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An Assessment of Water Budget of Ibadan, Nigeria

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ABSTRACT

The influence of climatic conditions of precipitation and evapotranspiration exercise great control on soil water budget. This is fundamental to crop production and hydrological processes. This study assessed the temporal variability of soil moisture condition of Ibadan, Nigeria using the water budget approach. Specifically the study analyzed the climatic variables of monthly rainfall and means monthly air temperature, computed the mean monthly evapotranspiration values, plots the water budget graph, and discussed the implications of the observed seasonal trend in water budget condition on agricultural activities and hydrological processes. Monthly rainfall and mean monthly air temperature data used were collected from the archives of the Nigeria meteorological agency for the period 2008-2020. Monthly potential evapotranspiration data used in the study was estimated from the mean monthly air temperature data. The monthly rainfall data and the monthly evapotranspiration data were used to plot the water budget graph. Results revealed temporal variability in soil moisture condition. Water deficit condition was observed between November and April while water surplus condition was observed between May and October. The highest water surplus condition was observed in September (111.9mm) while the highest deficit condition (-125.64mm) was observed in December. The month of October recorded the lowest water surplus condition (41.30mm) while the month of April recorded the lowest water deficit condition (-10.10mm). The implications of the observed seasonal variation in soil moisture status on agricultural activities and hydrological processes were discussed.

1. Introduction

A water budget is an accounting of hydrologic components of the water cycle, transfer within the components, and their relative contributions within a water system (Stanton et al., 2011). It is an accounting of the rates of water movement into and out of, and the change in water storage in all or parts of the atmosphere, land surface and subsurface (Healy, 2010). An understanding of water budget and underlying hydrologic processes provides foundations for effective water resource and environmental planning and management (Healy et al., 2007).

Water budget analysis helps in explaining the variability in condition of soil moisture from place to place and over time at a given location. Ayoade (2003) regards it as a tool that is useful in explaining the condition of soil moisture which is very important in both agricultural activities and hydrological processes. While temporal variations in soil moisture are almost always due to the varying amount of precipitation input viz-a-viz evapotranspiration losses from the soil (Albertson and Montaldo, 2003) spatial variations in soil can be ascribed to soil moisture type, slope, topography, vegetation and variations in climatic conditions, especially factors of precipitation and evapotranspiration (Weng, et al., 2018).

Analysis of water budget as being currently carried out in this study when combined with the understanding of hydrological processes will aid in providing a good foundation for effective watershed management in any drainage basin. It's analysis will not only provide the means for evaluating the availability and sustainability of water supply, especially in regions of rain-fed agriculture, but will also help in curtailing incidents of extreme hydro-meteorological event of flood. According to Ravazzini and Tjernell (2020) knowledge of water budget can be used by water agencies in:

i. water supply planning;
ii. preparation of feasibility studies;
iii. facilitation of integrated water resource management
iv. estimation and quantification of water resources, and
v. forecasting optimum water management actions

Despite the importance of soil moisture in watershed management; its measurement is hardly being carried out. Reasons for this may not be unconnected with the time consuming procedure required for its measurements i.e. gravimetric technique and its huge cost i.e. Neutron probe method (Rasti, et. al. 2020). Thus, the water budget approach which is being examined in this study provides a relatively rapid and cheaper method for estimating soil moisture (Ayoade, 2003). Specifically, this study

I. analyzed the climatic variables of rainfall and temperature for the study period
II. computed the mean monthly evapotranspiration values using the collected mean monthly temperature data,
III. plotted the water budget graph for the study area using (i) and (ii) above and;
IV. discussed the implications of the observed seasonal trend in soil moisture status on agricultural activities and hydrological processes.

2. Materials and Methods

Ibadan, the capital city of Oyo State Nigeria (Fig. 1) is the study area in this investigation. The city was chosen for investigation in this study because of the high reliance of a majority of the residents on rain-fed agriculture and the fact that flooding is a common occurrence in the area. The city is located between longitudes $3^{0}55^{1}$ and $4^{0}10^{1}$ East of the Greenwich Meridian and between latitudes $7^{0}05^{1}$ and $7^{0}42^{1}$ North of the equator.

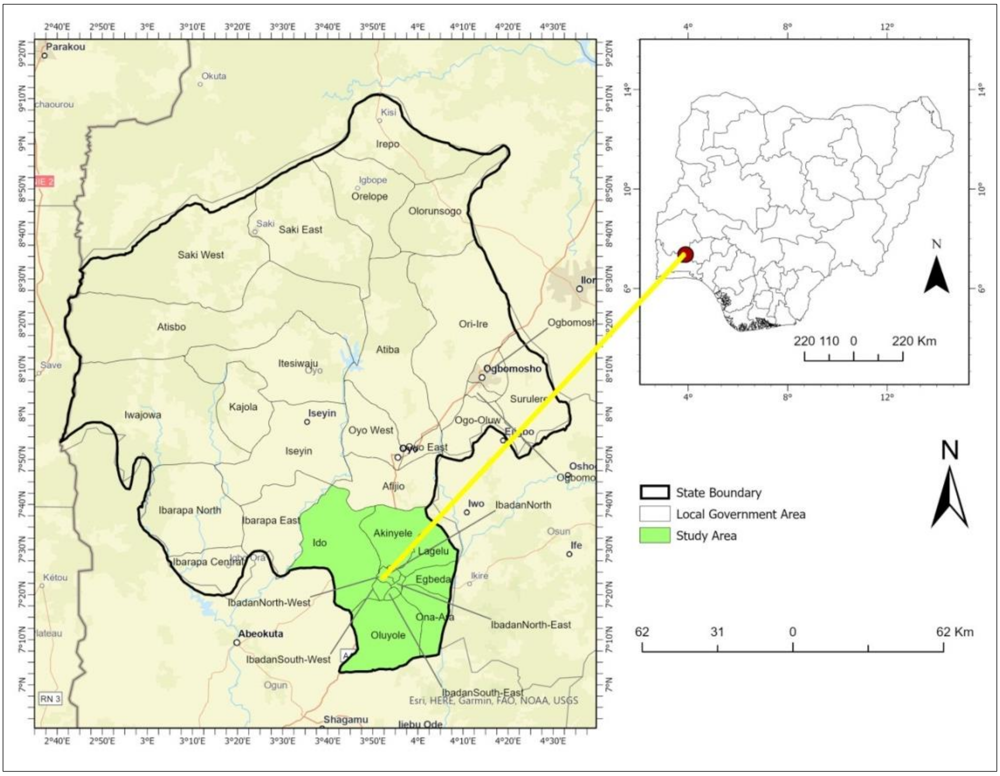

Figure 1. Map of Oyo State, Nigeria Showing Ibadan (Map Inventory of Oyo State Ministry of Land and Housing, 2021)

Ibadan with a landmass of about 400 sq km is located in the tropical rain forest zone of Nigeria (Egbinola, and Amobichukwu, 2013).

The wet season in the city begins in early March when the Tropical Maritime Airmass is prevalent and ends around November. The dry season in the city begins with the onset of Tropical Continental Airmass, which is predominant between the months of November and February. The mean annual total rainfall for Ibadan is 1,306 mmm (Ajayi et al., 2012). Rainfall concentration in the city is usually between the months of March and October, exhibiting double maxima rainfall pattern with peak periods in the months of June and September and a period of dry spell in August. Average daily temperature for the city range between $23^{0}C$ and $29^{0}C$ (Egbinola and Amobichukwu, 2013).

Ibadan is underlain by basement complex rocks which are mainly metamorphic rocks of Precambrian age with granite, quartzite, biotite and migmatite as the major rock types. The soils in the city are deeply weathered and predominantly loamy. These soils are heavily leached by the heavy rainfall in the region. Vegetation types within and around Ibadan comprises of trees, shrubs and grasses, most of which are evergreen. Examples of tree species in the region include *Mangifera India, Musa Paradisicum* and *Azadhirachta Indica* while *Pennistrum Purpureum, Heteropogon Canorous* and *Axonopus Fissifolius* are some of the examples of grass species that can be found in the region. Ibadan is drained by a network of rivers, many of which exhibit a dendritic drainage pattern. Among such rivers include Rivers Ona, Ogbere, Ogunpa and Kudeti.

Floods are a common occurrence in the city and have been officially recorded since 1951 (Agboola, et al., 2012). The fact that rain-fed agriculture is highly practiced within and around the settlement, this assessment of water budget will be of immense benefit to the farmers as it will assist in planning farm operations for optimum yields.

Data used in this study consists of monthly rainfall, mean monthly air temperature and monthly evapotranspiration records obtained for a period of 13 years (2008-2020). While the monthly rainfall and mean monthly air temperature data were obtained from data inventory Nigerian Meteorological Agency Office in Ibadan, the mean monthly evapotranspiration data was computed from temperature the mean monthly air temperature records obtained from data inventory of the above named meteorological agency using the modified Thorntwaite (1948) formula. The original Thornthwaite (1948) formula for computing potential evapotranspiration is of the form:

$$PE = 1.6 \left(\frac{IOT}{1}\right)^m$$

Where,
PE = Potential Evapotranspiration
T = Mean Monthly Year Temperature in ^oF
I = Annual Heat Index; and
m = Cubic function of I empirically determined and equal to
$(0.675\ I^3 - 77\ I^2 + 17920\ I + 492{,}390) \times 10^{-6}$

The above presented Thornthwaite (1948) formula has however been criticized by Pelton et al (1960) for being too temperature based. The formula according to Ayoade (1972) assumes that no evapotranspiration occurs when the mean air temperature is less than 0^0C. Garnier (1968) found the formula defective in computing potential evapotranspiration when the mean monthly temperature is greater than 14^0C while Olaniran (1981) reported that potential evapotranspiration values computed from the formula yields higher values in the rainy season when compared with the dry season. The modified Thornthwaite (1948) formula as explained by Mands (1993) was thus adopted in computing potential evapotranspiration in this study. The formula is of the form:

$$PE = \left(\frac{16\ 10tm}{J}\right)a \quad (mm/month)$$

Where,
PE = Potential Evapotranspiration
tm = Mean Monthly Temperature in ^0C
a = Constant = 0.018J + 0.5
j = Monthly Radiation Index = 0.09tm (1.5) and
J = Annual Radiation Index = Sum of Monthly j

The monthly potential evapotranspiration values computed from the above given formula was subsequently used alongside the monthly rainfall data to plot the water budget graph for the study period in Ibadan, the study area.

Deficit soil moisture situation is said to occur in the study area when the monthly evapotranspiration values exceed the monthly rainfall values on the graph while surplus soil moisture condition is said to occur when the monthly precipitation values exceed the monthly potential evapotranspiration values.

3. Results and Discussion

3.1 Variability of Rainfall in Ibadan, the Study Area

The variation in monthly rainfall values for the study period is as presented on Table 1.

Table 1. Monthly Rainfall Data of Ibadan from 2008-2020 (MM) (Rainfall Data Inventory, Nigerian Meteorological Agency 2021)

Month	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	SUM	MEAN	STD	CV%
2008	27.60	30.00	112.30	47.00	289.78	263.50	250.10	407.00	209.60	191.30	77.30	0.00	1905.5	158.80	128.60	81.00
2009	1.50	138.10	80.40	203.70	129.90	217.40	205.60	0.00	328.50	205.50	31.60	0.00	1542.2	128.50	107.20	83.40
2010	0.80	18.00	64.40	88.80	195.00	76.90	109.50	320.30	311.30	214.70	0.00	0.00	1399.7	116.60	114.00	97.8
2011	0.00	61.30	66.20	64.10	151.12	285.40	298.80	511.10	238.20	213.30	19.40	0.00	1908.9	159.00	155.50	97.80
2012	0.00	0.00	36.20	125.10	215.90	215.00	218.20	93.30	218.20	141.30	54.90	0.00	1318.1	109.80	91.41	83.20
2013	30.10	0.00	95.70	126.10	80.60	116.00	220.70	232.40	127.00	215.90	0.00	0.00	1244..	103.70	86.50	83.40
2014	0.00	8.40	121.60	142.20	231.20	114.90	257.10	53.20	285.60	72.30	2.10	1.10	1289.7	107.50	103.95	96.70
2015	0.00	6.90	57.00	122.80	184.30	323.80	171.70	247.20	114.50	207.40	79.70	0.00	1515.3	126.30	103.97	82.30
2016	25.20	81.60	3.60	184.10	191.30	147.80	156.20	40.90	128.50	132.10	51.70	0.00	1143	95.30	69.72	73.20
2017	78.70	32.50	92.00	231.90	183.90	181.20	161.20	156.20	196.30	0.30	0.00	0.00	1314.4	109.50	85.88	74.40
2018	0.00	33.10	101.90	118.20	114..7	212.60	182.90	64.00	225.70	134.90	4.00	12.20	1204.2	100.40	79.67	79.40
2019	19.10	1.50	109.10	79.00	197.30	164.50	65.20	128.10	312.50	166.00	17.80	0.00	1260.1	105.00	94.56	90.00
2020	0.00	0.50	36.20	39.50	303.80	173.70	138.30	98.10	231.70	254.00	6.50	8.30	1209.6	107.60	100.20	93.3
SUM	183.00	411.90	976.00	1572.5	2468.7	2492.7	2435.5	2351.8	3017.6	2149.0	345.00	21.60				
MEAN	14.10	31.68	75.12	120.90	189.90	191.70	187.40	180.90	232.10	165.30	26.54	1.66				
STD	22.89	40.76	35.14	59.00	63.36	71.26	63.85	154.60	65.66	69.35	29.74	3.91				
CV%	161.70	128.70	46.78	48.80	33.30	37.10	34.00	85.50	28.30	42.00	111.90	235.20				

Table 2. Mean Monthly Temperature Data of Ibadan from 2008-2020 (°C) (Temperature Data Inventory, Nigerian Meteorological Agency 2021)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Sum	Mean	STD	CV%
2000	28.05	28.35	30.00	28.45	27.85	26.45	25.10	24.50	25.65	26.50	28.30	27.85	327.05	27.25	1.71	5.90
2001	27.95	29.30	29.50	27.90	27.50	26.30	25.45	24.20	25.25	27.45	28.65	28.50	327.35	27.25	2.47	5.95
2002	27.55	26.75	29.75	28.20	27.55	26.25	25.60	24.85	21.90	26.25	28.25	27.95	324.70	27.10	2.68	9.85
2003	28.70	29.85	29.70	27.80	27.25	26.55	25.05	25.25	25.80	27.40	28.35	27.75	329.45	27.45	1.71	6.05
2004	28.15	29.85	28.55	27.80	30.75	25.75	24.65	25.65	26.70	27.35	28.45	32.15	335.83	28.00	2.76	10.00
2005	27.50	29.05	29.35	28.50	27.75	26.00	25.30	24.70	26.00	26.80	28.55	32.05	333.55	30.30	2.55	9.40
2006	27.45	28.40	29.10	28.15	26.70	25.70	24.40	24.00	25.70	25.80	26.70	25.35	317.45	26.50	1.94	7.05
2007	26.80	28.40	29.25	27.20	26.40	25.65	24.65	24.35	25.25	25.75	26.75	26.70	317.30	26.45	1.53	5.35
2008	27.65	28.00	28.05	27.35	26.40	25.10	24.55	23.95	25.35	25.15	26.55	25.65	499.50	26.23	1.67	6.20
2009	26.95	28.70	28.60	27.75	26.85	25.50	24.50	23.80	24.80	25.55	26.55	27.25	316.80	26.38	1.66	5.85
2010	26.95	28.75	28.85	27.55	27.85	25.65	24.15	23.80	26.60	25.15	26.20	26.25	313.65	26.10	1.78	6.20
2011	28.90	28.55	28.50	27.30	30.75	25.80	24.35	25.65	26.60	27.35	28.40	27.95	327.70	27.50	1.91	6.25
2012	28.30	29.25	29.60	28.55	27.55	26.00	25.30	24.85	25.65	26.80	28.55	28.55	328.50	27.30	1.65	5.65
SUM	362.90	373.20	378.80	360.08	361.15	336.70	323.05	319.55	331.25	343.12	360.25	363.95				
MEAN	27.70	28.7	29.10	27.9	27.70	25.9	24.80	24.60	25.60	26.40	27.70	27.60				
STD	1.02	2.63	0.98	0.95	1.61	0.64	0.58	0.82	0.64	0.79	1.00	1.78				
CV	3.18	5.67	3.40	3.45	5.50	2.55	2.35	3.20	2.35	3.15	3.80	7.60				

Monthly rainfall range between 1.1mm recorded in December 2014 and 328.5mm recorded in September 2009. The month of December received the lowest rainfall value (1.66mm) for the study period while the month of September had the highest rainfall value of 232.1mm which represents more than 16% of the total mean monthly rainfall value for the study period. The month of September exhibits the least (28.3%) variability in rainfall value for the study period while the month of December exhibits the highest (235.2%) variability.

The study revealed that the annual average total rainfall received between the year 2008 and 2020 is higher by almost 13% than the annual average rainfall of 1306mm earlier reported for the city by Ajayi, et al., (2012). This increment may not be unconnected with the incidence of climate change in the study area. Studies such as Sylla, et al., (2013) and Vizy, et al., (2012) have reported and projected increase in rainfall amounts and frequencies in different parts of Africa. According to the Secretary General of the World Meteorological Organization:

"Climate change is having a growing impact on the African continent, hitting the most vulnerable hardest, contributing to food insecurity, population displacement and stress on water resources. In recent months, we have seen devastating floods, an invasion of desert locusts and how face the looming specture of drought because of a La Nina event. (Taalas, 2020:1)

In the thirteen-year study period in this investigation, year 2011 received the highest rainfall amount (1908.9mm) while year 2016 received the least (1204.20mm).

3.2 Variability in Temperature in the Study Area

The mean monthly temperature in the study area range between 24.60mm in August and 29.10mm in March (Table 2).

The month of December exhibits the highest variability (7.60) in mean monthly temperature. This is understandable; it is the period when the Tropical Continental Airmass is prevalent in the study area. The wind which is dry usually brings harmattan to the study area. The month of September exhibits the lowest variability in mean temperature values in the study area.

3.3 Variations in Mean Monthly Potential Evapotranspiration in Ibadan

The mean monthly potential evapotranspiration values for the study area computed from the modified Thorntwaite (1948) formula is as presented on Table 3.

Table 3. Mean Monthly Evapotranspiration Data of Ibadan from 2008-2020 (MM)

Month	Mean monthly rain	Mean monthly temperature	Mean monthly radiation	Annual radiation index	Constant value	P.E
January	14.1	27.7	3.7395	43.6	1.28	130.1
February	37.68	28.1	3.7935	43.6	1.28	131.9
March	75.12	29.1	3.9285	43.6	1.28	136.7
April	120.9	27.9	3.7665	43.6	1.28	131.0
May	189.9	27.7	3.7395	43.6	1.28	130.1
June	191.7	25.9	3.4965	43.6	1.28	121.7
July	187.4	24.8	3.348	43.6	1.28	116.5
August	180.9	24.6	3.321	43.6	1.28	115.6
September	232.1	25.6	3.456	43.6	1.28	120.2

October	165.3	26.4	3.564	43.6	1.28	124.0
November	26.54	27.7	3.7395	43.6	1.28	130.1
December	1.66	27.1	3.6585	43.6	1.28	127.3
Mean	118.6	29.1				126.2
STD	82.91	1.410				6.921
CV%	70	4.8				5.5

(Source: Author's computation 2021)

Potential evapotranspiration values ranged between 115.6mm observed in August and 136.7mm observed in March. Potential Evapotranspiration values were generally high (above the mean) in the months of January, February, March, April, May, November and December. This period mainly falls within the dry season when the Tropical Continental Airmass is prevalent in the study area. This airmass which is usually dry and dusty, carries no moisture, hence the high potential evapotranspiration values during the period.

3.4 Water Balance Situation in Ibadan

The water budget graph of the Ibadan, study area (Fig. 2) was plotted from monthly rainfall values and the computed monthly potential evapotranspiration values to show the seasonal trend in water budget situation for the study period.

Table 3 further revealed that monthly potential evapotranspiration were higher than monthly rainfall values in the months of November, December, January, February, March and April while the monthly rainfall value were higher than the monthly potential evapotranspiration values in the months of May, June, July, August, September and October.

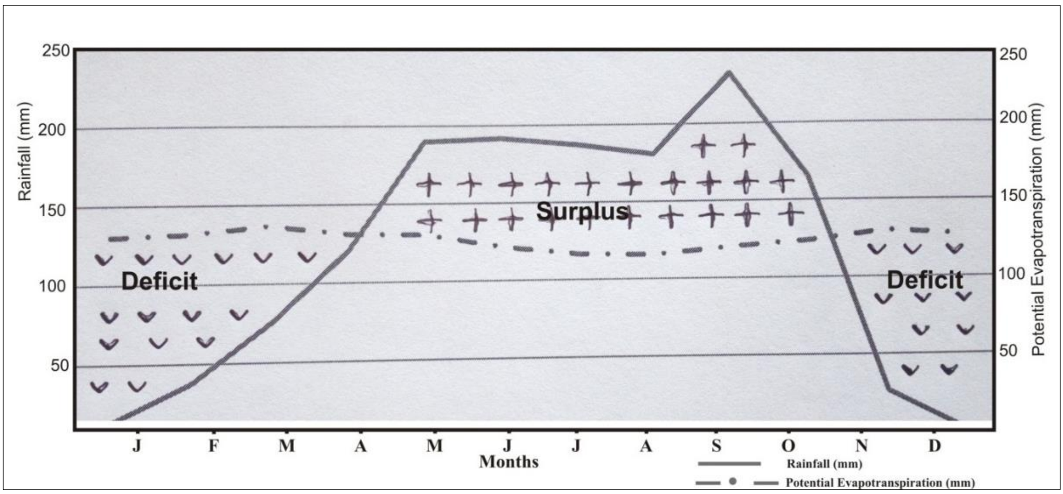

Figure 2. Water Budget Graph of Ibadan (Source: Author's Finding 2021)

The water budget graph reveals that soils in the study area have water deficit condition in the months of November, December, January, February, March and April. These are dry months in the study area when rainfall scarcely occurs. Water surplus condition was however observed in soils in the study area between May and October. The month of August, however, recorded a drop in water surplus condition because of the short dry spell in rainfall that was experienced during this period. This observed trend in seasonal variation of soil moisture status has great implications on flood and drought management in the study area.

Hydrologically, soil water surplus condition is a strong factor in flood generation (Horton, 1933, Olaniran, 1983; Ogunkoya, et al 1984; Iroye, 2009, Penna et al 2011; Ali et al 2015, Clifflard et al 2018). This according to Ward (1978) is by determining the potential area of stream flow generation. The larger the zone of soil at or near saturation, the quicker the stream's response to rainfall. While Olaniran (1983) linked the three flood events which took place in Ilorin in 1973, 1976 and 1979 to high water surplus condition, Dunne (1978) reported that the formation of summer floods requires higher rainfall intensities than autumn floods. This thus indicates, that runoff generation in summer occurred from only a limited part of the catchment, while substantial catchment area contributes to runoff processes in autumn due to water surplus condition in the soil.

In the same vein, soil deficit moisture condition induced crop failure, especially in regions of rain-fed agriculture. This is because, plant depends on soil moisture for growth and photosynthesis and also for the transfer of nutrients from one part of the soil to another (Ayoade, 2003; Jackson, 1977). Not only that, since soil nutrients can only be absorbed by plant in solution, lack of moisture in soil will deprive plants therein of moisture and nutrients needed for growth and development. Investigations such as this will not only help policy makers in taking decisions on how to reduce the risk of crop failure induced by water shortage in soil, but will also help in reducing the vulnerability of famers to climate change.

The water surplus condition depicted by the water balance graph between the months of May and June will first be utilized in recharging the high water deficit situation induced by the prolonged dry season which occurs between the months of November and March. The drop in water surplus condition in August can however be easily overcome by the very high September surplus which Olaniran (1983) earlier recognized as one of the causes of frequent flood in the study area.

Based on the findings from this analysis, residents of Ibadan, the study area in this investigation, will need to take adequate care to avoid flooding especially between the months of September and October. Effort by government and all agencies responsible should be directed during this period in educating the residents of the city on the need to clear their drainages and stop dumping of solid wastes into flowing water. In the same vein, farmers within this area should be prepared to embark on irrigation activities especially between the months of November and April in order to prevent crop failure.

4. Conclusion and Recommendations

This research revealed temporal variability in monthly water budget condition of soils in the study area. Water deficit condition was observed between the months of November and April while water surplus condition was observed between the months of May and October. Assessment of soil moisture condition in any geographical area is of fundamental importance. Apart from being agriculturally desirable as a way of meeting food production, especially for people; its assessment is also environmentally significant, particularly in the area of watershed management. Thus, if the moisture storage at different locations and different period of the year is known, the environmental hazards of drought and flooding could be better managed.

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