity.	U.S.A.This anticipates the combination of low precipitation & high evapotranspiration

21. Henin & Ternisien (1944)	Computed evapotranspiration and drainage from temperature and precipitation.	France, Procedure approved by Turc(1954) incorporating additional factors.
22. Thornthwaite (1947)	Cannot be defined as shortage in rainfall alone.	U.S.A.
23. Popov(1948)	Index of aridity $P = \frac{\Sigma g}{2.4\ (t-t')r}$ Where P is index of aridity; g is annual amount of effective precipitation; t-t' is annual mean wet-bulb depression °C; r is factor depending on day length; and g is that part of precipitation which is available for plants.	
24. Ivanov(1948)	Indices of K = P/E where P is annual precipitation in mm & E is annual evapotranspiration in mm derived from $E = 0.0018(25 + t)^2 (100-a)$; t is mean monthly temperature in °C; a is mean monthly relative humidity, Critical values of K: for regions of insignificant moisture, deserts 0.00-0.12; Scanty moisture, semi-deserts 0.13-0.29; Insufficient moisture, steppes 0.30-0.59; Moderate moisture, forested steppes 0.60-0.99; Sufficient moisture 1.00-1.49; Excess moisture 1.50	U.S.S.R.
25. Barger and Thom(1949)	Evaluated precipitation climate from productive performance of crops.	U.S.A.
26. Trumble(1937) Hounam(1948) Prescott(1949)	Waite index: $K = 0.38\ P/E\ 0.7$ Where P is monthly or annual rainfall or irrigation in mm; E is monthly or annual evaporation from Australian sunken pan in mm.	Australia

Tumble(1937) Hounam(1948) Prescott(1949) (contd.)	The index $K = 0.54$ was derived from a study of young sunflower plants & extrapolated to field crops and has been successfully used in defining climatic boundaries for land use & for frequency of periods of non-effective rainfall. This is an improvement on the original Transeau (P/E) ratio which has been applied in some form or another in many countries. To start and maintain growth $K > 0.54$. For nil drainage through drain gauges K 0.74. For balance between rainfall and potential evapotranspiration in catchments $K = 1.20$. For balance between rainfall & evapotranspiration in field vegetation $1.30 \leq K \leq 1.50$.	Australia (contd.)
27. Ramdas(1950)	When actual rainfall for a well is half of normal or less.	India
28. Fitzpatrick (1953)	Period terminated by at least 6.4 mm during any 48 hours.	Australia (based on Blu menstock). Evaluated probability that dry spells of any length would occur a any time throughout th year.
29. Van Bavel (1953)	Actual drought should be defined on the basis of soil-water status and resultant plant behaviour.	U.S.A.
30. Ture(1954)	$E = \frac{P}{(0.9+(P/L)^2)^{0.5}}$ mm/annum Where P is annual precipitation (mm); $L = 300 + 25T + 0.05T^3$ T is mean air temperature(^{o}C).	France
31. Gaussen(1954)	When total monthly precipitation in mm is less than twice the mean temperature in ^{o}C.	An approximation to rainfall less th evapotranspir tion based or Koppen.

32. Emberger (1955)	$$I = \frac{100\,P}{(M-m)\,(M+m)}$$ Where M is the mean maximum temperature in the hottest month and m is the mean minimum temperature in the coldest month; p in mm and M and m in ^{o}C.	France. Based on de Martonne's index, (M-m) is an index of continentality.
33. Thornthwaite and Maher (1955)	Used the water-balance concept with a variable store of soil water.	U.S.A. Use extended to other continents; some results of doubtful value
34. White (1955)	Defined drought with respect to Xerophilous species using comments on pasture conditions as guide.	Western N.S.W. Australia. Extrapolation to other areas not reliable.
35. Ture (1955)	For short periods $$E = \frac{P = a + V}{1 + \left(\frac{P+a}{L} + \frac{V}{2L}\right)^{2}\ 0.5}$$ Where E is evaporation in mm in 10-day period; P is precipitation in mm in 10-day period; a is estimated evaporation (10-day) from bare soil; V (a crop factor) = 25 $(MC/Z)^{0.5}$ 100 M is final yield of dry matter (kg/ha). 10 Z is length of growing season (days) C is a crop factor; L is evaporation capacity by the air from $L = (T + 2)\,\frac{i^{0.5}}{16}$ Where T is mean air temp. ^{o}C (in 10-day period) and i is incoming radiation (cal cm^{-2} day^{-1}).	France
36. Van Bavel & Verlinden (1956)	A condition in which there is insufficient soil water available to crops.	U.S.A.
37. Foley (1957)	Used reports of conditions of crops and livestock published in official bulletins or newspapers together with rainfall and analyses.	Australia. Necessarily rather qualitive but help to define the significance of rainfall deficiency.

38. Foley (1957)	Computed residual mass curves of rainfall. Divided values by average annual rainfall to give 'index of severity'.	Australia. Dividing by annual average makes comparison between stations more reliable. Index is dimensionle
39. Alpatev & Ivanova (1958)	Based definition of severity on crop yields as compared with long-term mean yields. Because all yield decreases are not result of drought author suggests that only years when yields decreased by 25% be classified as drought years.	Variations in yield due to different leve of agronomic practices are still greater than those due to droughts (Kulik, 1958).
40. Kulik (1958)	Used preceding meteorological conditions, soil characteristics and level of agronomic techniques in the region. Decrease of soil water in tilled layer to 20 mm means beginning of dry period and decrease to 10 mm beginning of drought. Semi-drought; ten days with soil water 20 mm in first 20 cm of soil. Drought; as above with 10 mm of water.	U.S.S.R.
41. Decon, Priestley, Swinbank (1958)	Urged the systematization of definitions of drought in relation to effectiveness of rainfall in different climates.	Australia
42. Huschke (1959)	A period of abnormally dry weather sufficiently prolonged for lack of water to cause serious hydrological imbalance (i.e. crop damage, water supply shortage).	
43. Linseley, Kohlar and Paulins (1959)	A sustained period of time without significant rainfall.	U.S.A. The problem is to define 'sustaind' and 'significant'.
44. Penman (1948) (1961) Ferguson (1952)	Estimates water loss from free surface from solar radiation (or sunshine), temperature, humidity and wind, evapotranspiration obtained by using seasonal conversion factor $E_t = fE$.	Originally U.I then Europe. Use now extenc to other conti nents with fa

		to good resul Of little val in dry areas where water supply to plants limite
45 Holmes (1962)	States that in the quantitative evaluation of drought for agricultural pruposes, precise and regular soil-water observations are most essential.	Canada
46 Palmer (1965)	A water balance model which involves rainfall, a coefficient of evapotranspiration, runoff and available soil water.	U.S.A. Method based on the Thornthwaite concept of potential evapotranspiratio
47. Fitzpatric (1965)	Developed a water-use model with range of available soil moisture 0.10 cm and evapotranspiration losses (E_t) computed from Australia sunken evaporimeter (E_A). $E_t = 0.8E_A$ when soil moisture $>$ 64 mm; $E_A = 0.4E_A$ when soil moisture $\leq$ 64 mm.	Australia. Has been used in climatic studies and land-use surveys.
48. Rickard (1966)	Agricultural drought exists when the soil-water in the rootzone is at or below the permanent wilting percentage. The condition continues until rainfalls in excess of daily evapotranspiration.	Newzealand Drought relief would not occur with say one day of excess rainfal e.g. 2.5 - 5 mm
49. Baier and Robertson (1966)	Versatile budget (VB) for estimating daily AE from changes in soil moisture per zone $AE_i = \frac{k \cdot S'(i-1) Z \cdot PE_i}{S} \exp(-w(PE_i - PE))$ integrated over soil zones 1 to n where AE_i is actual evapotranspiration for day i(mm); k is coefficient accounting for soil and plant characteristics in zone.	Canada. Satisfactory estimates obtained for growing season

50. Gibbs and Maher (1967)	State that rainfall is the best single index of drought and use rainfall deciles to demonstrate temporal and spatial distribution. Areas where rainfall in first decile range roughly coincides with drought areas.	Australia Provides a usefu presentation areal distribution of drought.
51. Subrahmanyam (1967)	To the meteorologist drought is a rainless situation for an extended period during which some precipitation should normally have been received depending on location and season. The agriculturalist considers drought as a shortage of moisture for his crop. The hydrologist views it as being responsible for depression of surface and underground water levels or diminution of streamflow. To the economist drought means a water shortage adversely affecting the established economy of the region. Water shortage is basic to drought; it is a relative rather than an absolute condition.	Inadequate in areas of seasonally low rainfall and in moist areas of high transpiration
52. Palmer (1968)	Severity of agricultural drought is defined in terms of the magnitude of the computed abnormal evapotranspiration deficit and expressed as a crop moisture index.	U.S.A. Inputs are weekly values of temperatures rainfall. A product of t 1965 drought work. Theoretcally of universal appli bility.
53. Mcllroy (1968)	Introduced variables to cover leaf wetness and improved aerodynamic functions.	Australia. Us for conditio of limited s moisture but measurement parameters r tricts wide application.

54. Budyko (1970)	Hydrothermal coefficient $K = \frac{r}{0.18 \Sigma \Theta}$ when $0.18\Sigma\Theta$ gives the potential evapotranspiration in mm, Θ being the annual sum of daily mean temperatures higher than 10°C; r is annual precipitation in mm.	U.S.S.R.
55. Sly (1970)	Climatic moisture index $I = \frac{P}{P + SM + IR} \times 100$ Where P is growing season precipitation; SM is soil water available to crops at beginning of growing season; IR is calculated growing season irrigation requirement.	Canada. Average seasonal values indicating differences in water balance, used for soil climate classification purposes.

Annexure III

SALIENT FEATURES OF STUDY AREA

1.	Name of the district	:	PALAMU
2.	State	:	BIHAR
3.	Location	:	$23^{o}20'$ to $24^{o}39'$ North Latitude and $83^{o}22'$ to $85^{o}00'$ East Longitude
4.	Geographical area of the district	:	12,019.90 Km^2
5.	No. of Sub-divisions	:	Three
6.	Total no. of inhabited villages	:	3218 (1971 census)
7.	Total no. uninhabited villages	:	365(1971 census)
8.	Total no. of towns and cities	:	5 nos.
9.	a) Population	:	i) 19,16,152 (as per 1981 census ii) 15,04,350 (as per 1971 census)
	b) Total no. of workers	:	6,20,466 (as per 1981 census)
	c) Total no. of cultivators)	:	3,00,032 (-do -)
	d) Total no. of Agricultural labourers	:	2,27,855 (-do-)
10.	Density of population	:	159 persons/sq.km.(1981)
11.	Decenial growth(1971-81)	:	27.40%
12.	Livestock population	:	14,73,281 (1977 census)
13.	Type of soils	:	Old alluvium-Reddish yellow-Yellow grey catenary soils, Red yellow light-grey catenary soils, Yellow-reddish yelow medium deep light textured catenary soils.

14. Land use details (Average of 1973-74 to 1978-79) — (Source : Directorate of Statistics & Evaluation, Govt. of Bihar, Patna)

a)	Reporting area	: 12,01,990 ha (100 %)
b)	Forests	: 5,64,872 Ha(47.00%)
c)	Land put to non-agricultural uses	: 35,699 Ha (2.97%)
d)	Barren and uncultivable land	: 79,572 Ha (6.62%)
e)	Permanent pasture and grazing land	: 6,490 Ha (0.54%)
f)	Misc. trees, crops and groves	: 3,005 Ha (0.25%)
g)	Cultivable waste	: 25,602Ha(2.13%)
h)	Other fallows	: 92,313 Ha(7.68%)
i)	Current fallows	: 1,58,783 Ha (13.21%)
j)	Net area sown	: 2,67,082 Ha (22.22%)
k)	Gross sown area	: 3,28,019 Ha.
l)	Area sown more than once and its percentage to net sown area	: 42,680 Ha (15.98%)
m)	Culturable area	: 5,46,785 Ha (45.49%)

15. Gross irrigated area sourcewise (average of 1972-73 to 1979-80)

a)	Total area	: 67,641 Ha. (100%)
b)	By canals	: 7,158 Ha.(10.6%)
c)	By tanks	: 6,816 Ha (10.1%)
d)	By Tubewells and wells	: 1,800 Ha.(26.6%)
e)	Other sources	: 35,666 Ha, (52.7%)

16.	Rivers system		
	a) Name of main river	:	Sone
	b) Name of important tributaries	:	Kanhar, North Koil, Auranga Amanat and Sadabat.
	c) Catchment area of Ganga basin in the district.	:	12019.9 sq.km. i.e. the whole of the district.
17.	Irrigation projects and their potentials		
	i) Existing		
	a) Major	:	Nil Nil
	b) Medium	:	7 Nos. 23,553 Ha.
	c) Minor	:	192 Nos. 46,739 Ha.
	ii) Under construction		
	a) Major	:	5 Nos. 3,12,800 Ha.
	b) Medium	:	4 Nos. 22,508 Ha
	c) Minor	:	128 nos. 22,842 Ha.
18.	Mineral wealth in the district	:	The district has promising deposits of lime stone coal, bauxite, graphite and fireclay.
19.	Electrification		
	a) Total no: of towns and villages electrified as on March 1980	:	631
	b) Percentage to the total no. of towns and villages	:	19.6%
	c) No. of wells electrified as on March 1981	:	N.A.
20.	Industries (as on 30.3.81)		
	a) Large scale industries	:	5 Nos.

	b) Medium scale industries	: N.A.
	c) Small scale industries	: 2 Nos.
21.	Communications	
	a) Total length of roads in the distt. as on March 1977	: 228 km.
	b) Total length of railway line	: 184 km.
	c) Post offices (as on 1976-77)	: 218 nos
	d) Telegraph offices	: 40 nos.
	e) Telephone exchanges (upto 30.9.79)	: 4 nos.
	f) Airports	: One no.
	g) Water ways	: 11 km.
22.	Drinking water facilities	
	a) No. of villages provided with drinking water facilities	: 500 nos.
	b) No. of proposed villages for which facility is under execution	: 311 nos.
23.	Rainfall (Data base 80 years 1901 to 1980)	
	a) Normal rainfall of the district	: 1194.75 mm.
	b) Normal no. of rainy days	: 60.21
	c) Normal intensity of rainfall	: 19.84 mm.
	d) Normal annual P.E. value of district	: 1388.3 mm.

(v)

e)	Percentage of normal rainfall in south-west monsoon	: 86.06%
f) i)	Total no. of raingauge stations in the district	: 25 nos.
ii)	No. of stations considered for study	: 3 nos.
g)	Density of raingauge stations	: 1 station per 480.80sq.km.
h)	Maximum annual rainfall and year in the district	: 1721.10 mm (1907)
i)	Minimum annual rainfall and year in the district	: 505.30(1966)
j)	Annual rainfall at 75% probability	: 1000-1100 mm and above
k)	No. of years having rainfall less than normal rainfall	: 38 years and 47.50%
l)	No. of years having rainfall less than 75% of normal rainfall	: 7 years and 8.75%
m)	Coefficient of variation for seasonal rainfall	: 20.86%
n)	Coefficient of variation for annual rainfall	: 19.40%
o)	Drought free crop years and percentage to total years (1971-1980)	: 6 years (60%)

24	a) Surface water availability	:	75% dependability 50% dependability
	i) Normal runoff	:	4908.63 M.C.M.
	ii) Utilisable flow (50% of normal)	:	2454.32 M.C.M.
	iii) Maximum runoff of the district	:	10,232.48 M.C.M.(1930) 208.46% of normal
	iv) Minimum runoff of the district	:	21.44 M.C.M.(1966)
	v) Normal yield per sqkm. of geographical area	:	0.39 M.C.M./sqkm.
	vi) 75% of normal yield per sq.km. of geographical area	:	.29 M.C.M./sq.k.m.
	vii) Depth of water available over the entire cultivable area for normal runoff	:	0.85 m.
	viii) Depth of water available over the entire culturable area for 75% of normal runoff	:	0.64M.
	ix) Ground Water Potential in the district(as per Central Ground Water Board)		
	Recharge	:	455.23 m.c.m.
	Draft	:	64.08 m.c.m.
	Surplus	:	391.15 m.c.m.

ANNEXURE - IV

ANNUAL PRODUCTION OF MAIN FOODGRAINS (IN TONNES)

S. N.	Year	Rice	Maize	Wheat	Gram	Barley & others	Total
1.	1948-49	22741	9953	1162	17802	7920	59578
2.	1949-50	64425	22399	3296	13772	10886	114778
3.	1950-51	26968	17615	2473	2539	1680	51275
4.	1951-52	29952	20965	1536	3537	3521	59511
5.	1952-53	46431	29534	2185	5168	5263	88581
6.	1953-54	52837	15312	2846	6251	2681	79927
7.	1954-55	8971	22534	1004	4950	5684	43143
8.	1955-56	19980	18741	3382	6418	11659	60180
9.	1956-57	66575	33971	1594	6781	13859	122780
10.	1957-58	27940	22781	1978	2313	4114	59126
11.	1958-59	93691	12245	5492	19259	26677	157364
12.	1959-60	63280	47640	4936	13241	18195	147292
13.	1960-61	95066	24411	7065	14604	15283	158002
14.	1961-62	104537	20045	7934	18711	20689	171916
15.	1962-63	61101	27593	7102	16527	17596	129919
16.	1963-64	66133	49912	9816	19580	22093	167534
17.	1964-65	75754	19646	8362	17381	17304	138447
18.	1965-66	71416	27628	8740	17139	17034	142007
19.	1966-67	2116	40653	2035	547	1891	47242
20.	1967-68	52535	44958	8794	5197	20412	129896
21.	1968-69	23707	27307	7165	3511	8670	70360
22.	1969-70	78309	50688	5401	4255	15778	154431
23.	1970-71	83270	57728	10475	13172	19232	183817
24.	1971-72	89419	12612	19815	10298	17993	150137
25.	1972-73	34935	28596	10485	10603	16710	101329
26.	1973-74	63500	51005	12120	10897	14249	151771
27.	1974-75	58838	44412	20864	8985	13680	146779
28.	1975-76	91468	29891	32788	9852	18104	182103
29.	1976-77	77927	53913	15242	206	10855	158143
30.	1977-78	105515	18179	18409	19986	16423	168512
31.	1978-79	108000	29000	27000	11000	18000	193000
32.	1979-80	14000	13000	10000	2000	5000	45000
33.	1980-81	65000	31000	17000	7000	17000	137000

ANNEXURE - V

MONTHLY RAINFALL IN PALAMU (MM)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
P.E.	67.4	82.6	132.5	167.6	199.2	162.9	118.3	108.2	106.3	111.1	75.4	56.3	1383.3
N.R.F.	24.74	26.95	17.73	9.37	15.79	152.59	338.46	335.23	201.92	55.95	10.98	5.03	1194.75
N.N.O. R.D.	1.81	2.06	1.69	0.90	1.38	7.31	15.34	15.46	9.96	3.21	0.62	0.47	60.21
N.I.O. R.F.	13.67	13.07	10.51	10.41	11.42	20.86	22.07	21.69	20.27	17.44	17.62	10.79	19.84
1901	89.41	24.55	3.81	7.37	4.23	46.06	203.79	377.87	257.22	21.17	1.02	0.00	1036.49
1902	16.09	15.16	1.95	1.91	2.29	35.64	349.76	132.67	409.45	3.73	1.19	0.34	973.16
1903	93.39	9.40	4.23	13.38	17.44	51.22	120.14	181.53	183.98	123.02	0.00	0.00	797.73
1904	3.05	8.81	41.49	2.12	95.93	170.01	382.27	458.30	61.13	35.73	1.02	0.34	1260.18
1905	57.15	21.93	37.51	16.85	20.49	19.98	367.20	229.95	431.46	5.67	0.00	3.13	1211.33
1906	27.09	127.59	21.51	0.08	17.02	130.13	531.71	182.63	216.75	58.93	0.34	1.10	1314.87
1907	2.20	109.14	42.93	41.66	22.01	449.16	182.20	745.74	122.60	0.00	0.08	3.39	1721.10
1908	14.14	82.80	21.08	0.00	1.10	53.42	266.42	337.40	153.42	57.32	0.00	0.00	987.13

Annexure - V Contd.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1909	48.43	7.62	0.00	54.36	12.11	315.55	360.76	222.17	189.79	7.20	0.00	13.38	1229.36
1910	20.15	8.30	17.36	9.96	14.66	108.83	197.70	326.14	226.48	49.36	25.15	0.00	1051.98
1911	6.43	0.00	24.89	12.78	5.08	455.17	72.05	341.46	252.48	86.61	79.33	0.00	1336.29
1912	1.69	15.66	1.86	6.94	20.74	61.04	483.53	358.56	71.80	1.19	23.37	0.08	1046.48
1913	8.55	30.06	44.03	0.00	16.85	394.04	433.66	458.72	140.72	41.57	3.13	19.05	1590.38
1914	0.00	15.58	31.67	17.95	85.60	111.42	204.39	393.70	102.87	1.78	0.00	15.32	980.27
1915	21.84	56.98	18.71	0.51	21.08	64.09	277.62	245.11	247.06	34.46	40.30	0.00	1027.77
1916	0.00	37.17	0.00	3.22	11.09	214.12	296.84	254.76	171.87	272.46	8.38	0.00	1269.91
1917	1.19	31.33	13.12	3.39	40.47	197.97	255.27	522.48	190.58	184.23	0.00	4.83	1440.86
1918	4.06	0.51	4.91	4.49	39.54	434.58	87.29	400.64	185.76	0.00	0.00	1.27	1072.05
1919	136.65	31.24	27.60	17.86	33.44	328.00	317.58	438.49	192.70	130.13	1.35	0.25	1655.32
1920	0.00	22.52	38.10	0.00	19.73	91.44	869.53	378.46	123.27	0.00	0.00	0.00	1543.05
1921	34.04	11.85	0.00	4.40	0.00	288.88	372.36	506.22	99.99	7.37	0.00	0.00	1325.12
1922	17.27	0.68	0.00	10.75	1.78	174.16	422.23	368.22	280.50	30.14	17.70	0.17	1323.59
1923	0.08	56.13	2.96	0.34	5.84	115.65	464.82	519.60	184.83	23.96	10.41	8.51	1385.15
1924	21.76	37.25	2.79	12.87	6.86	59.35	484.46	190.60	290.58	72.81	123.78	0.00	1283.12

Annexure - V Contd.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1925	0.25	9.48	4.06	0.00	25.40	147.32	532.30	449.24	144.10	31.24	29.21	0.00	1372.62
1926	24.30	2.20	83.06	3.64	45.89	53.09	365.91	316.57	320.63	39.12	10.50	24.21	1309.12
1927	85.98	33.65	53.76	0.00	14.90	15.16	391.08	391.67	210.65	42.42	47.41	0.00	1286.68
1928	73.07	22.18	0.17	38.35	15.41	216.92	393.62	213.11	135.81	93.64	0.00	5.67	1207.94
1929	57.66	24.81	7.37	5.08	5.59	66.46	497.92	378.88	65.53	154.94	0.00	57.83	1322.07
1930	0.00	5.00	4.23	23.03	0.17	59.35	433.83	392.26	262.38	4.91	67.23	12.70	1265.09
1931	0.76	130.05	15.49	0.00	6.86	45.64	408.26	391.41	193.21	115.06	20.74	2.62	1330.11
1932	0.00	35.73	0.00	5.00	42.76	94.57	441.45	362.81	143.76	27.77	57.23	10.33	1211.41
1933	94.66	70.02	3.64	26.33	44.87	189.57	281.94	327.58	135.47	92.52	0.00	8.47	1279.06
1934	35.39	2.62	1.10	4.23	0.00	102.95	293.20	394.12	254.53	39.03	30.31	0.34	1148.84
1935	50.46	11.68	1.35	16.09	0.00	96.94	334.01	585.89	186.18	0.00	0.00	0.00	1282.62
1936	15.47	25.93	18.97	3.13	33.87	289.73	268.40	311.97	317.67	150.87	10.23	16.27	1462.50
1937	0.00	90.67	4.73	18.97	22.27	88.30	401.50	270.83	208.13	109.80	0.00	0.00	1215.20
1938	42.67	27.47	0.00	1.00	43.07	236.23	232.17	270.67	222.50	21.43	0.10	0.00	1097.30

Annexure - V Contd.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1939	32.90	34.37	23.77	5.13	0.00	206.77	431.13	327.83	261.00	38.07	0.00	0.00	1360.97
1940	0.00	29.03	59.77	9.17	11.33	45.60	272.30	406.07	102.20	15.43	0.00	51.53	1002.43
1941	52.67	9.83	10.40	0.00	13.20	285.83	262.47	340.20	190.20	64.93	4.57	0.00	1234.33
1942	21.33	74.67	42.40	7.37	1.87	146.73	471.40	370.40	298.97	3.50	0.00	0.00	1438.63
1943	85.33	12.93	0.50	23.03	25.77	43.17	565.93	543.07	162.13	61.07	0.00	0.00	1465.93
1944	16.77	99.90	113.30	4.43	16.17	67.07	390.90	471.43	154.77	77.30	2.97	0.00	1400.00
1945	67.30	38.00	0.00	1.87	8.63	210.57	213.90	185.07	288.47	90.23	0.00	1.10	1105.13
1946	0.00	21.27	13.37	16.43	18.93	273.03	423.60	275.50	287.20	145.47	40.80	1.50	1517.10
1947	16.20	23.55	24.53	0.83	1.27	92.87	276.83	253.47	292.20	61.70	0.00	6.00	1049.43
1948	56.23	25.07	17.63	0.27	5.23	148.57	209.73	284.40	176.37	45.80	71.20	0.67	1041.17
1949	33.97	15.77	6.67	4.23	19.37	101.10	273.30	413.00	114.13	98.50	0.00	2.70	1082.73
1950	3.40	21.93	31.53	0.00	3.73	169.57	382.03	422.20	96.70	3.57	0.17	4.40	1142.23
1951	20.23	1.53	42.57	36.70	5.27	131.77	191.17	330.00	242.50	99.67	0.00	0.00	1101.40
1952	11.00	18.87	43.20	2.63	19.17	241.78	168.97	302.23	225.47	40.37	0.00	4.50	1078.13
1953	19.63	7.27	0.00	7.53	2.53	245.00	589.97	378.53	310.57	5.00	0.00	0.00	1565.97
1954	11.23	13.73	1.47	0.93	1.87	108.13	185.33	264.57	232.17	10.50	0.00	4.60	837.53

Annexure - V Contd.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1955	71.70	17.13	5.50	0.00	2.70	44.43	247.47	168.83	116.33	32.43	0.70	0.0	757.23
1956	20.90	21.00	14.50	0.00	25.57	219.97	275.83	363.97	371.37	106.67	12.47	13.43	1445.67
1957	32.17	7.37	37.0	0.77	2.10	55.70	518.43	215.33	187.10	1.10	0.00	0.00	1057.07
1958	10.57	23.00	16.93	16.90	0.00	67.87	457.67	269.2	235.70	141.60	0.00	0.0	1239.47
1959	64.13	6.00	0.0	0.00	10.17	71.50	295.67	309.17	197.63	138.60	0.00	0.0	1092.87
1960	2.23	0.00	30.20	7.37	0.00	70.33	314.9	336.57	199.57	42.73	0.00	0.0	1053.9
1961	12.70	78.47	11.20	14.00	2.00	321.8	259.33	411.33	263.93	95.87	0.87	12.17	1483.03
1962	8.13	4.50	2.77	5.00	1.13	123.67	235.20	301.10	250.33	35.37	0.0	10.43	1027.63
1963	0.70	3.83	15.43	4.13	38.73	88.93	286.63	292.00	119.50	47.8	0.0	0.0	897.7
1964	0.20	6.00	0.00	0.00	12.90	233.10	383.25	230.15	186.00	57.85	26.50	0.0	1135.95
1965	0.00	10.03	25.77	27.30	10.83	43.43	436.93	202.7	288.6	31.20	0.0	5.20	1082.0
1966	12.33	1.47	0.60	3.37	0.00	176.57	36.30	206.70	41.20	0.00	2.13	24.03	505.30
1967	0.00	0.00	54.77	4.07	5.90	79.57	316.13	529.83	247.33	7.80	0.00	12.97	1258.37
1968	82.70	7.07	0.00	0.00	2.00	98.80	213.80	312.23	115.93	35.70	0.00	14.93	883.17
1969	9.80	4.93	0.93	15.80	41.97	102.53	399.80	295.27	218.27	9.47	18.67	0.00	1097.43
1970	35.85	11.00	31.15	0.00	15.10	119.45	335.35	288.70	382.50	86.10	0.00	0.00	1307.20

Annexure - V Contd.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1971	13.87	2.40	1.07	9.93	19.80	437.23	437.07	497.23	155.97	37.93	0.00	0.00	1612.50
1972	2.60	28.20	0.40	12.13	0.00	33.87	275.62	368.20	61.70	110.47	10.67	0.00	903.85
1973	1.13	5.20	0.33	0.00	0.40	128.90	104.33	335.73	225.03	83.93	0.80	0.00	885.80
1974	0.00	11.03	1.13	0.00	18.00	63.87	405.13	268.27	116.33	15.37	11.33	0.00	970.47
1975	23.00	6.93	59.53	11.35	3.50	81.20	593.73	206.23	98.50	55.17	0.00	0.00	1130.13
1976	0.47	8.53	0.00	30.87	16.53	169.57	320.73	284.93	129.67	0.00	0.00	0.00	961.30
1977	16.63	4.47	0.00	50.73	44.33	206.43	589.13	242.47	234.53	30.90	39.93	19.60	1476.17
1978	35.30	110.33	25.73	11.67	10.07	297.70	213.17	329.33	444.87	55.97	0.00	6.80	1540.93
1979	17.57	40.13	9.77	8.33	0.00	113.77	251.07	143.40	134.67	13.80	24.80	0.00	757.30
1980	1.23	5.27	31.13	6.57	8.97	212.17	257.97	210.27	119.43	53.83	0.00	4.60	929.43

LEGENDS: N.R.F. - Normal Rainfall in mm.
NNORD - Normal Number of Rainy days
NIORF - Normal Intensity of Rainfall
P.E. - Potential Evapotranspiration in MM.

Computation of equivalent crop production, CPe

Sl. No.	Year	(Annual Crop Production in tonnes)	CPc (Tonnes) (Crop prod. from Y=85894.8 + 2402.76 x)	$CPe = \frac{CPcb}{CPc} \times CP$ (Tonnes) where CPcb= 165185.88 Tonnes
1.	1948-49	59,578	88297.56	1,11,458.42
2.	1949-50	114,778	90,700.32	2,09,036.80
3.	1950-51	51,275	93,103.08	90,973.42
4.	1951-52	59,511	95,505.84	1,02,929.58
5.	1952-53	88,581	97,908.60	1,49,448.87
6.	1953-54	79,927	100,311.36	1,31,618.31
7.	1954-55	43,143	102,714.12	69,383.006
8.	1955-56	60,180	105,116.88	94,569.84
9.	1956-57	122,780	107,519.64	1,88,630.86
10.	1957-58	59,126	109,922.40	88,851.59
11.	1958-59	157,364	112,325.16	2,31,420.19
12.	1959-60	147,292	114,727.92	2,12,071.81
13.	1960-61	158,002	117,130.68	2,22,825.47
14.	1961-62	171,916	119,533.44	2,37,574.48
15.	1962-63	129,919	121,936.20	1,76,000.10
16.	1963-64	167,534	124,338.96	2,22,571.03
17.	1964-65	138,447	126,741.72	1,80,441.68
18.	1965-66	142,007	129,144.48	1,81,638.04
19.	1966-67	47,242	131,547.24	59,322.50
20.	1967-68	129,896	133,950.00	1,60,186.52
21.	1968-69	70,360	136,352.76	85,238.31
22.	1969-70	154,431	138,755.52	1,83,847.24
23.	1970-71	183,817	141,158.28	2,15,105.85
24.	1971-72	150,137	143,561.04	1,72,752.38
25.	1972-73	101,329	145,963.80	1,14,673.09
26.	1973-74	151,771	148,366.56	1,68,976.25
27.	1974-75	146,779	150,769.32	1,60,814.00
28.	1975-76	182,103	153,172.08	1,96,385.94
29.	1976-77	158,143	155,574.84	1,67,912.69
30.	1977-78	168,512	157,977.60	1,76,200.94
31.	1978-79	193,000	160,380.36	1,98,782.91
32.	1979-80	45,000	162,783.12	45,664.22
33.	1980-81	137,000	165,185.88	1,37,000.00

Computation of the parameters Prd & Prdm

Sl. No.	Year	Ratio of %age rainfall dist. to %age gross water req. (Rm/REQm)					$\sum$ (2) to (7)	PA/PN	Prd =(8) x(10)	Pm/PREQm	Prdm= ([illegible])x(11)
		June 4.6% *	July 24.9% *	Aug. 23% *	Sept. 22.2% *	Oct. 25.3% *					
1	2	3	4	5	6	7	8	9	10	11	12
1.	1948	1.0	0.97	1.0	0.92	0.22	4.11	0.87	3.58	0.932	3.83
2.	1944	1.0	1.0	1.0	0.51	0.28	3.79	0.91	3.45	1.07	3.79
3.	1950	1.0	1.0	1.0	0.41	0.01	3.42	0.96	3.28	1.15	3.42
4.	1951	1.0	0.77	1.0	1.0	0.40	4.17	0.92	3.84	1.07	4.17
5.	1952	1.0	0.69	1.0	1.0	0.16	3.75	0.90	3.38	1.05	3.75
6.	1953	1.0	1.0	1.0	0.91	0.01	3.92	1.0	3.92	1.64	3.92
7.	1954	1.0	0.93	1.0	1.0	0.05	3.98	0.70	2.79	0.86	3.42
8.	1955	1.0	1.0	1.0	0.79	0.49	4.28	0.63	2.70	0.71	3.04
9.	1956	1.0	0.83	1.0	1.0	0.32	4.15	1.0	4.15	1.44	4.15
10.	1957	1.0	1.0	0.96	0.86	0.004	3.824	0.88	3.37	1.05	3.82
11.	1958	1.0	1.0	0.998	0.91	0.48	4.39	1.0	4.39	1.26	4.39
12.	1959	1.0	1.0	1.0	0.88	0.39	4.27	0.91	3.89	1.09	4.27
13.	1960	1.0	1.0	1.0	0.89	0.17	4.06	0.88	3.57	1.09	4.06
[illegible]	1961	1.0	0.77	1.0	0.90	0.20	3.87	1.0	3.87	1.46	3.87
15.	1962	1.0	1.0	1.0	1.0	0.14	4.14	0.86	3.56	1.07	4.14
16.	1963	1.0	1.0	1.0	0.64	0.23	3.87	0.75	2.90	0.90	3.48
17.	1964	1.0	1.0	0.92	0.80	0.21	3.93	0.95	3.73	1.17	3.93
18.	1965	0.94	1.0	0.88	1.0	0.12	3.94	0.91	3.59	1.08	3.94
19.	1966	1.0	0.32	1.0	0.40	0.0	2.72	0.42	1.14	0.49	1.33
20.	1967	1.0	1.0	1.0	0.94	0.03	3.97	1.0	3.97	1.27	3.97
21.	1968	1.0	1.0	1.0	0.67	0.18	3.85	0.74	2.85	0.83	3.20
22.	1969	1.0	1.0	1.0	0.98	0.04	4.02	0.92	3.70	1.08	4.02

1	2	3	4	5	6	7	8	9	10	11	12
23.	1970	1.0	1.0	1.0	1.0	0.21	4.21	1.0	4.21	1.30	4.21
24.	1971	1.0	1.0	1.0	0.45	0.068	3.52	1.0	3.52	1.68	3.52
25.	1972	0.87	1.0	1.0	0.33	0.51	3.71	0.76	2.82	0.91	3.38
26.	1973	1.0	0.48	1.0	1.0	0.27	3.75	0.74	2.78	0.84	3.15
27.	1974	1.0	1.0	1.0	0.56	0.32	3.88	0.81	3.14	0.998	3.87
28.	1975	1.0	1.0	0.87	0.43	0.21	3.51	0.95	3.33	1.11	3.51
29.	1976	1.0	1.0	1.0	0.65	0.0	3.65	0.80	2.92	0.77	2.59
30.	1977	1.0	1.0	0.81	0.81	0.07	3.69	1.0	3.69	1.18	3.69
31.	1978	1.0	0.64	1.0	1.0	0.12	3.76	1.0	3.76	1.44	3.76
32.	1979	1.0	1.0	0.95	0.92	0.08	3.95	0.63	2.49	0.71	2.80
33.	1980	1.0	1.0	1.0	0.62	0.24	3.86	0.78	3.01	0.94	3.63

* indicate the percentage gross water requirement during the respective month in monsoon period.

Computation of %age Rainfall Distribution during Monsoon period (Rm)

Sl.No.	Year	Rainfall in monsoon perion (mm/%)					
		June	July	August	Sept.	Oct.	Total
1.	1948	148.57 (17.12)	209.73 (24.17)	284.40 (32.78)	176.37 (20.33)	48.50 (5.6)	867.03
2.	1949	101.10 (10.11)	273.30 (27.33)	413.00 (41.30)	114.13 (11.41)	98.50 (9.85)	1000.03
3.	1950	169.57 (15.79)	382.03 (35.57)	422.20 (39.31)	96.70 (9.0)	3.57 (0.33)	1074.03
4.	1951	131.77 (13.24)	191.17 (19.21)	330.00 (33.16)	242.50 (24.37)	99.67 (10.02)	995.11
5.	1952	241.78 (24.7)	168.97 (17.26)	302.23 (30.88)	225.47 (23.03)	40.37 (4.12)	978.82
6.	1953	245.00 (16.02)	589.97 (38.58)	378.53 (24.76)	310.57 (20.31)	5.00 (0.33)	1529.07
7.	1954	108.13 (13.50)	185.33 (23.15)	264.57 (33.04)	232.17 (29.00)	10.50 (1.31)	800.70
8.	1955	44.43 (6.74)	247.47 (37.52)	168.83 (25.60)	116.33 (17.64)	82.43 (12.5)	659.49
9.	1956	219.97 (16.44)	275.83 (20.62)	363.97 (27.21)	371.37 (27.76)	106.67 (7.97)	1337.81
10.	1957	55.70 (5.7)	518.43 (53.03)	215.33 (22.03)	187.10 (19.14)	1.10 (0.11)	977.66
11.	1958	67.87 (5.8)	457.67 (39.05)	269.20 (22.97)	235.70 (20.11)	141.63 (12.08)	1172.07
12.	1959	71.50 (7.06)	295.67 (29.20)	309.17 (30.53)	197.63 (19.52)	138.60 (13.69)	1012.57
13.	1960	70.33 (6.94)	314.90 (31.03)	386.57 (38.12)	199.57 (19.68)	42.73 (4.21)	1014.10
14.	1961	321.80 (23.80)	259.33 (19.18)	411.33 (30.42)	263.93 (19.52)	95.87 (7.09)	1352.26
15.	1962	123.67 (12.42)	285.20 (28.64)	301.10 (30.24)	250.33 (25.14)	35.37 (3.55)	995.67
16.	1963	88.93 (10.65)	286.63 (34.33)	292.00 (34.98)	119.50 (14.31)	47.80 (5.73)	834.86
17.	1964	233.10 (21.39)	383.25 (35.17)	230.15 (21.12)	186.0 (17.68)	57.85 (5.31)	1089.75

1	2	3	4	5	6	7	8
18.	1965	43.43	436.93	202.70	288.60	31.20	1002.86
		(4.33)	(43.57)	(20.21)	(28.78)	(3.11)	
19.	1966.	176.57	36.30	206.70	41.20	0.0	460.77
		(38.32)	(7.88)	(44.86)	(8.94)	(0.1)	
20.	1967	79.57	316.13	529.83	247.33	7.80	1180.66
		(6.74)	(26.78)	(44.88)	(20.95)	(0.66)	
21.	1968	98.80	213.80	312.23	115.93	35.70	776.46
		(12.72)	(27.54)	(40.21)	(14.93)	(4.60	
22.	1969	102.53	399.80	275.27	218.27	9.47	1005.34
		(10.20)	(39.77)	(27.38)	(21.71)	(0.94)	
23.	1970	119.45	335.35	288.70	382.50	88.10	
24.	1971	437.23	437.07	497.23	155.97	37.93	1565.43
		(27.93)	((27.92)	(31.76)	(9.96)	(2.42)	
25.	1972	33.87	275.62	368.20	61.70	110.47	849.86
		(3.99)	(32.43)	(43.32)	(7.26)	(13.00)	
26.	1973	128.90	104.33	335.73	225.03	83.93	877.92
		(14.68)	(11.88)	(38.24)	((25.63)	(9.56)	
27.	1974	63.87	405.13	268.27	116.33	75.37	928.97
		(6.88)	(43.61)	(28.88)	(12.52)	(8.11)	
28.	1975	81.20	593.73	206.23	98.50	55.17	1034.83
		(7.85)	(57.37)	(19.93)	(9.52)	(5.33)	
29.	1976	169.57	320.73	284.93	129.67	0.0	904.90
		(18.74)	(35.44)	(31.45)	(14.33)	(0.0)	
30.	1977	206.43	589.13	242.47	234.53	30.90	1303.46
		(15.84)	(45.20)	(18.60)	(17.99)	(2.37)	
31.	1978	297.70	213.17	329.33	444.87	55.97	1341.04
		(22.20)	(15.90)	(24.56)	(33.17)	(4.17)	
32.	1979	113.77	251.07	143.40	34.67	13.80	656.71
		(17.32)	(38.23)	(21.84)	(20.51)	(2.10)	
33.	1980	212.17	275.97	210.27	119.43	53.83	871.67
		(24.34)	(31.66)	(24.12)	(13.70)	(6.18)	

Annexure.- VIII

Computation of DD_A, DD_N, WDD_N and ED

S.N.	Year	DD_A (mm)	DD_N (mm)	WDD_N (mm)	R_r	ED (mm) (4) x (6)
	(1)	(2)	(3)	(4)	(5)	(6)
1.	1948	681.63	163.68	331.8	1.15	380.74
2.	1949	772.69	196.64	305.77	1.10	337.41
3.	1950	829.97	183.18	271.40	1.05	283.88
4.	1951	797.26	203.93	323.88	1.08	351.33
5.	1952	752.36	185.34	363.18	1.11	402.46
6.	1953	850.20	91.09	50.25	0.76	38.33
7.	1954	899.54	300.88	425.84	1.43	608.91
8.	1955	834.71	423.72	681.92	1.58	1075.93
9.	1956	677.53	53.51	98.96	0.83	81.78
10.	1957	918.79	272.86	292.03	1.13	330.07
11.	1958	808.03	138.45	124.99	0.96	120.48
12.	1959	526.47	113.34	85.54	1.09	93.51
13.	1960	902.14	143.80	84.69	1.13	96.00
14.	1961	665.45	85.86	151.44	0.81	122.00
15.	1962	864.0	134.77	139.41	1.16	162.08
16.	1963	855.45	226.89	326.37	1.33	434.37
17.	1964	788.65	141.37	230.19	1.05	242.11
18.	1965	994.67	157.56	273.58	1.10	302.09
19.	1966	901.24	646.02	1243.95	2.36	2941.24
20.	1967	889.92	167.89	102.99	0.95	97.78
21.	1968	829.00	299.53	455.94	1.35	616.79
22.	1969	850.90	165.12	143.16	1.09	155.86
23.	1970	748.35	61.29	51.63	0.91	47.19
24.	1971	807.10	96.59	121.19	0.74	89.79
25.	1972	901.26	331.43	464.84	1.32	614.45
26.	1973	1194.54	305.49	536.47	1.35	723.58
27.	1974	874.27	248.8	325.75	1.23	401.03
28.	1975	822.12	286.62	461.13	1.06	487.50
29.	1976	856.03	288.60	478.52	1.24	594.72
30.	1977	685.51	116.06	170.78	0.81	137.94
31.	1978	663.96	113.29	239.36	0.78	185.59
32.	1979	826.78	376.56	680.84	1.58	1074.12
33.	1980	780.50	256.63	505.11	1.29	649.30

Annexure - VIII Contd.

Computation of K_i

(All figures in MM).

Year		1948		1949		1950		1951		1952	
Month	$\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$
Jan.	-48.26	-11.17	37.09	-33.43	14.83	-64.00	-15.74	-47.17	1.09	-56.40	-8.14
Feb.	-61.97	-57.53	4.44	-66.83	-4.86	-60.67	1.30	-81.07	-19.1	-63.73	-1.76
Mar.	-116.59	-114.87	1.72	-125.83	-9.24	-97.97	18.62	-89.93	26.66	-89.30	27.29
April	-158.73	-167.33	-8.60	-163.37	-4.64	-167.60	-8.87	-130.90	27.83	-64.97	-6.24
May	-188.60	-193.97	-5.37	-179.83	8.77	-195.47	-6.87	-193.93	-5.33	-180.03	8.57
June	-17.19	-14.33	2.86	-61.80	-44.61	6.67	23.86	-31.13	-13.94	78.88	96.07
July	200.76	91.43	-109.33	155.00	-45.76	263.73	62.97	72.87	-127.89	50.67	-150.09
Aug.	196.17	176.20	-19.97	304.80	108.63	314.00	117.83	221.80	25.63	194.03	-2.14
Sept.	88.50	70.07	-18.43	7.83	-80.67	-9.60	-98.10	136.20	47.7	119.17	30.67
Oct.	-60.62	-62.60	-1.98	-12.60	48.02	-107.53	-46.91	-91.43	-30.81	-70.73	-10.11
Nov.	-68.54	-4.20	63.34	-75.40	-6.86	-75.23	-6.69	-75.40	-6.86	-75.40	-6.86
Dec.	-52.63	-55.63	12.77	-53.60	14.80	-51.90	16.50	-56.30	12.10	-51.80	16.6
ΣK_i			163.68		196.64		183.18		203.93		185.34

Annexure -VIII contd.

Year	1953		1954		1955		1956		1957	
Month	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$
Jan.	-47.77	0.49	-56.17	-7.91	4.30	52.56	-46.50	1.76	-35.23	13.03
Feb.	-75.33	-13.36	-68.82	-6.90	-65.47	-3.50	-61.60	0.37	-75.23	-13.26
March.	-132.50	-15.91	-128.03	-11.44	-127.00	-10.41	-118.00	-1.41	-95.50	21.09
April	-160.07	-1.34	-166.67	-7.94	-167.60	-8.87	-167.60	-8.87	-166.83	-8.10
May	-196.73	-8.13	-197.33	-8.73	-196.50	-7.90	-173.63	14.97	-197.10	-8.50
June	82.10	99.29	-54.77	-37.58	-118.47	-101.28	57.07	74.26	-107.20	-90.01
July	471.67	270.91	67.03	-133.73	129.17	-71.59	157.53	-43.23	400.13	199.37
Aug.	270.33	74.16	156.37	-39.80	60.[illegible]	-135.54	255.77	59.60	107.13	-89.04
Sept.	204.27	115.77	25.87	37.37	10.03	-78.47	265.07	176.57	80.80	-7.70
Oct.	-136.10	-45.48	-100.40	-39.98	-28.67	31.95	-4.43	56.19	-110.00	-49.38
Nov.	-75.40	-6.87	-75.40	-6.87	-74.70	-6.16	-62.93	5.61	-75.40	-6.87
Dec.	-56.30	12.10	-51.70	16.70	-56.30	12.10	-42.87	25.53	-56.30	12.10
ΣK_i		91.09		300.88		423.72		53.51		272.86

Annexure VIII contd.

Year	1958		1959		1960		1961		1962	
Month	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$
Jan.	-56.83	-7.97	-3.27	44.99	-65.17	-16.91	-55.33	-7.07	-59.27	-11.01
Feb,	-59.60	2.30	76.60	138.57	-82.60	-20.63	-4.13	57.84	-78.10	-16.13
March	-115.57	1.02	-132.50	15.91	-102.30	14.29	-121.30	-4.47	-129.73	-13.14
April	-150.70	8.03	-167.60	-8.87	-160.23	-1.50	-153.60	5.13	-162.60	-3.87
May	-199.20	-10.60	189.03	377.63	-199.20	-10.60	-197.20	-8.60	-198.03	-9.47
June	-95.03	-77.84	-91.40	-74.21	-92.57	-75.38	158.90	176.09	-39.23	-22.04
July	339.37	138.61	177.37	-23.39	196.60	-4.16	141.03	-59.73	166.90	-33.86
Aug.	161.00	-35.17	200.97	4.80	278.37	82.20	303.13	106.96	192.90	-3.27
Sept.	129.40	40.90	91.33	2.83	93.27	4.77	157.63	69.13	144.03	55.53
Oct.	30.53	91.15	27.50	[illegible].12	-68.37	-7.75	-15.23	45.39	-75.73	-15.11
Nov.	-75.40	-6.87	-75.40	-6.87	-75.40	-6.87	-74.53	-5.99	-75.40	-6.87
Dec.	-56.30	12.10	-56.30	12.10	-56.30	12.10	-44.13	24.27	-45.87	22.53
ΣK_i		138.45		113.34		143.80		85.86		134.77

Annexure VIII contd.

Year	1963		1964		1965		1966		1967	
Month	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$	V_i	$V_i-\bar{V}_i$
Jan.	-66.70	-18.44	-67.20	-18.94	-67.40	-19.14	-54.47	-6.21	-67.40	-19.14
Feb.	-78.77	-16.80	-76.60	-14.63	-72.57	-10.60	-81.13	-19.16	-82.60	-20.63
March	-117.07	-0.48	-132.50	-15.91	-106.73	9.86	-131.90	15.31	-77.73	38.86
April	-163.47	-4.74	-167.60	-8.87	-140.30	18.43	-164.23	-5.50	-163.53	-4.80
May	-160.47	28.13	-186.30	2.30	-188.37	0.23	-199.20	-10.60	-193.30	-4.70
June	-73.97	-56.78	70.20	87.39	-119.47	102.28	13.67	30.86	-83.33	-66.14
July	168.33	-32.43	264.95	64.19	318.63	117.87	-82.00	-282.76	197.83	-2.93
Aug.	183.80	-12.37	121.95	-14.22	94.50	-101.67	98.50	-97.67	421.63	225.46
Sept.	13.20	-75.30	79.10	-8.80	182.30	93.80	-65.10	-153.60	141.03	52.53
Oct.	-63.30	-2.68	-53.25	7.37	-79.90	-19.28	-111.10	-50.48	-103.30	-42.68
Nov.	-75.40	-6.87	-48.90	19.64	-75.40	-6.87	-73.27	-4.73	-75.40	-6.87
Dec.	-56.30	12.1	-56.30	12.1	-51.10	17.30	-32.27	36.13	-43.33	25.07
ΣK_i	226.89	226.89		141.37		157.56		646.02		167.89

Annexure VIII contd.

Year	1968		1969		1970		1971		1972	
Month	V_i	$V_i - \bar{V}_i$	V_i	$V_i - \bar{V}_i$	V_i	$V_i - \bar{V}_i$	V_i	$V_i - \bar{V}_i$	V_i	$V_i - \bar{V}_i$
Jan.	15.30	53.56	-57.60	-9.34	-31.55	16.71	-53.53	-5.27	-64.80	-16.54
Feb.	-75.43	-13.46	-77.67	-15.70	-71.60	-9.63	-80.20	-18.23	-54.40	7.57
March	-132.50	-15.91	-131.57	-14.98	-101.35	15.24	-131.43	-14.84	-132.10	-15.91
April	-167.60	-8.87	-151.80	6.93	-167.60	-8.87	-157.67	1.06	-155.47	3.26
May	-197.20	-8.60	-157.23	31.37	-184.10	4.50	-179.40	9.20	-199.20	-10.60
June	-64.10	-46.91	-60.37	-43.18	-43.45	-26.26	274.33	291.52	-129.03	-111.84
July	95.50	-105.26	281.50	80.74	217.05	16.29	318.77	118.01	157.32	-43.44
Aug.	204.03	7.86	167.07	-29.10	180.50	-15.67	389.03	192.86	260.00	63.83
Sept.	9.63	-78.87	111.97	23.47	276.20	187.70	49.67	-38.83	-44.60	-133.10
Oct.	-75.40	-14.78	-101.63	-41.01	-23.00	37.62	-73.13	-12.55	-0.63	59.99
Nov.	-75.40	-6.87	-56.73	-11.81	-69.40	-0.86	-75.40	-6.87	-64.73	3.81
Dec.	-41.37	27.03	-56.30	12.10	-56.30	12.10	-56.30	12.10	-56.30	12.10
ΣK_i		299.53		165.12		61.29		96.59		331.43

Computation of ED_e for Different Years

S. N.	Year	$\left[\sum(W_i \times K_i)^2\right]^{\frac{1}{2}}$ (mm)	R_r	ED_e (mm) (2) x (3)
(1)		(2)	(3)	(4)
1.	1948	251.06	1.50	376.59
2.	1949	202.88	1.10	223.17
3.	1950	215.36	1.05	226.13
4.	1951	286.21	1.08	309.11
5.	1952	335.18	1.11	372.05
6.	1953	31.18	0.76	23.70
7.	1954	312.71	1.43	447.18
8.	1955	381.24	1.58	602.36
9.	1956	96.46	0.83	80.06
10.	1957	202.80	1.13	229.16
11.	1958	84.20	0.96	80.83
12.	1959	59.66	1.09	65.03
13.	1960	41.56	1.13	46.96
14.	1961	133.75	0.81	108.34
15.	1962	79.63	1.16	92.37
16.	1963	183.83	1.33	244.94
17.	1964	167.80	1.05	176.19
18.	1965	226.62	1.10	249.28
19.	1966	745.58	2.36	1759.57
20.	1967	48.58	0.95	46.15
21.	1968	291.16	1.35	393.07
22.	1969	73.76	1.09	80.40
23.	1970	36.41	0.91	33.13
24.	1971	85.71	0.74	63.43
25.	1972	307.76	1.32	406.24
26.	1973	480.04	1.35	648.05
27.	1974	192.46	1.23	236.73
28.	1975	301.50	1.06	319.59
29.	1976	362.10	1.24	449.00
30.	1977	137.82	0.81	111.63
31.	1978	236.26	0.78	184.28
32.	1979	408.43	1.53	645.32
33.	1980	282.30	1.29	364.17

Annexure - X

Computation of CP_e with the help of Parameter ED and ED_e

S. N.	Year (1)	ED (mm) (2)	CP_e from Eqn.(5.8) (Th. Tonnes) (3)	ED_e (mm) (4)	CP_e from Eqn.(5.9) (Th. Tonnes) (5)
1.	1948	380.74	132.48	376.59	111.00
2.	1949	337.41	138.53	223.17	137.00
3.	1950	283.88	147.25	226.13	136.00
4.	1951	351.33	153.44	309.11	121.00
5.	1952	402.46	129.72	372.05	112.00
6.	1953	38.33	238.63	23.70	282.00
7.	1954	608.91	106.84	447.18	104.00
8.	1955	1075.93	84.88	602.36	91.00
9.	1956	81.78	208.12	80.06	198.00
10.	1957	330.07	139.63	229.16	136.00
11.	1958	120.48	190.13	80.83	198.00
12.	1959	93.51	202.05	65.03	212.00
13.	1960	96.00	200.84	46.96	234.00
14.	1961	122.00	189.53	108.34	179.00
15.	1962	162.08	175.59	92.37	189.00
16.	1963	434.37	125.96	244.94	132.00
17.	1964	242.11	155.34	176.19	150.00
18.	1965	302.09	144.10	249.28	131.00
19.	1966	2941.24	50.18	1759.57	57.00
20.	1967	97.78	200.00	46.15	236.00
21.	1968	616.79	109.17	393.07	109.00
22.	1969	155.86	177.54	80.40	180.00
23.	1970	47.19	230.96	33.13	259.00
24.	1971	89.79	203.91	63.43	212.00
25.	1972	614.45	109.34	406.24	108.00
26.	1973	723.58	101.87	648.05	89.00
27.	1974	401.03	129.90	236.73	134.00
28.	1975	487.50	120.33	319.59	119.00
29.	1976	594.72	110.91	449.00	103.00
30.	1977	137.94	183.56	111.63	177.00
31.	1978	185.59	168.80	184.28	148.00
32.	1979	1074.12	84.94	645.32	88.00
33.	1980	649.30	106.79	364.17	113.00

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