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Rainfall and soil wetness response to ENSO and soil wetness estimation from remote sensing data

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ABSTRACT
Studies on water budget elements are of great importance in the context of geo-hydrological scenario. The estimation and analysis of soil wetness for a particular region is helpful in understanding the various mechanisms involved in the land surface hydrology. The present study attempts to understand the daily rainfall and soil wetness variations with respect to the geophysical indices of ENSO phases such as NINO 3 sea surface temperature and Southern Oscillation Index. The parameter soil wetness is derived from the water balance model on a daily basis. The study has been performed for the monsoon seasons of 1999 to 2002 over selected stations of Andhra Pradesh (12^0-20^0N; 76^0-86^0E). The study then proceeds in estimating the soil wetness using the brightness temperature data of Multichannel Scanning Microwave Radiometer of IRS-P4. As the study region consists of different types of soils such as medium black, redloam and laterite soils, the investigation makes use of the brightness temperature variations with reference to soil category in relation to soil wetness.

INTRODUCTION

Hydrological budget analysis is accounting of water received in the form of rainfall and expending for evaporation, recharging the soils, surface and subsurface run-offs. The soil wetness which is very next to rainfall is the principal component in many social and economic activities. The study region in the present investigation experiences considerable variations of rainfall on different time-scales. It is widely reported that the global rainfall is influenced by coupled ocean - atmosphere interactions through the sea surface temperature of NINO-3 and the Southern Oscillation Index (Ropelewski & Halpert 1996; Smith & Ropelewski 1997). Sarma, Srinivas & Karthikeya (2005) pointed out that the hydrological cycle of India is affected in accordance with the LA-NINA-Southern Oscillation and EL-NINO Southern Oscillation signals.

The soil wetness, defined as the ratio of soil water to the field capacity of the soil can be derived from the model following the revised method of Thornthwaite & Mather (1955). Through the process of evapotranspiration from land and vegetal cover to the atmosphere, soil wetness plays a major role in controlling the climate. Timbal *et al*.,(2002), reported the striking relation between soil wetness and sea surface temperature anomalies. According to Haibin Li *et al*., (2004), global circulation model simulations indicate that soil moisture contributes to precipitation predictability which in turn is affected by the boundary conditions of sea surface temperatures. Huqiang Zhang (2004) studied the underlying relationships between large scale SST forcing that is represented by SOI and the slow varying land surface processes in explaining the variations of soil wetness over Australia.

With the advent of the satellite era, it is possible to understand and study the land surface mechanism by using satellite data. Operational satellites are playing crucial role in the present days for extreme event forecasting and climate modeling (Thapliyal et al., 2005). Remote sensing allows the retrieval of soil moisture, classification of soil types, land use and the suitability of the landscape. Utilization of microwave remote sensing data for the estimation of land surface parameters such as soil wetness, vegetal cover etc has greatly benefited the hydrological community (Sarma & Lakshmi Kumar 2005). Choudhury & Glolus (1988) reported the soil moisture over large regions using passive microwave observations. The polar nature of the water molecule tends the moisture content in the soil to respond greatly with the microwave frequencies. Since the study region consists of different types of soils like laterite, medium black and redloam soils, an attempt has been made here to obtain soil wetness by using the brightness temperature data derived from Multichannel Scanning Microwave Radiometer (MSMR) of IRS -P4 satellite from the frequency channel of 6.6GHz. Since, the brightness temperature for a particular region or soil will be influenced by the soil wetness, soil type, soil colour, soil texture and organic matter in that soil (Jackson & Schmugge 1991), the present study illustrates the variations of brightness temperature with the type of soils and the implications are also discussed.

METHODOLOGY

The daily variations of All Andhra Pradesh rainfall (RR) in relation to the ocean surface of NINO-3 region and the nature of the monsoon seasons of 1999 to 2002 are studied. The NINO-3 sea surface temperature and Southern Oscillation Indices for the respective study period are downloaded from the website *poet.jpl.nasa.gov.* The correlation and regression analysis is applied for NINO 3 SST and Southern Oscillation Index (SOI) with rainfall of All Andhra Pradesh in understanding the implications.

The book keeping method of water balance by Thornthwaite & Mather (1955) is used for simulating soil moisture storage values over the study region. The soil wetness is derived from the following expression

Soil wetness, $S_{WT} = (S_T/F_C) * 100$

where S_T is soil moisture storage and F_C is the field capacity for the station under consideration.

The daily march of soil wetness (S_{WT}) of All Andhra Pradesh is plotted in relation to SOI and NINO 3 SST anomalies and the correlation and regression statistical analysis has been applied to understand the influence of these indices on the soil wetness.

The brightness temperature data (nighttime observations) of Anantapur ($14^0.41^1$, $77^0.37^1$), Kurnool ($15^0.50^1$, $78^0.04^1$), Hyderabad ($17^0.27^1$, $78^0.28^1$) and Ramagundam ($18^0.46^1$, $79^0.26^1$) that belong to medium black soil, Nellore($14^0.27^1$, $79^0.59^1$), Ongole ($15^0.34^1$, $80^0.03^1$) and Machilipatnam($16^0.11^1$, $81^0.03^1$) for redloam soil and Visakhapatnam ($17^0.43^1$, $83^0.14^1$) for laterite soil are considered as foot prints for the respective locations. Average brightness temperature data for each soil type is obtained and are plotted against mean soil wetness values. The correlation and regression have been carried out for soil wetness and brightness temperature for each of the soil type and are tabulated.

RESULTS AND DISCUSSION

Rainfall - SOI AND NINO 3 SST anomalies

Daily variations of rainfall of All Andhra Pradesh with southern oscillation index and NINO 3 SST anomalies are plotted in figs 1 and 2. The rainfall varied from 0 to 19mm in the year 1999 for the corresponding variations of SOI anomales from -32 to +32 and NINO 3 SST anomalies from -2.0 to -0.6 (Fig.1a and 2a). It is reported that from the earlier investigations that weak signal of SOI causes low rainfall in association with higher SSTs (Sarma, Padma Kumari & Srinivas 1999 and Sarma, Srinivas & Sastry 2000). The correlation between rainfall and SOI is 0.161 and for rainfall and NINO 3 SST, it is -0.145. The 17th day of June experienced highest rainfall in the monsoon period of 1999 with an SOI of +15 and SST of -1.2. Higher rainfall events are observed in the 3rd week of July, 1st and last weeks of September. The SOI anomalies dipped drastically in the 4th week of June, 4th week of July, 2nd week of August and 3rd week of September and for which the corresponding rainfall did not exceed 8mm per day. From the figs (1a and 2a), during the second half of September a decreased trend is observed in Nino 3 SST anomalies accompanied by increase in rainfall that varied from 7mm to 17mm.

The year 2000 witnessed the rainfall with a range of 0 to 55mm per day over All Andhra Pradesh. The SOI varied from -32 to +20 while NINO 3 SST fluctuated from 0.2 to -1.4 (Figs 1b and 2b). The 22nd day of August recorded highest rainfall with a SST of -1.2 and SOI of 0.5. The second half of the August and last week of September experienced major rainfall events in the year 2000. The correlation coefficient between rainfall and SOI is +0.014 and with NINO 3 SST, it is - 0.247. The correlation informs that the affect of SOI on Andhra Pradesh rainfall during the year 2000 is less.

The rainfall of the monsoon period of 2001 registered a maximum of 30mm on 30th day of September (figs 1c and 2c). Eventhough, Nino 3 SST anomalies are less than the normal, less rainfall is observed during the study period. The affect of SOI is well reflected on the rainfall pattern of 2001 year compared to 2000 as the correlation for this year between rainfall and SOI is 0.116. The SOI of June went up to +30 and from thereafter, the anomalies decreased gradually. The small anomalies of SSTs of NINO 3 implied that the ENSO features affecting the monsoon performance were low.

The year 2002 presented a considerable affect of ENSO on the monsoon rainfall. Both SOI and Nino 3 SST variations reciprocated to lowest rainfall. It is worth mentioning from the figs (1d) and (2d), that the study area throughout the monsoon period did not experience sufficient rainfall and might have caused very low crop performance. The NINO 3 SST anomalies are almost above the normal followed by the weak SOI through out the monsoon season.

The correlation coefficients and the regression equations for rainfall with SOI and NINO 3 SST anomalies are presented in Table 1. The correlation of rainfall with SOI for the entire period was +0.16 and with Nnio 3 SST, it was -0.17. The correlations, in these cases are at 0.01 significant level. The linear fit is approximated for All Andhra Pradesh rainfall with the anomalies of SOI and NINO 3 SSTs respectively.

Table 1. Correlation coefficients and regression equations for All Andhra Pradesh rainfall (RR) with SOI and NINO 3 SST anomalies.

Year	SOI anomalies		Nino 3 SST anomalies	
	Correlation(r)	Regression	Correlation(r)	Regression
1999	+0.161	RR= 3.99 + 0.06 * (SOI)	-0.145	RR = 1.83 - 2.31* (SST)
2000	+0.014	RR = 6.15 + 0.01 * (SOI)	-0.247	RR = 2.38 - 8.2* (SST)
2001	+0.116	RR = 3.67 + 0.04 * (SOI)	+0.064	RR = 3.64 + 0.26*(SST)
2002	-0.080	RR = 2.72 - 0.01 * (SOI)	+0.077	RR = 2.27 + 0.83*(SST)
1999 to 2002	+0.16	RR = 3.96 + 0.07*(SOI)	-0.17	RR = 3.99 – 1.5*(SST)

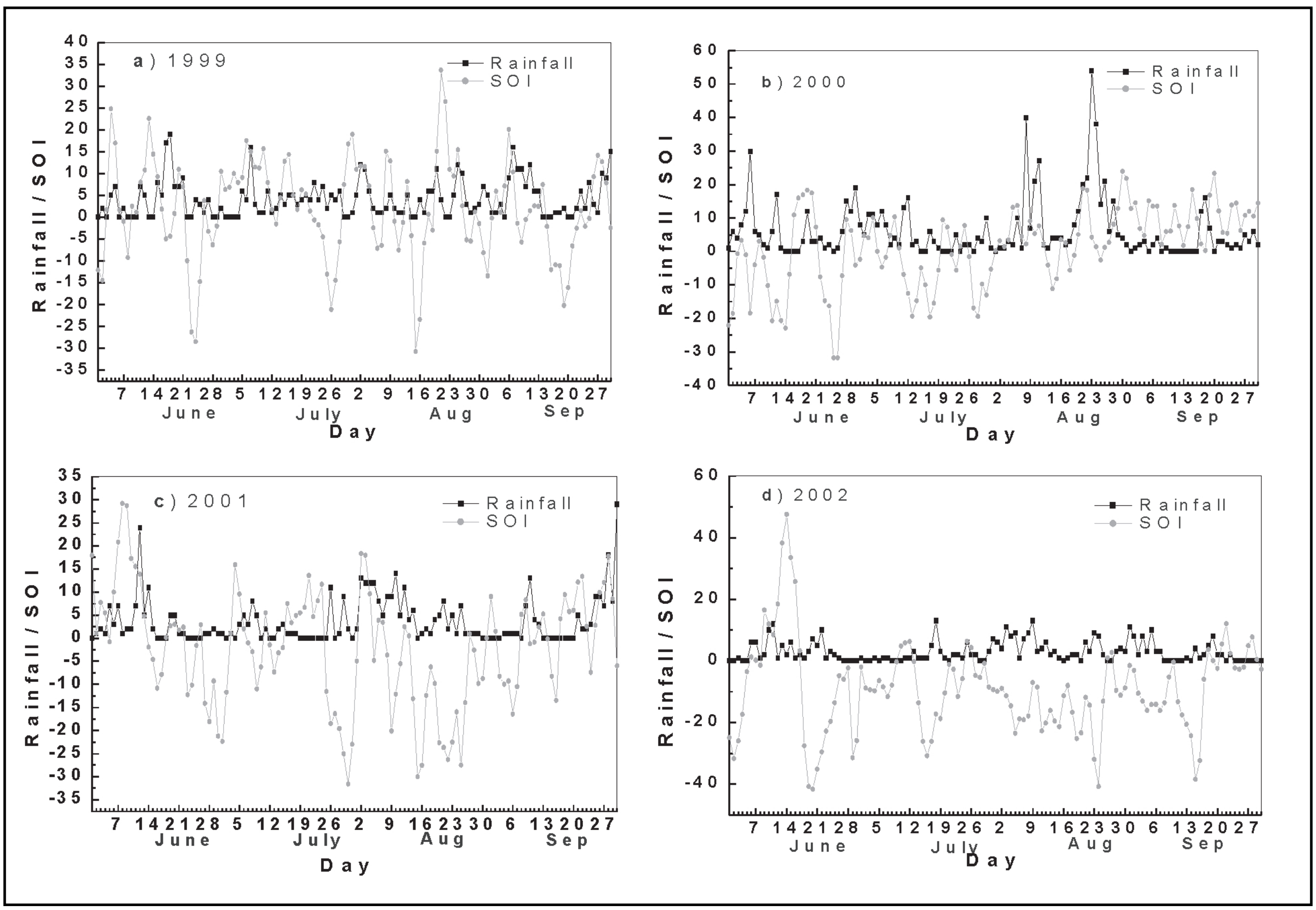

Figure 1. March of daily rainfall of All Andhra Pradesh and SOI for the monsoon period.

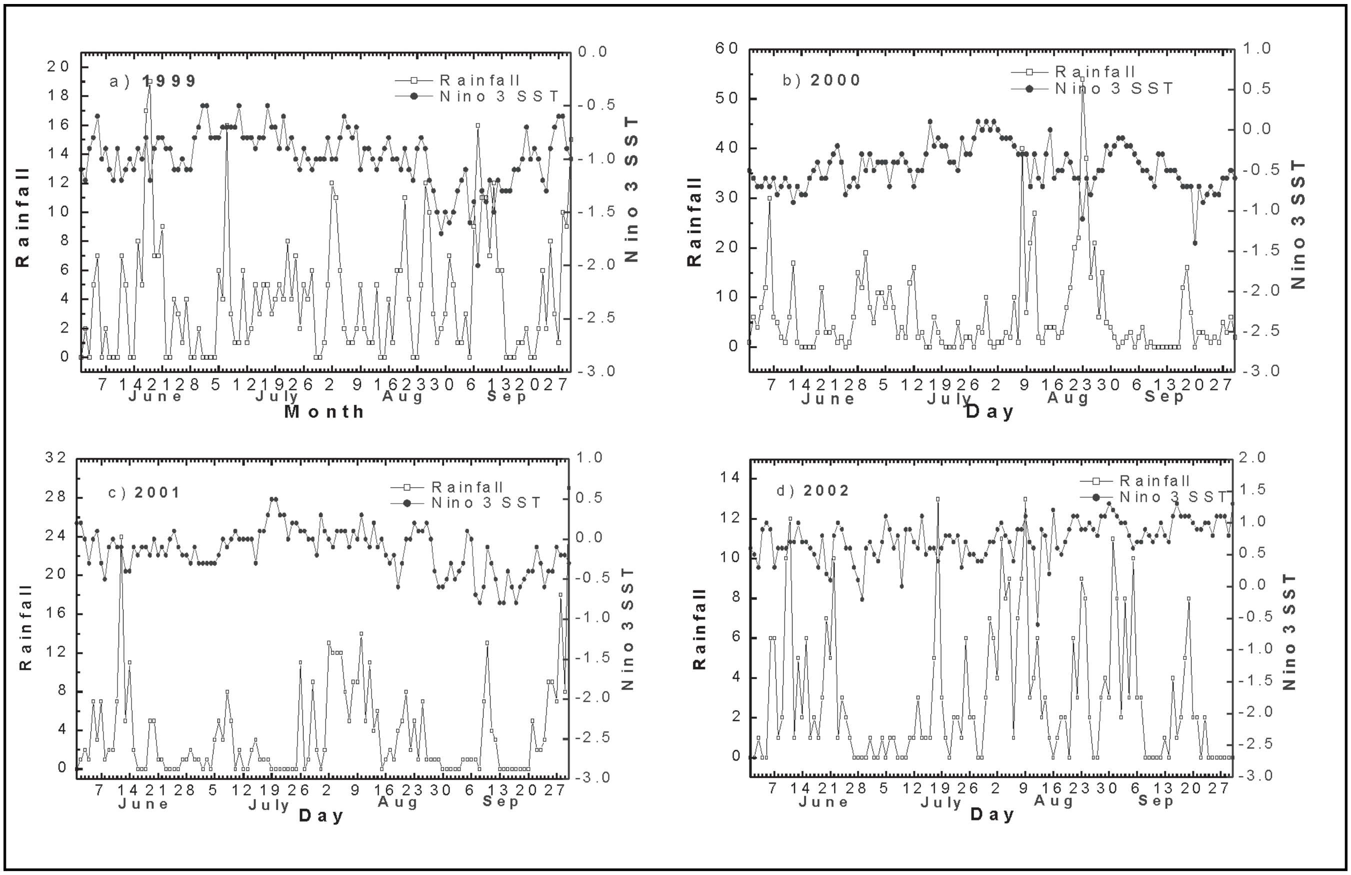

Figure 2. March of daily rainfall of All Andhra Pradesh and NINO 3 SST for the monsoon period.

Soil Wetness — SOI AND NINO 3 SST anomalies

The soil wetness variations with reference to the SOI and SST of Nino 3 are depicted in figs 3 and 4.

The soil wetness in the year 1999 (figs 3a and 4a) recorded a maximum of 60% during the monsoon period and the increase is small from the onset of monsoon but reached 60% by September. The negative correlation (r = -0.280) showed that the soil wetness is well responded for the Nino 3 SST anomalies i.e the soil wetness is in increase trend with the opposite trend of SST. Since the soil wetness is as a consequence of the past occurrence of rainfall (Eltahir, 1998) and as such there is no much degradation of soil wetness even though, a low signal of SOI has taken place (r = -0.165).

The soil wetness of the year 2000 (Fig.3a) is higher compared to 1999 as it reached to 100% and maintained the same for several days. Since 2nd week of July, the soil wetness accumulated to 50% value and by 4th week of August, it was further elevated to 100% and was in accordance with the increased signal of SOI (r = +0.372). During the 4th week of August, the NINO 3 SST anomalies (Fig.4a) dropped below the normal level with an increase of soil wetness. During the last week of July, the soil wetness diminished to 40% from 60% with an increase of Nino 3 SST anomalies.

During the year 2001, the soil wetness magnitude varied only up to 57% through out the monsoon season. In the first half of the monsoon period, the soil wetness varied between 0 and 20% only with the very low SOI values. The month of August received considerable variations in soil wetness due to the weak signal of SOI (Fig.3c) but the SST anomalies (Fig.4c) strengthened through rainfall pattern on wetness patterns as usual (r=-0.231). September 30th day witnessed the maximum soil wetness of 57% compared to any other day in the monsoon season.

The year 2002 experienced very low soil wetness and varied only up to 35% through out the monsoon period. In June, the soil wetness was only 0% and there after, it increased to 35% by the 2nd week of September. The abnormal increase of NINO-3 SSTs in 2002 (Fig.4d) might be responsible for reduction in the strength of the monsoon current for low soil wetness accompanied by subnormal SOI (Fig.3d).

The correlation obtained for the entire period for soil wetness with SOI and NINO-3 SST are +0.15 and -0.30 respectively that are at 0.01 level of significance. The correlation coefficients and the regression equations for soil wetness with SOI and NINO 3 SST anomalies are presented in Table 2. The linear fit is approximated to develop the regression model.

Table 2. Correlation coefficients and regression equations for All Andhra Pradesh soil wetness (S_{WT}) with SOI and NINO 3 SST anomalies.

Year	SOI anomalies		Nino 3 SST anomalies	
	Correlation	Regression	Correlation	Regression
1999	-0.165	S_{WT} = 5.55 - 0.13*(SOI)	-0.280	S_{WT} = 12.67 - 15.3*(SST)
2000	+0.372	S_{WT} = -8.76 + 0.16*(SOI)	+0.107	S_{WT} = 64.77 + 10.62*(SST)
2001	-0.355	S_{WT} = 4.78 - 0.31*(SOI)	-0.231	S_{WT} = 20.15-11.78*(SST)
2002	-0.121	S_{WT} = -6.82 - 0.14*(SOI)	+0.362	S_{WT} = 7.45 + 11.73*(SST)
1999 to 2002	+0.15	S_{WT} = 31.9 + 0.27*(SOI)	-0.30	S_{WT} = 29.2 – 10.4*(SST)

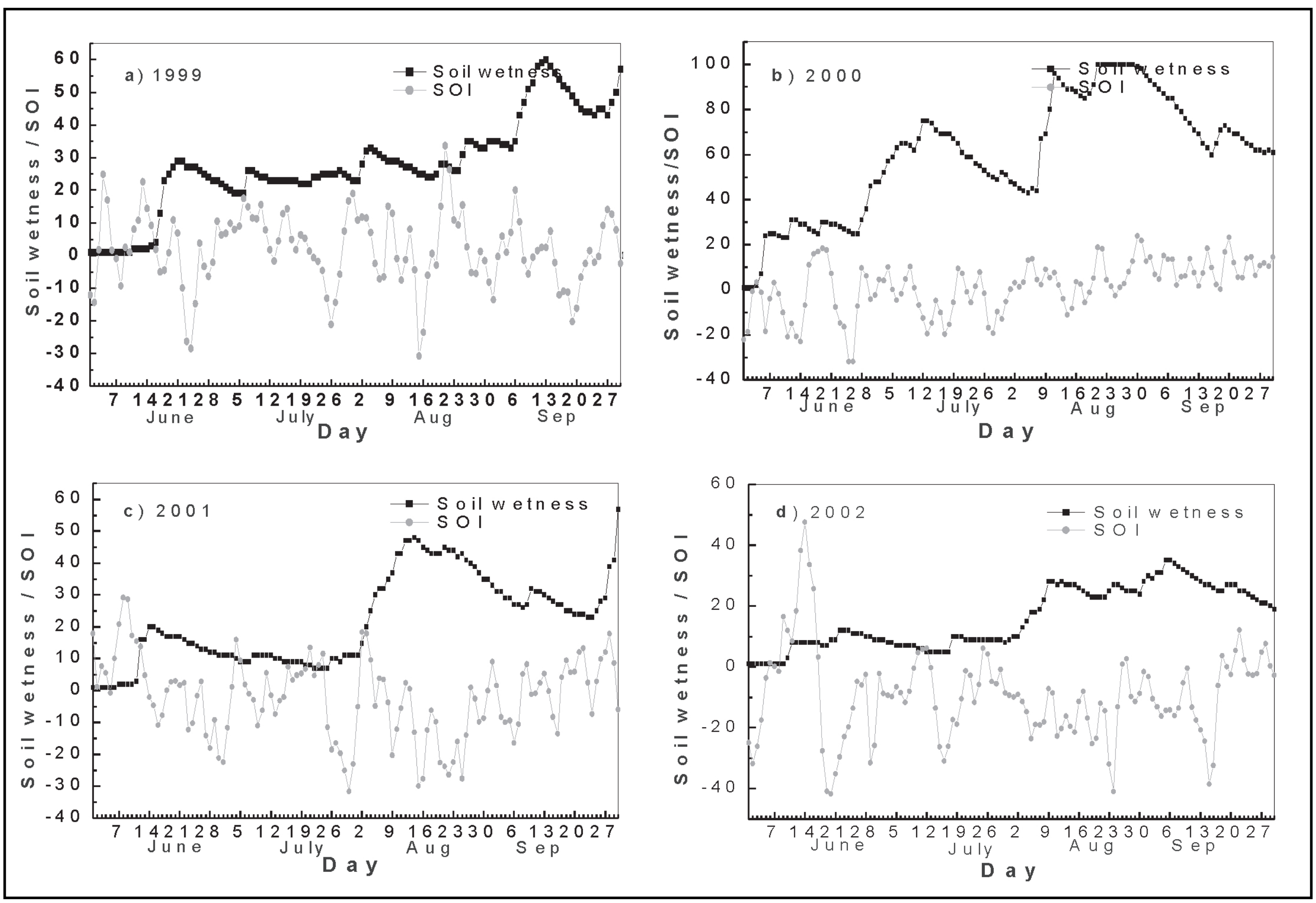

Figure 3. March of daily soil wetness of All Andhra Pradesh and SOI for the monsoon period.

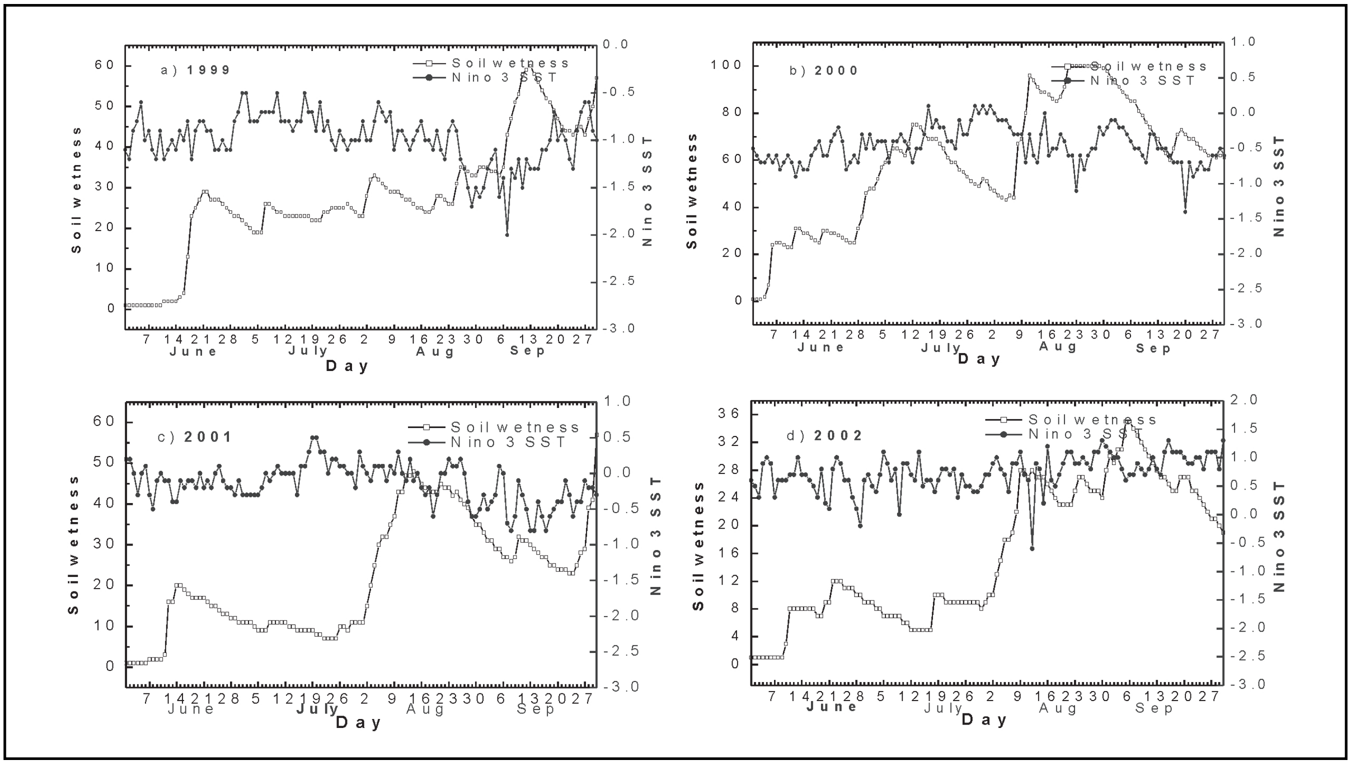

Figure 4. March of daily soil wetness of All Andhra Pradesh and NINO 3 SST for the monsoon period.

Soil Wetness and Brightness Temperature

Leone, Wright & Corves (1995) studied the soils in the Apennine Mountains of Southern Italy using the satellite remote sensing data. Thapliyal et al., (2003) reported that the high rainfall over a region exhibits high soil moisture status, which results in the low brightness temperature due to less emissivity. The test sites are categorized according to soil types of Andhra Pradesh namely medium black, red loam and laterite soils. The mean soil wetness of June to August of 1999, 2000 and 2001 yielded inverse relation with brightness temperature.

Temporal variations of Brightness Temperature with soil wetness

It is observed that the BTD varied from 212 to 264 for the medium black soils (Fig.5a), 151 to 256 for the red loam soils (Fig.5b) and 91 to 245 for the laterite soils (Fig.5c). The medium black soils displayed small variations in BTD for the marked increase or decrease of soil wetness compared to the remaining types of soils. It is obvious from the Figure.5 that the least BTD values are registered in the year 2000 which means good moisture status that might be favourable for crops. From Figure.5, it is clear that the red loam soils experienced soil wetness of less than 50% in several days compared to medium black and laterite soils and might be an indication of timely irrigation requirement for these soils to expect good results in agriculture. The correlation for the soil wetness and brightness temperature for the respective soil types are presented in Table.3. The quadratic fit is approximated taking BTD as independent variable as presented in Table.4.

Table 3. Correlation coefficients for brightness temperature and soil wetness for different soil types of Andhra Pradesh

Soil type	Correlation (r)			
	1999	2000	2001	1999 - 2001
Medium black soils	-0.225	-0.240	-0.273	-0.35
Redloam soils	-0.334	-0.545	-0.363	-0.45
Laterite soils	+ 0.171	-0.187	0.024	-0.03

Table 4. The regression equations for brightness temperature and soil wetness for different soil types of Andhra Pradesh.

Soil type	Regression		
	1999	2000	2001
Medium black soils	S_{WT} =-0.067 $(BTD)^2$+31.2(BTD)-3588.6 BTD = -0.005 $(S_{WT})^2$+0.32(S_{WT})+233.2	S_{WT} =0.012 $(BTD)^2$-5.87(BTD)+807.2 BTD = 0.002 $(S_{WT})^2$-0.3(S_{WT})+248.1	S_{WT} =-0.034 $(BTD)^2$+15.7(BTD)-1780 BTD= -0.007$(S_{WT})^2$+0.74(S_{WT})+219.4
Red loam soils	S_{WT} =-0.009 $(BTD)^2$+3.45(BTD)-313.3 BTD= 0.025$(S_{WT})^2$-1.67(S_{WT})+227.2	S_{WT} =0.0024 $(BTD)^2$-1.4(BTD)+234.3 BTD= 0.017 $(S_{WT})^2$-2.6(S_{WT})+280.1	S_{WT} =0.018$(BTD)^2$-8.74(BTD)+1077.1 BTD = -0.013$(S_{WT})^2$+0.06(S_{WT})+239.8
Laterite soils	S_{WT}= -0.0034 $(BTD)^2$+1.5098(BTD)-121.12 BTD = 0.015 $(S_{WT})^2$-1.22(S_{WT})+205.6	S_{WT} =-0.0007 $(BTD)^2$+0.0853(BTD)+53.6 BTD = 0.044$(S_{WT})^2$-0.76(S_{WT})+157.3	S_{WT} =0.015 $(BTD)^2$-4.38(BTD)+342.7 BTD = 0.005 $(S_{WT})^2$-0.39(S_{WT})+140.2

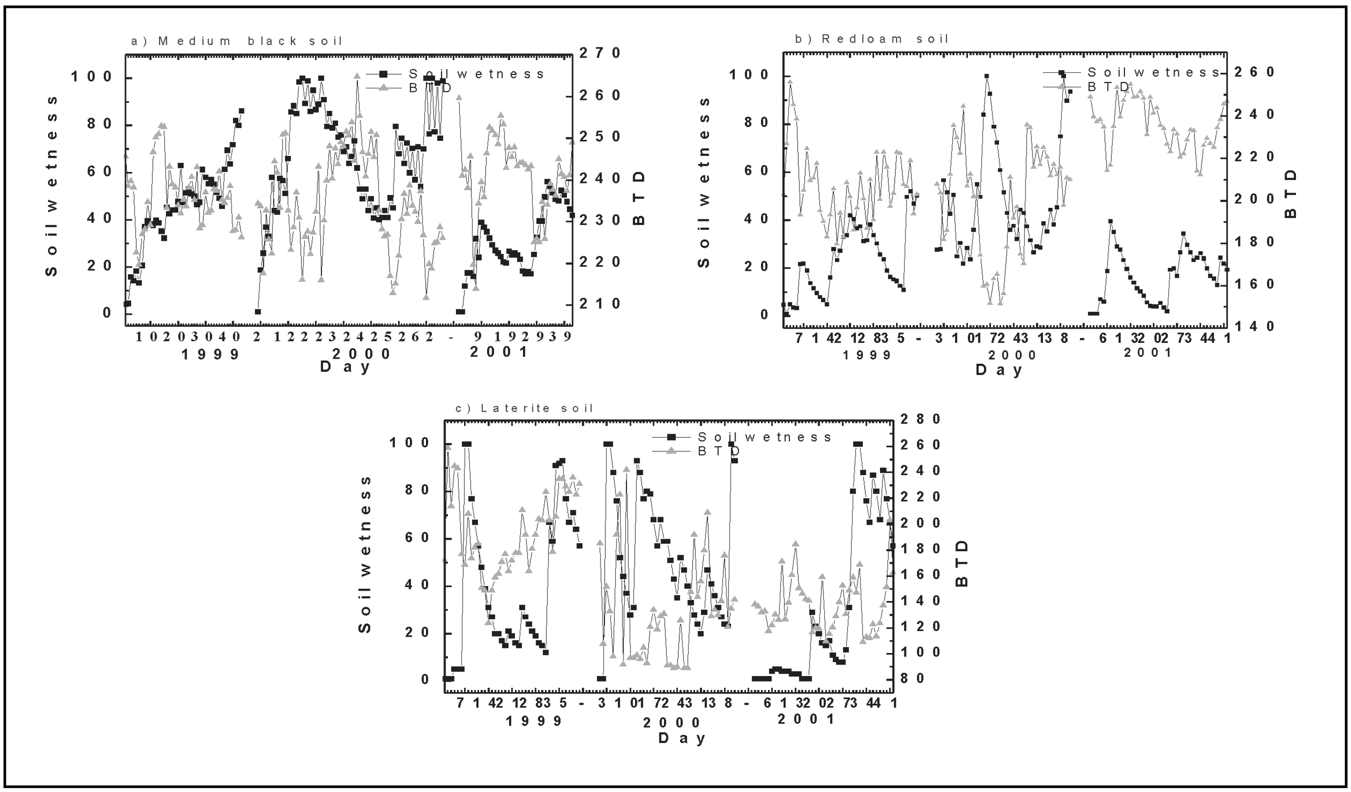

Figure 5. March of soil wetness and brightness temperature for different types of soils - Andhra Pradesh.

Medium Black Soils

The soil wetness in the case of medium black soils (Fig.6) varied from 24.7 at Anantapur to 63.6 for Hyderabad with the corresponding variations in BTD from 242.8 to 233.4. As the medium black soils are deep soils with depth ranging from 75 to 120cm and also contain high clay content and cation exchange capacity, the soil has the capacity to accumulate and preserve wetness during the wet spells and this might be the responsible in retaining the soil moisture of Ramagundam and Hyderabad at 62.4% and 63.6% respectively. Also, it is to worth mentioning that the field capacity of Ramagundam and Hyderabad are 150mm. The brightness temperature for Ramagundam and Hyderabad are 236.6 and 233.4 and the inverse relation of wetness with BTD is reflected in its correlation, i.e the correlation coefficients for Ramagundam and Hyderabad are -0.12 and -0.18. The soil structure of Kurnool and Anantapur comes under the saline and alkali type with pH varies from 8.5 to 10 and the exchangeable sodium percentage will be

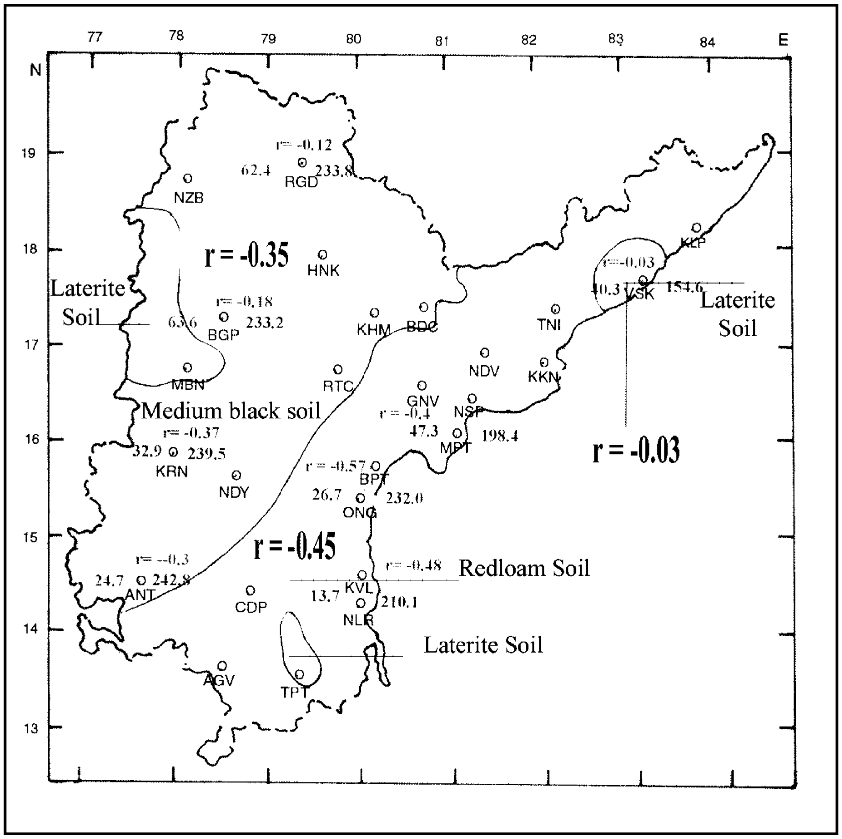

Figure 6. Correlation coefficients for different types of soils of Andhra Pradesh

greater than 15. The clay and organic matter are dispersed on account of high sodium content which results in poor values of soil wetness and consequently, the brightness temperature values are more at these stations and the correlation is -0.3 and -0.37 for Anantapur and Kurnool respectively. The overall correlation coefficient of soil wetness and brightness temperature for the medium black soils in the study period is -0.35.

Red Loam Soils

The soil wetness of red loam soils (Fig.6) varied from 13.7 to 47.3 for the corresponding variations of brightness temperature from 232 to 198.4. The correlation for red loam soils is yielded for a much better inverse relationship and the overall correlation coefficient was -0.45 and was more than that of medium black soils. The red loam soils are characterized with less capability for storing water compared to medium black soils. This is proved here that no single station experienced more than 60% of soil wetness. Right from Nellore, the soil wetness increased gradually from 13.7 to 47.3 for Machilipatnam since the soils are not highly clay natured compared to medium black soils. According to Horvath, Post & Kelsey (1984), the coarse texture soils have lesser reflectance than the textured soils. The soil of Nellore is coarse textured which might be responsible for low soil wetness rates and low BTDs. Ongole experienced a soil wetness of 26.7 with a strong inverse correlation of -0.57 with 232 as brightness temperature. The correlation for soil wetness and BTD in the case of Nellore was -0.48 and -0.4 at Machilipatnam. The correlations indicate the strong inverse relation between soil wetness and BTD. Machilipatnam, being the coastal station, recorded a soil wetness of 47.3% for a low brightness temperature of 198.4.

Laterite Soils

The laterite soil of Visakhapatnam (Fig.6) accumulated a soil wetness of 40.3% for a brightness temperature of 154.6. The inverse relation between soil wetness and BTD is very poor in this case (r = -0.03). As Visakhapatnam is a coastal station, there will not be much response to brightness temperature with the soil wetness and for time to time variations. In fact, the laterite soils are very sandy in nature, and the reflectance of the soil is very low which causes to low brightness temperatures.

From the study, it is clear that the cutoff brightness temperature for the medium black soils is above 233, where as it was less than 233 for red loam soils and was 154.6 for laterite soils which was much below than red loam soils.

CONCLUSIONS

The variations in rainfall as well as in soil wetness of Andhra Pradesh in relation to the variability in indices of SOI and SST are presented. From the correlation study, it can be reported that the influence of NINO 3 sea surface temperature is more compared to SOI on the rainfall and soil wetness. The present study helps in understanding the soil wetness variability over Andhra Pradesh based on soil category. The study suggests the importance of irrigation especially for red loam soils for better yields. This study is useful in estimating the soil wetness variability in relation to brightness temperature derived from the satellite.

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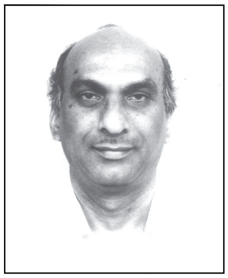

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