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RESEARCH ARTICLE

Climatic shifts over Mahanadi river basin

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The inter-annual variability and the long-term trends in the monsoon rainfall and in two derived climatic parameters, aridity index (I_a) and moisture index (I_m), have been examined for the Mahanadi basin using the rainfall and temperature data for the 80-year period (1901–80). The study shows that the basin has experienced a good number of deficit years during the last two decades of the study period. The yearly values of aridity and moisture indices show increase in the aridity conditions over the basin, with the semi-arid type climate in as many as five years during 1965–80. The trend analysis shows that the increasing and decreasing trends in the aridity index and moisture index respectively are statistically significant. The trend in the seasonal rainfall, though negative, is not statistically significant.

In recent years there has been considerable interest in the study of climatic changes on global and regional scales because of their socioeconomic impacts. There is a vast literature on the subject; a critical review has been given by Ellsaesser *et al.*[1]. In the Indian context two recent studies are those of Pant *et al.*[2] and Rupa Kumar *et al.*[3]. In the latter study the authors found a decreasing trend in the monsoon rainfall of India for the period 1871–1984, over the area covering a major part of Madhya Pradesh, Orissa, Bihar and adjoining areas of Maharashtra, Uttar Pradesh and West Bengal. The trends are highly significant over eastern parts of Madhya Pradesh. Such decrease has adverse impact on national activities in which water has a major role. The present study is addressed to temporal variations in the climatic regime over the Mahanadi river basin on the basis of relevant meteorological data for the 80-year period (1901–80).

The Mahanadi river rises from a pond near Sihawa village in Raipur district of Madhya Pradesh. It drains an area of 141,600 km^2 of which 53% is in Madhya Pradesh, 46.4% in Orissa and the balance in Bihar (0.5%) and Maharashtra (0.1%). The length of the river is 857 km. The basin is located geographically between the longitudes 80°25′E and 86°70′E and latitudes 19°15′ and 23°35′N (Figure 1). The average annual flow of the basin is about 66,640 million cu m. About 80–90% of the annual rainfall is received in the four months, June through September. After the completion of Hirakud project at Sambalpur (Orissa), the climatological and hydrometeorological studies are generally being carried out separately for the controlled part of the basin, called upper Mahanadi that is up to Hirakud; and the uncontrolled part that is lower Mahanadi, which is below Hirakud. The normal monsoon rainfall values for the upper and lower basins are 1122 mm and 1254 mm with the coefficients of variation 18% and 17% respectively.

In the present study, the inter-annual variability and the long-term trends in the monsoon rainfall and also in two derived climatic parameters, aridity index (I_a) and moisture index (I_m), have been examined, for the upper and lower basins as well as for the entire basin. As there are no substantial differences, the results for the whole basin only are reported.

Data

Rainfall data from a dense network of 125 raingauge stations (Figure 1) have been used to compute the daily areal rainfall values for the basin from which the monthly and monsoon seasonal rainfall series were constructed for the individual years. Monthly mean temperature data of seven available surface observatory stations (Jabalpur, Raipur, Kanker, Jagadalpur, Sambalpur, Cuttack and Puri) located in and around the basin

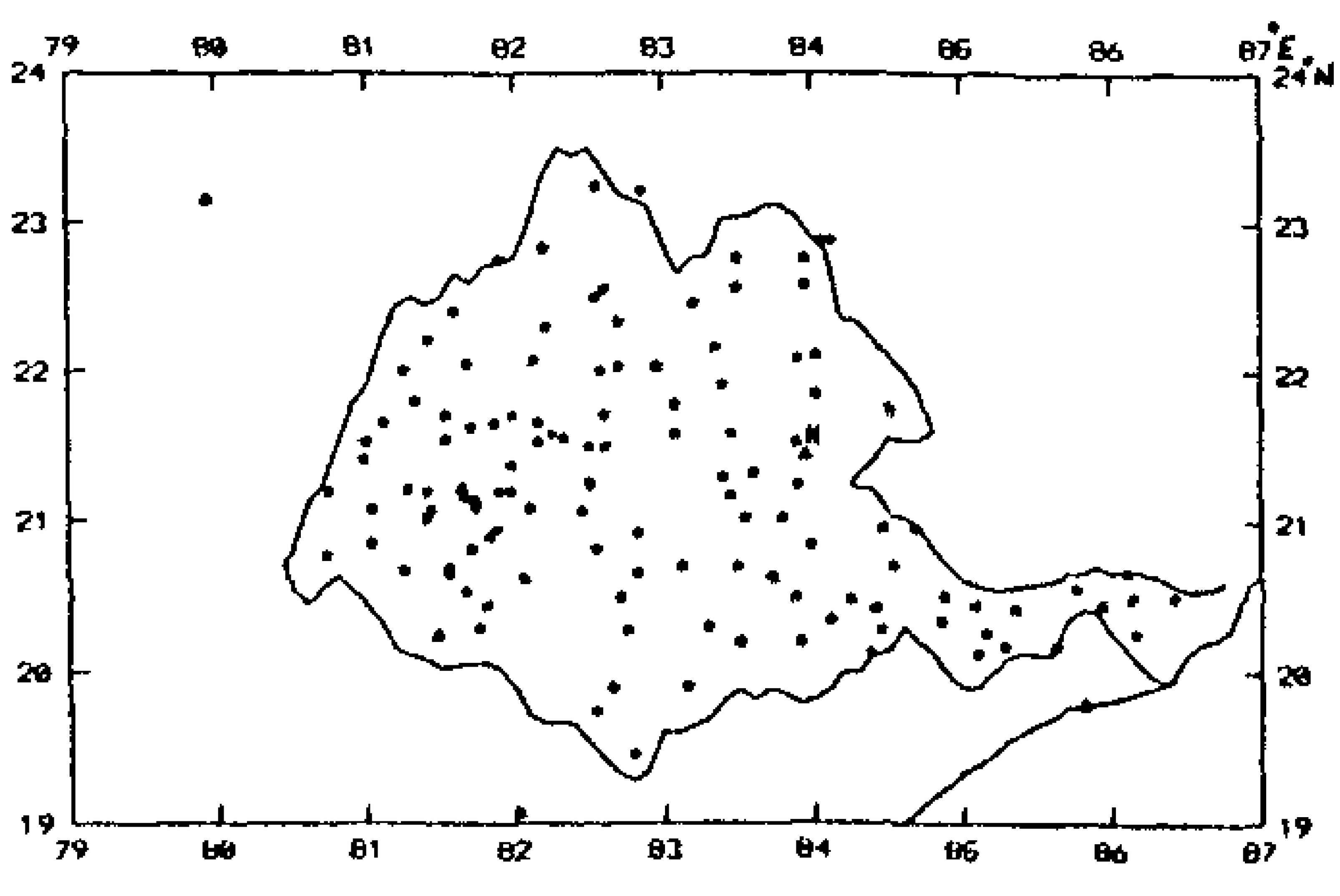

Figure 1. Location of raingauge stations (•) and surface observatory stations (Δ) in the Mahanadi basin. H-location of the Hirakud dam.

(Figure 1) have been used to obtain the monthly basin average temperature series for the period, required for computing the derived parameters.

Inter-annual variability

Monsoon rainfall

The mean ($\bar{R}$), the standard deviation (SD) and the coefficient of variation (CV) of the monsoon rainfall series of the basin for the 80-year period are 1170 mm, 175 mm and 15% respectively. Years with rainfall $>(\bar{R}+\mathrm{SD})$ and $<(\bar{R}-\mathrm{SD})$ are considered as excess/deficit rainfall years respectively. The departures of rainfall from the normal for the individual years are shown in Figure 2*a*. The salient features are:

a) The years 1961 (1776 mm) and 1974 (713 mm) were those of highest and lowest rainfall giving a range of 1063 mm (~85% of the normal)
b) The basin has experienced eleven excess and eleven deficit years in the 80-year period
c) There were two cases of consecutive excess years, 1933–34 and 1936–37 and two cases of consecutive deficient years, 1901–02 and 1965–66
d) The year 1925 was an excess preceded by a deficient year, while the year 1962 was a deficit preceded by an excess year
e) Deficit rainfall years were more frequent during 1961–80 and excess years during 1921–40.

In order to assess the severity of excess and deficient monsoon rainfall situations in the basin, a criterion based on the percentage departure of seasonal rainfall from the normal has been adopted. This method is followed on operational basis by the India Meteorological Department[4] and was also adopted by the National Commission on Agriculture[5]. According to this, drought is considered to be moderate when the percentage departure of rainfall deficiency is between −25% and −50% of normal and severe if it is less than −50%. Similarly, the percentage departure of rainfall between 25 and 50% is considered as moderate flood and that more than 50% as severe flood. Based on these criteria the basin has experienced two years of moderate flood (1925, 1936), one year of severe flood (1961) and three years of moderate drought (1965, 1974, 1979).

Aridity and moisture indices

As seen from Figure 2*a* the occurrence of droughts has been more frequent in the recent two decades 1961–80. To examine the fluctuations and shifts, if any, in the climatic conditions over the basin during the data period, the yearly values of aridity and moisture indices, I_a and I_m were worked out for the basin during the

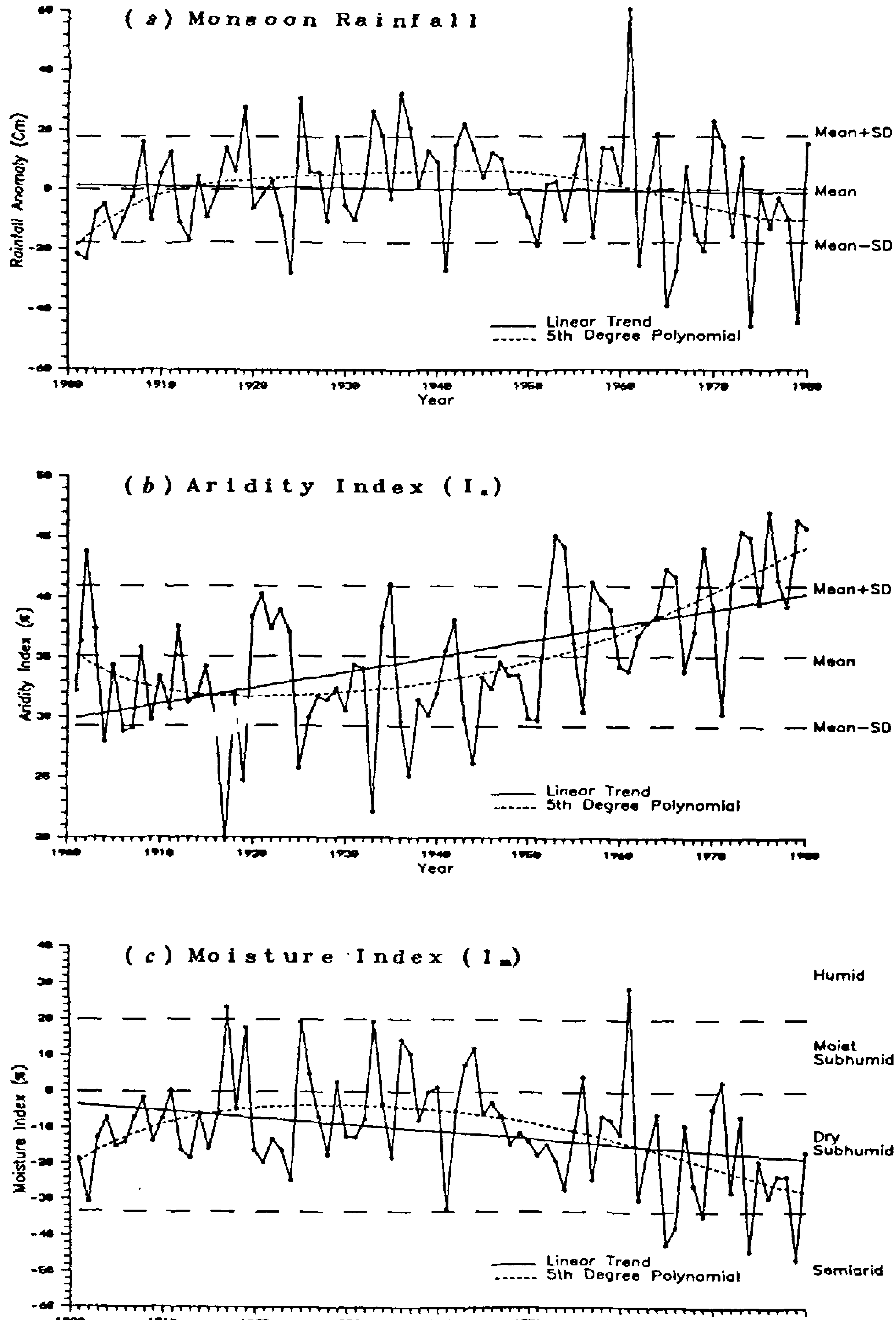

Figure 2. Time series plots of (a) monsoon seasonal rainfall anomalies, (b) aridity index (I_a), and (c) moisture index (I_m) during the period 1901–80 over Mahanadi basin.

study period following the Thornthwaite's water balance technique.

Thornthwaite[6] introduced a parameter called 'potential evapotranspiration (PE)' defined as the maximum amount of water that would evaporate and transpire from a thickly vegetated extensive territory with no deficiency of water for full use at any time. This by its very definition represents the water need of a place. The dryness or wetness of a place can be evaluated by comparison of this water need with the amount of water supply received through precipitation. The water balance technique, which makes these comparisons on a monthly basis, gives quantitatively the periods and amounts of water deficit or surplus and also the degree of dryness or wetness at a place. This procedure also takes into account the role played by the soil in storing moisture during rains and releasing the same to the atmosphere during rainless periods. The water surplus and water deficit in relation to the water need on an annual basis is used to define the aridity and moisture indices. The aridity index (I_a), which is a quantitative indicator of the degree of water deficiency present at a given location, is expressed in percentage as 100 (water deficit/water need). The moisture index, according to which different climatic types were evolved, is defined as 100 {(water surplus − water deficit)/water need}. The computational details of Thornthwaite's water balance are presented in detail by Subrahmanyam[7]. FORTRAN code for the above computations was taken from Willmott[8].

Figure 2*b* shows the annual aridity index (I_a) values of the basin, along with the linear trend line and the smoothened curve fitted with a 5th degree polynomial. The aridity conditions in the basin show a progressive increase during the period under study. This is also evident from the trend line. From the smoothed curve it appears that the upward trend started around the early twenties. The mean, (mean + SD) and (mean − SD) lines are also given in the figure. The yearly march of aridity index shows that, during the last two decades (1961–80), I_a has exceeded the (mean + SD) line in the ten years, whereas such excess was only four times during the earlier six decades (1901–1960).

Figure 2*c* shows the I_m values during the period along with a linear trend line and a smoothed curve fitted with a 5th degree polynomial. The different climatic regimes based on the values of I_m, as delineated by Carter and Mather[9], are also marked in the figure. The mean value of I_m for the basin is −11.0, which represents dry sub-humid climate. The year-to-year fluctuations of I_m are also generally within the range of dry sub-humid climatic regime. However, there have been frequent excursions into the moist-subhumid regime during the period 1915–1945. A significant aspect of the fluctuations in I_m is that the basin has experienced, for the first time, the semi-arid type climatic conditions in as many as five years (1965, 1966, 1969, 1974 and 1979) during the period 1965–80, resulting in a downward trend of moisture index.

Long-term climatic trends

Long-term trends in the monsoon seasonal rainfall, aridity index and moisture index over Mahanadi basin have been studied using the Mann–Kendall rank test and the linear trend. The Mann–Kendall rank test, which is based on the run-test of a ranked time series, is sensitive to nonlinear trends as shown by Mitchell *et al.*[10]. However, it indicates only the direction and significance of the trend and cannot quantify the trend. On the other hand, the linear trend has the advantage of giving magnitude, direction and statistical significance. The linear trend, which is the slope of the simple least-square regression line with time as the independent variable, has been tested for its statistical significance by means of F-ratio, giving due consideration to the autocorrelation of the series as suggested by Wigley and Jones[11]. The statistical parameters of the trend analysis in respect of rainfall and aridity and moisture indices, based on 80 years data using the above two methods, are given in Table 1. From the table it is seen that the aridity and moisture indices show statistically significant increasing and decreasing trends respectively. The trend in the rainfall, though negative, is not statistically significant. The increasing trend in the aridity index is more pronounced with both the tests, showing a statistical significance at 1% level.

Summary and discussion

The study shows that the Mahanadi basin has experienced several deficit rainfall years during the last two decades of the period 1901–80. The yearly values of aridity and moisture indices show a gradual increase in the aridity conditions over the basin. The moisture index indicates that the basin has experienced semi-arid

Table 1. Trend analysis

	Monsoon seasonal rainfall (mm)	Aridity index (I_a)	Moisture index (I_m)
Mean	1170.0	35.1	11.0
Std. Dev.	179.2	5.9	14.8
Autocorrelation	-0.0348	0.4569	0.1720
Intercept	1184.0	29.8	3.3
Trend per 100 yr	34.6	13.1	19.1
Trend per av.(%)	-2.96	37.37	173.75
F-value	0.155	10.818**	5.392*
Mann Kendall	0.01	0.38**	0.18

* Significant at 5% level

** Significant at 1% level.

type climate for the first time in 1965, with frequent recurrence thereafter until the end of 1980. The increasing trend in aridity index and decreasing trend in moisture index are statistically significant. The negative trend shown by the monsoon rainfall is not statistically significant.

Hingane *et al.*[12] studied the long-term trends of surface air temperature over India and reported a pronounced warming in the mean annual temperature over the northcentral and northeast Indian regions. The Mahanadi basin is in close proximity of the region of significant warming observed by them. Further, we have noticed significant decreasing trends in the pre-monsoon and post-monsoon seasonal rainfall (details not presented here). These factors can contribute to the observed significant trends in the yearly aridity and moisture indices.

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RESEARCH COMMUNICATIONS

A mathematical prey–predator model for tree and man

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A prey-predator model can be developed to preserve the environment with two interdependent variables, labelled as man and tree. The parameter tree is measured in terms of the land covered by vegetation. The system of simultaneous differential equations representing the interaction is nonlinear. The equilibrium condition provides the critical values for their populations. The nonequilibrium behaviour of this interacting system is studied as a perturbation from the equilibrium state. When a portion of the land is continuously made unusable the population of man irreversibly goes to zero.

Deforestation and the subsequent loss of environmental protection is a matter of serious concern in the study of ecology. One has reason to believe that under desirable conditions there should be an upper limit for the population of man and a lower limit for trees[1,2]. We were motivated to attempt this problem on the World Environmental Day. In this article we present our mathematical analysis of this problem. Our approach to this problem is similar to the original work by Volterra applied to the case of foxes and rabbits[3–8].

There are several factors which contribute to the growth and decay of the two competing variables, man and tree. These factors make the problem of man–tree coexistence a very complex one. Nevertheless we can make a beginning by starting with a simple model that qualitatively describes the system. We need to make reasonable assumptions and approximations in the first stage of the problem. To begin with, we simplify the many-variable problem into a two-variable problem by making the following assumption—the variable man is actually a function of many factors which result in the destruction of trees and the variable tree is a function of many variables which are resourceful to man. In simple words we assume that man always benefits from trees either directly or indirectly at the cost of the trees. In this way we build the variable tree as a representative of agricultural farms, forests, etc. which are of biological origin, enabling the survival of mankind. The variable man represents many factors such as human beings, pests and other creatures which thrive on green food.