OBJECTIVE ESTIMATION OF DROUGHT SEVERITY AND ASSOCIATED PARAMETERS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I do hereby certify that the work which is being presented in this dissertation entitled as **"OBJECTIVE ESTIMATION OF DROUGHT SEVERITY AND ASSOCIATED PARAMETERS"** in partial fulfillment of the requirement for the award of the degree of Master of Technology, Water Resources Development, submitted in the Water Resources Development and Management Department, (WRD&MD), Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July, 2005 to June 2006 under the supervision of Dr. S.K.Mishra, Asst.Professor, (WRD&MD), Indian Institute of Technology Roorkee and Sri R.P.Pandey, Scientist 'E1', National Institute of Hydrology, Roorkee.

The mater covered in this dissertation has not been submitted by me for award of any other degree.

Dated the 20th June 2006

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Drought is a temporary random and complex phenomenon mainly originating due to lack of precipitation leading to water deficit and causing economic loss. The success to drought alleviation depends on how well droughts are defined and their severity quantified. A quantitative definition identifies the beginning, end, spatial extent and the severity of drought. Among the available indices, no single index is capable of fully describing all the physical characteristics of drought. Therefore, in most cases it is useful and necessary to consider more then one index, examine their sensitivity and accuracy, correlate them and investigate, if they complement each other.

In this study, the versatile GIS-based Spatial and Time Series Information Modeling (SPATSIM) and Daily Water Resources Assessment Modeling (DWRAM) software were used for drought analysis on monthly and daily bases, respectively, and its spatial distribution in both dry and wet years. The former utilizes the popular indices Standardized Precipitation Index (SPI), Effective Drought Index (EDI), Deciles Index and departure from long term Mean and Median; and the latter employs only EDI. The analysis of data from Kalahandi and Nuapada Districts of Orissa revealed that (a) the drought in the area occurred with a frequency of once in every 3 to 4 years; (b) in a year if Pae/PET < 0.6, it is a drought; (c) EDI better represented the drought in the area than any other indices; (d) all SPI, EDI and the annual deviation from mean showed a similar trend. The comparison of all indices and results of analysis led to many useful and practicable inferences in understanding drought attributes in the study area.

Important Notations and Abbreviations

Notations/ Abbreviations	Description/Full Form
D	Duration
I	Intensity
F	Frequency
S	Severity
S_L	The Run Sum
M_L	Run intensity
D_L	Run length
e	Effective scaling factor
cv	Coefficient of Variation
Id	Dryness Index
IA	DeMertonne's Index
PQ	Pluvothermic Quotient
AI	Aridity Anomaly Index
PDSI	Palmer Drought Severity Index,
SPI	Standardized Precipitation Index,
CMI	Crop Moisture Index
NMI	Negative Moisture Index
CWSI	Crop Water Stress Index
RDI	Reclamation Drought Index
EDI	Effective Drought Index

RM	Running means
EP	Effective Precipitation
α,β	Parameters of the Gamma Function
Z	Standard Normal Random Variable
DS	Duration of Summation
APD	Accumulated Precipitation Deficit
PRN	Precipitation for Return to Normal
SPATSIM	Spatial and Time Series Information Modeling
DWRAM	Daily Water Resources Assessment Modeling
PET	Potential Evapotranspiration
Pa	Annual Precipitation
Pae	Annual Aerial Precipitation
IMD	Indian Meteorological Department
NIH	National Institute of Hydrology
GIS	Geographical Information System
WMO	World Meteorological Organization

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXURE

CHAPTER 1

INTRODUCTION

1.1. General

The sun is the source of all energy for the earth and the climate of earth solely driven by it. The temperature pattern of last 1000 years shows that the northern hemisphere has recorded 1^0C increase and the trend still persists. Due to rise in global temperature, earth is more likely to be subjected to frequent and prolonged hot days and dry spells and fewer frost and cold spells (Rosenberg, 1986). The increasing frequency of dry spells triggers the drought situation leading to adverse economic and social impacts. Particularly a developing country like India can suffer significantly by drought events. To improve our knowledge on impacts of drought, it is necessary to understand the phenomena and its development in both qualitative and quantitative terms.

Rainfall data are widely used to calculate drought indices, because long term rainfall records are more readily available then any other types of hydrological or climatic data. Though rainfall data alone may not reflect the spectrum of all the drought related conditions, it is the primary indicator of drought and is the basis of most of drought watch systems, particularly with regard to the probability of receiving a specified amount of rainfall in a data-deficit region. Of all the meteorological elements, rainfall exhibits frequency distribution which appears to show greatest departure from the Normal Distribution. Rainfall is different from other meteorological elements in that it may be present or absent, whereas in a given location, it is possible to measure all other meteorological elements such as atmospheric pressure, temperature, humidity etc. Also the soil type cropping pattern, land use, slope etc can be assessed. The difference however is the in the measurement of temperature, pressure and humidity usually is a mean value over a very short period (some second) whereas rainfall is measured by the amount accumulated over a stated time period most commonly 24 hour (one day). Therefore it is necessary to understand the probability and frequency distribution of rainfall before examining the drought analysis. Stream flow comes next which also varies greatly and is either present or absent in non-perennial rivers which intern depend largely on rainfall. Melting of snow in some region regulates the quantum of flow in perennial streams. In a hydro-meteorologically homogeneous region, both rainfall and stream flow can fairly characterize the associated drought pattern, provided, all other data have been correctly managed and stored in the database without appreciable error. The factors like ocean-atmosphere system, sea surface temperature anomalies, the high albedo, solar-weather relationships, monsoon mechanism, extra-tropical factors that controls the amount of rainfall also controls drought. Many software have been developed using rainfall data alone which can be successfully used for assessing both dry and wet conditions.

Several indices under different category of droughts have been developed by many researchers and scientists to characterize attributes and impacts of drought. The study of drought can be classified into four categories: 1.The cause of drought, understanding atmospheric circulation with respect to occurrence of drought. 2. Determining the frequency and severity of drought to characterize probability distribution of droughts of various magnitudes. 3. Evaluation of impacts of drought and the loss and cost involved due to occurrences of drought. 4. Response, preparedness, appropriate mitigation and reduction of impacts. Most of the work has been carried out in categories 1 and 2.

Presently the work on category 4 is gaining momentum with more researchers trying to develop a full proof system to understand the drought before the remedial measures are suggested.

In spite of all these studies, in giving a full proof quantification to drought intensity and duration there exist the following problems; (Byun and Wilhite, 1999)

1. Most of the current indices are not precise enough in detecting the onset, end and accumulated stress of drought.
2. They do not effectively take into account the aggravating effect of runoff and evapotranspiration, which build up with time.
3. They have a limited usefulness in monitoring drought because they are mostly based on monthly time step.
4. Most of them fail to differentiate the effect of drought on surface and sub-surface water supply.

As experienced the average drought frequency decrease from dry to wet regions in India. The mean return period of drought varies from 2 to 3 years in arid regions 3 to 5 years in semi-arid regions and 5 to 8 years in sub-humid regions (Pandey and Ramasastri, 2001). The area considered for study in this dissertation work falls in dry sub-humid climatic region. It is subjected to high frequency of drought and because this is predominantly tribal region, it is very much under developed The analysis and correct quantification of drought in usable format for this area appears to be a challenging task.. This study may help in preparing the drought preparedness and mitigation plan in realistic and appropriate manner. It is not possible to avoid drought but it is quite possible to prepare to cope with drought. It needs to understand the rainfall pattern and use various indices in different ways to find out the quantitative value of severity, the onset and termination of drought and accordingly plan for remedies..

1.2. Objective of the Study

The specific objectives of the study are as follows:

1. Analysis of long-term records, for determination of historical drought events and their characteristics.
2. To generate time series of a range of drought indices from daily & monthly rainfall.
3. To generate summery of drought index for subsequent mapping of index values
4. To study the ground water fluctuations in the focus area.
5. To calculate and tests check the quantum of drought severity of different years in the study area with different time steps and analyze yield loss of major crops.
6. To analyze mean annual evapotranspiration, mean annual rainfall and different drought indices for likely existence of a relationship for use in the study area.
7. To suggest on a Drought watch system.

1.3. Data Used for the Study

In this study monthly and yearly data of 9 stations from 12 to 34 years have been used for Kalahandi Bolangir and Koraput districts (KBK district)) to study past drought events and calculate drought indices. The daily indices have been calculated using daily point rainfall of three rain gauge stations with 12 to 26 years of data for Nuapada and Kalahandi districts termed as the 'focus area' in this study.. Agricultural coverage, production, yields etc for last 12 years (1993 to 2005) of Kalahandi and Nuapada district have been utilized in the analysis. The pre and post monsoon data of piezomatric head for 8 to 10 years of Hydrographic Networking Stations have been utilized to study groundwater table fluctuations in the focus area.

1.4. Scope of the Study

Chapter 2 presents a brief literature review of different aspects related to drought analysis including differences in various regions regarding its definition and perception. The development of different methods for drought analysis has also been narrated in brief.

Chapter 3 describes the features of the study area precisely. The information related to climate, rainfall and documented drought events has been discussed in particular. The severely affected area within the study area has been identified for more analysis.

Chapter 4 details regarding the methodology that has been followed while preparing the dissertation. It includes the calculation procedures for various drought indices and their boundary values.

Chapter 5 narrates the working and running process of the two models namely Spatial and Time Series information Modeling (SPATSIM) and Daily Water Resources Assessment Modeling (DWRAM) used in the analysis of drought in the study area.

Chapter 6 presents the details of discussion for assessing the historical drought events with respect to the annual departure of rainfall and summarizes the results obtained from the analysis of various drought indices for the study area. It also includes the analysis of crop yield loss and ground water table fluctuations in the drought years and explores possible relationship of drought indices with the mean annual evapo-transpiration.

Chapter 7 hint up for drought watch system and describes briefly the various aspects of drought precautions to be taken care of for effective monitoring before and during the drought periods.

Chapter 8 briefly summarizes the results and discussions made in previous chapters. It also contains the conclusions made out of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The drought events are becoming increasingly frequent world wide for many reasons including global warming, anthropogenic reasons and climate change. It affects all countries whether developed, developing or under developed. Experts from different scientific disciplines in various climatologic regions employ different approaches in identifying and evaluating the phenomenon of drought. Therefore at present there exists no definition which is universally accepted by all researchers and scientists. Also there is no promising or reliable method for prediction of drought that is unanimously accepted.

It is a matter of concern that different climate models predict that the world is likely to experience more hot days and heat waves and fewer frost days and cold spells (Gibbs, 1987). Even though periods of extreme dry/wet & cold/hot are normal phenomena within the dynamic climatic system their severity/duration is expected to exaggerate. The period of unusual dryness i.e. drought is a normal feature in the mid-climatic regions (arid, semi arid & dry sub-humid regions) of the tropic of the world and covers more then one third of the earth's land surface which is vulnerable to drought and desertification. Much of the earth surface has become desert since the dawn of civilization and many areas are in the process of desertification. The spatial distribution of rainfall variability of the earth as people heavily depend on rainfall is significant in tropical areas and the average deviation from normal vary between ± 40%, which clearly indicates the susceptibility of mid climatic regions to flood/drought (Nagrajan,2003).

Drought ranks first among the natural disaster so far the number of population affected is concerned. Due to its slow progress and unclear start & end points this can be termed as a creeping disaster.

Table 2.1: Historical droughts and population affected (1900-1998)

YEAR	GLOBAL SCENARIO			INDIAN SCENE			REMARK
	EVENTS	KILLED	AFFECTED	EVENTS	KILLED	AFFECTED	
1998	34	3875	24942285	01	2541	125421	
1997	18	930	7236100	-	-	-	
1996	08	--	8485590	01	558	-	
1995	14	--	30230904	01	161	-	
1994	09	--	15515000	01	-	1175000	
1993	12	--	16331507	01	-	-	
1992	29	2571	39444103	-	-	-	
1991	20	2632	27418282	01	500	-	
1990	14	--	19253160	-	-	-	
1989	10	5437	17632000	-	-	-	
1988	22	--	12377500	02	450	200	
1987	19	1427	317155767	03	510	30000000	
1986	04	84	1499000	-	-	-	
1985	18	100000	12016000	01	103	-	
1984	35	458230	33546800	-	-	-	
1983	55	520	162919729	01	-	10000000	
1982	29	280	118057180	01	-	10000000	
1981	20	--	5146180	-	-	-	
1980	25	15	27418000	01	50	-	
1979	13	18	205529000	05	599	20000000	
1978	15	63	13574953	01	150	-	
1977	21	--	9571400	-	-	-	
1976	10	--	--	-	-	-	
1975	15	--	625000	-	-	-	
1974	18	281500	1062000	-	-	-	
1973	18	1625000	160916665	01	-	10000000	
1972	19	662500	102996665	01	-	10000000	
1971	17	--	5930665	01	-	-	
1970	04	--	10225000	-	-	-	
1969	14	200	2174204	-	-	-	
1968	09	--	3914217	-	-	-	
1967	10	500600	1984427	01	500000	-	
1966	09	508000	50360000	01	500000	50000000	
1965	07	502000	51966000	02	500100	50000000	
1964	09	50	2896000	02	-	-	
1900-63	139	14581000	25282000	05	2751051	-	
Total	**742**	**17774432**		**35**	**4256773**		

(Source: EM-DAT: The OFDA/CRED International Disaster Database, Universite Catholic De Louvain, Brussels, Belgium)

2.2 Definition of Drought

Various definitions of drought have emerged from time to time depending on the subject of interest of various researchers and economic/human activities of specific regions. Some are presented here for giving a comprehensive view.

- U.S Weather Bureau (1967): Drought is lack of rains so great and long continued as to affect injuriously plant and animal life of a place and to deplete water supply both for domestic purpose and for operation of power plants especially in those regions where rainfall is normally sufficient for such purpose.
- India Meteorological Department (IMD, 1975): For a given time period (seasonal/ yearly) if meteorological station/division receives total rainfall less then 75% of the normal it is considered as drought.
- Baron (1979) described the drought as moisture deficiency of such magnitude as to adversely affect the accustomed human activity of that region.
- According to Wendland (1990) drought exists when water demand exceeds supply for an extended period and it is a function of the sensitivity of an activity to water availability, the time of the year and the magnitude of deficit relative to some expected value.
- Kontantinove (1968) believed that drought should be studied using the analysis of the deficit of evapotranspiration which is defined as the difference between the potential and the real evapotranspiration.
- Dracup (1980) he enumerated the list of ingredients/variables for defining the drought e.g. rainfall, runoff aquifer level, palmer drought index, duration

(season/year) instantaneous minimum, truncation level (percentage, quartile, standard anomaly), and area or region (single site, river basin, zone).

- **Regional recognitions:**
  - In Bali, period of six days without rainfall is a drought.
  - In Libya, a drought is recognized only after 2years of without rainfall.
  - In Egypt, if the river Nile does not flood in a year then it is termed as a drought.

Thus, the above definitions of drought may be summarized as "a period of prolonged dry weather", "a condition when precipitation is insufficient to meet the requirement of animal and vegetation", "an index established on hydrologic accounting based on precipitation, evapotranspiration, time and its relation with the normal", "a situation when the supply of water /moisture is injuriously lower than the average demand for safe yield of crop as well as other related activity of life".

2.3 Categorization of drought

Considering regional climatic condition, Thornthwhite (1947) categorized drought into following three types:

Seasonal – planting dates and crop duration are to be synchronized with the rainy season and the residual moisture storage (arid and semi arid regions)

Contingent – irregular occurrence and there is no regular season of occurrence.

Invisible – occurrence even when there is sufficient rainfall and it occurs in the humid regions.

Subsequently, droughts have been categorized into five basic types depending on their physical characteristics:

1. Meteorological drought
2. Agricultural drought
3. Hydrologic drought
4. Socio-economic drought, and
5. Environmental drought

Meteorological drought:

It is related to the deficiency of rainfall compared to the mean annual rainfall of an area. So this is a situation when the effective amount of precipitation over an area is decreased. In general this is the drought that leads for all the types of drought as discussed above. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region (Palmer,1965)

Agricultural drought:

It refers to a short term soil moisture deficiency to sustain crop and live stock. It occurs when soil moisture and rainfall are inadequate / erratic during the growing season to support healthy crop growth till yield and causes extreme crop water stress & wilt (Palutikof et al., 1982). If the duration of dry spells exceed certain limiting period when the moisture stress is experienced by crop (in rain fed condition), then it becomes a critical dry spell (CDS). For calculating CDS, an appropriate approach is to divide the crop growth period into some important growth phase according to water demand as the evapotranspiration of crop varies according to growth stage. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. In contrast, a physiological drought refers to the condition of plants that suffers from an excess of salty water often on poorly drained irrigated land.

Hydrological drought:

It is associated with shortfall on surface and/or sub surface water i.e. stream flow, reservoir, lake level, ground water level etc. on a watershed or river basin scale. Meteorological drought when prolonged gives rise to Hydrological drought with remarkable depletion of surface & ground water (Dracup et al.,1980). For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to agriculturalists, but the impact of this deficiency on reservoir levels may not affect hydroelectric power production or recreational uses for many months. Also, water in hydrologic storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., flood control, irrigation, recreation, navigation, hydropower, wildlife habitat etc.), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly. Although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, and the construction of dams all affect the hydrological characteristics of the basin. Because regions are interconnected by hydrologic systems, the impact of meteorological drought may extend well beyond the borders of the precipitation deficient area.

Socioeconomic drought:

It is associated with the deficiency of water needed to meet the industrial and urban activities. Socioeconomic definitions of drought associate the supply and demand of some economic goods with elements of meteorological, hydrological, and agricultural droughts. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is ample in some years but unable to meet human and environmental needs in other years. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. For example, in Uruguay in 1988-89, drought resulted in significantly reduced hydroelectric power production because power plants were dependent on stream flow rather than storage for power generation. Reducing hydroelectric power production required the government to convert to more expensive (imported) petroleum and stringent energy conservation measures to meet the nation's power requirements.

Environmental drought:

In the current hydrologic literature the term environmental drought is commonly referred to define the impact of water stress/deficit on the ecosystem of the region.

It is comparatively new in its existence and is characterized by the impact of water shortfall in the ecosystem.

2.4 Characterization of Drought

Droughts are cyclical and regional climatic phenomena. The occurrences, propagation, severity and impact of this phenomenon are characterized as follows:

1. It is a creeping phenomenon making it difficult to find the onset & the termination points. The effect of drought accumulates slowly over a considerable period of time, sometime more then three to four years.
2. The concept of drought definition is conflicting in the literature and it depends upon or varies according to the subject of interest of the researcher and within regions of different climate. This ultimately affects the drought management decisions.
3. The impacts of drought are less obvious and extend to a large geographical area with different severity and without any structural damage unlike other calamities. So the quantification of the impact and the provision for abatement of drought is quite difficult task.

To cope with drought hardship it is necessary to understand its characteristics i.e. its possible duration, its intensity/severity, and its frequency. For a given region if these attributes are specified or known the planning for drought mitigation will be easier. (Pandey & Ramsastri, 2001)

Duration (D)

It is the period of time exhibiting deficiency of precipitation/stream flow/soil moisture preceded and followed by a period showing no deficiency. A drought event is a series of one or more consecutive drought month/year. Drought persistency describes the tendency of drought event to last more than one season or year, e.g. 4 years drought is a very persistent drought.

Intensity (I)

It is the magnitude to which annual precipitation/stream flow/soil moisture is lesser than the mean or the threshold value. Drought intensity is nearly independent of duration. (Bonacci, 1993)

Frequency (F)

It refers to the number of years that it would take a drought of certain intensity to recur in units of year. The reciprocal of frequency is the return period. The average drought frequency (i.e. y^{-1}) is found to decrease gradually from dry to wet regions in India. (Pandey and Ramasastri, 2000). Average drought frequency is obtained as the number of years of rainfall record analyzed divided by number of meteorological drought years.

Severity(S)

It refers to the accumulated drought through out the drought duration i.e. (I=S/D). So severity can be predicted if the intensity and duration are known. The drought severity is critical for hydrologic drought, whereas the critical duration even in less severity is important for agricultural droughts. A strong correlation between the severity and duration has been found by Zelenhasic and Salvia (1987) and Chang and Stenson (1990) using daily stream flow data, and by Bonacci (1993) using monthly and annual rainfall and flow data. In the context of hydrological drought, Yevjevich (1972), and Dracup et al. (1980) defined the severity as the cumulative shortage or deficit sum with reference to a desired truncation level, and therefore severity has the unit of mm or cubic meters.

The aerial extent of drought also plays an important role in identification of the spatial distribution of drought and its effect in hydro-meteorologically homogeneous region. Due to development and availability of GIS based packages it is also possible to reproduce different aerial extents very easily as per requirement.

It can be concluded here that the climatic parameters that drive a drought event and its characteristics are: Precipitation: which in turns depends on, latitude, season, orografic factors, and proximity to ocean, mesoscale atmospheric circulations, atmospheric pressure & characteristics of earth surface; Potential evapotranspiration: depends on, net solar radiation, vapor pressure deficit, surface roughness & leaf area index. The other most important feature presently being explored are the climatic changes attributed to atmospheric activities. There is wide consensus exists on the fact that these climatic changes will intensify the extreme events such as drought and flood before the temperature changes are severe enough to be noticed.

2.5 Time Units in Drought Analysis

The choice of time limit is of utmost importance in analysis of the hydrology of extreme events. So far flood is concerned it may vary from ½ an hour flood analysis to a decade or more for climatic changes. For drought events the commonly used time limits are months followed by season and year. Drought events are easily detected from a continuous series of monthly, seasonal or yearly data. The selection of time limit for a particular drought study is almost totally dependent on the purpose for which the study is being carried out. The size of the set of historical drought samples is also important in determining the type and accuracy of the analysis that may be performed for the purpose. The sample size must be large enough to guarantee that the sample statistics e.g. mean, variance, serial correlations etc are reasonable approximation of the corresponding population parameter. The selection of time unit also affects the degree of correlation between the successive drought events. In general a shorter averaging period tends to result in greater serial correlation in the time series. Thus monthly drought events usually exhibit more serial correlation than do the yearly ones. The use of longer time period apparently smoothens the short term affects of natural carry over storage and climatic stability which may have a substantial impact on drought based on a shorter time unit. Often the choice of time limit relies on the purpose for which the study or analysis is intended.

2.6 Concept of Truncation/Threshold Level

It is a component to define a complete drought event which is used to divide the time series into above normal and/or below normal sections. The concept and effect of truncation level is clearly seen when the statistical theory of run is adopted for the analysis of time series. The run methodology is useful in analyzing a sequential time series of stochastic or deterministic variable and hence is better utilized for study of hydrological and meteorological drought events. However a complete drought analysis is invariably concerned with both duration and severity. A simultaneous use of both is not practical as the use of two different truncation levels, will end up with two different sets of drought events. Also while using the mean of historic time series one must have to be cautious of grossly unrepresentative events included in the sample, particularly when the sample size is small. The fundamental parameters are X0: it is the truncation level set arbitrarily to cut the series at various points and its relationship to other values of X is the basis of defining the run parameters.

For low flow: S_L= The Run Sum (cumulative deviation from X_0)

M_L= Run intensity (average deviation from X_0)

D_L= Run length (distance or time between successive crossings with X_0)

For high flow the parameters can be denoted as S_H, M_H & D_H respectively.

In drought terminology: Run Sum = Severity of Drought, Run Intensity = Magnitude of Drought. Run Length =Duration of Drought. They are related by the equation $S_L=M_L*D_L$

In practice X_0 is selected as, for hydrological drought study, mean annual runoff of the watershed and for agricultural drought study, mean soil moisture present during the season. X_0 can be a constant, a stochastic variable, a deterministic function or a combination as per requirement and purpose of its use. In general the truncation level is chosen to be some measure of the central tendency of the drought sample thus resulting in approximately half the event being classified as high and half as low. (Dracup, 1980). Dracup modified the truncation level equation with the expression X_0 =Xm-e.S = Xm(1-e.cv), where X0 is the truncation level, Xm is the mean, S is the standard deviation, cv is the coefficient of variation of the time series of the drought variable X, such as rain fall or stream flow time series and e is the effective scaling factor. If e is zero, then X_0=Xm, i.e. the truncation level is the mean of the series. If one chooses 90% of the mean annual rain fall or runoff (say cv of 0.4), then e= (1-0.9)/0.4=0.25. Since the important drought characteristics depend on the truncation level, the selection of a truncation level assumes prime importance in drought analysis. Virtually all the hydrological records are skewed and the mean differs from the median. It has to be chosen properly for an analysis what is to be adopted. The mean is more sensitive to extreme value of the distribution. As drought is an extreme event it is better to use the mean instead of median, this has been justified in the results of this study also.

2.7 Indicators/ Indices

A drought index value is a single number used for decision making. The common indices which are used are narrated below. Their different values are used for the different purposes by different researchers and agencies.

2.7.1 Meteorological Indices

It is defined on the basis of degree of dryness in comparison to normal or average dryness and the duration of dry period.

Dryness Index (Id): Id=56*log10 (120*T)/P, Where T=Annual average temperature in ^{0}C, P=Annual average precipitation in mm. This index becomes positive for dry climatic region and negative for moist climate. It is classified as, Arid extreme (>72), Arid moderate (>50-71) and Arid mild (<50).

DeMertonne's Index (IA): IA=P/ (T-10), **P** & T as defined above. This is classified as: IA<5, it is true desert, if IA=5-10, arid zone and if IA=20-30, it is semiarid zone.

Pluvothermic Quotient(PQ): PQ=100* P/ (TM+Tm)/(TM-Tm), P is the mean precipitation in mm; TM is the average maximum temperature in the warmest month. Tm is average minimum temperature in the coolest month and classified as: if PQ<40, it is desert, if PQ=60-100 it is semi arid and if PQ>300 it is humid zone.

Aridity Anomaly Index (AI): AI = (PE-AE)/PE*100, Where, PE=potential evapotranspiration, AE =actual evapotranspiration and PE- AE = the deficit. The difference between the actual AI for the week and the normal aridity intensity is estimated and are grouped as: 0 – 25 = mild arid, 26 – 50 = moderate, >50 = severe. India Meteorological Department follows this criterion for classification of the drought severity.

Bhalme Mooley Index: It is also known as accumulated Negative Moisture Index (NMI). The NMI values are classified from mild to extreme drought by use of Palmer Drought Intensity classification. NMI (M) = 100* (Pm tot – Pm mean)/e, Where Pm-tot = total monthly rainfall of M month under consideration, Pm mean = mean monthly rainfall over N years, e = standard deviation. NMI indicates the boundary condition between monthly moisture conditions.

Percent of Normal Precipitation (PN): It is the simplest method and best suited for layman and general audience through television, in expressing the variation. It is estimated by dividing the actual precipitation by the normal precipitation (30 years mean) and expressed as a percentage. In our country when the deviation is -25% or less it is treated as a deficient year.

Standardized Precipitation Index (SPI): It quantifies the precipitation deficit for multiple time scales. It helps in issuing warnings of drought and helps in the assessment of drought severity. The long term record is fitted to a probability curve and then transformed into a normal distribution so that the mean desired period is zero. McKee et al. (1993) classified the SPI values and indicated suitable drought conditions. Monthly maps of SPI are used by the National Drought Mitigation Centre, and Colorado State University in U.S.A.

Palmer Drought Severity Index (PDSI): It is a soil moisture algorithm which is calibrated for relatively homogeneous region, and not suitable for mountainous area. This was prepared by Palmer (1965) from US weather bureau. Since its inception it has been modified to various versions like Palmers hydrological drought index (PHDI), the results of which are used to indicate the duration required to end the present drought condition. It is widely used in US for monitoring of water supply during drought conditions. The PDSI gives the classification as, PDSI<4 (extreme drought) and PDSI > 4 (extreme wet).The calculation procedure is bit complicated and involves factors like hydrological accounting i.e. Climatic water balance, climatic coefficients by simulating water balance, CAFEC values i.e. Climatically approximate for existing conditions), moisture anomaly index, drought severity or the Z-index etc. While estimating PDSI, many assumptions are made for unavailable data which may sometimes lead to unrealistic results.

2.7.2 Hydrological Indices

The persistence of hydrological drought is due to several land surface feedback conditions, which was first addressed by Rowdier & Beran 1979.

Water budget method: It uses the Palmer Hydrological Parameters considering the effective soil to be made up of two layers viz. surface layer (25mm) and under laying layer holding the moisture that depends on the water holding capacity of the soil. Drought spells in Bihar and Tamilnadu are agreement with the computed PHDI

Surface Water Supply Index (SWSI): It is calculated for a river basin, stream flow, precipitation and reservoir storage. It represents water supply conditions unique to each basin or water management requirement of each basin. Hence inter-basin comparison is not possible. Monthly precipitation data are collected and summed up for all the raingauge stations, reservoir and snow-pack/stream flow measuring stations and the summed up components are normalized using a frequency analysis gathered from a long term data set. The probability of non existence i.e. the probability that subsequent sums of that component will not be greater than the current sum is determined for each component based on the frequency analysis. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin and these weighted components are summed up to determine SWSI. It ranges between - 4.2 and +4.2. SWSI and PDSI are used in the drought warning in Colorado, USA.

Reclamation Drought Index (RDI): It is calculated for river basin level. It is a tool for defining drought severity and duration. It is unique for a river basin and incorporates the supply components of precipitation, snow pack, and stream flow and reservoir levels.

2.7.3 Agricultural Indices

Crop Moisture Index (CMI): It uses a meteorological approach for week to week crop condition and evaluates moisture condition across the major crop producing region. It reflects moisture supply in a short term basis and is not intended for long term drought. It responds rapidly to changing conditions and location. The availability of soil moisture to plant from the field capacity to permanent wilting percentage determines the nature of soil drying rate. Linear (Thornthwaite and Mather, 1955) and exponential (Lemon and Sinn 1968) relationship exists between relative transpiration rate and available soil water. Crop water stress index (CWSI) developed by Jackson et al. (1983) normalizes the seasonal and daily differences.

CWSI = 1- mad = 1- Ed/Epd, where Ed = daily actual evaporation, Epd = daily potential evapotranspiration, mad = moisture availability.

2.7.4 Socio-economics Indicators

Social impacts of drought affect various sectors of life and also the quality of living. Its impacts involves mainly public safety, health, conflict between different water users, migration of population etc. the drought maps of different utilities are prepared time to time for monitoring its effect. The different field sectors for analysis are, Revenue units- no of villages chronically affected by drought and its demographic details, scarcity of essential resources, Water scarcity, Crop production, Energy requirements, Health condition and mortality, Occupational diversification, Change in social values, Consumption pattern, level of self sufficiency, Income, Financial institutions, Migration details etc. In most instances, the demand for economic goods is increasing as a result of increasing population and per capita consumption. Supply may also increase because of improved production efficiency, technology, or the construction of reservoirs that increase surface water storage capacity. If both supply and demand are increasing, the critical factor is the relative rate of change. Is demand increasing more rapidly than supply? If so, vulnerability and the incidence of drought may increase in the future as supply and demand trend to converge.

2.8 Summary of Important Indices

There exist a number of indices in the literature and the important ones are: Bhalme and Mooly Drought Index (BMDI; Bhalme and Mooly 1980), Crop Moisture Index (CMI; Palmer, 1968), Deciles (Gibbs and Maher 1967), National Rainfall Index (RI; Gommes and Petrassi 1994), Palmer Drought Severity Index (PDSI; Palmer 1965), Percent Normal (PN; Willeke et al. 1994), Rainfall Anomaly Index (RAI; Rooy 1965), Reclamation Drought Index (RDI; Weghorst 1996), Standardized Precipitation Index (SPI; Mckee et al. 1993, 1995), Surface Water Supply Index (SWSI; Shafer and Dezman 1982), etc. Recently, the Soil Moisture Drought Index (SMDI; Hollinger et al. 1993) and Crop-Specific Drought Index (CSDI; Meyer et al. 1993; Meyer and Hubbard 1995) appeared after the CMI. Furthermore, CSDI is divided into a Corn Drought Index (Meyer et al. 1993) and Soybean Drought Index (Meyer and Hubbard 1995). Besides, the indices made by Penman (1948), Thornthwaite (1948, 1963), Keetch and Byrum (1968) are also been used. (Steila 1986; Hayes 1996).The characteristics of each index are summarized in Table 2.1.

Table 2.2: Summary of Important Drought indices:

NAME	Factors Used	Time scale	Main concept
PDSI	r,t,et,sm,rf	m	Based on moisture inflow, outflow and storage.
SWSI	P,sn	m	Like the PDSI except considering sn.
PN	r	m	Dividing actual r by the normal value.
Deciles	r	m	Dividing the distribution. of the occurrences over long-term r records into sections each representing ten percent.
SPI	r	3m,6m,12 m,24m,48 m	Difference of the r from the mean for a particular time & divide by standard deviation.
CMI	r,t	w	Like PDSI except considering available moisture in top 5ft soil.
SMDI	sm	y	Summation of daily sm for a year.
CSDI	ev	s	Summation of the value of the calculated ev divided by ev possible during growth of crop
RI	r	y,c	Patterns & abnormalities of r on a continenta scale.
RAI	r	m,y	r compared to arbitrary values of +3 and -3 which is assigned to the mean of ten extreme (+) and (-) anomalies of r.
BMDI	r	m,y	Percent departure of r from the long term mean.

Abbreviations: **P**: factors used in PDSI, **r**: precipitation, **et**: evapotranspiration, **ev**: Evaporation, **t**: temperature, **sm**: soil moisture, **rf**: runoff, sn: snow pack, **w**: week, **m**: month, **s**: season, **y**: year, **c**: century, 3m: 3 months, etc.

2.9 Methods of Data Acquisition:

The identification and prediction of drought are achieved through analysis of time series of drought variables such as rainfall, stream flow and soil moisture data on a variety of time series. At times data series can be generated stochastically or through physically based concept such as generated soil moisture accounting algorithm (Palmer, 1965). Other proxy data, which can be invoked in the analysis and synthesis of drought are: Dedrochronology (Tree Ring procedure), Mud verves, Ice coring, Polynology (i.e. analysis of pollen), Paleontology (i.e. continental and marine fossils), Geological movements, Sea level fluctuations, Paleomagnetic data etc. (Chin, 1979).

The most commonly used method is the tree-ring procedure which is found to be more reliable by many researchers.

2.10 Development of Methods for Analysis

Frequency or probability based method: In these methods low flow or flow volumes during a specified period are analyzed in a manner similar to flood peak analysis. (Joseph 1970, Yevjernich et al, 1978, Clausen and Pearson, 1995)

Regression based method: In this method regression analysis is conducted to relate drought parameters with geomorphic and /or climatic features, crop yield features and other relevant features for prediction of duration and severity of drought. Paulson et al, 1985, Minicon et al, 1993, Kumar &Panu, 1997.

Theory of runs based method: The probabilistic structure of drought duration (run length) and severity (run sum) are analyzed using the notion of run. (Yevjevich, 1972). In this method the drought parameter such as the longest duration and longest severity are analyzed. The analysis is carried on the time series of random or Markovian drought variables (Sen, 1980, Sharma, 2000). Another approach in this category is the discrete autoregressive and moving average (DARMA) process to model the variability of dry and wet years.(Chang and Salas ,2000).

Group Theory Based Method: The characteristics of drought in terms of their duration and length can be expressed in groups and in cluster of groups. In turn such data sets can be analyzed to develop drought prediction and forecasting technique utilizing the concept of pattern recognition (Kumar and Panu, 1994) and neural network (Shin and Salas 2000). However the group theory method is in initial stage and needs future research.

PDSI Based Method: The time series of Palmer Drought Series Index (PDSI) are synthesized to identify characterize the severity of drought. Since PDSI structure displays a Marcovian structure such indices and their derivatives are focused for forecasting of agricultural drought (Lohani and Lognatham, 1999).

MAI Based Method: The Moisture Adequacy Index (MAI) is a measure of the degree of soil moisture availability for plant growth. The food and agriculture department of US has developed algorithm to generate MAI time series for characterization of agricultural drought and their severity, (Kumar and Panu, 1997).

Effective Drought Index (EDI): For monitoring the drought event effectively on a daily basis the concept of EDI has now gained momentum to asses' drought severity world wide. (Byun and Wilhite, 1999). To represent daily depletion of water resources a new concept of Effective Precipitation (EP) is proposed by them with the following three equations:

$$EP_i = \sum_{n=1}^{i} \left[\left(\sum_{m=1}^{n} P_m \right) \Big/ n \right] \qquad (2.1)$$

$$EP_i = \sum_{m=1}^{i} \left[a(i-m+1)P_m \Big/ \sum_{n=1}^{i} n \right] \quad (2.2)$$

$$EP_i = \sum_{m=1}^{i} P_m^{\ -m/i} \quad (2.3)$$

Where i= Duration Summation (DS)

Pm= Precipitation of m days before, and

a= constant (if i is 365, a=100)

Equation (1) is derived from the concept that the precipitation m days before is added to the total water resources as a form of average precipitation of m days. Equation (2) is derived by the empirical method. Many other equations can show the depletion of water over time and the choice of the best equation depends on many other parameters like topography, (3) is derived from the equation d(EP)/dt = -C* (EP), C is the constant and t is day. This equation shows that daily depletion of EP is proportional to the amount of EP, soil characteristics, ability of water retention in the reservoir, air temperature, humidity and wind speed. Hence by actual testing through the daily rainfall record of 193 stations in the United States, Byun and Wilhite, (1999) concluded that the equation (1) and (2) has practical utility and can be used in the manner that (1) is more sensitive to precipitation and can be used for upper basin of river, mountainous area and area with low water retention whereas (2) can be used for lower basin of river, areas with good water retention and for long term drought analysis. The Daily Water Resources Assessment Modeling (DWRAM) devised by Byun and Wilhite, (1999) for analysis of daily data using equation (1), which is relevant to this study area is discussed in the methodology chapter in this thesis.

EDI in its original form has been devised to use daily rainfall and to generate drought index on a daily basis. Later on it was modified by other researchers to use also in the monthly time scale.

As a matter of fact due to the complexity of the drought phenomenon and due to the fact that it has a creeping affect and has region specific character many researchers and scholars prefers analyzing the drought situation with more than one index and see their effectiveness to define the droughts. One such attempt has been made by Smakhtin and. Hughes (2005).They also developed a software (SPATSIM-2005)) capable of analyzing five indices at a time and giving summery of results.

CHAPTER 3

FEATURES OF STUDYAREA

3.1 General

Kalahandi, Bolangir and Koraput in Orissa are popularly known as KBK districts. These districts have special status under RLTAP (Revised Long Term Action Plan) of Government of India. The KBK districts are considered to be highly under developed regions, situated in south- western part of Orissa between the latitude 17^0 40'30" N to 21^0-15'-20" N and longitude 81^0-20'-10" E to 84^0-30'-40" E in the Eastern ghat range. The KBK districts are now divided into eight districts: (i) Koraput: Malkangiri, Nawrangpur, Rayagada, and Koraput (ii) Bolangir: Sonepur, and Bolangir, and (iii) Kalahandi: Nuapada and Kalahandi. These eight districts comprise of 14 Sub-divisions, 37 Tahsils, 80 Blocks, 1,437 Gram Panchayats and 12,104 villages. Other details of KBK districts are given in Table 3.1. Figs.3.1(a) and 3.1(b) show location of the KBK Districts.

Table 3.1: List of New Districts under KBK

Sl.No	District Name	Area in (Sq.Km)	NO. of Block	No. of Village
1	Kalahandi	7920	13	2205
2	Nuapada	3852	5	659
3	Bolangir	6575	14	1792
4	Sonepur	2337	6	959
5	Koraput	8807	14	1997
6	Raygada	7073	11	2667
7	Nabrangpur	5291	10	897
8	Malkangiri	5791	7	928
	TOTAL	44546	80	12104

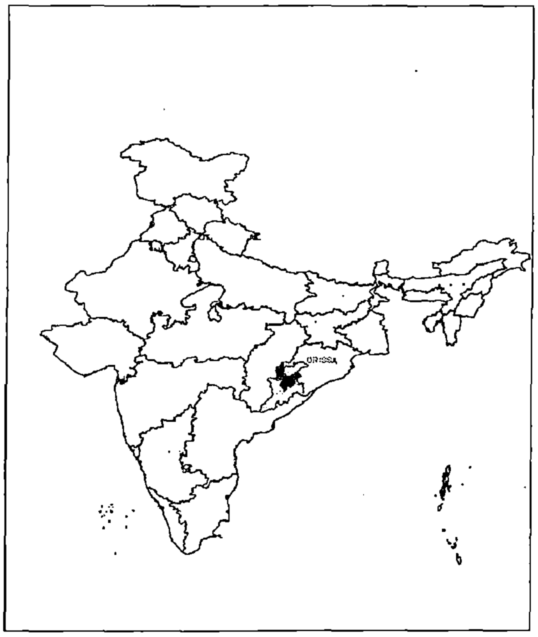


Fig. 3.1(a): Location of KBK Districts in India

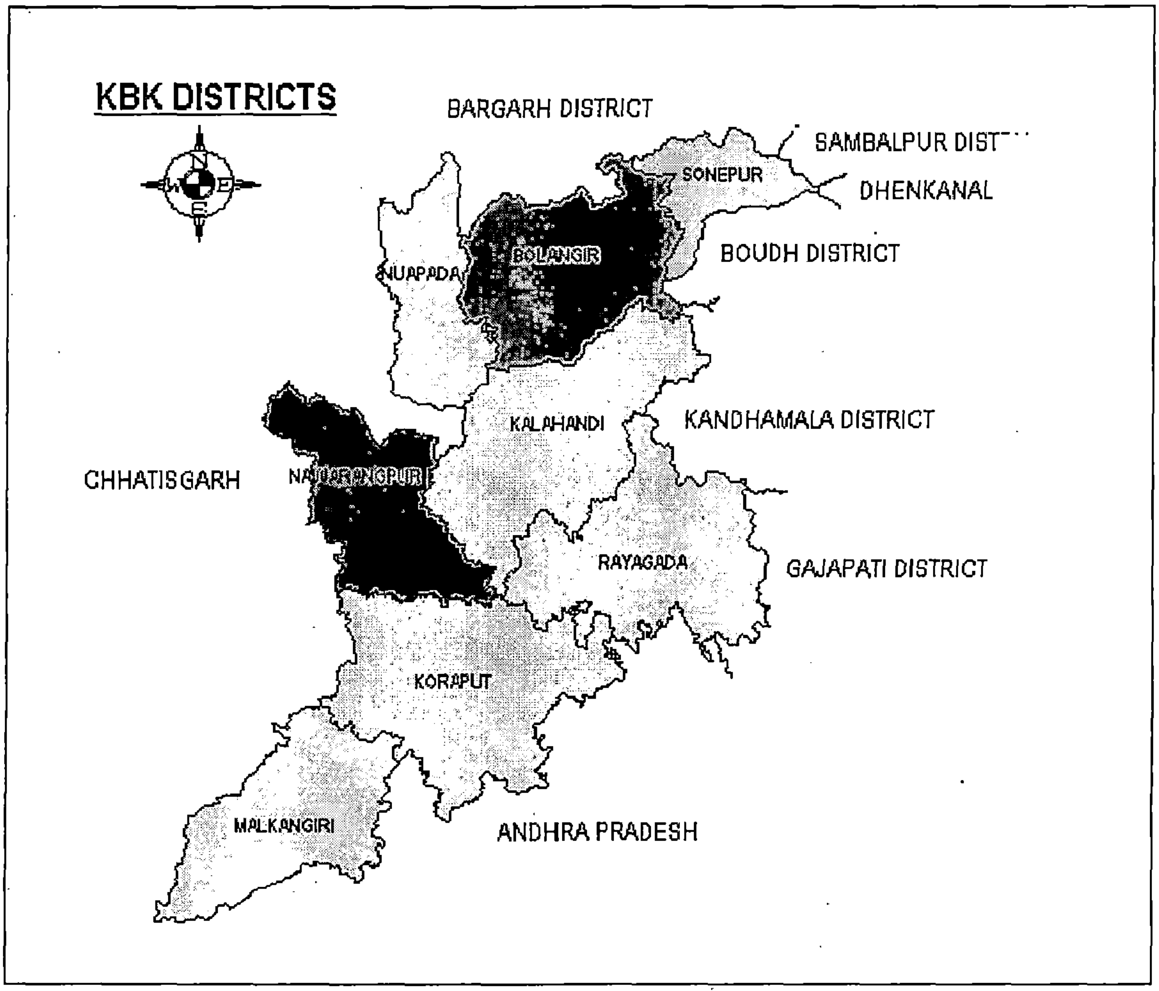


Fig. 3.1 (b): KBK Districts

3.2 Typical Features of KBK Districts

The KBK districts of Orissa are popular in the country for their typical socio-economic features. Some of these features are as follows (Govt. of Orissa, 2002):

- The KBK districts account for 19.72% population over 30.59% geographical area of the State of Orissa. Tribal communities comprising up to 38.72%, dominate this region.
- This is one of the poorest regions in the country and of rural backward character. According to NSS (1999-2000) nearly 87.14% of population in the Southern Orissa belongs to below poverty line (BPL) category.
- The literacy rate (36.58%) is much lower than the State average of 63.61%. The female literacy rate (24.72%) also compares unfavorably with the State average of 50.97%
- Road connectivity is a major constraint in the region. Missing links pose significant challenges to the people to access market places, educational institutions and health services.
- Rainfall is generally erratic and unevenly distributed. Irrigation facilities (both surface and lift) are inadequate. Thus, the region often experiences acute problems of moisture stress and drought.
- At present all the eight KBK districts are ecologically disturbed. More than 50% of forests of these districts are degraded.
- There exist alarming problems of soil erosion and land degradation. Region is dominated by light loamy soils with low water retention capacity. These problems, among others, significantly contribute to low land productivity.

Compare to the state's average, per hectare yield of rice in the KBK district is substantially low.

- Employment opportunities in the region are limited. Agriculture, which is the major economic activity, does not generate adequate avenues of employment for the rural poor. As a result, many men and women migrate to urban areas both inside and outside the State in search of employment.

In general, KBK districts are classified predominantly as drought prone region, with high concentration in entire Nuapada and western part of Kalahandi. Among the KBK districts, Bolangir and Sonepur often face acute shortage of water and high temperature in summer, recorded up to 50.5^0C in the year 1999 at Titlagarh.

3.3 Climate and Rainfall

This region belongs to the sub-humid temperate region of India with an average rainfall ranging from 1100 mm to 1400 mm. Out of the total annual rainfall, nearly 90% is received during the monsoon season and rest part of the year remain almost dry. The months of July and August are wettest months of the year receiving average rainfall of the order of 360 mm and 380 mm respectively. The monsoon is very erratic with record of 1170 mm rain fall in one month, i.e. August 1978, Bhawanipatna, and there are evidences of zero rainfall for 7-8 consecutive months. This region, therefore, often suffers both from droughts and flash floods from time to time. But its vulnerability to drought is more than floods because of high variability of seasonal rainfall, dominant rain- fed paddy cultivation, light loamy soils, dominant hilly terrain and lack of other sources of livelihood for backward tribal population. The climate is of extreme type with May being the hottest month with mean daily maximum and minimum temperature of 42^{0}C and 31^{0}C respectively. December is the coolest month with mean daily maximum and minimum temperature of 28^{0}C and 12^{0}C respectively. The south west monsoon which is the single largest contributor of monsoon rainfall in this region normally sets in mid June.

3.4 Documented Drought Events

Drought is one of the common characteristics of this area. According to the documents of Revenue Dept. Govt. of Orissa (1972-76) severe droughts had occurred in KBK districts. In the year 1964-65 there was severe drought and it continued till 1966-67. Again in 1972 the scanty rainfall in monsoon period led to failure of crop and a sizeable area came under the grip of drought during 1973-74. The White paper, Govt. of Orissa, 1974 clearly indicated the effect of drought in the drinking water sector as well as agriculture. Again in 1979 a severe drought caused considerable Kharif crop losses in the area. Thereafter 1981-85 was mixed years with maluniform distribution of drought and flood. The year 1987 again came with the ugly face of drought with a deviation of rainfall to the tune of 55%. In 1996 the delayed monsoon played the mischief to create another drought event so also in 1997. The year 2000 was again bad but only few pockets of the area were affected. Now the situation of 1987 was again repeated in 2001-02 with a wide spread drought which of course affected the entire State and the State Govt. again submitted a memorandum on Drought situation to Govt. of India. This is how the story of drought stricken KBK districts goes. On reviewing the documents one can easily asses the grave situation the area is facing with drought coming in every 3-4 years and often continued for more than one year.

3.5 Focusing on Severest Drought Area within Study Area

To explore the applicability of different drought indices and to determine more appropriate index for drought identification, severity quantification and assessment of other drought characteristics, Kalahandi and Nuapada districts which regularly experience droughts of severe intensity, as compare to other KBK districts, have been chosen as the Focus Area. Henceforth, the above two districts are referred as Focus Area. The Focus Area as a mater of fact needs sincere efforts to scientifically analyze pattern and characteristics of past drought events and to find out the suitable drought identification techniques, time scale, type of drought index etc. However to generate monthly aerial time series the raingauges of the Focus Area as well as some peripheral stations of the KBK district have been utilized which are shown in Fig: 3.2.The annual average rainfall of the Focus Area is about 1347.9 mm (Kalahandi district is 1378.2 mm and Nuapada is 1317.5mm). As usual rainfall is mostly erratic and there is large variation from year to year. The population in Focus Area has a sole dependence on agriculture any deficiency in production of major crop Paddy often leads to large scale migration of population to neighboring states in search for work. This has also been reflected in the Memorandum for drought, Govt. of Orissa in 2002. Table 3.2 and Fig.3.3 give the details of crop coverage averaged over last 12 years (1993 to 2005).

Table 3.2: Average Kharif Crop coverage in Focus Area

Sl.no.	Name of Crop	Average coverage area (in Ha.)	Percentage of total cropped area
1	Paddy	269700	55.7
2	Oil seeds	50000	10.3
3	Cotton	14600	3.0
4	Pulses	150200	31.1
5	Others	4500	0.9
	TOTAL	**357000**	**100**

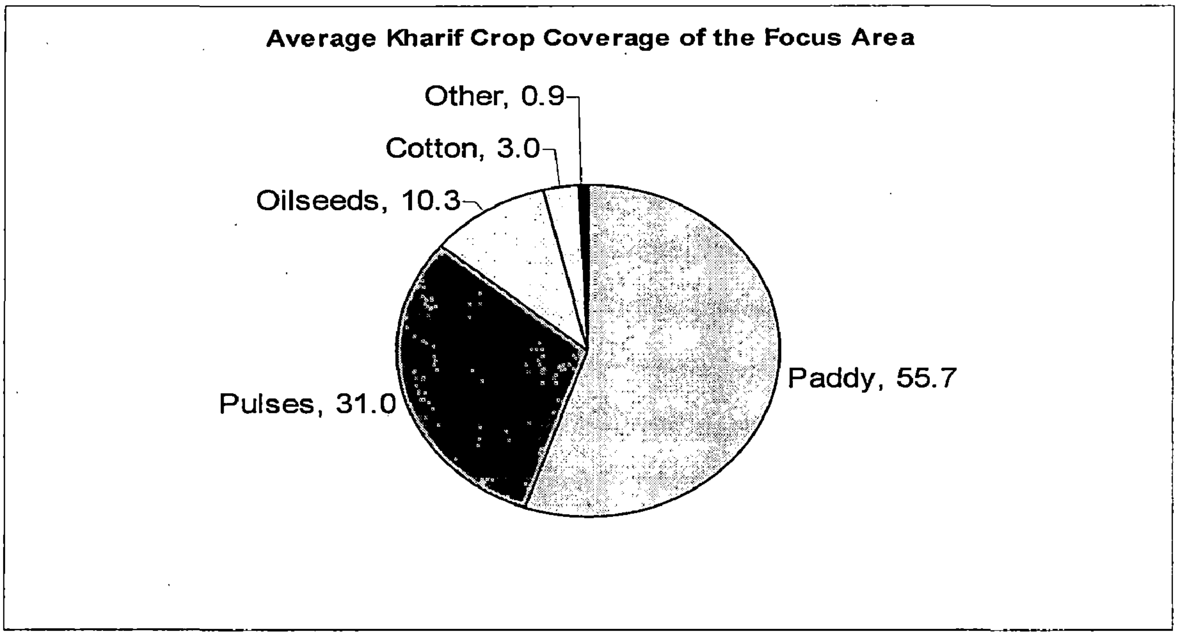


Fig. 3.3: Average Kharif Crop Coverage in Focus Area

The deviation in the yield/production of major crops may be taken as one of the indicators in establishing suitability of particular drought indices for analysis. The severity of drought may be quantified using different indices viz. SPI, EDI, Deciles and Departure from Mean and Median. The methodologies for estimation of these indices are described in the subsequent chapters.

CHPTER 4

METHODOLOGY

4.1 General

Rainfall is considered to be the primary indicator of drought and is the basis for most drought watch systems, particularly with regard to the probability of receiving a specified amount of rainfall. Of all the meteorological elements, rainfall exhibits frequency distribution which shows greatest departure from the Gaussian distribution and needs better understanding. In this study point rainfall from 9 rain gauge stations covering the KBK districts in Orissa has been used. This includes daily rainfall from 3 stations namely Bhawanipatna, Kesinga and Lanjigarh varying from 11 years to 26 years. The monthly and yearly rain fall records was obtained for all the nine stations i.e. Bhawanipatna, Kesinga, Lanjigarh, M.Rampur, Khariar, Dumerbahal, Muniguda, Umerkote and Bolangir. This record varies from 11 years to 34 years. The rainfall data was collected from the Water Resources Department, Govt. of Orissa.

4.2 Annual and Seasonal Rainfall Departures and Crop Yield

4.2.1 Annual and Seasonal Rainfall

Mean annual rainfall of a station was estimated as simple arithmetic average over the period of record used in the study. The annual rainfall departure is calculated as the deviation of rainfall from the corresponding mean value. Similarly the seasonal rainfall departure was estimated using the rainfall record of monsoon season i.e., June, July, August, September, October (JJASO). This has been plotted with the yearly departure to present a comparative picture of annual and seasonal rainfall surplus/deficiency. Rainfall departures have been correlated with the historical documented drought events in the region.

To determine probability of occurrence of rainfall equivalent to 75% of normal, yearly rainfall records are arranged in descending order and ranked as 1 for the highest rainfall to n as the lowest, where n is the number of annual rainfall record used in the analysis. The data were then utilized to calculate the probability of exceedance using the Weebull formula. The formula utilized is Probability of exceedance P= R/ (n+1), where R is the rank particular annual rainfall value. For example if 30 years data have been used for a given station then n is equal to 30. From such calculations for all the stations probability distribution curves ware plotted for each. The yearly and seasonal curves were plotted together to present a comparison of both the distribution.

Tables 6.4 & 6.5 show the probability of exceedance to rainfall equivalent to 75% of mean were calculated from the distribution curves. The rainfall amount corresponding to 75% and 80% of dependability were also given in the subsequent columns of these tables. All these estimates were made to assess vulnerability of the region to drought.

4.2.2 Crop Yield Loss

The major crop coverage of the focus area i.e. Kalahandi and Nuapada has been plotted for both Kharif and Rabi seasons. The deviation of the yield from the maximum yield, of the available 12 years data, has been calculated to show the deviations in sufficient and deficient years. The crop deviation and the deviation of the seasonal/annual rainfall of the district from the long term mean is calculated and analyzed to visualize the effect of drought on crop yield.

4.3 Monthly and Daily Rainfall Data Processing

This is comparatively an important part of the study as the monthly rainfall of all the stations is utilized after converting all of them to the aerial average rainfall of the focus area. The methods of averaging rainfall have been the inverse distance squared weighting procedure i.e. the closure points to the focus area have more influence in the interpolated data. Five indices viz. Standardized Precipitation Index (SPI), Effective Drought Index (EDI), Decile Index (DI), Deviation from Mean (DvMn) and Deviation from Median (DvMd) have been generated to quantify the drought severity. The daily index has been generated for the station using the point rainfall to analyze dry duration and to compare drought severity in different years. The methodology for each index is described below.

4.3.1 Standardized Precipitation Index (SPI) (McKee et al. 1993):

It is primarily a tool for defining and monitoring drought events. It allows an analyst to determine the rarity of drought at a given time scale (temporal resolution).

Calculating SPI:

Computing of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a climate station. The gamma distribution is defined by its frequency or probability density function (eqn.4.1).

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \chi^{\alpha-1} e^{-x/\beta} \qquad (4.1)$$

The alpha (α) and beta (β) parameters of the gamma probability density function are estimated for each station, for each time scale of interest (1- month, 3-months, 6-months, and 12-months). The maximum likelihood solutions were used to optimally estimate α and β:

$$\alpha = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right) \qquad (4.2)$$

$$\beta = \frac{\bar{x}}{\alpha} \qquad (4.3)$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad (4.4)$$

Where, n = number of precipitation observations.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given time scale for the station in question. The cumulative probability is given by

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \qquad (4.5)$$

Let t = x/β the equation become the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(a)}\int_0^t t^{a-1}e^{-t}dt \qquad (4.6)$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)\,G(x) \tag{4.7}$$

Where, q is the probability of a zero value. The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI.

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0 < H(x) \le 0.5$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0.5 < H(x) \le 1.0$$

where t = $\sqrt{\ln(1/(H(x))^2)}$ for $0 < H(x) \le 0.5$, t = $\sqrt{\ln(1/(1.0 - H(x))^2)}$ for $0.5 < H(x) \le 1.0$, $C_o = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, and $d_3 = 0.001308$.

Drought Severity Assessment using Standardized Precipitation Index

The standardized precipitation index (SPI) represents a statistical z-score or the number of standard deviation (following a gamma probability distribution transformation to a normal distribution). Above or below that an event is demarcated with reference to mean (Edward and McKee, 1997). The estimated values of SPI (z-score) demarcate precipitation events over specified time period into surplus (heavy precipitation), medium/normal and low/deficits precipitation. The greater value of SPI close to 1 and above indicates the wet event. The values Z >2.0 show very heavy precipitation over the specified time scale as shown in Table 4.1 which gives indication about the range fixed for different events.

Table 4.1: SPI Boundary Values for Different Conditions

SPI Values	Conditions
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

A software package namely 'Spatial and Time Series Information Model (SPATSIM)' has also been applied for the quantification of drought severity in the 'focus area'. In the SPATSIM application described in the next chapter many options are available for accumulating the monthly rainfall values into a time series before SPI is calculated. The time series is then normalized using an automated procedure of the Box-Cox approximation for transformation to normal distribution. The software uses following equation for transformation:

$$y = (x\lambda-1)/ \lambda, \lambda \neq 0. \qquad (4.8)$$

Where, y is the transformed value of the variable, x is the value of the variable and λ is the transformation parameter.

4.3.2. Effective Drought Index (EDI) (Byun and Wilhite, 1999):

The EDI in its original form has been devised to analyse drought severity and duration using daily rainfall data. The original and the modified forms used to analyse the monthly data is discussed below:

Effective precipitation (EP): To represent daily depletion of water resources equation (2.1) as discussed in the chapter 2 which is applicable for the study area is given below:

$$EP_i = \sum_{n=1}^{i} \left[\frac{\left(\sum_{m=1}^{n} P_m \right)}{n} \right] \tag{4.9}$$

Where i = Duration of Summation (DS) and

Pm =Precipitation of m days before.

It is derived from the concept that precipitation m days before is added in the form of average precipitation of m days. The first step beyond EP is the mean of EP i.e. (MEP). A five days running mean is applied to smoothen the strong daily variation. From the EP the other useful terms derived and utilized are: DEP (deviation of EP) = EP-MEP (i.e. mean of EP), SEP (standardized value of DEP) =DEP/ST (EP), ST (EP) is the standard deviation of each day's EP.

Quantification of drought severity: Using the values of DS, many kinds of daily drought severity indices can be defined:

a. Consecutive days of negative SEP (CNS): The duration of precipitation deficit provides good information on drought. Consecutive days of negative SEP (CNS) show this duration quantitatively.

b. Accumulation of consecutive negative SEP (ANES): All positive SEP's are translated into zeroes of accumulation of CNS (ANES). Only consecutive negative SEPs are accumulated to make ANES.

c. Benefit of the ANES is that drought duration is easily determined by the ANES, as the absolute value of SEP is almost always less than 2.0.

d. Accumulated precipitation deficit (APD_j): APD_j is calculated by a simple accumulation of precipitation deficit, as seen in equation below.

$$APD_j = \sum_{n=1}^{j} P_N - AVG_j \qquad (4.10)$$

where, j is DS, which is a different value from the dummy value of i. And AVGj is the averaged daily precipitation of the date for many years during a predefined DS. The EP function in (4.9) is not used in APD. The APD is useful because the general public is more accustomed to simple precipitation accumulation than to the EP. And the APD is the best of all indexes when it is used for comparing drought damage in the same climatic conditions. If APD is calculated during the predefined dry duration instead of DS, it can also form an index that shows drought intensity.

e. Precipitation needed for a return to normal (PRNj): Negative values of DEP_j can be calculated directly to convert it to 1-day precipitation needed for a return to normal condition (PRN_j) as follow,

$$PRN_j = \frac{DEP_j}{\sum_{N=1}^{j} (1/N)} \qquad (4.11)$$

where "j" is same as above. For example, PRN_{400} shows the needed precipitation for recovery from the deficit accumulated during the last 400 days, in which daily depletion of water resources is taken into account. PRN_{365} is a little more important, because if PRN_{365} is positive, all other drought indices are not calculated, in spite of accumulated water deficit.

f. Drought index (EDIj): Although CNS and ANES can be useful for drought assessment; APD and PRN are superior in description of drought intensity. But, since APD and PRN depend on background climatology another index like eqn. 4.12 as given below is often needed for worldwide drought assessment:

$$EDI_j = \frac{PRN_j}{ST(PRN_j)} \tag{4.12}$$

OR

$$EDI_j = \frac{DEP_j}{ST(DEP_j)}$$

Where ST [f (N)] denotes the standard deviation of function f (N) and j is DS. EDI is the most useful for universal application because it is independent of climatic characteristics of the locations.

Quantification of drought duration: For the better assessment, prediction, and mitigation of drought a robust scientifically quantified definition is needed. In this situation, by studying the concept of "severity," drought duration may be categorized as the consecutive days of EDI less than (−1.0). Also, by the concept of "long lasting," the duration of consecutive negative SEP values between drought periods has to be included in the drought duration. Using this definition, the onset, end, and duration of drought become clear describes. As one year i.e. 365 days is the most dominant precipitation cycle world wide here i is chosen as 365 days and represented as dummy DS. For defining dry duration DS, the consecutive negative SEP is used e.g. if 35 days of consecutive negative SEP occurred on June 5 then DS of June 5 is (365+35-1) =399, DS of June 4 is 398 and so on.

From verification at different sites it is seen that this method is best suited to tropical area where a single day rain can terminate a drought event.

Advantages of EDI: For eliminating the weaknesses of the current indices and for monitoring the drought event effectively the concept of Effective Drought Index (EDI) has now gained momentum to asses' drought severity globally

1. It is calculated with the concept of 'consecutive occurrence of water deficit whereas other indices use the deviation from a predefined mean.
2. Daily index is available to indicate the severity, which is helpful for the common man to calculate the risk.
3. Soil dryness is influenced very quickly and deficiency in reservoirs which is affected rather late and can be separated out for practical uses.
4. A time dependent reduction factor is used to estimate the current water deficiency, as a simple summation may not give good results.

The data used in this case is the daily precipitation which is easily available for any unit of area and also in a number of stationary points. Rainfall is the stem of all other generated data which has got wide variability depending on the topography and soil characteristics. The EDI values and their characteristics for different conditions are tabulated below.

Table 4.2: EDI Boundary Values for Different Conditions

EDI Values	Classification/Condition
> 2.5	Extremely wet condition (Danger of Flood)
2.5. to 1.5	Wet condition (Possibility of flood)
1.50. to 0.7	Slight Surplus
0.7 to -0.7	Near Normal
-0.7 to -1.5	Mild to Moderate drought
-1.5 to -2.5	Moderate to Severe drought
< -2.5	Extreme Drought

The SPATSIM application uses monthly data to analyze the process by EDI. The calculations are similar to the original index which was based on daily rainfall data and involved the use of some running means in parts of the calculation. These are not necessary when using monthly data. EDI is a function of the rainfall required for a return to normal conditions and similar to the SPI, is based on standardized values to permit comparisons between areas with different rainfall characteristics. The first step is the calculation of the effective precipitation (EP), defined as a function of current month's rainfall and weighted rainfall over a defined preceding period and can be up to 48 months. For example if Pm is the rainfall m-1 months before the current month and the duration is 3 then $EP = P1 + (P1+P2)/2 + (P1+P2+P3)/3$.The mean and standard deviations of the EP values for each month are then calculated and the time series of EP values converted to deviations from the mean (DEP). PRN values (rain required to return to normal) are then calculated using $PRN = DEP / \sum(1/N)$. The summation term is the sum of the reciprocals of all the months in the duration (i.e. for 3 months $1/1 + 1/2 + 1/3$). Finally EDI is calculated as in the daily case, using EDI = PRN / Std (PRN), where Std (PRN) is the standard deviation of the relevant months PRN values. No normalization of the index or rainfall data is performed and the skewness of the original time series is preserved. This means that positively skewed rainfall data can result in a larger range of positive EDI values than the range of negative EDI values. This is not a critical issue as the negative values are important in that they represent the 'rainfall' that is required for a return to normal from a drought.

4.3.3 Deciles Index (Gibbs and Maher, 1967).

The initial frequency (of non exceedence) analysis of the rainfall data can be based on individual months rainfall or on the same combination of months as used for the SPI. A separate cumulative frequency distribution is generated for each calendar month (or group of months) and then the accumulated time series of rainfall data converted into a time series of frequency values. The data are stored as the frequency of non-exceedence. The assumption therefore is that periods with low frequencies (less than 20% for example) represent drought conditions and those with high % frequency values are wet periods. The analysis was done in this way as 'high' values are intuitively wet and 'low' values dry. The rises and falls of the frequency time series will also follow the same patterns as the other drought indices. The time series of this drought index is therefore based on the same type of analysis as the original deciles index of Gibbs and Maher, but does not actually contain deciles. When rendering drought index values based on the frequency data it has been suggested that 5 groups are used with a minimum value of 0 and an interval of 20. The lowest will therefore represent the two lowest deciles (0 to 20%), while the highest will represent the two highest deciles (80 to 100%) as has been summarized in the Table 4.3.The Deciles in its original were considered to be integers only, but here exact vales have been generated for the interval at which the rainfall lies.

Table: 4.3 Classifications of Deciles Values in Percentages

Deciles Classifications	
deciles 1-2: lowest 20%	much below normal
deciles 3-4: next lowest 20%	below normal
deciles 5-6: middle 20%	near normal
deciles 7-8: next highest 20%	above normal
deciles 9-10: highest 20%	much above normal

4.3.4 Departure from the Mean

This is a simple departure from the mean rainfall (for the selected period types) and is neither normalized nor standardized. The same month grouping and combination has been calculated as have been performed for other indices. The unit of these simple deviations is in percentage and is used only for referencing and not for comparing with the other drought indices of different area.

4.3.5. Departure from the Median

This is a simple departure from the median rainfall (for the selected period types) and is neither normalized nor standardized. The same month grouping and combination has been calculated as have been performed for other indices. The unit of these simple deviations is in percentage and is used only for referencing and not for comparing with the other drought indices of different area.

All the above indices have been generated and critically analyzed by using software **Spatial And Time Series Information Modeling (SPATSIM) for** monthly time series precipitation data and **the Daily Water Resources Assessment Modeling (DWRAM)** for analyzing the daily precipitation data and calculation of original EDI and other related parameters to quantify severity of drought events on a daily time scale basis. The working and running process of the models is discussed in Chapter 5.

CHAPTER 5

DESCRIPTION OF MODELS

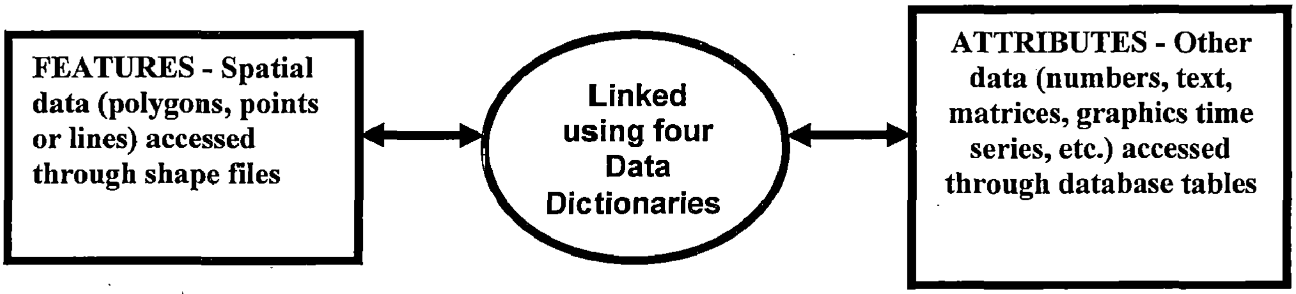
5.1 General

The two models namely 'Spatial and Time Series Information Modeling (SPATSIM)' and the 'Daily Water Resources Assessment Modeling (DWRAM)' are relatively new and represent the state-of-the-act for drought analysis world wide. SPATSIM is developed jointly by the International Water Management Institute, Colombo, Sri Lanka and Institute for Water Research, Rhodes University, South Africa (Smakhtin and Hughus, 2005). The GIS based SPATSIM package works in the Window environment. On the other hand the DWARM software is used for daily analysis works in DOS environment and is coded in MS-Fortran Version 11.0.The working procedure for both these models are discussed briefly as below.

5.2 Structure of the SPATSIM Package

The Spatial and Time Series Information Modeling software version 2.0.0.6 is designed to make use of a spatial interface to access other data and to have a series of additional utilities that either use those data, or generate and store additional data. Some of the utilities are part of the main program, while others are external programs that can be called from the main program. Utilities include data importing routines, database management routines, model parameter estimation and editing routines, time series simulation models and graphical display programs. The software is so flexible that the number of possible add-on utilities is almost unlimited and their implementation is quick and efficient.

The design of the data access process forms the core of SPATSIM. Spatial data (referred to as FEATURES) are accessed through shape files, while other data (referred to as ATTRIBUTES) associated with the spatial data are accessed through database tables. The links between the two data sources are controlled by a set of four data dictionary tables. Each application of SPATSIM is based upon a database alias name that contains a unique set of the four data dictionaries, as well as all the associated attribute tables.



Eight generic table types have been identified to store the different types of data commonly used in a variety of water resource related problems. These correspond to the definitions given by the Datatype field in Data Dictionary 1. One integer field is common to all the different table types, provides the links to Data Dictionary 4 and is the only indexed field.

The data types are:-

Text type: A text type is to store data upto 80 characters for naming.

Integer type: Giving values to integer type data.

Real Type: Giving values to real type data

Time Series Type: For defining the metadata and to store time series data.

Bitmap Type: For defining and storing the graphic data.

Array Type: This forms tables to store array or matrices (1D or 2D).

Memo Type: Used for storing longer text then text type if required.

Link Type: To establish link between an attribute associated with one feature to that of another feature.

5.1.1 Inputs for the Model

The inputs those are required for successful running of the model for drought analysis are listed below:

1. The area for drought analysis which is nothing but polygon features in the model is to be selected first. The adding of such polygons can be successfully done by assigning each polygon a unique integer identification code (ID) and unique text string (Description Field). The polygon features are called 'shape files' and are added or modified from any standard GIS software (ARC VIEW, MAP INFO etc.) which contains appropriate field for assigning ID, Description field and other optional information like Country code, State code, Geographical area, Latitude, Longitude, Population etc.
2. The software uses the monthly rainfall of different raingauge stations that are to be added in the SPATSIM interface. The raingauge stations are nothing but the 'Point features' and can be directly added (without help of any GIS software) assigning a unique ID and Description Field for each.
3. Each point feature is then loaded with the monthly rainfall data in the 'Time series' type attributes. Many options are available for proper formatting of the data to be loaded for the point feature. The 'Continues spread sheet' type format is used in this thesis. A unique name is assigned to each attribute table containing a particular type of data which are later on utilized for analysis.

4. The import of files from any other SPATSIM application also can be made by appropriate menu option. Adding new points, deleting points, renaming the points or attributes can be performed from the other suitable menu options available in the main SPATSIM window.

5.1.2 Analysis by the Model

The analysis is performed by following the steps as narrated below after all the relevant data for polygon and point feature as discussed above are loaded and stored in the relevant attribute table.

1. Point to area interpolation: This is the main process which determines the weighted catchment's average rainfall from coverage of point rainfall. The area for which this operation is to be performed is zoomed and the relevant polygons selected. The interpolation is carried out using the inverse distance squared weighting procedure such that the closer points to the polygon have greater influence on interpolated result. The raingauge stations that are located within the selected search radius are utilized by the SPATSIM application for interpolation. If there are missing data at one or more of the closer points, the search will continue until either the number of points equals the number of maximum search items, or until all the points within the search radius have been used. Any missing monthly rainfall time series data is automatically substituted by average values of rainfall for that month.
2. Drought index generation: This facility is utilized to generate a variety of drought indices from the interpolated aerial time series attribute. This process calculates

the drought indices from the selected source attribute containing the interpolated data. The result of the calculation for each type and category of drought index is then stored in a separate attribute table for recognition and further analysis. The main steps in this process includes the selection of drought index from the list of 5 indices viz. SPI, EDI .Deciles, Deviation from Mean and Deviation from Median. The options available for SPI, .Deciles, Deviation from Mean and Deviation from Median are Single Annual Value, Multiple Annual Values and Running Mean Values, whereas foe the EDI the only option available for selection is the Duration Summation (DS).

5.1.3 Output from the Model

After all types of indices are generated with different options as per requirement for critical analysis of drought the output is obtained by two ways as detailed below.

1. The different drought indices generated can be plotted in shape of graphs by using the option TSOFT of the SPATSIM application. By this facility the drought index time series graphs for different time interval with different start and end dates can be plotted together. The comparison of trend of different drought indices can be made by plotting them together in a single Window. From the TSOFT facility further analysis like probability of exceedence of a drought index (month wise) and run length of dry duration can be made and their distributions can be plotted.
2. The time series of standardized drought index i.e. SPI, EDI and Deciles are utilized to display the spatial distribution of drought in the region selected for analysis. This can be done in two ways: first is the spatial distribution of drought

in the region for a given month and second is to find distribution of a given severity of drought in the region for the same month.

5.2 Features of DWRAM

The Daly Water Resources Assessment Modeling (Version 1.93, 2004) has been devised by Byun and Wilhite, (1999) to primarily use daily rain fall data from raingauge stations. The analysis of data for a number of stations is performed by repeating the running process for each station. The averaging of all the obtained result is then carried out separately for further analysis and use.

.2.1 Input for the Package.

The daily rainfall data record of a station is to be converted to the format [Number of the station] [Year] [Month][Day][Precipitation] ==> Format (I5, 1X, I4, 2I2, 1x, I6) for putting the file into the input directory of the package. This can be achieved by use of relevant version of FORTRAN.

5.2.2 Analysis by the Package

Daily drought index and other related outcomes are calculated by using the equations 4.9 to 4.12 as described in the methodology chapter of this thesis. 5 days running mean is carried out in the package for the smooth daily variation of mean and standard deviation.

5.2.3 Output from the Package

The result of the daily drought indices is displayed on daily basis after one year from the start date of the input data. The first year (365 days) daily data is used as dummy Duration Summation (DS) by the package for further calculation. The end date of the result is also extended to longer period i.e. 365 days, than the last date of the observed input data. It is therefore important to understand the period of input and output data and their use in the calculation procedure. The various indices generated and the terms used thereof are detailed below:

- IAN: Consecutive days of precipitation that is consecutively below (-) or above (+) normal. In this version, IAN is always less than or equal to 365 and greater than or equal to -365. It means the accumulation more than two years has not been taken into account.
- APN: Precipitation accumulated during IAN. Negative IAN has same accumulating effect with positive value.
- VPN: Normal value of accumulated precipitation during IAN at pinpointed day.
- DPS: Accumulated Precipitation Deficit during IAN. (APN-VPN), Negative IAN has same effect with positive value.
- APL: Precipitation accumulated during (IAN+365).
- VPL: Normal value of accumulated precipitation during (IAN+365) at pinpointed day
- DPL: Accumulated Precipitation Deficit during (IAN+365). (APL-VPL).
- PRN: This value is made by IAN and Effective precipitation function which has already been discussed in the Methodology.

The unit of IAN is 'day'; unit of EDI is dimensionless and of precipitation is 0.1mm. The units of all others are in mm. Positive value of DPS, PDP and PRN means above normal of precipitation. The case of PRN > DPL is caused by that heavy rain long time ago contributes only a little in effective precipitation.

5.2.4. Running Process.

The Existing Directories

- INPUT: Directory input data stored
- OUPUT: Directory output data stored
- BIN : Directory executive files exist

The generation of the Name list File (in INPUT DIRECTORY)

- F_INPUT: Input file name and pass (../INPUT/input file name)
- MISS: During the data conformation, if some missed data detected, the model choose whether it revise the data or it terminates the program.
- TRUE. => revise .FALSE. => terminate the program

If it revises, the values of the missing data become zero. If missing data are more than 364, the program will terminate.

- F_OUPUT: Output file name and pass (../OUPUT/ Output file name)
- The year and period used for the calculation of the average value

KYS: starting year of the data

KYE: Ending year of the data

YR: period (year)

- Run of the program

In Window version, 'run. bat' is executed in Bin directory.

The file name in the input and output directory is to be changed for each station. After the successful run of data for all the required stations the output text file is transferred to the MS-EXCEL worksheet to carry out further analysis and plotting of graphs of different periods as per necessity. Only the selected period result has been appended. Because, for each station for which daily data is available, the generated results are more than hundreds of pages.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 General

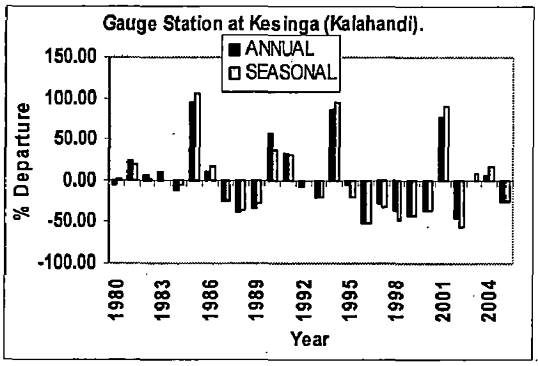
The objective of this study to quantify the severity of different drought situations and to analyze various indicators of drought has been achieved by studying the rainfall in daily, monthly and annual time steps. The annual rainfall departure and their relevance with the historical drought events has been analyzed and established through probability distribution and return period calculated from different stations in the study area. The influence of drought on ground water table, crop yield and on surface water has been substantiated and the trend discussed for summarizing the drought affects. The applicability of some important drought indices as discussed in the methodology chapter has been determined for use in the study area after converting the point rainfall to aerial average rainfall. Possible relationship of potential evapotranspiration with various drought indices has been explored for use in the study area. The daily index of drought has been generated for few raingauge stations to establish its applicability in the study area by use of DWRAM package. After all the indices generated and compared the index that best describes the drought situation in the study area has been utilized for showing spatial distribution of drought in the study area using SPATSIM software.

6.2 Rainfall Distribution and Departure

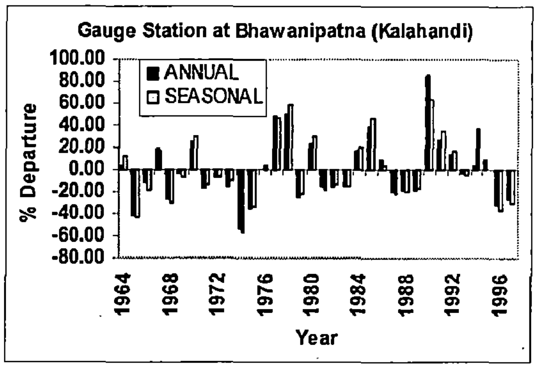
Annual rainfall departure analysis indicates that the annual rainfall deficiency during a drought year varies from -25% in 1988 to -55% in 1987 and -51% in 1996. Similarly the monsoon rainfall deviation ranges from -25% (in 1968) to -63% (in 1987). The point rainfall record of 9 stations has been analyzed. For example looking at the rainfall deviation plot of Kesinga station (Fig. 6.1(a)) of Kalahandi district, the drought year 2002 became more severe due to the fact that, while the yearly departure was -44.67 % the seasonal deficiency was recorded still higher i.e. up to -57.03%. Similar is the case of Bhawanipatna station (Fig. 6.1 (b)) for the year 1996 wherein the annual and seasonal departure is -37.48 and -32.24mm respectively. The rainfall pattern of Muniguda station of Raygada district, (Fig. 6.1 (c)) also reveals the same pattern of dominance of monsoon deficiency over drought year's annual deficiency. The plots for annual and seasonal rainfall departure for all other stations are shown in Annexure-I (A). From all the plots, it revealed that, in all cases where there is annual rainfall deficiency, there is deficiency recorded in monsoon rainfall also. In drought years the magnitude of monsoon rainfall deficiency has been more pronounced then the annual one. The details of some major deviations over various stations for monsoon season rainfall and yearly rainfall for two major drought years i.e. 1987 and 1996 are shown in Table 6.1

Table 6.1: Annual and Seasonal events of rainfall Departures w.r.t Mean Rainfall (Drought Years 1987 &1996)

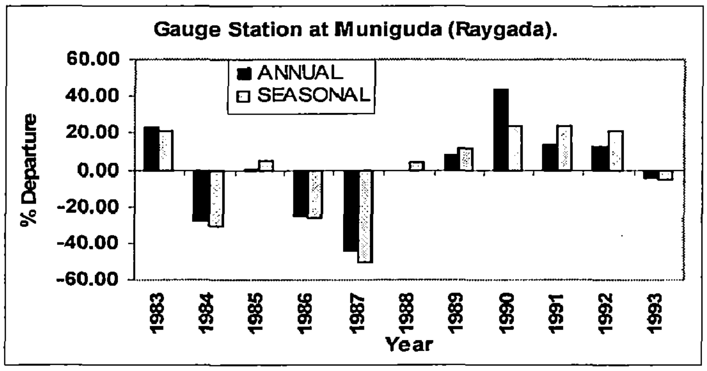
Sl.No.	Name of Station	Year-1987		Year-1996	
		Annual Deviation	Monsoon Deviation	Annual Deviation	Monsoon Deviation
1	Kesinga	-25.42	-24.87	-50.67	-50.76
2	Bhawanipatna	-20.41	-22.15	-32.45	-37.48
3	Lanjigarh	-54.14	-63.33	NA	NA
4	M.Rampur	-44.33	-47.50	-33.51	-32.93
5	Umerkote	-14.63	-20.32	NA	NA
6	Muniguda	-43.85	-50.53	NA	NA
7	Khariar	-32.12	-32.62	-54.15	-55.22
8	Dumerbahal	-23.32	-33.03	-33.15	-40.75
9	Bolangir	NA	NA	-51.96	-57.65



(a) Kesinga (Kalahandi)

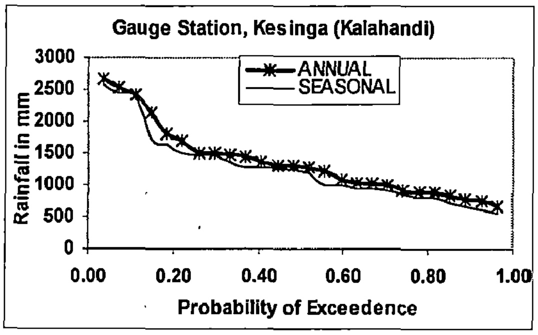


(b) Bhawanipatna (Kalahandi)

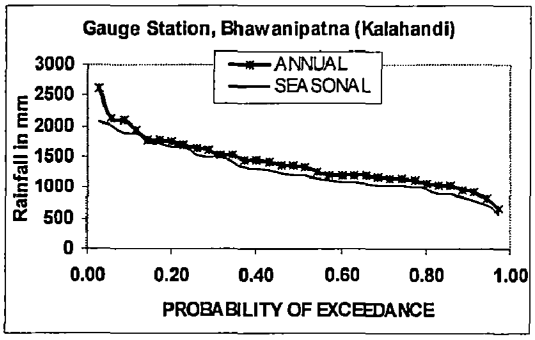


(c) Muniguda (Raygada)

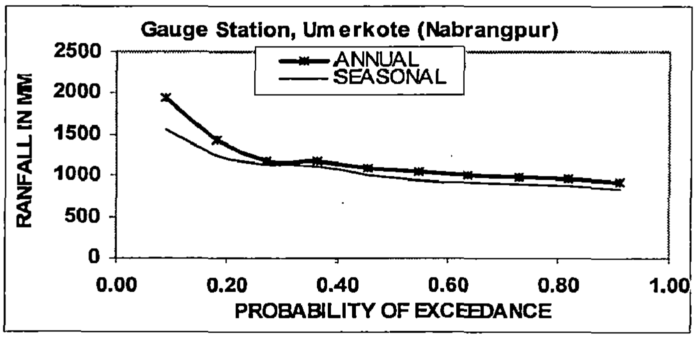
Fig. 6.1: Rainfall Percentage Departure from mean



(a) Kesinga (Kalahandi)



(b) Bhawanipatna (Kalahandi)



(c) Umarkote (Raygada)

Fig. 6.2: Probability Distribution Curves at Different Stations

In the year 1996 the highest annual rainfall deviation of -54.15% was recorded at Khariar in Nuapada District. However, the highest seasonal (monsoon) rainfall deviation of -57.65% occurred at Bolangir in the same year. Similarly the highest deviation for annual and monthly rainfall of -54.14 and -63.33 mm was recorded at in 1987 at Lanjigarh. It reveals that rainfall deficiency in the KBK districts may climb up to -54.15% and -63.33% of mean annual and mean seasonal rainfall respectively. As the south west monsoon is the only big contributor of rainfall, the deficiency caused in monsoon season adversely affects the major crops yield in this region. The identification of drought years in different stations according to rainfall deficit has been listed in Tables 6.2 & 6.3 considering deficiencies in annual & seasonal rainfall respectively.

Table 6.2:Drought Years at Different Stations (from Annual Rainfall Departure)

Sl.No	Station (length of records used)	Average annual rainfall (mm)	Drought year with rainfall departure of -25% or less	Maximum annual departure
1	Kesinga (1980-2005)	1362	1987,88,89,96,97,98,99,2000,2002	1996 (-47%)
2	Bhawanipatna (1964-1997)	1399	1965,68,74,75,79,87,96,1997	1974 (-54%)
3	Lanjigarh (1966-1993)	1193	1968,74,79,81,82,84,86,87,88,1989	1987 (-54%)
4	M.Rampur (1987-1996)	1672	1987,88,1996	1987 (-45%)
5	Umerkote (1987-1996)	1175	1988	1988 (-25%)
6	Muniguda (1983-1993)	1119	1984,86,1987	1987 (-44%)
7	Dumerbahal (1977-2000)	1175	1988,96,2000	1996 (-33%)
8	Khariar (1987-1996)	1045	1987,92,1996	1996 (-54%)
9	Bolangir (1961-1996)	1318	1962,64,69,74,75,79,1996	1996 (-52%)

Table 6.3: Drought Years at Different Stations (from Seasonal Rainfall Departure)

Sl.No	Station	Average annual rainfall (mm)	Drought year with 25% less rainfall	Maximum Seasonal departure
1	Kesinga (1980-2005)	1255	1987,88,89,96,97,98,99,2000,2002	2002 (-57%)
2	Bhawanipatna (1964-1997)	1277	1965,68,74,75,79,87,96,1997	1974 (-56%)
3	Lanjigarh (1966-1993)	1066	1968,74,79,81,82,84,86,87,88,1989	1987 (-63%)
4	M.Rampur (1987-1996)	1511	1987,88,1996	1987 (-48%)
6	Muniguda (1983-1993)	1021	1984,86,1987	1987 (-51%)
7	Dumerbahal	981	1987,88,95,1996	1996 (-46%)
8	Khariar (1987-1996)	952	1987,92,1996	1996 (-55%)
9	Bolangir	1061	1962,64,69,74,75,79,1996	1996 (-58%)

6.3 Probability Distribution of Annual Rainfall

The probability distribution curves have been plotted both for annual and seasonal rainfall against the probability of exceedance. Range of annual and seasonal rainfall at 75% probability level and probability of occurrence of rainfall equivalent to 75% and 80% of normal rainfall are also shown in the Tables 6.4 & 6.5. It can be seen from the Table 6.4 that, for Annual rainfall, there is considerable variation in the mean annual rainfall values which range from 1045 mm at Khariar to 1672 mm at M.Rampur. The probability of occurrence of 75% of normal rainfall obtained from the graph is as low as 64% for Kesinga and 92% for Umerkote. Also, two neighboring stations, namely, Muniguda and Lanjigarh recorded the occurrence of 75% of normal rainfall at the probability levels of 75% and 67% respectively. This clearly indicates the wide variability of rainfall in this area. One station has better chances of getting normal rainfall while at the same time other neighboring station may suffer from rainfall deficiency. The overall ranges of variation of annual rainfall at 80% and 75% dependability levels vary from 739-1013 mm and 770- 1130 mm respectively. The probability pattern of seasonal (JJOSO) rainfall more or less follows the same pattern as of annual rainfall. The probability of occurrence of 75% of seasonal normal rainfall ranges from 64% for Kesinga to 92% for Umerkote. It indicates that one part of the KBK districts has nearly one third more chances of facing deficient rainfall events. In the other words, it can be stated that the frequency of occurrences of drought in different parts of KBK districts varies significantly.

In case of seasonal rainfall distribution, it can be seen from Table 6.6 that Bhawanipatna station with mean seasonal rainfall of 1277 mm has 82% chance of getting rainfall equivalent to 75% of its mean value i.e. 1049 mm. The probability distribution curves of Kesinga, Bhawanipatna, and Umerkote stations are shown in Figs. 6.2 (a), 6.2 (b) and 6.2 (c) respectively for a reference. The same curves for other raingauge stations are shown in the Annexure- I (B).

Table 6.4: Probability Distribution of Annual Rainfall at Different Stations.

Sl.No.	Station Name	Mean annual Rainfall (mm)	Probability of occurrence at 75% of normal	Rainfall at 80% dependability	Rainfall at 75% dependability
1	Kesinga	1362	63%(1021)	880	930
2	Bhawanipatna	1399	82%(1049)	1066	1130
3	Lanjigarh	1193	67%(894)	848	867
4	M.Rampur	1672	68%(1254)	1013	1040
5	Umerkote	1175	92%(881)	960	974
6	Muniguda	1119	75%(838)	796	838
7	Dumerbahal	1175	72%(990)	948	988
8	Khariar	1045	73%(783)	739	770
9	Bolangir	1318	78%(990)	975	1030

Table 6.5: Probability Distribution of Seasonal Rainfall.

Sl.No.	Station Name	Mean Seasonal Rainfall (mm)	Probability of occurrence at 75% of normal	Rainfall at 80% dependability	Rainfall at 75% dependability
1	Kesinga	1255	64%(941)	810	855
2	Bhawanipatna	1277	80%(957)	957	1015
3	Lanjigarh	1066	70%(799)	722	765
4	M.Rampur	1511	69%(1133)	960	985
5	Umerkote	1038	92%(778)	890	920
6	Muniguda	1021	76%(765)	730	760
7	Dumerbahal	981	80%(736)	730	770
8	Khariar	952	73%(713)	725	770
9	Bolangir	1061	79%(795)	800	870

6.4 Analysis of Focus Area

6.4.1 Drought years and Probability of Occurrence

The block wise severe drought experienced in different parts of Kalahandi and Nuapada districts is given in Table 6.6. This summarizes the occurrence of drought events and compiles the magnitude of departure in severely affected block in given drought year. For instance, in a particular year, say 1974, Bhawanipatna station recorded more deficit than any other station in the focus area and same has been referred to describe the drought situation in the corresponding year. The probability distribution curve of the above identified station was then utilized to find the probability of exceedence (P) of rainfall in 1974.

Table 6.6: Summary of Drought Years with Severest Block in Focus Area.

Year	RF in mm	Annual Deviation in %	Worst effected Block	Type of Drought.
1965	824	-41.65	Bhawanipatna	Moderate
1968	1025	-27.42	Bhawanipatna	Mild
1974	654	-53.69	Bhawanipatna	**Severe**
1975	924	-34.57	Bhawanipatna	Moderate
1979	847	-28.98	Lanjigarh	Mild
1981	752	-36.94	Lanjigarh	Moderate
1982	742	-37.78	Lanjigarh	Moderate
1984	806	-32.42	Lanjigarh	Mild
1986	889	-25.46	Lanjigarh	Mild
1987	541	-54.64	Lanjigarh	**Severe**
1988	836	-38.63	Kesinga	Moderate
1989	914	-32.91	Kesinga	Mild
1996	484	-53.66	Kharair	**Severe**
1997	*1002*	-26.45	Kesinga	Mild
1998	878	-35.55	Kesinga	Moderate
1999	*779*	-42.82	Kesinga	Moderate
2000	*882*	-35.26	Kesinga	Moderate
2002	*749*	-45.02	Kesinga	**Severe**

Where, Mild = -25% to -34%; Moderate =-35% to -44% and Severe =-45% to -60%

From the Table 6.6 it is seen that the range of magnitude of rainfall for different stations describing a particular type of drought differs from one station to the other. For example, 806 mm of rainfall at Lanjigarh corresponds to mild drought while the same amount of rainfall for adjoining Bhawanipatna station refers to moderate drought situation. On the other hand 1025 mm of rainfall in a year correspond to mild drought at Bhawanipatna but near normal condition for Lanjigarh.The deficit years and their highest negative deviation recorded in the focus area is shown in Fig.6.3.

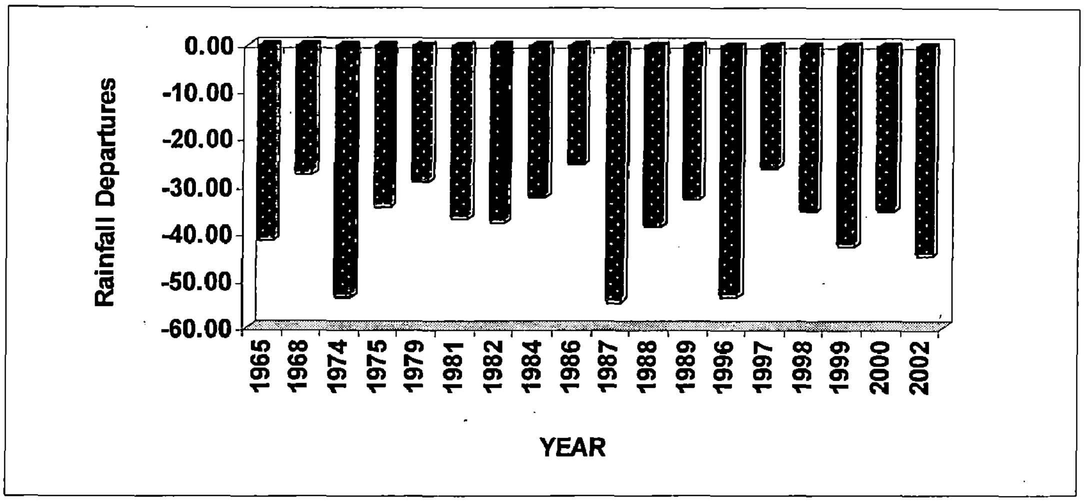


Fig. 6.3: Record of Deficient Years (Below -25%) in Focus area

Table 6.7: Return Period of Lower range of Rainfall in the reference Blocks.

Sl.no.	Drought Type	Ref Block	Rainfall in mm (Probability P)	Return-Period (T=1/1-P)
1	Mild	Lanjigarh	806 (P=0.69)	3.11 Year
2	Moderate	Lanjigarh	752 (P=0.89)	9 Year
3	Severe	Khariar	484 (P=0.93)	14.28 Year

Taking into account the lower range of the rainfall and using the corresponding block's probability distribution curve Table 6.7 is generated for the Focus Area. It is seen that the frequency of drought in the focus area varies from once in every 3 years to once in every4 years. If we take a successive 10 years period, the probability of occurrence of at least one of a particular type drought event (P_o) is

$$P_o = 1\text{-}P^{10}$$

So the occurrence of Mild Drought in 10 successive years has the chance of

$$1\text{-}0.69^{10}=98\%$$

The occurrence of Moderate Drought in 10 successive years has the chance of

$$1\text{-}0.9^{10} = 65\%$$

The occurrence of Severe Drought in 10 successive years has the chance of

$$1\text{-}0.93^{10} = 52\%$$

This shows that the district of Nuapada and Kalahandi has more then 50% chance of facing at least one severe drought in every 10 years period.

6.4.2. Monthly Aerial Time Series (ATS) Generation

Rainfall time series has been the subject of intense scrutiny since the days when the analysis of drought events and its severity gained momentum. In this study the aerial monthly time series of the Focus Area i.e. Kalahandi and Nuapada has been generated by taking into account the point rainfall of 7-stations inside the district as well as the stations in the vicinity of the districts. These raingauge stations are Bhawanipatna, Khariar, Lanjigarh, Muniguda, Kesinga, M.Rampur and Umarkote. The location map of the raingauge stations is shown in the Fig: 6.4. These are well distributed to cover and represent the entire Focus area evenly.,

The software SPATSIM is used for this and to generate the monthly aerial time series data for the period, January1964 to December 2005.The procedure for the calculation is described in the Description of Models (Chapter 5). For a station if data of some month is found missing by the software the average value of that month is automatically substituted. For clarity reason the period has been divided into two laps the first being from 1964 to 1984 and the second from 1985 to 2005 (Figs.6.5 (a) and 6.5 (b)). The time series indicates that the rainfall in August (monsoon season) can go up to as high as 1135 mm (as in the year 1978) and the lowest value deep up to 210 mm (as in the year1996), which is recorded as severe drought. This indicates highly erratic behavior of rainfall in the focus area. The monthly average of aerial time series over the period of 1964 to 2005 is 111.422 mm yields an average annual value of 1337 mm. This is fairly compatible to the long term average of point rainfall for the

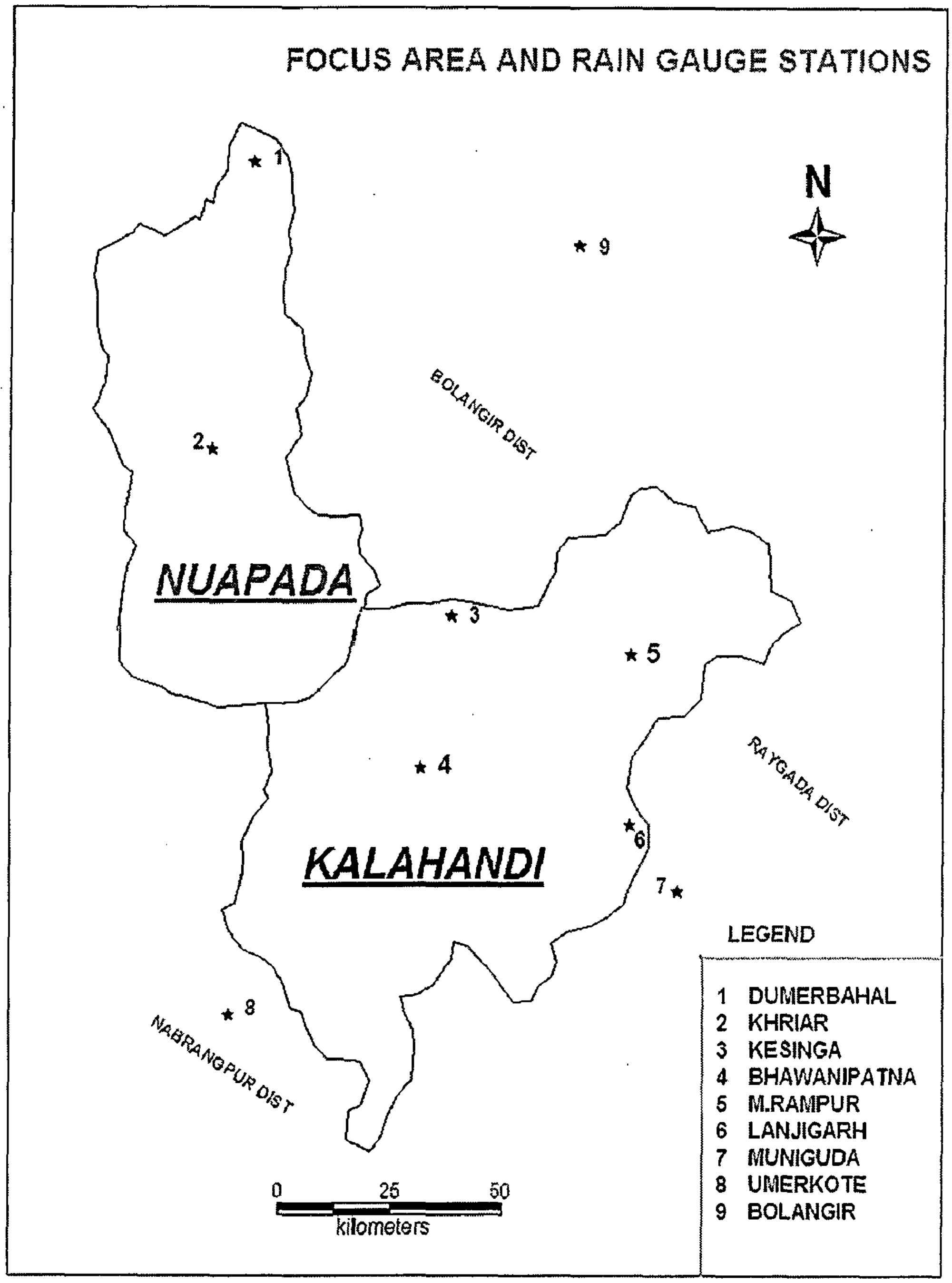


Fig.6.4: Location of Raingauge Stations in and around the Focus Area.

Focus area i.e.1347.9 mm. This reveals that the generated aerial time series appropriately represents the rainfall for the focus area.

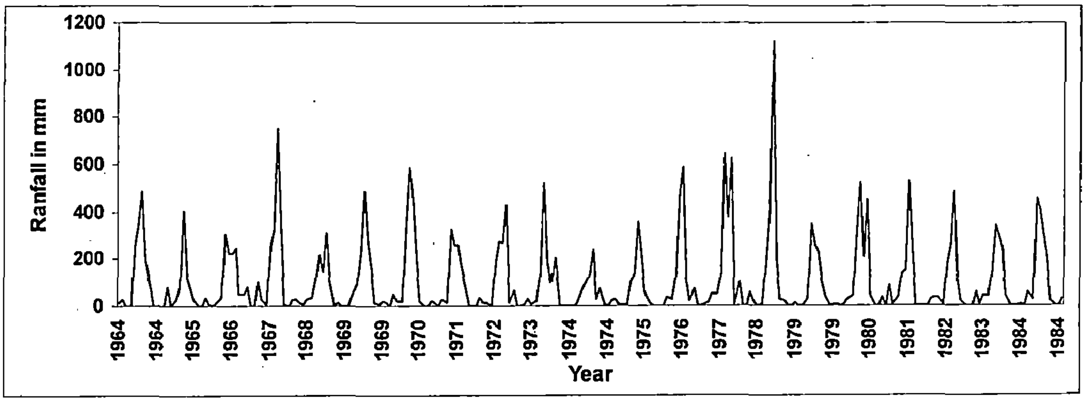


Fig. 6.5 (a): Monthly Aerial Time Series Rainfall of the Focus Area (1964 -1984)

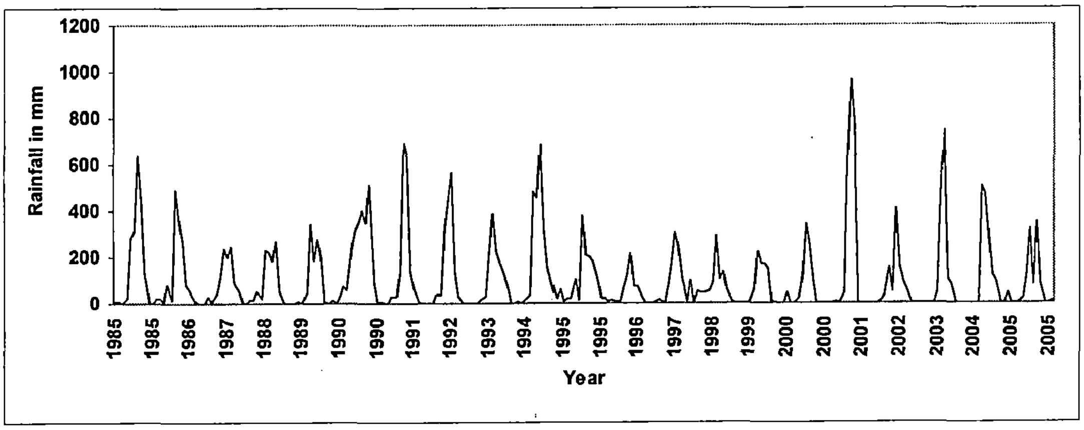


Fig. 6.5 (b): Monthly Aerial Time Series Rainfall of Focus Area (1985 - 2005)

From Figs 6.5 (a) & 6.5 (b) it is clear that the scanty rainfall period extends over consecutive years followed by an excessively wet year which causes flash flood in the area. This unruly pattern of rainfall in this region is the root cause of the risk of prolonged drought in the focus area.

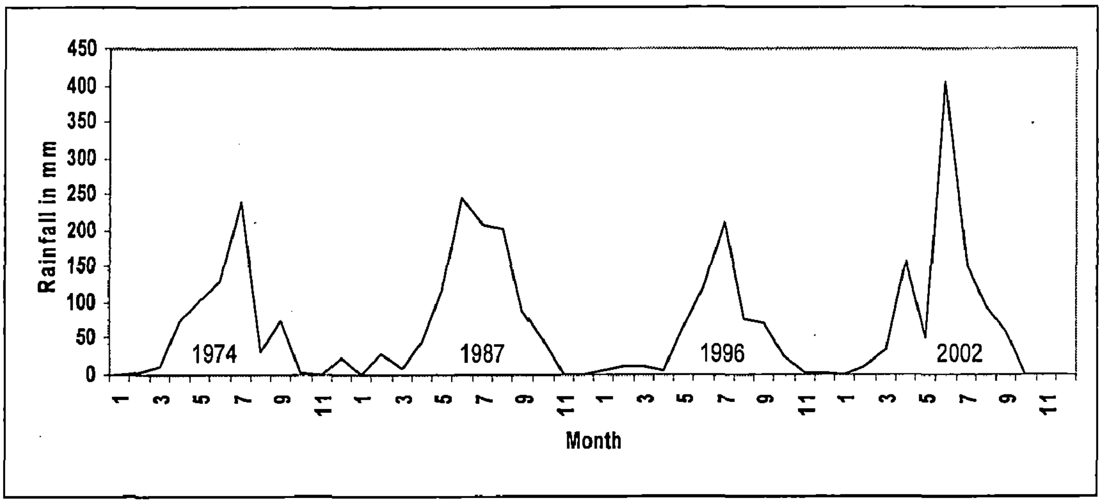


Fig.6.6: Rainfall Distributions in Severe Drought Years (1974, 1987, 1996 & 2002).

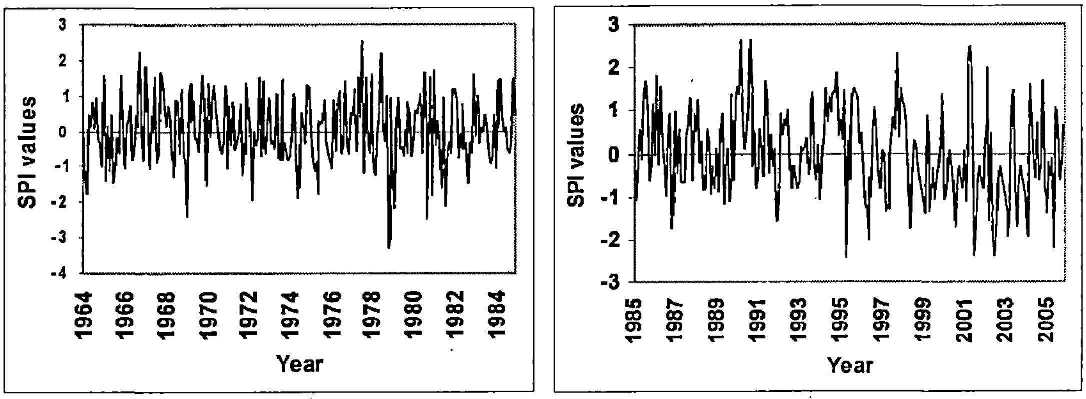
To clearly visualize the rainfall pattern in severe drought years four years viz. 1974, 1987, 1996 and 2002 were selected and plotted together in Fig. 6.6. It can be seen that in all cases the highest of rainfall has occurred during June and July. However, in case of normal and wet years the highest rainfall occurs in the month of August. Also in drought years there is a sharp decline of rainfall in August and it was even still worse in September and October. The total annual aerial rainfall received in the year 1974, 1987, 1996 and 2002 was 691 993, 607 and 964 mm respectively.

6.4.3 Monthly Drought Indices and their Probability Distribution

For quantification of the drought severity and dry durations the indices like SPI, EDI, Deciles have been estimated for monthly time scale. These indices were estimated using SPATSIM package with different averaging process. Also the deviations of aerial rainfall from the corresponding mean and median were computed using the same averaging process to find the deficit. SPI Values in 1month, 3 month, 6 month and 12 month running mean values have been plotted and shown in Figs. 6.7 (a) to 6. 10 (b). For clarity only two laps has been adopted i.e. year 1964 to 1984 and 1985 to

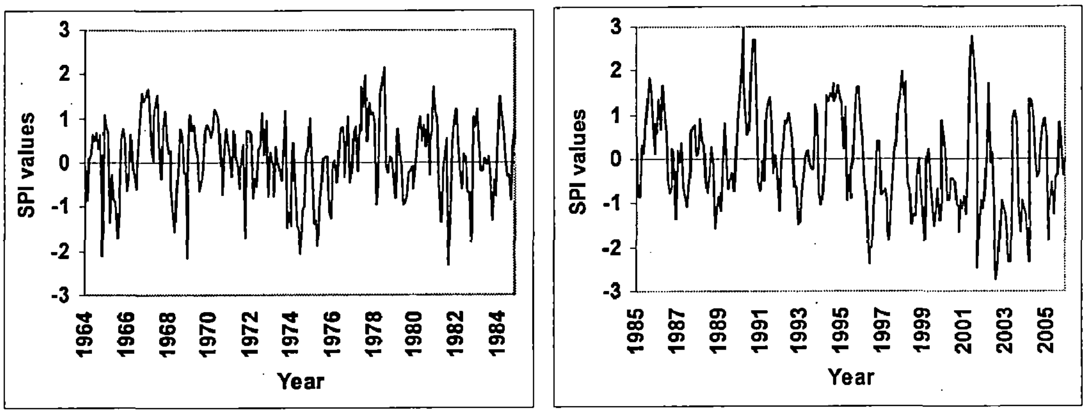
2005. The monthly index values show more abrupt changes than that of three monthly. Similarly, the three monthly values show more variation than six monthly values and so on. Twelve month values thus show relatively smooth curve (Fig. 6.10 (a) & 10 (b)). But for practical use, as the rainfall in the focus area is concentrated in 4 to 5 months the 12 months running mean values may give unrealistic estimates of above drought indices. The running mean values of one month and three months are therefore considered in the analysis to investigate and quantify duration and severity of drought events and probability of their occurrences in the focus area.

In SPI, the values between -1.00 to -1.49 are generally considered as moderate dry condition. The probability distribution curves have been plotted for each month starting from January to December for the generated time series data. The curves for the months of June through September (for both 3 month and 1 month SPI values) have been given in Figs.6.11 (a) to 6.12 (d). Other curves have been appended in Annexure- III (A) and the results summarized in Table 6.8 both for one and three month running means averaging process.



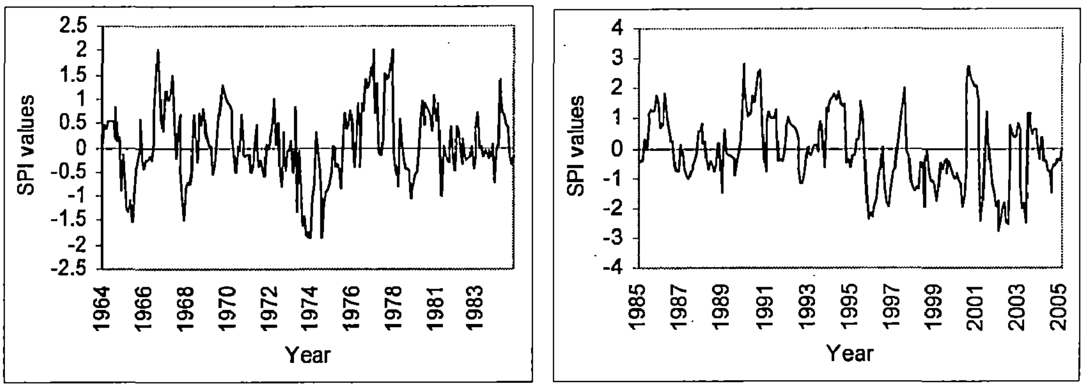
(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.7: SPI 1month Running Mean Values of Focus Area



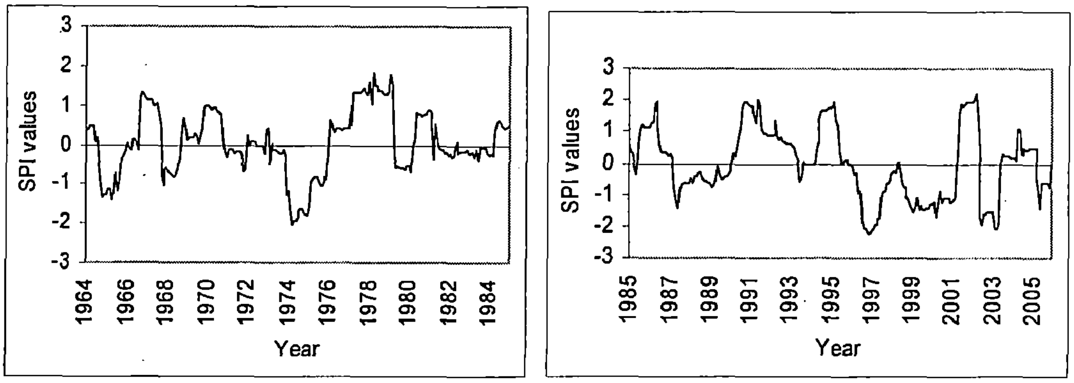
(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.8: SPI 3month Running Mean Values of Focus Area



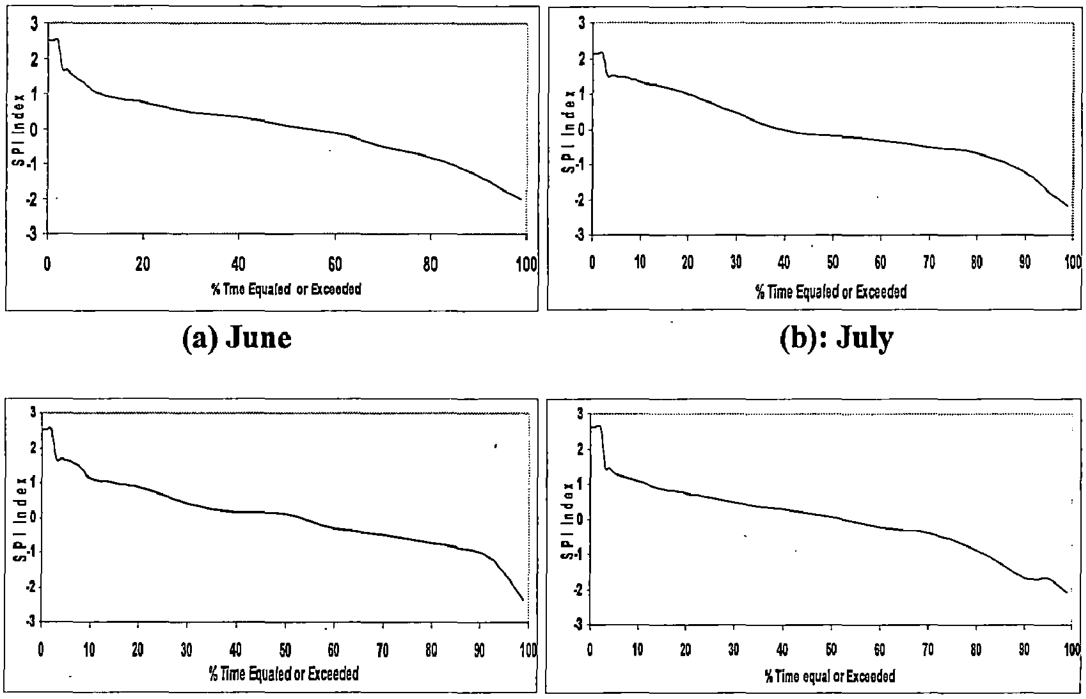
(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.9: SPI 6month Running Mean Values of Focus Area



(a) 1964 to 1984 **(b) 1985 to 2005**

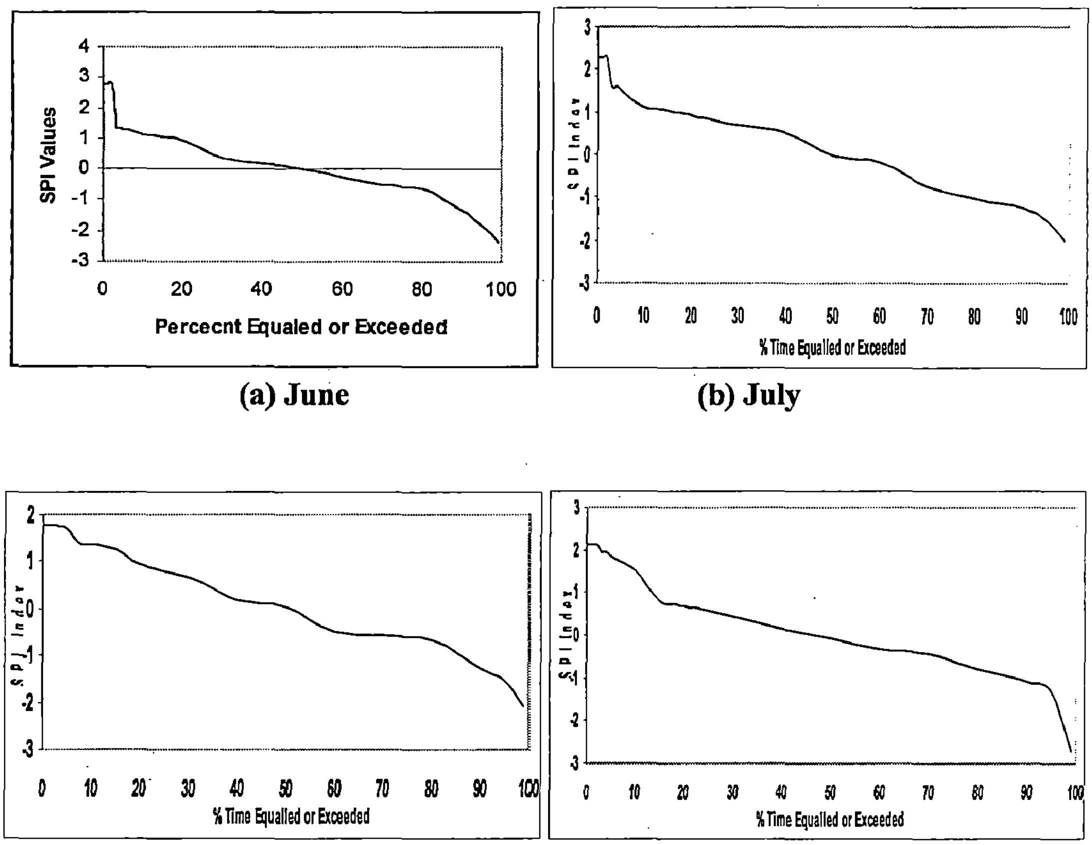
Fig. 6.10: SPI 12month Running Mean Values of Focus Area



(a) June **(b): July**

(c) August **(d) September**

Fig. 6.11: Probability Distribution of SPI 1month RM Values



(a) June (b) July

(c) August (d) September

Fig. 6.12: Probability Distribution of SPI 3 Month RM Values

From the Table 6.8 it can seen that the month of June has shown a comparatively better probability trend with 12% chance of non-exceeding the SPI value of -1.25 (the mid value of -1.00 to -1.50). Also, the SPI values have been obtained from the graph at 90% probability of occurrence for all the twelve months and shown in the same table. The average of June, July and August for 1month mean gives the occurrence of -1.25 SPI (moderate drought event) at 89% whereas the 3monthly mean for the above three months gives that at 91% probability level. This also confirms the results obtained from the point rainfall data for a moderate drought event (considering the most severely affected station) and it has 90% chance of occurrence. Hence 3 month averaging is more suitable because of the rainfall pattern and cultivation practice of the focus area. The 91% probability of occurrence of a moderate drought event can be safely considered for risk analysis and planning for drought watch system.

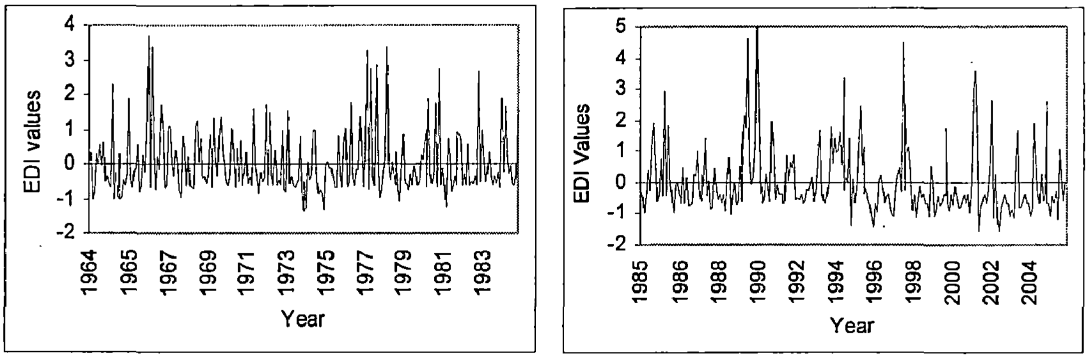
Table 6.8: Probability Distribution of SPI Values for 1-month and 3-month

Month	Probability of Occurrence (-1.25) (1month Run)	Probability of Occurrence (-1.25) (3month Run)	Drought Index at 90% Probability of Occurrence (1 month Run)	Drought Index at 90% Probability of Occurrence (3month Run)
January	92%	96%	-0.79	-1.02
February	96%	89%	-1.06	-1.27
March	88%	88%	-1.38	-1.27
April	90%	93%	-1.22	-0.99
May	91%	88%	-1.21	-1.32
June	88%	88%	-1.34	-1.33
July	90%	90%	-1.25	-1.25
August	92%	89%	-1.00	-1.28
September	85%	86%	-1.48	-1.37
October	95%	96%	-0.79	-1.05
November	96%	86%	-0.29	-1.63
December	96%	88%	-0.62	-1.45

The EDI values have been calculated similarly. The EDI plots with Duration Summation (DS) 1 month and 3 months are shown in Fig. 6.13 (a) to 6.14(b). Other plots for 6 month DS, and 12 month DS are shown in the Annexure II. In EDI, when the values are between -0.70 to -1.50 it is generally considered as moderate drought condition. So the value of EDI equal to -1.00 has been selected to compute the probability of exceedence of moderate drought periods. The Table 6.9 shows different probabilities for DS 1month and 3 months.

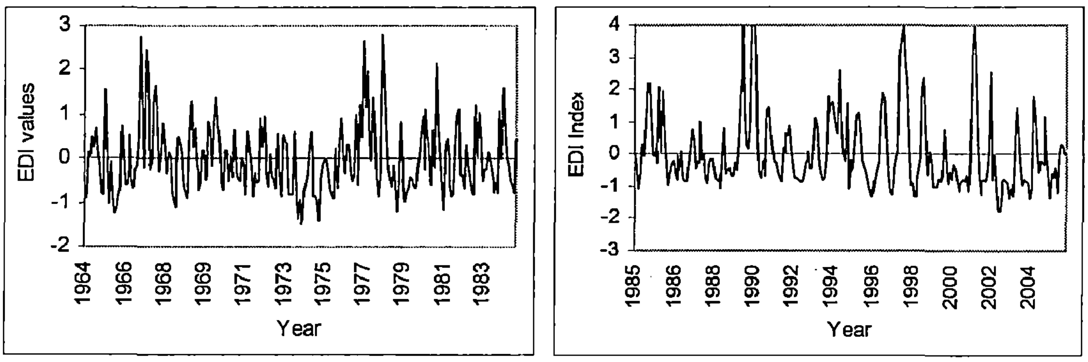
Table 6.9: Probability Distribution of EDI 1month and 3month DS values

Month	Probability of Occurrence (-1.0) (1month Run)	Probability of Occurrence (-1.0) (3month Run)	Drought Index at 90% Probability of Occurrence (1month Run)	Drought Index at 90% Probability of Occurrence (3month Run)
January	NA	NA	-0.61	-0.80
February	NA	NA	-0.68	-0.81
March	NA	NA	-0.66	-0.86
April	89%	85%	-1.07	-1.12
May	NA	96%	-0.76	-0.85
June	89%	88%	-1.03	-1.02
July	88%	85%	-1.12	-1.15
August	91%	90%	-0.97	-1.00
September	87%	88%	-1.29	-1.20
October	NA	92%	-0.78	-0.86
November	NA	96%	-0.6	-0.84
December	NA	NA	-0.36	-0.85



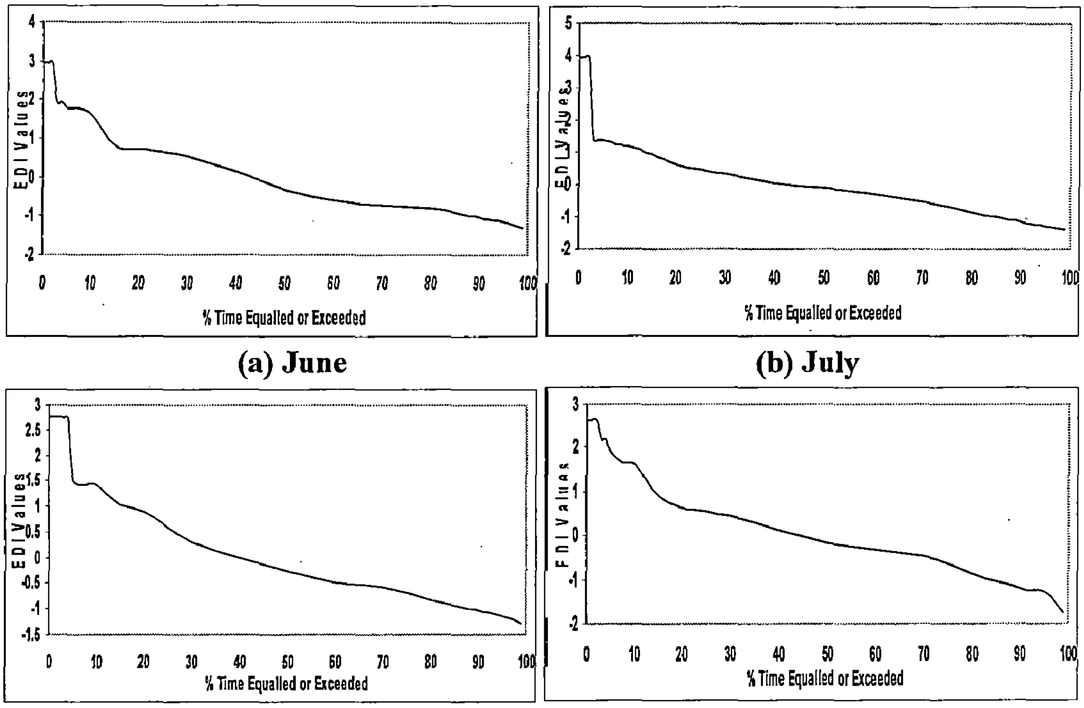
(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.13: EDI Values with 1month DS of Focus Area



(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.14: EDI Values with 3month DS of Focus Area



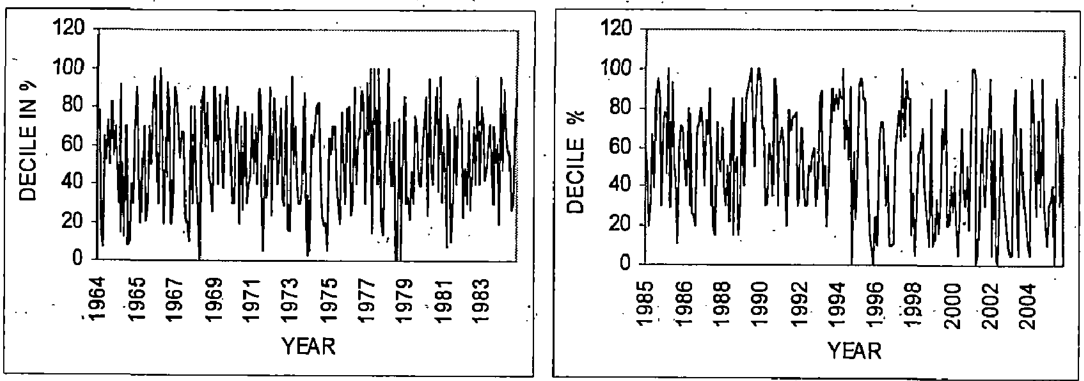
(a) June (b) July

(c) August (d) September

Fig. 6.15: Probability Distribution of EDI 3 Month D.S. Value

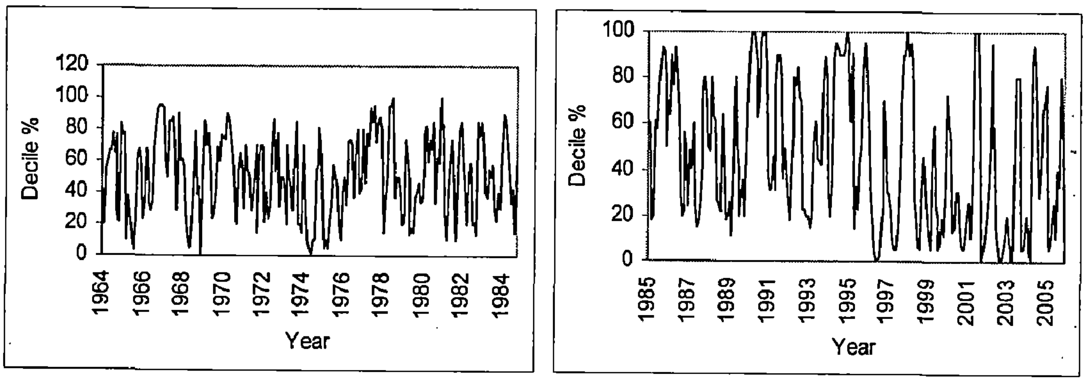
EDI is the index that is based on the accumulating effect of rainfall and due to the fact that the non-monsoon months i.e. January, February, March and November & December generally receive either very little or nil rainfall, the index values don't go below -1.00. However the values showing close to -0.80 represent the dryness in non monsoon months. While considering the monsoon period in both SPI and EDI the month of September shows the largest variation in both 1month and 3month values and gives the highest negative value at 90% probability. It indicates that the focus area has greatest chances of facing severe drought conditions in September. This month in fact is crucial for area with such high percentage coverage of Paddy and plays an important role in determining the occurrence and severity of drought in the region. The probability curve for the months of June through September for the 3 month DS is plotted and shown in Fig. 6.15 (a) to 6.15 (d) for a reference. All other probability curves of EDI are appended in the Annexure III (B).

For Deciles Index, 5 groups' ranges of probability of rainfall are used with a minimum value of zero and an interval of 20. The lowest deciles class (0 to 20%) represents the greatest deficit of rainfall, while deciles class (80 to 100%) represents the wettest condition. Hence the two group ranges viz. 0 to 20% and 20% to 40% correspond to below normal precipitation. The Deciles Index values for 1 month and 3 month running mean has been plotted and shown in Figs. 6.16 (a) to 6.17 (b). All other plots are appended in the Annexure- II.



(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.16: Deciles Index with 1month RM in the Focus Area



(a) 1964 to 1984 (b) 1985 to 2005

Fig. 6.17: Deciles Index with 3 month RM in the Focus Area

The probability for the index value at and below 30% (considered to be moderately dry) has been tabulated. As this process is based on placing a particular amount of rainfall in a pre defined range it is best suited for places which experience uniform rainfall throughout the year. It can be seen from Table 6.10 that the 90% probability of occurrence is continuously observed at deciles value 10 for all the 12 months except February which is not that significant month for drought severity calculations. The index also gives probability of occurrence of a moderate drought i.e. Deciles value category 30 at 70% which does not match any of the calculation confirming the actual occurrences of drought in the focus area. The probability curves for 3 month running mean values of all the 12 months drawn in a single plot is given in Fig.6.18 to show how identically the curves behaves in all the 12 months in a year. The individual plot for each month's probability distribution for this index is appended in Annexure-III (C). Comparisons of the probability distribution of all the indices for 12 months are shown in Annexure III (D).

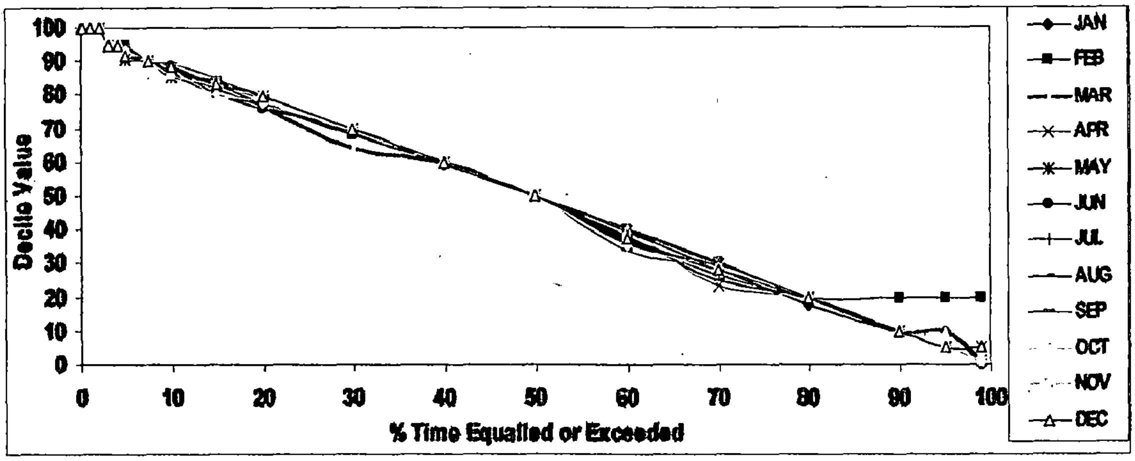


Fig. 6.18: Probability Distribution of Deciles (3 Month) Index for all 12 Months

Table 6.10: Deciles Probability Distribution for 1 month and 3 month Values

Month	Probability of occurrence of index 30 (1month Run)	Probability of occurrence of index 30 (3month Run)	Index at 90% probability of occurrence (1month.Run)	Index at 90% probability of occurrence (3month Run).
1	2	3	4	5
January	97%	72%	40	10
February	70%	70%	30	20
March	66%	70%	20	10
April	67%	65%	10	10
May	69%	69%	10	10
June	70%	69%	10	10
July	70%	69%	10	10
August	70%	65%	10	10
September	65%	68%	10	10
October	70%	68%	10	10
November	70%	68%	30	10
December	97%	68%	70	10

Table 6.11: Month wise Drought Events (SPI<= -1.2, EDI<=-1.00, Deciles<= 30)

Month	1 month Values			3 month Values		
	1m SPI	1m EDI	1m Deciles	3m SPI	3m EDI	3m Deciles
January	3	0	3	3	0	7
February	3	0	7	5	0	7
March	2	0	7	5	0	7
April	4	5	7	4	5	7
May	4	0	7	5	3	7
June	4	5	7	5	5	7
July	4	5	7	5	5	7
August	3	4	7	5	5	7
September	4	4	7	4	5	7
October	3	0	7	4	4	7
November	2	0	7	5	3	7
December	2	0	3	5	0	7

The number of drought events for each month in the total analysis period of 42 years (1964 to 2005) for values of SPI below or at -1.25, for EDI at or below -1.00 and for Deciles at or below 30 are summarized in Table 6.11 both for 1 month and 3 month values and results are explained through Histogram (Fig. 6.19 (a) and 6.19 (b)). It is important to note that the SPI in the 1month run consistently giving 4 scarcity events and 3month averaging gives 5 scarcity events in almost all months. This means on an average a scarcity event occurs at 8 to 10 year interval.

The Deciles index appears to be blunt as giving a constant value of 7 events in almost all months both in 1month and 3month averaging. This gives an average return period of 6 years for a scarcity period. The EDI on the other hand does not signify scarcity events in the non monsoon periods i.e. January through April and November & December. This is acceptable because this region falls in r dry-sub humid climatic group and these months generally remain dry. So moderate to normal negative values has resulted in EDI calculations. Also, estimates of drought index bellow average in above non monsoon months is not of much practical importance. In the monsoon months the EDI has resulted on an average 5 events both in 1month and 3 month run. This gives the average return period of scarcity events to be 8 years which is also agreeable with that obtained from SPI computations. So it is clear that SPI yields moderate result while the results of Deciles are less representative of the study area. Thus, EDI is a better representative of scarcity events in the focus areas and it yields pin-pointed results and also identifies the date of onset and termination of drought.

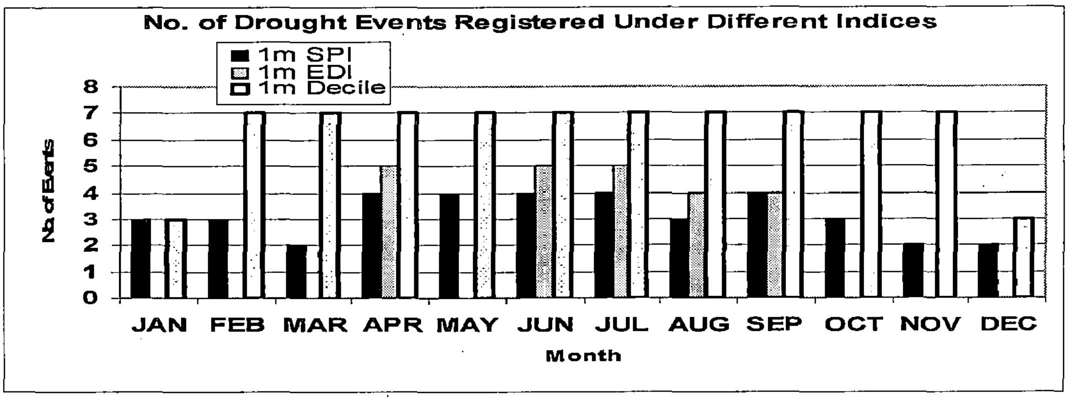


Fig.6.19 (a): No. of Drought Events in different Months under SPI, EDI & Deciles (1 Month RM. Table 6.11)

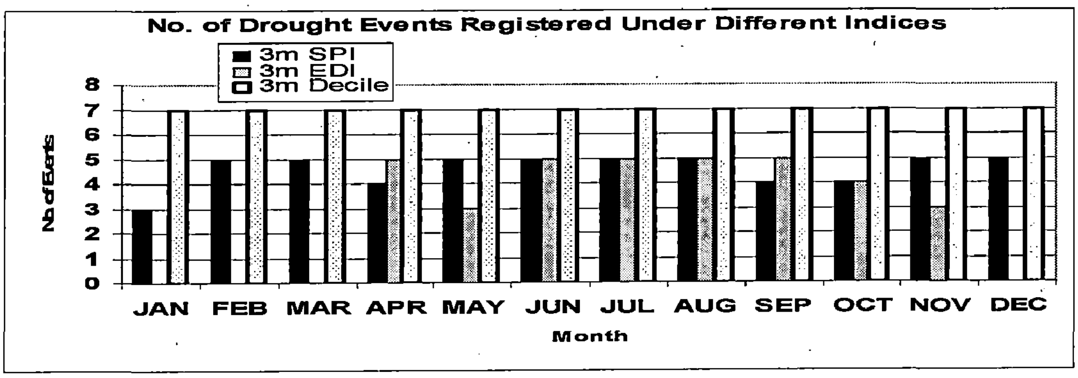


Fig.6.19 (b): No. of Drought Events in different Months under SPI, EDI & Deciles (3 Month RM, Table 6.11)

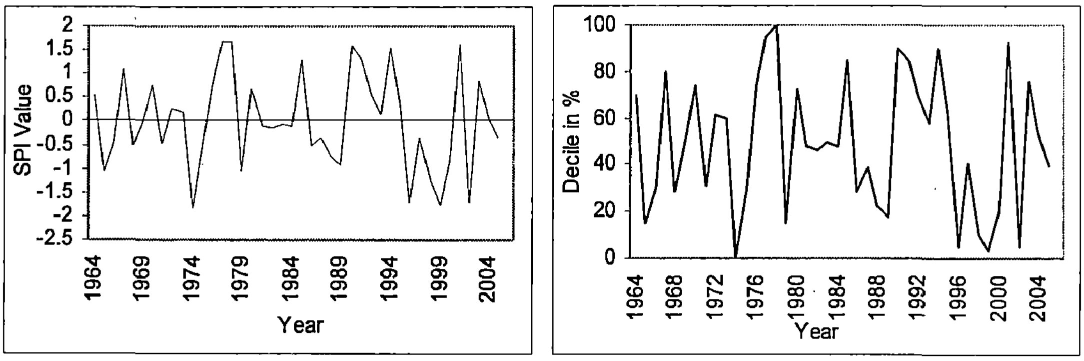
The return period of a moderate to severe drought events by using above three drought indices is summarized in Table 6.12 for comparison. From Table 6.12 it can be seen that using EDI and SPI return period for scarcity events during monsoon months vary on an average from 7-10 years. But Deciles index yield the return period of 3 years. This again confirms the non applicability of Deciles index in the focus area.

Table 6.12: Summery of Return Period by 3 month Running Mean Averaging Process (SPI=1.2, EDI=1.00 and Deciles=30)

Sl. No.	Month	SPI		EDI		Deciles	
		Probability of non Exceedence (N=1-P)	Return Period T=1/N (Yr)	Probability of non Exceedence (N=1-P)	Return Period T=1/N (Yr)	Probability of non Exceedence (N=1-P)	Return Period T=1/N (Yr)
1	January	0.08	12.5	NA	NA	0.28	3.57
2	February	0.11	9.1	NA	NA	0.3	3.33
3	March	0.12	8.3	NA	NA	0.3	3.33
4	April	0.07	14.3	0.15	6.7	0.35	2.86
5	May	0.12	8.3	0.05	20.0	0.31	3.23
6	June	0.12	8.3	0.12	8.3	0.31	3.23
7	July	0.1	10.0	0.15	6.7	0.31	3.23
8	August	0.11	9.1	0.09	11.1	0.35	2.86
9	September	0.14	7.14	0.12	8.3	0.32	3.13
10	October	0.15	6.7	0.1	10.0	0.32	3.13
11	November	0.14	7.1	0.05	20.0	0.32	3.13
12	December	0.08	12.5	NA	NA	0.32	3.13

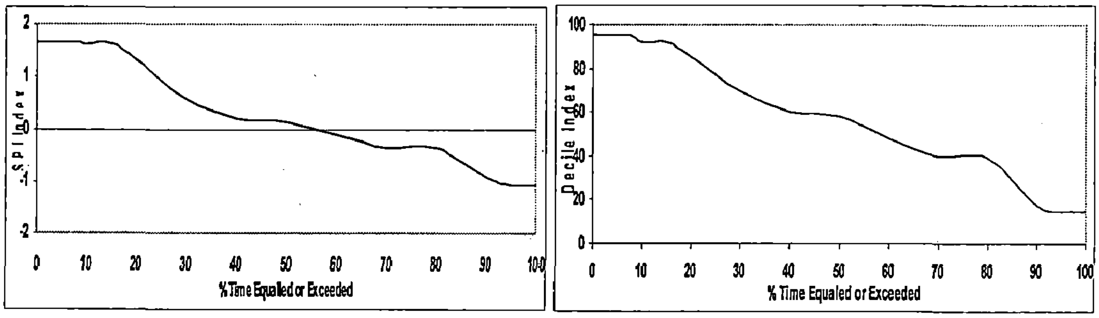
6.4.4. Seasonal Drought Index Generation.

Keeping in view that the monsoon season contributes nearly 90% of annual rainfall, single indices for the months June through October (JJASO) has been generated and plotted for SPI and Decile values in Figs. 6.20 (a) and 6.20 (b). EDI by its definition always takes accumulative running values. The probability distribution curve has also been prepared for single seasonal drought index Fig.6.21 (a), 6.21 (b) and 6.21 (c). It can be seen that the results obtained using single seasonal index values are not encouraging as the lowest value of SPI indicates a maximum severity index value of -1.6 and for wet period as 1.65. It contrasts the monthly values generated index which explains the real scenario in a better way. In case of Decile index value it explains the situation in a better way with a minimum deciles value of 14 and maximum of 95 for dry and wet periods respectively. It may be because of relatively upturn distribution of rainfall in the monsoon season. Therefore, while using SPI, it is always better to have a minimum of one month time step to describe the severity of drought events. In seasonal category the Deviation from Mean and Deviation from Median plotted in a single Fig: 6.22. These Plots give an important indication that for all excess rainfall years the median has given high values whereas in deficient years it invariably shows conservative low values. As drought is an extreme event related to less rainfall periods and the common concern is to prefer high deficit values to be in safer side in drought mitigation and planning. As shown in Fig: 6.22 in drought years 1974, 1987, 1996 and 2002 the deviation from median has been recorded as -47, -18, -45% and -45% respectively, whereas based on mean the deviations were recorded as -53,-28,-50 and -51% respectively. This may be one of the reasons for preferred use of mean than median values in drought analysis.

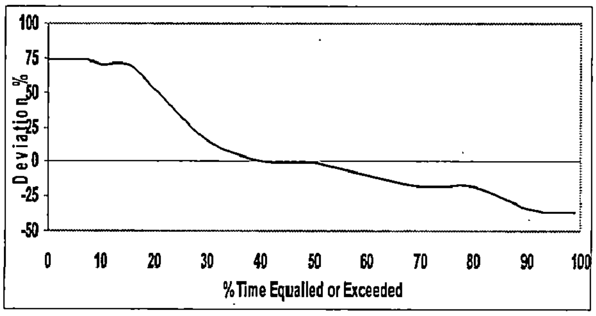


(a) SPI Values (b) Deciles Values

Fig. 6.20: Single Seasonal (JJOSO) Plot of Focus area



(a) SPI (b) Deciles



(c) Deviation from Mean

Fig.21: Probability Distribution of Single Seasonal (JJOSO) Index in Focus Area

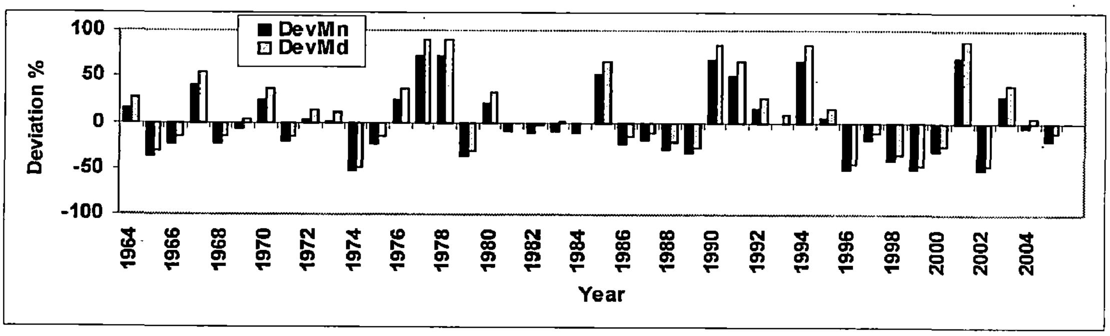


Fig.6.22: Comparison of Rainfall Deviation from Mean and Median

6.4.5 Comparison of Drought Events

Comparison of EDI and SPI for monthly time scale (Fig. 6.23 (a) to 6.23 (d)) indicates that, in general, the estimates of EDI follow the pattern of SPI in severe drought years. As discussed above and also reported by Govt. of Orissa White Paper 1974 and Memorandum 2002 the severe drought years are 1974, 1987, 1996 and 2002. Though both the indices show the same trend, the response to wet days is slower in case of EDI than SPI, which has responded very quickly from a dry month to a comparatively wet month. Out of the four drought years 1996 has recorded a maximum duration of dry spell starting from January to September. This may be one of the reasons that the Focus area has received more attention after 1996 and it was highlighted for its drought hardship in media headlines in a big way. The year 1987 experienced a continuous drought spell in May, June and July. Though the intensity was not very high the duration exaggerated the severity.

Year 2002 which had mixed dry and wet spells till June, started suffering from drought from July which continued till December worsening the drought situation and caused heavy crop loss.

The year 1974 also exhibits a prolonged dry duration from April to September. After this month both the indices have shown a positive trend but the crop failed as it was too late and crops could not recover. The generated indices for the entire 40 years period for SPI & EDI divided into 3 laps for clarity have been superimposed for comparison and appended in Annexure-IV for all the 1month, 3 month, 6 month and 12 month values separately.

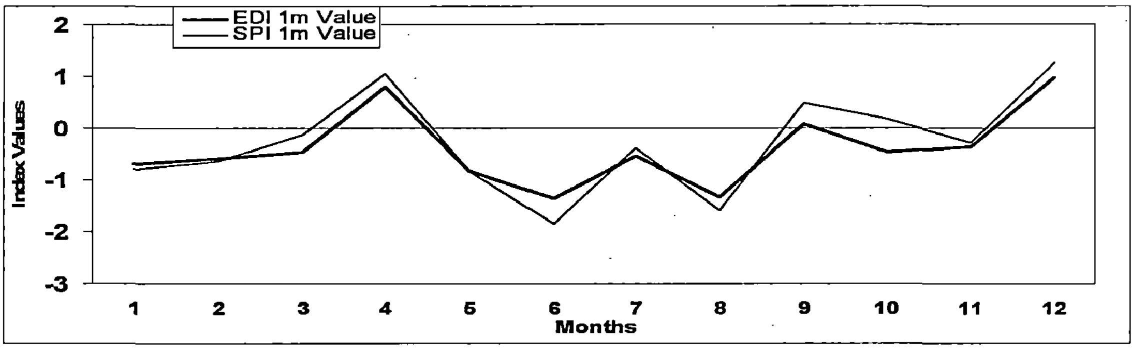


Fig. 6.23 (a): Comparison of SPI and EDI 1 Month Values in Drought Year 1974

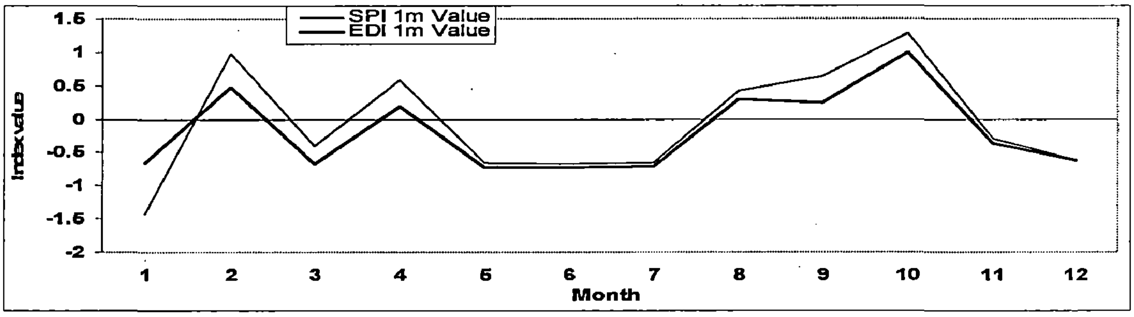


Fig. 6.23 (b): Comparison of SPI and EDI 1 Month Values in Drought Year 1987

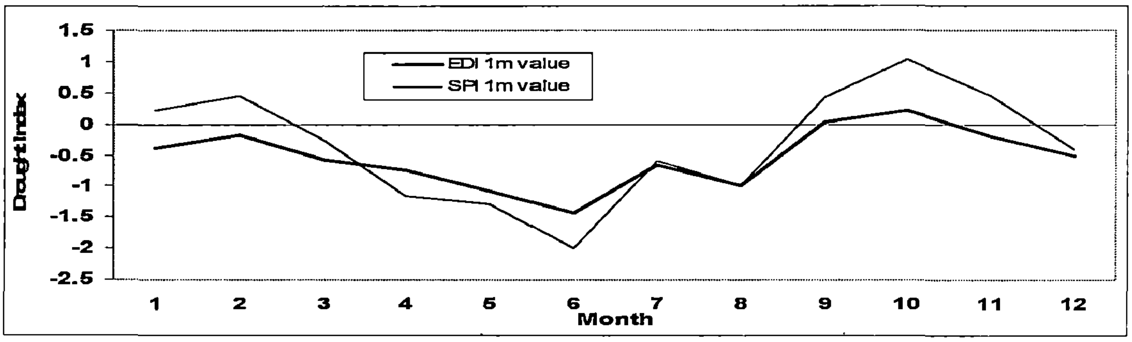


Fig: 6.23 (c): Comparisons of SPI and EDI 1Month Values in Drought Year 1996

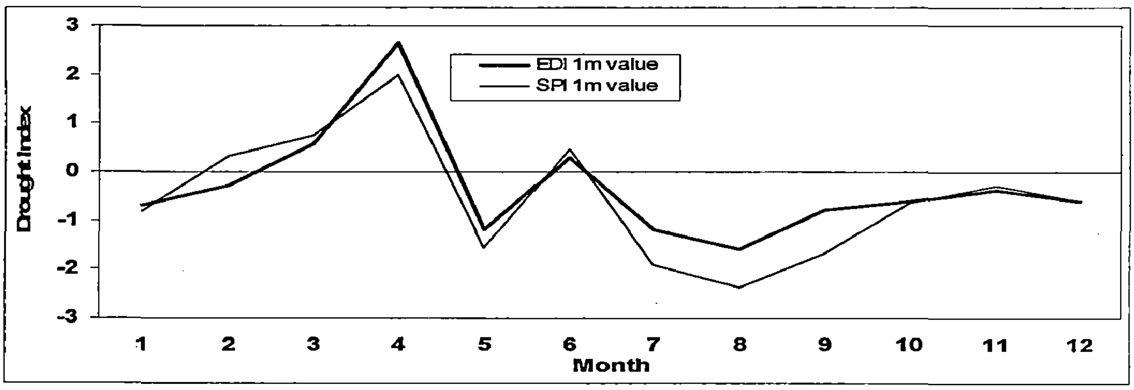


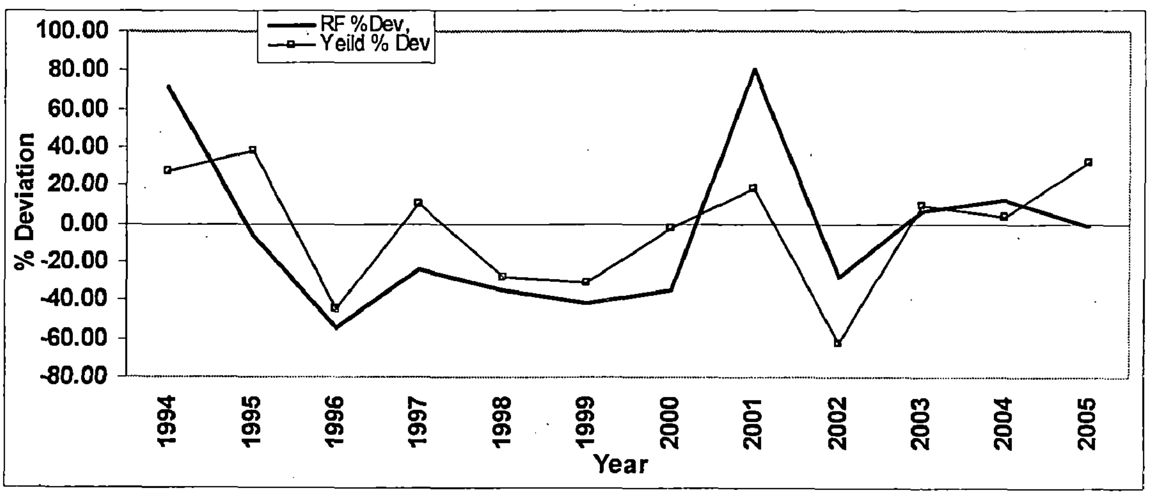
Fig: 6.23(d): Comparisons of SPI and EDI 1Month Values in Drought Year 2002.

6.4.6. Crop Yield Loss Analysis

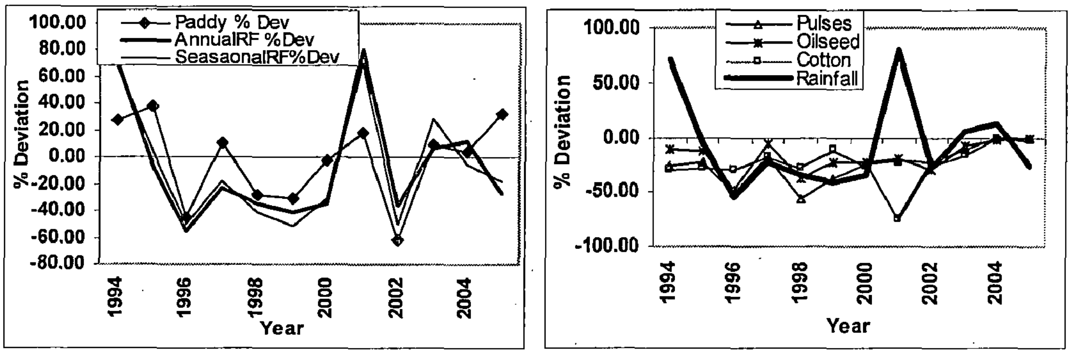
The yield of major crops in the focus area plotted against the yearly percentage departure of rainfall for the period from 1994 to 2005. As seen in Fig. 6.24 (a) , 6.24 (b) & Table 6.13; the lowest yield of Kharif Paddy was recorded in 2002 which is only 6.08 Q/Ha with percent deviation of upto -62% from average yield and next comes the year 1996 with yield 8.83 Q/Ha nearing -45% deviation from the average crop yield. The trend of rainfall and yield are almost identical indicating how the crops in this region are solely dependent on rainfall and how the drought indices are able to completely describe the situation quantitatively. So far other major crops like Oilseed and Pulses are concerned they follow the trend similar to paddy yield. Pulses and Oilseed recorded nearly -35% yield loss in 1996. However, in the drought year 2002 the loss in yield was near average for Pulses and -13% for Oil seed. This may be because of occurrence of lesser prolonged dry spells in 2002 than in 1996. Cotton yield showed a different trend with reduced crop yield record in excessively wet year. For example, there was surplus rainfall (+80%) in the year 2001 but the cotton yield was nearly -67% of its average. The cotton crop recorded moderate reduction in yield in mild drought years whereas other major crops showed relatively greater yield loss. In 1998 the loss recorded for Pulses and Oilseed was -42.71% & -23.50% respectively; Cotton recorded a better Yield i.e. only -4.09% less than the average yields. Similar plots Fig. 6.26 (a) and 6.26 (b) were prepared for Rabi season crop and statistics provided in Table 6.14. The Rabi paddy deviation does not match with the trend of rainfall deviation due to the fact that the Rabi cultivation is done only on small patches with irrigation facility. The rainfall is almost negligible during the Rabi season. The comparison of Yield of Kharif and Rabi paddy is shown in Fig.6.25. Cotton is not grown in Rabi season here.

Table 6.13: Yield and Percentage Deviation of Major Crops in Kharif Season

Year	Paddy.		Pulses		Oilseed.		Cotton	
	Yield Q/Ha.	% Dev, from Average Yield	Yield Q/Ha.	% Dev, from Average Yield	Yield Q/Ha.	% Dev, from Average Yield	Yield Q/Ha.	% Dev, from Average Yield
1	2	3	4	5	6	7	8	9
1994	20.4	27.50	4.8	-1.44	6	9.29	7.26	-7.16
1995	22.1	38.13	5	2.67	5.9	7.47	7.5	-4.09
1996	8.8	-44.81	3.18	-34.70	3.52	-35.88	7.22	-7.67
1997	17.6	10.13	5.28	8.42	6.3	14.75	8.5	8.70
1998	11.6	-27.63	2.79	-42.71	4.2	-23.50	7.5	-4.09
1999	17.1	-30.63	4	-17.86	5.17	-5.83	9.16	17.14
2000	15.7	-2.06	4.86	-0.21	5.22	-4.92	7.65	-2.17
2001	18.9	18.25	5.04	3.49	5.35	-2.55	2.55	-67.39
2002	6.1	-62.00	4.96	1.85	4.75	-13.48	7.57	-3.20
2003	17.5	9.13	5.72	17.45	6.16	12.20	8.67	10.87
2004	16.6	3.88	6.35	30.39	6.55	19.31	10.27	31.33
2005	21.2	32.56	6.42	31.83	6.7	22.04	10	27.88



(a) Percentage Deviation of Khrif Paddy and Annual Rainfall w.r.t Their Mean Values (1994 to 2005)



(b) Kharif Paddy (c) Kharif Other Crop

Fig. 6.24: Percentage Deviation of Annual /Seasonal Rainfall and Kharif Major Crops w.r.t their Mean Values, 1994 to 2005

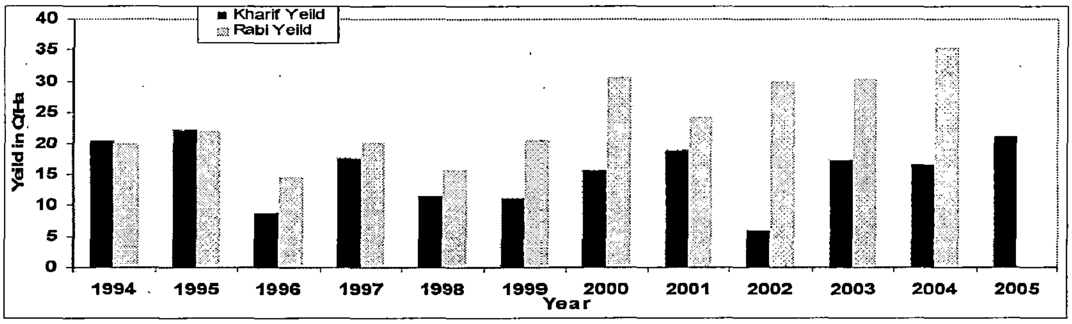
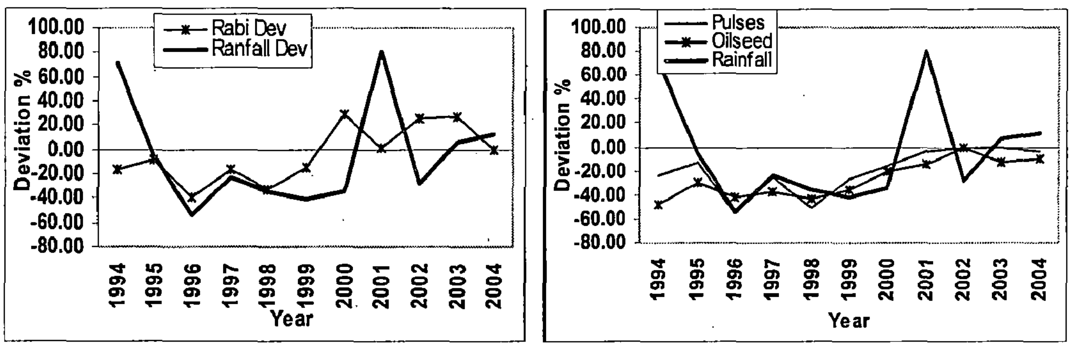


Fig.6.25: Comparison of Kharif and Rabi Paddy Yield in the Focus area.



(a) Rabi Paddy (b) Rabi Other Crop

Fig.6.26: Percentage Deviation of Rabi Crops and Annual Rainfall, 1994 to 2004

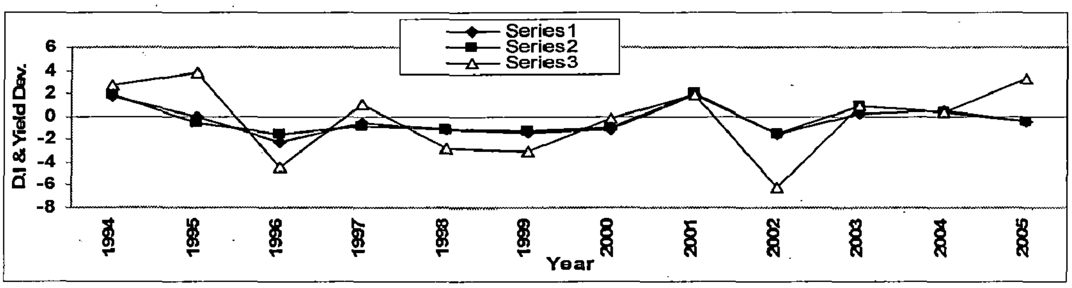


Fig. 6.27: Percentage Deviation of Khrif Paddy and Drought Indices (1994 to 2005). Series 1, 2, & 3 denotes SPI, EDI and % Yield Deviation *10 respectively

Table: 6.14 Yield and Percentage Deviation of Major Rabi Crops in Focus area.

Year	Paddy		Pulses		Oilseed	
	Yield Q/Ha.	% Dev, from Average Yield	Yield Q/Ha.	% Dev, from Average Yield	Yield Q/Ha.	% Dev, from Average Yield
1	2	3	4	5	6	7
1994	19.95	-16.88	4.86	-4.89	5.04	-28.10
1995	22.04	-8.17	5.52	8.02	6.69	-4.56
1996	14.68	-38.83	2.8	-45.21	5.52	-21.26
1997	20.1	-16.25	4.8	-6.07	6	-14.41
1998	15.9	-33.75	3.1	-39.33	5.4	-22.97
1999	20.42	-14.92	4.65	-9.00	6.11	-12.84
2000	30.72	28.00	5.41	5.87	7.64	8.99
2001	24.21	0.88	6.17	20.74	8.19	16.83
2002	30	25.00	6.39	25.05	9.55	36.23
2003	30.5	27.08	6.36	24.46	8.26	17.83
2004	35.43	47.63	6.11	19.57	8.66	23.54

The variation of Paddy crop yield with respect to the drought indices i.e. SPI and EDI has been shown in the Fig. 6.27. The percentage deviation of Paddy crop yield from the average has been multiplied with ten to represent all the three variations viz. SPI, EDI and the percent deviation in a single plot. Both the drought indices have been able to indicate the drought year's yield in a similar pattern showing maximum negative value in 2002 which has also recorded the maximum deviation of Paddy yield below average.

6.4.7 Generation of Daily Index

Keeping in view the usefulness of the EDI the analysis of three vulnerable stations namely Bhawanipatna, Kesinga and Lanjigarh was carried out taking into account the original Daily Time Step Procedure. This analysis answers the unsolved question of all the above analysis i.e. the onset of drought, termination of drought, accumulated precipitation deficit and single day precipitation required to return to normal condition. The general public as well as Government Agencies are more interested in such aspects to deal with the disastrous consequences of drought.

Bhawanipatna Station:

The daily Precipitation of the station for 12 years has been analyzed and the results for two typical years are discussed, as follows. Figs. 6.28 and 6.29 (a) & (b) show the daily precipitation and the drought indicators respectively for the sample years 1995 and 1996, starting from the date 1st January 1995. The year 1996 started the first negative IAN on day 499 i.e. on 14th May, with DPS -4 mm and EDI -.02. Before 14th May 1996 it was positive because 1995 was a good rainfall year. The dry duration starts when the PRY value goes negative but the drought duration starts when the EDI goes below -0.7. Then the actual drought spell started from day 527 i.e. DT. 11th June with EDI crossing the mark -0.7 and that continued unabated till the day 579 i.e. 2nd August 1996, with EDI -1.0. So 52 days of drought duration with a maximum downfall of EDI to -1.49, DPS to – 292 mm and PRY to -148mm occurred in the main production season. On the day 580 it has suddenly moved positive for one day, i.e. 3rd August 1996. This is explained by the fact that there was good rainfall on days 579 and 580 which is 93 mm 68 mm respectively (Fig.6.28). But it was too late for the major Paddy crop of that region to sustain an average stress of EDI -1.00 for 52 days. Again from day 581 the stress started and continued till the end of the year killing all hopes of crop production. All other information that can be quantified from the results is narrated in Table 6.15 for a typical 4 days period of the year 1996. This period has been chosen deliberately to show that one day's rain can change the drought severity as well as the drought index value.

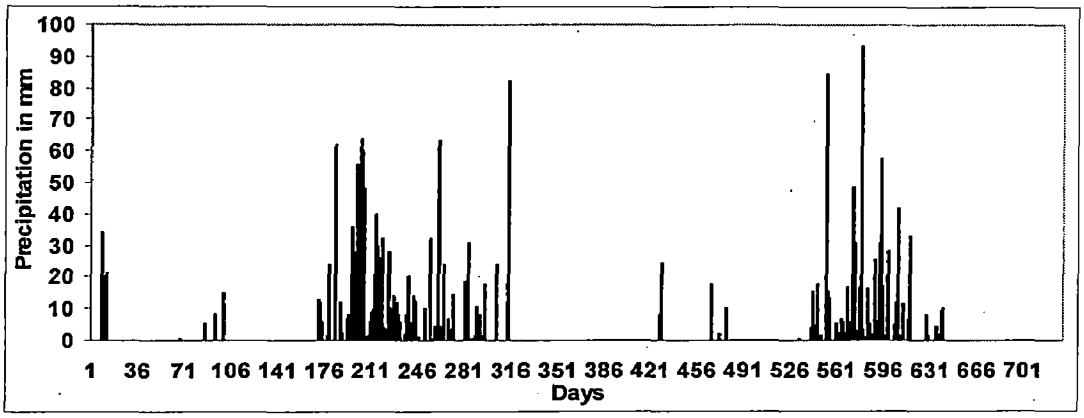


Fig.6.28: Daily Precipitation Plot of Bhawanipatna (Kalahandi) from Dt.01/01/1995 to 31/12/1996

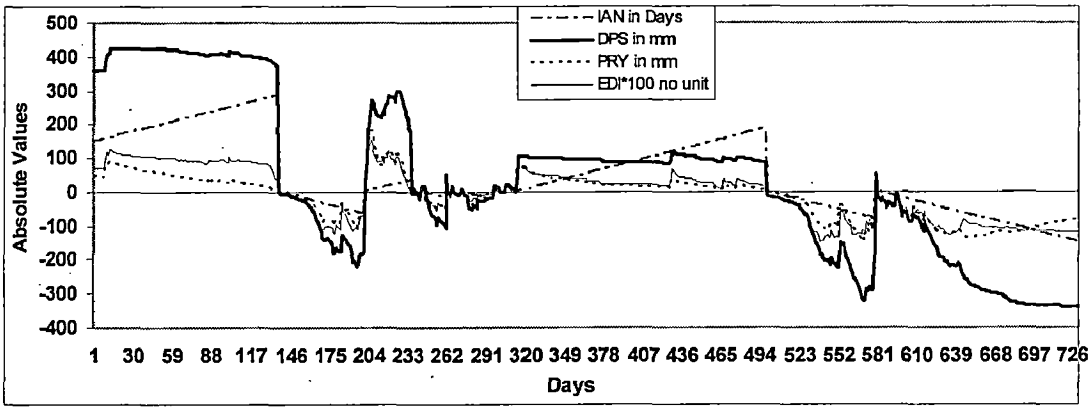


Fig. 6.29 (a): Consecutive Days of - ve or + ve Precipitation (IAN), Deviation of Accumulated Precipitation from Mean (DPS), Precipitation Required to Return to Normal (PRY) (for365 day's deficit) and Effective Drought Index (EDI)*100, from Dt.01/01/1995 to 31/12/1996 at Bhawanipatna Station

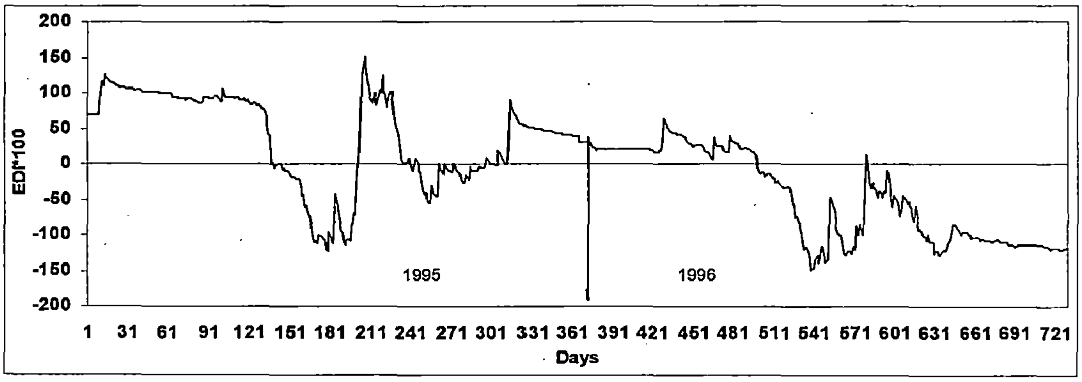


Fig. 6.29 (b): Variation of EDI from DT 01/01/1995 to 31/12/1996 at Bhawanipatna Station

Table 6.15: Typical 4 days Reading of Daily Information (DT 02/08/1996 to 05/08/1996) at Bhawanipatna from EDI Daily Index Package

YearMM DD	IAN	APN	VPN	DPS	APL	VPL	DPL	PRN	PRY	DI	PCN
199608 02	-81	410	629	-219	1893	2086	-193	-34	-27	(-) 0.31	675
199608 03	1	68	14	54	1236	1404	-168	13	15	0.12	32
199608 04	-1	3	11	-8	1209	1403	-194	-7	-8	(-) 0.07	8
199608 05	-2	4	25	-21	1210	1418	-208	-27	-23	(-) 0.26	2

The results of Table 6.15 are explained one by one as follows:

In August 2nd, 81 consecutive days have shown below normal precipitation.

Accumulated precipitation (APN) during 81 days is 410 mm.

Analysis period mean value precipitation for the 81 days (VPN) is 629mm.

Deviation of APN from VPN is DPS i.e. (VPN-APN) comes to -219 mm.

During (81+365=446) day's accumulated precipitation (APL) is 1893 mm.

Analysis period mean value precipitation for the 446 days VPL is 2086 mm.

Deviation of APL from VPL, i.e. DPL is (VPL-APL) comes to – 193 mm.

Precipitation needed to return to normal condition from 446 days (PRN) is 34 mm.

Precipitation needed to return to normal from 365 days (1 Year) PRY is 27 mm.

The Effective Drought Index, (DI) is -0.31.

Precipitation on 2nd August PCN is 67.5 mm.

The total available water resources, described as (EP365) i.e. AWR is 28 mm.

The rainfall of 67.5mm helped to reduce the negative PRN and PRY to come to positive and accordingly the IAN turned to positive i.e. 1. But the situation turned again as the precipitation on 3rd August was only 3.2mm .On 4th August against a requirement of 8 mm rainfall it was only 0.8 mm which further started a negative count down.

Similar analysis for the period of 26 years for Kesinga Station and 10 years for Lanjigarh Station was carried out and details are presented in Annexure- V. The observations of the same period DT 01/01/1995 to 31/12/1996 have been summarized in Table 6.16. The consecutive days of dry spell and drought duration observed in the three stations of Kalhandi district gives a clearer picture of the severity of 1996 drought which badly affected the area.

Table 6.16: Daily Index and Dry Spells For Drought Year 1996

Sl. No.	Rain Gauge Station	Consecutive Days of (-)ve IAN	Drought Duration	Drought Period	Lowest DPS value	Lowest PRY value	Lowest EDI Value
1	Bh.patna	81 Days	52 Days	11/06 to 02/08	(-) 292mm	(-) 148mm	-1.49
2	Kesinga	205 Days	198 Days	17/06 to 31/12	(-) 666mm	(-) 221mm	-1.29
3	Lanjigarh	200 Days	196 Days	15/06 to 31/12	(-) 322mm	(-) 248mm	-2.48

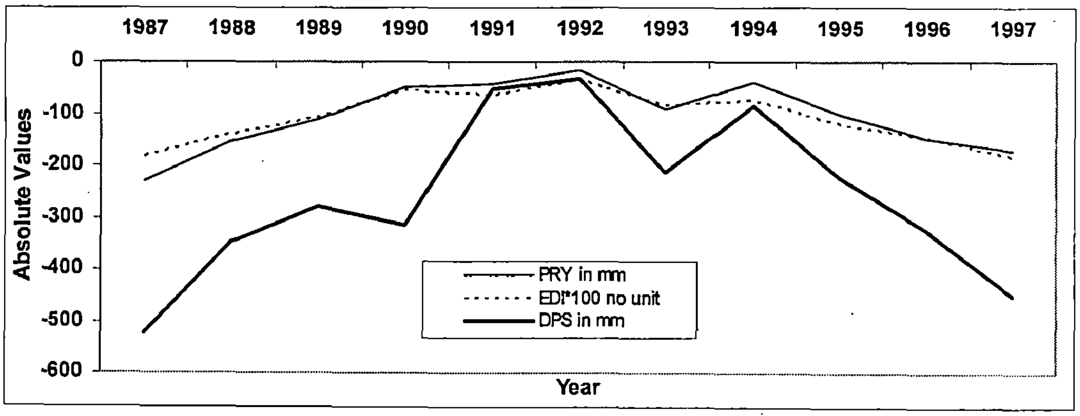


Fig. 6.30 (a): Inter Annual Variations from Daily Reading of Bhawanipatna Station.

Next the inter-annual variability of EDI, PRY and the DPS values of Bhawanipatna & Kesinga station was evaluated. Fig 6.30 (a), for Bhawanipatna, is plotted with the minimum values of EDI, PRY and DPS for all the years considered in daily analysis. Both EDI & PRY derived from the EP and the DPS derived from simple rainfall departure from mean shows a similar trend. This again confirms EDI values suitability for the focus area. The similar is the trend of Kesinga station (Fig. 6.30 (b)). This analysis can be further extended by taking the mean of the minimum values of all the raingauge stations of a region, to broadly represent the annual variability of the drought year and similarly the sufficient rainfall years for that region.

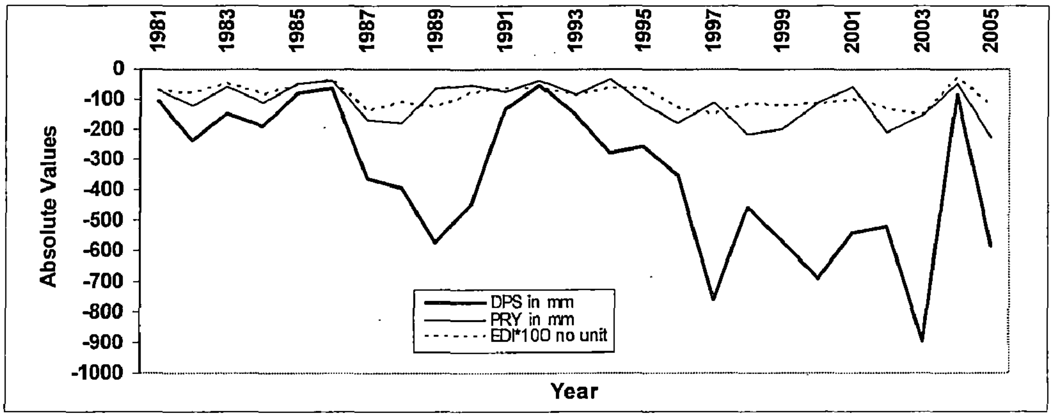


Fig. 6.30 (b): Inter Annual Variations from Daily Reading of Kesinga Station.

6.4.8 Ground Water Fluctuations

The fluctuations of water table reflect the effect of precipitation, recharge and discharge of ground water to streams or lakes or well withdrawals. Usually the change of storage is a seasonal phenomenon. During the period of scanty rainfall or drought period the dependence on groundwater however increases and consequently pumping from groundwater amplifies. Kalahandi district has a vast unexploited ground water potential to a tune of 495116 thousand Cubic meter per year with level of ground water development at 1110 thousand cubic meter (NIH, 1999). The effect of drought gets reflected on groundwater availability after the elapse of considerable time from onset of drought in the region. For example, sudden drop in water table at Karalamunda (Fig. 6.31 (a)) in the drought of 1996-97 may be due to either one or both of the following two reasons (a) less recharge of groundwater due to scanty rainfall in 1996-97 and (b) excess pumping. Similar is the case of Bhawanipatna-1 point as shown in Fig .6.31 (b).

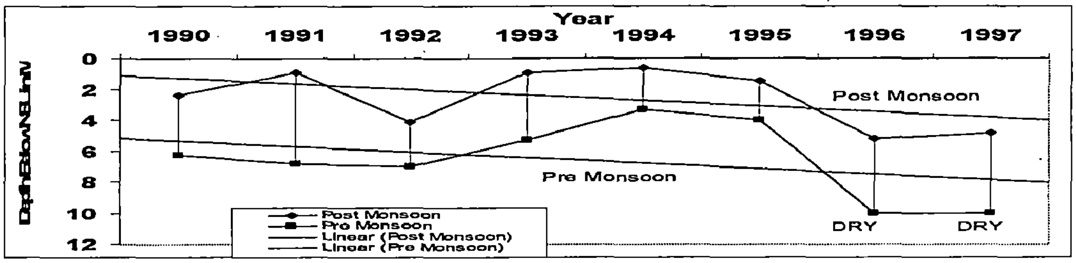


Fig. 6.31 (a): Ground Water Fluctuation and Trend Line, D/W at Karlamunda (Kalahandi), Lat. 20^0-15'-00" N and Long. 83^0-33'-00" E

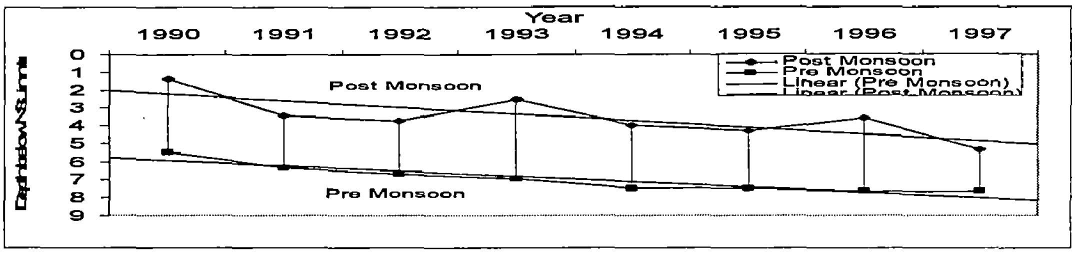


Fig. 6.31 (b): Ground Water Fluctuation and Trend Line, D/W at Bhawanipatna-1, Lat. 20^0-55'-00" N and Long. 83^0-11'-00"E

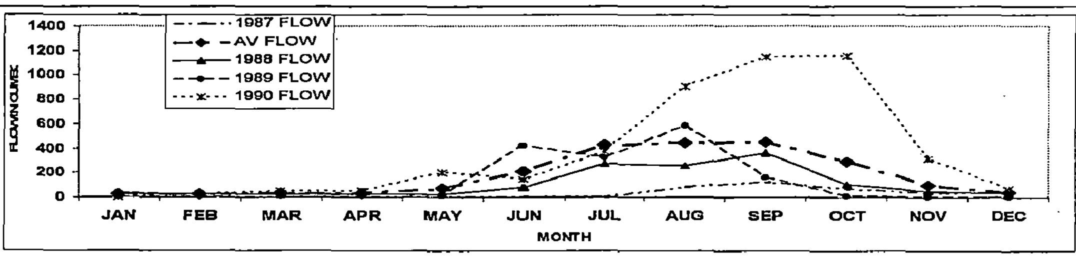


Fig. 6.32 (a): Average Monthly Flow of Ret River

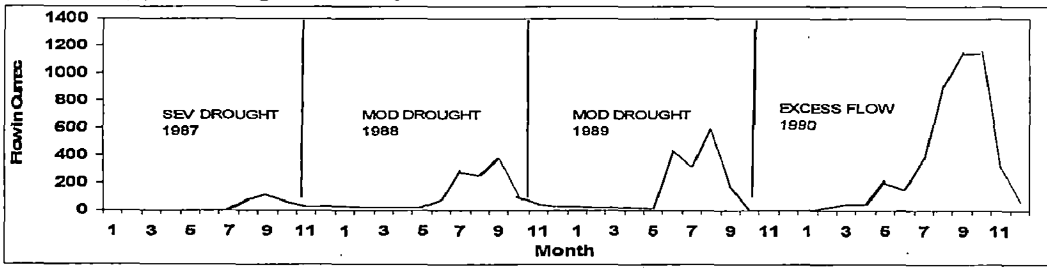


Fig. 6.32 (b): Monthly Time Series Flow of Ret River (4 critical years)

The drought year of 1996 has largely affected the Post monsoon water level of the next year viz. 1997 which has declined on an average of about 2 m. Plots of water table fluctuation for various locations in the focus area are shown in Annexure –VI.

6.4.9. Effects on Surface Water

Tel River, a major tributary of river Mahanadi flows through the heart of this region with an average daily discharge above 500 cumecs at Kesinga during monsoon. But flows in Tel river reduces sharply and even the river course runs dry during severe drought year as it happened in the year 1989 and 1996. Now some Dam project and Diversion schemes has come up in some major tributary of river Tel. The example of Ret River which is one of the major tributaries of river Tel, and not yet exploited has been studied. Typical virgin flow hydrographs for four year (1987-90) for Ret River is shown in Figs. 6.32 (a) and 6.32 (b) to visualize the natural conditions of streams in the study region. A medium Dam project has come up as the first scheme in Ret River near Bhawanipatna and is now under active proposal

6.5 Potential Evapotranspiration and Drought Indices

This area falls under the sub-humid climatic region in India. The ratio of mean annual Potential evapotranspiration (PET) to the mean annual precipitation (Pa) of Bhawanipatna, Nuapada and Bolangir is 1.112, 1.242 and 1.434 respectively (Pandey and Ramsastri, 2001). Since the focus area in this study is Kalahandi and Nuapada, the simple average of these three may be considered as the best approximation to be used for the focus area. Accordingly, the estimated average value of PET/Pa comes out to be 1.263 and the reverse of this viz. Pa/PET has been computed as 0.792.

The mean annual rainfall for the focus area is 1347.9 mm and therefore, the average PET was obtained as 1347.9/0.792 = 1702.4 mm. Now this PET value has been utilized to calculate ratio of yearly aerial precipitation (Pae) to PET for the period from 1964-2005. This Pae/PET ratio has been plotted against the estimated values of three drought index namely SPI, EDI and Percentage departure from mean to establish relationship among them.

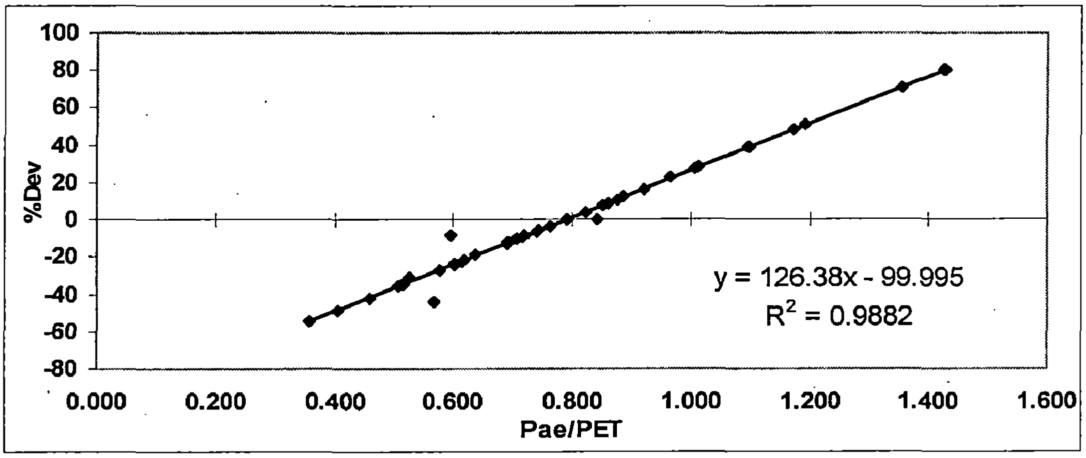


Fig. 6.33: Plot between Annual Percentage Departures of Rainfall from mean and Pae/ PET

Using Figure 6.33 or the equation Y=126.38X- 99.995 we can find the percentage deviation of rainfall for any given ratio of Pae to PET. For example for the -25% deviation the corresponding Rae/Pet is 0.6. This can be taken as the threshold value for our focus area to determine the dry condition and drought. Any year for which the Pae/PET value falls below 0.6 indicates a drought event. The typical values of Pae/PET were used to find the corresponding percentage deviations of rainfall using equation 6.1, and these are summarized in Table 6.17.

Y = 126.38X- 99.995 (6.1)

Where Y = Rainfall Percentage Departure from mean

And X = Ratio between Pae and PET

At X=0 the value of Y comes to 99.995 say 100, which means that in a no rainfall year i.e. Pae=0 which leads to Pae/PET to be zero, the percentage deviation is 100%. This satisfies the mathematical calculation procedure of the percentage deviation.

Table 6.17: Typical Values of Pae/PET to Rainfall % Deviation for Focus area

X=Pae/PET	Y=Rainfall% Deviation	Drought Type	Remark
0.60 to 0.50	-24% to -37%	Mild	
0.50 to 0.40	-37% to -43%	Moderate	
0.40 to 0.35	-43% to -59%	Severe	
Below 0.35	-60% and below	Extreme	

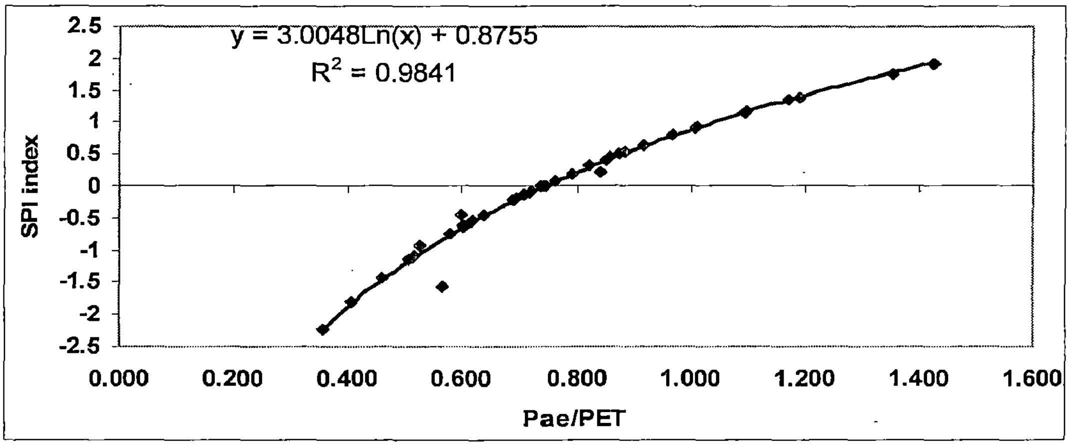


Fig: 6.34: Plotting of Annual SPI Values vs. Pae/Pet ratio

Now the Pae/PET ratio of 0.6 can be utilized in the Fig. 6.34 to find out the threshold value of the drought index and to calibrate the index for the focus area. The equation Y=3.0048LnX+0.8755 at X=0.6 gives the value of SPI= -0.66. Hence for the focus area the index going below the value-0.66 indicates a drought event. But in the original SPI index it has been prescribed that 0.99 to -0.99 is a normal condition, which is not correct in this case. This reveals that the use of SPI may not be able to identify the drought situation appropriately in sub-humid climatic region. However to represent the severity of the drought events in the focus area the values of SPI were recalculated using the relationship between SPI and Pae/PET (Equation 6.2) and given in Table 6.18.

Y = 3.0048LnX+0.8775 (6.2)

Where Y = SPI values and X= Ratio between Pae to PET

Table 6.18: Typical Values Pae/PET for Focus area w.r.t SPI Values

X=Pae/PET	Y= SPI index	Drought Type	Remark
0.60 to 0.50	-0.66 to -1.20	Mild Drought	
0.50 to 0.40	-1.20 to -1.87	Moderate	
0.40 to .35	-1.87 to -2.28	Severe	
0.35 below	-2.28 and below	Extreme	

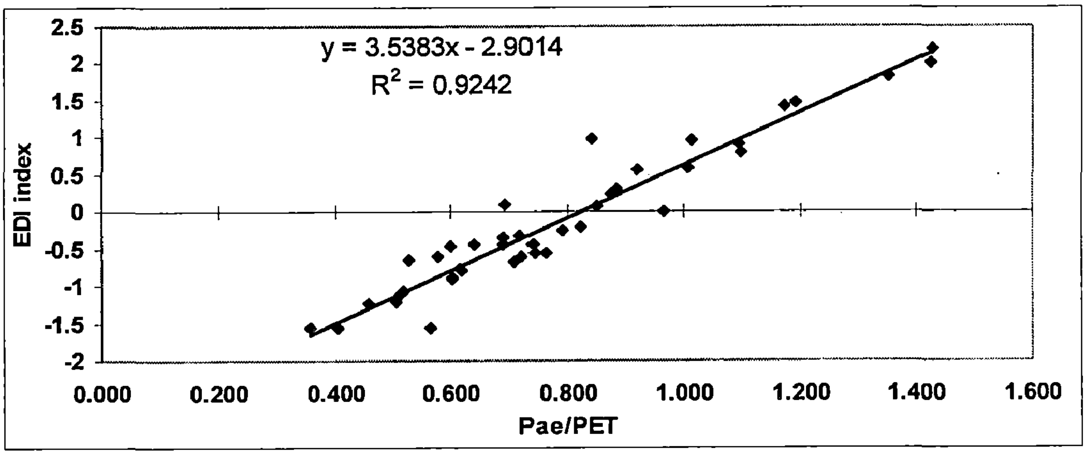


Fig: 6.35: Plotting of Annual EDI Values Vs Pae/PET

Similarly the relationship between EDI and Pae/PET has been derived and shown in the Fig 6.35. The linear relationship between EDI and Pae/PET gives maximum co-relation coefficient value and has been represented by the following equation.

Y = 3.5383X – 2.9014 (6.3)

where Y = EDI values

and X = Ratio between Pae to PET

Using equation 6.3 the values of EDI has been estimated and summarized in Table 6.19. It is found that for zero annual rainfall, X=0 and the EDI value becomes -2.9.

The original classification of EDI values Table 4.2 appears to be close to the computed values given in Table 6.19. This reveals that the identification and quantification of drought severity using EDI may better represent the drought situation in the focus area.

Table 6.19: Typical Values of Pae/PET for Focus area w.r.t EDI Values

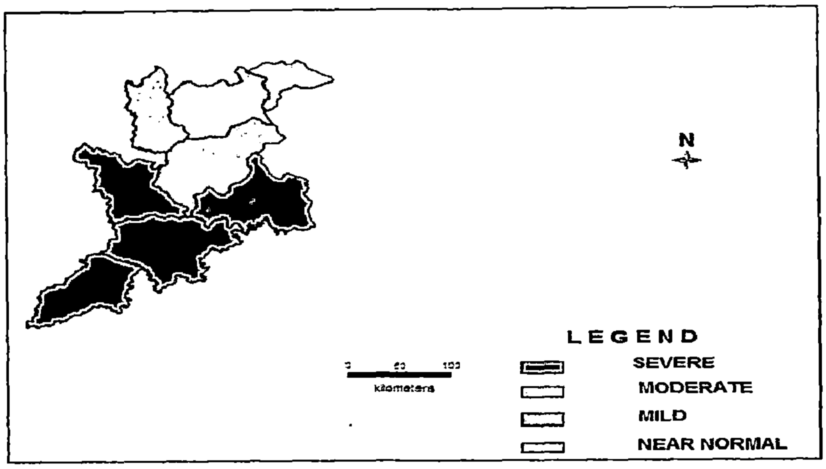
X= Pae/PET	Y= EDI index	Drought Type	Remark
0.60 to 0.50	-0.75 to -1.11	Mild Drought	
0.50 to 0.40	-1.11 to -1.47	Moderate	
0.40 to 0.35	-1.47 to -1.65	Severe	
Below 0.35	below-1.65	Extreme	

Thus by knowing the annual precipitation of a given location in the focus area one can quantify the drought severity in terms of SPI and EDI values. The ratio of rainfall to the potential evapotranspiration is to be the first input in the percentage departure curve to know the deviation and then be used to compute EDI or SPI values for annual time scale using above derived relationships.

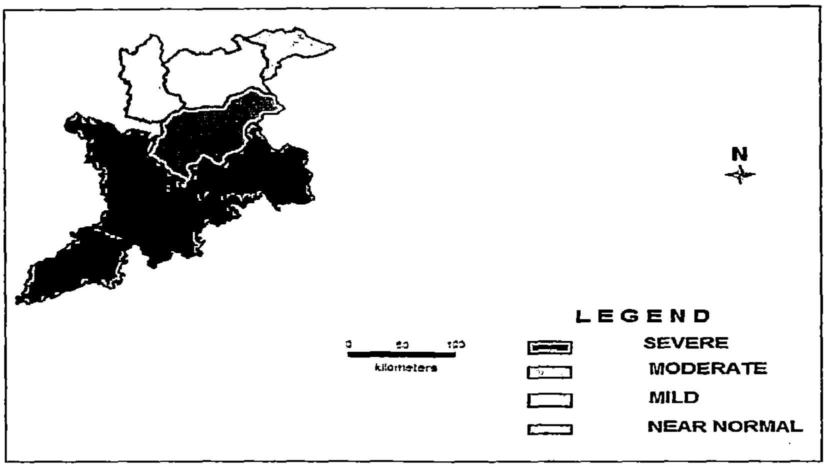
6.6 Spatial Distribution of Drought

The aerial extent and pattern of drought can be presented using any of the drought indices viz. EDI, SPI or Deciles. Since the EDI is found to be more suitable for focus area, the EDI values have been used to generate the spatial distribution of drought in the KBK region. Similar to the above analysis, it may be possible to generate spatial distribution of drought index for monthly time scale for all the indices. However, it has not been attempted in this study and remains the future scope of this study.

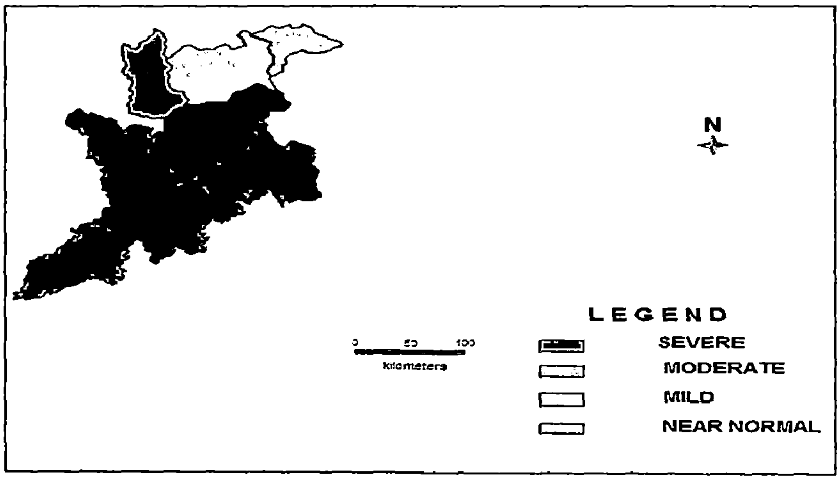
Figs 6.36 (a) to 6.37 (c) compare the spatial distribution of drought situation of two drought years i.e. 1974 and the 1996. These Figures show the aerial distribution and its propagation in the critical months of June, July and August. It can be seen that drought has propagated just in reverse order in the year 1996 as compare to that in the year 1974. For a region, such maps may be very useful to both droughts' understanding and monitoring .This is also helpful for forecasting of propagation of a drought event. This can be analyzed in two ways i.e. comparing a drought severity between different areas or monitoring different levels of severity for the same area. This has been generated using the "save summary information" option of the SPATSIM application. The maximum severity has been set at -2.5 with an interval of 0.50 and ten classes have been specified for the spatial distribution of severity district wise in the KBK region. One can decrease the polygon size to even Panchayat level (instead of District wise as presented here) with relevant rainfall record of that level. It will be a very precise tool for identifying severity in any area and will be of utmost practical importance. Increase or decrease in the interval of severity can be made as per requirement and use.



(a) JUNE

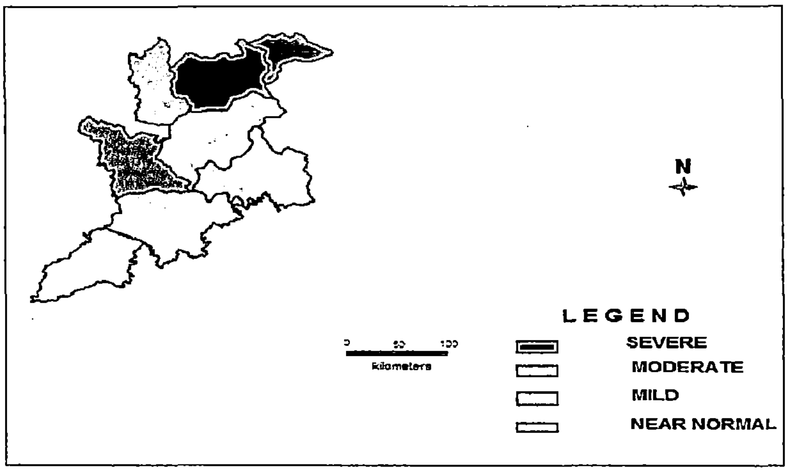


(b) JULY

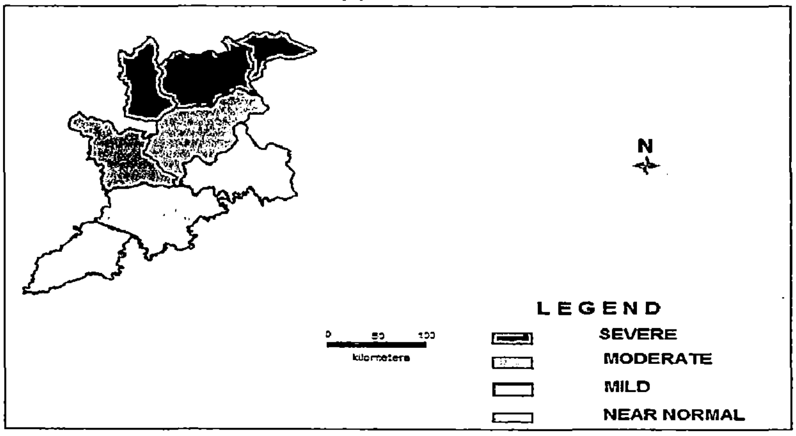


(c) AUGUST

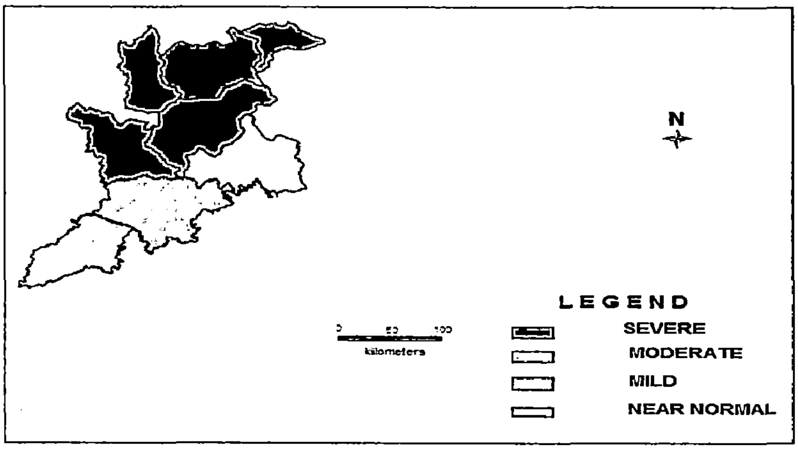
Fig.6.36: Spatial Distribution of Drought through I month DS Value of EDI in KBK District, Orissa, during 1974



(a) JUNE



(b) JULY



(c) AUGUST

Fig.6.37: Spatial Distribution of Drought through I month DS Value of EDI in KBK District, Orissa, during 1996

CHAPTER 7

DROUGHT WATCH SYSTEM

7.1 General

Drought is the most fatal and devastating of the entire meteorological phenomenon. The impacts of flood, tropical cyclones etc. are sudden, panic and receding type. The loss of life and property can be high but drought comes with a very ugly face and many hidden dangers for which even the most developed countries may not be fully prepared to face. The consequences are multifarious and insidious. Other natural disaster of extreme type are usually dealt with specific planning and apply the latest knowledge to minimize the effect, the same is needed to be followed in case of drought also. Drought is basically a localized phenomenon and the perception of drought is also different for different region and different people. Therefore the approach for its preparedness can obviously vary widely across a country. In a vast country like India the monitoring of such events is more critical and requires dedicated cells at various levels like national, state and district and block level with specific responsibilities and obligations for the drought hit area.

7.2 Long term Planning

The long planning of drought includes both strategies for precaution and action. Like other extreme meteorological events the actions may be same but the sequence of their adoption may differ. For example the precaution when drought is imminent and the treatment during the period of its occurrences form quite different sets of actions. As the perception of drought largely depend on the use of water to which it is put, its impact also may have different meaning to different people with variety of water demands to meet their daily needs. One thing common is the insufficiency in the availability of water at the user's point, whatsoever the use may be. Therefore, the record of past drought events not only from government departments but also from all sources like news paper, and other non-meteorological sources has to be cataloged for each meteorologically homogeneous area in a systematic manner for ready reference and guidance. The maps showing the spatial distribution of drought in the concerned area for each month is to be prepared and made available in a usable format for a long term period. Those records can be further analyzed for simulation and predictions. When a drought situation is found imminent after analyzing all possible indicators/indices as discussed for monthly and even daily time steps and supporting documents as cataloged, the users have to be cautioned first. Their water use has to be restricted and wastage to be minimized. For example the focus area in this study which is basically dependent on agriculture with traditional irrigation habits of flooding the field causing lot of wastage of water first has to be educated against that practice. Instead of using long-duration variety of paddy as the usual practice of these areas, has to be perused for short duration variety of paddy crop capable of withstanding moisture stress. However the prediction of drought is very important and crucial at this moment. All the analysis such as the probability of occurrence of a drought type of particular severity, the most probable rainfall amount and its pattern, the applicability of a particular drought index type and its time scale, the demand of the area and the variety of associated users etc are to be very carefully made before reaching any conclusion. The planning needs appropriate computation of demand for all sectors like agriculture, drinking water, industry, and power generation etc as applicable for the region. Thus, while planning for drought emphasis is to be given not only on meteorological factors but also to agriculture, economics, sociology and decision making for suitable formulation of strategies. Since much uncertainty prevails in the forecasting of rainfall, utilization of an expert system can be an appropriate option.

7.3 Onset and Termination of Drought

Identification of onset and termination are the most difficult part of a drought analysis. The onset of the drought event primarily depends on the time scale in which the analysis has been carried out. For example if one month is the unit of analysis then the onset can be in terms of month. A drought can be said to be continuing if the index is continuously below the negative index. Similarly in a daily drought analysis, as in EDI, the index for each day can be studied and the onset of drought can be determined when consecutive days record the specified negative index. This can be used in addition to monthly index to confirm the drought event as well as to pin point the date of onset of drought in the affected month. For example the daily study of indices of the focus area started showing negative values from date 14^{th} May 1996, but crossed the threshold mark of -0.7 on date 11^{th} June indicating the onset of drought situation on 11^{th} June 1996.

The task of identifying the termination or 'end of drought' is still more difficult. The system which has been established for the region to detect the onset has to be utilized for termination. A careful study of the monthly as well as daily indices has to be made to establish the change from negative values to a positive value. In EDI there is index to know the precipitation required to return to normal (PRN) from one year and from the duration summation for the study. Consecutive days of positive index values and precipitation above the PRN values can terminate a drought event. This study area falls in a temperate sub-humid climatic region and one day precipitation can terminate a long drought event. In such a situation the daily monitoring of drought is the real requirement. Of course the loss that would have already occurred is irreversible, but it can help in minimizing further negative impact on the society.

7.4 Setup for Drought Monitoring

In the developing world it has become a primary requirement to establish drought monitoring unit at different administrative levels and keep them equipped with the facilities as detailed below

1. The raingauge, stream gauge and groundwater gauge stations network should be adequate and uniformly distributed and feedback of records to various centralized administrative units for keeping watch on day to day situation especially in the rainy season.
2. Weekly to monthly scrutiny of records of rainfall/stream flow/water table/remote sensing of vegetation index etc. in non rainy season may serve the purpose of regular drought monitoring.
3. The monitoring cell should be equipped with latest computer facility and software to keep continuous watch of the situation and make available the monthly rainfall frequency and probability distribution for all months as and when required. It should also be equipped with all relevant information on historical drought events.
4. The monitoring units should have expertise to such a level that it should be capable of issuing drought warnings weekly in monsoon season and monthly in

other seasons. The mode of warnings has to be region specific, simple, understandable and reachable to the general public in remote areas. The common man should also be made aware of the prevailing situation and relevant resources.

CHAPTER 8

SUMMARY AND CONCLUSIONS

Various definitions of drought have emerged from time to time depending on subject of interest of various researchers. Socioeconomic definitions of drought associate the supply and demand of some economic considerations with elements of meteorological, hydrological, and agricultural drought. Because of the natural variability of climate, water supply is ample in some years but may happen to be unable to meet human and environmental needs in other years. To cope with drought hardship it is necessary to understand its characteristics i.e. its possible duration, its intensity/severity, frequency and aerial extent (spatial distribution). Choice of time step is other utmost important component in analyzing the hydrology of extreme events.

A drought index value is a single number used for quantifying the severity of drought and decision making. Due to the complexity of the drought phenomenon and due to the fact that it has a creeping effect and is region specific many researchers and scholars prefers for analyzing the drought situation with more then one index and see their effectiveness to define the drought situation and use them to effectively determine the drought severity, its spatial distribution and further use for near real time monitoring and forecasting. Statistical techniques dealing with duration aspect of drought are reasonably well developed. The techniques for severity aspect and to quantify it properly in a user friendly format are now under active research considerations.

In this study the monthly point rainfall of nine stations were utilized to find out the percent deviation, probability distribution, and authentication of historical drought events of the study area (KBK Districts). The frequency of occurrences of drought in different parts of the study area was found to vary significantly. The point rainfalls were converted to aerial rainfall to calculate various indices at monthly time step for the Focus area (Kalahandi & Nuapada). The scanty rainfall period often extends over consecutive years followed by an excessively wet year which causes flash flood in the area. This unruly pattern of rainfall in this region is the root cause of the risk of prolonged drought in the focus area. As the rainfall in the focus area is concentrated in 4 to 5 months the 1 & 3 months running mean values appeared to yield more realistic estimates of drought conditions. Point rainfall as well as converted aerial average of monthly rainfall and subsequent annual values can be successfully utilized to generate drought indices like SPI, EDI and Docile and other drought related parameters. The applicability and standardization of a particular index that has to be used in the drought watch system has to be fixed after a detail investigation.

Out of the four severe drought years 1974, 1987 1996 and 2002, the year 1996 has recorded a maximum duration of dry spell starting from January to September. The lowest negative index value was experienced in 2002, which also has recorded maximum deviation of Paddy yield below average. The drought year of 1996 has largely affected the Post monsoon water level of the next year viz. 1997 which has further declined about 2 m below the corresponding average depth.

Using the derived relationships between ratio of Pae to PET and Percentage deviation from mean the percentage deviations of rainfall for the focus area were obtained for any given ratio of Pae to PET. Then to represent the severity of the drought events in the focus area the values of SPI and EDI were recalculated using their relationship with Pae/PET ratio. Various indices were compared to see the rainfall pattern best suiting the type of index with respect to the number of drought events. The crop yield loss, ground water fluctuation and discharge in river Ret were used to assess the severity of drought years.

The following conclusions can be drawn from the study:

1. The frequency of drought in the focus area is once in every 3 to 4 years and it has got more then 50% chance of facing at least one severe drought in a 10 years period. In a given year if the Pae/PET value is below 0.6 indicates a drought event.
2. While considering the monsoon period in both SPI and EDI the month of September shows the largest variation in both 1month and 3month running mean values and gives the highest negative value at 90% probability level.
3. The Deciles index appears to be blunt in its applicability for the focus area. It was observed that the Deciles method may be suitable for regions with uniform monthly rainfalls.
4. The original classification of EDI values matched closer to the computed EDI values through Pae/PET relationship. This indicates that the identification and quantification of drought severity using EDI may better represent the drought situation in the focus area. The pattern of variation of crop yield of Paddy with respect to the drought indices i.e. SPI, EDI and the annual deviation from mean has been similar.
5. Comparison of all the drought indices and results of analysis lead to many useful and practicable inferences in understanding drought attributes in the study area.

The results of the study may provide significant inputs to the local/district administration in the planning of drought mitigation strategies for the region.

Future Scope of Study

1. Due to development of Geographical Information System (GIS) packages it is now possible to generate easily the variety of frequency analysis maps of drought on a regional basis analogous to regional flood frequency analysis. The drought maps of drought prone areas for all the twelve months with different time scales and averaging procedures can be prepared and kept in the monitoring unit for reference and simulation. Comparison of spatial distribution of drought severity through the SPATSIM software enables identification of the drought index that best suits the requirement of a particular region.

2. For effective monitoring of drought, daily index using EDI can be calculated from a number of raingauge stations (where data for 30 years or more is available) in a hydro-meteorologically homogeneous region and averaged to give a comprehensive tool for simulation, monitoring and preparedness for drought events of varying intensity and severity on a daily basis. This can be effectively utilized during severe drought conditions.

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ANNEXURE- I (A)

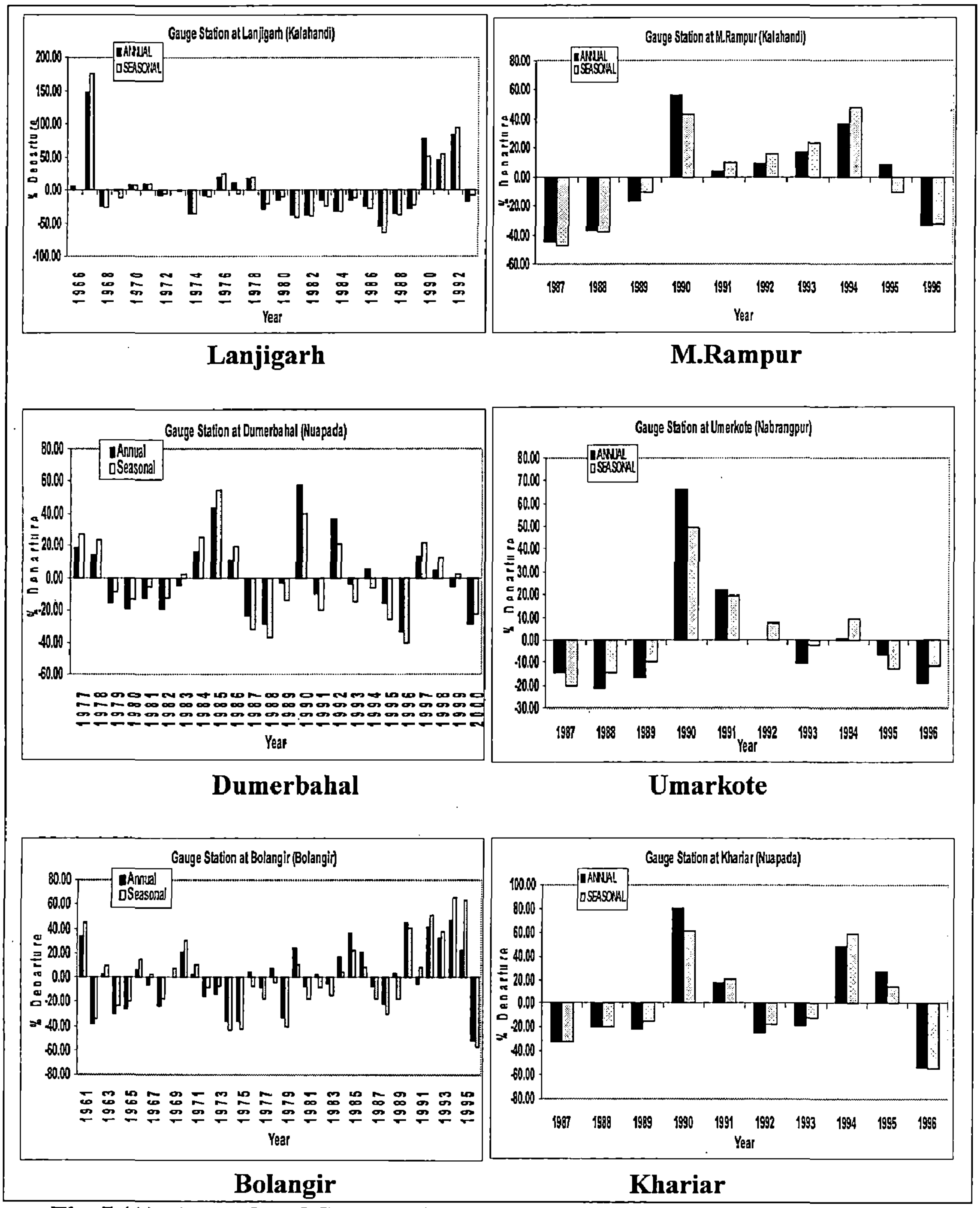


Fig. I (A): Annual and Seasonal Rainfall Percentage Departure at Different Gauge Stations in KBK District

ANNEXURE- I (B)

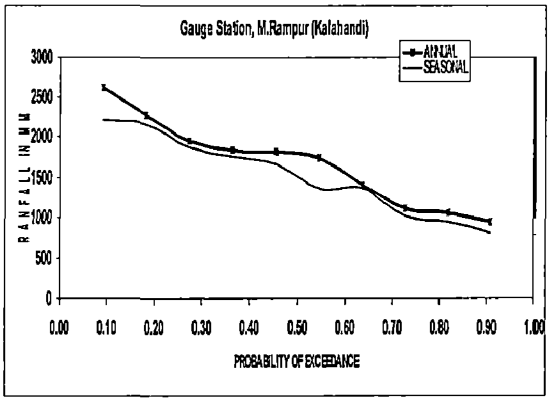


Fig.1: M.Rampur

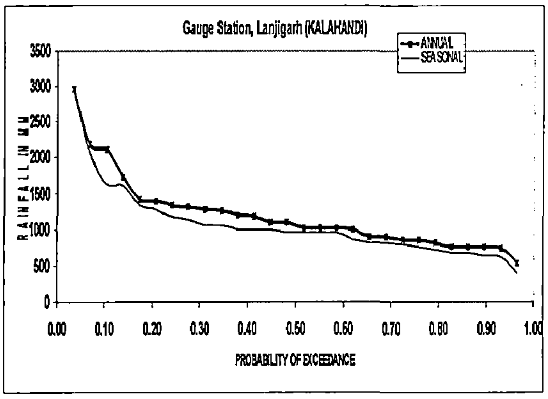


Fig. 2: Lanjigarh

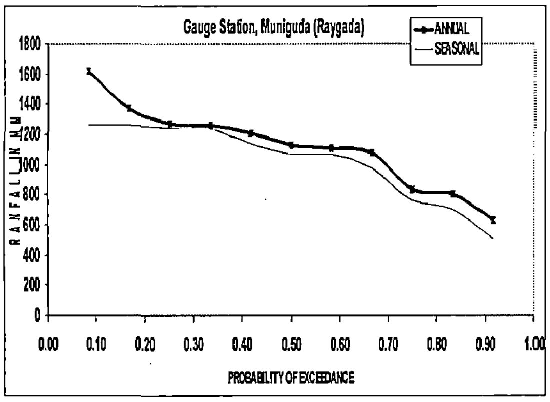


Fig.3:Muniguda

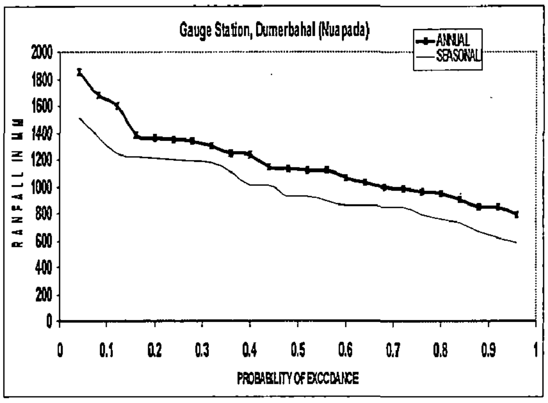


Fig. 4: Dumerbahal

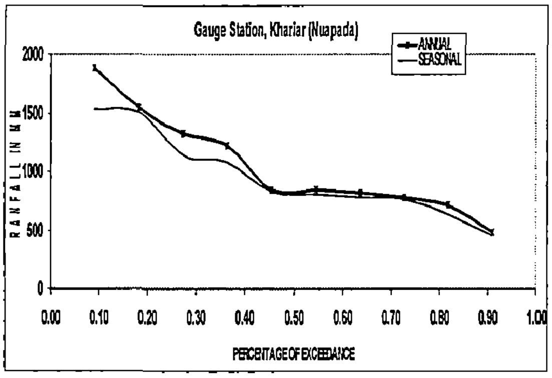


Fig. 5: Khariar

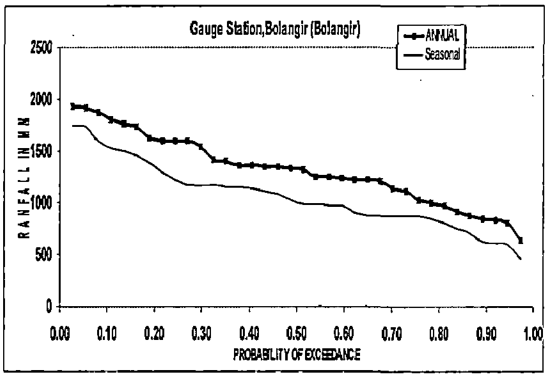


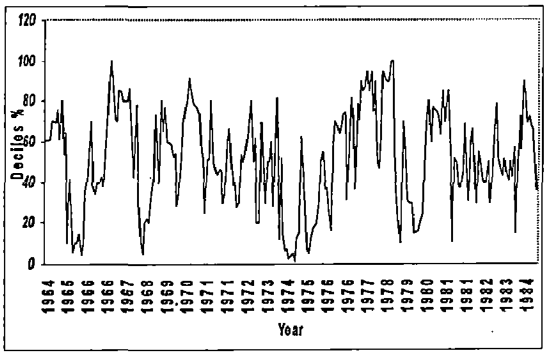
Fig. 6: Bolangir

Fig. I (B): Rainfall Probability Distributions at different Gauge Stations in KBK Districts

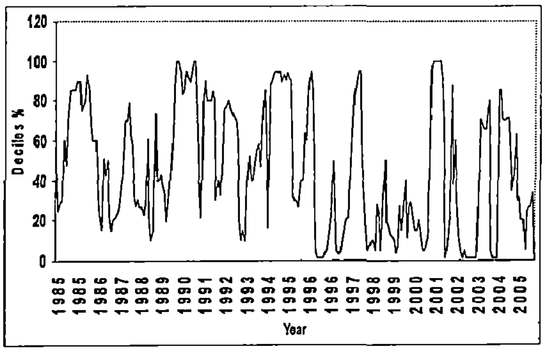
ANNEXURE- II

Drought Indices Duration Curves

Deciles (6 month) values

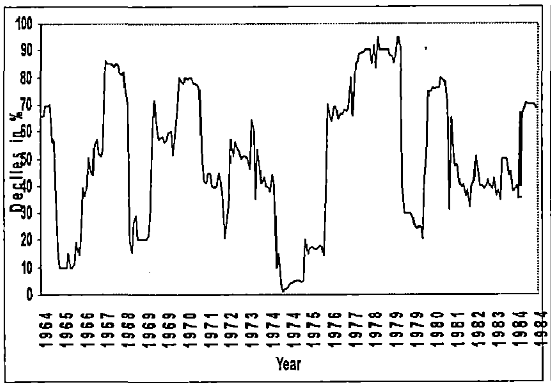


1964- 1984

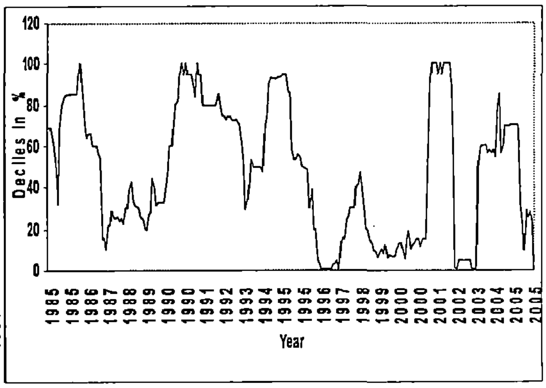


1985-2005

Deciles (12 month) values

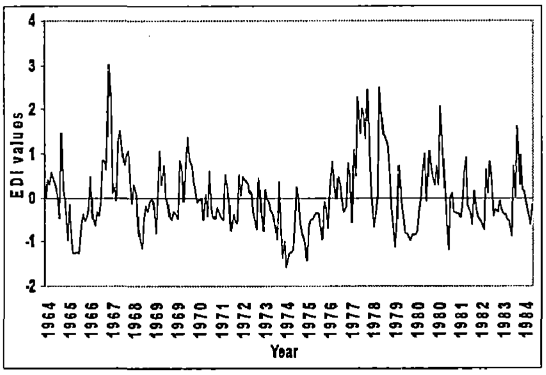


1964 to 1984

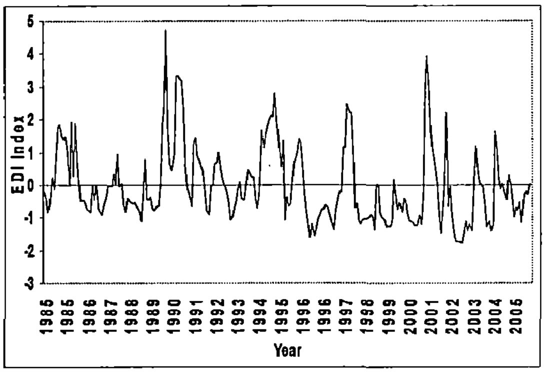


1985-2005

EDI 6month DS values



1964 to 1984

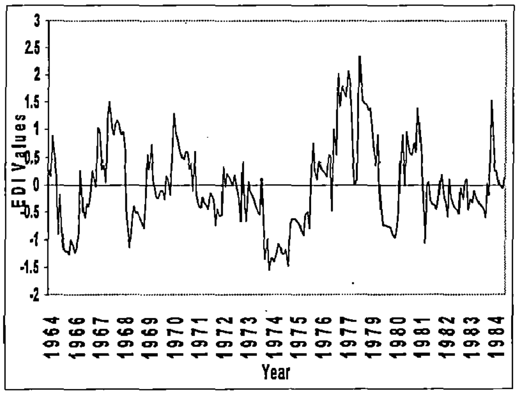


1985-2005

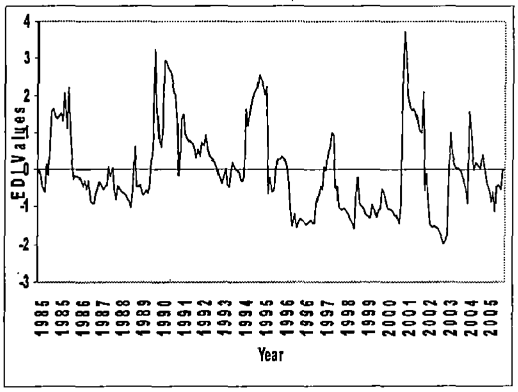
Fig. II: Drought Indices Duration Curves with 6 months and 12 months RM in the Focus area

ANNEXURE- II, Continued

EDI 12month DS values

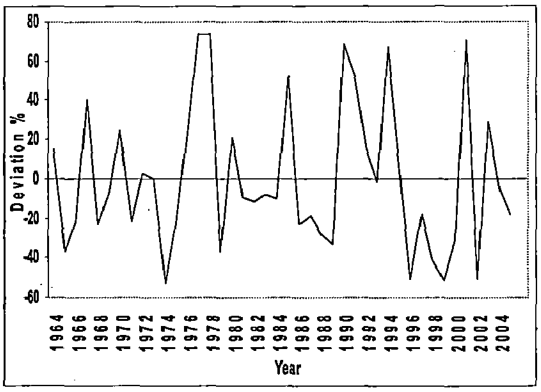


1964-1984

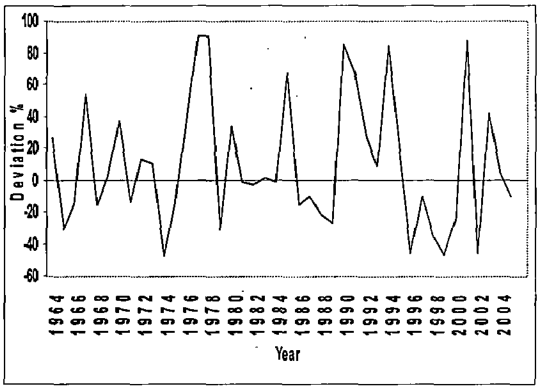


1985-2005

Single Seasonal Value (JJASO)



Deviation from Mean



Deviation from Median

Fig. II: Continued

ANNEXURE- III (A)

Probability Distribution Curves of SPI in the Focus Area

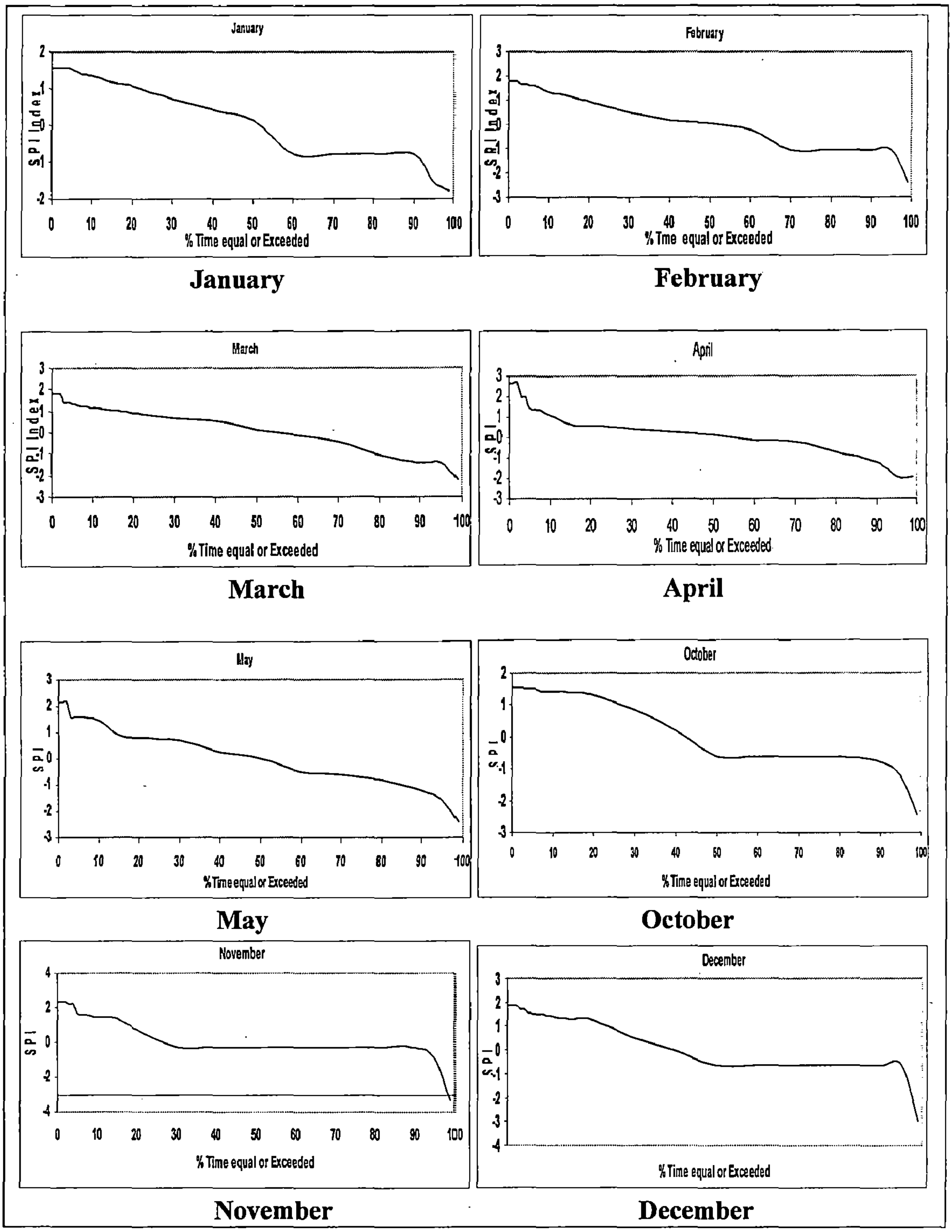
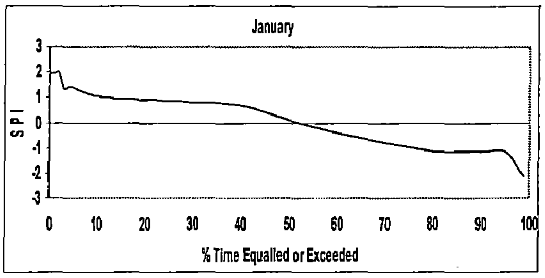
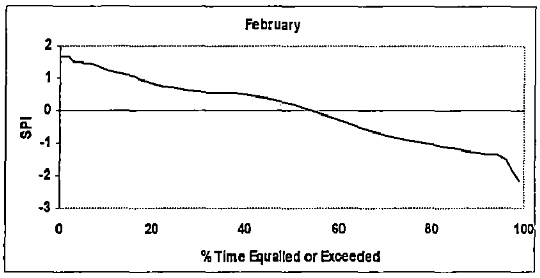


Fig. III (A): SPI (1 month) Probability Distribution Curves

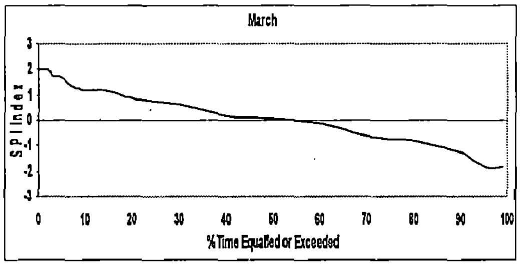
Annexure -III (A) Contd.



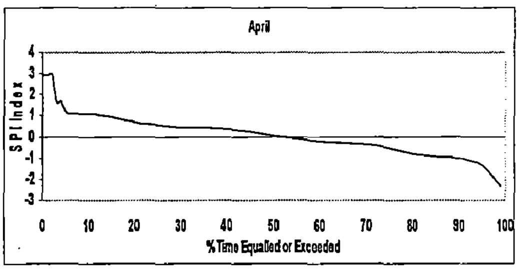
January



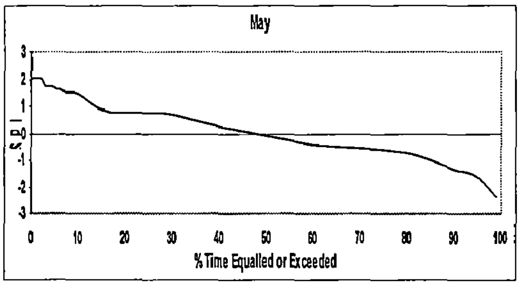
February



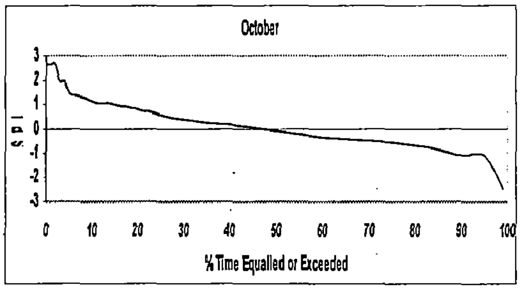
March



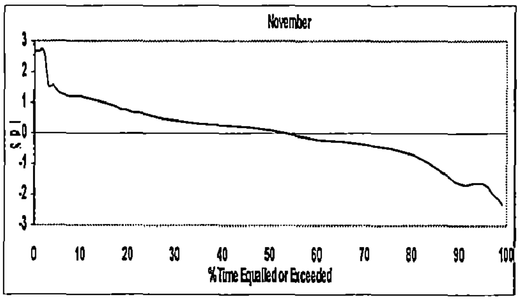
April



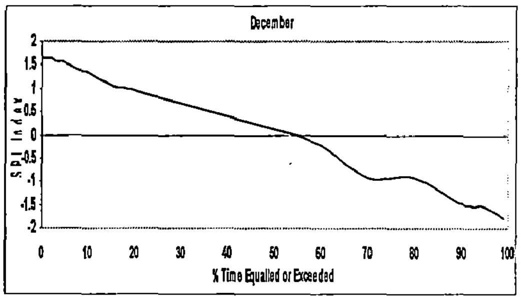
May



October



November

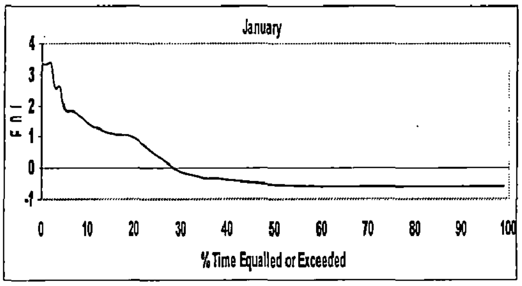


December

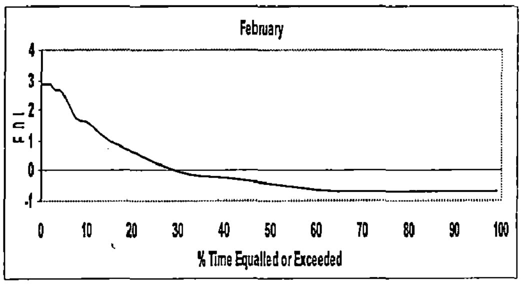
Fig. III (A): Contd. SPI (3 month) Probability Distribution Curves

ANNEXURE- III (B)

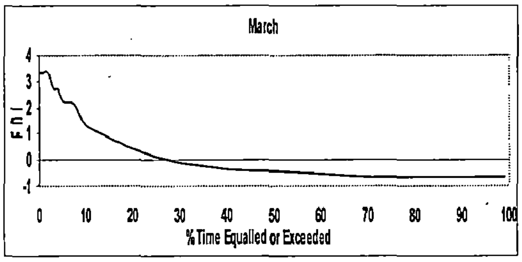
Probability Distribution Curves of EDI in the Focus Area



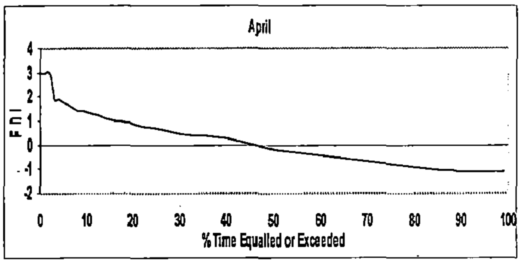
January



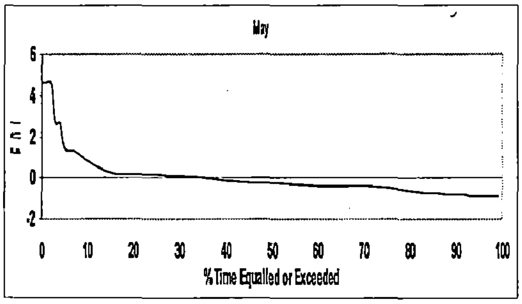
February



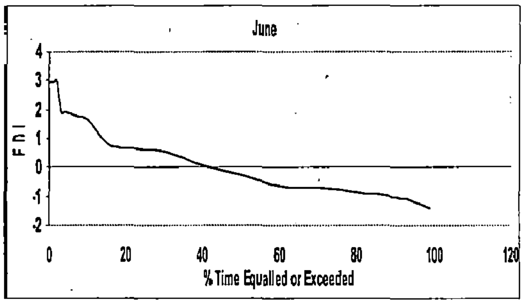
March



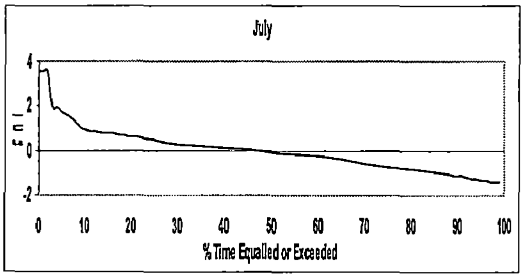
April



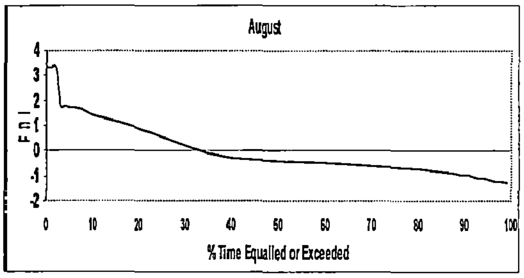
May



June



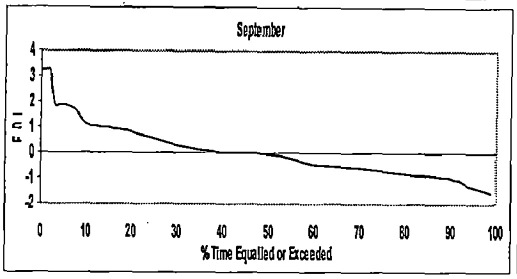
July



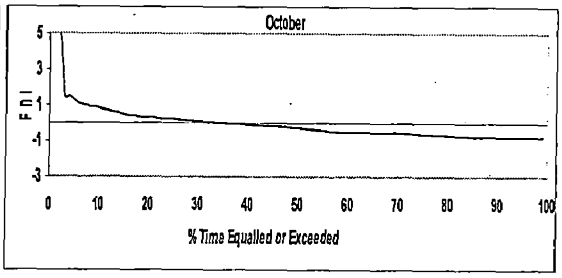
August

Fig. III (B): EDI (1 month) Probability Distribution Curves

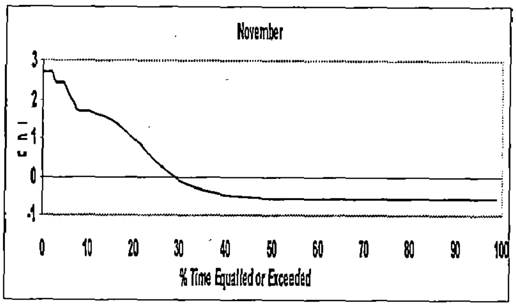
Annexure- III (B) Contd.



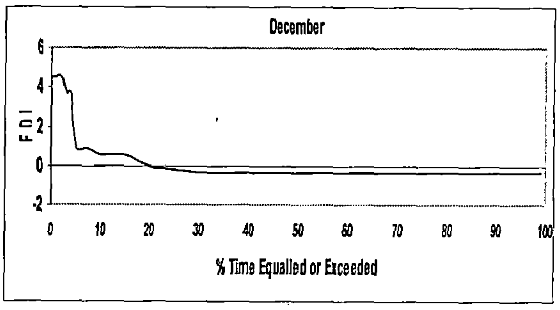
September



October

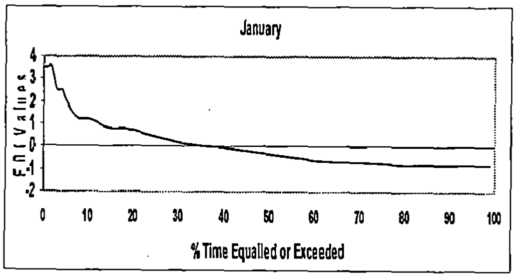


November

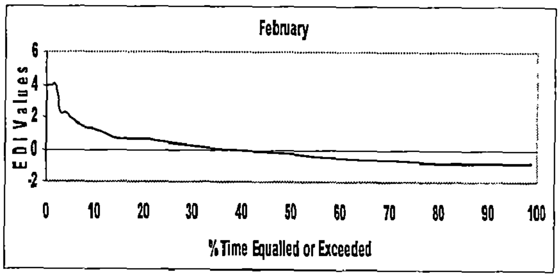


December

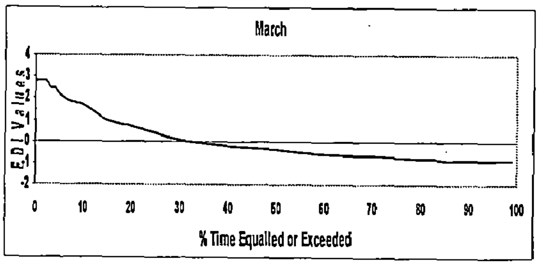
EDI (1 month) Probability Distribution Curves. Contd.



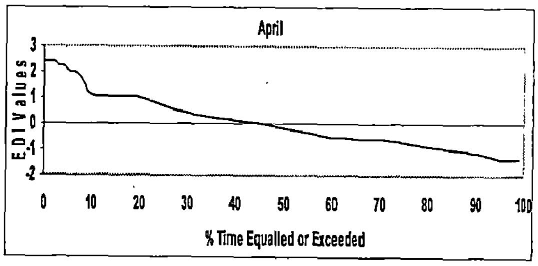
January



February



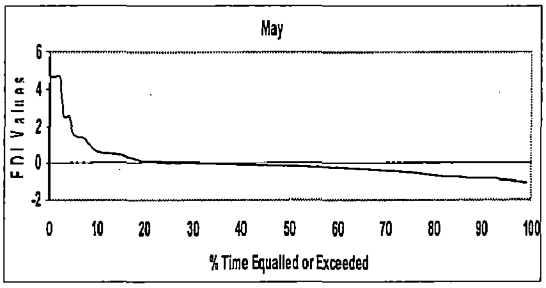
March



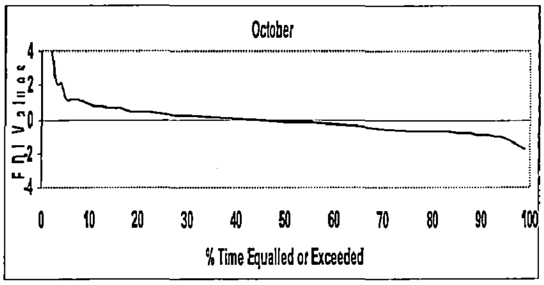
April

Fig. III (B): Conntd. EDI (3 month) Probability Distribution Curves

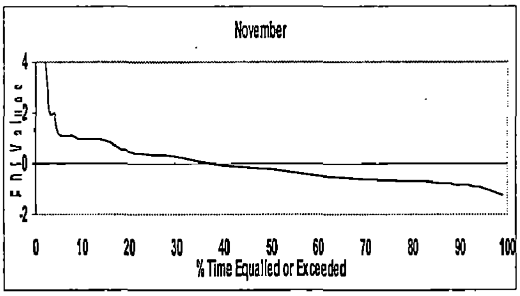
Annexure- III (B) Contd.



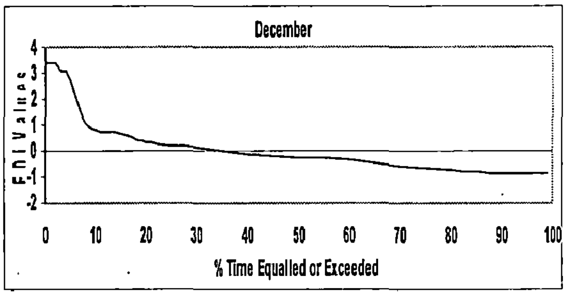
May



October



November



December

EDI (3 month) Probability Distribution Curves, Contd.

ANNEXURE- III (C)

Probability Distribution Curves of Deciles Indices in the Focus Area

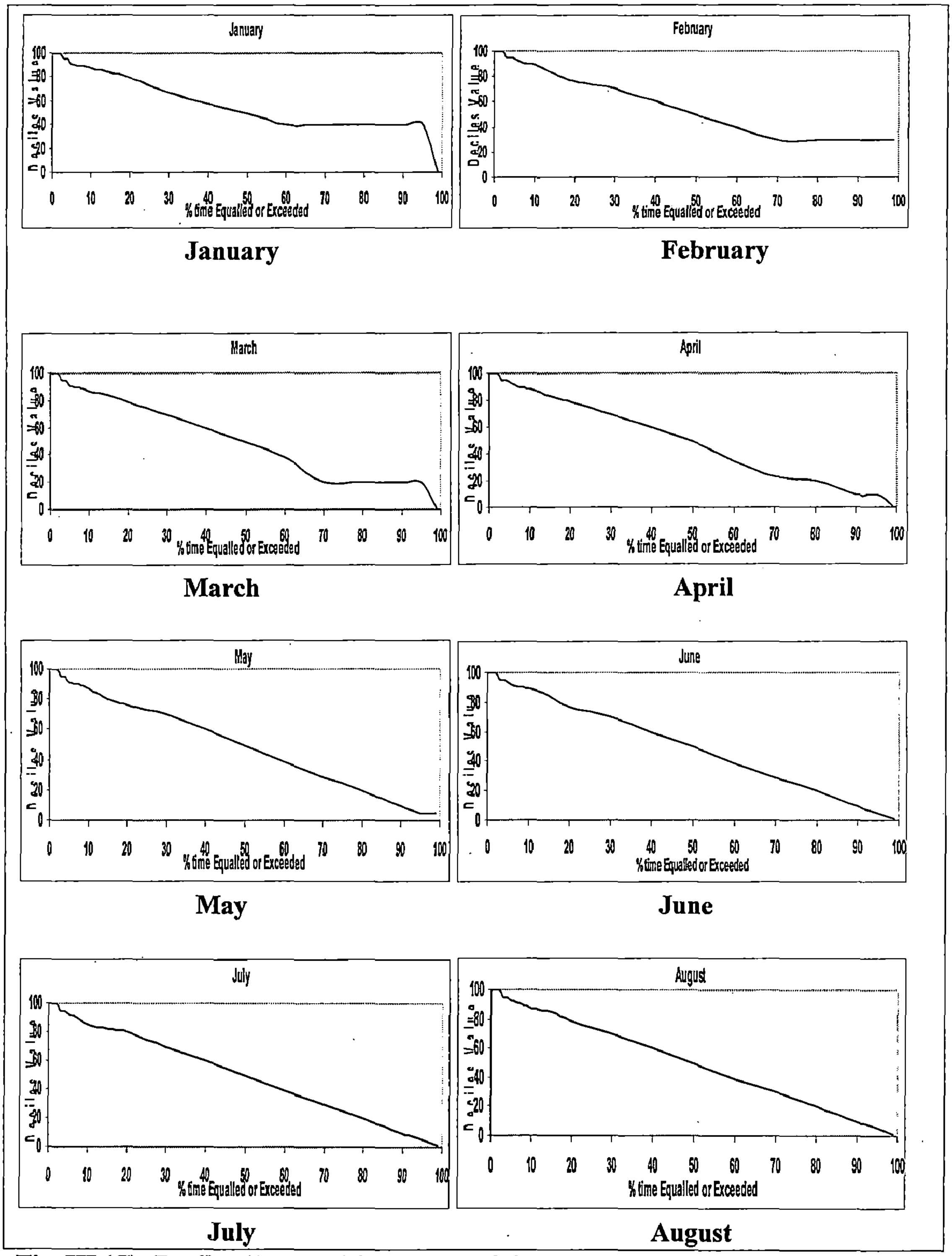
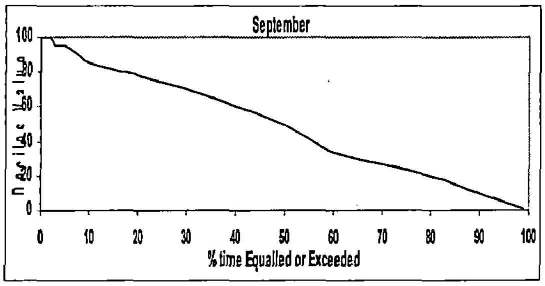
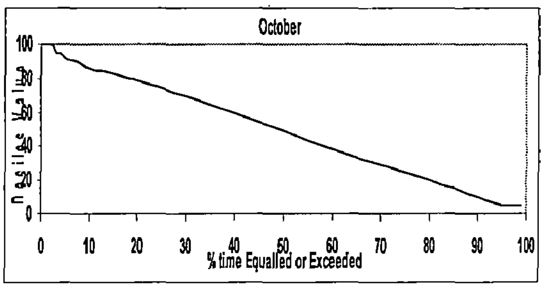


Fig. III (C): Deciles (1 month) Probability Distribution Curves

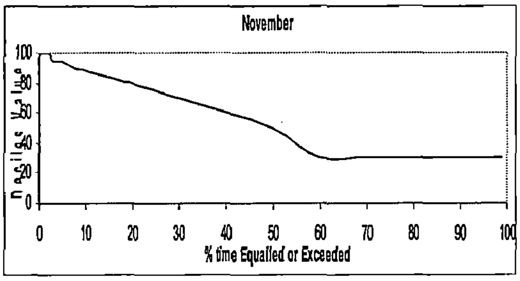
Annexure- III (C) Contd.



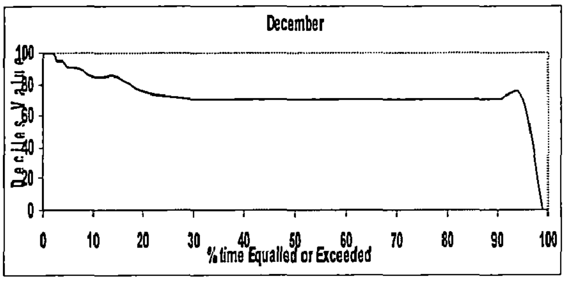
September



October



November



December

Deciles (1 month) Probability Distribution Curves Contd.

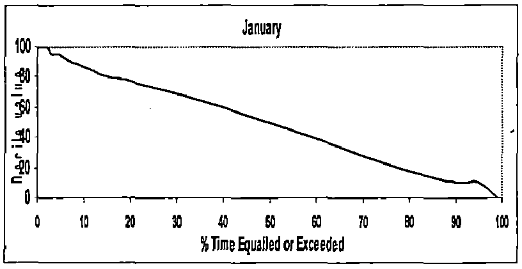


Fig.13 January

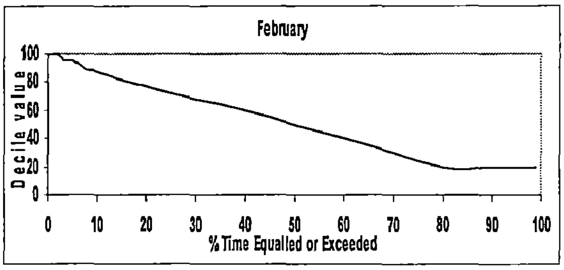


Fig.14 February

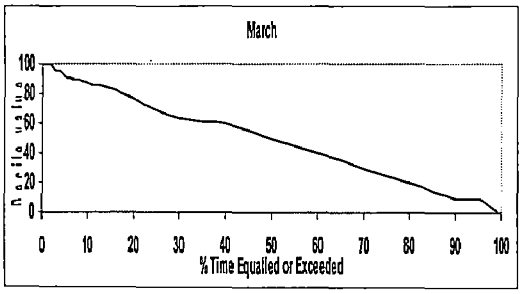


Fig.15: March

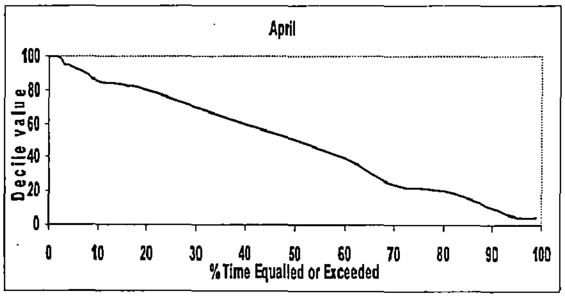


Fig.16: April

Fig. III (C): Contd. Deciles (3 month) Probability Distribution Curves

Annexure- III (C) Contd.

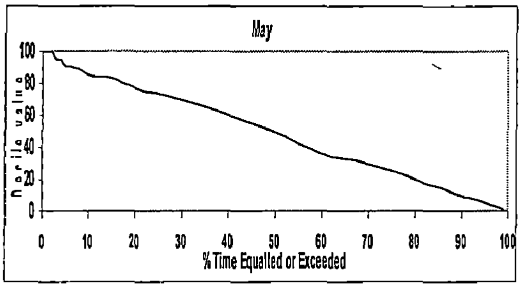


Fig.17: May

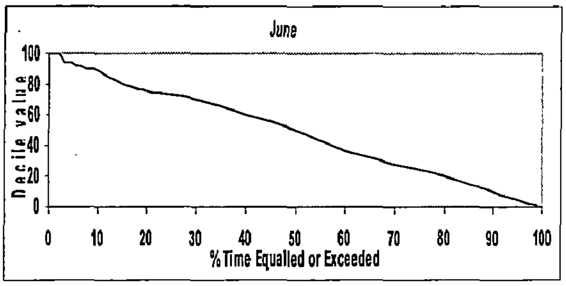


Fig.18: June

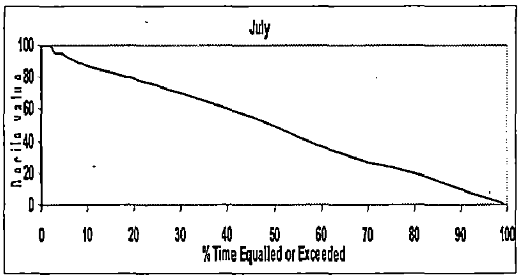


Fig.19: July

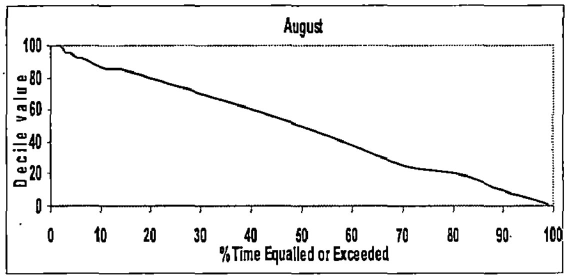


Fig.20 August

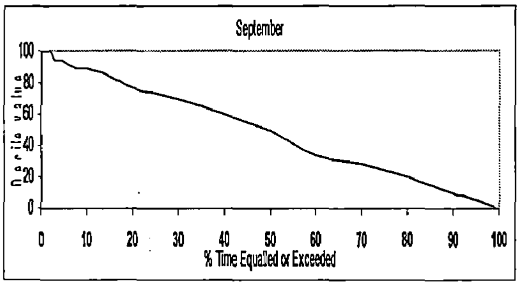


Fig.21: September

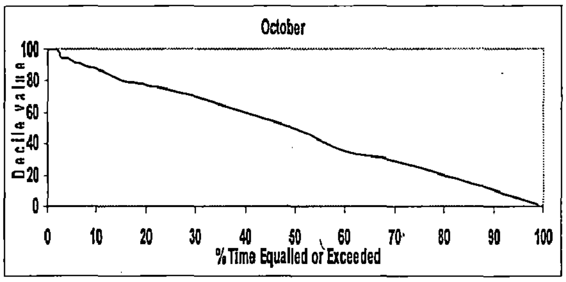


Fig.22: October

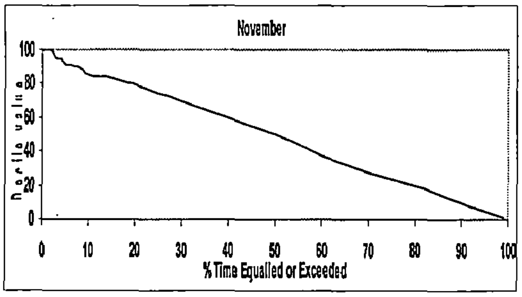


Fig.23: November

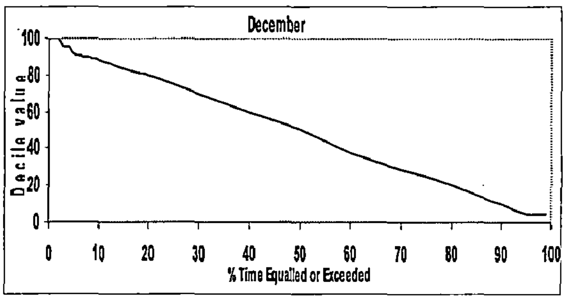
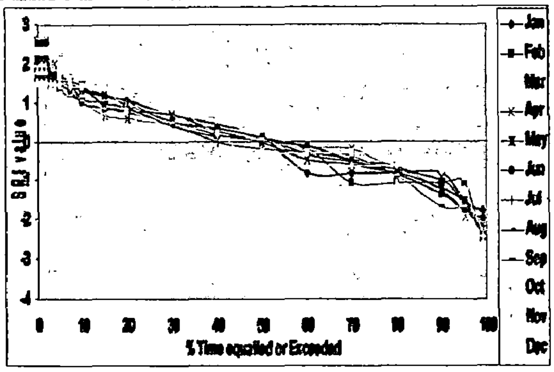


Fig.24: December

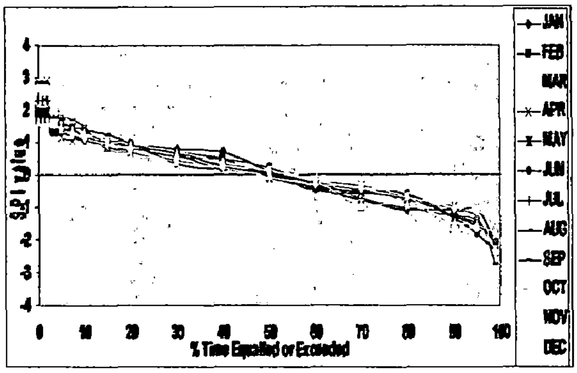
Deciles (3 month) Probability Distribution Curves, Contd.

ANNEXURE- III (D)

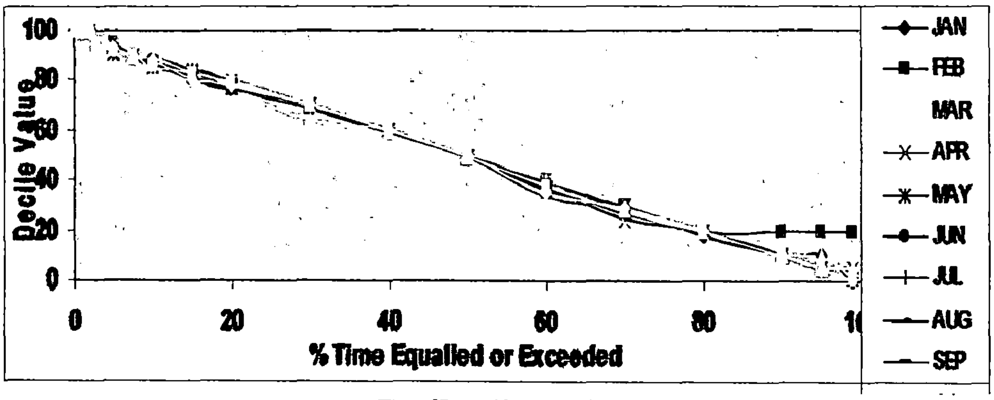
Compare of Probability Distribution of all 12 months in a Year



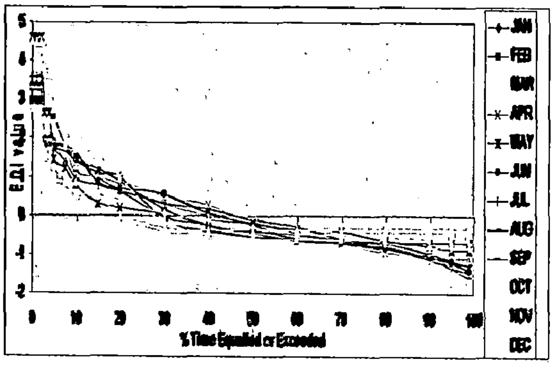
SPI (1month)



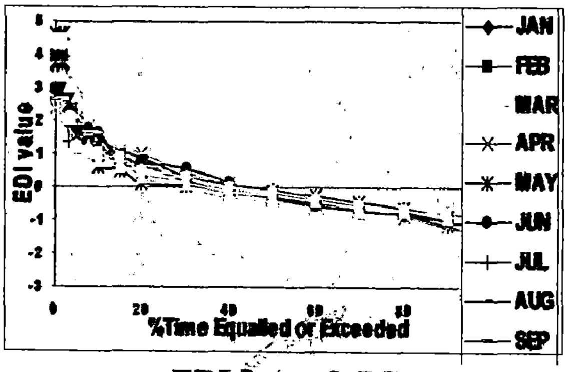
SPI (3month)



Deciles (3month)



EDI 1month DS

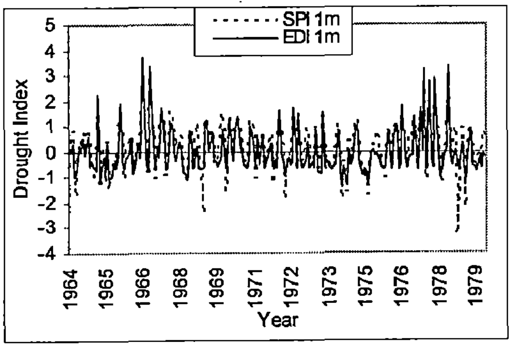


EDI 3month DS

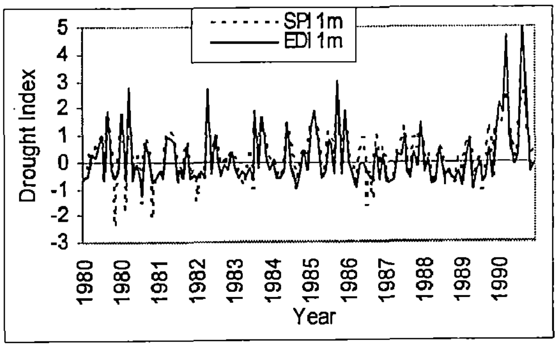
Fig. III (D): Probability Distribution of all 12 months of SPI, Deciles and EDI

ANNEXURE - IV

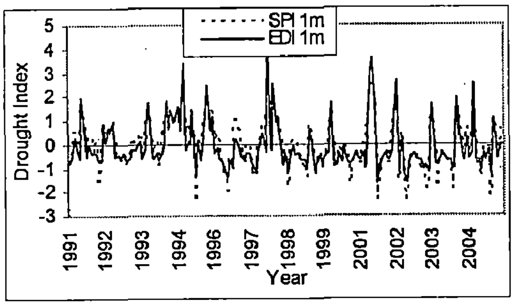
Comparison of SPI and EDI Values in the Focus area



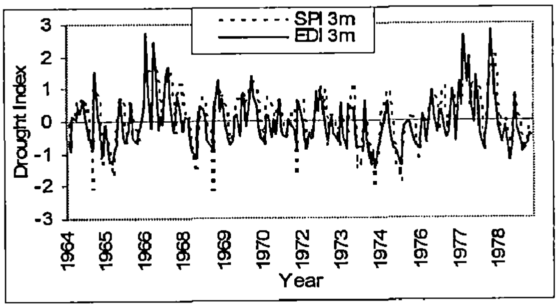
1-Month RM Values (1964-1979)



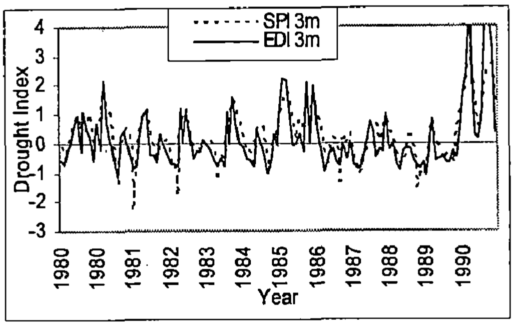
1-Month RM Values (1980-1990)



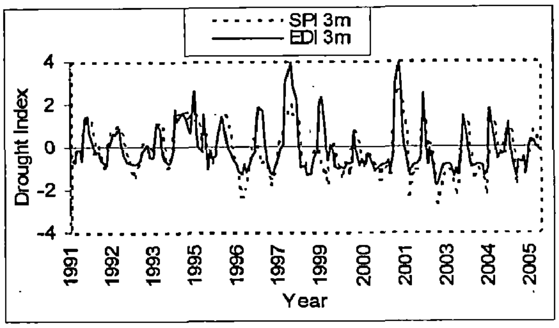
1-Month Values RM (1991-2005)



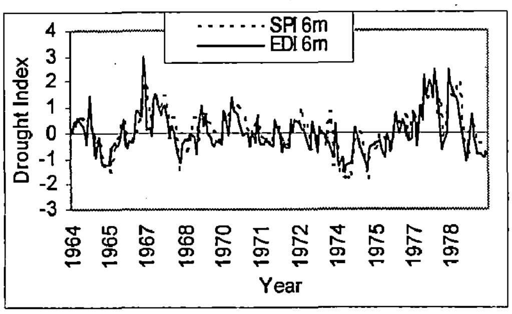
3-Month RM Values (1964-1979)



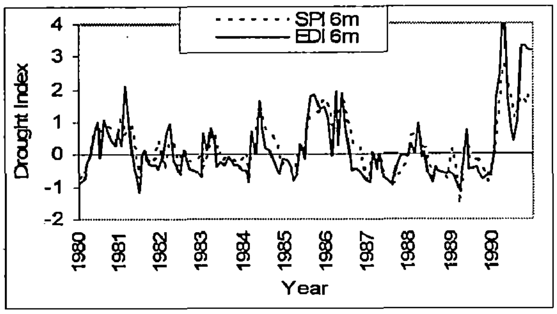
3-Month RM Values (1980-1990)



3-Month RM Values (1991-2005)



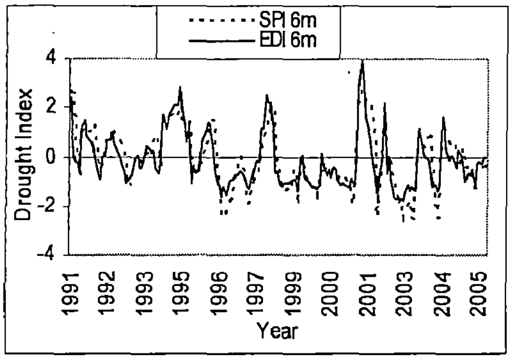
6-Month RM Values (1964-1979)



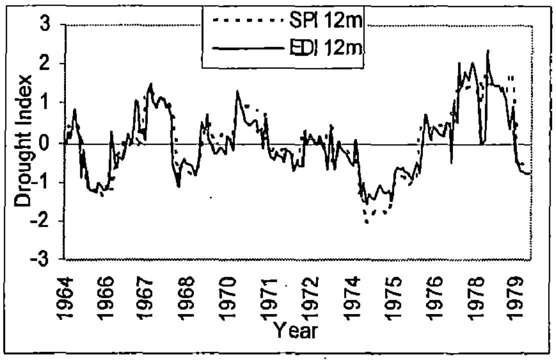
6-Month RM Values (1980-1990)

Fig. IV: Comparison of SPI and EDI Values with Different RM.

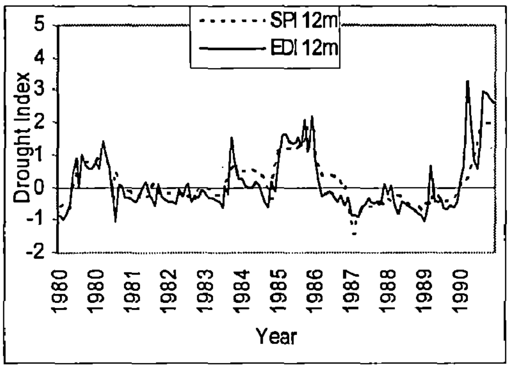
Annexure- IV contd.



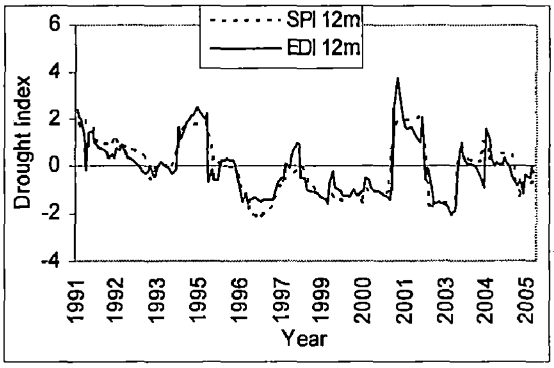
6-Month RM Values (1991-2005)



12-Month RM Values (1964-1979)



12-Month RM Values (1980-1990)

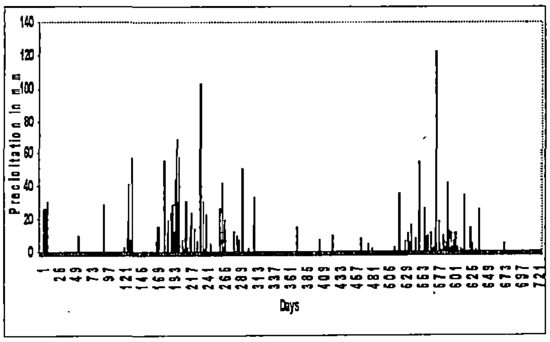


12-Month RM Values (1991-2005)

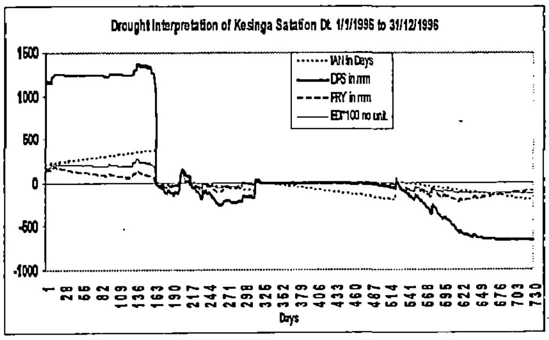
Comparison of SPI and EDI Values with Different RM, Contd.

ANNEXURE- V

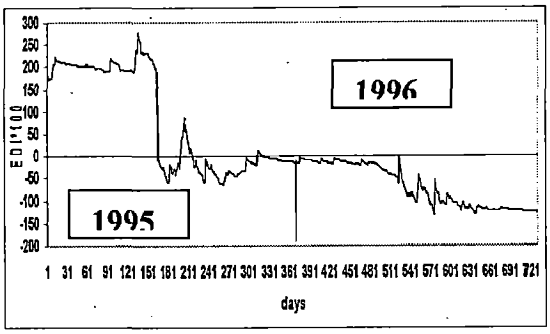
EDI Daily Precipitation and Drought Analysis for Consecutive two Years (DT 1/1/1995 to 31/12/1996) at Selected Stations in Focus area



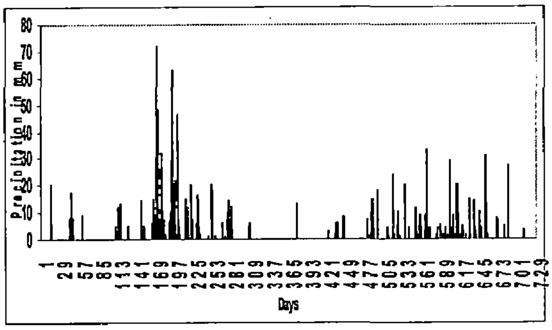
Daily Precipitation at Kesinga Station



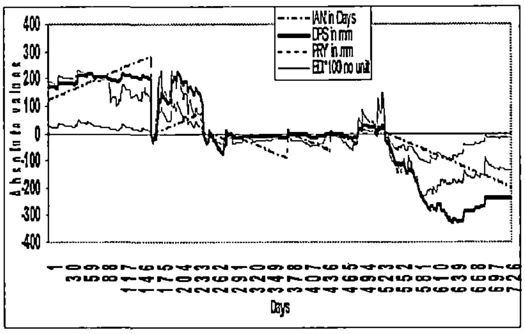
Variation of Drought indicators at Kesinga



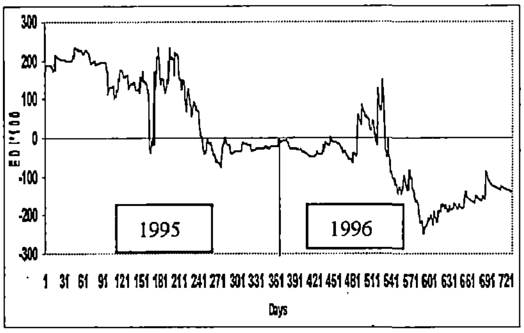
Daly Variation of EDI at Kesinga



Daily Precipitation at Lanjigarh Station



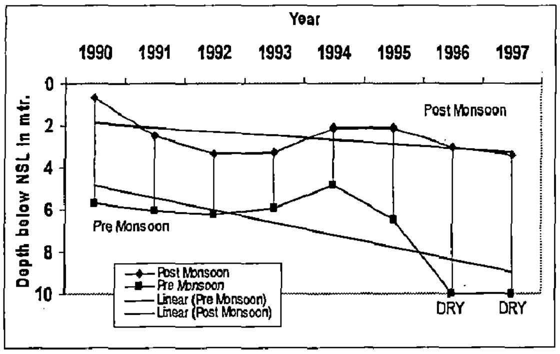
Variation of Drought indicators at Lanjigarh



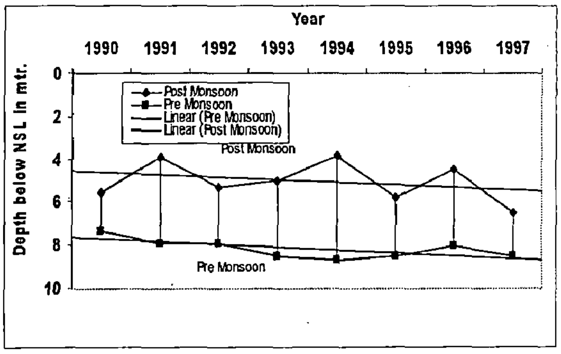
Variation of EDI at Lanjigarh

ANNEXURE- VI

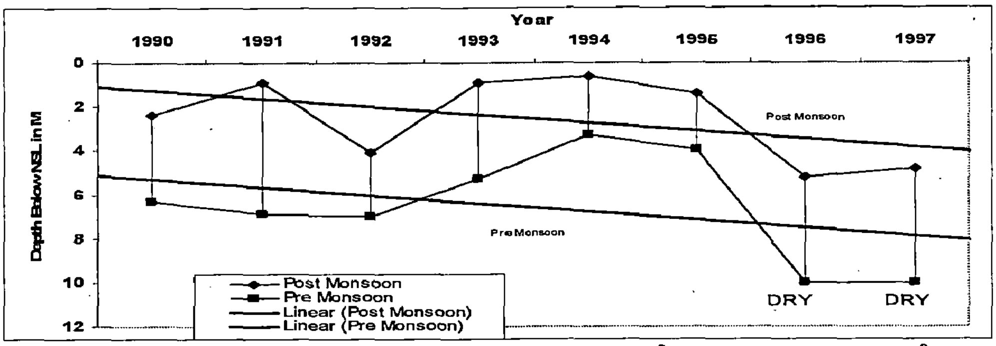
Ground Water table Fluctuations at Hydrograph Networking Stations in the Focus area (Kalahandi and Nuapada District)



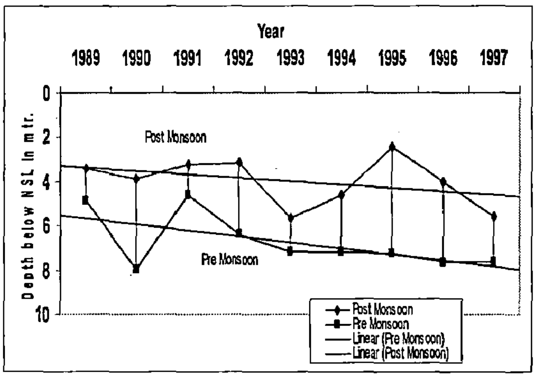
Station Lanjigarh (Chendia) D/W
Lat 19⁰-53'-00"N & Long 82⁰-49'E



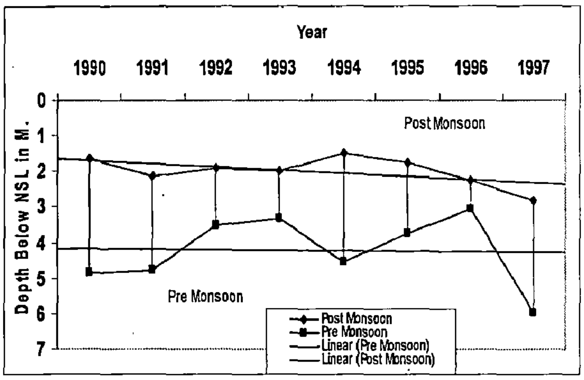
Station Khariar (Daldali) D/W
Lat 20⁰-42'-00"N & Long 82⁰-36' E



Station M. Rampur (Bisnathpur) D/W Lat 20⁰-50'"N & Long 83⁰-25'E



Station Nuapada (Palsada) D/
Lat 20⁰-18'-00"N & Long 82⁰-42' E



Station Kesinga, Baddungriguda
D/W Lat 20⁰-22'-00"N & Long 83⁰-36' E