Fig 7: Spatial Pattern of Trend (^{0}c/ 100 years) in Mean Annual Temperature Anomalies (1901-2009). Areas where trends are significant are shaded (red : warming, blue : cooling)
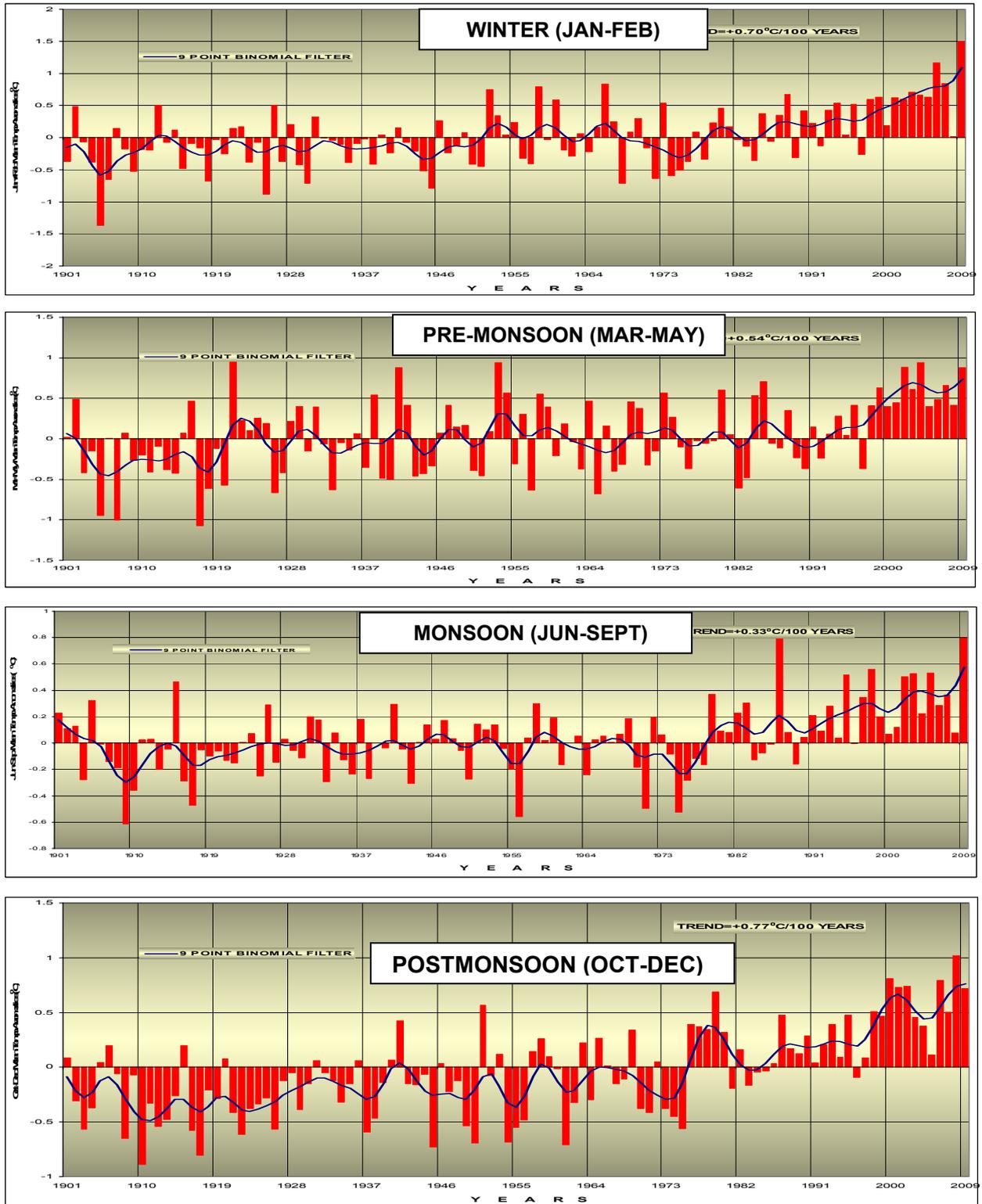
25

Fig 8: All India Mean Temperature Anomalies for the four seasons for the period 1901-2009 (based on 1961-1990 average)
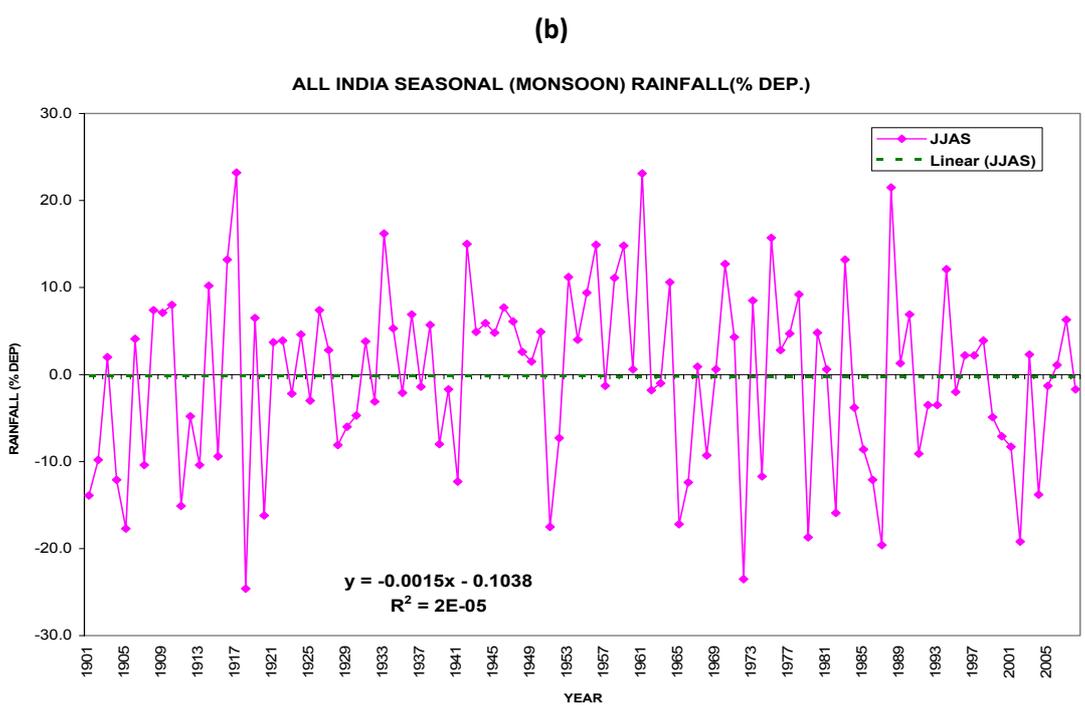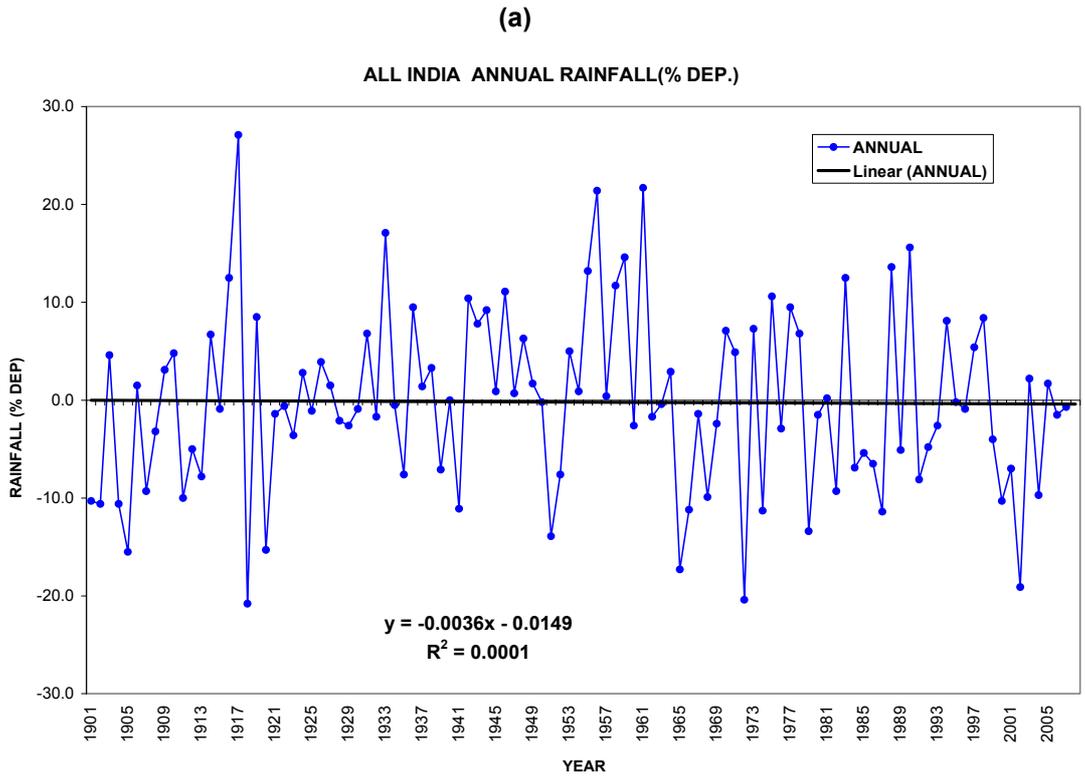
26

(a)

ALL INDIA ANNUAL RAINFALL(% DEP.)

$$y = -0.0036x - 0.0149$$
$$R^2 = 0.0001$$

(b)

ALL INDIA SEASONAL (MONSOON) RAINFALL(% DEP.)

$$y = -0.0015x - 0.1038$$
$$R^2 = 2E-05$$

**Fig 9: Trend in all India rainfall data for country as a whole, a) annual
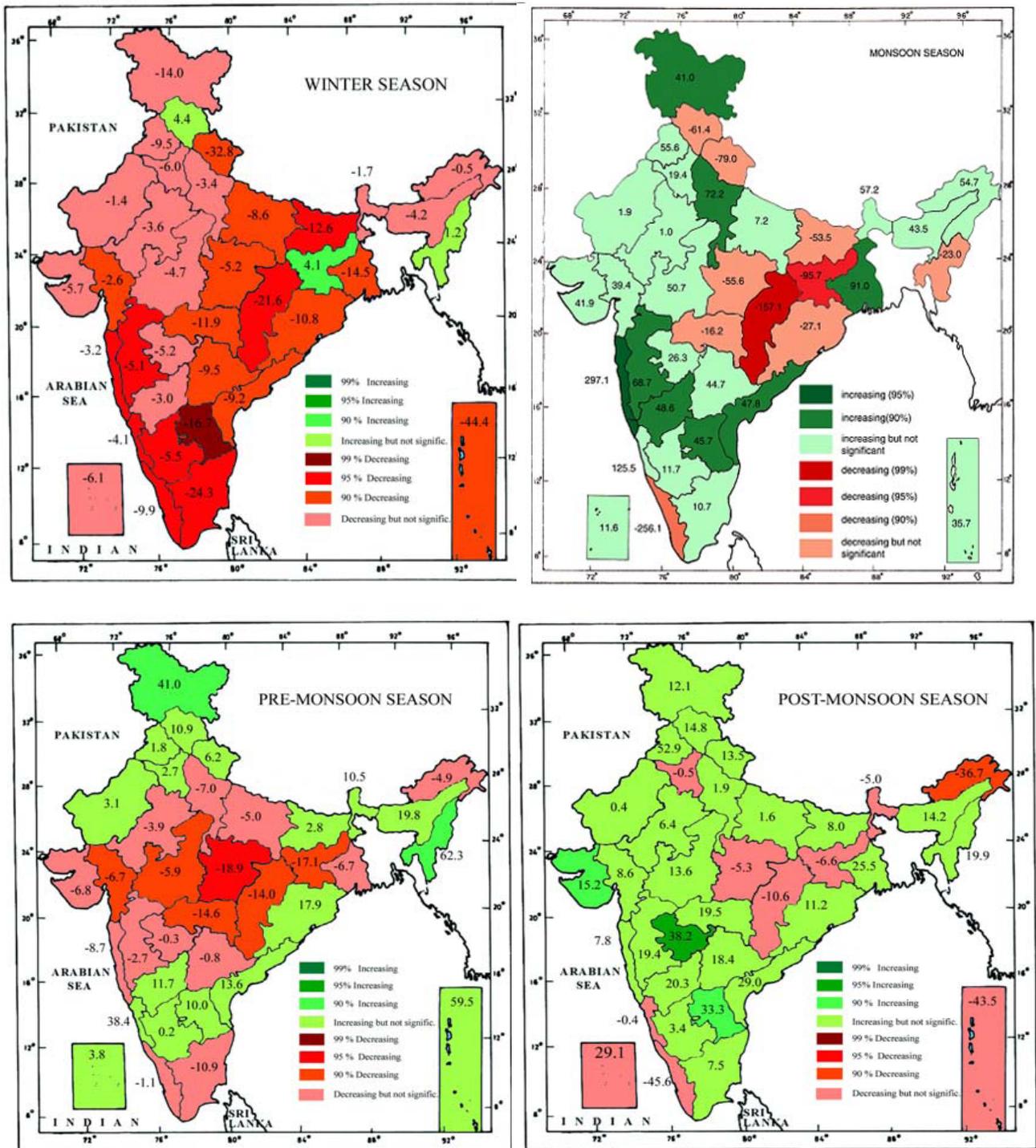b) monsoon season, for the period 1901-2009.**

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Fig 10: Trend in sub- divisional rainfall data (increase/decrease in rainfall in mm) for different seasons season (1901-2003). Different levels of significance are shaded with colors.
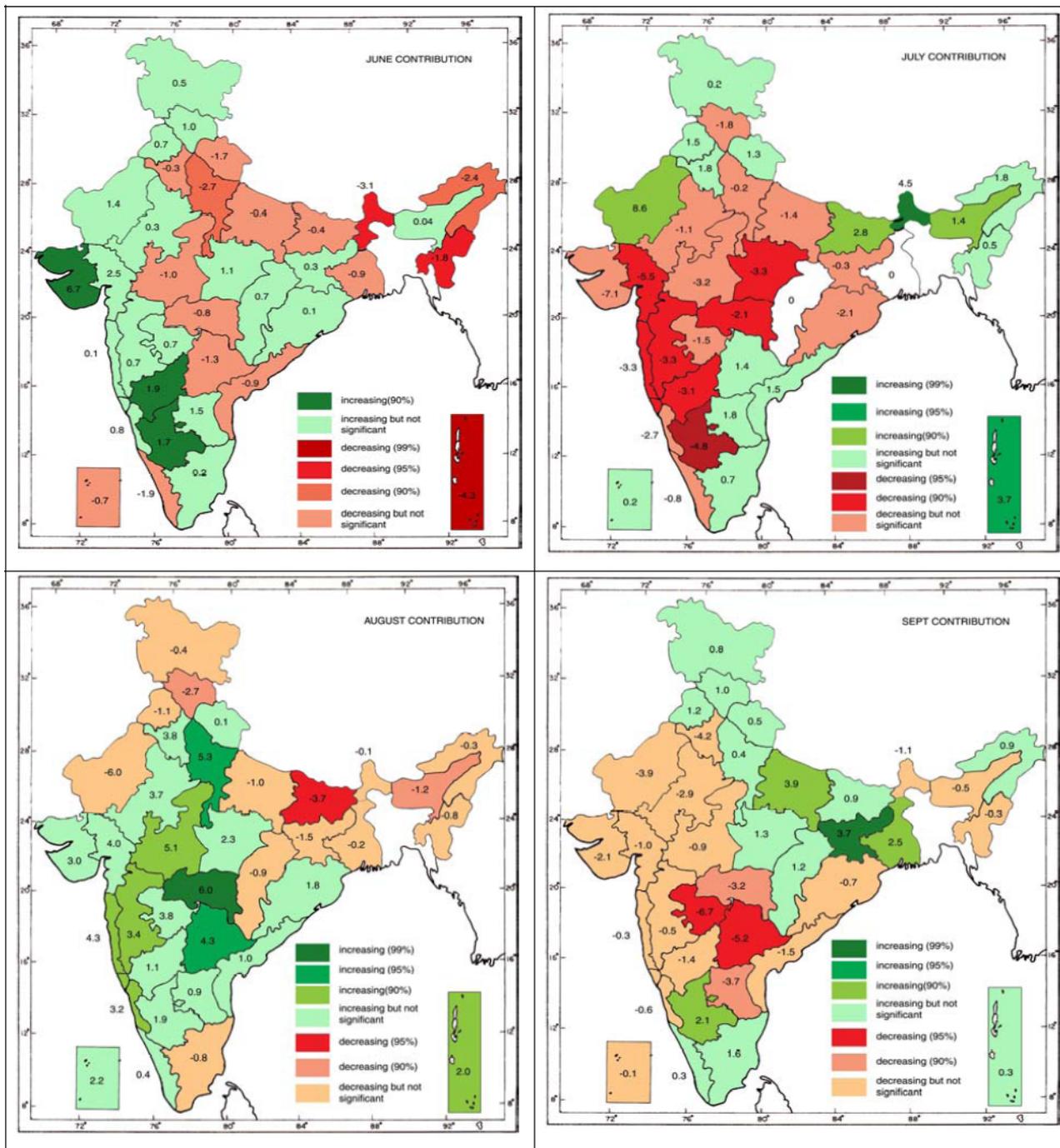
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Fig 11: Trend in sub- divisional rainfall data of monsoon months (increase/Decrease in rainfall in percentage) to annual rainfall (1901-2003).

29

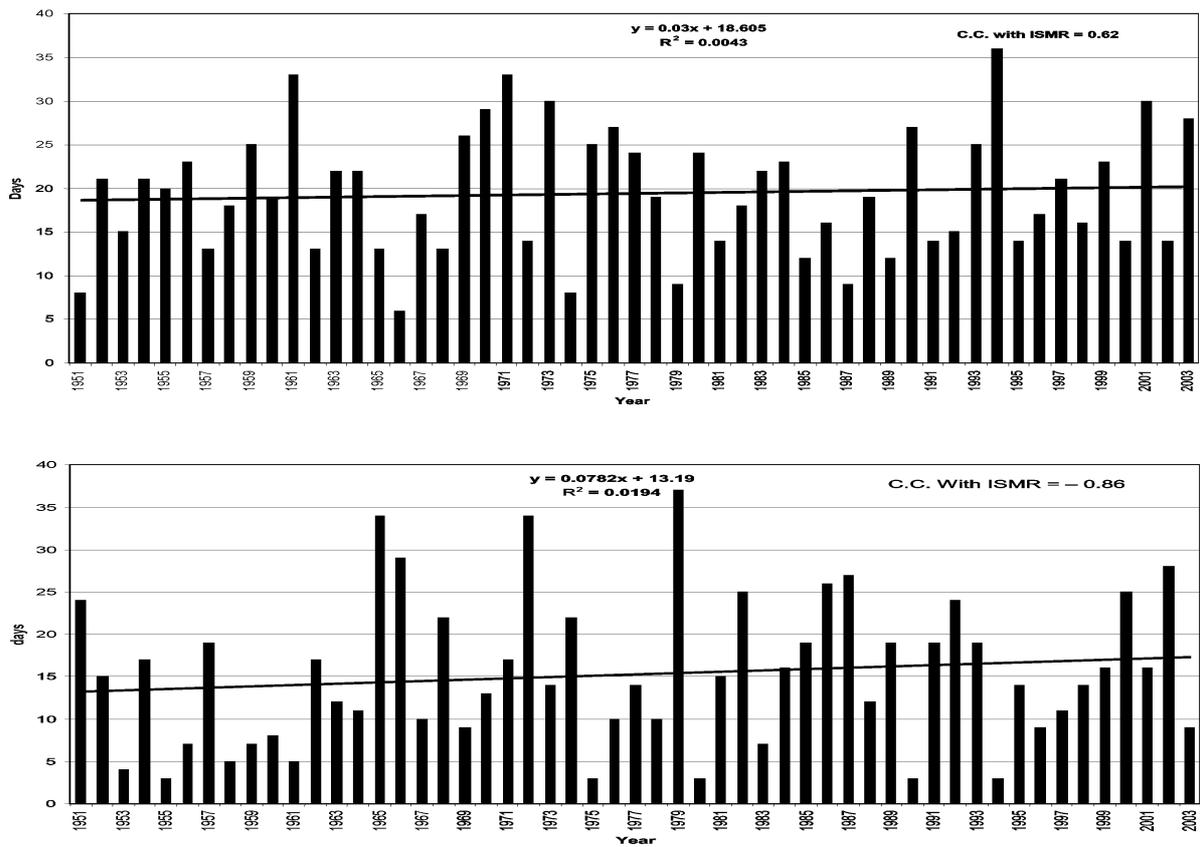**Fig. 12 : Time series of active days (*a*) and (*b*) break days during the monsoon season (1951–2003).**
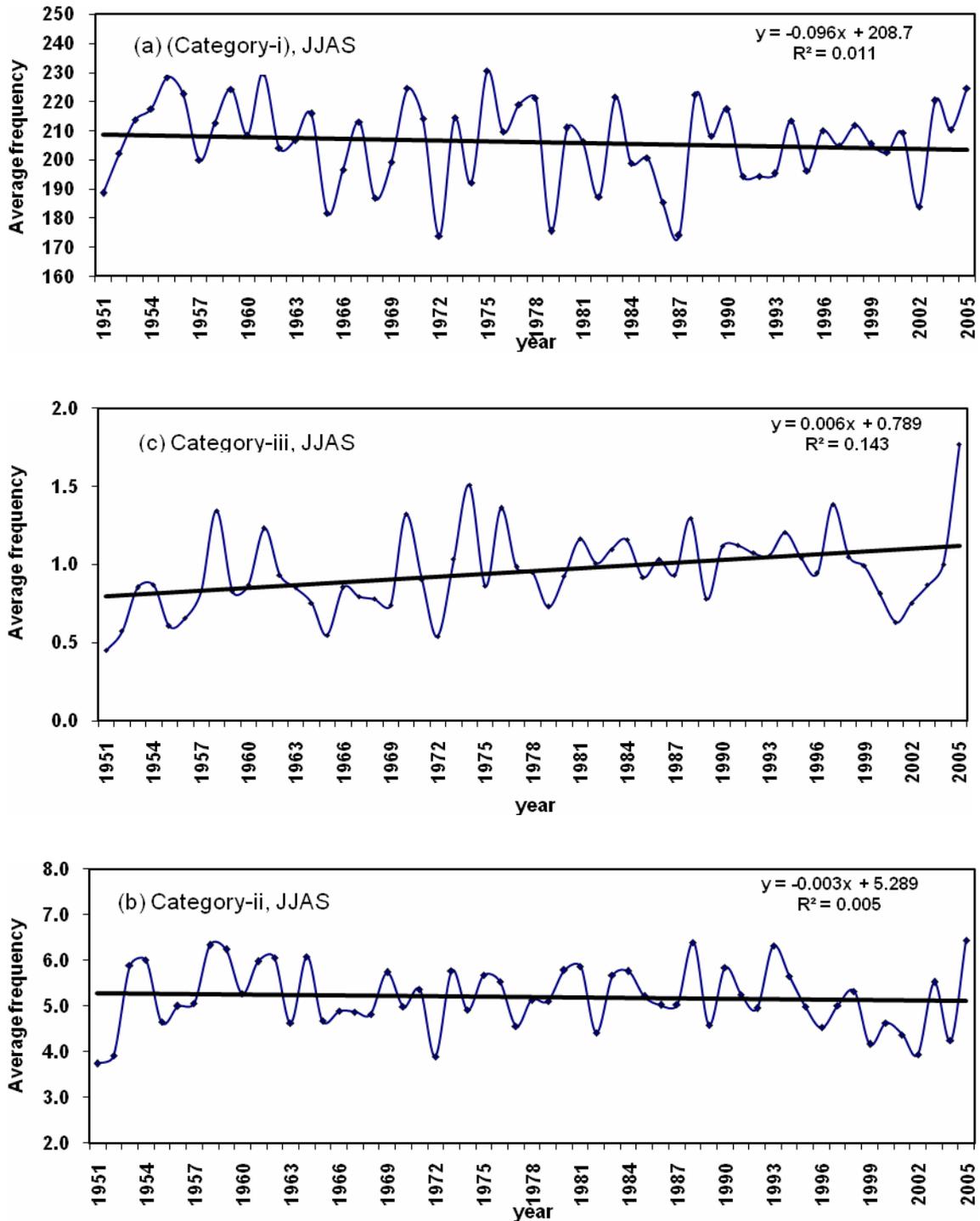
Fig. 13 : Average frequency (count per day) of occurrence of different rainfall (R) events during monsoon season (June to September) from 1951 to 2005. (a) Category-i with 'R' ≤ 64.4 mm in a day, (b) Category-ii with 64.4 < 'R' ≤ 124.4 mm in a day & (c) Category-iii with 'R' > 124.4 mm in a day.

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Fig 14: Average frequency (count per day) of occurrence of category-iii rainfall events (rainfall > 124.4 mm in a day) on monthly scale from (a) June to (d) September during the period from 1951 to 2005

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Chapter - IV

BEHAVIOUR OF MONSOONS

Southwest / Summer Monsoon

The behavior of major features of Southwest Monsoon can be analysed for any characteristic trend exhibited by them over the period of years in terms of the following:
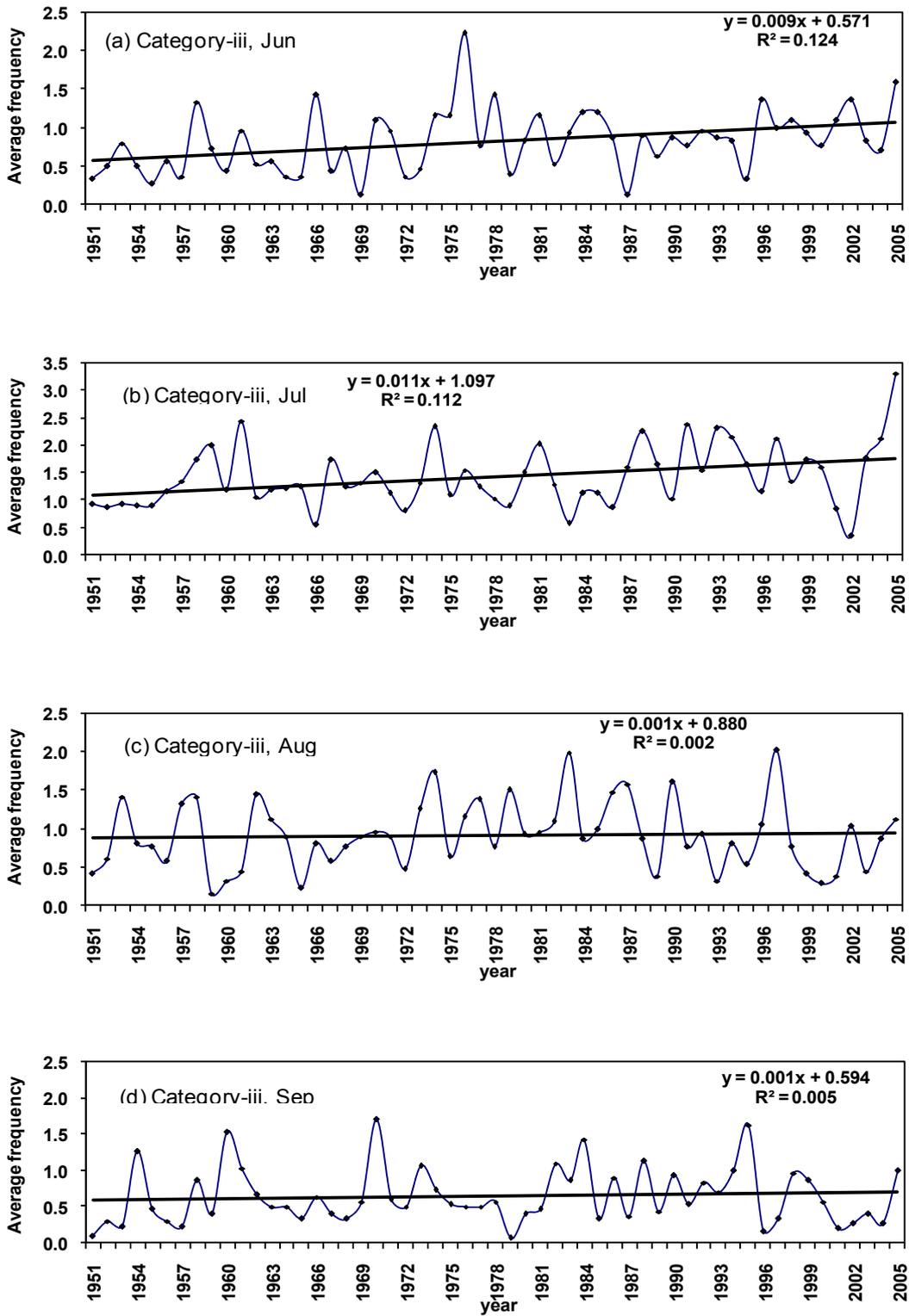
- Dates of monsoon onset, duration of monsoon over the country in terms of number of days and dates of withdrawal (Mazumdar et al 2001)

- Quantum of monsoon rainfall over various meteorological sub-divisions during June to September.

- Frequency of monsoon low pressure systems viz. Depressions, well marked lows, low pressure areas etc.

4.1   Variability in monsoon Onset and Withdrawal

A study of mean dates of onset of monsoon for the period 1941-2000 (Mazumdar et al 2001) revealed that the mean onset dates over majority of subdivisions have been later than normal in both the 30 years' time slots of 1941-1970 and 1971-2000.The magnitudes of late onset during 1941 – 1970 have been higher than those during 1971 – 2000. Some of these deviations are statistically significant. The maximum deviation being 11 and 7 days over Andaman & Nicobar Islands during 1941 – 1970 and 1971 – 2000 respectively. Since, for India as a whole, the commencement of onset starts from Andaman & Nicobar Islands, the SW monsoon had a late start by about a week during the period of study.

Based on 100 years (1901 – 2000) of data, the onset dates for the twentieth century, when compared to the existing normals, the differences for the period are marginal except for Andaman Nicobar Islands where it has been greater (late onset) by about 5 days.

The lowest Standard Deviation (SD) of date of onset of about 5 days is over Andaman & Nicobar Islands during 1971-2000 and the highest of 14 days is over Jammu and Kashmir. For every subdivision of India, the values of SD are higher during 1941-1970 as compared to 1971-2000. Generally, the SDs of onset dates are about one week over high rainfall area and North Eastern parts, increasing to one and half week towards low rainfall areas of West and North Western parts of India. Generally, decreasing trends are found over northern parts (North of 25ºN) and increasing trends over southern parts of India.

The mean withdrawal dates are found to be later than the existing normal, in both the 30 years slot of 1941 – 1970 and 1971 – 2000, by about one to one and a half week. A general late onset, as concluded earlier coupled with late withdrawal suggests a shift in the monsoon activity. The SDs of withdrawal dates range from 11 to 14 days during 1941 – 1970 and from 7 to 10 days during 1971 – 2000. This indicates that the variability in the withdrawal of monsoon has been greater during the first 30 years period as compared to the later half, not only in temporal but also in spatial scales.

The duration of southwest monsoon is found to be higher than normal almost in all meteorological sub-divisions in both the 30 years' period. The duration is much higher in the first half as compared to that during the second half. The SDs of duration of monsoon varies between 13 and 19 days and 7 to 15 days during 1941-1970 and 1971-2000, respectively. These results are shown in Fig. 15 and Fig. 16. Decadal and epochal variability indicates near 30 year's periodicity in onset, withdrawal and duration of the monsoon.

Trends in the sub divisional rainfall data for the individual monsoon months are depicted as under:

- June rainfall has shown significant increasing trend for the western and southwestern parts of the country, whereas significant decreasing trend is observed for the central and eastern parts of the country.

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- July rainfall has significantly decreased for most parts of the central and peninsular India   but has increased significantly in the northeastern parts of the country.

- August rainfall has increased significantly for the subdivisions Konkan & Goa, Marathwada, Madhya Maharashtra, Vidarbha, West Madhya Pradesh, Telengana and West Uttar Pradesh.

- September rainfall has shown significantly decreasing trend for subdivisions Vidarbha, Marathwada and Telangana and increasing trend for the subdivision Sub Himalayan Gangetic West Bengal (Guhathakurta and Rajeevan, 2008).

4.2.   Trend in Withdrawal of monsoon

The mean withdrawal dates are found to be later than the existing normal, in both the 30 years slot of 1941 – 1970 and 1971 – 2000, by about one to one and a half week. A general late onset, as concluded earlier coupled with late withdrawal suggests a shift in the monsoon activity. The SDs of withdrawal dates range from 11 to 14 days during 1941 – 1970 and from 7 to 10 days during 1971 – 2000. This indicates that the variability in the withdrawal of monsoon has been greater during the first 30 years period as compared to the later half, not only in temporal but also in spatial scales.

4.3   Duration of SW monsoon

The duration of southwest monsoon is found to be higher than normal almost in all meteorological sub-divisions in both the 30 years' period. The duration is much higher in the first half as compared to that during the second half.

The SDs of duration of monsoon varies between 13 and 19 days and 7 to 15 days during 1941-1970 and 1971-2000, respectively.

Major findings of analyses of onset, withdrawal and duration of SW monsoon as during the period 1941-2000 are:

(i)   Slight shift of monsoon activity with late onset and late withdrawal.

(ii)   Increase in the duration of the monsoon by about a week, as compared to normal duration.

(iii)   Decreasing trends in onset dates, roughly north of 25°N and general decreasing trends in both withdrawal and duration of the monsoon ;

(iv)   Decadal and epochal variability indicate near 30 year's periodicity in onset, withdrawal and duration of the monsoon.

4.4   Monsoon Forecasting (Long Range/ Seasonal Forecasting)

4.4.1 History

IMD started issuing tentative forecasts from 1882 to 1885 utilizing the indications provided by the snowfall in Himalayas. The success achieved infused greater confidence and the first of the regular series of forecasts was given on the 4th June 1886 and is continuing practically till date but for changes in its format and content.   In 1892, long range forecast (LRF) for the rainfall for the second half of the monsoon season (August-September) was also started. In December 1893, the first forecast for winter precipitation over the Northern and central India was issued. Various subjective methods such as analogue and curve parallels for the LRF of Indian Summer Monsoon Rainfall (ISMR). The efforts for better forecasts continued during the period during 1904-1924 and IMD started the forecasts based on objective techniques using   correlation and regression techniques for preparing long range forecasts and discovered importance of Southern Oscillation, North Atlantic Oscillation and North Pacific Oscillation for monsoons. In 1922, India was divided into three main homogenous areas, namely, i) Peninsula ii) N.E. India and iii) North-west India. In 1935, forecast for NE India was discontinued. The issuance of forecast for two homogenous regions (NW India and Peninsula) was continued till 1987.

In 1988, IMD introduced operational 16 parameter power regression for issuing   quantitative forecasts and parametric models for   qualitative forecasts (whether normal/excess or deficient) for the southwest monsoon rainfall over the country as a whole. IMD introduced a new two stage forecast strategy in 2003 viz. the first stage forecast for the seasonal (June to September) rainfall over the country

as a whole is issued in April and the update for the April forecasts is issued in June. Along with the update forecast, forecast for seasonal rainfall over broad homogeneous rainfall regions of India and July rainfall over country as a whole are also issued. During the period 2003-2006, the first stage quantitative and 5 category probabilistic forecast for the season rainfall over the country as a whole were issued using 8-parameter power regression (PR) model and Linear Discriminant Analysis (LDA) model respectively. Update for the first stage forecasts were issued using 10 Parameter PR and LDA models. In 2007, IMD introduced new statistical forecasting system based on ensemble technique for the south-west monsoon season (June to September) rainfall over the country as a whole.

4.4.2 Present forecasting system

At present, the forecast for the South-West monsoon rainfall is issued in two stages. The first stage forecast for the seasonal (June to September) rainfall over the country as a whole is issued in April and the update of the April forecast in June. Along with the update forecast, forecast for seasonal rainfall over four broad geographical regions of India and July rainfall over country as a whole are also issued.

For issuing the forecast for the seasonal rainfall over the country, a new statistical forecasting system based on the ensemble technique was introduced in 2007 using   8 predictors for the new ensemble forecast system as summarized in Table 2. The predictors used for the April forecast and the updated forecast in June are   presented in Table 3 and table 4 respectively. The model error of the April forecast system is 5% and for the June forecast system, it is 4%. For developing the models, two different statistical techniques viz. Multiple Regression and Projection Pursuit Regression were considered

For the forecast of July rainfall over the country as a whole, a statistical model with 6 predictors was developed using Principal Component Regression (PCR) technique. The predictors used are: North Atlantic Sea surface temperature (December of previous year), NINO 3.4 Sea Surface Temperature (May +June), North Pacific mean sea level pressure (March), East Asia mean sea level pressure

(February + March), North Atlantic mean sea level pressure (May) and Equatorial Indian Ocean mean sea level pressure (November of previous year). The model error of the model for July rainfall is 9%.

For forecasting of South-West monsoon season rainfall over the four broad geographical regions of India (NW India, Central India, South Peninsula and NE India), multiple regression (MR) models based on separate set of predictors are used. All the four multiple linear regression models have model errors of 8% of LPA.

IMD also prepares an extended range forecast for the onset of southwest monsoon rainfall over Kerala. This forecast was first issued in 2005 using indigenously developed statistical model with 6 predictors (Table 5).

In addition, IMD prepares operational long range forecasts for the Winter Precipitation (Jan to March) over Northwest India and Northeast Monsoon rainfall (October to December) over South Peninsula. For this purpose, separate statistical models have been developed.

Table 2
Predictors used in new ensemble forecast system of Monsoon over India

S.N.	Predictor (Period)	Used for the forecasts in
1	North Atlantic Sea Surface Temperature (December + January)	April and June
2	Equatorial SE Indian Ocean Sea Surface Temperature (February + March)	April and June
3	East Asia Mean Sea Level Pressure (February + March)	April and June
4	NW Europe Land Surface Air Temperatures (January)	April
5	Equatorial Pacific Warm Water Volume (February+March)	April
6	Central Pacific (Nino 3.4) Sea Surface Temperature Tendency (MAM-DJF)	June
7	North Atlantic Mean Sea Level Pressure(May)	June
8	North Central Pacific Wind at 1.5 Km above sea level (May)	June

Table 3
Details of predictors used for the first stage forecast (April)

No.	Parameter	Period	Spatial domain	CC with ISMR (1958-2000)
A1	North Atlantic SST anomaly	December + January	20N-30N, 100W-80W	-0.45 **
A2	Equatorial SE Indian Ocean SST anomaly	February + March	20S-10S, 100E-120E	0.52 **
A3	East Asia surface pressure anomaly	February + March	35N-45N, 120E-130E	0.36 *
A4	Europe land surface air temperature anomaly	January	Five stations	0.42 **
A5	Northwest Europe surface pressure anomaly tendency	DJF(0) – SON (-1)	65N-75N, 20E-40E	-0.40 **
A6	WWV anomaly	February + March	5S-5N, 120E-80W	-0.32 *

* Significant at and above 5% level

** Significant at and above 1% level

Table 4
Details of predictors used for the second stage forecast (June)

| No.	Parameter	Period	Spatial domain	CC with ISMR (1958-2000)
J1	North Atlantic SST anomaly	December + January	20N-30N, 100W-80W	-0.45 **
J2	Equatorial SE Indian Ocean SST anomaly	February + March	20S-10S, 100E-120E	0.52 **
J3	East Asia surface pressure anomaly	February + March	35N-45N, 120E-130E	0.36 *
J4	Nino-3,4 SST anomaly tendency	MAM(0) – DJF (0)	5S-5N, 170W-120W	- 0.46 **
J5	North Atlantic surface pressure anomaly	May	35N-45N, 30W-41W	-0.402**
J6	North Central Pacific zonal wind anomaly at 850 hPa	May	5N-15N, 180E-150W	-0.55 **

* Significant at and above 5% level

** Significant at and above 1% level

Table 5

Prediction of monsoon onset date over Kerala

No	Name of Predictor	Temporal Domain	Geographical Domain	C.C 1975-2000
1	SE Indian Ocean SST anomaly	JAN	24S-14S, 80E-100E	0.41
2	NW India Minimum Surface air Temperature Anomaly	Deesa, Rajko, Guna Bikaner, Akola, Barmer	16th April to 15th May	-0.63
3	Zonal Wind Anomaly at 1000hpa over Equatorial South Indian Ocean	1-15may	10S-0, 80E-100E	0.52
4	OLR Anomaly Over Indo-China	1-15may	17.5N-27.5N, 95E-105E	0.43
5	OLR Anomaly Over Southwest Pacific	1-15may	30S,20S, 145E-160E	-0.54
6	Pre-Monsoon Rainfall Peak Date	Pre-monsoon	South Peninsula (8N-13N, 74E-78E)	0.65

ONSET
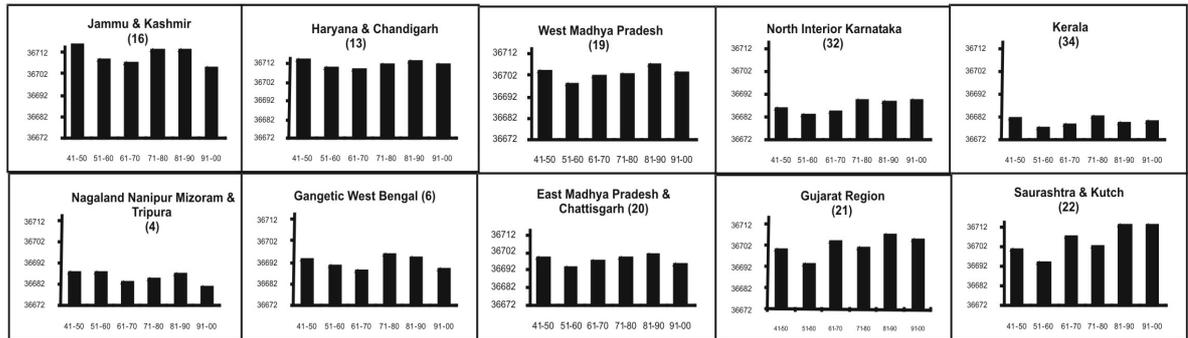
WITHDRAWAL
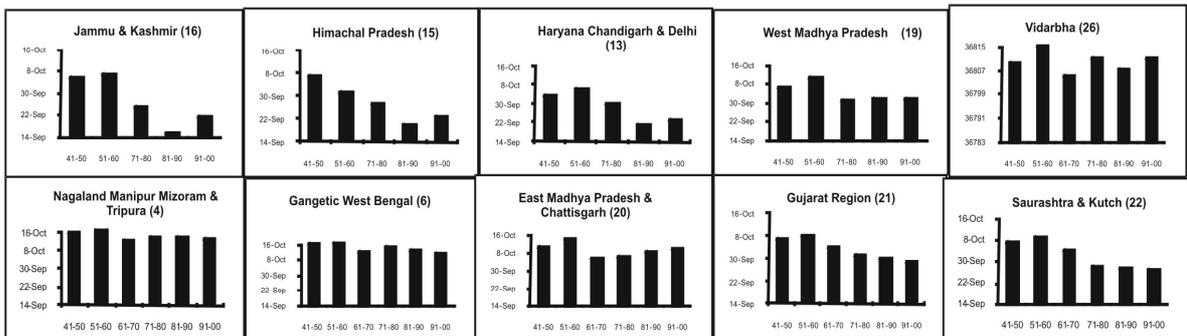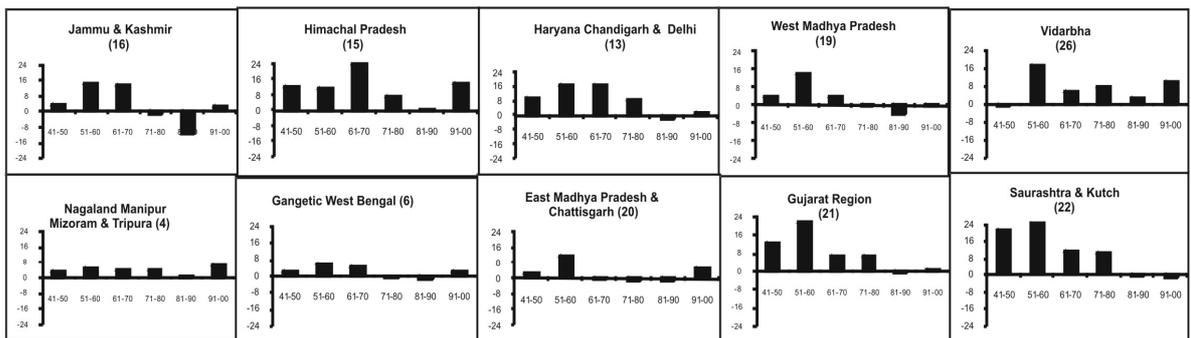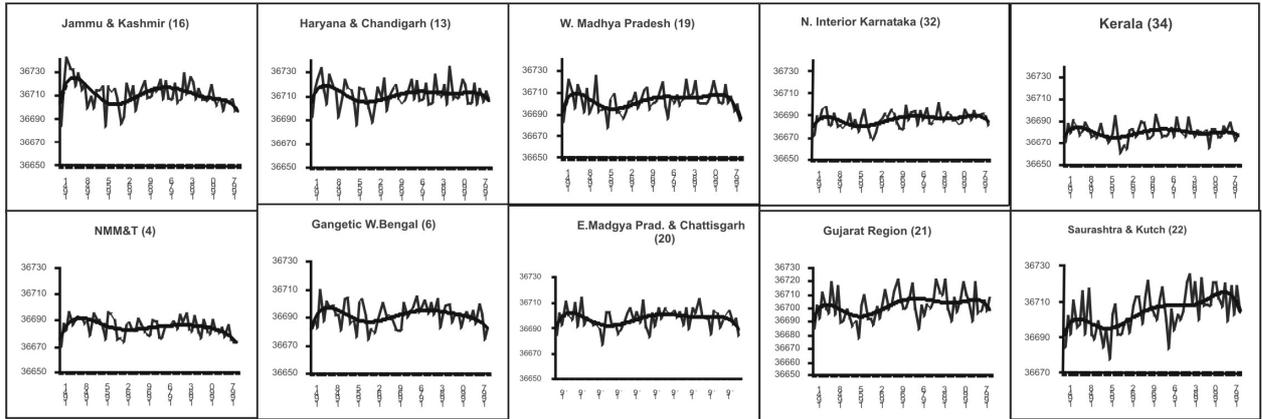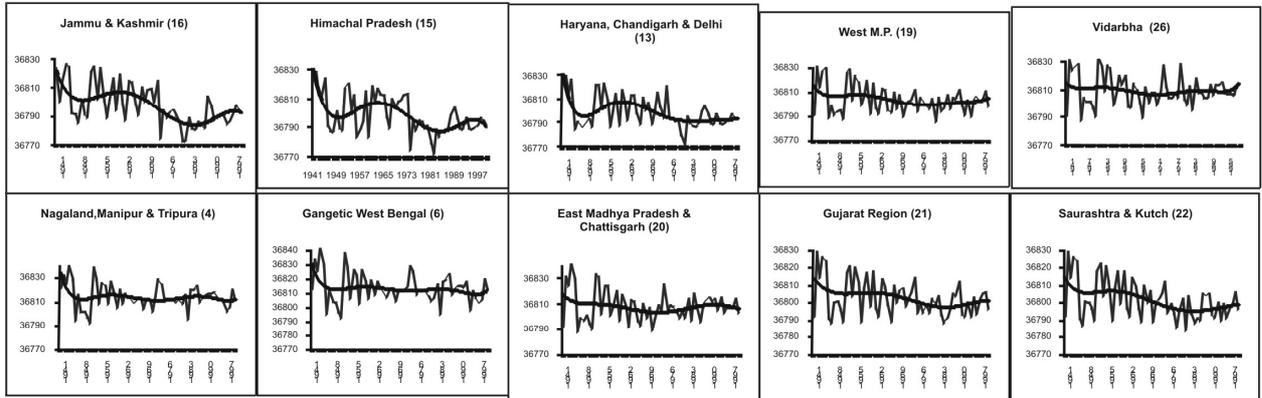

DURATION

Fig 15: Decadal mean values of onset, withdrawal and duration of monsoon
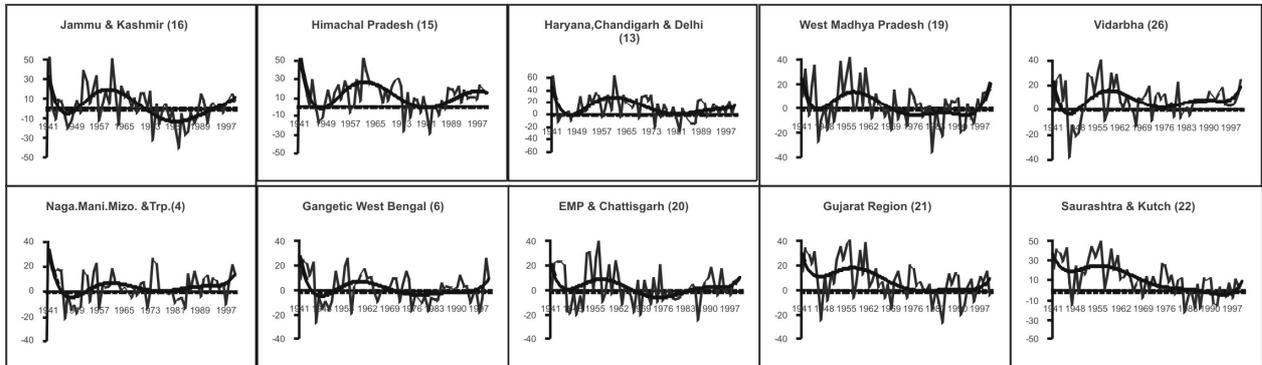
41

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ONSET

WITHDRAWAL

DURATION

Fig 16: Epochal variation of onset, withdrawal and duration of SW Monsoon

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4.5   Northeast Monsoon

The southeast peninsular India which falls under the rain shadow region during the summer season due to the presence of the Western Ghats receives rainfall from the subsequent northeast monsoon (NEM) which supplements the inadequate precipitation received during the SW monsoon. It is a small scale monsoon experienced by the southern peninsular India during October to December. Meteorological features associated with the NEM have been described in detail by IMD (1973). The onset of NEM is well defined with dramatic reversal of low level winds from southwesterly to northeasterly during mid-October followed by the commencement of fairly widespread rainfall activity along the coastal districts in about a week. The seasonal rainfall manifests high inter-annual variability characterised by the occurrence of years of large scale droughts and large scale floods. The intra-seasonal variation of NEM is frequently associated with long dry spells.

4.5.1 Climatology

The meteorological subdivisions of Coastal Andhra Pradesh (CAP), Rayalaseema (RYS), Tamil Nadu (TN), Kerala (KER) and South Interior Karnataka (SIK) are the beneficiaries of the northeast monsoon (Fig.17). These sub-divisions receive about 35% of their annual total during this season. Normal rainfall received by these 5 sub-divisions based on the long period (1941-1990) are presented in Table 6.   All the 5 sub-divisions receive good rainfall in October. The sub-divisions of TN, KER and CAP receive good rainfall in November, while, the rainfall is confined to TN and KER during December. This season is the main rainfall period for TN during which nearly 47% of the annual total of 91cm is received. Further, the coastal districts of Tamil Nadu normally receive about 75-100cm of rainfall during this season thereby constituting nearly 60% of their annual total. Onset and the various features associated with the onset of NEM have been described by Raj (1992,1998 & 2003).

4.5.2 Trends in NEM rainfall

Seasonal and monthly linear rainfall trends in October, November and December (OND) over these 5 sub-divisions during 1900-2008 have been depicted in Fig.18 (a-e) and Figs.19 (i-v)(a-c) respectively. Actual linear increase or decrease in seasonal (OND) and monthly (OCT, NOV and DEC) rainfall per year during this period are presented in Table 7. The Salient findings are summarized as under:

(i) There is an increase in seasonal (OND) rainfall over the eastern sub-divisions of CAP (0.406mm/year), RYS (0.475mm/year) and TN (0.265mm/year) and a very modest decrease of OND rainfall over the western sub-divisions of KER (-0.19 mm/year) and SIK (-0.061mm/year). The increasing trend over RYS is statistically significant at 10% level.

(ii) The October rainfall shows a positive trend over all the five sub-divisions with rainfall over RYS and CAP increasing at the rate of 0.548mm and 0.490mm per year respectively. The increase over RYS is statistically significant at 1% level.

(iii) Excepting TN, all other sub-divisions show a negative trend in the November rainfall. The November rainfall over SIK, RYS and CAP has decreased at the rate of -0.153mm, -0.081mm and -0.099mm per year respectively.

(iv) The December rainfall over Kerala has decreased at the rate of -0.197mm per year.

(v) Overall, there is a modest increase in the NEM seasonal rainfall over the eastern sub-divisions of CAP, RYS and TN and a very modest decrease in the seasonal rainfall over the western sub-divisions of KER and SIK.

(vi) By and large, rainfall during October has increased and that during November has decreased.

(vii) There is a significant increase in the October rainfall of RYS.

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Table 6
Normal seasonal / monthly rainfall
during October-December (1941-80)

Sub-division	Month / Season	Normal rainfall in (mm)
TN	OND	431.8
	OCT	181.5
	NOV	165.3
	DEC	85.0
CAP	OND	326.2
	OCT	196.8
	NOV	103.5
	DEC	25.9
RYS	OND	212.1
	OCT	121.3
	NOV	66.3
	DEC	24.5
KER	OND	498.5
	OCT	291.6
	NOV	163.8
	DEC	43.1
SIK	OND	199.7
	OCT	138.6
	NOV	48.1
	DEC	13.0

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Table 7
Trend in the seasonal / monthly rainfall of the
5 sub-divisions during 1900-2008

| Sub-division	Month / Season	Increase/Decrease of rainfall per year in mm	Linear correlation coefficient (r)
TN	OND	0.265	0.063
	OCT	0.069	0.032
	NOV	0.112	0.032
	DEC	0.083	0.032
CAP	OND	0.406	0.089
	OCT	0.490	0.145
	NOV	-0.099	-0.000
	DEC	0.016	0.000
RYS	OND	0.475	0.164*
	OCT	0.548	0.251**
	NOV	-0.081	-0.045
	DEC	0.008	0.000
KER	OND	-0.190	-0.032
	OCT	0.081	0.000
	NOV	-0.075	-0.000
	DEC	-0.197	-0.152
SIK	OND	-0.061	-0.000
	OCT	0.111	0.045
	NOV	-0.153	-0.105
	DEC	-0.019	-0.032

*: significant at 1% level
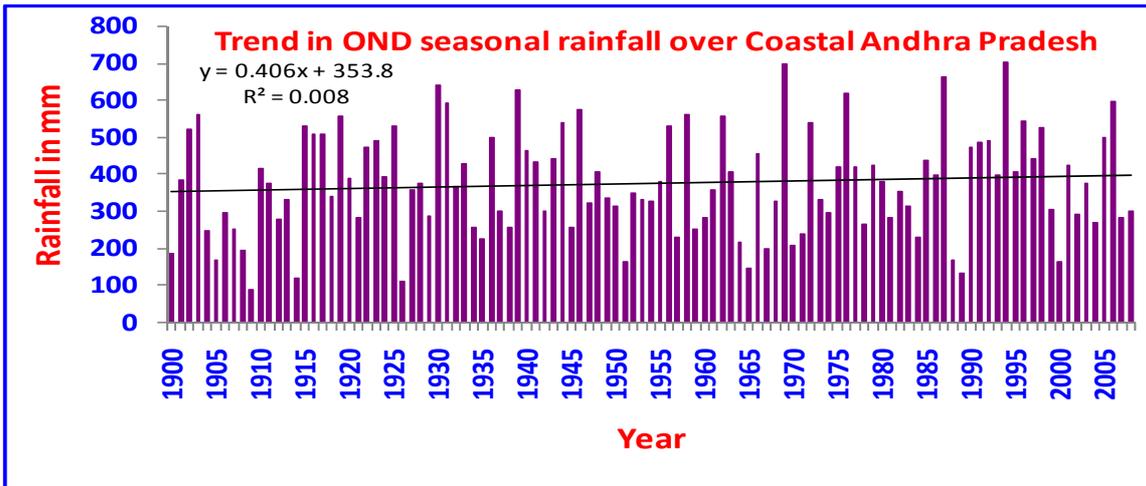**: significant at 10% level

46
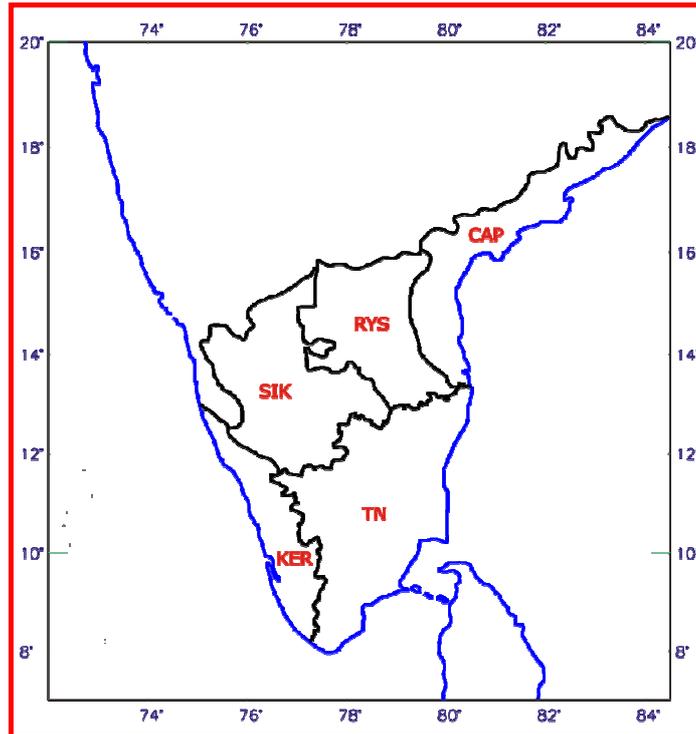
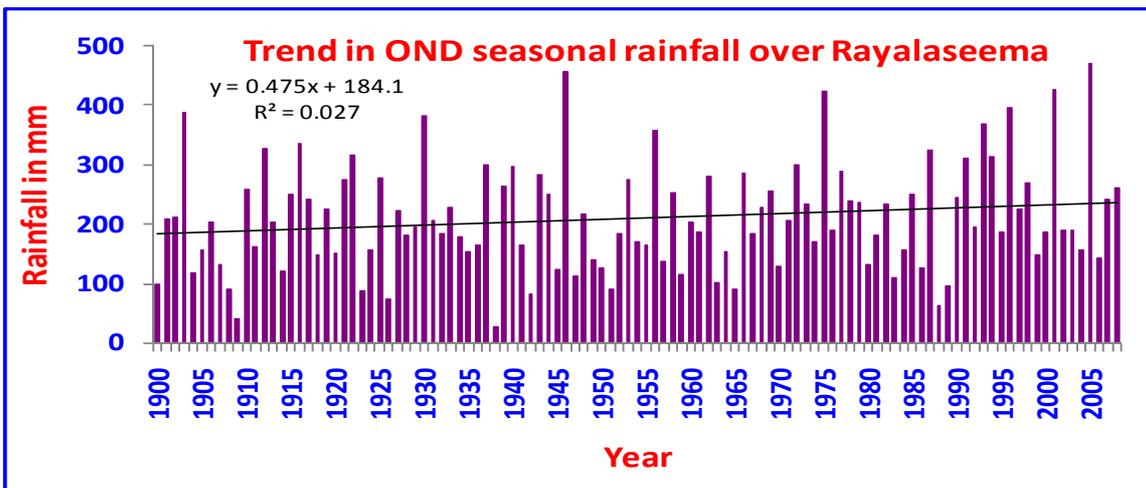**Fig. 17: The five meteorological sub-divisions of southern peninsular India influenced by the Northeast monsoon**

Trend in OND seasonal rainfall over Coastal Andhra Pradesh

y = 0.406x + 353.8
R² = 0.008

(18a)

Trend in OND seasonal rainfall over Rayalaseema

y = 0.475x + 184.1
R² = 0.027

(18b)

Trend in OND seasonal rainfall over Tamil Nadu

y = 0.265x + 444.6
R² = 0.004

(18c)

48

123
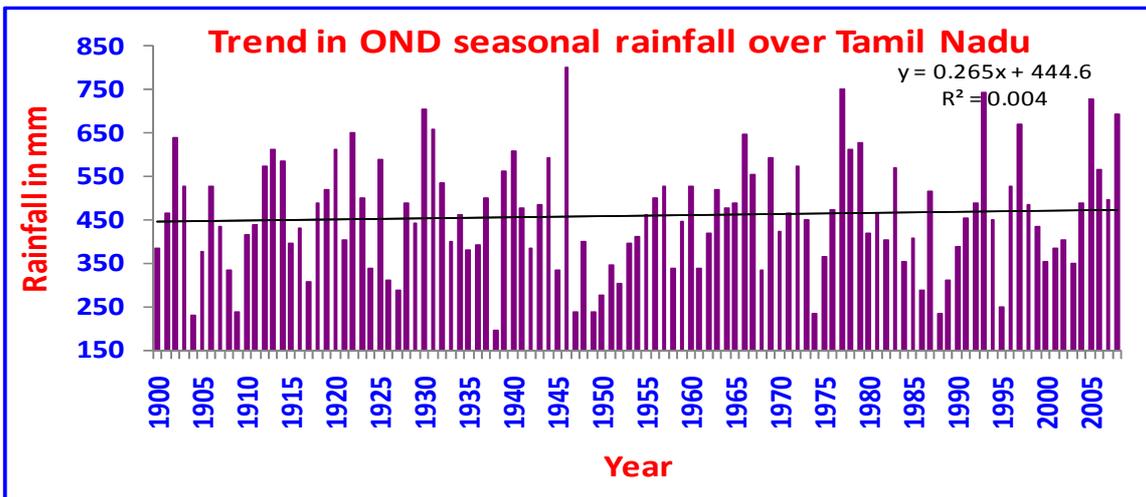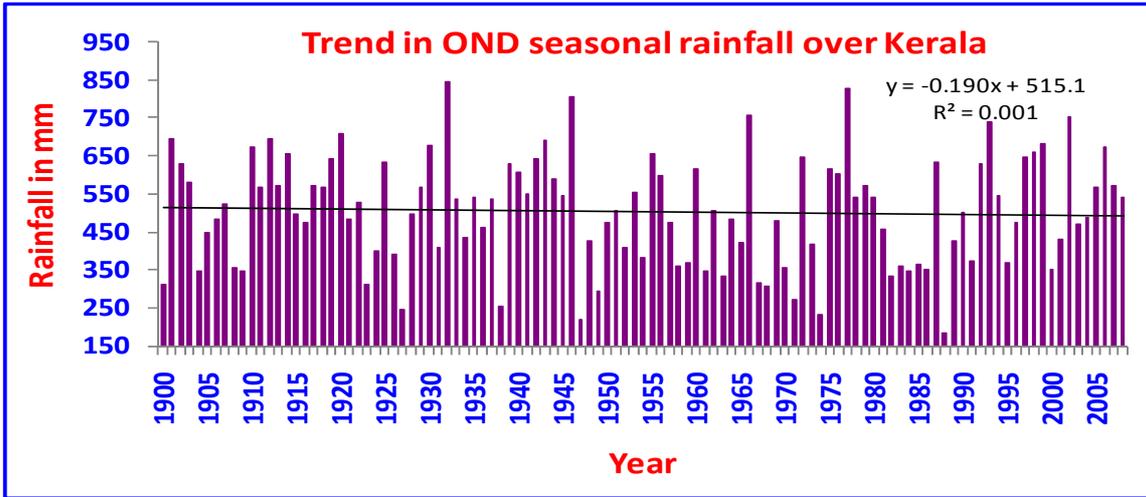
(18d)
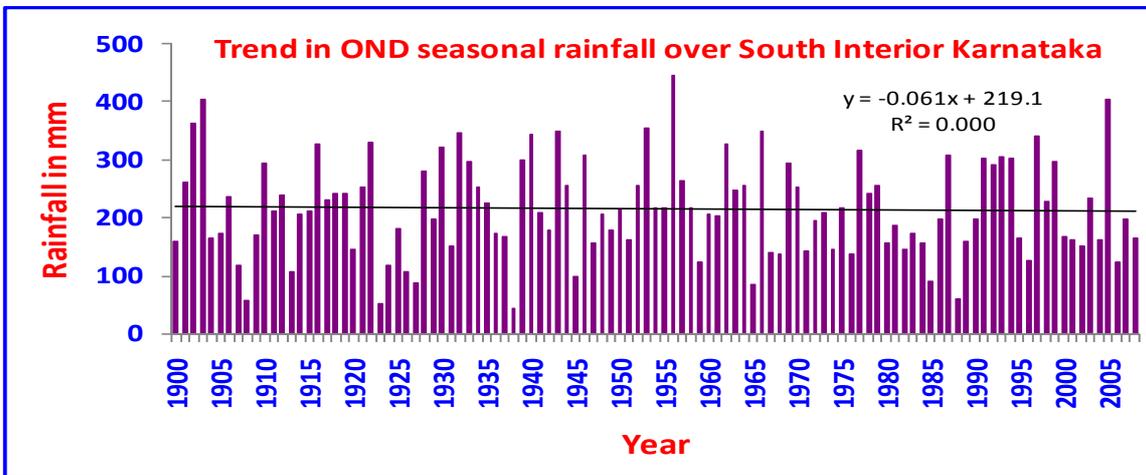
(18e)

Fig. 18: Trend in the NEM seasonal (OND) rainfall of (a)CAP, (b)RYS, (c)TN, (d)KER and (e)SIK during the period 1900-2008

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Trend in October rainfall over Coastal Andhra Pradesh

$y = 0.490x + 188.2$
$R^2 = 0.021$

19(i a)

Trend in November rainfall over Coastal Andhra Pradesh

$y = -0.099x + 139.2$
$R^2 = 0.000$

19(I b)

Trend in December rainfall over Coastal Andhra Pradesh

$y = 0.016x + 26.25$
$R^2 = 0.000$

19(i c)

50

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Trend in October rainfall over Rayalaseema

$y = 0.548x + 89.65$
$R^2 = 0.063$

19 (ii a)

Trend in November rainfall over Rayalaseema

$y = -0.081x + 74.86$
$R^2 = 0.002$

19 (ii b)

Trend in December rainfall over Rayalaseema

$y = 0.008x + 19.6$
$R^2 = 0.000$

19 (ii c)

51

19 (iii a)

19 (iii b)

19 (iii c)

52

Trend in October rainfall over Kerala

y = 0.081x + 294.9
R² = 0.000

19 (iv a)

Trend in November rainfall over Kerala

y = -0.075x + 170.0
R² = 0.000

19 (iv b)

Trend in December rainfall over Kerala

y = -0.197x + 50.11
R² = 0.023

19 (iv c)

53

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Trend in October rainfall over South Interior Karnataka

y = 0.111x + 139.8
R² = 0.002

19 (v a)

Trend in November rainfall over South Interior Karnataka

y = -0.153x + 65.18
R² = 0.011

19 (v b)

Trend in December rainfall over South Interior Karnataka

y = -0.019x + 14.09
R² = 0.001

19 (v c)

Fig.19: Trends in the sub-divisional rainfall of CAP (19 i: a-c), RYS(19 ii: a-c), TN(19 iii: a-c), KER(19 iv:a-c) and SIK(19 v:a-c) during the NEM months of (a)October, (b) November and (c) December during the period 1900-2008

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Chapter – V

FLOODS

Floods are caused by the inadequate capacity within the banks of the rivers to contain the high flows brought down from the upper catchment due to heavy rainfall. In coastal areas, they are caused by cyclones and typhoons. Other causes include backing up of waters in tributaries at their outfalls into the main river often with synchronization of floods in them; ice jams or landslides blocking stream courses resulting in the backwater overflowing river banks. Flash flood occurs in areas near foot hills. However the root cause of flood is excessive rainfall which occurs mainly in the monsoon months of July to September. Floods are also sometimes caused by Glacial Lake Outburst called Glacial Lake Outburst Floods (GLOFs) which can be catastrophic for people living immediately downstream and can cause serious damage to infrastructure and the economy.

Floods are recurrent phenomena since time immemorial. Almost every year some parts of the world or the other are affected by the floods of varying magnitude. Even in the same country of the region different parts have different climates and rainfall patterns and, as such, it is also experienced that while some parts are suffering under devastating floods, another part is suffering under drought. With the increase in population and developmenta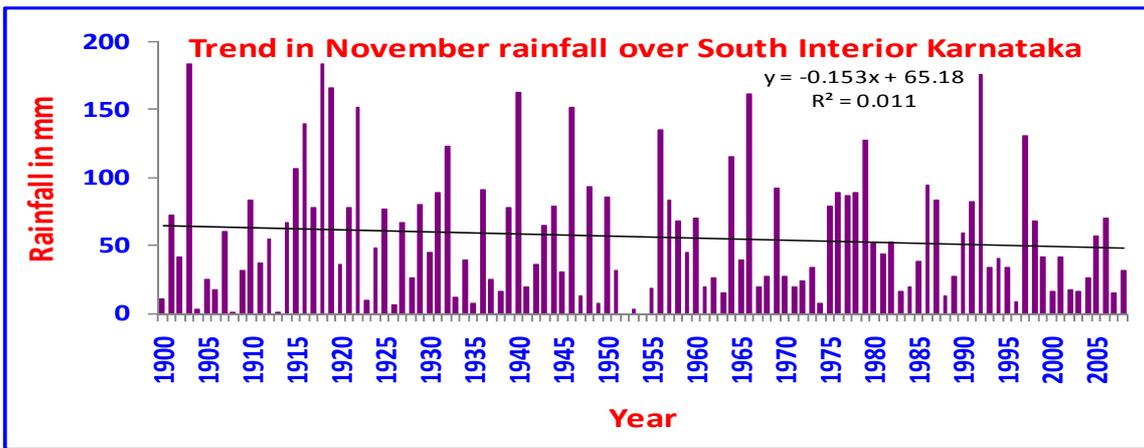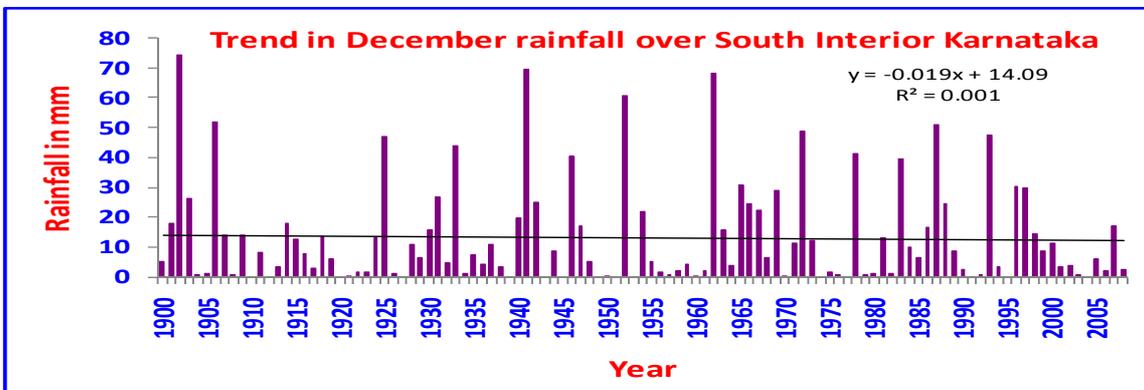l activity, there has been tendency to occupy the flood plains which has resulted in more serious nature of damages over the years. Because of the varying rainfall distribution, many a times, areas which are not traditionally prone to floods also experience severe inundation. Flood indeed is the single most frequent disaster faced not only in India but by various part of world including the South Asia region.

Losses due to floods

Floods inundate the banks, destroy crops, damage properties, perish live stock, disturb communication and power supply and endanger human life. Floods are followed by epidemics. Supply of drinking water and restore sanitation are post

flood challenge. In past 50 years, India had lost assets of more than Rs 65000 crore and loss of more than 75000 human lives due to floods alone. However absolute immunity from floods is not technologically/ economically feasible. Damages (Rs. in crore) during the period 1953-2004 are shown in Fig. 20. The year wise frequency of floods such as Flash Floods, and total floods occurred are shown in the following bar diagram during the period 1980-2005. There is a sharp increase in flash floods and a slight decreasing pattern in total floods (Fig 21).

The flood problem in India is mostly confined to the states located in the Indo-Gangetic plains, northeast India and occasionally in the rivers of Central India. Heavy rainfall, inadequate capacity of rivers to carry the high flood discharge, inadequate drainage to carry away the rainwater quickly to Streams/ Rivers, storm surges, Man made factors such as failure of dams and other control works like reservoirs are the main causes of floods. Ice jams or landslides blocking streams, debris flow, back water, and cyclones also cause floods. Excessive rainfall combined with inadequate carrying capacity of streams resulting in over spilling of banks is the cause for flooding in majority of cases.

Rashtriya Barh Ayog (RBA) constituted by the Government of India in 1976 carried out an extensive analysis to estimate the flood-affected area in the country. RBA in its report (1980) has assessed the area liable to floods as 40 million hectares. It was determined by summing up the maximum area affected by floods in any one year in each state during the period from 1953 to 1978 for which data was analysed by the Ayog. This sum has been corrected for the area that was provided with protection at that time and for the protected area that got affected due to failure of protection works during the period under analysis to arrive at the total area liable to floods in the country as per break-up given in Table 8. The area affected by flood in the country from 1953 to 2007 is also depicted in Table 9. Decadal mean frequency of flood years is presented in Table 10

After the heavy floods in 1954, national policy on, "Floods in the country" was set up in 1954 by government of India which provides measures of flood control and its protection. The central flood board was set up in 1954. Flood prone areas of the country are depicted in Fig. 22. Flood forecasting has been recognized most

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important reliable and cost effective non-structural measure for flood mitigation. India meteorological department (IMD) and Central Water Commission (CWC) are working in close co-ordination for issue of flood forecasts. IMD has 10 flood meteorological offices (FMOs) and CWC has 20 flood forecasting divisions located in different flood prone river basins.

Table 8	
Area liable to Floods (million Ha.)	
1. Andhra Pradesh	1.39
2. Assam	3.15
3. Bihar	4.26
4. Gujarat	1.39
5. Haryana	2.35
6. Himachal Pradesh	0.23
7. Jammu & Kashmir	0.08
8. Karnataka	0.02
9. Kerala	0.87
10. Madhya Pradesh	0.26
11. Maharashtra	0.23
12. Manipur	0.08
13. Meghalaya	0.02
14. Orissa	1.40
15. Punjab	3.70
16. Rajasthan	3.26
17. Tamil Nadu	0.45
18. Tripura	0.33
19. Uttar Pradesh	7.336
20. West Bengal	2.65
21. Delhi	0.05
22. Pondicherry	0.01
Total	**33.516**

| **Table 9** |
| **Flood Affected Area (Million Ha) during 1953-2007** |

Year	*Flood Affected Area*	*Year*	*Flood Affected Area*
1953	2.29	1981	6.12
1954	7.49	1982	8.87
1955	9.44	1983	9.02
1956	9.24	1984	10.71
1957	4.86	1985	8.38
1958	6.26	1986	8.81
1959	5.77	1987	8.89
1960	7.53	1988	16.29
1961	6.56	1989	8.06
1962	6.12	1990	9.303
1963	3.49	1991	6.357
1964	4.9	1992	2.645
1965	1.46	1993	11.439
1966	4.74	1994	4.805
1967	7.15	1995	5.245
1968	7.15	1996	8.049
1969	6.2	1997	4.569
1970	8.46	1998	9.133
1971	13.25	1999	3.978
1972	4.1	2000	5.166
1973	11.79	2001	3.008
1974	6.7	2002	7.09
1975	6.17	2003	6.503
1976	11.91	2004	8.031
1977	11.46	2005	3.376
1978	17.5	2006	0.437
1979	3.99	2007	3.549
1980	11.46	2008	---

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Table 10
Decadal mean (% departure from normal), frequency of flood years

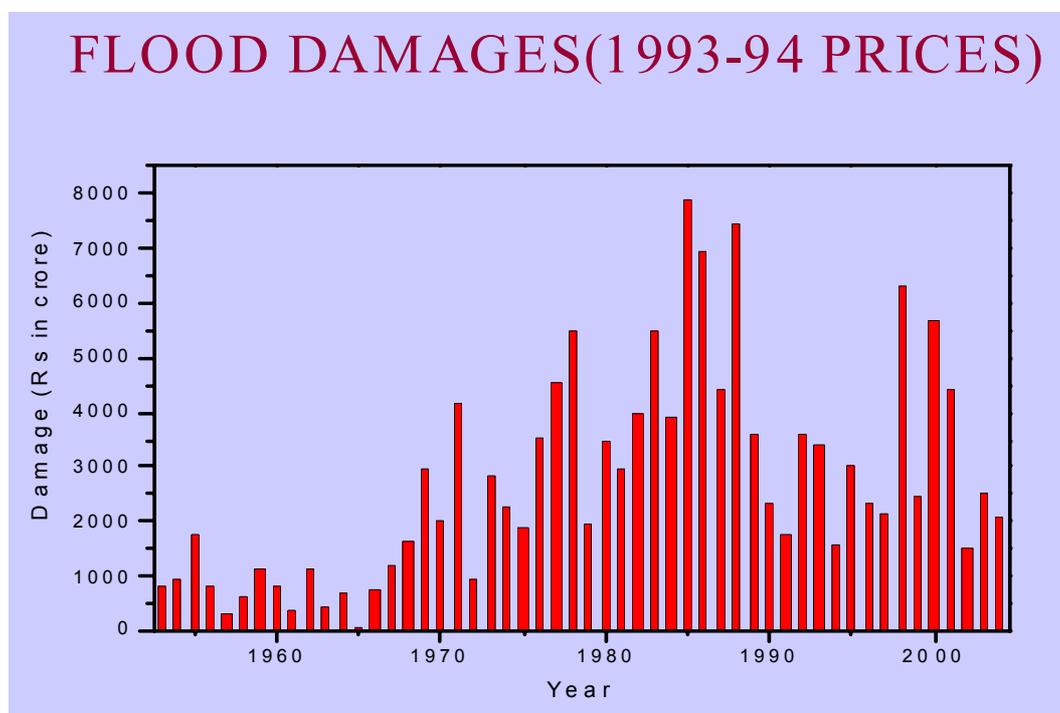| Decade	Decadal mean % departure from normal	Freq. of Excess year
1901-10	-2.2	0
1911-20	-2.5	3
1921-30	-0.4	0
1931-40	1.7	1
1941-50	3.3	1
1951-60	2.5	3
1961-70	-0.1	1
1971-80	-0.8	1
1981-90	-0.3	2
1991-2000	0.6	1
2001-2003	-5.9	0

FLOOD DAMAGES(1993-94 PRICES)

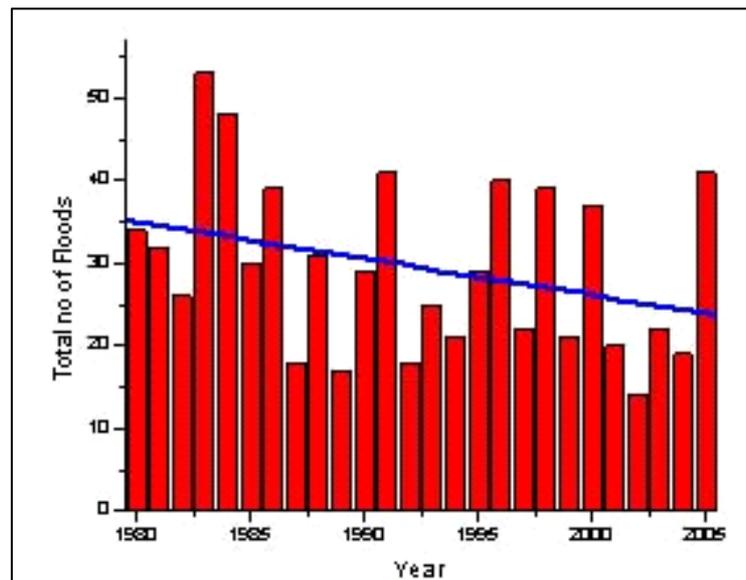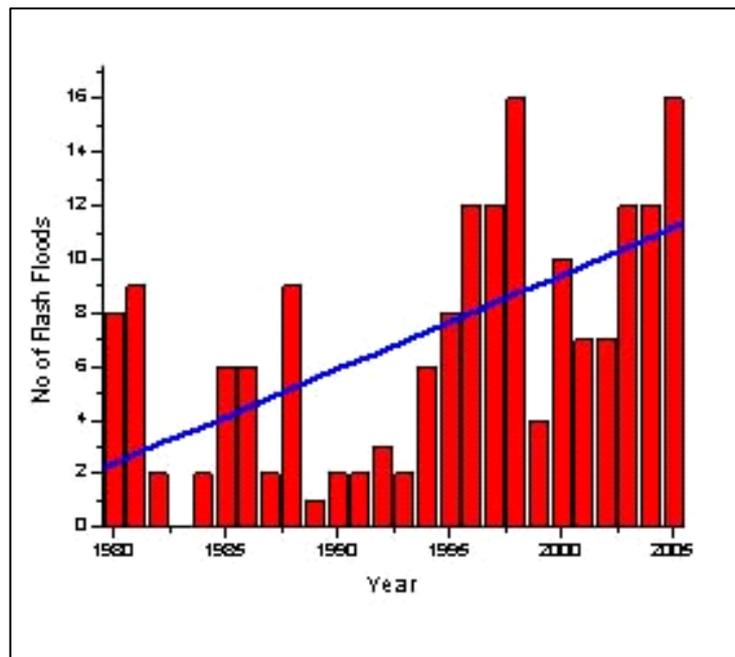**Fig. 20: Damages (Rs. in crore) during the period 1953-2004**

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Fig. 21: Pattern of Flash and Total floods during 1980-2005
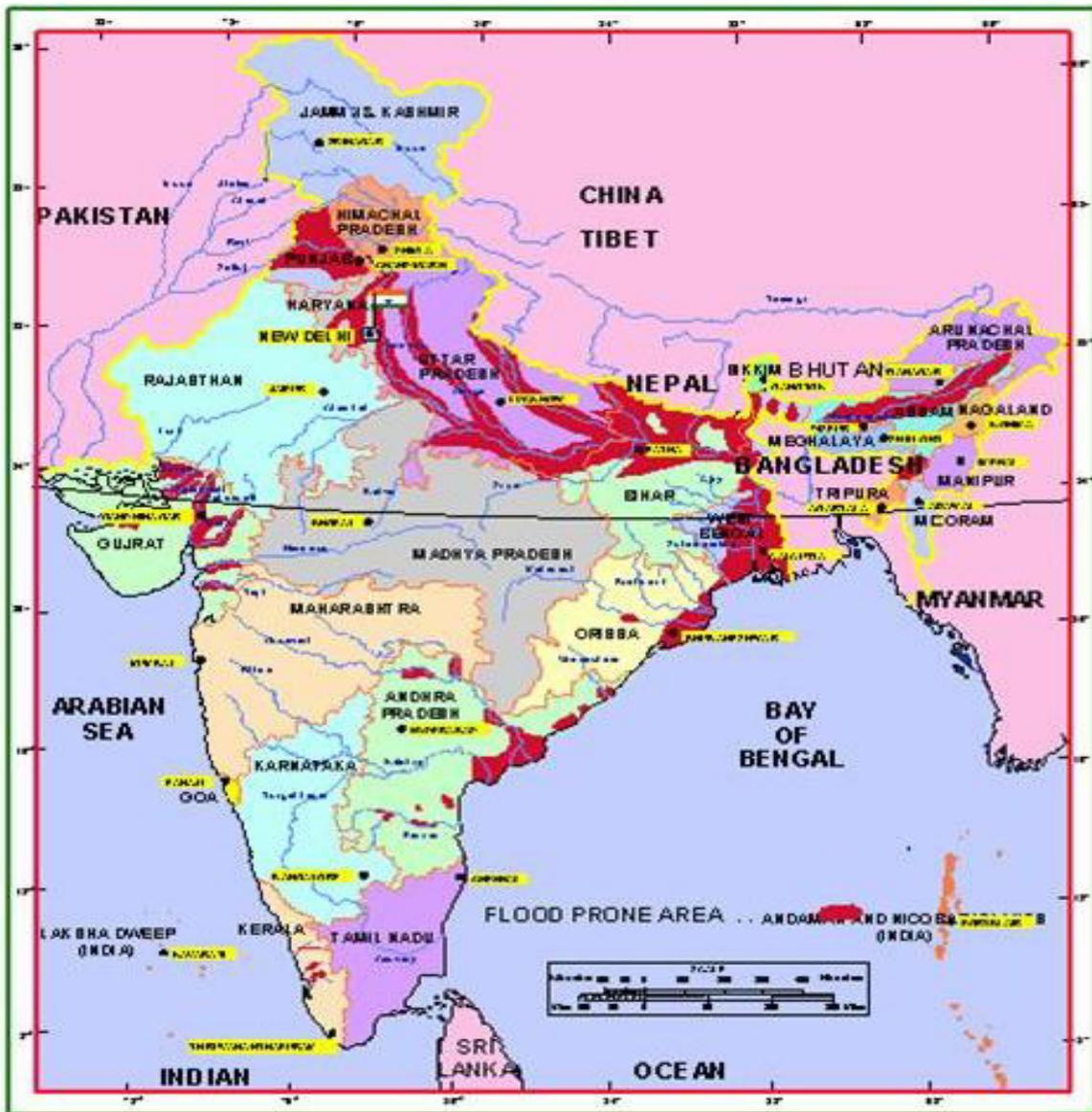
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Fig. 22: Flood prone areas of India

Chapter – VI

TROPICAL CYCLONES

6.1   Introduction

Tropical cyclones (TC) are the most devastating phenomena among all natural disasters, having taken more than half a million lives all over the world in the last five decades. The havoc caused by tropical cyclones to shipping in the high seas and coastal habitats along the Indian coasts have been known since hundreds of years. They are large synoptic scale weather systems which originate over warm oceans, develop into massive vortices comprising of swirling winds, intense clouds and torrential rains by drawing energy from the ocean and move poleward. The formation and intensification are controlled by several atmospheric and oceanic parameters such as low level relative vorticity and humidity, vertical wind shear, low level convergence, upper level divergence, conditional instability and sea surface temperature (SST) (Gray,1968). A TC generally dissipates when it enters into land (which is generally referred as 'landfall') or into colder seas. The destructive potential of a TC is associated with strong and destructive *gale force winds* with speeds in the order of 200 kmph, *heavy rains* up to 40-50 cm per day and above all, *storm surge* which cause large scale damages over a vast area. The Bay of Bengal has experienced more than 75% of the total world-wide TCs causing human death of 5000 or more in last 300 years. India Meteorological Department (IMD) has maintained a meticulous record of tracks of cyclones and depressions that formed over the NIO since 1891 in the form of "*Storm track Atlas*". The same has recently been brought out electronically as '*Cyclone eAtlas – IMD*' CD (IMD, 2008). This software is extensively used in this work for generating most of the climatological and statistical information.

It is now a well known fact (IMD, 2008) that about 5 to 6 TCs occur in the North Indian Ocean (NIO) prominently during the pre-monsoon season (March-April-May) and the post-monsoon season (October-November-December). Nearly 7 percent of the global TCs form in the North Indian Ocean. Damage potential of cyclones and adaptation/ mitigate actions are summarized in Table 11.

Table 11
Damage potential of cyclonic disturbances

System Intensity	Damage expected	Action Suggested
Deep Depression (28-33 Kts or 52-61Kmph)	Minor damage to loose and unsecured structures	Fishermen advised not to venture into the open seas.
Cyclonic Storm (34-47kts or 62-87 kmph)	Damage to thatched huts. Breaking of tree branches causing minor damage to power and communication lines	Total suspension of fishing operations
Severe Cyclonic Storm (48-63 kts or 88-117 kmph)	Extensive damage to thatched roofs and huts. Minor damage to power and communication lines due to uprooting of large avenue trees. Flooding of escape routes.	Total suspension of fishing operations. Coastal hutment dwellers to be moved to safer places. People in affected areas to remain indoors.
Very Severe Cyclonic Storm (64-90 kts or 118-167 kmph)	Extensive damage to kutcha houses. Partial disruption of power and communication line. Minor disruption of rail and road traffic. Potential threat from flying debris. Flooding of escape routes.	Total suspension of fishing operations. Mobilise evacuation from coastal areas. Judicious regulation of rail and road traffic. People in affected areas to remain indoors.
Very Severe Cyclonic Storm (91-119 kts or 168- 221 kmph)	Extensive damage to kutcha houses. Some damage to old buildings. Large-scale disruption of power and communication lines. Disruption of rail and road traffic due to extensive flooding. Potential threat from flying debris.	Total suspension of fishing operations. Extensive evacuation from coastal areas. Diversion or suspension of rail and road traffic. People in affected areas to remain indoors.
Super Cyclone (120kts or more or 222 kmph or more)	Extensive structural damage to residential and industrial buildings. Total disruption of communication and power supply. Extensive damage to bridges causing large-scale disruption of rail and road traffic. Large-scale flooding and inundation of sea water. Air full of flying debris.	Total suspension of fishing operations. Large-scale evacuation of coastal population. Total suspension of rail and road traffic in vulnerable areas. People in affected areas to remain indoors.

6.2   Climatology of cyclones

Every year, about 80-90 TCs form over the oceanic regions, out of which, about 45 TCs develop into severe cyclonic storms and cause damages over the landfalling areas of the various coastal regions (Landsea, 2007). Monthly frequency of cyclonic disturbances (Depression, Cyclonic Storm and Severe Cyclonic Storm: D,

CS and SCS) that formed over the North Indian Ocean (NIO) during the 110 year period of 1900-2009 is presented in Table 12. It can be seen that 1387 cyclonic disturbances formed over the NIO out of which, 1081 (78%) formed over the Bay of Bengal (BOB), 191 (14%) over the Arabian Sea (AS) and 115 (8%) over the land. Of the 1387 disturbances that formed over the NIO, 568 intensified into CS and 268 further intensified into SCS. Of the 568 TCs that formed over the NIO, 449 were over the BOB and 106 over the AS. Only 13 out of 115 land depressions intensified into TCs. Thus, land depressions very rarely intensify into TCs. Of the 268 SCS that formed over the NIO, 202 were over the BOB, 63 over the AS and only three over the land.

From the monthly distribution of the frequencies, it can be seen that 714 depressions formed during the southwest monsoon season of June-September, 494 during the post-monsoon season of October-December, 156 during the pre-monsoon summer season of March-May and only 23 during the winter season of January–February. Of the 714 depressions that formed over the NIO during the southwest monsoon season, only 165 (23%) intensified into TC and 46 (6%) into SCS. On the contrary, during the post-monsoon season 284 out of 494 (57%) intensified into TC and 146 (30%) further intensified into SCS. Also, during the pre-monsoon season, 109 out of 156 (70%) intensified into TC and 76 (47%) further intensified into SCS. Thus the post-monsoon season of October to December is the principal cyclonic season over the NIO, followed by the pre-monsoon season of March to May.

Table12

Monthly frequency of cyclonic disturbances that formed over the various basins of NIO and reached various intensity levels during the period 1900-2009

Basin	Intensity level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
BOB +AS +Land	D+CS+SCS	18	5	7	37	112	155	167	203	189	217	189	88	1387
	CS+SCS	8	2	5	27	77	56	38	28	43	103	130	51	568
	SCS	2	1	2	16	55	18	7	3	18	47	76	23	268
BOB	D+CS+SCS	17	5	7	29	81	100	133	168	142	170	152	77	1081
	CS+SCS	7	2	5	22	55	32	36	24	31	78	111	46	449
	SCS	2	1	2	13	38	3	7	3	13	36	63	21	202
AS	D+CS+SCS	1	0	0	7	30	46	8	2	11	42	35	9	191
	CS+SCS	1	0	0	5	22	22	1	1	8	24	17	5	106
	SCS	0	0	0	3	17	15	0	0	4	10	12	2	63
Land	D+CS+SCS	0	0	0	1	1	9	26	33	36	5	2	2	115
	CS+SCS	0	0	0	0	0	2	1	3	4	1	2	0	13
	SCS	0	0	0	0	0	0	0	0	1	1	1	0	3

6.3 Trends in frequency and intensity of cyclones over the North Indian Ocean

An extensive work on decadal variation in the 'Variability and Trend in the Cyclonic Storms over the North Indian Ocean' by analysing separately the long term data of 1891-2008 as well as during the recent 4-5 decades since 1961 have been undertaken by Niyas et al (2009). The results obtained are furnished below:

i. Taking the North Indian Ocean as a whole, on an average 5.2 cyclonic storms and 2.4 severe cyclonic storms form per year.

ii. For the North Indian Ocean as a whole, the number of cyclonic and severe cyclonic storms showed distinct decadal variability. The maximum number (67) occurred in the decade 1921-30 and minimum (38) during 1981-90.

iii. Long term linear trend (1891-2008) in frequency of tropical cyclones over the North Indian Ocean as a whole, the Bay of Bengal and the Arabian Sea for different seasons, generally, show a significant decreasing trend.

iv. However, an increasing trend in the frequency of tropical cyclones forming over the Bay of Bengal in the months of May and November, the principal cyclone months, was observed.

v. It may be observed that rate of decrease in frequency of tropical cyclone, is maximum for the monsoon season.

vi. Cyclone frequency data for the last four decades (1961 onwards), since when significant monitoring tools are available, show a significant decreasing trend for all the months and seasons; once again the maximum decrease was noticed in the monsoon season, however, their intensity appears to have increased.

Long term linear trend in the frequency of tropical cyclones over the north Indian Ocean, the Bay of Bengal and the Arabian Sea for different seasons and annual, generally, shows a significant decreasing trend (Srivastava et al.2000; Singh et al. 2000). Sharp decrease in the frequency of cyclones during the monsoon season was observed (Singh, 2001). However, an increasing trend in the frequency of tropical cyclones over the Bay of Bengal in the months of May and November is observed.

6.3.1. Trends in the annual and seasonal frequencies over NIO

(i) A decreasing trend in the annual frequency of cyclones (CS+SCS) that formed over NIO during 1900-2009 is discernible. However, there is a very slight increasing trend in the annual frequency of severe cyclones (SCS) that formed over the NIO during the said period (Fig.23 (i), a&b). An increasing trend in the intensification of CS to SCS is also seen (Fig.23 (i)c).

(ii) A decreasing trend in the formation of cyclones during the southwest monsoon season (Fig.23 (ii-iv),a&b) and an increasing trend in the formation of severe cyclones during the post-monsoon has been observed. The trends in the intensification of cyclones to severe cyclones is presented in Fig.23 (ii-iv)c

6.3.2 Trends in the annual frequencies of formation over BOB and AS

(i) Trends in the annual frequency of formation of cyclones (CS+SCS) and severe cyclones (SCS) over the BOB during the period 1900-2009 are presented in Fig.24(i),a&b. The trend in the frequency of SCS to total cyclones is presented in Fig.24(i)c. A slight decreasing trend in the annual frequency of cyclones that formed over BOB during 1900-2009 is seen. But,

there is a slight increasing trend in the annual frequency of severe cyclones that formed over the BOB during the said period. Also, there is an increasing trend in the intensification of cyclones to severe cyclones.

(ii) Trends in the annual frequency of formation of cyclones (CS+SCS) and severe cyclones (SCS) over the AS during the period 1900-2009 are presented in Fig.24(ii),a&b. The trend in the frequency of SCS to total cyclones is presented in Fig.24(ii)c. No trend is noticeable in the frequencies of cyclones and severe cyclones that formed over the AS during the period 1900-2009.

(iii) Decreasing trend in frequency of cyclonic disturbances (depression and above) during 1891-2009 (Fig 25) and increase in low pressure areas during 1888-2009 (Fig 26) have been observed

6.3.3. Trends in the coastal crossings of the TCs over NIO

The trends in the frequency of TCs crossing various coastal regions of NIO during the period 1900-2009 have been studied. The frequency of TCs crossing various coasts of NIO as CS+SCS / SCS are presented in Table 13.

Table 13
Number of TCs crossing various coasts of NIO as
CS+SCS / SCS during the period 1900-2009

Sl. No	Coast	CS+SCS	SCS
1	Tamil Nadu	50	26
2	Andhra Pradesh	68	27
3	Orissa	76	18
4	West Bengal	39	20
5	Bangladesh	65	32
6	Arakan	28	16
7	Kerala	2	1
8	Karnataka	-	-
9	Konkan & Goa	6	4
10	Gujarat	16	11
11	Pakistan	6	4
12	Sri Lanka	15	5
13	Iran, Arabia and Africa	13	5

The eastern coastal regions of India, viz., Tamil Nadu (TN), Andhra Pradesh (AP), Orissa and West Bengal (WB) are highly vulnerable to TC landfall whereas the western coastal regions of Kerala, Karnataka and Konkan & Goa are rarely affected by TC landfall. However, the state of Gujarat is affected by TC landfall. Further, Bangladesh, Arakan and Sri Lankan coasts are also greatly affected by landfalling TCs. It may be mentioned here that the TCs that crossed the TN and AP coasts were predominantly during the post-monsoon season and Orissa is mainly affected by TCs that form during the monsoon season. Fig. 27 (i-vii) a&b present the trends in the frequency of TC landfall over TN, AP, Orissa, WB, Bangladesh, Arakan and Gujarat coasts as CS+SCS / SCS. Here, those CS and SCS that retained their respective intensities at the time of coastal crossing are only considered for this analysis. Fig. 27(i-vii) c depicts the frequency of SCS to total cyclones that crossed these coasts.

The decreasing trend in the frequency of cyclones crossing Orissa and Arakan coasts and a slight increasing trend in the frequency of severe cyclones crossing Bangladesh and Gujarat coasts were observed. There is also an increasing trend in the frequency of CS intensifying into SCS and crossing TN, Orissa, Bangladesh, Arakan and Gujarat coasts.

6.3.4 Trends in the frequency of TCs dissipating over sea without making landfall

No trends in the frequency of TCs (CS+SCS / SCS) forming over NIO dissipating over BOB and AS without making any landfall were observed during 1900-2009 (Fig 28 a-d).

6.4   Storm Surge

Storm surge is the abnormal rise of sea level which occurs when the cyclone moves from ocean to continent. It is a disastrous and destructive feature of cyclone, which could cause massive destruction in the coastal region and misery to the coastal human population and livestock. Vulnerability in terms of the height of storm

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surge for the Bangladesh, East coast of India, West coast of India, Pakistan and Sri Lanka are available in Chapter 6 of SMRC(1998).

The crucial inputs for preparation of vulnerability atlases are the Probable Maximum Storm Surge (PMSS) over the various coastal areas. Infrastructure development over coastal regions has to take into consideration the respective PMSS values. The "Probable maximum storm surge heights for the maritime districts of India" by Kalsi et al, 2007 is an extensive work on computation of PMSS and the values obtained by them for the Indian coastal districts are given in Fig.29.
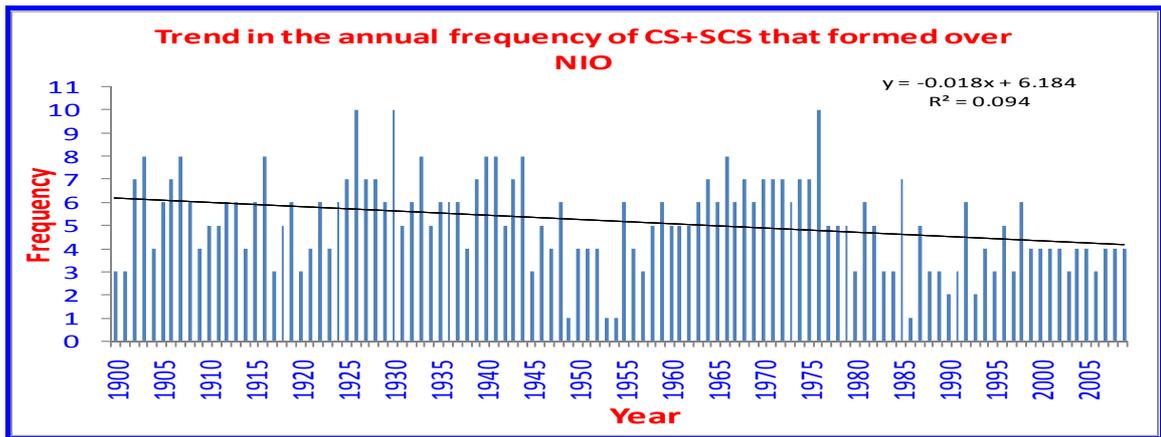
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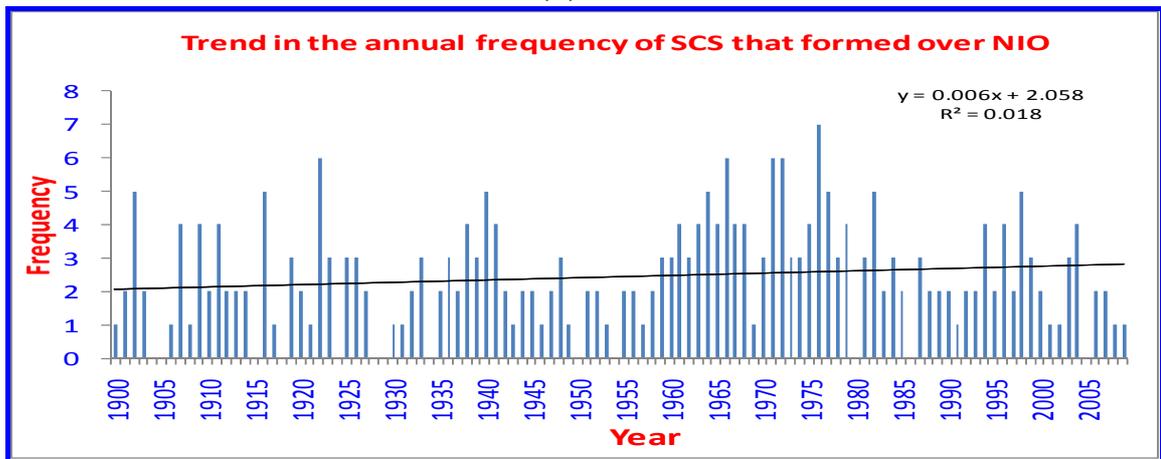
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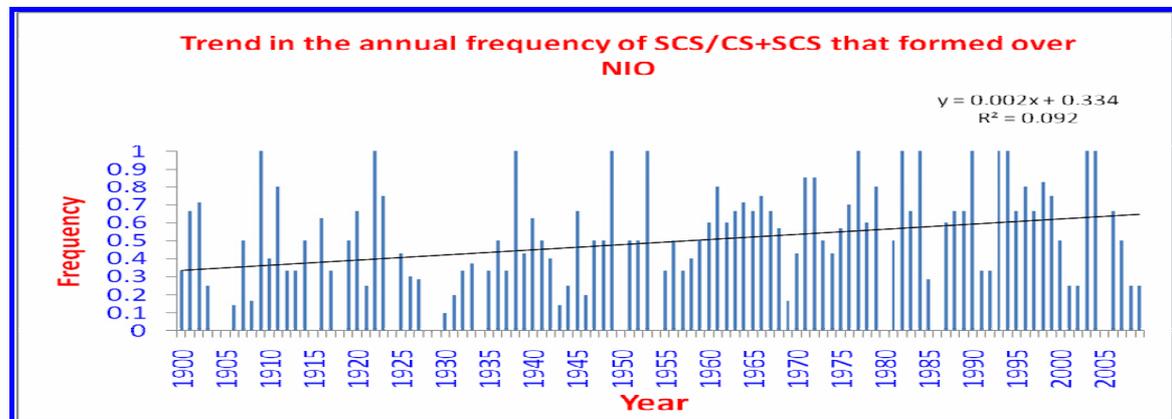
(c)

Fig.23 (i): Trends in the annual frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed over the NIO during 1900-2009

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(a)

(b)

(c)

Fig.23 (ii): Trends in the seasonal frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed in the pre-monsoon season (MAM) over the NIO during 1900-2009

(a)

(b)

(c)

Fig.23 (iii): Trends in the seasonal frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed in the monsoon season (JJAS) over the NIO during 1900-2009

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(a)

(b)

(c)

Fig.23 (iv): Trends in the frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed in the post-monsoon season (OND) over the NIO during 1900-2009

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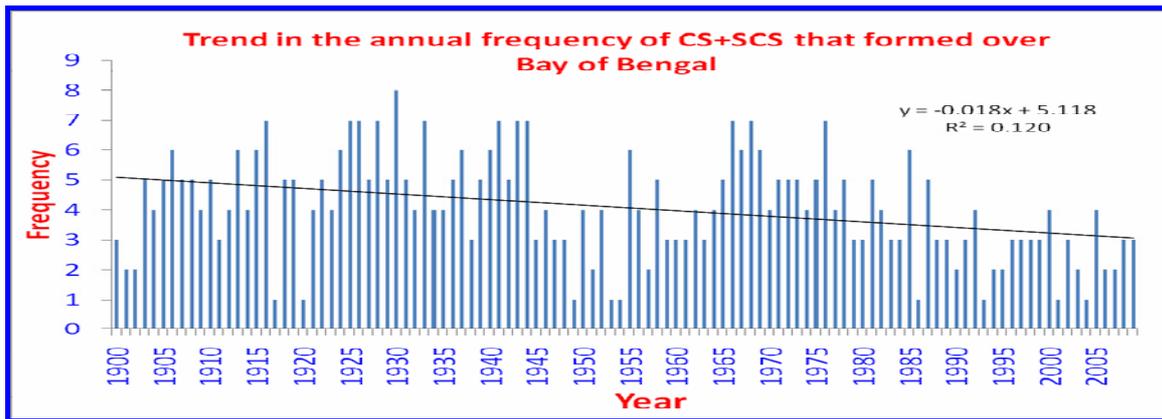
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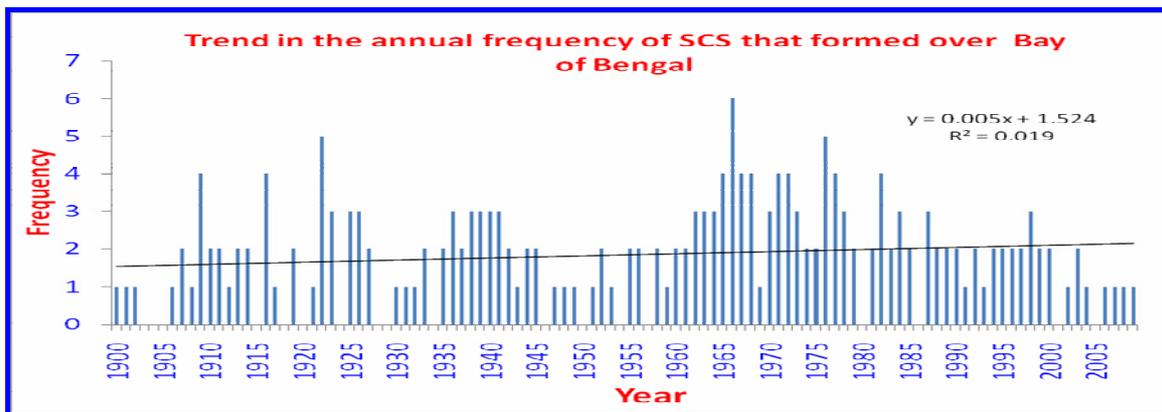
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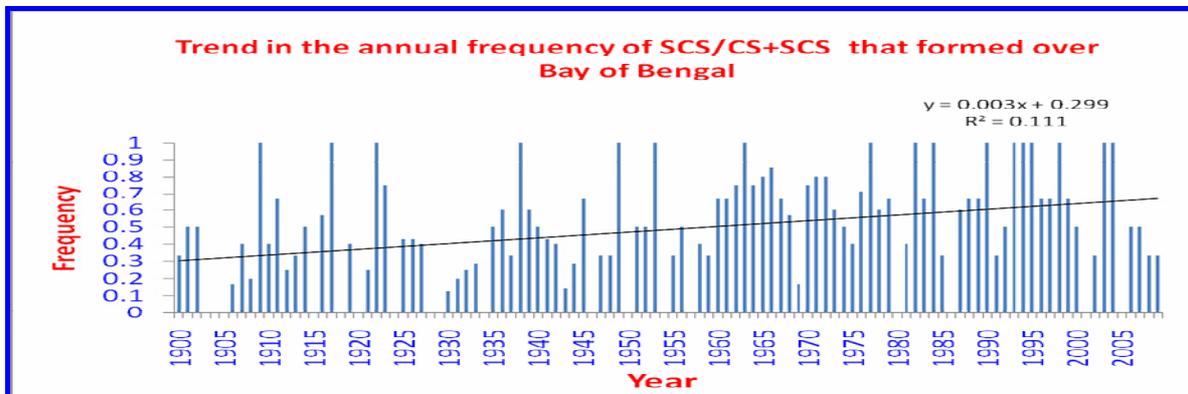
(c)

Fig. 24 (i): Trends in the annual frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed over the Bay of Bengal during 1900-2009

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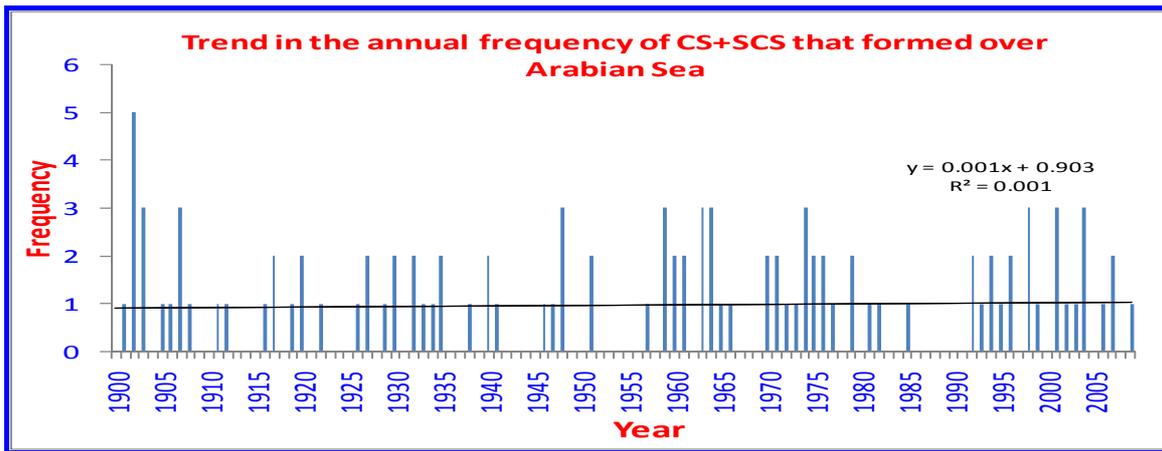
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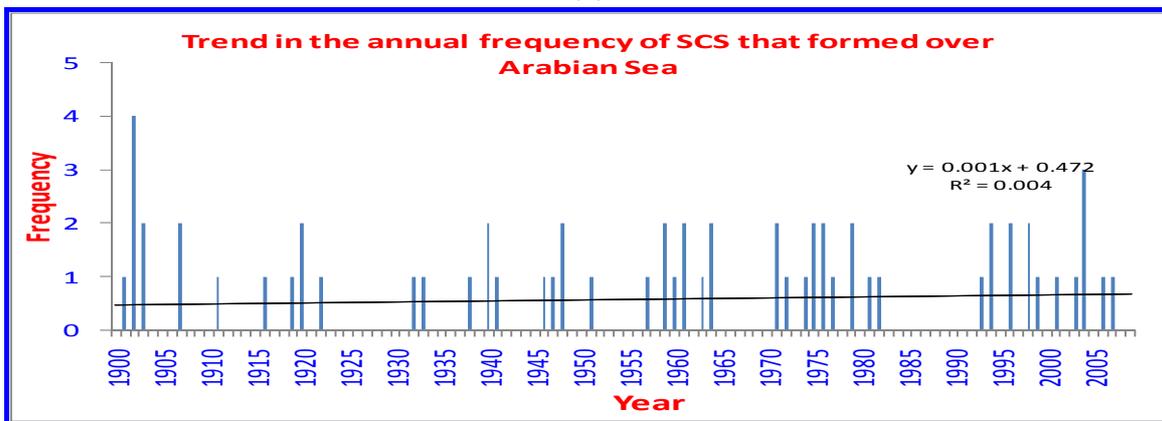
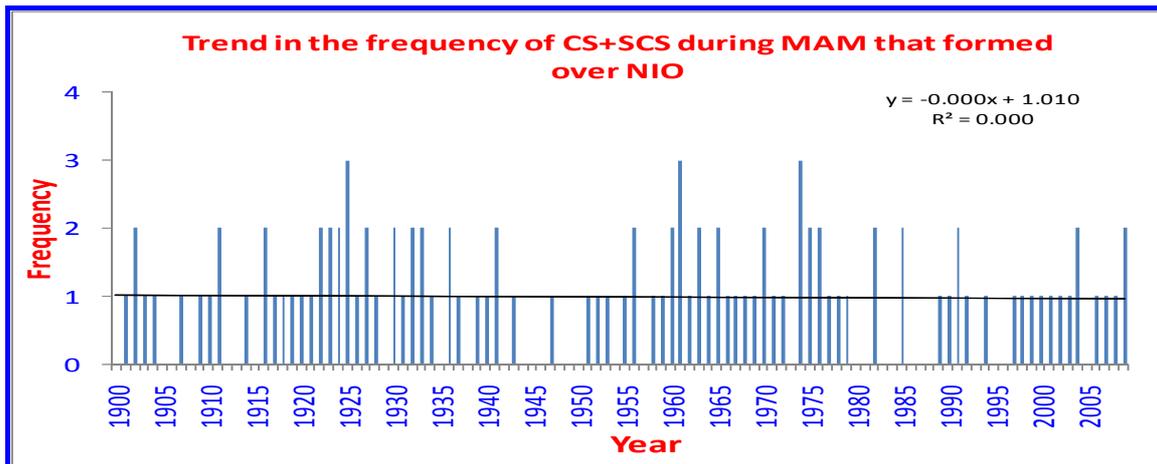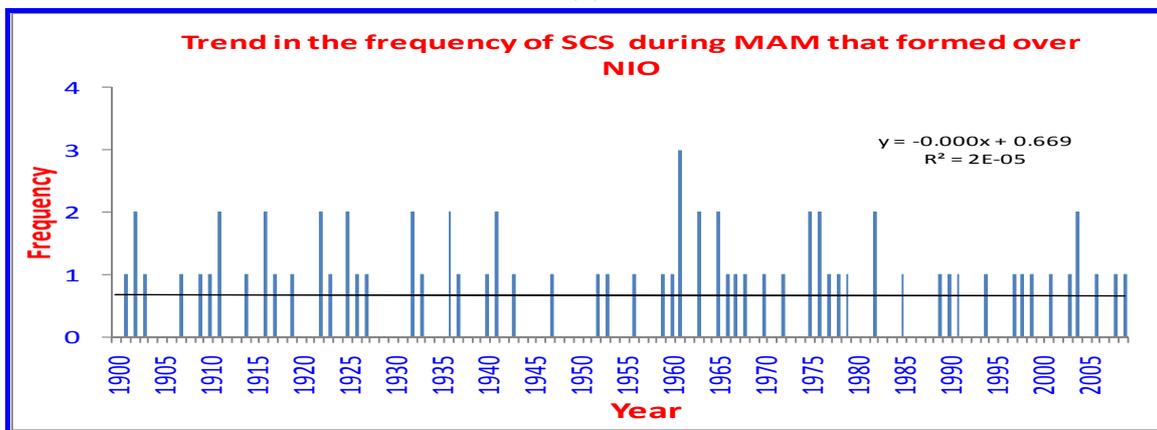(b)
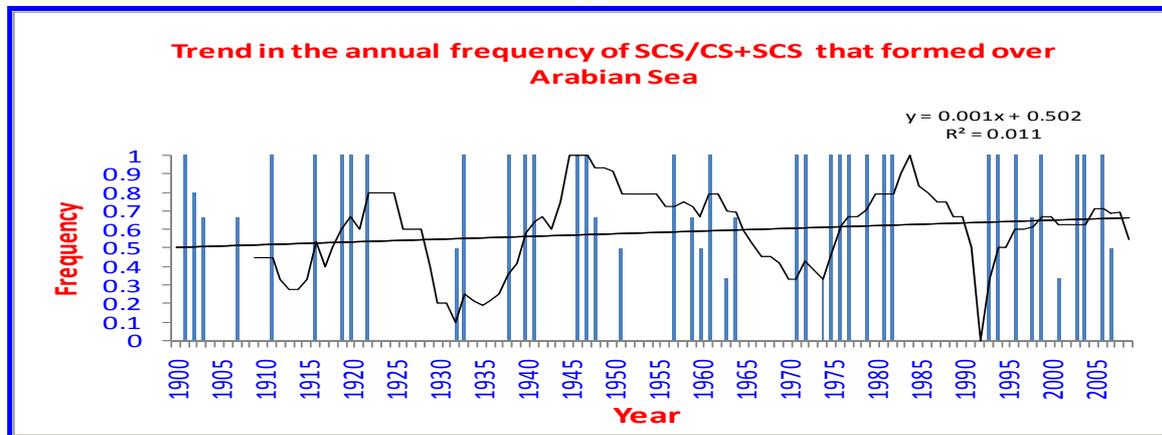
(c)

Fig.24(ii): Trends in the annual frequency of (a) cyclones (b) severe cyclones (c) severe cyclones to total cyclones that formed over the Arabian Sea during 1900-2009

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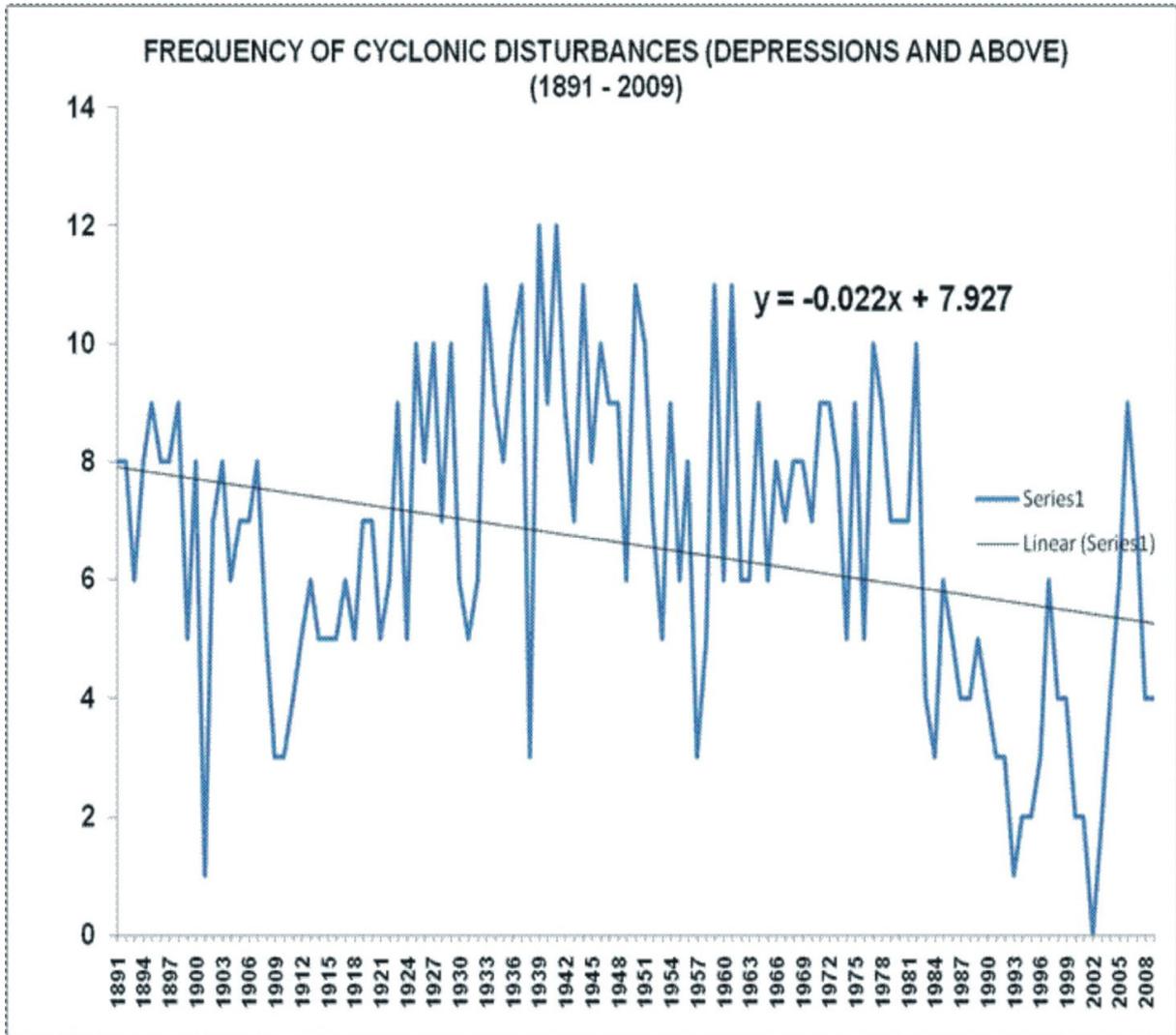
Fig. 25: Frequency of cyclones and depressions during 1891-2009

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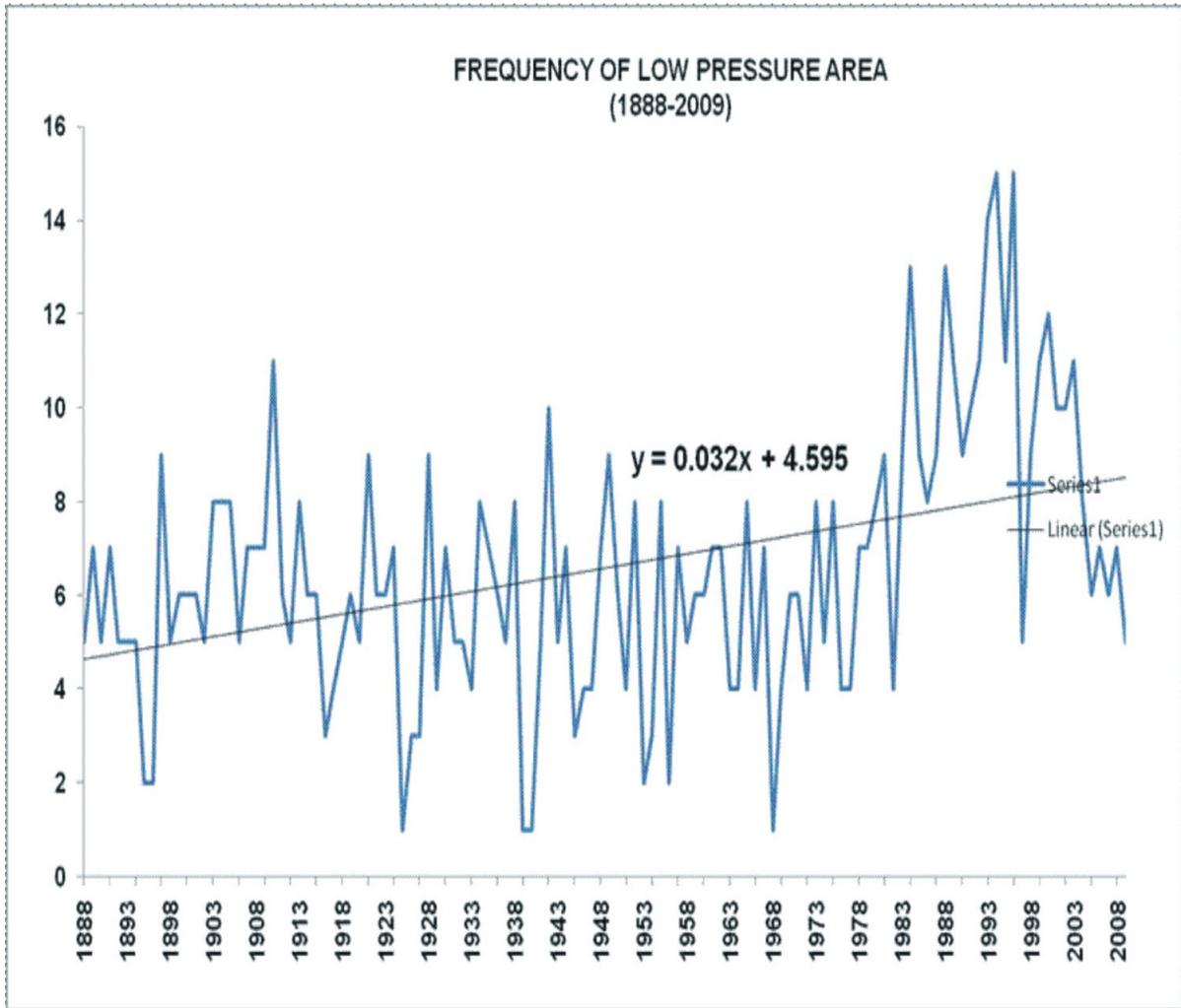
Fig 26: Trend in frequency of low pressure areas during 1888-2009
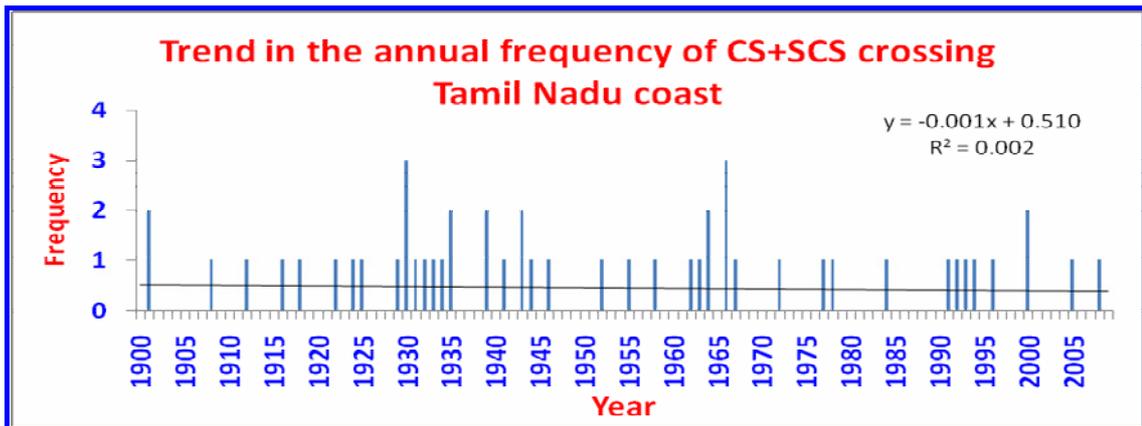
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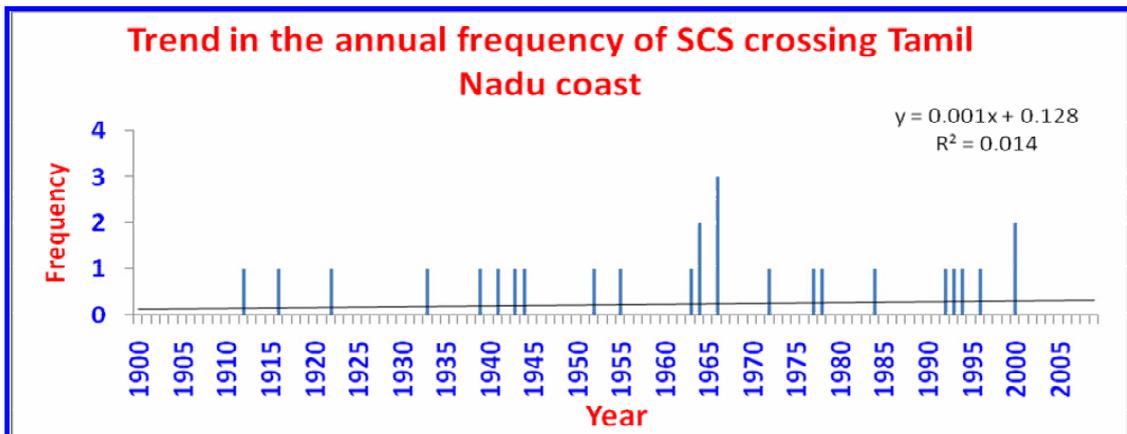
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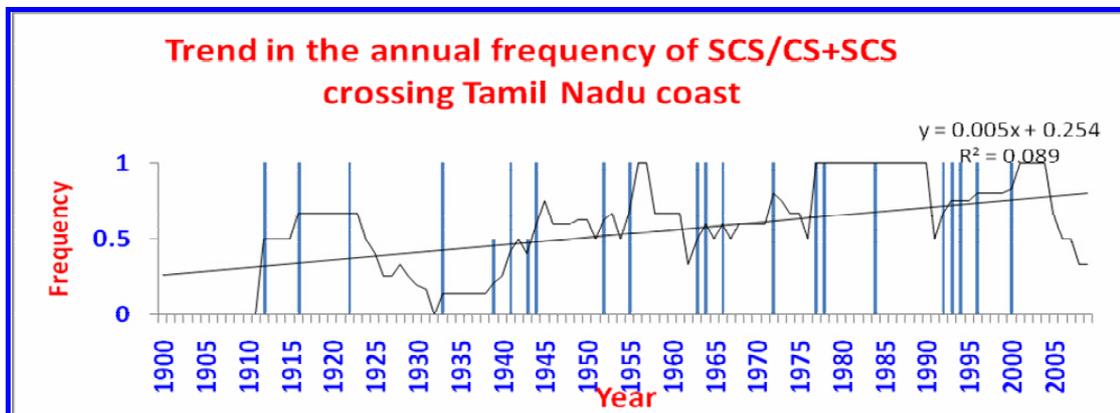
(c)

Fig.27 (i): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Tamil Nadu coast during 1900-2009

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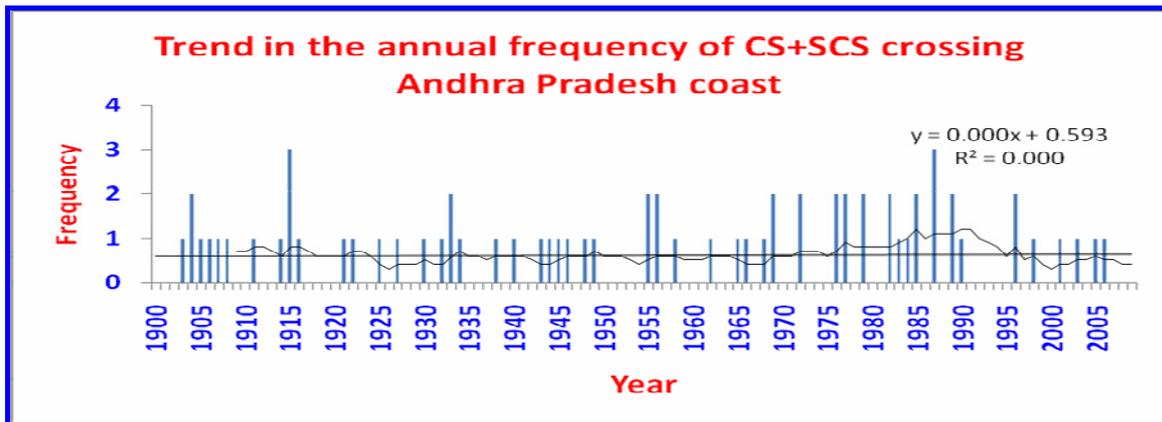
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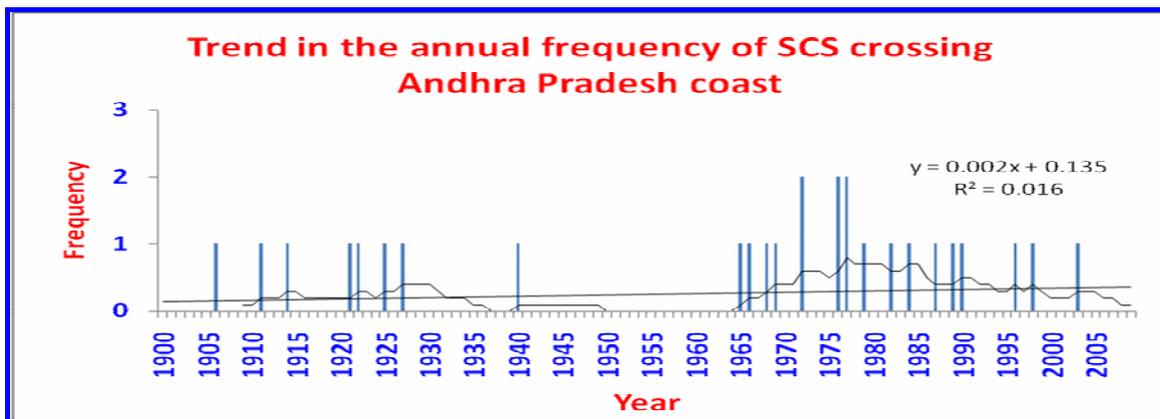
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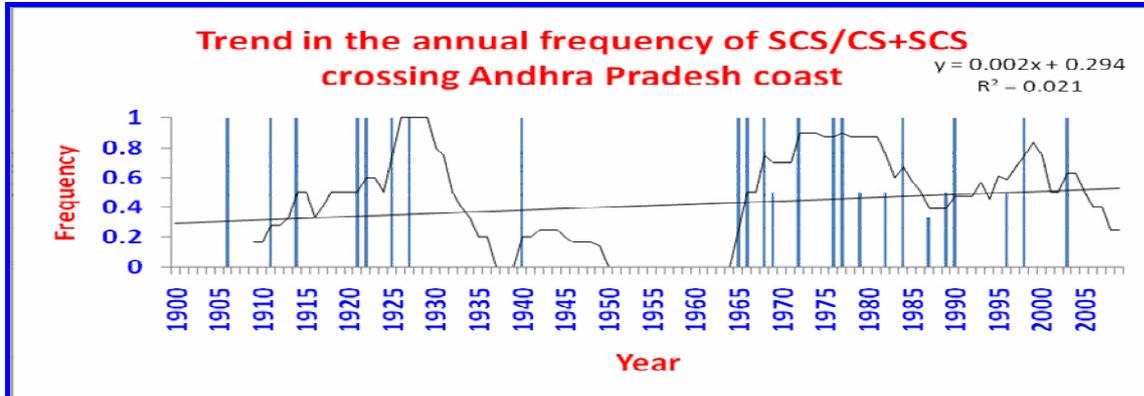
(c)

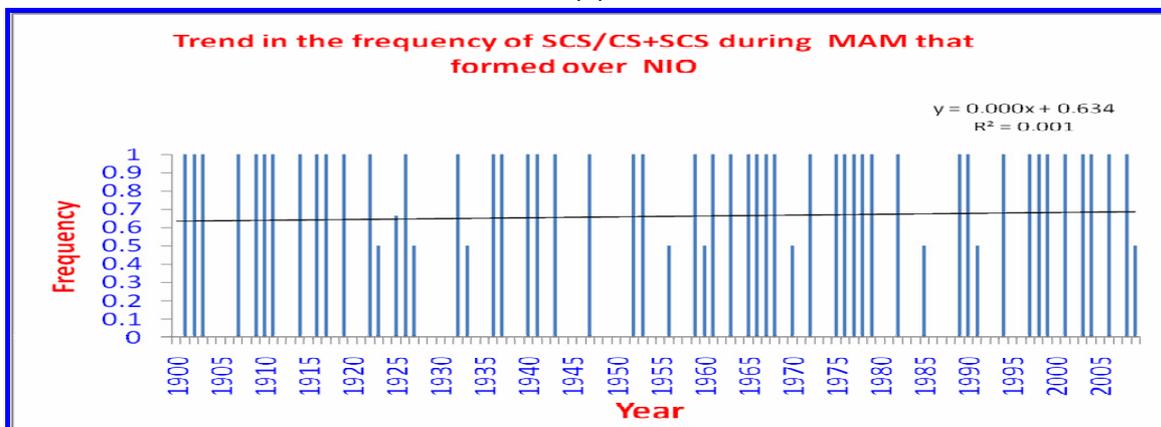**Fig.27 (ii): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Andhra Pradesh coast during 1900-2009**

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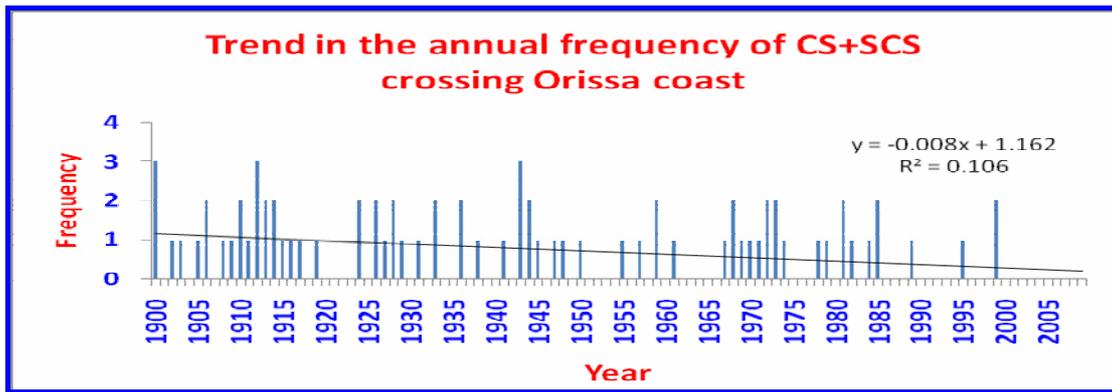
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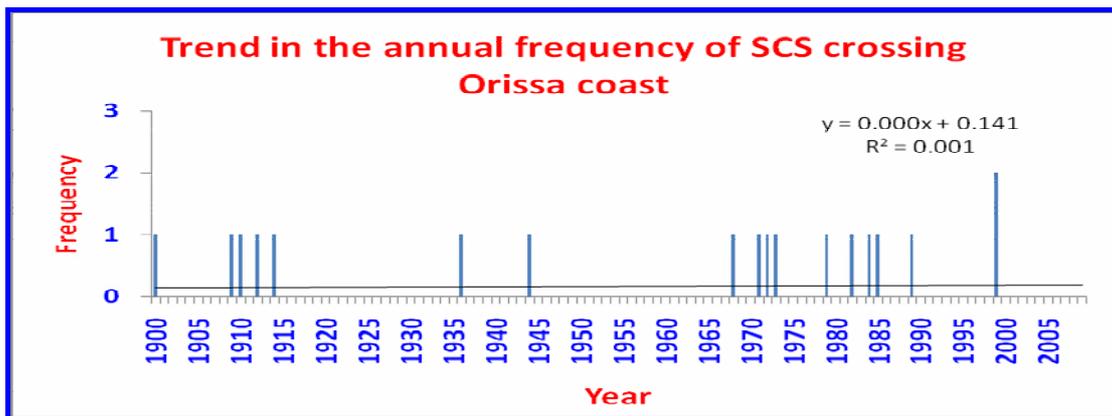
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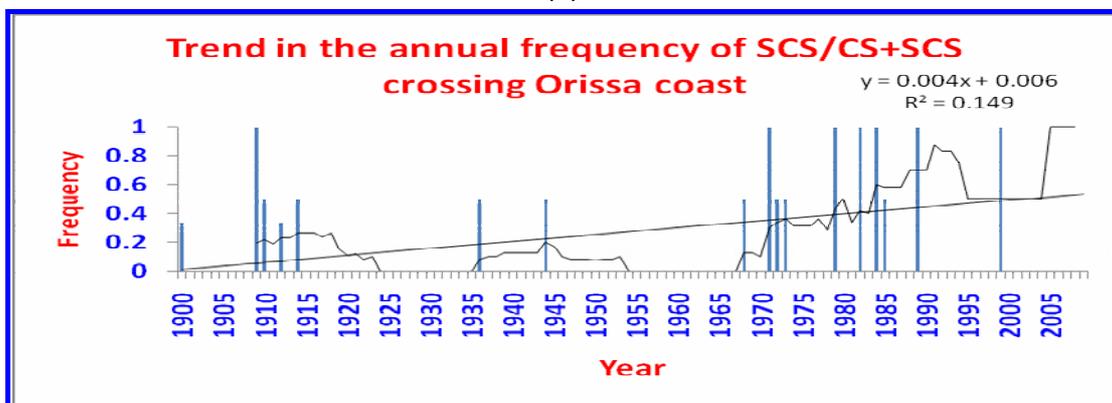
(c)

Fig.27 (iii): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Orissa coast during 1900-2009
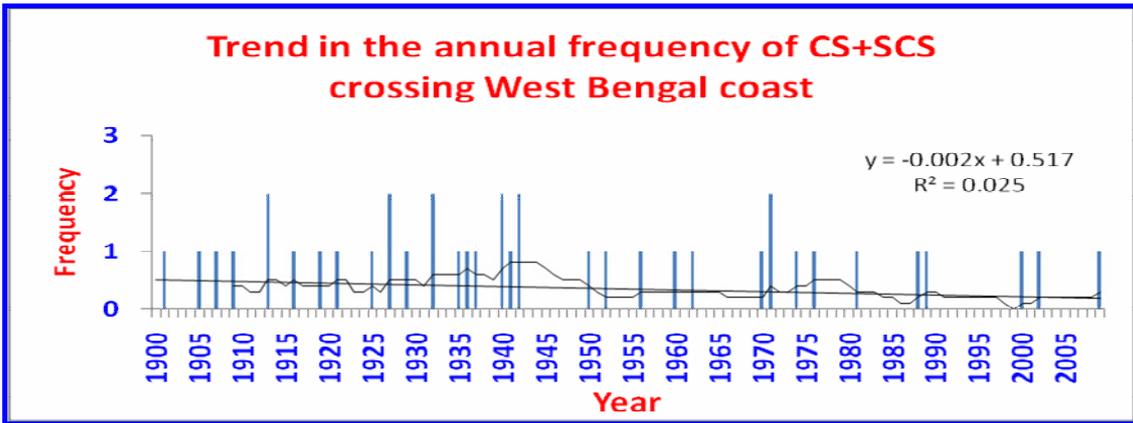
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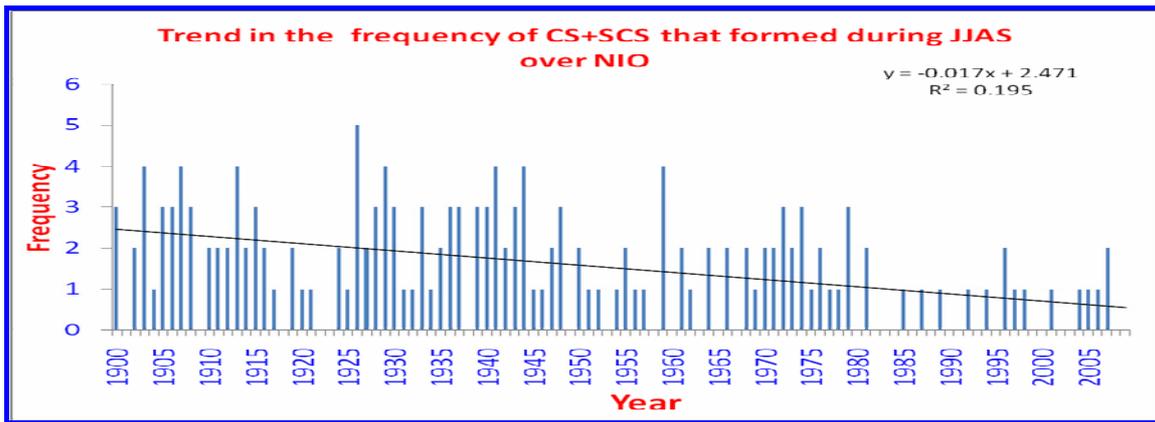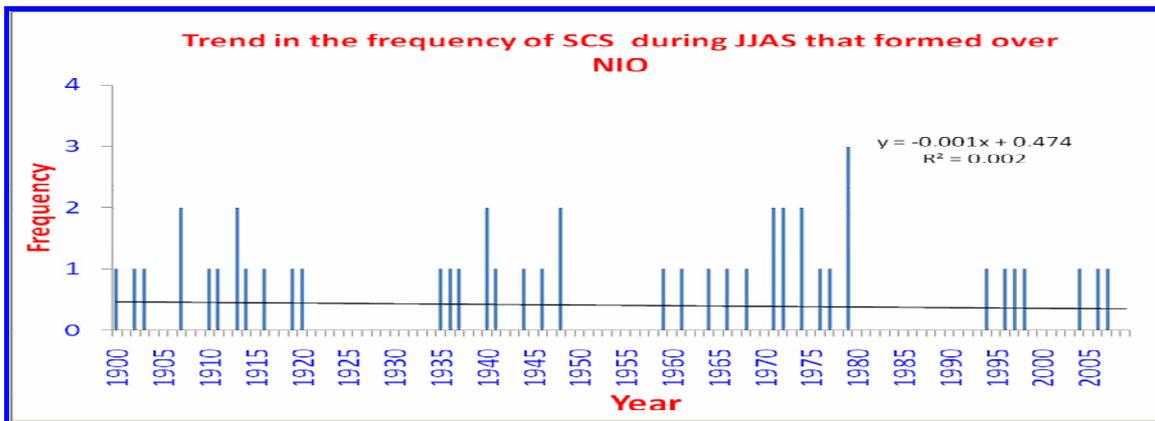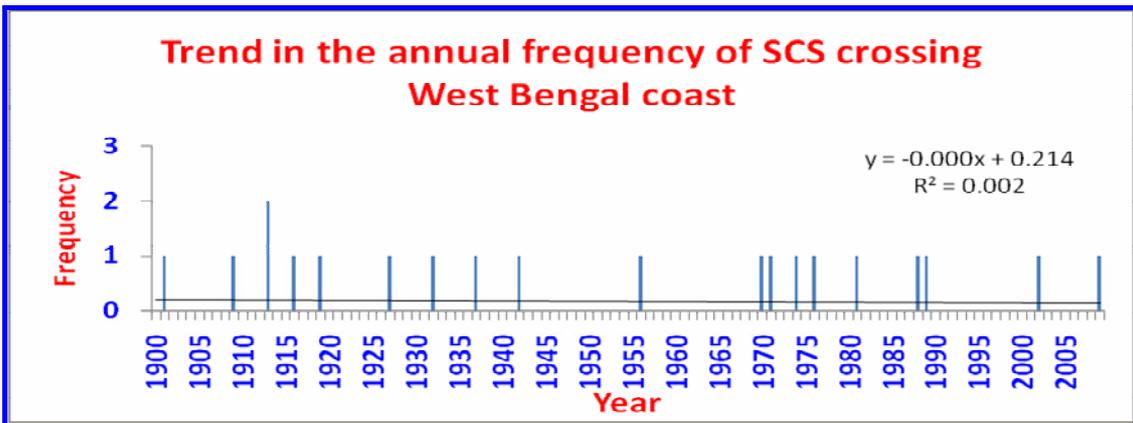

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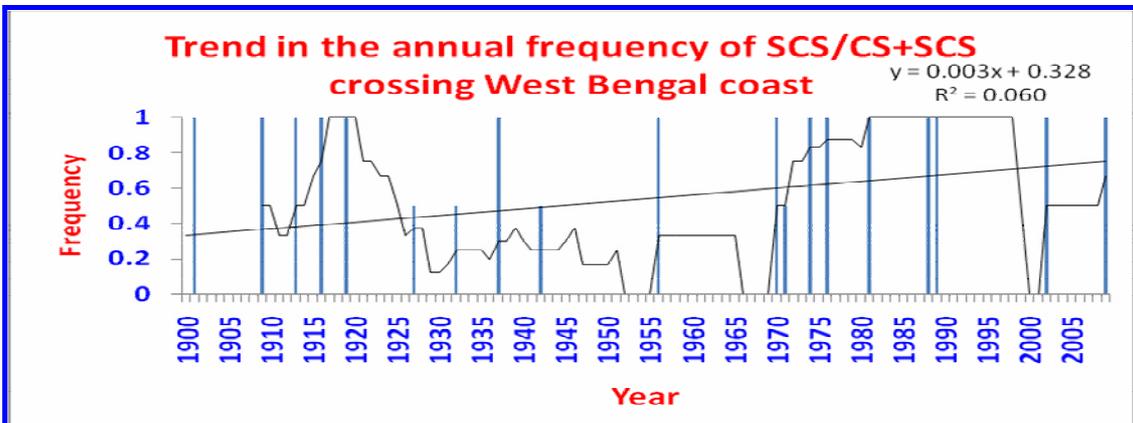
(c)

Fig.27 (iv): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed West Bengal coast during 1900-2009

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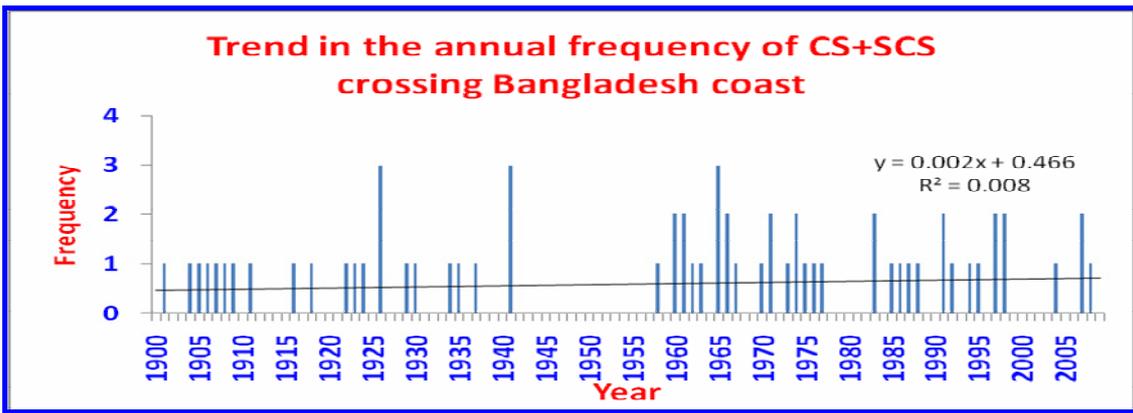
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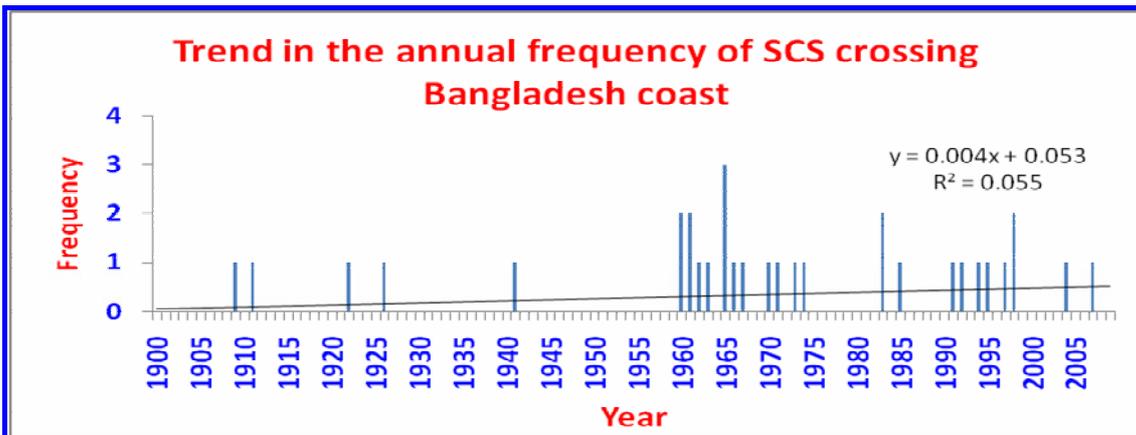
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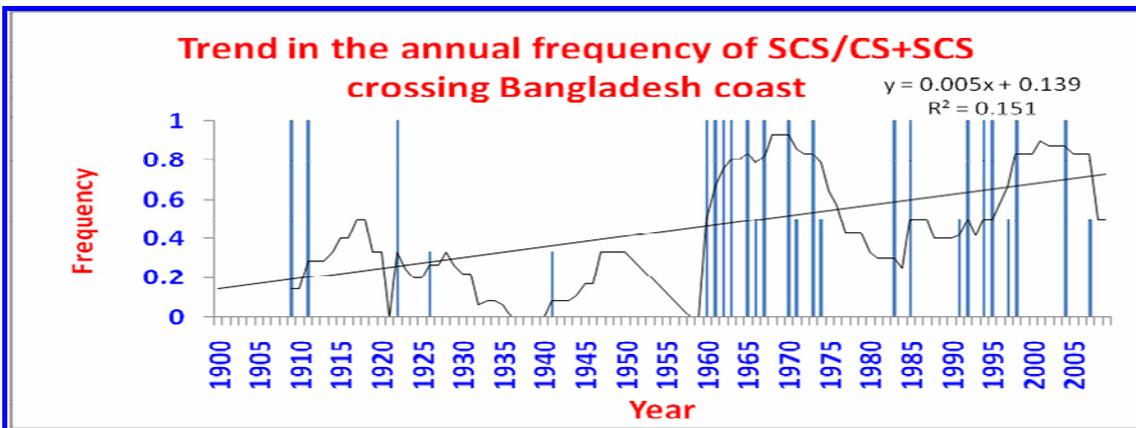
(c)

Fig.27 (v): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Bangladesh coast during 1900-2009
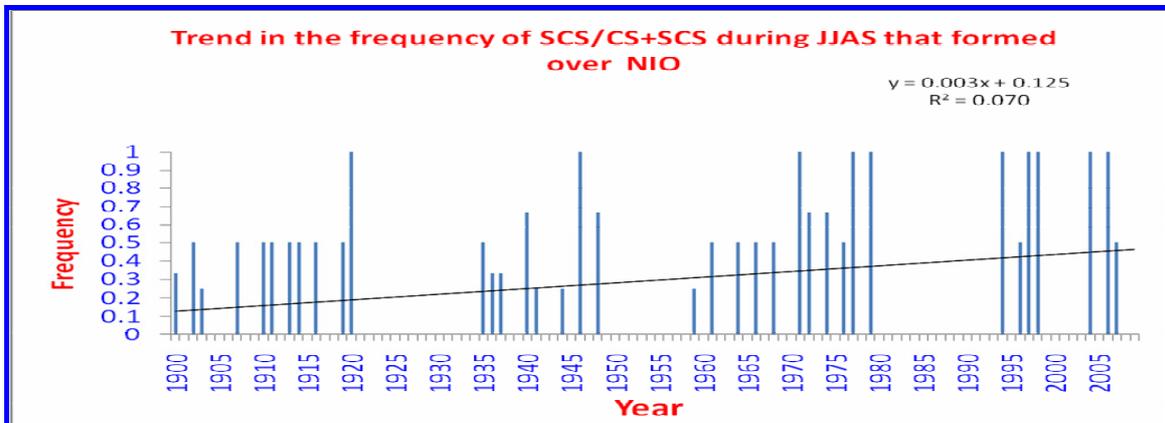
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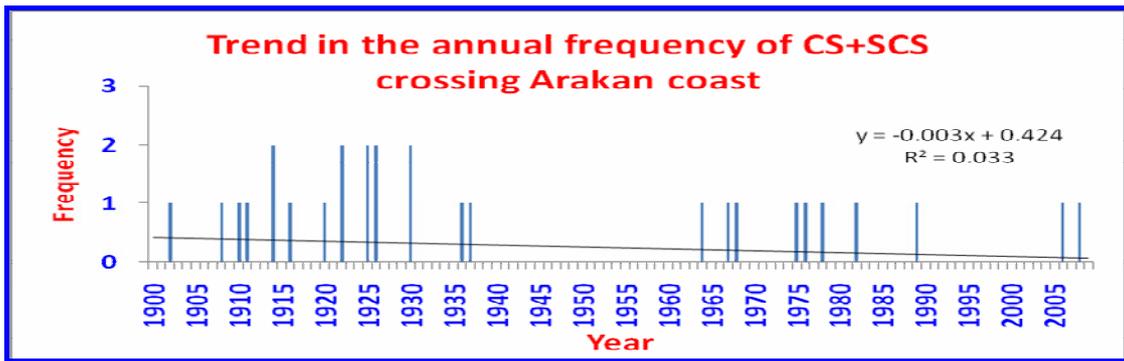
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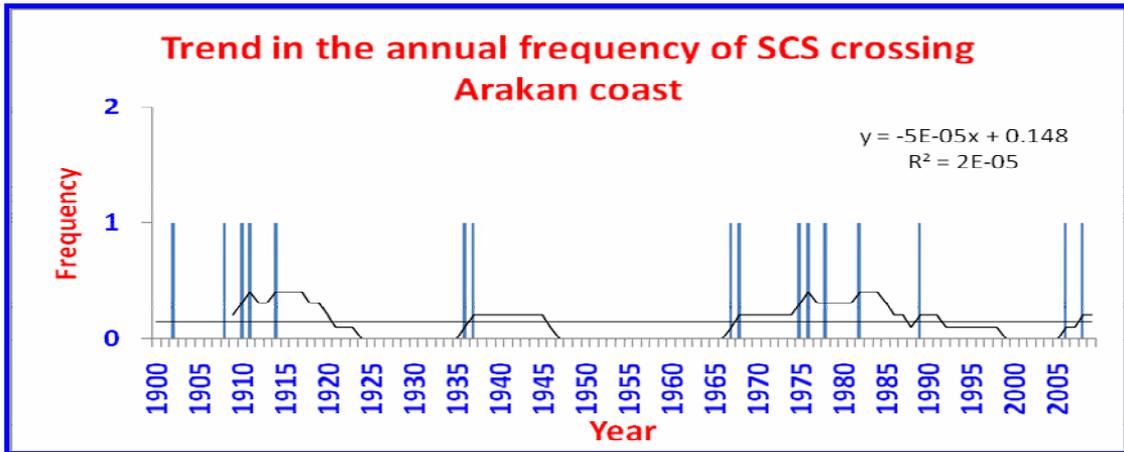
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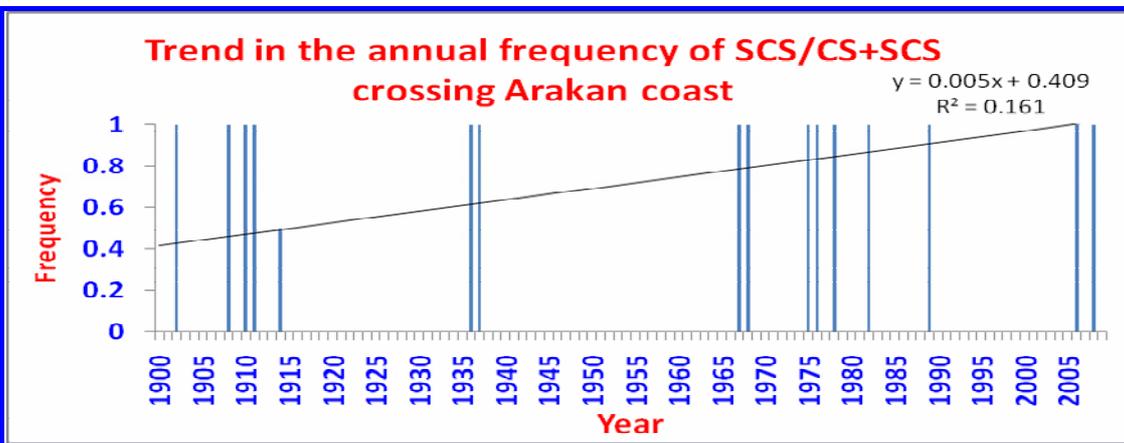
(c)

Fig. 27 (vi): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Arakan coast during 1900-2009

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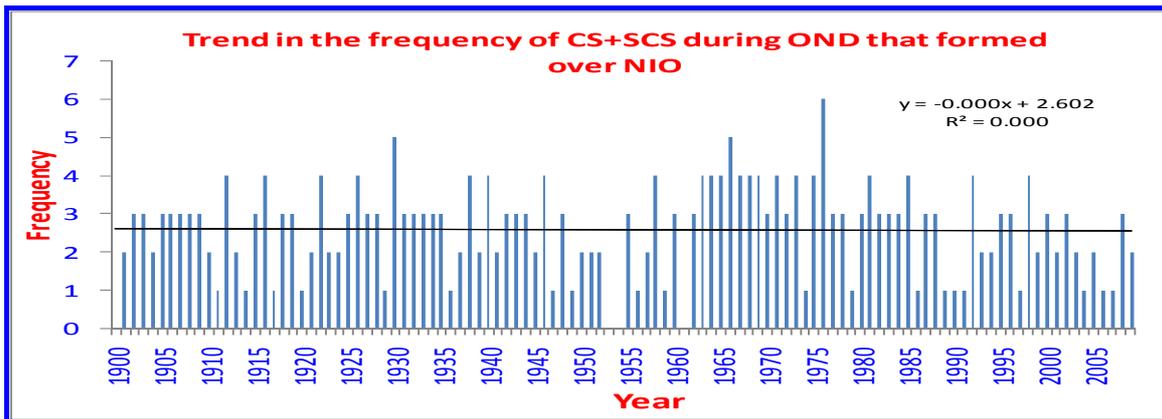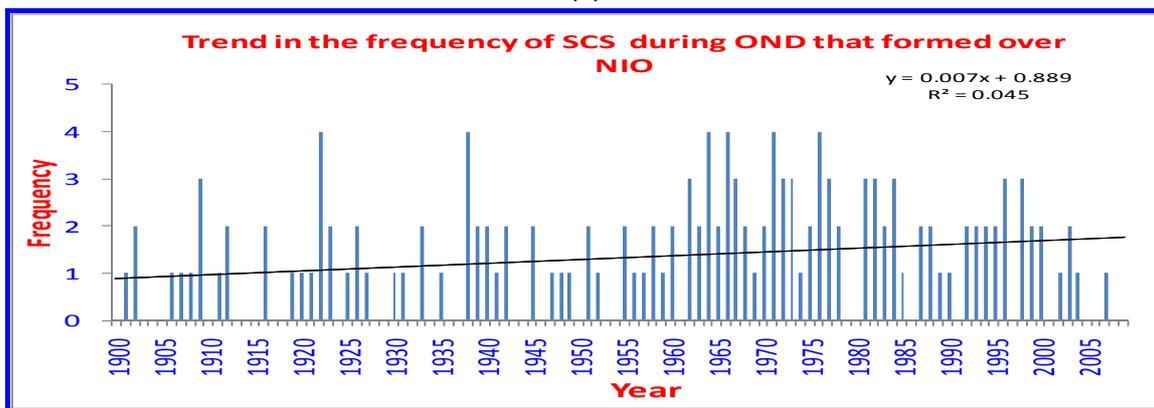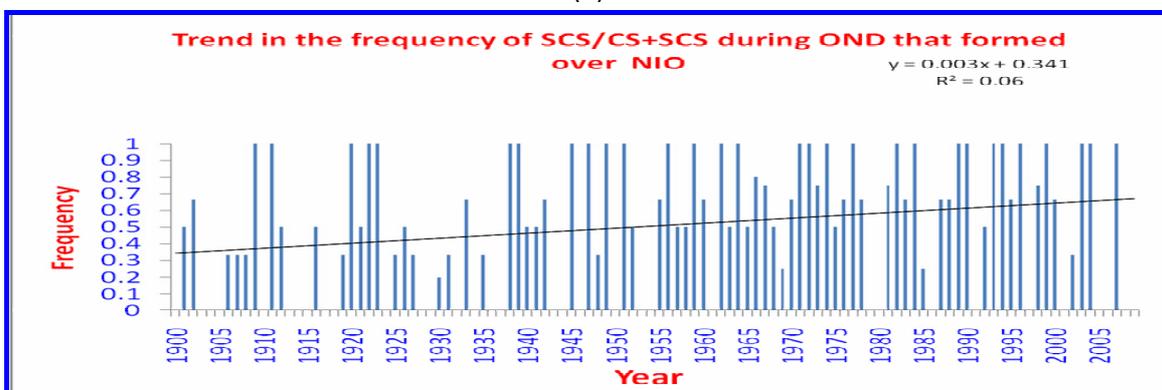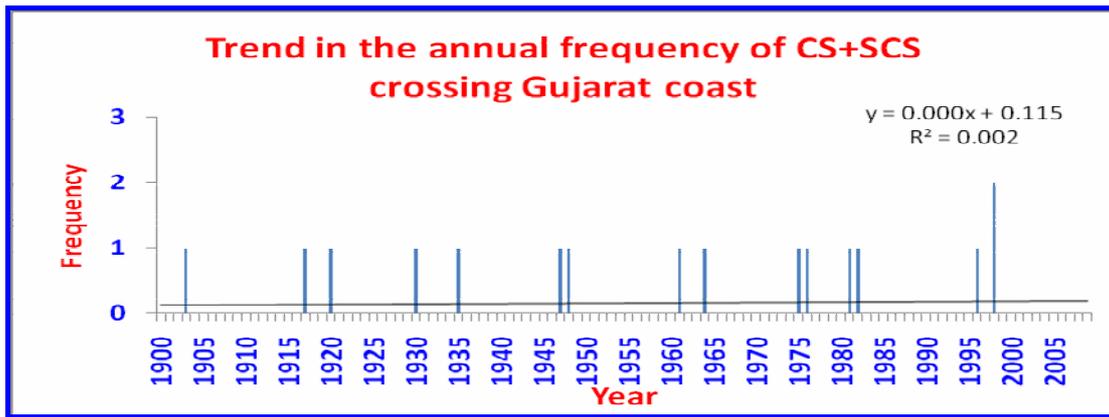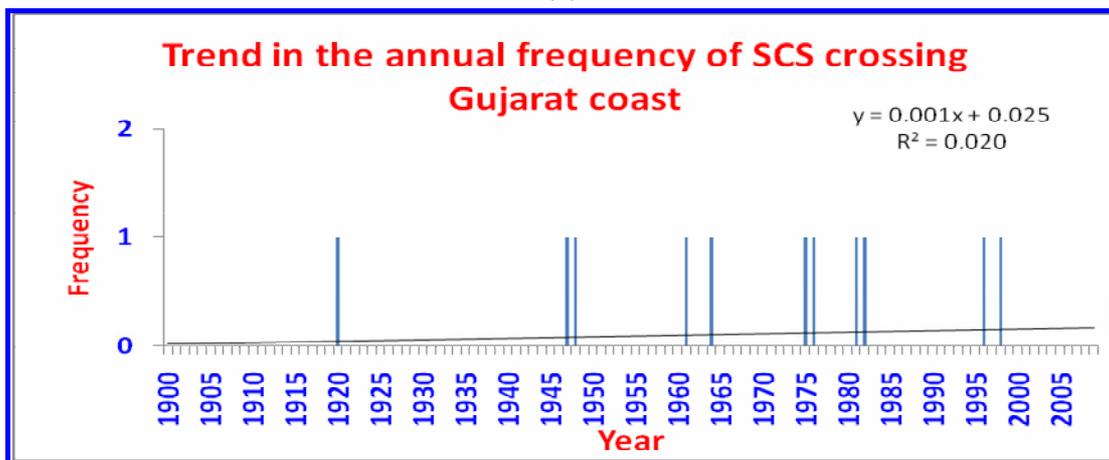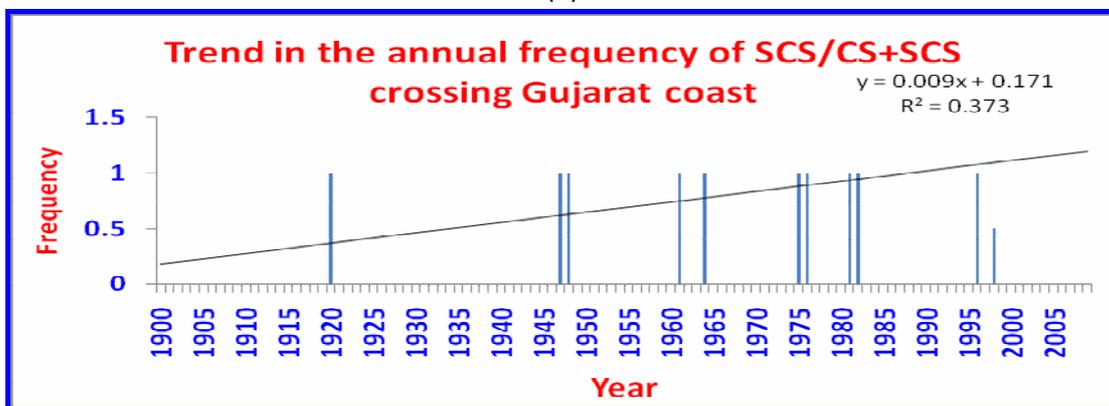**Fig. 27(vii): Trends in the annual frequency of (a) cyclones and (b) severe cyclones (c) severe cyclones to total cyclones that crossed Gujarat coast during 1900-2009**

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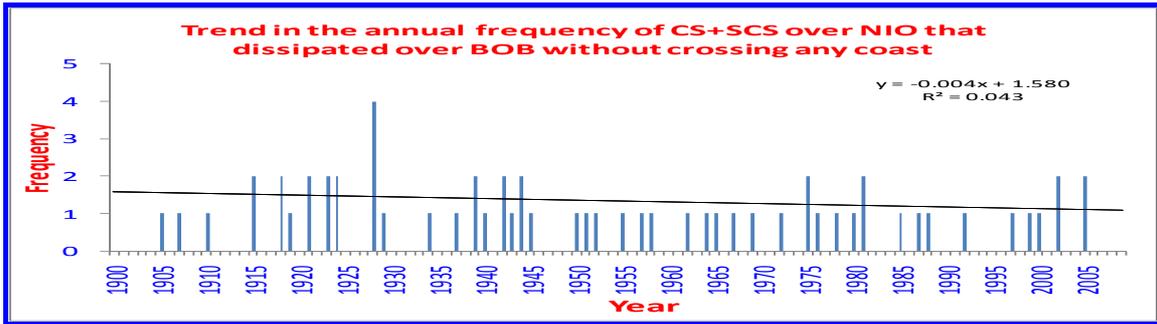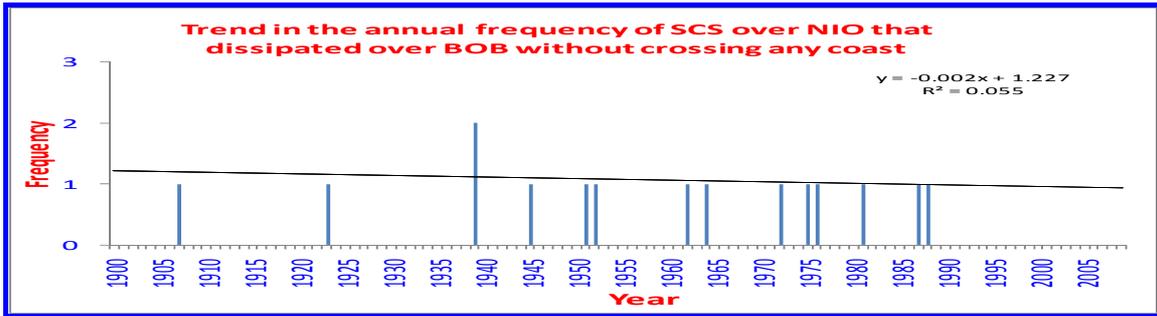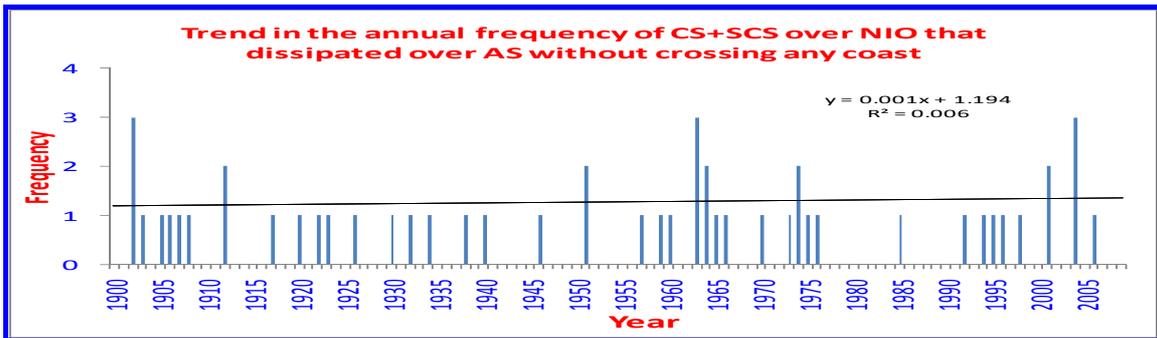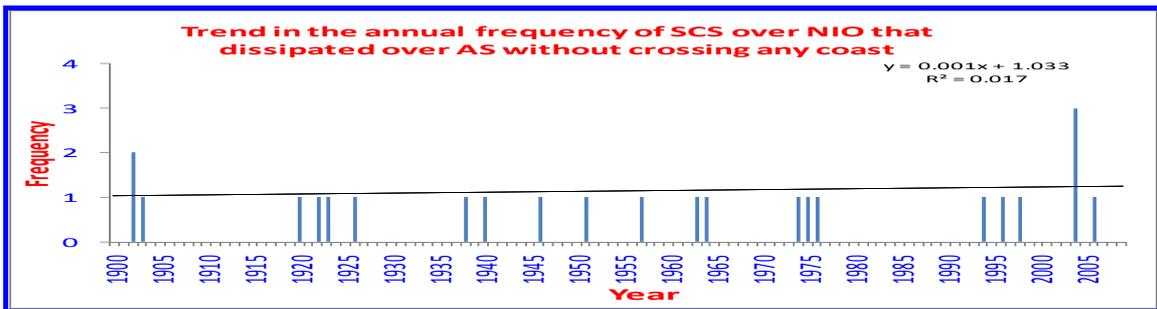
Fig 28 a-d: Trends in the annual frequency of cyclones / severe cyclones that formed over NIO and dissipated over the Bay of Bengal (BOB) / Arabian Sea (AS) without crossing any coast

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Fig. 29: PMSS above tide level (in metres) over maritime districts of east and west coast of India

6.5 Forecasting and Warning of cyclones

Cyclone warning is one of the most important functions of India Meteorological Department (IMD) and it was the first service undertaken by the Department as early as in 1865 and thus the service started before the establishment of the department in 1875. IMD at present is the nodal agency in the country to monitor and predict the cyclonic disturbances and issue the warning and advisory bulletins. IMD, New Delhi also acts as a Regional Specialised Meteorological Centre (RSMC) for providing tropical cyclone advisories to the World Meteorological Organisation (WMO)/ Economic and social cooperation for Asia and the Pacific (ESCAP) Panel member countries, viz., Bangladesh, Myanmar, Thailand, Srilanka, Maldives, Pakistan and Oman. IMD, New Delhi also works as a Tropical Cyclone Advisory Centre (TCAC) for international civil aviation as per the requirement of International Civil Aviation Organisation (ICAO).

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Cyclones are monitored using various technique like Synoptic technique, Satellite technique, *Radar Techniques etc. Different models like* Quasi-Lagrangian Model (QLM, Non-hydrostatic Meso-scale Model MM-5 (Version 3.6), WRF Model, Multi-model ensemble (MME) technique are run at IMD for forecasting of cyclones. Apart from the models run in IMD, the model product from other centers like ECMWF, UKMO, JMA, NCMRWF (T254) IIT, Delhi, Indian Air Force (MM5) and INCOIS (wave forecast models) are considered. Various stations models like CLIPPER, Chaos/Senaric algorithim model developed by Space Application Centres, Indian Space Research Organisation, Ahmedabad run operationally in IMD for track prediction.

The cyclone warnings are issued to state government officials in four stages:

- First Stage warning known as "PRE CYCLONE WATCH" issued 72 hours in advance
- Second Stage "CYCLONE ALERT"issued at least 48 hrs in advance of the expected commencement of adverse weather over the coastal areas
- Third Stage warning known as "CYCLONE WARNING" issued at least 24 hours in advance of the expected commencement of adverse weather over the coastal areas.
- Fourth Stage of warning known as "POST LANDFALL OUTLOOK" issued at least 12 hours in advance of expected time of landfall

IMD has prepared Road map for cyclogenesis and further intensification , monitoring and prediction which are presented are under:

Step I
- SST exceeding 26°C and a deep thermocline (50 m)
- Analysis of SST in models available
- http://www.aoml.noaa.gov/phod/cyclone/data/ni.html
- IMD (Satellite)
- Depth of the 26°C isotherm. SST field provided on a daily basis from TMI measurements (Tropical Rainfall Measuring Mission's Microwave Imager).

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Step II

- Conditional instability through a deep atmospheric layer
- Area of deep convection on satellite imagery
- Favorable synoptic scale conditions for development of deep convection (Madden Julian Oscillation/Outgoing Longwave Radiation) :
  http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/
- Maps of the MJO real-time filtered OLR anomalies, each averaged for a period of 7 days.

Step III

- Large values of relative humidity in the lower and middle troposphere.
- Location of deep convection areas on geostationary satellite imagery
- Presence of a pre-existing disturbance in the lower atmosphere : analysis of pre-existing lows in the ITCZ (their location, organization, intensity)
- Satellite imagery
- Animated visible and IR geostationary imagery on Synergie : estimation of the areas of organizing deep convection, their evolution during the last 24 hours; first estimation of associated LLCCs (low level circulation centers); analysis of exposed LLCCs (when out of deep convection).
- Micro-Wave imagery over suspected convective areas (Monterey website, or Synergie Cyclone), to see the low or mid-level improving cyclonic organization, under Cirrus clouds.
  (http://www.nrlmry.navy.mil/tc_pages/tc_home.html)

Step IV

- Ocean surface winds derived from satellite :
- Quikscat : http://manati.orbit.nesdis.noaa.gov/quikscat/ Ocean Surface Winds derived from the SeaWinds Scatterometer aboard the QuikSCAT satellite
- Ascat : http://manati.orbit.nesdis.noaa.gov/ascat/ Ocean Surface Vector Winds derived from the Advanced Scatterometer (ASCAT - 50km) aboard the EUMETSAT METOP satellite
- Windsat : http://manati.orbit.nesdis.noaa.gov/windsat/ Ocean Surface Winds derived from WindSat/Coriolis Measurements

Step V

- Significant value of planetary vorticity (Coriolis force) ~5 deg. from Equator.

- Tropical storm can been observed ~ 2.5° sometimes also

- Weak vertical shear of the horizontal winds

- Upper level winds at 200/300 hPa

- http://cimss.ssec.wisc.edu/tropic2/

- Good upper level outflow: Models analysis

- Good low level inflow

- Models analysis

- Low level winds data (Quikscat, …)

- Wind Shear based on satellite observation is defined as follows:

- Wind Shear =(150-300) mb layer mean minus (700-925)mb layer mean

- Wind shear is classified as follows:

   5-10 kt : weak (favorable for development)

   10-20 kt : moderate (unfavorable for weak system, or neutral for mature cyclone) more than 20kt: strong (unfavorable)

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CHAPTER – VII

DROUGHT

7.1   Introduction

Drought is universally acknowledged a phenomenon associated with scarcity of water. It is a normal, recurrent feature of climate and is observed in all the climatic zones. It is still largely unpredictable   and varies with regard to the time of occurrence, duration intensity, and extent of the area affected from year to year.   It is a temporary condition caused by significantly less (deficient) rainfall for an extended period of time, usually during a season when substantial   rainfall is normally expected over the area. The deficiency in the rainfall is measured relative to the long-period average (LPA) of rainfall over the area. The severity of the drought can also be aggravated by other climatic factors such as high temperature, high wind and low humidity. Though the number of deaths directly attributable to drought during 1963-1992 is quite less (3%) compared to that caused by floods (26%) and tropical cyclones (19%), yet the number of persons affected by drought (33%) is the highest amongst all the natural disasters (number of persons affected by floods and tropical cyclones being 32% and 20% respectively) and the significant damage caused by drought is 22% which is comparable to the corresponding values of floods (32%) and tropical cyclones (30%) (WMO, 1994).

7.2   Monitoring of Meteorological Drought

India Meteorological Department (IMD) monitors meteorological and agricultural drought based on 'percentage of rainfall departure' and 'aridity anomaly index' respectively.

Meteorological drought over an area is defined as a situation when the monsoon seasonal (June-September) rainfall over the area is less than 75% of its long-term average value. It is further classified as 'moderate drought. if the rainfall deficit is 26-50% and 'severe drought' when the deficit exceeds 50% of the normal. Further, a year is considered as a 'drought year' when the area affected by moderate

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and severe drought either individually or together is 20-40% of the total area of the country and seasonal rainfall deficiency during southwest monsoon season for the country as a whole is at least 10% or more. When the spatial coverage of drought is more than 40% then it is called as all India severe drought year. Based on the index of percentage departure of rainfall from normal, IMD has delineated sub-divisionwise drought since 1875 and frequency of moderate and severe drought and occurrences of probabilities of drought years during 1875-2009 have been presented in Table 14.   It is observed that arid west viz. West Rajasthan (34 cases) and Saurashtra and Kutch (31 cases), have the highest occurrences of drought. The adjoining Gujarat Region which mostly belongs to semi-arid climate also experiences high incidences of drought (28). Other areas recording large incidences of drought are Haryana, Delhi & Chandigarh, Punjab, Himachal Pradesh and East Rajasthan in northwest India and Rayalaseema in southern peninsula. The per-humid and humid areas of the east and north-east India (viz. Arunachal Pradesh, Assam& Meghalaya, Orissa, Gangetic West Bengal and Jharkhand), for obvious reasons, have the lowest occurrences of drought.

Percent area of the country affected by drought during 1901-2003 and details of moderate and severe droughts during 1875-2003 are   depicted in Fig 30, and Fig 31 respectively. Based on the probabilities of occurrence of drought (percentage), the entire country has been divided (Fig. 32) into chronically drought prone area (probability of occurrence of drought more than 20%), frequently drought prone area (probability of occurrence of drought 10-20%) and least drought prone area (probability of occurrence of drought less than 10%). West Rajasthan and the entire Gujarat State fall in the category of chronically drought prone area. Therefore, these areas deserve special attention for drought proofing like evolving crop varieties resistant to moisture stress, better water management, effective land management etc. East Uttar Pradesh, Uttarakhand, Haryana, Punjab, Himachal Pradesh, East Rajasthan, West Madhya Pradesh, Marathwada, Vidarbha, Telangana, Coastal Andhra Pradesh and Rayalaseema fell in the category of frequently drought prone areas which can expect drought once in 6-10 years. These areas generally belong to sub-humid climate zone (IMD Met. Monograph No. 21/2005).

7.2.1 Drought Index based on Standardized Precipitation Index (SPI)

Although rainfall deviation from the long-term mean continues to be a widely adopted indicator for drought intensity assessment because of its simplicity, yet its application is strongly limited by its inherent nature of dependence on mean. Rainfall deviations cannot be applied uniformly to different areas having different amounts of mean rainfall since a high and a low rainfall area can have the same rainfall deviation for two different amounts of actual rainfall. Therefore, rainfall deviations across space and time need to be interpreted with utmost care. SPI expresses the actual rainfall as standardized departure from rainfall probability distribution function. Computation of SPI involved fitting a gamma probability density function to a given frequency distribution of precipitation totals. The alpha and beta, shape and scale parameters respectively, of the gamma distribution were estimated for a suitable timescale of for each year. Alpha and beta parameters were then used to find the cumulative probability of an observed precipitation amount, which was then transformed into the standardized normal distribution. This index has gained importance in recent years as a potential drought indicator permitting comparisons across space and time (Naresh Kumar et al, 2009). SPI as a drought index is very versatile as it can be calculated on any timescale. This versatility is also critical for monitoring the temporal dynamics of a drought, including its development and decline. These aspects of a drought have always been difficult to track with other indices; further, as SPI values are normally distributed, the frequencies of extreme and severe drought events for any location and timescale are consistent. The classification of the drought intensities based on the SPI value is as follows; It is called moderately dry/ moderate drought for SPI value from -1.0 to -1.49, severely dry/ severe drought for SPI value from -1.5 to -1.99 and extremely dry/ extreme drought for SPI value of - 2 and less

The analysis of long series data during 1875 – 2009 (Table 15) , indicates that five years – 1877, 1899, 1918, 1972 and 2009 were All India extreme drought years when SPI value exceeded -2.0. Mooley (1994) defined Phenomenal All India drought as a phenomenon when % departure of monsoon season's rainfall was ≤ -2 SD i.e. -20% and the percentage area under deficient monsoon rainfall was equal to

or more than mean+2SD i.e. 47.7%. Therefore, phenomenal drought years identified by Mooley (1994) has been effectively diagnosed as extreme drought years by the SPI. Further, SPI was also able to diagnose properly the other All India moderate/severe drought years that affected our country.

However, it may be mentioned that despite the current optimism about the SPI, it cannot solve all moisture monitoring concerns. Rather, it can be considered as a tool that can be used in coordination with other tools, such as aridity anomaly index or remote sensing data, to detect the development of droughts and monitor their intensity and duration. This will further improve the timely identification of emerging drought conditions that can trigger appropriate responses by the policy makers.

7.2.2 Drought Climatology of the District Rainfall

District wise Drought Climatology of the Southwest Monsoon Season over India based on Standardized Precipitation Index (SPI) during 1901-2003 has been brought out by Pai et al (2010). The Percent of Normal (PN) was calculated by dividing actual rainfall by its long period average. While for SPI, long time series of rainfall is fitted to a probability distribution, which is then transformed into a standardized normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median rainfall and negative values indicate less than median rainfall. Important results are summarised as under:

- Based on PN, majority of the districts in the northwest part of the country consisting of Rajasthan, Gujarat, Jammu & Kashmir, Punjab, Haryana have drought probabilities of ≥20%. The probabilities decrease as moving eastwards from northwest India to northeast India. Over northeast India, most of the districts have probabilities of less than 10%. Over the peninsula, many of the interior districts have probability of ≥20%. Districts along the west coast show less than 10% probability. The probability for severe drought are also highest in the districts from northwest India. Some isolated districts over various other parts of the country shows probability for severe drought of more than 5% (Fig. 33 a&b).

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- The highest probabilities of drought of various intensities are not distributed only over the arid or semi-arid regions based on SPI. It can be seen that for all the districts, the probability for the moderate drought is more than 10% and over majority of the districts the probability of the severe drought is more than 5% (Fig. 34 a ,b & c).The districts with probabilities more than 15%, though spread in almost all parts of the country, are somewhat concentrated in northwestern part of the country (consisting of Gujarat, Rajasthan, Punjab, Haryana, Chandigarh, Delhi and Jammu & Kashmir) and eastern part of the Peninsula (Gangetic West Bengal, Orissa, Vidarbha, Marathwada, Andhra Pradesh, Interior Karnataka and Tamil Nadu).

- The trend analysis of district-wise SPI series showed significant decreasing trends over many districts in Uttanranchal, Kerala and in the subdivisions from east central India and such as east Madhya Pradesh, Vidarbha, Chhattisgarh, Jharkhand, Bihar etc., and significant increasing trend was observed over several districts from Konkan region, Karnataka, west Madhya Pradesh, Andhra Pradesh, Punjab and West Uttar Pradesh. Some districts from Kerala and Chhattisgarh showed decreasing trends in SPI series and relatively high probability for drought occurrences of moderate and above intensity (Fig 35).

7.2.3 Drought mapping over different regions

Drought is one of the short term extreme events. There is no operational practice to forecast the drought. As such, mapping of drought prone areas is required for developmental planning (Fig 36). The results of mapping study (Gore et al 2010) are summarised as under:

1) In the Northwest region of India, the probability of moderate drought varies from 12 to 30% and that for severe drought varies from 1 to 20% in most of the parts and about 20-30% in the extreme north-western parts.
2) In West Central India, the probability of moderate drought varies from 5 to 26% and that for severe drought varies from 1 to 8%.

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3) In the Peninsular region, the probability of moderate drought varies from 3 to 27%, and that for severe drought varies from 1 to 9% in major parts.

4) In the Central Northeast region, the probability of moderate drought varies from 6 to 37% and that for severe drought varies from 1 to 10%.

5) In the Northeast region, the probability of moderate drought varies from 1 to 26% and that for severe drought varies from 1 to 3%.

6) In the hilly region, the probability of moderate drought varies from 9 to 31% and that for severe drought varies from 1 to 12% except in Leh and Lahul & Spiti.

In general it can be concluded that in most parts of India, probabilities of moderate drought are in the range 11 to 20%. Major parts of India show probabilities of severe drought in the range 1 to 5%. In some West Central, Central Northeast and Northeast region of India, no severe drought is experienced.

7.3   Monitoring of Agricultural Drought

IMD identifies meteorological drought for subdivisions every year based on rainfall analysis since its establishment in 1875. An aridity anomaly index (AI) is developed to monitor the incidence, spread, intensification, and recession of agricultural drought . AI is given as

$$AI = \frac{PE - AE}{PE} \times 100$$

where PE is potential evapotranspiration and AE actual evapotranspiration. The aridity anomaly is calculated by using the normal Aridity Index for 210 well-distributed stations over the country. These anomalies are be used for crop planning and in the early warning system during drought/desertification.

Criterion for Aridity Anomaly Areas

0 or negative	Non-arid
1 – 25	Mild arid
26-50	Moderate arid
> 50	Severe arid

It should be remembered that aridity is different from drought. It is a permanent climatic situation of a region, while drought may occur at any place and on any time scale. As such, anomaly reports do not indicate arid regions; on the contrary, they give an indication of the moisture stress in any region on the time scale of one or two weeks, and they are useful early warning indicators of agricultural drought. Based on this aridity index, weekly/fortnightly Aridity Anomaly Maps/ Reports are prepared for the country as a whole during the southwest monsoon season and over 5 subdivisions (Coastal Andhra Pradesh, Rayalaseema, South Interior Karnataka, Tamil Nadu, and Pondicherry and Kerala) during the northeast monsoon season. A Weekly Aridity Report during September 2010 is depicted in Fig 37.

Table - 14
Sub-divisionwise frequencies of Moderate and Severe drought during 1875-2009 and probabilities of drought years

S.N.	Name of Sub-division	Moderate	Severe	Total	Drought probabilities (Total) %
1.	Andaman & Nicobar Islands	17	0	17	13
2.	Arunachal Pradsh	7	1	8	6
3.	Assam & Meghalaya	5	0	5	4
4.	Nagaland, Manipur, Mizoram & Tripura	12	0	12	9
5.	Sub-Himalayan West Bengal	7	0	7	5
6.	Gangetic West Bengal	2	0	2	1
7.	Orissa	5	0	5	4
8.	Bihar	12	0	12	9
9.	Jharkhand	6	0	6	4
10.	East Uttar Pradesh	13	1	14	10
11.	West Uttar Pradesh	13	1	14	10
12.	Uttarakhand	16	2	18	13
13.	Haryana, Delhi & Chandigarh	21	4	25	19
14.	Punjab	20	4	24	18
15.	Himachal Pradesh	20	3	23	17
16.	Jammu & Kashmir	21	6	27	20
17.	West Rajasthan	22	12	34	25
18.	East Rajasthan	18	5	23	17
19.	West Madhya Pradesh	14	0	14	10
20	East Madhya Pradesh (including Chhattisgarh)	12	0	12	9
21.	Gujarat Region	17	11	28	21
22.	Saurashtra & Kutch	16	15	31	23
23.	Konkan & Goa	9	0	9	7
24.	Madhya Maharashtra	7	2	9	7
25.	Marathwada	17	1	18	13
26.	Vidarbha	16	1	17	13
27.	Coastal Andhra Pradesh	13	0	13	10
28.	Telangana	18	0	18	13
29.	Rayalaseema	20	2	22	16
30.	Tamil Nadu & Pondicherry	12	0	12	9
31.	Coastal Karnataka	5	0	5	4
32.	North Interior Karnataka	10	0	10	7
33.	South Interior Karnataka	9	0	9	7
34.	Kerala	10	0	10	7
35.	Lakshadweep	10	3	13	10

Table – 15
Drought Intensity over India based on
Standardized Precipitation Index (SPI)

Drought Year	Seasonal (June –Sept.) Rainfall (cm)	SPI value	Drought intensity as per SPI value
1877	58.7	-3.47	ED
1899	62.1	-3.01	ED
1901	76.5	-1.21	MD
1904	77.6	-1.08	MD
1905	72.7	-1.66	SD
1911	75.1	-1.38	MD
1918	66.1	-2.48	ED
1920	73.3	-1.59	SD
1941	76.3	-1.23	MD
1951	71.5	-1.81	SD
1965	72.0	-1.75	SD
1966	76.4	-1.22	MD
1972	67.0	-2.37	ED
1974	77.4	-1.11	MD
1979	71.4	-1.82	SD
1982	75.2	-1.36	MD
1986	76.8	1.18	MD
1987	70.9	-1.88	SD
2002	71.3	-1.83	SD
2004	76.6	-1.20	MD
2009	69.8	-2.02	ED

ED = Extreme Drought (SPI: More than -2.0)

SD = Severe Drought (SPI: -1.50 to -1.99)

MD = Moderate Drought (SPI: -1.0 to -1.49)

% DROUGHT AFFECTED AREA , COUNTRY
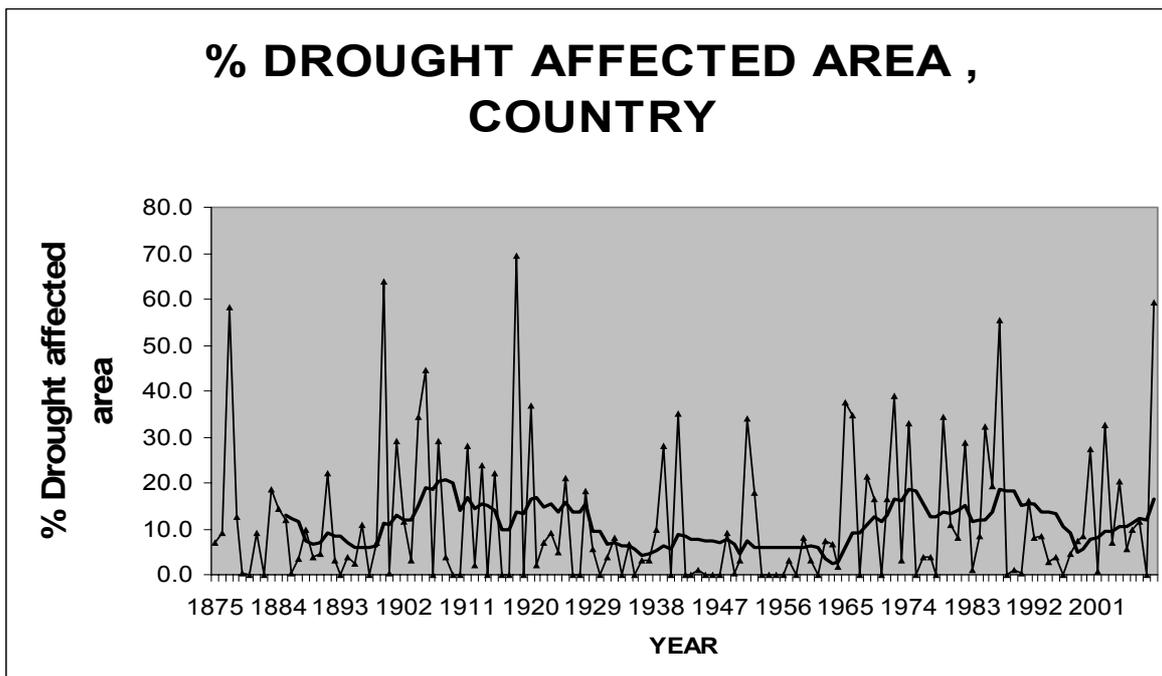
Fig 30: Percentage drought affected area over India during 1875-2003
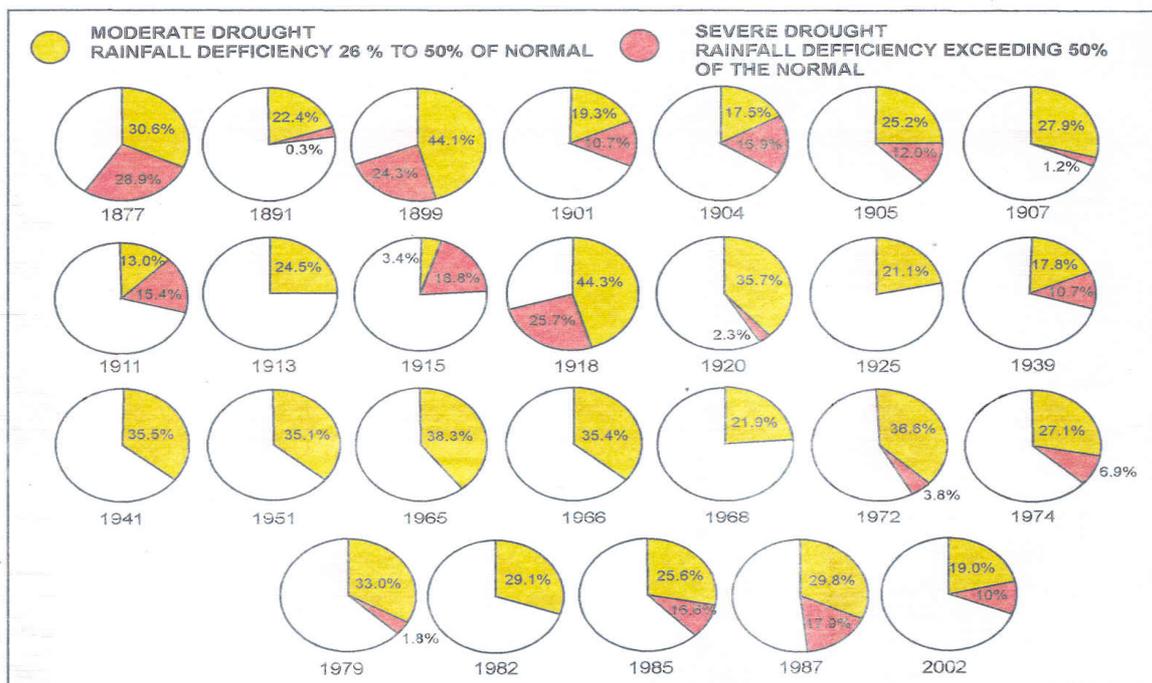
Fig 31: Details of individual drought years since 1875

99
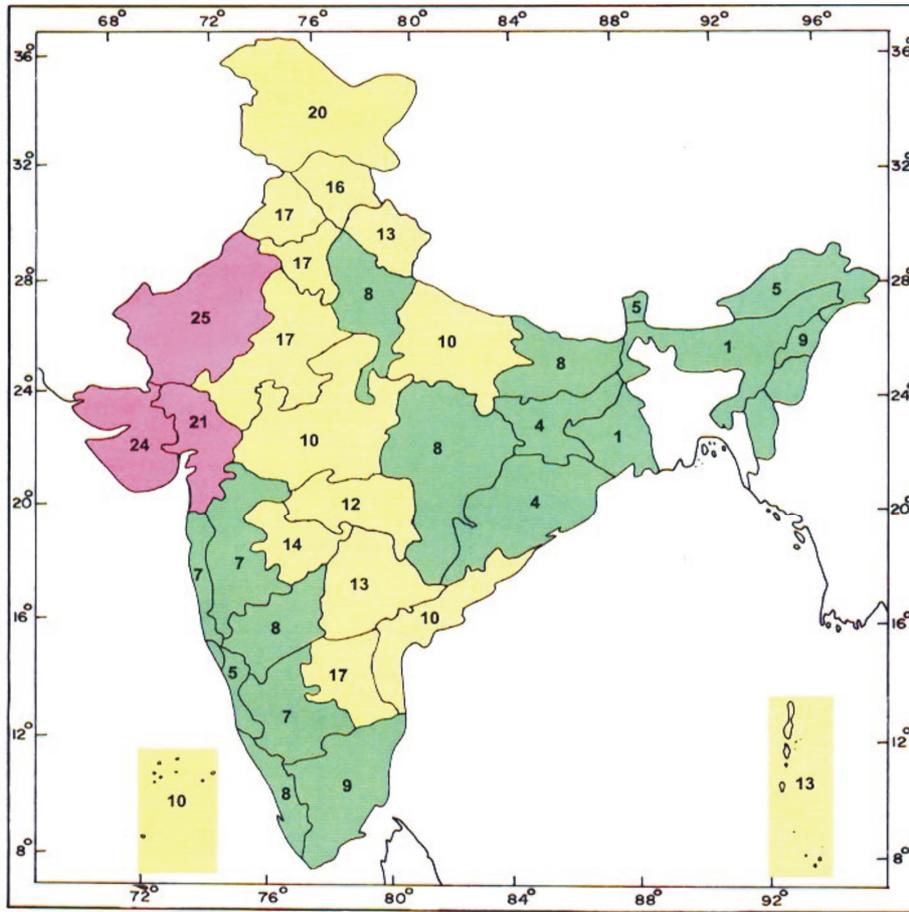
**PROBABILITY OF OCCURRENCE OF DROUGHT (%)
AND DROUGHT PRONE AREAS 1875 - 2004**

CRONICALLY DROUGHT PRONE AREA
(PROBABLITY OF OCCURRENCE OF DROUGHT MORE THAN 20%)

FREQUENTLY DROUGHT PRONE AREA
(PROBABILITY OF OCCURRENCE OF DROUGHT 10% TO 20%)

LEAST DROUGHT PRONE AREA
 (PROBABILITY OF OCCURRENCE OF DROUGHT LESS THAN 10%   )

Fig. 32: Probability of Occurrence of Drought and

Drought Prone areas during 1875-2004
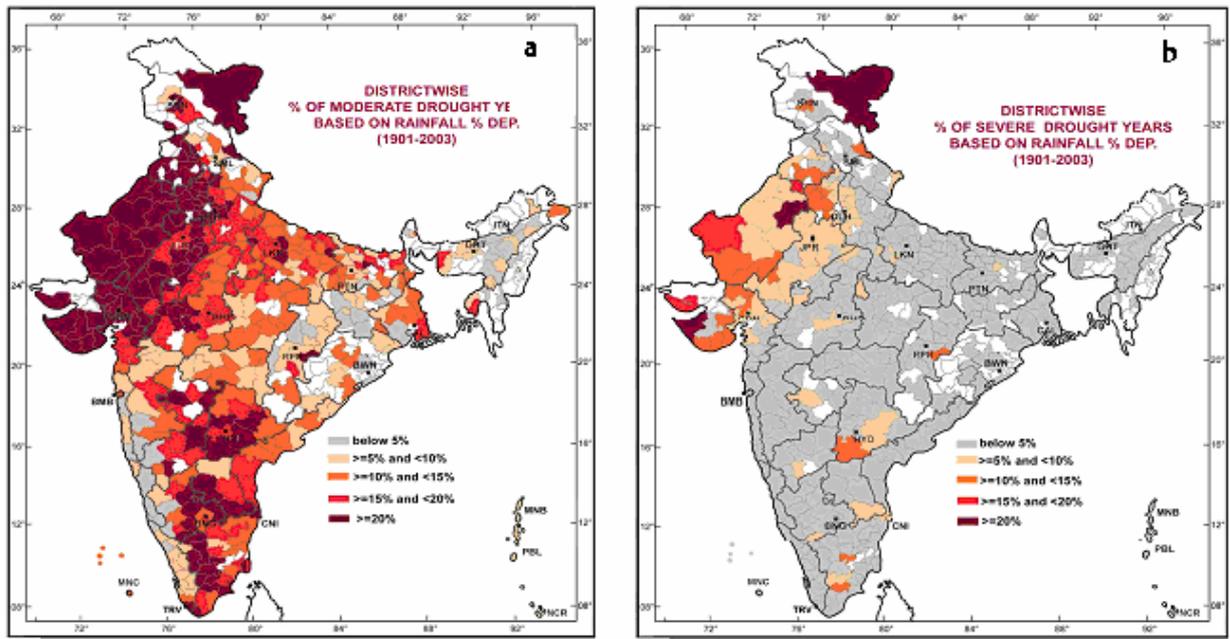
Fig 33: District-wise percentage of incidences (probability) of drought of (a) moderate intensity and (b) severe intensity during the southwest monsoon season for the period 1901-2003
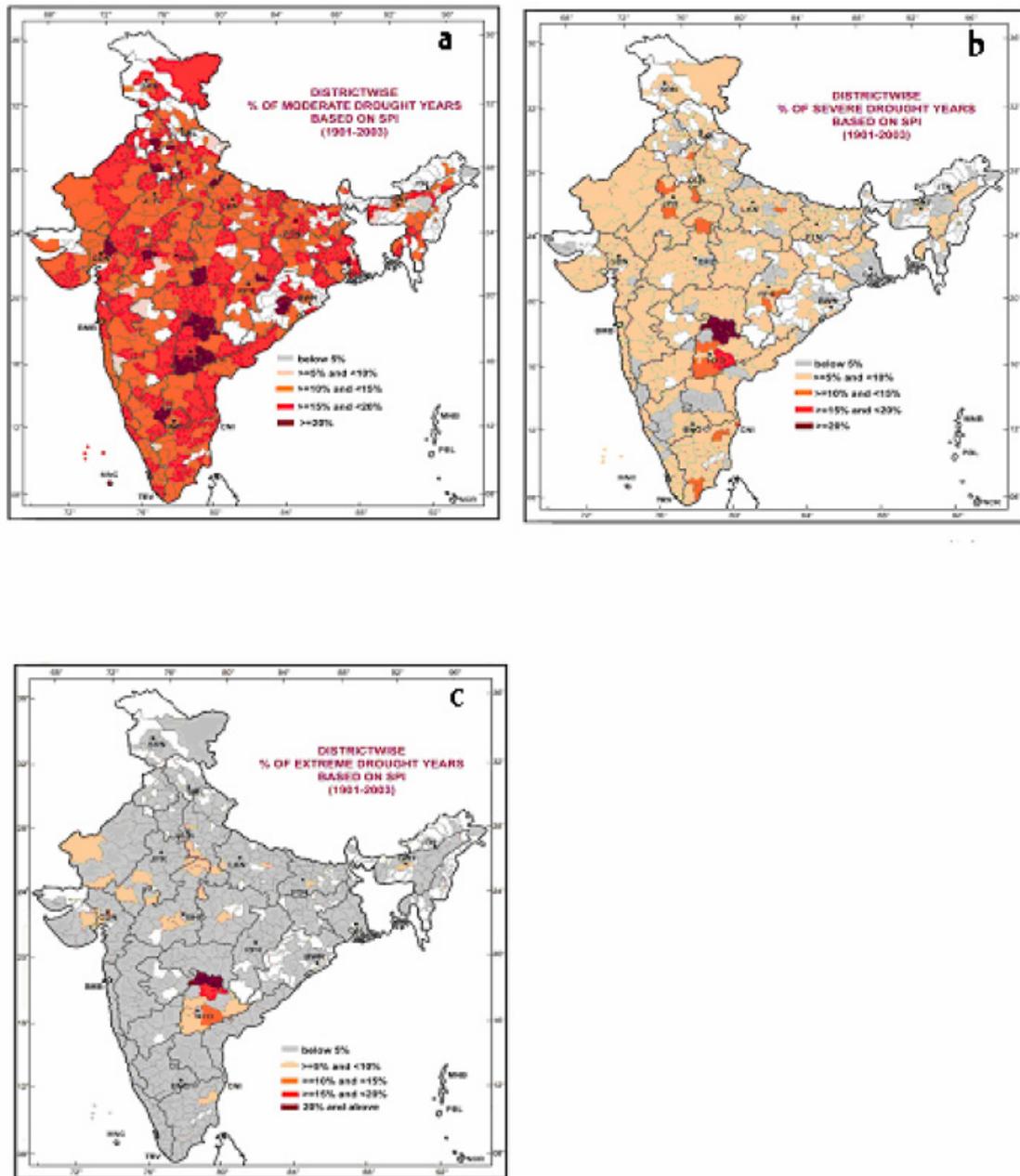
Fig 34: District-wise percentage of incidences (probability) of drought of
(a) moderate and above intensity, (b) severe and above intensity, and
(c) extreme intensity during the southwest monsoon season
based on SPI during the period 1901-2003
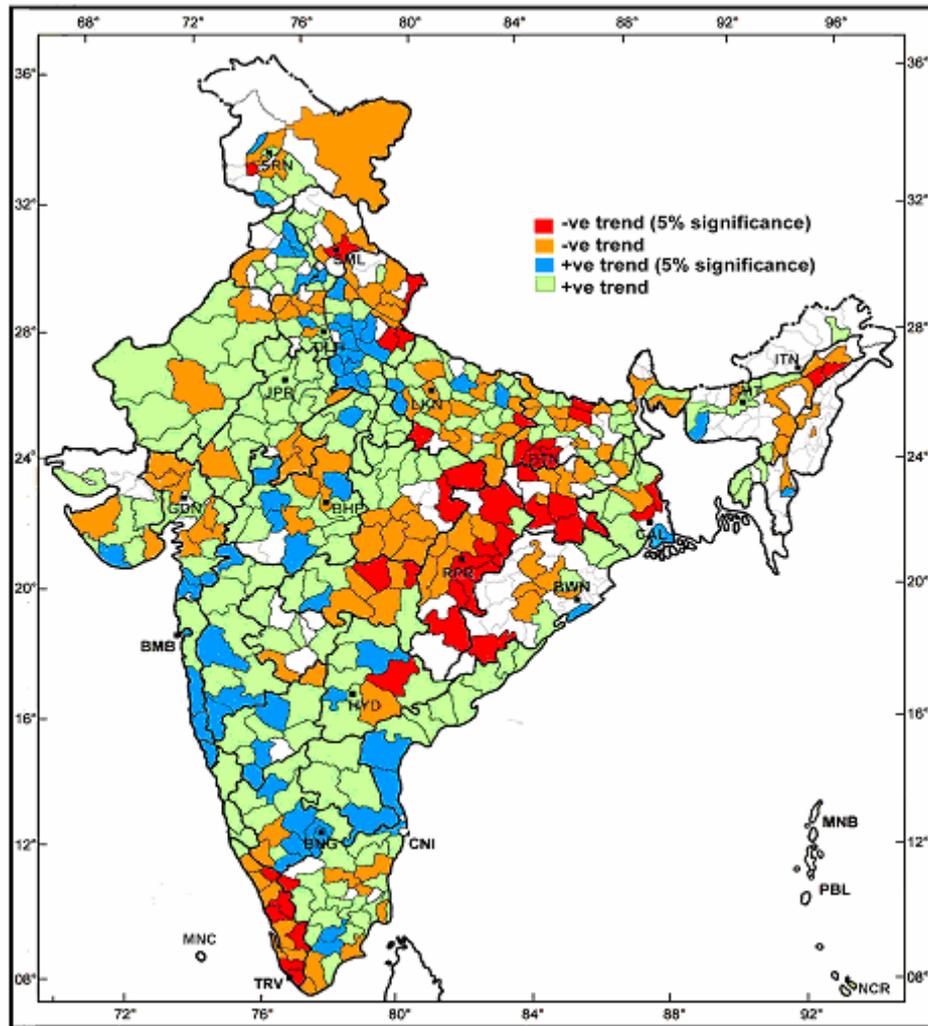
Fig 35: Long-term linear trends in the district-wise SPI during the period 1901-2003

FIG. 1
AREAS SHOWING CLASSIFICATION OF MODERATE DROUGHT
PROBABILITY OVER INDIA (1901 - 2000)

LEGEND
≤ 10
11-15
16-20
21-26
≥ 26

FIG. 2
AREAS SHOWING CLASSIFICATION OF SEVERE DROUGHT
PROBABILITY OVER INDIA (1901 - 2000)

LEGEND
≤ 1
1-5
6-10
11-16
≥ 16
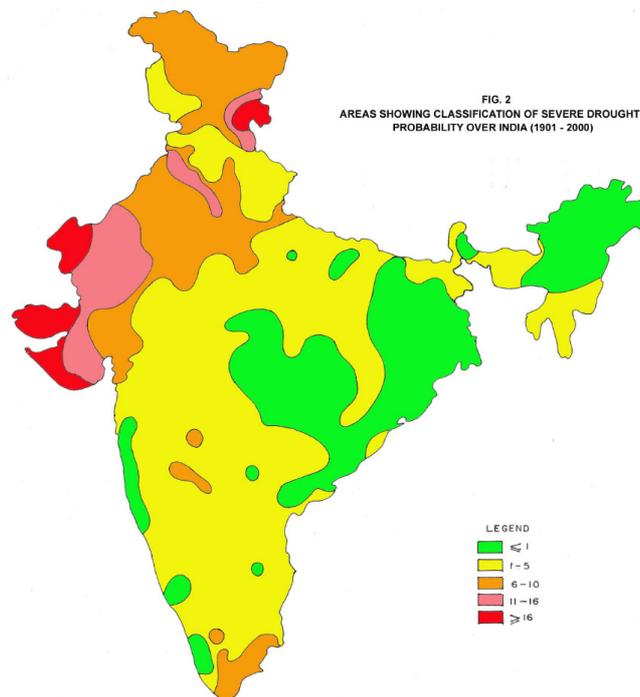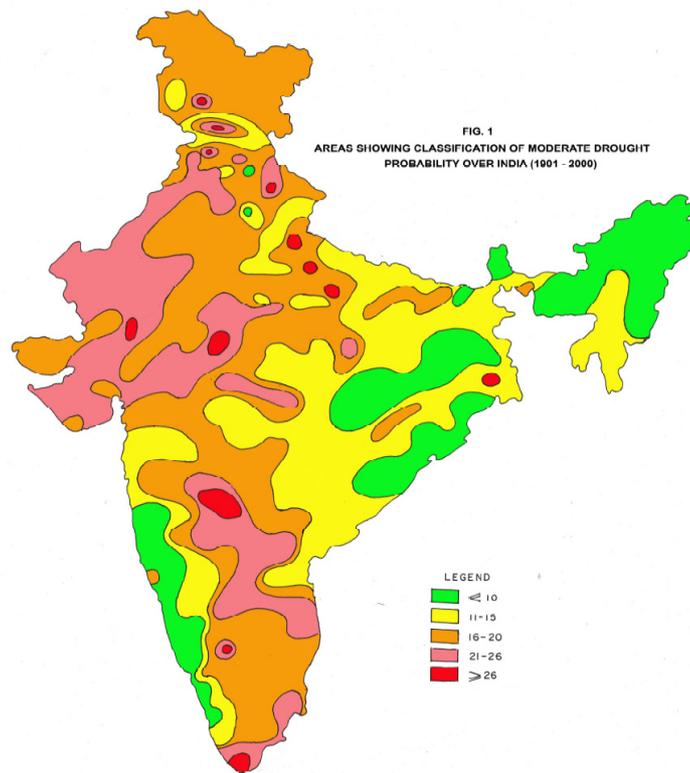
Fig 36: Mapping of (a) Moderate drought (b) severe drought during 1901-2000

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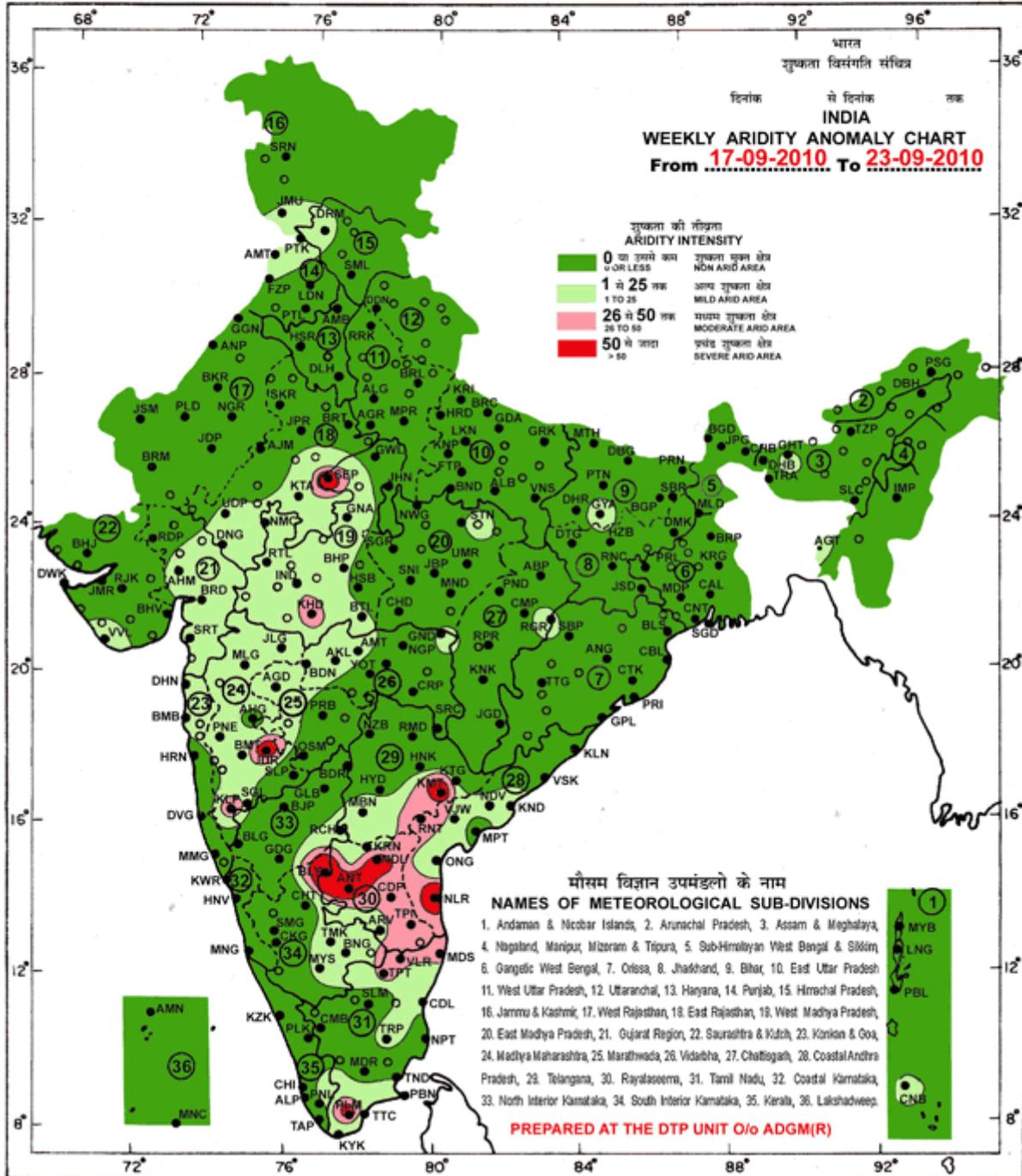
Fig 37: Weekly Aridity Anomaly Report during 2010

CHAPTER – VIII

ENVIRONMENTAL STATUS IN INDIA

India Meteorological Department's (IMD) tradition of monitoring weather and climate spans more than 135 years giving it a sound and useful dataset to fall back upon for environmental assessment. Ozone network was started as a globally pioneering effort as early as in 1954 realizing that this trace gas plays a very important role in atmospheric chemical mechanisms. It also started radiation measurements about 50 years back and currently maintaining 45 stations in the country for providing exclusive countrywide dataset for assessment of solar energy resources. Atlas on "Hourly Mixing Height and Assimilative Capacity of Atmosphere in India" has been brought out by Attri et al (2008)

A network of 10 Global Atmosphere Watch stations (GAW, formerly Background Air Pollution Monitoring Network or BAPMoN) consisting of Allahabad, Jodhpur, Kodaikanal, Minicoy, Mohanbari, Port Blair, Pune, Nagpur, Srinagar and Vishakhapatnam, is maintained by IMD as per WMO protocols and standards since 1974 to generate data/ information on the exchange of trace materials between the atmosphere and the earth's surface, making atmospheric turbidity and air quality measurements to quantify trends and acid rain threats. The ultimate fate of most biogenic or anthropogenic gaseous emissions is their highest state of oxidation which are acidic and render them water soluble too. In recent years it has been noted that when certain areas are subjected to high load of acidic deposition the natural alkaline buffer action of soil derived crust gives way to acid rain, which is potentially harmful.

8.1   Precipitation Chemistry (Acid rain threats)

The trends of pH monitored in rain water samples during last two decades at GAW stations are presented in Fig 38 and the salient finding of various studies (Krishna Nand and Maske, 1983; Krishn Nand, 1984, 1986; Mukherjee et al, 1985,

1986; Mukhopadhyay et al, 1992, 1993; Sarkar et al, 2004; Soni and Sarkar, 2006; Soni et al., 2006, Srivastava et al., 1992, Varma, 1989) are summarized as under:

- All the GAW stations except Jodhpur indicate a lowering trend of pH of rainwater (increasing acidity). This can be attributed not only to increasing sulfate concentration but even more by increasing nitrate concentration. The data showed that rather than large-scale geographical influences, local effects seem to be more important for chemical wet deposition, e.g. the vicinity of a large urban and industrial area, major combustion sources, sea, arable fields or forest, etc. It is observed that upto 1980, pH values from Indian GAW stations were around 7.0 or even higher. Around the year 2000, large number of pH values ranged between 5.0 and 6.0.

- The concentration of H^+ ions showed a major geographical gradient from west to east. At north-western station (Jodhpur), the range of annual average pH values was 6.6 to 7.8, whereas at Allahabad it was 5.2 to 7.6 and low values of the order of 4.5 to 6.8 were found in north-east (Mohanbari).

- Kodaikanal shows the least mineralized samples among other stations. Except for the H^+ values, the concentrations of all compounds either represent the minimum among all stations or else close to it. Strong influence of NO_3^- was observed over Kodaikanal, which could be the product of biogenic process from abundant vegetation around the station. Organic acids (formic and acetic mainly) can also play a significant role in lowering the rainwater pH values at densely vegetated areas like Mohanbari in north-east India and Kodaikanal in Tamil Nadu. Low content of alkaline radicals in the precipitation is also one of the cause of low pH values at these stations.

- Analysis of the decadal mean data of sulfate and nitrate indicate that concentration of both the anions have gone up significantly in last two decades. Significant increasing trend in concentration of nitrate at Pune, Minicoy Portblair and Jodhpur and that of sulphate at all the stations except at Kodaikanal have been observed in later decade.

- A somewhat positive feature emerging from the comparison of pH and other wet deposition data is that India is much better off compared to many other countries as far as acid rain situation is concerned.

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- TSPM values at Jodhpur exhibited significant positive correlation with pH indicating its alkaline behavior. The soil derived aerosols have pronounced effect on the precipitation acidity at a place.

- Principal Component analysis of rain water constituents indicate that marine and coastal aerosols predominantly govern the acidity of rainwater.

8.2   Atmospheric turbidity

Significant increase in atmospheric turbidity during the last few decades has been reported by several authors (Mani et al., 1973; Krishnand and Maske, 1983; Singh et al, 1997; Singh et al, 2004; Srivastava et al., 1992, Soni and Kannan, 2003). The observed atmospheric turbidity values at all the Indian GAW stations showed systematic seasonal as well as long-term variation apart from random fluctuations (Fig 39). However, the nature of variation is station dependent. Annual mean values of the turbidity coefficients showed a general increase of turbidity at all stations except Kodaikanal. The increasing trend of the turbidity at short wavelength (500 nm) indicates that it is caused more by fine size range aerosol, which are the product of primary and secondary production processes associated with anthropogenic activities. On an annual basis, the lowest turbidity was observed at Kodaikanal and Srinagar and highest in the north and central India.

Diurnal and seasonal variations of radiative properties of aerosols have been monitored during 2006-2007 in New Delhi using Sky-radiometer (POM-I) operating at wavelengths 315, 340, 400, 500, 670, 1020 nm. The results indicate that Aerosol Optical Depth (AOD) remains lowest at all wavelengths during Monsoon season while high values of Single Scattering Albedo (SSA) and Alpha (α) represent the presence of small aerosols and washout effect of large aerosols by rains. In Pre-monsoon season, AOD was found as second minimum with SSA and AOD lower than Monsoon season. However, AOD was lower in winter season as compared to Post-monsoon season because of movement of westerly systems   (Singh et al, 2008). Measurements have also shown that AOD values were higher at shorter wavelengths in comparison to the values at longer wavelengths for all four seasons of the year (Fig 40). Comprehensive studies in the country are planned.

Volcanic eruptions across the globe in tropical latitudes have shown increased turbidity over the Indian region. Sony (2006) and Mukhopadhyay (1992) have reported a seasonal scale anomaly to the extent of 10-15% increase from mean values.

8.3   Radiation

Solar radiation data from 12 stations of IMD network having continuous long-term measurement from 1971-2009 were evaluated and the results are presented in Table 16. Long-term trend of global solar radiation during last four decades at four stations in different geographic regions are depicted in Fig 41. Analysis of the data indicates   that the Global Solar Radiation (Direct + Diffuse) and Bright Sunshine duration are showing decreasing trend while Diffuse Solar Radiation is showing increasing trend at most of the stations.   The change in solar radiation can be attributed to change in aerosol load in the atmosphere and cloud cover. Aerosol loading in the atmosphere may be attributed to the biomass burning and smoke released by the industries. The   decline in global solar radiation (solar dimming) continues over India while recent evidence suggests that the decreasing trend did not persist beyond 1990 at several locations (North America, western Europe, China).

8.3.1 Global Radiation

All the four major cities with population more than ten million, show significant decline in global irradiance of 3.4% (7.8 Wm^{-2}) per decade at Delhi, 4.1% (8.4 Wm^{-2}) per decade at Kolkata, 1.7% (4.1 Wm^{-2}) per decade at Chennai and 2.4% (5.5 Wm^{-2}) per decade at Mumbai. The decline was stronger from 1990 onwards at all the four stations. Delhi is one of the highly polluted major cities of Asia and is also subjected to heavy injection of dust load brought by winds blown dust from the desert in the west. Total suspended particulate matter concentration during the pre-monsoon season goes enormously high and local radiative forcing is significantly affected (Singh et al. 2004).   The   long-term average of global irradiance at Delhi is 216.2Wm^{-2} with a standard deviation in the annual mean of 10.2 Wm^{-2}. Kolkata is heavily populated with large industrial installations; it is situated in the Gangetic delta

and nearer to the east coasts. The long-term average of global irradiance at Kolkata is 191.4 Wm^{-2} with a standard deviation in the annual mean of 10.5 Wm^{-2}. Another major city is Chennai (earlier Madras), located along the east coast of India. The long-term average global irradiance at Chennai is 224.8 Wm^{-2} with a standard deviation in the annual mean of 7.7 Wm^{-2}. Mumbai is also a major city situated along the west coast of India. The long-term average global irradiance at Mumbai is 215.4 Wm^{-2} with a standard deviation in the annual mean of 8.4 Wm^{-2}.

Ahmedabad is located south of desert region and is an industrialized place since long. Ahmedabad received an average 226.2 Wm^{-2} of global irradiance. The statistically significant decrease in global irradiance was found to be 7.8 Wm^{-2} (3.3%) at Ahmedabad. Over the coastal stations Panjim, Trivandrum and Visakhapatnam global radiation decreased at the rate of 2.0% (4.8 Wm^{-2}), 3.4% (8.0 Wm^{-2}) and 3.9% (9.0 Wm^{-2}) per decade, respectively.

8.3.2 Diffuse Radiation

Spatial and temporal pattern of observed trends in diffuse irradiance is complex and inhomogeneous. Jodhpur has the lowest long-term average diffuse irradiance of 85.2 Wm^{-2} and also the smallest inter-annual variability with a standard deviation of 5.2 Wm^{-2} in the annual mean. Ten of the twelve stations evaluated in this study for diffuse irradiance showed increasing trend ranging from 0.4% (0.3 Wm^{-2}) per decade at Ahmedabad to 2.2% (1.9 Wm^{-2}) per decade at Nagpur, although the trend is statistically significant only at four stations: Chennai, Mumbai, Nagpur and Panjim. Chennai showed statistically significant increasing trend of 2.0 Wm^{-2} per decade. Given the geographic distribution of these stations, there does not appear to be any spatial pattern to this decline/increase in diffuse irradiance. The relative portion of the diffuse radiation in the global solar radiation varies from 37% to 50% in annual mean. The diffuse component accounts for 50% of the global irradiance at Kolkata which is highest among all the stations. The diffuse component formed 37% at Hyderabad and 39% at Jodhpur of global solar radiation in annual mean.

8.4   Sunshine Duration

The sunshine duration, defined as the amount of time when solar direct irradiance exceeds a specified threshold is often used as a substitute of radiation measurement. Bright sunshine duration has large uncertainty in measurement. All the stations showed decreasing trend in sunshine duration except Jodhpur. The duration of sunshine shows a maximum over central and northwest India. In the arid and semi-arid zones of central and northwest India, average bright sunshine duration of more than 8 hours a day is observed during all-sky conditions. The lowest values are found in NE India due to clouding associated with and the decrease in the length of the day with increasing latitude. The significant decreasing trend in bright sunshine duration at Delhi, Kolkata, Chennai, Nagpur, Pune, Panjim, Shilong, Trivandrum and Visakhapatnam was observed which ranged from 2,4 to 6.3% per decade. The decrease in sunshine duration was concomitant with the decrease in global solar irradiance.

8.5   Evaporation

A reduction in surface solar radiation can lead to a reduction in surface evaporation because _50–85% of the radiative heating at the surface is balanced by evaporation (Kiehl and Trenberth, 1997).   The decline in global radiation is consistent with decreased pan evaporation from Indian region. Significant decreasing trend over all parts of India except northeast have been observed. For the country as a whole the evaporation declined by 19% during the period 1971-2000. The annual evaporation trends vary from as high as -42.5 mm per year at Delhi to -5.5 mm per year at Trivandrum. They also observed that the decline in evaporation was comparatively more during the decade 1991-2000.

8.6   Ozone

Ozone has a strong relationship with biomass burning, traditionally seen over eastern parts of the subcontinent extending into that East Asia. This area is also a thickly vegetated region releasing organic compounds that participate in atmospheric photochemistry in whish ozone has a significant role to play. Thus the anthropogenic

emission define the residence times of various GHGs of biogenic origin via the ozone link in this region.

Total ozone and Umkehr observation by Dobson Ozone spectrophotometer are taken daily basis from 4 stations viz. Delhi, Varanasi, Pune and Srinagar. At Delhi, Kodaikanal and Maitri (Antarctica) ozone is monitored with Brewer Spectrophotometer, which has an additional facility to measure NO_2, SO_2 and UV-B radiation also. Vertical distribution of ozone is measured by balloon-borne ozonesonde (IMD-made) fortnightly frequency at Delhi, Pune, Thiruvananthapuram and Maitri (Antarctica). Surface ozone measurement is taken at 6 stations viz. New Delhi, Nagpur, Pune, Kodaikanal, Thiruvananthpuram, and Maitri (Antarctica). Monitoring is being augmented by establishing stations in NE India and A&N Islands. Important results from the Ozone Programme spanning over more than 50 years are as follow:

- Ozone data of Maitri (Antarctica) has also confirmed occurrence of ozone hole during spring months over Antarctica (Peshin, 2006).
- Analysis of the data available so far does not establish any clear ozone trends in the total ozone over India. However, increasing trend in tropospheric and decreasing trend in stratospheric ozone have been observed.
- From the equator to about 20ºN, the tropospheric ozone concentration remains practically the same throughout the year.
- The maximum ozone concentration of the order of 150μmb occurs at a height of 26-27 Km over Thiruvananthapuram, 25-26 Km over Pune and 23-25 Km over New Delhi. Double maxima appears over New Delhi during winter and spring.

Table 16

Long-term mean values and trend analyses of global irradiance (G), diffuse irradiance (D) and daily bright sunshine duration (S) in India under all sky conditions for 1971-2009. Trend values in bold are statistically significant.

Station Name	Long-term Mean (Standard Deviation)			Trend (% per decade)		
	G (Wm^{-2})	D (Wm^{-2})	S (Hours)	G	D	S
Ahmedabad	226.2 (11.7)	87.6 (4.6)	8.2 (0.3)	**-3.3**	0.4	-1.3
Jodhpur	228.4 (12.1)	85.2 (5.2)	8.5 (0.4)	**-3.6**	0.8	0.0
Delhi	216.2 (10.2)	93.4 (3.8)	7.5 (0.7)	**-3.4**	0.4	**-6.3**
Kolkata	191.4 (10.5)	95.5 (5.0)	6.1 (0.6)	**-4.1**	-0.4	**-3.5**
Chennai	224.8 (7.7)	98.4 (6.8)	7.4 (0.4)	**-1.7**	**2.1**	**-3.6**
Mumbai	215.4 (8.5)	92.7 (4.9)	7.3 (0.4)	**-2.4**	**1.6**	-0.4
Nagpur	214.6 (7.1)	88.1 (4.8)	7.5 (0.5)	**-2.0**	**2.2**	**-2.4**
Pune	228.7 (8.6)	88.6 (3.5)	7.8 (0.4)	**-1.5**	-1.4	**-2.5**
Panjim	228.3 (12.2)	95.7 (5.1)	7.6 (0.4)	**-2.0**	**1.7**	**-2.8**
Shillong	191.0 (8.6)	90.6 (3.7)	5.7 (0.3)	-0.1	0.5	**-2.4**
Trivandrum	226.1 (11.4)	101.1 (3.6)	6.3 (0.4)	**-3.4**	0.8	**-3.0**
Visakhapatnam	218.5 (10.8)	94.3 (5.3)	7.2 (0.6)	**-3.9**	1.0	**-5.7**

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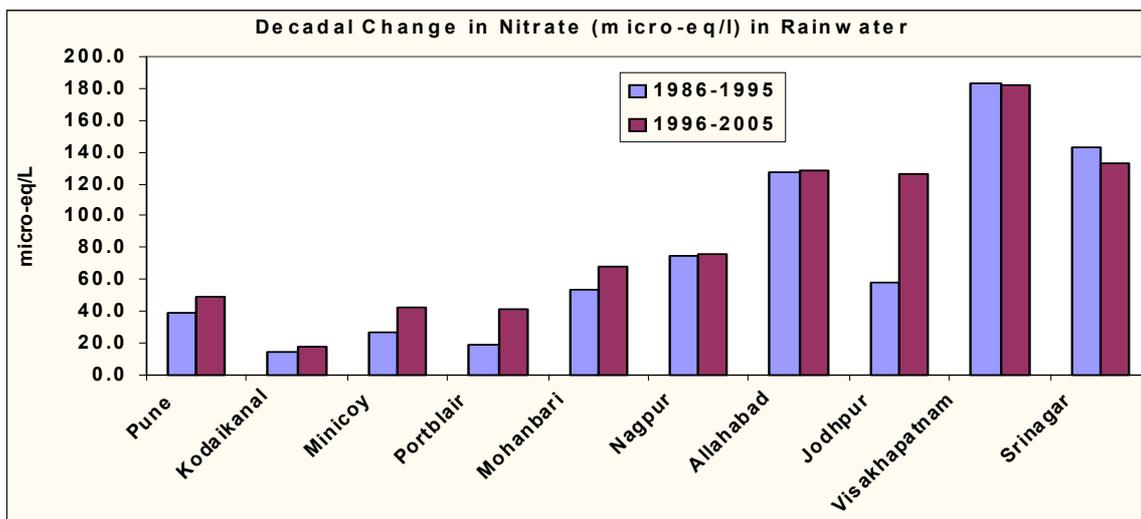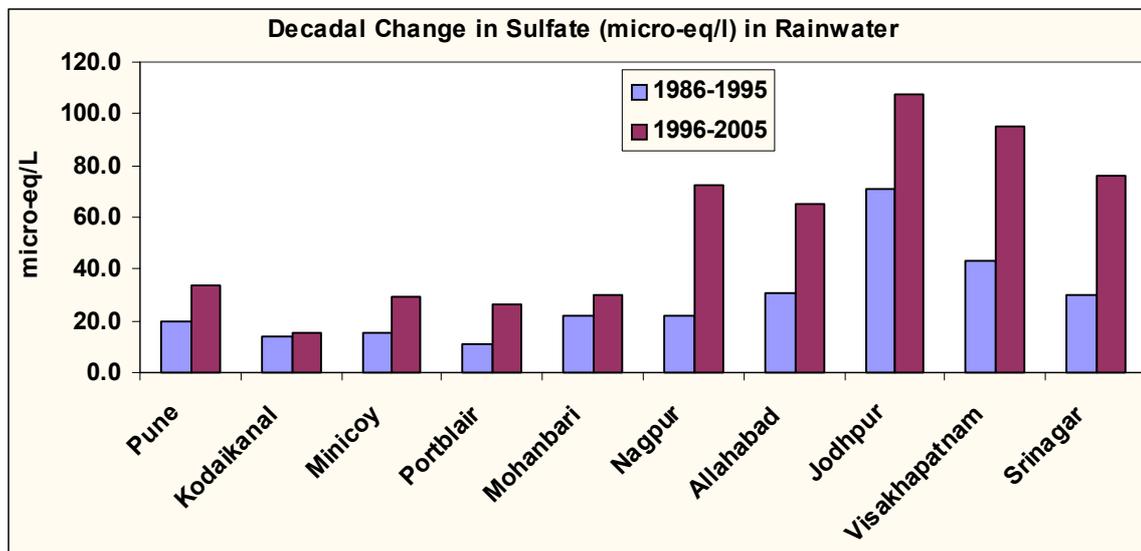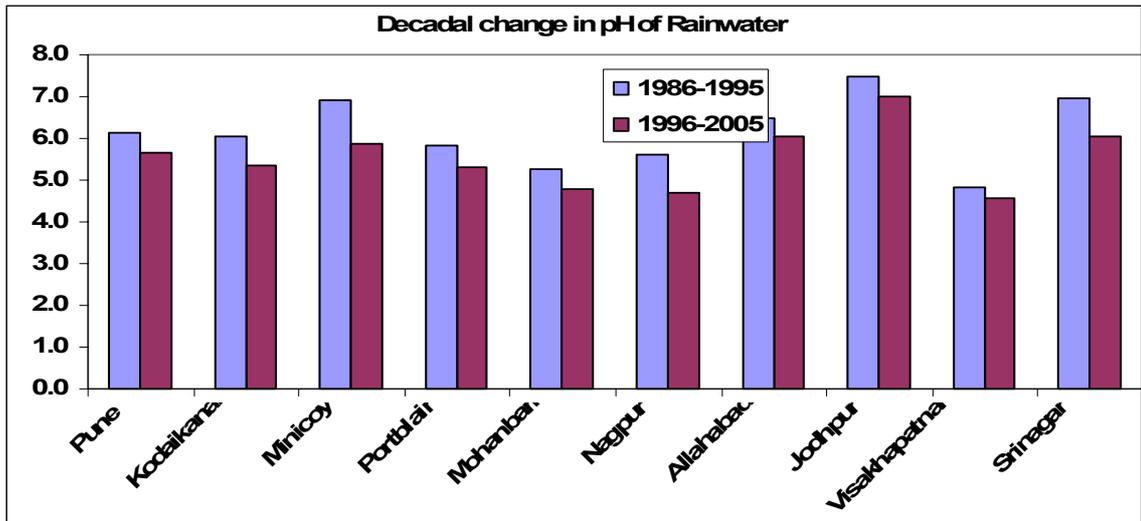
Fig 36: Trends of pH, SO₄ and NO₃ at GAW stations in India

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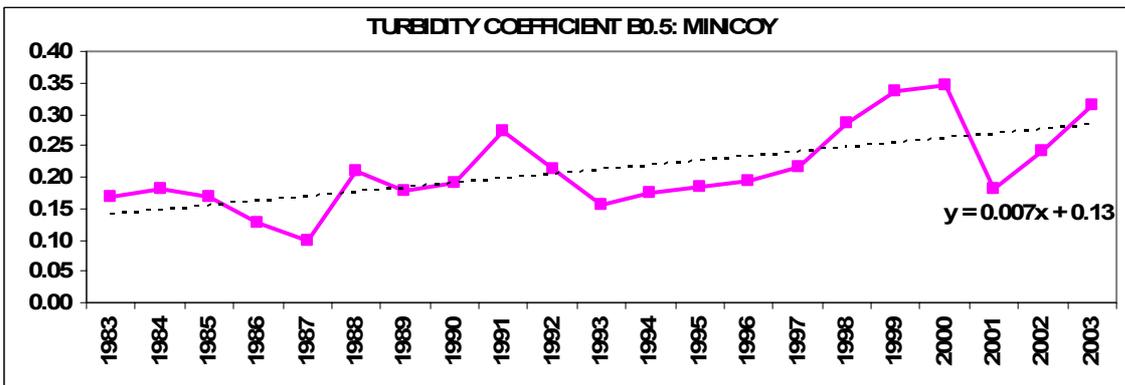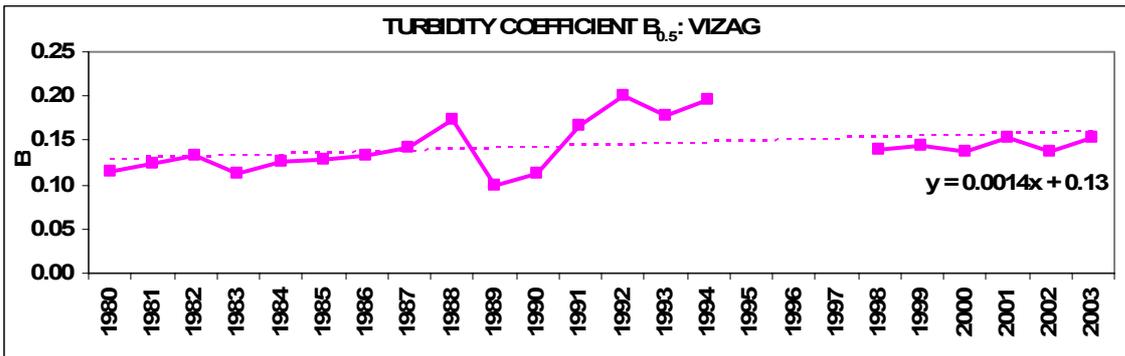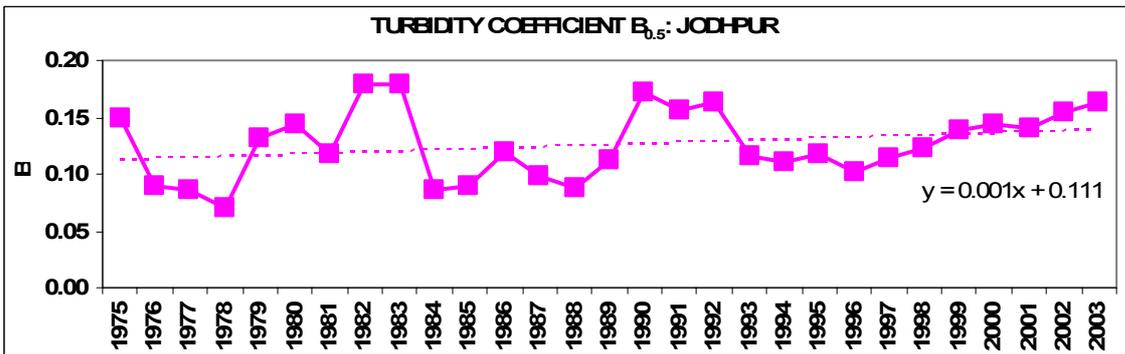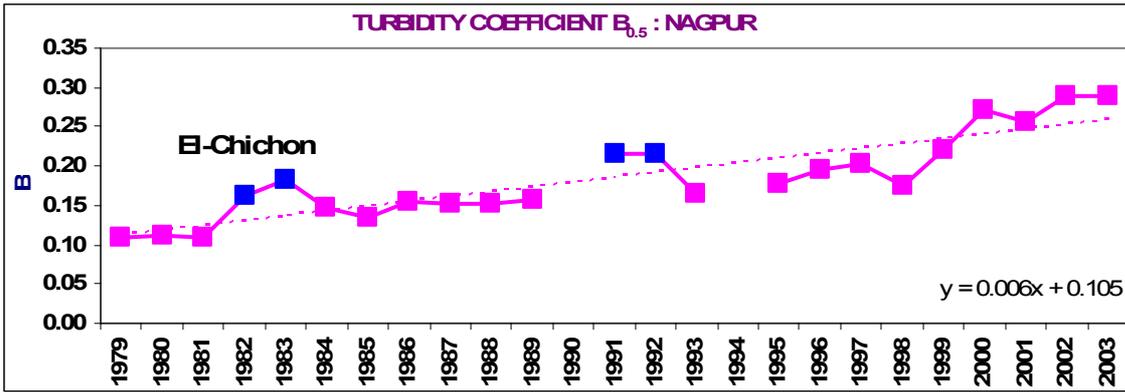
Fig 37: Aerosol loading at GAW stations in India
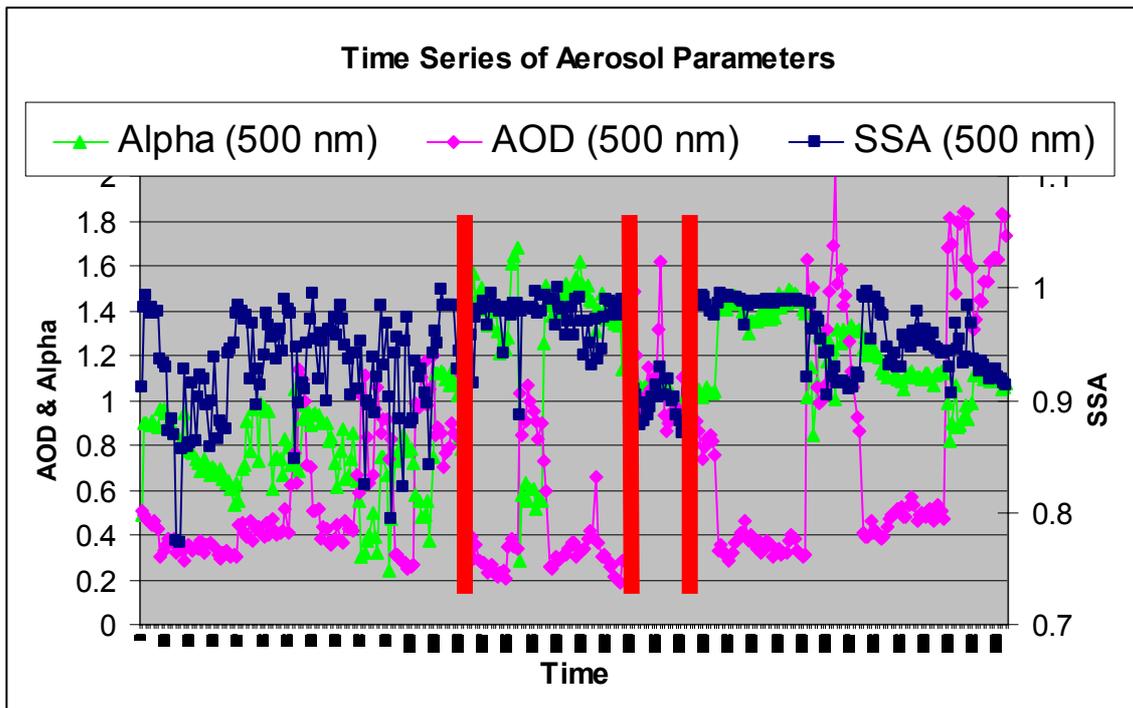
Fig 38: Aerosol radiative properties in Delhi
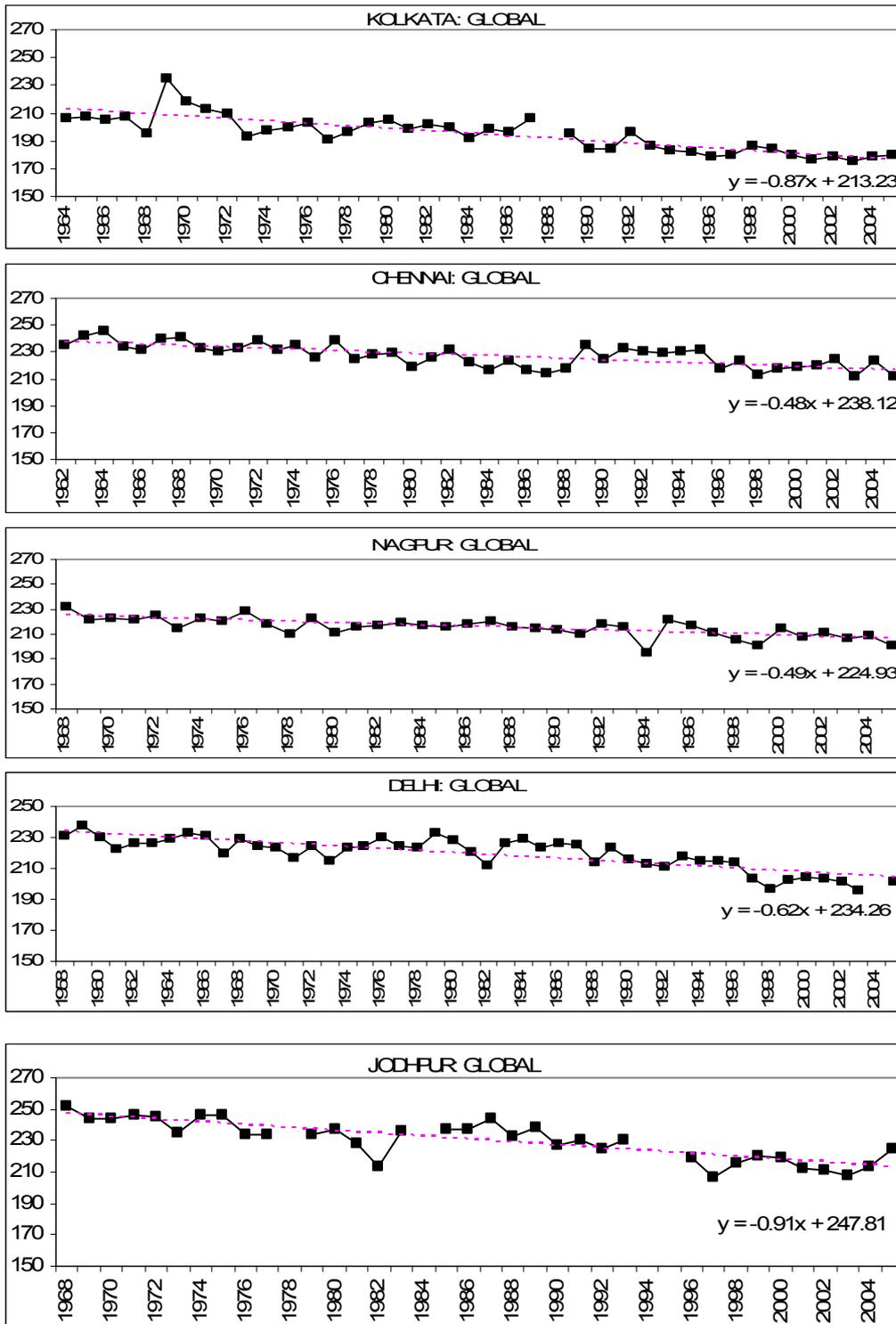
Fig 39: Long Term Trends of Global Solar Radiation (W/m^2) over GAW stations

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Annexure-4

F. No. 3-3/2019-IA.III
Government of India
Ministry of Environment, Forest and Climate Change
Impact Assessment Division
***

Indira Paryavaran Bhawan
Jor Bagh Road, Aliganj
New Delhi – 110003
sharath.kr@gov.in

Date: 5th February, 2020

OFFICE MEMORANDUM

Subject: Modalities for making CTE and EC a one step process - regarding.

In order to expedite the process of CTE, CPCB vide letter dated 02.02.2017 issued an advisory to all the SPCBs/PCCs to follow the modified mechanism for granting consent to various categories of industries as:-

"*All the projects requiring Environmental Clearance may be exempted from obtaining the Consent to Establish (CTE). Such projects may be directly granted Consent to Operate subject to EC and installation of pollution control devices*".

2.   Further, CPCB issued the directions under Section 18(1)(b) of the Water Act, 1974 and the Air Act, 1981 regarding streamlining of consent mechanism vide Letter No. B-29012/MSMEs/IPC-VI/2017-18/12189-12230 dated 2nd November, 2018.

3.   The Hon'ble High Court of Delhi has stayed the directions of the CPCB vide order dated 2nd November 2018 in W.P. (CIVIL) 13521 of 2018 in the matter of Social Action for Forest and Environment vs. Union of India and Ors. The CPCB has further informed that a similar case has also been filed before Hon'ble High Court of Madras (WP No. 3046 of 2019 and WMP No. 3316 & 3320 of 2019).

4.   A meeting was convened under chairmanship of Secretary, Environment, Forest and Climate Change with CPCB and after detailed deliberations, the following mechanism of one step process of CTE and EC has been decided.

```
┌─────────────────────────────────────────────────────────────────────────┐
│       Application by PP through PARIVESH in specially designed form        │
└─────────────────────────────────────────────────────────────────────────┘
         │                                                    │
         ▼                                                    ▼
┌──────────────────────────────┐              ┌──────────────────────────────┐
│ Forwarding of Application to  │              │     Appraisal by EAC/SEAC     │
│ MS, SPCB along with the online│              └──────────────────────────────┘
│      communication to PP      │                             │
└──────────────────────────────┘                             ▼
         │                                      ┌──────────────────────────────┐
         ▼                                      │         Grant of ToR          │
┌──────────────────────────────┐              └──────────────────────────────┘
│ Payment of the requisite fees │                             │
│    by the PP within 15 days   │                             ▼
└──────────────────────────────┘              ┌──────────────────────────────┐
         │                                      │   Collection of baseline data │
         ▼                                      └──────────────────────────────┘
┌──────────────────────────────┐                             │
│ Forwarding of the application │                             ▼
│          to RO, SPCB          │              ┌──────────────────────────────┐
└──────────────────────────────┘              │  Preparation of draft EIA/EMP │
         │                                      └──────────────────────────────┘
         ▼                                                    │
┌──────────────────────────────┐                             ▼
│ Site inspection by RO, SPCB & │              ┌──────────────────────────────┐
│      Submission of Report     │              │      Public Consultation      │
└──────────────────────────────┘              └──────────────────────────────┘
         │                                                    │
         ▼                                                    ▼
┌──────────────────────────────┐              ┌──────────────────────────────┐
│ Appraisal by Technical        │              │        Final EIA/EMP          │
│         Committee             │              └──────────────────────────────┘
└──────────────────────────────┘                             │
         │                                                    ▼
         ▼                                      ┌──────────────────────────────┐
┌──────────────────────────────┐              │ Submission of application for EC│
│ Decision of SPCB to           │              └──────────────────────────────┘
│        Grant/Reject           │                             │
└──────────────────────────────┘                             │
      │            │                                          │
      ▼            ▼                                          ▼
┌───────────┐ ┌───────────────┐              ┌──────────────────────────────┐
│If the     │ │If the decision │─────────────▶│ Appraisal by EAC/SEAC for EC  │
│decision is│ │is for rejection│              │ by considering the inputs of  │
│for grant  │ │    of CTE      │              │        SPCB, if any           │
│of CTE     │ └───────────────┘              └──────────────────────────────┘
└───────────┘                                              │
      │                                                    ▼
      ▼                                      ┌──────────────────────────────┐
┌──────────────────────────────┐            │ Grant / Rejection of EC by     │
│ Grant of CTE within 30 days   │            │     Regulatory Authority       │
│ from the date of              │            └──────────────────────────────┘
│ recommendations of EAC        │                   │            │
└──────────────────────────────┘                   ▼            ▼
                                          ┌───────────┐  ┌───────────────┐
                                          │If the     │  │If the decision │
                                          │decision is│  │is for rejection│
                                          │for grant  │  │    of EC       │
                                          │of EC      │  └───────────────┘
                                          └───────────┘
                                                │
                                                ▼
┌─────────────────────────────────────────────────────────────────────────┐
│ SPCB to reconsider decision to reject CTE within 30 days and communicate    │
│ rejection or grant of CTE within another 30 days, failing which deemed grant│
│                              of CTE                                         │
└─────────────────────────────────────────────────────────────────────────┘
```

Provided:-

i.   If the PP fails to pay the requisite fee, grant of CTE will be at the discretion of the SPCB/UTPCC concerned;

ii.   If the decision for rejection of CTE is not communicated by SPCB/UTPCC to the Ministry or SEIAA, as the case may be, before the meeting of EAC, it will be deemed that there are no specific comments / objections to the SPCB/UTPCC

iii.   In case of deemed grant of CTE, the conditions of the EC will also be applicable for the deemed CTE.

iv.   The deemed clause may not be applicable for cases, where public consultation is exempted for grant of EC.

5. The above, mechanism may be followed while granting EC and CTE.

6. This issues with the approval of the competent authority.

05/02/2020

(Sharath Kumar Pallerla)
Scientist 'F', IA (Policy) Division

To

1. All the officers of IA Division
2. Chairperson/Member Secretaries of all the SEIAAs/SEACs
3. Chairman of all the Expert Appraisal Committees
4. Chairman, CPCB
5. Chairpersons/Member Secretaries of all SPCBs/UTPCCs

Copy for information:

1. PS to Minister for Environment, Forest and Climate Change
2. PS to MoS (EF&CC)
3. PPS to Secretary(EF&CC)
4. PPS to AS(RSP) / AS (RA)/JS (GM)/ JS (AKN)/ JS (SKB)
5. Website, MoEF&CC and Guard file

Annexure-5

ABSTRACT

Forests – Wildlife – Declaration of Kazhuveli Swamp / Wetland situated in Vanur and Marakkanam Taluks of Villupuram District as Kazhuveli Birds Sanctuary – Notification under section 18 (1) of the Wild Life (Protection) Act, 1972 (Central Act 53 of 1972) – Published.

ENVIRONMENT, CLIMATE CHANGE AND FORESTS (FR.5) DEPARTMENT

G.O.(Ms) No.123

Dated: 06.12.2021
பிலவ, கார்த்திகை -20
திருவள்ளுவர் ஆண்டு- 2052
Read:

From the Principal Chief Conservator of Forests and Chief Wildlife Warden letter No.WL5/28221/2017, dated 29.04.2019 and 24.12.2020 .

ORDER: -

In the letter read above, the Principal Chief Conservator of Forests and Chief Wildlife Warden has sent a draft notification for declaration of an extent of 5151.60 hectares in Vanur and Marakkanam Taluks of Villupuram District situated in Kazhuveli Swamp / Wetland as Kazhuveli Birds Sanctuary under sub section (1) of section 18 of the Wild Life (Protection) Act, 1972 (Central Act 53 of 1972).

2. The Government, after careful examination of the proposal of the Principal Chief Conservator of Forests and Chief Wild Life Warden have intention to declare the area to an extent of 5151.60 hectares in Vanur and Marakkanam Taluks of Villupuram District as Kazhuveli Birds Sanctuary under sub section (1) of section 18 of the Wild Life (Protection) Act, 1972 (Central Act 53 of 1972). Accordingly, the notification appended to this order will be published both in English and Tamil in Tamil Nadu Government Gazette and in Tamil in the District Gazette of the Villupuram District.

3. The Works Manager, Government Central Press, Chennai is requested to send 25 copies of each of the notification to Government, the Principal Chief Conservator of Forests / Principal Chief Conservator of Forests and Chief Wild Life Warden and the Collector of Villupuram District as soon as the notification is published.

(P.T.O)

4. The Tamil Development and Information Department is requested to send immediately a tamil translation of the Notification to the Works Manager, Government Central Press, Chennai for publication in the Tamil Nadu Government Gazette and in the District Gazette of Villupuram District.

(BY ORDER OF THE GOVERNOR)

SUPRIYA SAHU
PRINCIPAL SECRETARY TO GOVERNMENT

To
The Works Manager,
Government Central Press, Chennai-01.(we)
The Principal Chief Conservator of Forests,
  (Head of Department) Chennai-15.
The Principal Chief Conservator of Forests and
Chief Wildlife Warden, Chennai-15.
The Secretary to Government of India,
Ministry of Environment, Forests and Climate Change,
  (CS.I Division), 5th Floor, Vayu Wing,
  Indira Paryavaran Bhawan, Jor Bagh Road,
New Delhi – 110 003.
Copy to:-
The Special Personal Assistant to Hon'ble Minister (Forests),
Chennai-9.

Office of the Hon'ble Chief Minister, Chennai-9.
The Private Secretary to Principal Secretary to Government,
Environment, Climate Change and Forests Department,
Chennai – 9.
The Tamil Development and Information Department,
Chennai – 9.
The Law Department, Chennai – 9.
The Collector, Villupuram District .
The District Forest Officer, Villupuram .
SF/SCs.

/FORWARDED BY ORDER/

SECTION OFFICER

APPENDIX

NOTIFICATION

Whereas, the Government of Tamil Nadu considers that the area of Kazhuveli brackish water lake wetland in Nadukuppam, Seyyankuppam, Chettikuppam, Anumandai, Urani, Keelputhupattu, Koonimedu, Thirukkanur villages of Marakkanam Taluk and Kilapakkam, Kozhuvari, Kazhuperumpakkam, Karattai and Devanandal villages of Vanur taluk in Villupuram district described in the Schedule below is of adequate ecological, faunal, floral and geomorphological significance, for the purpose of protecting, propagating and developing wildlife and its environment.

Now, therefore, in exercise of the powers conferred in sub section (1) of section 18 of the Wildlife (Protection) Act, 1972 (Central Act 53 of 1972), the Governor of Tamil Nadu hereby declares his intention to constitute the said area as **Kazhuveli Wetland Birds Sanctuary**.

THE SCHEDULE

1. Name of the District   :   Villupuram
2. Name of the Taluk   :   1. Marakkanam

        2. Vanur

Name of the Revenue villages and Resurvey number (Taluk wise)

Name of villages	Resurvey numbers	Extent (in hectares)
Marakkanam Taluk		
38.Nadukuppam	593	9.40.0
	655	24.38.0
	662/3	1.62.0
	663	3.27.0
	666	0.70.0
	674/2	1.24.5
	678/2	2.15.5
	682	1234.45.0
		1277.22.0
53 .Seyyankuppam	1/1	48.24.0
	15/4	0.20.5
		48.44.5
54. Chettikuppam	1	152.93.5
		152.93.5
52.Anumandai	1 / 1	75.89.5
		75.89.5

(P.T.O)

47. Urani	1	102.87.0
	5/9	0.41.5
	6/10	0.33.5
	7/1	0.79.0
	13	5.05.0
		109.46.0
56. Keelputhupattu	1	349.22.0
		349.22.0
55. Koonimedu	1/1	981.16.0
		981.16.0
46. Thirukkanur	75/1	4.08.5
	75/9	28.83.0
		32.91.5
Vanur Taluk		
14. Kilapakkam	195	382.12.5
		382.12.5
16. Devanandal	80/2	0.01.0
	91/1	0.56.0
	91/3	1.35.0
	92/1	2.96.0
	93/2	1.94.0
	94/3	3.88.0
	95/1	3.36.0
	96/1	2.02.0
	97/1	1.70.0
	98/1	1.72.0
	99/1	1.94.0
	102/3	0.84.0
	103	2.05.0
	104	1.50.0
	105	1.48.0
	106	1.52.5
	107/1	1.42.0
	108//1	1.32.0
	109/1	1.70.0
	110/1	2.10.0
	111	1.76.0
	112	2.40.0
	113	1.66.0
	114	1.90.0

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	115	79.94.0
		123.03.5
17. Karattai	205	426.65.50
		426.65.50
36. Kozhuvari	1	900.23.5
		900.23.5
35. Kazhuperumpakkam	1	292.30.0
		292.30.0

Extract
Villupuram District

Name of Taluk	Name of villages	Extent (in hectares)
Marakkanam Taluk	38 Nadukuppam	1277.22.0
	53 Seyyankuppam	48.44.5
	54 Chettikuppam	152.93.5
	52 Anumandai	75.89.5
	47 Urani	109.46.0
	56 Keelputhupattu	349.22.0
	55 Koonimedu	981.16.0
	46 Thirukkanur	32.91.5
		3027.25.0
Vanur Taluk	14 Kilapakkam	382.12.5
	16 Devanandal	123.03.5
	17 Karattai	426.65.5
	36 Kozhuvari	900.23.5
	35 Kazhuperumpakkam	292.30.0
		2124.35.0
	Grand Total	**5151.60.0**

4.   **Name of the Sanctuary**

Kazhuveli Wetland Birds Sanctuary

(P.T.O)

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BOUNDARY DESCRIPTION

East	:	Pondicherry to Chennai East Coast road; Village boundaries of Urani village No.47, Anumandai village No.52, Seyyankuppam village No.53, Chettikuppam village No.54 and Koonimedu village No.55.
West	:	Village boundaries of Aruvadi village No.223, Karattai village No.17 and Devanandal village No.16.
South	:	Village boundaries of Keelputhupattu village No.56, Kozhuvari village No.36 and Kazhuperumpakkam village No.35.
North	:	Village boundaries of Kilapakkam village No.14, Nadukuppam village No.38 and Thirukkanur village No.46.

The tank is in between 70° 45' to 70° 55' longitude and in between 12° to 12° 10' latitude. The tank lies adjacent to Bay of Bengal along the east coast. The tank is partly in Marakkanam and in Vanur taluk of Villupuram district.

SUPRIYA SAHU
PRINCIPAL SECRETARY TO GOVERNMENT

//True Copy//

B. Subochana.
SECTION OFFICER

209

Annexure-6

TAMIL NADU GOVERNMENT GAZETTE

EXTRAORDINARY   PUBLISHED BY AUTHORITY

No.230]   CHENNAI, TUESDAY, SEPTEMBER 27, 2016
Purattasi 11, Thunmugi, Thiruvalluvar Aandu-2047

Part II—Section 1

Notifications or Orders of specific character or of particular interest to the public issued by Secretariat Departments.

NOTIFICATIONS BY GOVERNMENT

ANIMAL HUSBANDRY, DAIRYING AND FISHERIES DEPARTMENT

PROHIBITION OF FISHING BY ANY KIND OF FISHING VESSELS IN A RADIUS OF 5 NAUTICAL MILES AROUND THE POTENTIAL NESTING AND BREADING SITES OF SEA TURTLES IN THE COASTAL AREAS UNDER THE TAMIL NADU MARINE FISHING REGULATION ACT, 1983.

[G.O. Ms. No. 146, Animal Husbandry, Dairying and Fisheries (FS-3), 27th September 2016,
புரட்டாசி 11, துன்முகி, திருவள்ளுவர் ஆண்டு–2047.]

No.II(1)/AHDF/11(b)/2016.

In exercise of the powers conferred by clause (a) of sub-section (1) of section 5 of the Tamil Nadu Marine Fishing Regulation Act, 1983 (Tamil Nadu Act 8 of 1983), the Governor of Tamil Nadu hereby prohibit the fishing by mechanized fishing vessels, motorized country crafts and those using mechanized fishing techniques in a radius of 5 (five) nautical miles around the following potential nesting and breeding sites of sea turtles identified by Central Marine Fisheries Research Institute and Department of Forest in the coastal areas of Chennai, Kanchipuram, Cuddalore, Villupuram, Nagapattinam, Ramanathapuram, Thoothukudi and Kanniyakumari Districts of Tamil Nadu during the turtle breeding season *i.e.,* for a period of four months from the 1st January to 30th April of every year (both days inclusive)

Potential nesting sites of Sea Turtle along the coast of Tamil Nadu

S.No. (1)	District (2)	Location (3)
1.	Chennai	1. From Napier Bridge to Tiruvanmiyur Regional Transport office backside
2.	Kanchipuram	1. Kottivakkam to Kovalam beach

DTP—II-1 Ex. (230)

[1]

S.No. (1)	District (2)	Location (3)
3.	Cuddalore	1. Pillumedu - Chinna vaikkal
		2. Chinna vaikkal - Mudasalodai
		3. Chinoor - Saamiyar pettai
		4. Saamiyar pettai - Aiyampettai
		5. Aiyampettai to Thamanampettai
		6. Thamanampettai to Sothikuppam
		7. Gori to Devanampattinam Beach
		8. Devanampattinam Beach
		9. Devanampattinam Village- Suba Uppalavaadi
4	Villupuram	1. Alagankuppam
		2. Vasavankuppam
		3. Kaipanikuppam
		4. Ekkiyarkuppam
		5. Anumandaikuppam
		6. Mudhaliyarkuppam
		7. Pudhukuppam
		8. Bommiyarpalayam
5.	Nagapattinam	1. Kodiyampalayam
		2. Madavamedu
		3. Kottaimedu
		4. Chinna Kottaimedu
		5. Koolaiyar
		6. Thoduvai
		7. Thirumullaivasal
		8. Keelamoovarkarai
		9. Chavadikuppam
		10. Naickerkuppam
		11. Madhthukuppam
		12. Pudhukuppam
		13. Vanagiri
		14. Chinnamedu
		15. Chinnankudi
		16. Thazhampettai
		17. Pudhupettai
		18. Perumalpettai
		19. Vellakoil
		20. Kuttiyandiyur
		21. Chandrapadi
		22. Chinnoorpettai

S.No. (1)	District (2)	Location (3)
	Nagapattinam—*Cont.*	23. Nagoorpattinacheri
		24. Samanthanpettai
		25. Velankanni
		26. Kameshwaram
		27. Viluthamavadi (Vettaikaraniruppu)
		28. Vanavanmahadevi
		29. Vellapallam
		30. Pushpavanam
		31. Arcattuthurai
		32. Kodiakadu
		33. Kodiakarai
6.	Ramanathapuram	**I Mandapam (Gulf of Mannar)**
		1. Kannirajapuram
		2. Mookaiyur
		3. Opilan
		4. Ervadi
		5. Sethukarai
		6. Pudumadam
		II Mandapam – SP. Pattinam (Palk Bay)
		7. Arriyaman beach
		8. Atrangarai
		9. Azhangankulam
		10. Puduvalasai
		III Rameshwaram Island
		11. Pamban
		12. Kundukal
		13. Danushkodi
7.	Thoothukudi	1. Periyasamypuram
		2. Kombuthurai
		3. Amalinagar
		4. Alanthalai
		5. Kulasekarapattinam
		6. Manapadu
		7. Periyathalai

S.No. (1)	District (2)	Location (3)
8.	Kanniyakumari	1. Kellamanakudi
		2. Pallam
		3. Puthanthurai
		4. Kesavan Puthanthurai
		5. Pozhikarai
		6. Periakadu
		7. Rajakkamangalamthurai
		8. Azhikkal
		9. Kottilpadu
		10. Kodimunai
		11. Keezhmidalam
		12. Melmidalam
		13. Enaiyam
		14. Enaiyamchinnathurai
		15. Eraviputhanthurai
		16. Vallavilai
		17. Marthandamthurai
		18. Neerodi

GAGANDEEP SINGH BEDI
Secretary to Government.

Annexure-7

SHORELINE CHANGE MAP
TAMIL NADU

Alankankuppam

Talankadu

Buckingham Canal

Kaipani

Narapakkam

Konavayankuppam

Eggaiyakuppam

Bay of Bengal

Pudukuppam

Komutichavadi

SH-134

SH-49
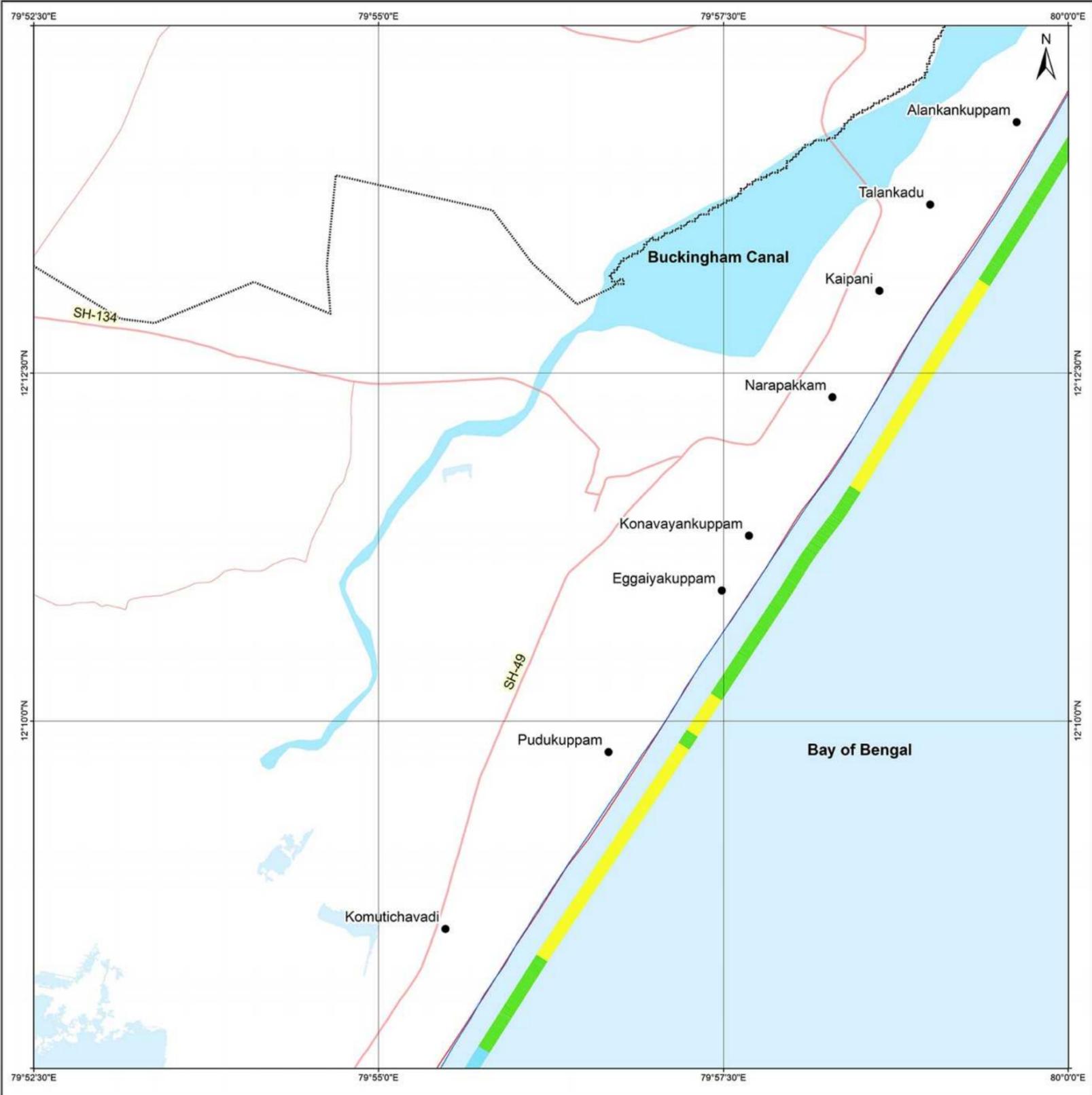
*Shoreline Change Trend
for Period* 1990 - 2018

High Erosion
Moderate Erosion
Low Erosion
Stable Coast
Low Accretion
Moderate Accretion
High Accretion

Shoreline date
07/25/1990
04/04/2018

Index to sheets

57 P / 15 / SW	57 P / 15 / SE	66 D / 3 / SW
57 P / 16 / NW	57 P / 16 / NE	66 D / 4 / NW
57 P / 16 / SW	57 P / 16 / SE	66 D / 4 / SW

**Incidence on
1:50,000 Sheets**

57 P / 11	57 P / 15	66 D / 3
57 P / 12	57 P / 16	66 D / 4
58 M / 9	58 M / 13	67 A / 1

Scale

1000 m 500   0   1   2 km

1:25,000

UTM Coordinates Zone 44
Datum   : The World Geodetic System
              1984 (WGS84)
Spheroid : The World Geodetic System
              1984 (WGS84)
Data Sources: Satellite Data

Sensors	Date of acquisition
LISS-IV	04/04/2018
LISS-IV	02/06/2017
LISS-IV	04/14/2016
LISS-IV	07/01/2015
LISS-IV	06/12/2014
LISS-IV	05/24/2013
LISS-IV	03/18/2012
LISS-III	10/29/2008
PAN (Cartosat-1)	07/01/2006
ETM+	10/28/2000
TM	07/25/1990

India

TAMIL NADU

Settlements
Port
Harbour
Groynes
Jetty
Breakwater
Seawall/Ripraps
Rocky Coast
Administrative Boundary
National Highways
State Highways
Other Roads
Railways
Lakes
Rivers

**Prepared by
Government of India
Ministry of Earth Sciences**
National Centre for Coastal Research (NCCR)
Pallikaranai, Chennai - 600100

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SHORELINE CHANGE MAP
TAMIL NADU

66 D / 4 / NW
Map No. : NCCR/SCM/350
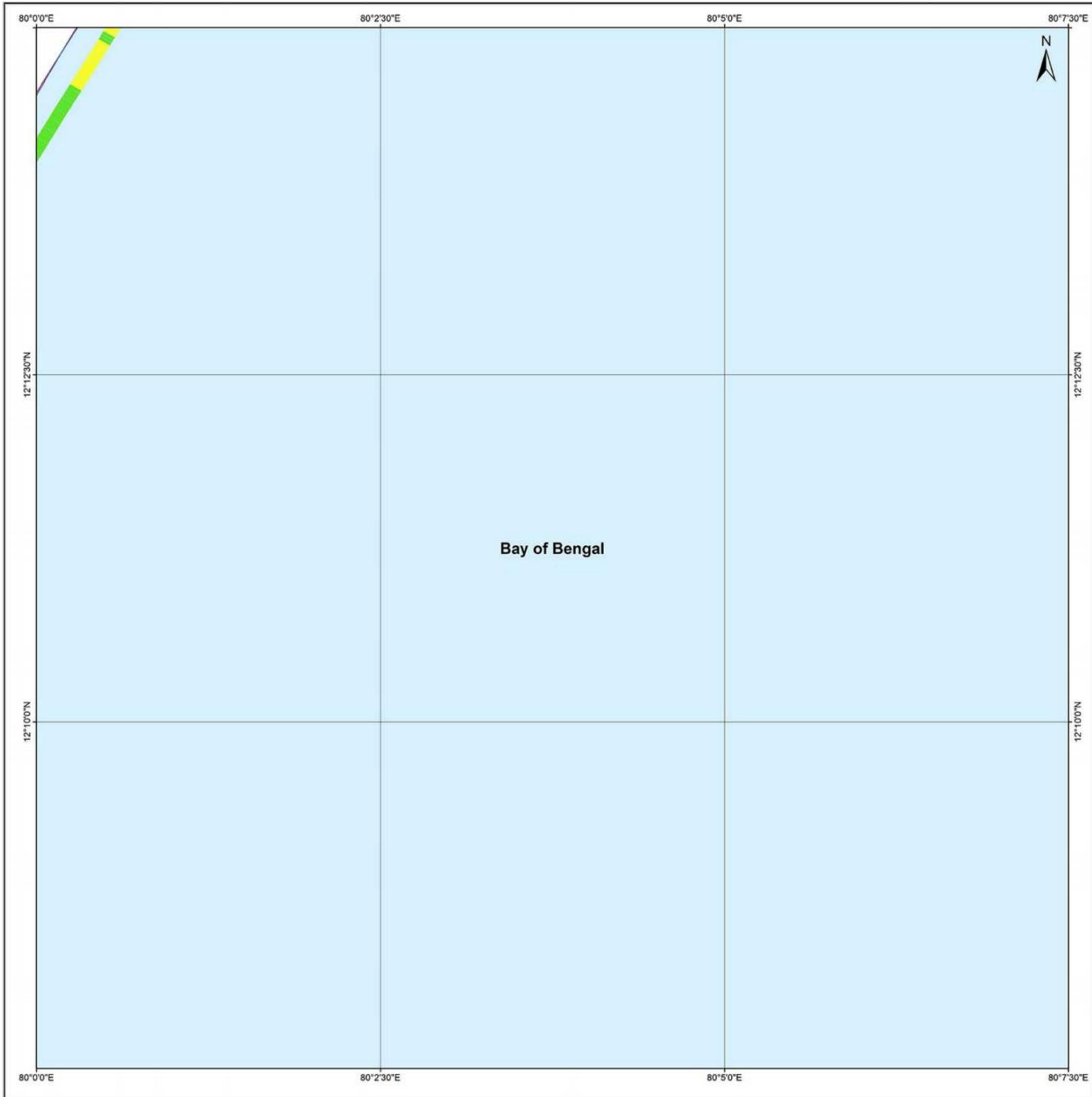
80°0'0"E 80°2'30"E 80°5'0"E 80°7'30"E

N

12°12'30"N

Bay of Bengal

12°10'0"N

80°0'0"E 80°2'30"E 80°5'0"E 80°7'30"E

Shoreline Change Trend for Period 1990 - 2018

- High Erosion
- Moderate Erosion
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- Low Accretion
- Moderate Accretion
- High Accretion

Shoreline date
— 07/25/1990
— 04/04/2018

Index to sheets

57 P / 15 / SE	66 D / 3 / SW	66 D / 3 / SE
57 P / 16 / NE	66 D / 4 / NW	66 D / 4 / NE
57 P / 16 / SE	66 D / 4 / SW	66 D / 4 / SE

Incidence on 1:50,000 Sheets

57 P / 15	66 D / 3	66 D / 7
57 P / 16	66 D / 4	66 D / 8
58 M / 13	67 A / 1	67 A / 5

Scale
1000 m 500 0 1 2 km
1:25,000

UTM Coordinates Zone 44
Datum : The World Geodetic System 1984 (WGS84)
Spheroid : The World Geodetic System 1984 (WGS84)

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India

TAMIL NADU

- Settlements
- Port
- Harbour
- Groynes
- Jetty
- Breakwater
- Seawall/Ripraps
- Rocky Coast
- Administrative Boundary
- National Highways
- State Highways
- Other Roads
- Railways
- Lakes
- Rivers

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SHORELINE CHANGE MAP
TAMIL NADU

66 D / 3 / SW
Map No. : NCCR/SCM/351

Maduvankaranai

Muttukadu

SH-115

SH-49

12°20'0"N

Otaiyur

Chinnakuppam

Bay of Bengal

12°17'30"N

Alamparai

Buckingham Canal

80°0'0"E   80°2'30"E   80°5'0"E   80°7'30"E

Shoreline Change Trend for Period 1990 - 2018

- High Erosion
- Moderate Erosion
- Low Erosion
- Stable Coast
- Low Accretion
- Moderate Accretion
- High Accretion

Shoreline date
— 07/25/1990
— 04/04/2018

Index to sheets

57 P / 15 / NE	66 D / 3 / NW	66 D / 3 / NE
57 P / 15 / SE	66 D / 3 / SW	66 D / 3 / SE
57 P / 16 / NE	66 D / 4 / NW	66 D / 4 / NE

Incidence on 1:50,000 Sheets

57 P / 14	66 D / 2	66 D / 6
57 P / 15	66 D / 3	66 D / 7
57 P / 16	66 D / 4	66 D / 8

Scale
1000 m 500   0   1   2 km
1:25,000

UTM Coordinates Zone 44
Datum   : The World Geodetic System
                1984 (WGS84)
Spheroid : The World Geodetic System
                1984 (WGS84)

Data Sources: Satellite Data

Sensors	Date of acquisition
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India

TAMIL NADU

- Settlements
- Port
- Harbour
- Groynes
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- State Highways
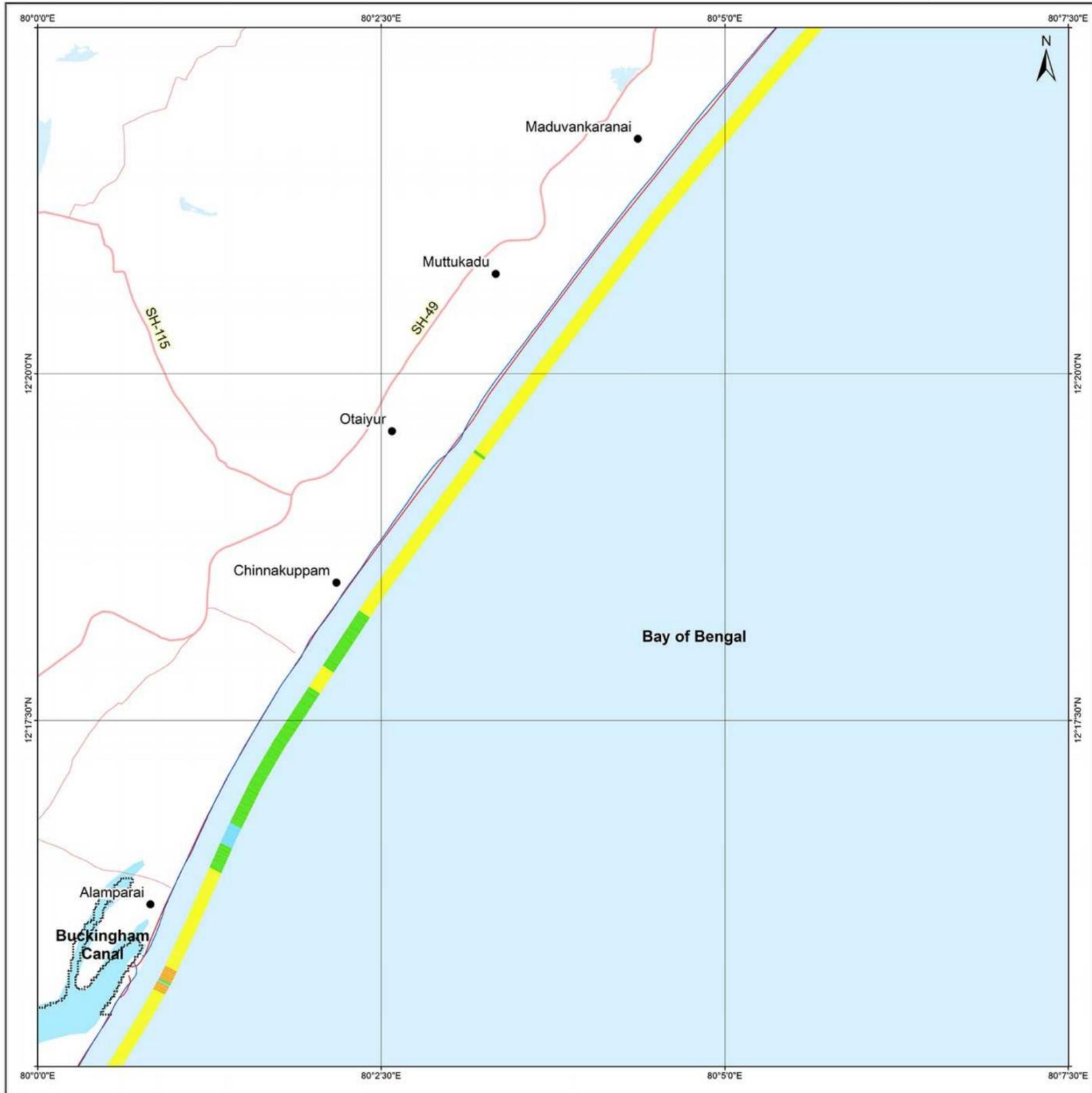- Other Roads
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HOTSPOTS REGIONS IN EAST COAST

Tamil Nadu

Erosion trend based on long-term (1990-2018) satellite data and field verification

Locations	District	Grid No
Kattupalli Port North	Thiruvallur	361
Chinnakuppam	Thiruvallur	360
Pulicat north	Thiruvallur	363
Periyakuppam	Thiruvallur	360
Kasikovil kuppam	Thiruvallur	360
Periyakuppam	Kancheepuram	353
Chinnakuppam	Kancheepuram	353
Oyalikuppam	Kancheepuram	353
Chinna Mudaliyarchavadi	Villupuram	346
Periya Mudaliyarchavadi	Villupuram	346
Madavamedu Beach	Nagapattinam	341
Kodiampalayam beach	Nagapattinam	342
Chinnamedu	Nagapattinam	339
Tarangambadi	Nagapattinam	339
North of Poombhuhar port	Nagapattinam	340
Mannaram island, Kodiyakadu	Thiruvarur	331
Ariyamaan Beach, Uchipuli	Ramanathapuram	314
Agni Theertham Beach, Palayakkayal	Thoothukudi	299
Thengapattanam	Kanniyakumari	284
Midalam	Kanniyakumari	284
Pillayarkovil	Kanniyakumari	285
Bommaiyarpalaiyam	Puducherry	346

Accretion trend based on long-term (1990-2018) satellite data and field verification

Location	District	Grid No
Pazhaverkadu	Thiruvallur	362
Marina Beach	Chennai	359
Silver beach	Cuddalore	243
Vellapallam	Nagapattinam	335
Arucottuthurai	Nagapattinam	334
Vilundamavadi Beach	Nagapattinam	335
Maniyantheevu Beach	Nagapattinam	332
Mullakkadu Beach	Thoothukudi	299
Virampattinum	Puducherry	346

Legend

Shoreline Change Trend

- High Erosion
- Moderate Erosion
- Low Erosion
- Stable
- Low Accretion
- Moderate Accretion
- High Accretion

- Grid Number
- ★ Hot-spot (Erosion trend)
- ★ Hot-spot (Accretion trend)

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