Assessment of Soil Moisture Storage In Nigeria Using Climatic Water Budgeting Approach

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Abstract

The estimation of soil moisture storage is fundamental to crop production, hydrological and biological processes. This study assessed soil moisture storage in Nigeria using the Climatic Water Budgeting Approach. Mean monthly air temperature and monthly rainfall data were collected from the archives of the Nigerian Meteorological Agency from 27 weather stations in Nigeria. The data were subjected to Climatic Water Budgeting Approach to compute the monthly soil moisture storage at different locations in Nigeria over two years with contrasting moisture conditions (1983 and 2003). The mean monthly air temperature data were used to estimate the monthly potential evapotranspiration (PE) while the PE in conjunction with the mean monthly rainfall and the soil water holding capacity of 250mm were used to calculate the monthly soil moisture storage. The results showed that most locations north of latitude 9°N recorded low soil moisture storage below 10 mm from April to July especially in 1983. The soil moisture storage was high in all the places in January and February due to low potential evapotranspiration and accumulated potential water loss (APWL). Most Places South of latitude 9°N recorded higher soil moisture storage between 20 mm and 100 mm from January to May compared to their counterparts north of latitude 9°N in both 1983 and 2003. The soil moisture storage attained 250 mm (100%) from July-October across Nigeria. This study concluded that the soil moisture varies spatially and temporally in Nigeria decreasing from South to North. A paired sample test revealed a significant difference between the soil moisture storage of 2003 and 1983 in Nigeria (p=.000).

Key words: Accumulated potential water loss, Potential evapotranspiration, Water holding capacity, Soil moisture storage

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Introduction

Soil moisture storage is difficult to define because it means different thing to different disciplines. For example, a farmer's concept of soil moisture is different from that of a weather forecaster or water resource manager (James 1999). In a general term, soil moisture storage refers to the amount of water that is stored in the soil of any particular place at any particular time based on the environmental condition of that particular place and the soil water holding capacity. The major source of moisture in the soil is from the precipitation. Apart from the input from precipitation, the amount of potential evapotranspiration and the soil's ability to hold water plays a significant role in determining the amount of water that will be retained in the soil at any particular time. The moisture storage in the soil at a given time is very crucial for agriculture, especially in places where they so much depend on rainfall for the cultivation of their crops.

The International Water Management Institute (IWMI, 2011) asserts that rain-fed agriculture accounts for 95% of the total farmed land in Africa. Due to rainfall variability, dry spells and climate change, over reliance on rainfall for cultivation of crops has been a major challenge to farmers over the years. Several studies have demonstrated the effect of soil moisture stress on different crops grown in Nigeria and found out that soil moisture stress result indecline in crop growth and yield (Odunze, Kudi, Daudu, Adeosun, Ayoola, Amapu, Abu, Mand, Ezul, & Contance, 2010; Fasinmirin & Olufayo, 2009; Fasinmirin & Oguntuase, 2008; Shiwachi, Komoda &Takashi, 2008; Aina, Dixon, & Akinrinde, 2007). From the foregoing, the estimation of soil moisture storage at different locations and different time will be of immense benefit to the farmers in order to design properly the best time to cultivate their crops for optimum yield. The assessment of soil moisture storage will serve as a very important tool in unfolding the need for irrigation scheme in different parts of Nigeria to augment crop production throughout the year. It will also assist on the quantity of water needed by crop at a particular time. If the farmers have the knowledge about the quantity of water in the soil at different period of the year, they will know whether the water in the soil is sustainable for their crop growth or not. Isoteim (2014) examined the mathematical relationship between the soil moisture and ground water level on a loamy soil in the Niger Delta region of Nigeria. The method made it possible for the people of the region to use the level of water in their shallow wells to determine the moisture status of the soil by measuring the level of water in the wells. Therefore, the method of Isoteim (2014) has become a veritable tool in irrigation scheduling.

Soil moisture has a greater influence on the microclimate of any place at a particular time (Jose, Cristiam, Maria, Patricia, and Renan, 2015; Kirien and Sonia, 2015; Syed, Stephane, & Sylvie, 2013;; Ahmad and Hashim, 2007 and Andrew, Thomas and Mark, 2002; Oke, 1987). Soil moisture has an effect on the thermal properties of a soil profile as well as conductance and the heat capacity (Varallyay, 2010). Soil moisture and soil thermal properties have a significant influence on seed germination, flowering and fauna activities (Ceri and John, 1991; Maraghni and Neffati, 2010). More water in the soil leads to soil temperature gain or lose (Oke, 1987). The soil moisture in the soil determines the partitioning of the incoming solar radiation into sensible and latent heat (Copernicus, 2013). If there is adequate water in the soil for the incoming radiation to act upon, this will induce convective activities. On the contrary, if there is moisture deficit in the soil, the incoming solar radiation will transform into a sensible heat and make the environment to be very hot thereby bringing physiological discomfort. The recent Climate model by Timbal, Power, Colman, Viviand, and Lirola, (2002) suggested a strong nexus between the soil moisture and the persistence variability of surface temperature and precipitation. They further posited that soil moisture is a significant factor for the accuracy of “inter-annular” predictions regarding the Australian Climate. Soil moisture storage is a veritable tool in controlling the exchange of heat energy between the land surface and the atmosphere through evapotranspiration. In view of this, soil moisture plays an important role in the development of weather pattern and the formation of precipitation (James, 1999)

Nigeria is one of the African countries that rely heavily on rainfall for the cultivation of crops. As such, the knowledge of soil moisture storage will be of tremendous help for efficient crop production. Just like rainfall, irrigation water yields the best result when an optimum quantity of water is applied to a crop. The study of soil moisture storage will not only assist rain-fed agriculture, rather it will serve as a useful guide in the rational scheduling of the application of irrigation water to ensure optimum crop growth (Isoteim, 2014 and Fabura, 2005). The information on soil moisture storage will be useful across varieties of disciplines such as ecology, hydrology, soil science, agronomy and meteorology (Lunt, Hubbard, and Rubin, 2004). If the soil moisture storage at different locations and different period of the year is known, it will serve to define and identify places that suffer from water deficit, a situation that can seriously affect crop production. This will also enables us to determine the soil moisture seasons (Ritter, 2012). Soil moisture storage is very useful information for the determination of the onset and cessation of growing season (Chukwudi, Emma, Ifeanyi and Nwabueze, 2017;Ufoegbune, 2016; Ngetich and Mugendi, 2014; Umar, 2010, Rita, 2007; Ati, Stigter, and Oladepo, 2001; Ati, 1996). When there is adequate moisture in the soil for crop growth, the growing season commences. On the other hand, when there is soil moisture deficiency for crop growth, the growing ceases.

There is a growing interest in improving the indigenous techniques to assist farmers to adapt to challenges of inadequate water for their crop production. Aboyade, (1990) suggested that efforts be geared towards bridging the gap between the indigenous and the global techniques as a way to facilitate the transfer, acceptance and adoption of modern knowledge system. In the past, fallowing has been described as the best way to improve soil physical, chemical and biological attributes (Hausb and Asawalam, 1998). The long fallow (more than 5 years) is becoming obsolete due to the population pressure on the available land leading to a short fallow (2 to 3 years). With time, this fallow system may go into extinction. As such, scientific research like the soil moisture storage will assist to identify places that are characterized by soil moisture deficit as well as those places that have soil moisture surplus. This information will therefore serve a useful guide in adopting the best technology to boost crop production and water resources management. See Fabura (2005) and Kumar (1995).

The spatial and temporal pattern of water balance indices such as rainfall, potential evapotranspiration, actual evapotranspiration, water deficit, water surplus and runoff have been studied in Nigeria and their monthly and annual values have been mapped out (Ayoade, 1995 and kehinde, 2017. This study aims at bridging the existing gap in literature by assessing the spatio-temporal pattern of soil moisture storage in Nigeria using the Thornthwaite's method of estimating Potential Evapotranspiration (PE) and Climatic Water budgeting Approach.

Methods

Study Area

Location

Nigeria is located approximately between latitude 4˚N and 14˚N of the equator and longitude 3˚E and 15˚E of the Greenwich meridian. It is bounded in the North by Niger Republic, in the South by Atlantic Ocean and the Gulf of Guinea, in the West by Benin Republic, in the East by Cameroun Republic and in the Northeast by Chad Republic. The total landmass of Nigeria is approximately 923, 768km^2 (Iwena, 2000). Nigeria currently comprises thirty-six states and the Federal Capital Territory Abuja. It has 774 Local government areas. See Figure 1 for the location map of Nigeria and the distribution of the weather stations used in this study.

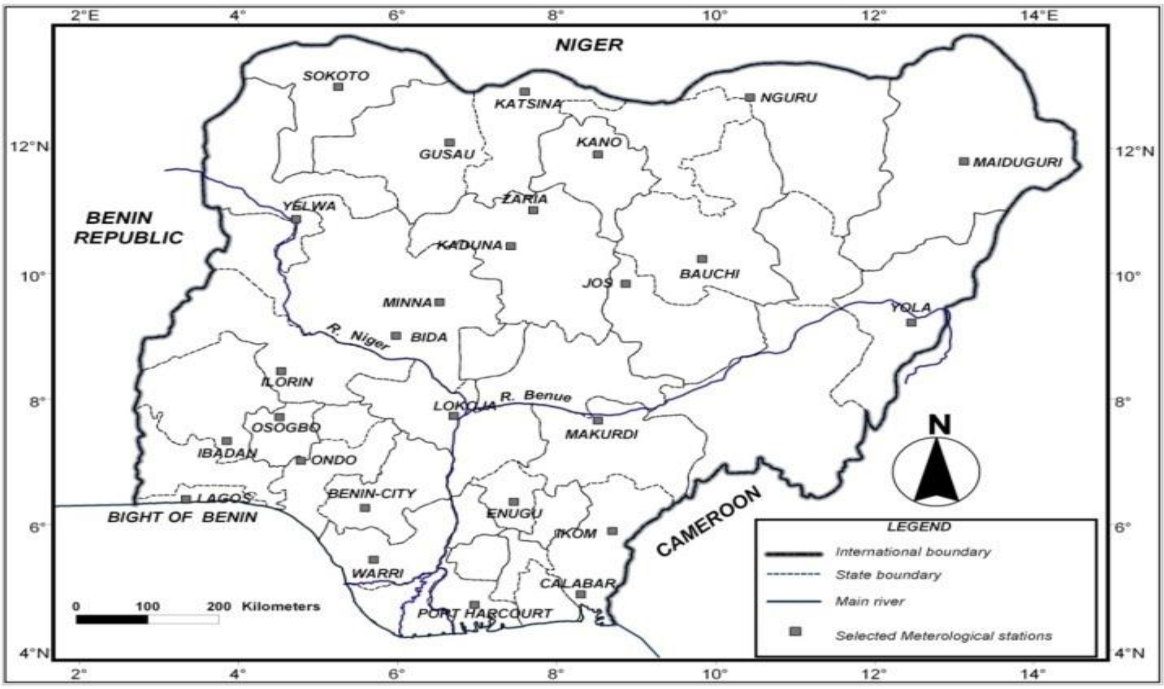


Figure 1. Distribution of Selected Synoptic Meteorological Stations in Nigeria
Source: Adapted from Umar (2013)

Thornthwaite Monthly Water Balance Model

This study followed the Thornthwaite water balance model (Thornthwaite, 1948) which used an accounting procedure to analyze the allocation of water among various components of the hydrologic system. Computation of monthly water balance components of hydrologic cycle were made for a specified location. The inputs into the model are monthly temperature and precipitation. Outputs include monthly potential evapotranspiration and actual evapotranspiration, soil moisture storage, surplus and runoff. The Figure 2shows the component and connectivity of the Thornthwaite water model. The boxes represent the components; the arrows show the data-folw between components

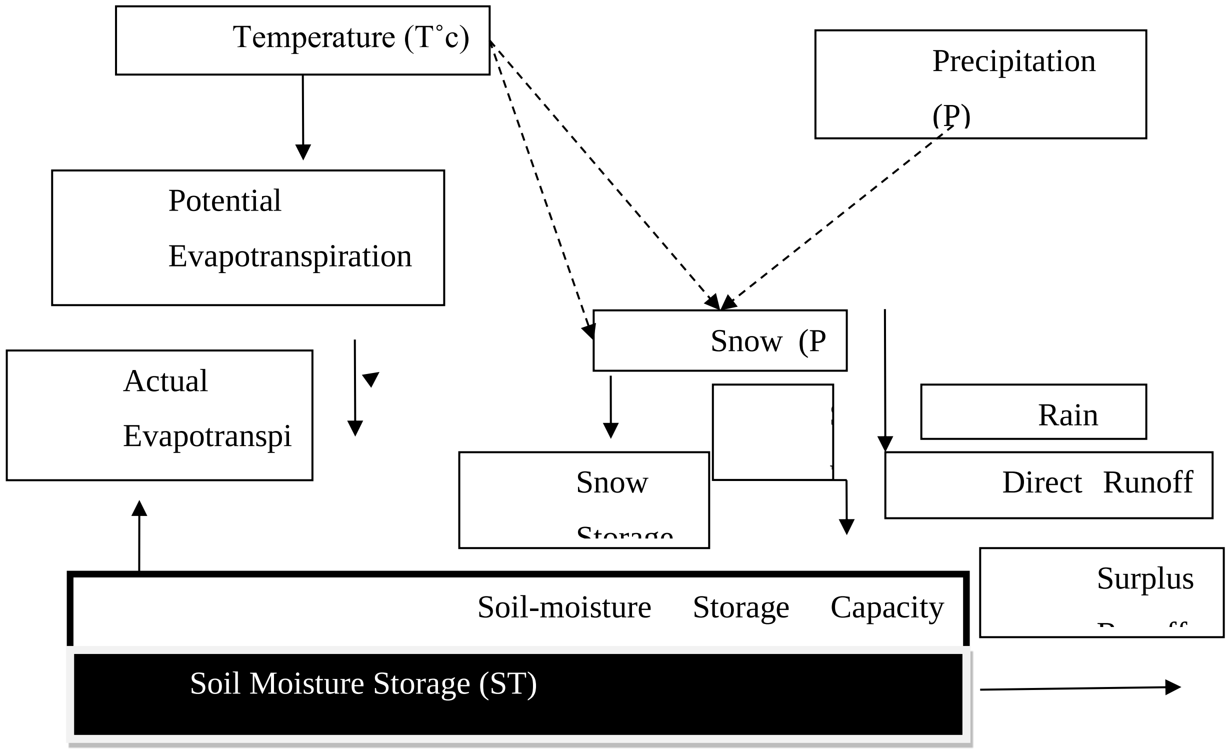


Figure 2: Water Balance Model Schematic

Source: (Thornthwaite Monthly Water Balance Model 2020)

The input data into the model are the monthly air temperature, monthly precipitation (rainfall) and soil water holding capacity. The outputs in the model are potential evapotranspiration (PE or PET), actual soil moisture storage (ST), evapotranspiration (AE), water deficit, water surplus and Runoff.

Types and source of data

This study used the mean monthly air temperature; the mean monthly rainfall data and the soil water holding capacity of 250mm contained in the Thornthwaite's monograph to determine the monthly soil moisture storage. The air temperature and rainfall data were collected from the archives of the Nigerian Meteorological Agency (NIMET) based on twenty-seven weather stations in Nigeria (Figure 1). Two years with contrasting surface moisture condition were selected for this study. The selection of dry year (1983 and wet year (2003) were selected consequence upon the study of dry and wet years by Umar (2013) This is to see whether there is any significant different between the soil moisture storage of the year 1983 and 2003 in Nigeria.

Method of Data Analysis and Presentation

The computation of soil moisture storage for different locations in Nigeria was done via the Thornthwaite's water balance model, which deals with computation of a water balance sheet. The balance sheet requires inputs of monthly estimated PE values and monthly precipitation to arrive at the monthly soil moisture storage. The water balance sheet begins with the estimation of monthly PE thus:

Calculation of Potential Evapotranspiration

The air temperature data collected from the archives of the Nigerian Meteorological Agency was subjected to the Thornthwaite, (1948) approach to calculate the monthly potential evapotranspiration. Thornthwaite (1948) developed empirical equation for estimating potential evapotranspiration and this is given as:

$$ET_0 = 16 \times ({}^{10i}/_{I})^{a} ({}^{N}/_{12}) ({}^{1}/_{30}) \qquad \text{(i)}$$

$$I = \sum_{I=1}^{12} (Ti/5)\ 1.514 \qquad \text{(ii)}$$

Where,

Ti = the mean monthly temperature in (°C).

N = the monthly Sunshine hours.

I = the heat index.

The equation has been packaged into a monograph for easy estimation of PE. Therefore, the estimation of PE was done with the aid of Thornthwaite's monograph. The monograph contained the values of air temperature in degree Celsius with their corresponding values of monthly heat index, values of unadjusted daily potential evapotranspiration (mm) for different mean temperature (°C) and annual heat index (I) values. Thornthwaite's monograph also contained mean possible monthly duration of sunlight in the northern hemisphere and southern hemisphere respectively.

After estimating the monthly PE for each location across Nigeria, the values in conjunction with the monthly rainfall were subjected to the water balance sheet to determine the soil moisture storage.The water balance sheet was computed for each location and it involves the following the steps:

Step 1: P-PE: This is the difference between the monthly precipitation and the monthly potential evapotranspiration.**P** is the monthly precipitation in a year while **PE** is the monthly estimated potential evapotranspiration.

Step 2: APWL: This is the accumulated potential water loss. This only arises when PE>P.* If PE>P, then APWL is a cumulative value of (P-PE). * If PE<P, then no APWL.

Step 3: Thisinvolvesdetermining the exactmonthly soil moisture storage **(ST)**with the aid of Thornthwaite's monograph of water holding capacity of 250mm**.** This is obtained in the monograph but only in months where the APWL occurs. Other months without APWL, ST = preceding ST + P-PE.

This estimation of soil moisture storage was done for each of the twenty-seven (27) weather stations selected across Nigeria for the study and the presentation of results was made using tables, spatial maps and charts for better understanding. A paired t test was used to test whether there is any significant difference between the soil moisture storage of 2003 and 1983 in Nigeria.

Result

Spatial variation of soil moisture storage in Nigeria

It is very important to note that the monthly potential evapotranspiration (PE), monthly rainfall and monthly-accumulated potential water loss (APWL) are perquisite for determining the monthly values of soil moisture storage (ST). Therefore, the results of each of these parameters are presented in different tables for better understanding the study. Table 1ashowed the computed monthly values of PEfor the different locationsacross Nigeria for 1983. The table revealed that the potential evapotranspiration values are higher during from the months of April to October where many of the locations recorded monthly PE values between 150mm and 192mm. When the PE is high, the APWL will also be high. It further implies the higher the APWL, the higher lower the soil moisture storage. On the contrary, the monthly values of PE were low between December and January where most of the locations north of latitude 10˚N recorded PE as low as between 25mm and 100mm in January.

Table 1a Monthly Potential evapotranspiration for 1983 in Nigeria

Station	Lat.	Jan.	Feb.	Mar.	Apr	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Katsina	13.01	37	181	182	192	191	190	179	172	180	187	182	173
Sokoto	13.01	192	192	192	169	159	168	184	181	165	185	185	159
Nguru	12.53	24	175	169	192	188	190	182	174	181	185	176	153
Gusau	12.1	66	190	190	189	192	188	179	169	179	189	191	184
Kano	12.03	28	157	162	190	191	178	164	156	167	177	167	143
Zaria	11.6	54	182	183	192	190	172	157	152	159	179	179	171
Maiduguri	11.51	30	170	173	192	191	185	173	171	180	188	179	164
Bauchi	10.7	43	170	171	190	185	159	147	144	158	171	173	160
Yelwa	10.53	190	183	173	192	191	182	174	165	175	191	192	191
Kaduna	10.36	117	163	182	180	157	152	117	143	127	157	166	119
Jos	9.52	51	141	142	160	106	83	74	67	97	125	132	115
Minna	9.37	173	192	192	192	188	167	156	150	158	182	188	187
Yola	9.14	90	188	190	191	190	170	155	157	162	175	181	180
Bida	9.06	176	192	192	192	189	173	165	158	165	183	189	187
Ilorin	8.29	120	174	179	176	165	145	110	103	140	160	170	156
Lokoja	7.47	153	185	188	186	178	157	153	148	156	172	179	174
Oshogbo	7.47	181	190	191	187	173	153	147	107	155	172	179	172
Makurdi	7.44	176	192	192	192	183	165	157	160	164	178	186	187
Ibadan	7.26	176	190	181	173	159	142	11	95	123	155	88	162
Ondo	7.06	182	188	191	183	169	145	140	93	144	164	173	169
Enugu	6.28	152	180	184	183	166	151	144	119	147	159	171	168
Lag os	6.27	156	171	176	174	163	142	126	112	141	157	163	157
Benin	6.19	183	189	189	182	177	152	150	103	146	169	173	176
Ikom	5.58	171	190	192	187	177	163	154	146	160	171	177	177
Warri	5.31	157	172	176	175	163	147	120	114	122	155	161	156
Calabar	4.58	175	186	188	178	164	147	140	102	143	151	165	167
Port/H	4.51	157	177	181	167	159	146	122	113	124	146	157	156

Source: Author's Computation (2017)

The result in Table 1b contained the monthly rainfall recorded at different locations in Nigeria for the year 1983. The table revealed that most of the places north of latitude 10˚Nrecorded little or no rainfall from January to May and October to December compared to other locations south of latitude 10˚N. Significant rainfall between 50mm and 250mm were recorded in only four months (June to September) in locations north of latitude 10˚N while most of the places south of latitude 9˚N recorded significant rainfall between 50mm and 300mm at least 8 months (March to October). The amount of rainfall and PE at different locations contribute immensely to the amount of ST.

The Accumulated Potential Water Loss (APWL) for 1983 in Table 1c is a strong prerequisite for the determinant of the monthly values of soil moisture storage every monthly PE. The result in the Table 1c showed that the monthly APWL are higher in most places north of latitude 10˚N in virtually all the months compared to their counterparts in the south of latitude 10˚N. This implies that places north of latitude 10˚N with higher APWL will experience low soil moisture storage compared to those locations south of latitude 10˚N.The higher the APWLthe lower the Soil moisture storage (ST) will be. This assertion is in line with the finding of Kehinde,Umar and Bulama(2019),which examined the relationship between APWL and soil moisture storage in semi-Arid Region of Nigeria and found that there is a significant negative relationship between the soil moisture storage and the APWL in all the place in Nigeria.

Tables 2a showed that the computed monthly PE for 2003 varies across different locations in Nigeria. It could be seen from the table that the monthly PE is higher across different locations in 2003 compared to that of 1983. The monthly PE values are higher (between 150mm and 192mm) in many places north of latitude 9˚N especially from March to August compared otter months. In contrast, the monthly PE values ranges from 140mm to 190mm in many locations south of latitude 9˚N from March to October. This implies that rate of amount of PE is increases from south to north in Nigeria.

The result in Table 2b contained the monthly amount of rainfall for 2003 across different locations in Nigeria. It could be observed from the table that the monthly rainfall varies 4mm and 500m between April and September. The table also revealed that amount of rainfall decreases from the south towards the north.

The APWLas a prerequisite for determining the monthly values of the soil moisture storage for the year 2003 is depicted in Table 2c. The result shows that the monthly APWL is high from January to June across different locations north of latitude 9˚N compared to locations south of 9˚N. The high-accumulated potential water loss in many places across Nigeria is an indication of low soil moisture storage.

Table 1b Monthly Rainfall for 1983 in Nigeria Values (mm)

Station	Lat.	Jan	Feb	Mar.	Apr	May	June	Jul	Aug.	Sep.	Oct.	Nov	Dec.
Katsina	13.01	0	0	0.1	0	0.4	90	109	101	101	0	0	0
Sokoto	13.01	0	0	0	0	45	154	229	128	62	0	0	0
Nguru	12.53	0	0	2	0	0	56	42	89	38	0	0	0
Gusau	12.1	0	0	7	0	57	107	229	287	161	0	0	0
Kano	12.03	0	0	0	0	34	40	92	231	67	0	0	0
Zaria	11.6	0	0	0	0	63	129	133	287	71	0.4	0	0
Maiduguri	11.51	0	0	8	0	2	40	71	100	36	0	0	0
Bauchi	10.7	0	0	13	0	95	124	227	184	136	0	0	0
Yelwa	10.53	0	0	0	11	124	59	129	137	103	0	0	0
Kaduna	10.36	0	0	18	0	135	180	113	204	235	0	0	0
Jos	9.52	0	0	21	0	150	250	327	359	69	0	0	0
Minna	9.37	0	0	0	12	97	97	159	300	229	34	0	0
Yola	9.14	0	0	0	0	99	107	223	209	89	11	0	0
Bida	9.06	0	0	0	8	54	121	149	170	244	2	0	0
Ilorin	8.29	0	9	15	92	169	146	92	216	228	34	2	149
Lokoja	7.47	0	0	48	62	100	193	120	191	125	15	0	0
Oshogbo	7.47	0	37	23	81	252	178	84	62	220	74	26	52
Makurdi	7.44	0	0	1.2	3	193	214	232	158	128	0.8	0	0
Ibadan	7.26	0	17	0	85	241	200	47	46	93	70	17	42
Ondo	7.06	0	18	35	0	155	283	129	45	312	80	47	22
Enugu	6.28	0	0	4	42	152	101	251	100	241	24	3	0
Lagos	6.27	0	0	48	58	221	326	51	19	77	37	33	23
Benin	6.19	0	49	39	77	267	278	167	127	425	148	30	23
Ikom	5.58	0	189	27	157	279	293	318	360	361	61	62	3
Warri	5.31	0	49	6	128	352	407	351	103	671	177	88	191
Calabar	4.58	0	14	16	138	290	504	291	342	293	229	114	67
Port/H	4.51	0	0	33	114	141	184	311	155	324	305	20	46

Source: Author's Computation (2017)

Table 1c Monthly Accumulated Potential Water Loss (APWL) (mm) in Nigeria for 1983

Station	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov.	Dec
Minna	9.37	-360	-525	-744	-924	-1015	-1155	0	0	0	-148	-336	-523
Zaria	11.6	-225	-407	-590	-782	-909	-952	-976	0	-88	-267	-446	1617
Yelwa	10.53	-381	-564	-737	-918	-976	-1099	-1144	-1172	-1244	-1435	-1627	-1818
Kano	12.03	-171	-328	-490	-680	-837	-975	-1047	0	-100	-277	-444	-587
Maid	11.51	-194	-364	-529	-721	-910	-1055	-1157	-1228	-1372	-1560	-1739	-1903
Kadu	10.36	-236	-399	-563	-743	-765	0	-4	0	0	-157	-323	-442
Yola	9.14	-270	-458	-648	-839	-930	-993	0	0	-73	-237	-418	-598
Bauch	10.7	-203	-373	-531	721	-811	-846	0	0	-22	-193	-366	-526
Nguru	12.53	-177	-352	-519	-711	-899	-1033	-1173	-1288	-1401	1586	-1762	-1915
Katsin	13.01	-210	-391	-573	-765	-956	-1048	-1118	1189	-1268	-1455	-1637	-1810
Jos	9.52	-166	-307	-428	-588	0	0	0	0	-28	-153	-285	-400
Enugu	6.28	1320	-500	-680	-821	-835	-885	0	-19	0	-135	-303	-471
Benin	6.19	-336	-476	-626	-731	0	0	0	0	0	-21	-164	-317
Lokoja	7.47	-32	-512	-652	-776	-854	0	-33	0	-31	-188	-367	-541
Makurdi	7.44	-363	-555	-746	-935	0	0	0	-2	-38	-215	-401	-588
Ondo	7.6	-329	-499	-655	-838	-852	0	-11	-55	0	-84	-210	-357
Oshogbo	7.47	-301	-454	-622	-728	0	0	-63	-108	0	-98	-251	-371
Warri	5.31	-122	-245	-415	-462	0	0	0	-11	0	0	-73	0
Pot/H	4.51	-267	-444	-592	-645	-663	0	0	0	0	0	-137	-247
Soot	13.01	-351	-543	-735	-904	-1018	1032	0	-53	-156	-341	-526	-685
Ilorin	8.25	-127	-292	-456	-540	0	0	-18	0	0	-126	-294	-301
Bida	9.06	-363	-555	-747	931	-932	-984	-1000	0	0	-181	-370	-557
Iba	7.27	-296	-469	-650	-738	0	0	-64	113	-143	-228	-299	-419
Lagos	6.27	-290	-461	-589	-705	0	0	-75	-168	-232	-352	-482	-616
Calab	4.58	-275	-447	-609	-649	0	0	0	0	0	0	-51	-151
Ikom	5.58	-345	-346	-510	-540	0	0	0	0	0	-110	-225	-399
Gusa	12.1	-250	-440	-623	-812	-947	-1028	0	0	-18	-207	-398	-582

Source: Author's Computation (2017)

Table 2a. Monthly Potential Evapotranspiration (mm) for 2003 in Nigeria

Station	Lat	Jan.	Feb.	Mar.	Apr	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Katsina	13.01	171	188	189	191	192	186	173	164	170	189	186	163
Sokoto	13.01	161	183	186	192	192	181	167	151	165	185	185	159
Nguru	12.53	148	172	182	192	192	180	171	163	176	188	181	142
Gusau	12.1	183	192	192	192	192	159	180	170	180	190	191	184
Kano	12.03	111	166	175	189	190	167	153	146	159	178	172	105
Zaria	11.6	171	187	188	190	189	166	157	145	159	176	178	162
Maiduguri	11.51	156	177	185	192	192	181	171	153	170	191	182	151
Bauchi	10.7	153	189	190	187	188	164	159	153	170	175	149	169
Yelwa	10.53	167	192	190	192	186	180	167	155	171	181	173	90
Kaduna	10.36	157	178	181	176	175	147	124	114	120	160	168	148
Jos	9.52	122	147	157	125	117	80	71	69	84	117	129	110
Minna	9.37	189	192	192	191	189	164	162	158	160	173	188	187
Yola	9.14	175	189	191	192	191	183	159	155	157	170	181	169
Bida	9.06	190	192	192	192	189	169	171	167	163	181	189	189
Ilorin	8.29	168	178	181	171	169	147	121	118	143	157	167	167
Lokoja	7.47	174	185	187	181	180	156	153	169	165	179	185	187
Oshogbo	7.47	184	187	189	176	177	160	149	149	156	168	177	186
Makurdi	7.44	190	192	192	190	190	171	168	163	163	177	186	188
Ibadan	7.26	164	173	178	165	165	146	121	119	143	158	155	162
Ondo	7.06	178	187	187	172	172	158	82	141	149	171	174	182
Enugu	6.28	174	181	182	174	169	149	151	151	147	162	170	167
Lagos	6.27	162	172	174	168	170	146	146	146	149	160	163	169
Benin	6.19	181	187	183	176	173	155	150	145	141	167	177	178
Ikom	5.58	181	189	190	179	175	161	157	149	157	170	173	173
Warri	5.31	165	172	176	166	160	150	177	123	147	158	165	162
Calabar	4.58	179	182	180	172	168	160	155	144	153	157	165	172
Port/ H	4.51	179	186	181	173	164	152	149	147	150	160	166	175

Source: Author's Computation (2017)

Table 2b. Monthly Rainfall (mm) for 2003 in Nigeria.

Station	Lat.	Jan.	Feb.	Mar.	Apr	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Katsina	13.01	0	0	0	4	13	46	115	276	76	16	0	0
Soot	13.01	0	0	0	9	18	71	288	300	108	7	0	0
Nguru	12.53	0	0	0	0	2	2	97	188	41	0	0	0
Gusau	12.1	0	1	1	12	151	176	271	437	199	18	0	0
Kano	12.03	0	0	0	10	67	247	338	458	233	13	0	0
Zaria	11.6	0	0	0	56	93	72	254	407	238	63	0	0
Maiduguri	11.51	0	0	0	4	13	89	203	232	79	15	0	0
Bauchi	10.7	0	0	0	31	26	309	134	263	173	31	0	0
Yelwa	10.53	0	0	24	18	199	98	126	397	173	45	0	0
Kaduna	10.36	0	0	28	76	84	152	399	426	397	71	0	0
Jos	9.52	0	0	0	200	156	184	161	283	258	36	2	0
Minna	9.37	0	6	0	17	98	213	117	192	187	192	2	0
Yola	9.14	0	0	0	7	73	113	175	236	262	61	0	0
Bida	9.06	0	0	0	9	146	154	147	179	144	81	31	0
Ilorin	8.29	0	0	25	82	96	371	84	81	400	0	18	0
Lokoja	7.47	0	0	0	0	93	181	271	53	164	147	15	0
Oshogbo	7.47	21	0	15	176	99	146	105	93	287	266	85	0
Makurdi	7.44	0	0	0	56	31	200	119	133	136	40	34	0
Ibadan	7.26	25	82	4	184	91	315	228	58	215	206	52	0
Ondo	7.06	16	13	54	289	81	192	61	81	557	184	123	0
Enugu	6.28	1	3	8	187	306	222	285	137	296	269	22	33
Lagos	6.27	174	53	79	308	156	321	70	19	185	141	185	0
Benin	6.19	0	14	109	233	189	331	124	263	173	237	160	0
Ikom	5.58	8	0	65	151	144	304	363	224	315	410	50	7
Warri	5.31	54	6	153	239	90	234	351	199	436	365	115	10
Calabar	4.58	27	103	197	283	318	202	282	381	309	186	149	3
Port/H	4.51	17	86	93	169	166	242	433	200	535	204	99	4

Source: Author's Computation (2017)

Table 2c. Monthly Accumulated Potential Water Loss in Nigeria for 2003

Station	Lat	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minna	9.37	-376	-562	-754	-928	-1019	0	-45	0	0	0	-186	-373
Zaria	11.6	-333	-520	-708	-842	-938	-1032	0	0	0	-113	-291	-453
Yelwa	10.53	-257	-449	-615	-789	0	-82	-123	0	0	-136	-309	-399
Kano	12.03	-216	-382	-557	-736	-859	0	0	0	0	-165	-337	-442
Maidu,	11.51	-307	-484	-669	-857	-1036	-1128	0	0	-91	-287	-469	-620
Kad	10.36	-305	-483	-636	-736	-827	0	0	0	0	-89	-257	-405
Yola	9.14	-344	-533	-724	-909	-1027	-1097	0	0	0	-109	-290	-350
Bauc	10.7	-322	-511	-701	-857	-1019	0	-25	0	0	-144	-293	-462
Nguru	12.53	-290	-462	-644	-836	-1026	-1204	-1278	0	-135	-323	-504	-646
Kats	13.01	-334	-522	-711	-898	-1077	-1217	-1275	0	-94	-267	-453	-616
Jos	9.52	-232	-379	-536	0	0	0	0	0	0	-81	-208	-318
Enu	6.28	-307	-485	-659	0	0	0	0	-14	0	0	-148	-282
Benin	6.19	-198	-371	-445	0	0	0	-26	0	0	0	-17	-195
Lok	7.47	-361	-546	-733	-914	-100	0	0	-116	-117	-149	-319	-506
Mak	7.44	-378	-570	-762	-896	-1055	0	-49	-79	-106	-243	-395	-583
Ondo	7.6	-344	-518	-651	0	-91	0	-21	-81	0	0	-51	-233
Osho	7.47	-349	-536	-710	0	-78	-92	-136	-190	0	0	-92	-278
Warri	5.31	-263	-429	-452	0	-70	0	0	0	0	0	-50	-202
Port/H	4.51	-333	-433	-521	-525	0	0	0	0	0	0	-67	-238
Sokoto	13.01	-320	-503	-689	-872	-1046	-1156	0	0	-57	-235	-420	-579
Ilorin	8.25	-335	-513	-669	-758	-831	0	-37	-74	0	-157	-309	-473
Bida	9.06	-379	-571	-763	-946	-989	-1004	-1028	0	-19	-119	-277	-466
Ibadan	7.27	-301	-392	-566	0	-74	0	0	-61	0	0	-103	-265
Lagos	6.27	-157	-276	-371	0	-14	0	-76	-203	0	-19	0	-169
Calabar	4.58	-321	-400	0	0	0	0	0	0	0	0	-16	-185
Ikom	5.58	-339	-528	-653	-681	-712	0	0	0	0	0	-123	-289
Gusau	12.1	-367	-558	-749	-929	-970	0	0	0	0	-172	-363	-547

Source: Author's Computation (2017)

The monthly spatial patterns of soil moisture storage in Nigeria for 1983 and 2003 are contained in Figure 3. The result revealed that there was variation in the soil moisture storage across different places in Nigeria in the years. It could be inferred from Figure 3 that most of the places North of latitude 9°N recorded significantly low moisture storage below 10mm in most of the months in 1983. Among the places that experienced low soil moisture storage below 10mm in most of the months in 1983 included Nguru, Katsina, Kano, Maiduguri whereas Yelwa. Ngru recorded the lowest monthly soil moisture storage of between 0 and 5mm in most of the months. It recorded high soil moisture storage of 122mm, 60mm and 31mm in January, February and March respectively in 1983. This high record of soil moisture storage between January and March was not because of rainfall rather, because of low potential evapotranspiration and low accumulated potential water loss (APWL). It meant less water was being taking away from the soil into the atmosphere during those months. As a result of that, more water was reserved in the soil compared to other months when the amount of PE was higher to take out more water from the soil (see Tables 1a and 1b). It could be observed that stations like Jos and Kaduna recorded higher soil moisture storage of between 200mm and 250mm (90%-100% saturation) from the months of July to September.

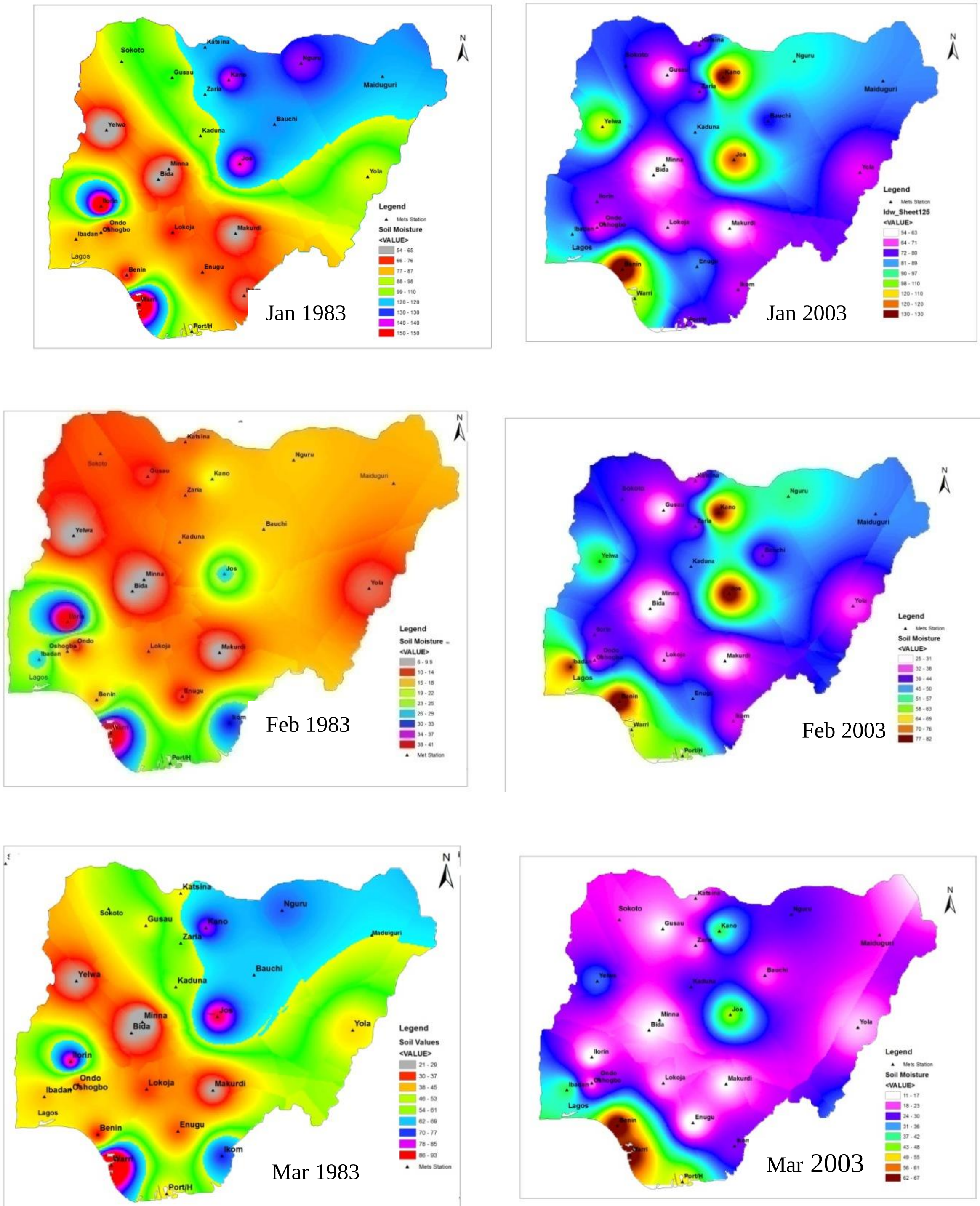


Figure 3. Spatial Pattern of monthly values of Soil Moisture Storage in Nigeria for the dry year (1983) and wet year (2003)

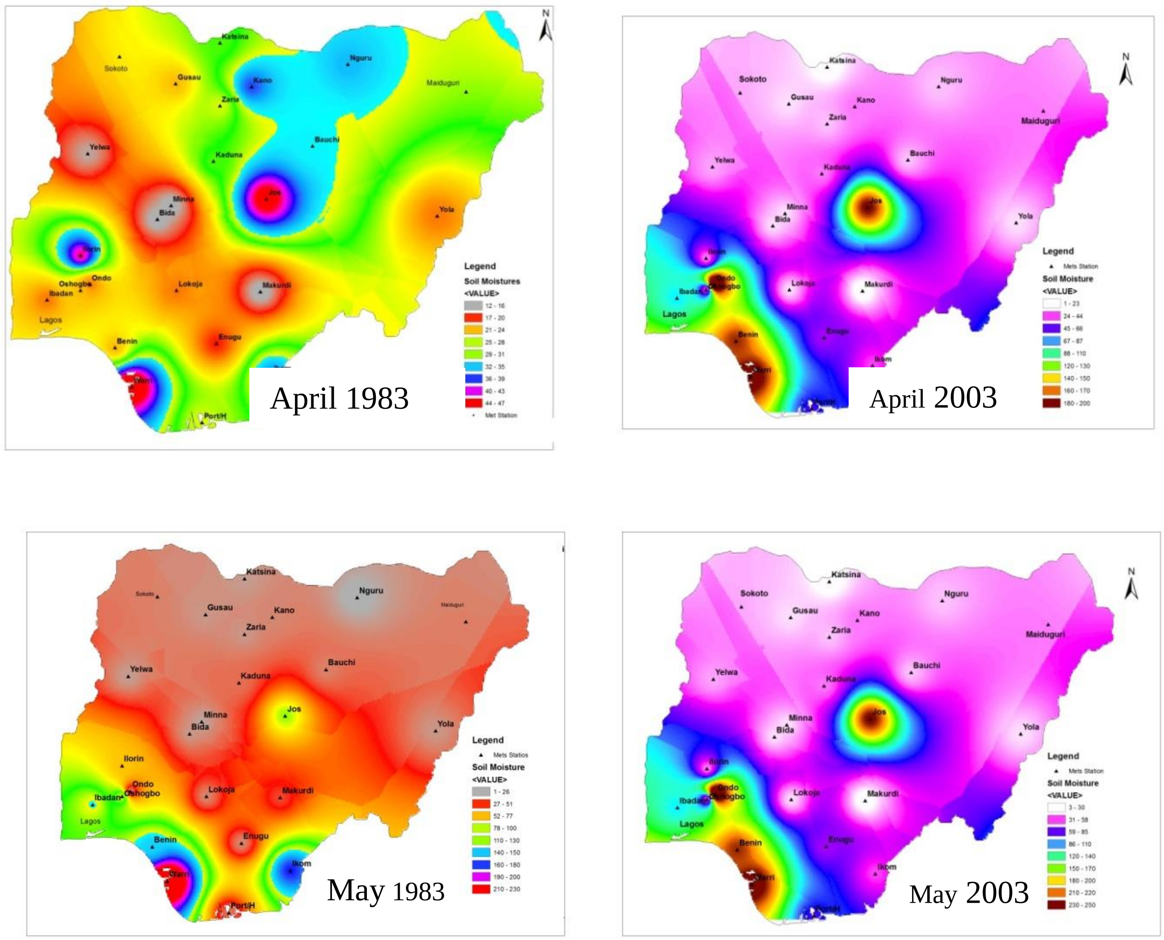
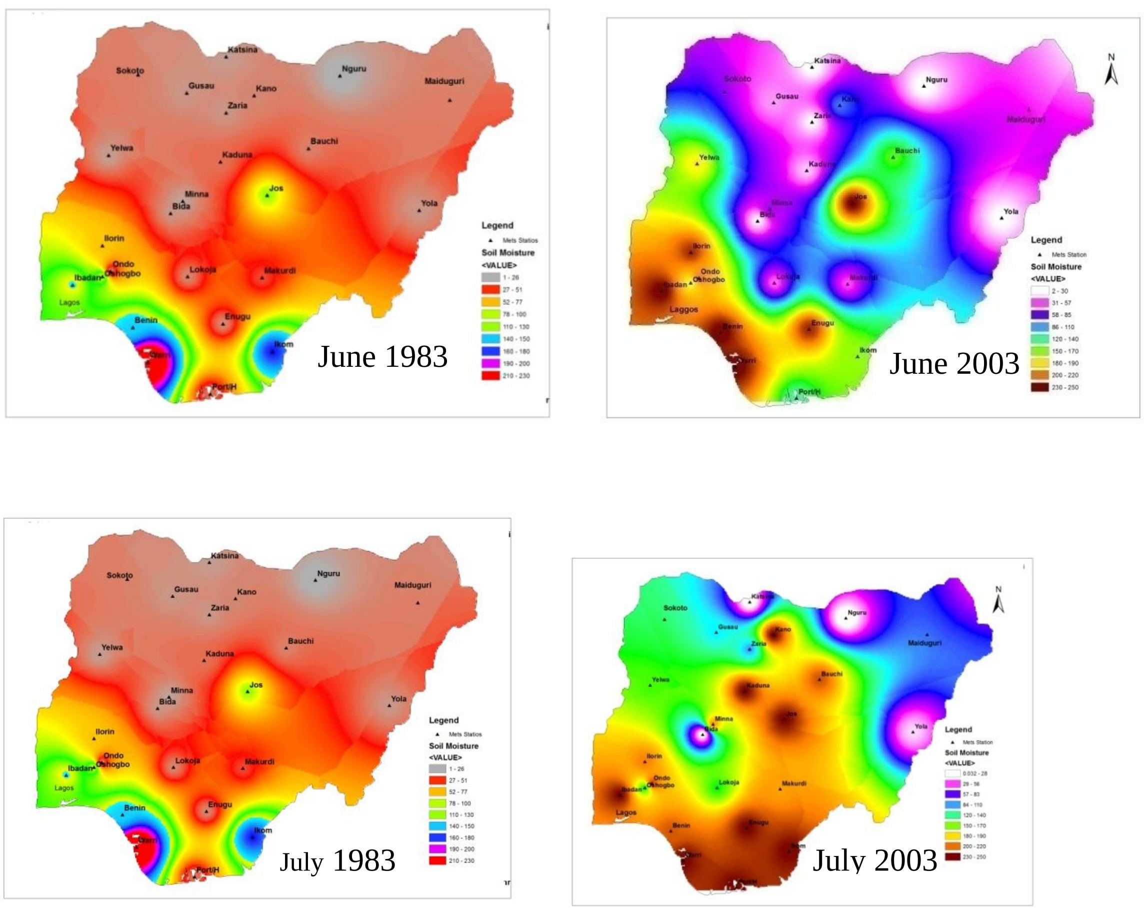


Figure 3 (continued). Spatial Pattern of monthly values of Soil Moisture Storage in Nigeria for the dry year (1983) and wet year (2003)

The result in Figure 3 also indicates that places north of latitude 9˚N recorded low soil moisture storage between 0mm to 50mm between January and May in 2003 with the values of ST a bit higher in January than that of February, March, April and May. On the contrary, placesSouth of latitude 9°N recorded higher amount of soil moisture ranging from 100mm to 250mm especially between the month of July and October compared to their counterparts North of latitude 9°N in 2003. Notable among the places with higher soil moisture storage of 250mm (100% saturation) in four to five months in the south of latitude 9°N include Ikom, Calabar, Ilorin, Warri and Benin. The higher soil moisture storage recorded in the Southern part of the country may not be unconnected with the higher amount of rainfall, lower amount of potential evapotranspiration and lower accumulated potential water loss (APWL) (Tables 2a, 2b and 2c). The result in Figure 3 indicate that contrary to the year 1983, many places in the north of latitude 9°N recorded higher soil moisture storage between 200mm and 250mm between the months of July and September. Locations such as: Jos, Minna, Zaria, Yelwa, Kano, Kaduna, Bauchi and Gusau north of latitude 9˚N recorded higher monthly soil moisture storage between 200mm and 250mm between the month of July and September in 2003 (Figure 3). Similar to what was obtained in 1983; Ngururecorded the lowest soil moisture storage of less than 200mm even during the months of July to September when the soil of other place has attained 100% saturation (250mm). The result in Figure 3 further reveal that most of the places south of latitude 9°N recorded significantly higher soil moisture storage between 200mm and 250mm in most of the months compared to their counterpart north of latitude 9°N.



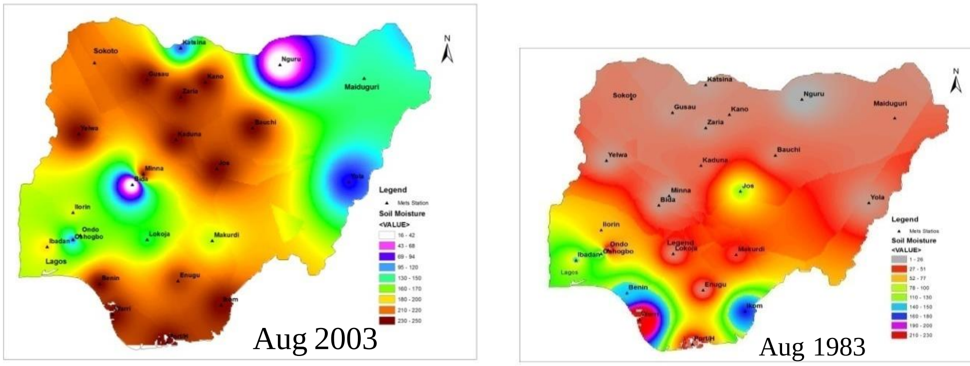
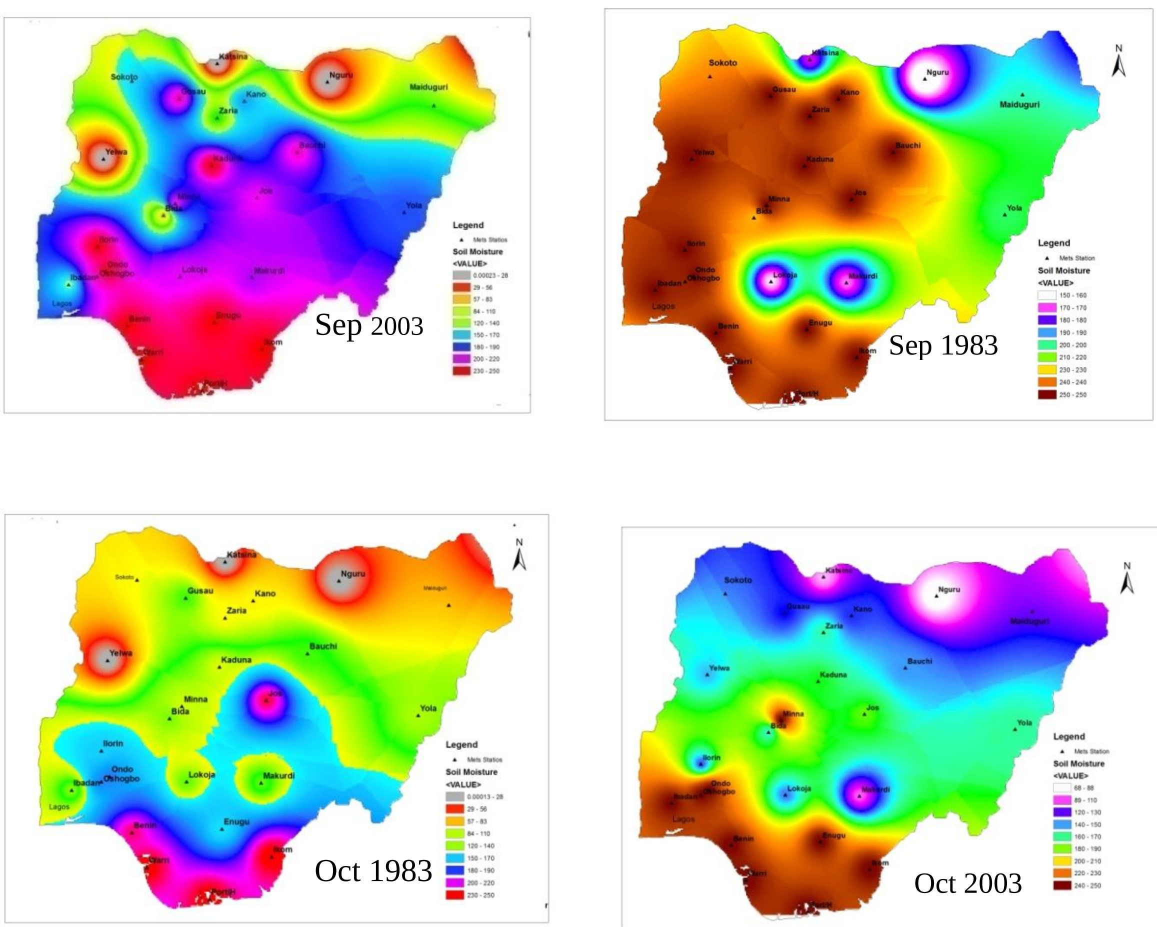


Figure 3 (continued). Spatial Pattern of monthly values of Soil Moisture Storage in Nigeria for the dry year (1983) and wet year (2003)



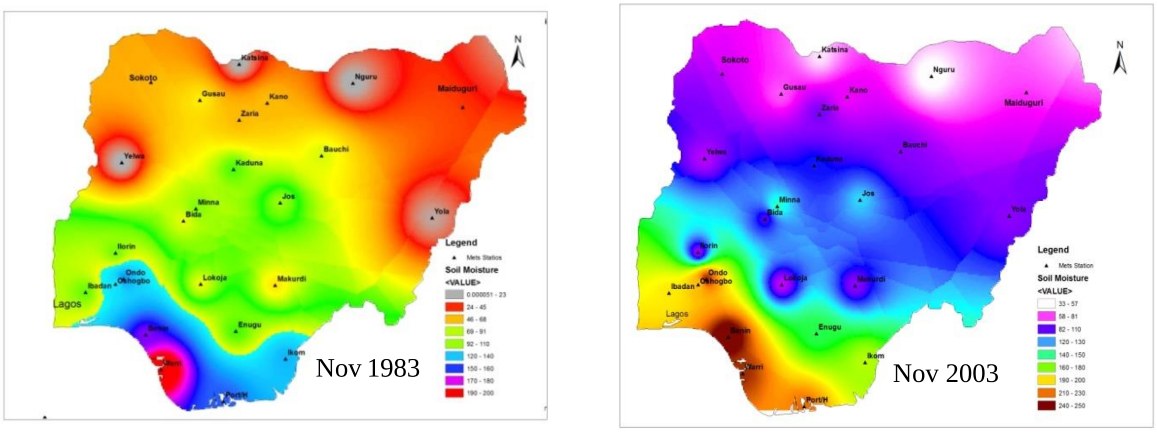


Figure 3 (continued). Spatial Pattern of monthly values of Soil Moisture Storage in Nigeria for the dry year (1983) and wet year (2003)

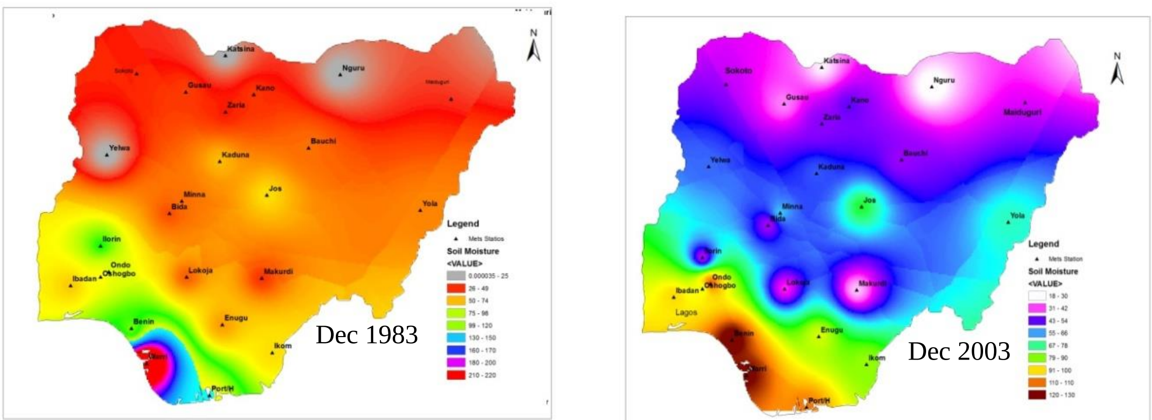


Figure 3 (continued). Spatial Pattern of monthly values of Soil Moisture Storage in Nigeria for the dry year (1983) and wet year (2003)

The factors responsible for the high soil moisture storage in Jos and Kaduna located north of latitude 9°N may be attributable to the high rainfall and low potential evapotranspiration recorded in those places. Jos is located on the plateau and the influence of the relief makes the temperature of the place always low compared to her counterparts within north of latitude 9°N. It is very important to note that the amount of temperature in a place plays a significant role in the rate of PE of that particular place. When the temperature is high, the PE is also expected to be high and vice versa. The low soil moisture storage in most of the places North of latitude 9°N could be ascribed to the little or no rainfall, high amount of potential evapotranspiration and high Accumulated Potential Water Loss (APWL). The higher the amount of APWL, the lower the amount of soil moisture storage and the lower the amount of APWL, the higher the soil moisture storage (Tables 1a 1b; 1c; 2a, 2b and 2c). This could be the reason why most of the places recorded high soil moisture storage especially during the months of January and February (Figure 3). The implication of the low soil moisture storage recorded in some of the places across the country is an indication of insufficient water for crop production and other fauna activities (Aina et al. 2007) Even if crop manages to germinate under insufficient soil moisture condition, it may likely withers after longer days of soil moisture deficit. Likewise, some organisms cannot survive under low soil moisture storage. Rather, they survive when the soil has attained reasonable amount of moisture storage for their survival e.g earthworm and some other amphibians (Tyler, 2017)

It is equally crucial to note that, the higher soil moisture storage recorded in most of the months signify sufficient water for crop production. Soil moisture storage does not only influence crop growth. Rather, it also influences the micro and the boundary layer climate (Oke, 1987). If there is adequate water in the soil, the incoming solar radiation will be used for convective activities. On the contrary, if the moisture is very low or totally in deficit on the earth's surface, the incoming solar radiation will only be used to warm the environment thereby bringing physiological discomfort (Ayoade, 1995). The more water in the soil, the more slowly the soil gets heated during the daytime and the less during the night (Zachary, 2013 and Oke,1987). The less the water in the soil, the faster the soil gets heated during the daytime and the faster it loses the heat. The computed values of soil moisture storage give an indication of the pattern of soil moisture profile across different locations in Nigeria. This is vital information to assessing the risk of flooding in an area given the input precipitation (Ayoade, 1995). Any additional input precipitation after the soil has attained its storage capacity runs off either to a nearby river or a stream. If runoff could not get its way through a proper drainage channel, it may lead to flooding. An incident that can claim many lives and properties. The spatial pattern of soil moisture storage across different locations in Nigeria is a panacea to identify places that deserve irrigation schemes to boost agriculture production.

Temporal Pattern of Soil Moisture Storage in Nigeria

The result indicates that many places across Nigeria recorded very low soil moisture storage especially during the months of March, April and May in both 1983 and 2003 in Nigeria. It is important to note that most places across Nigeria recorded high soil moisture storage between

50mm and 150mm during the months of January and February in both 1983 and 2003. This is not because of the input precipitation but rather, due to the influence of the harmattan wind, which significantly reduces the amount of potential evapotranspiration (see Tables 1a and 1b; 2a and 2b). The values of monthly soil moisture storage for individual location in Nigeria are shown in Figure 3. It could be observed from Figure 4 that most of the stations recorded low soil moisture storage of between 2mm and 20mm from the month of February to May in both 1983 and 2003 especially in the North. In fact, some locations recorded less than 2mm soil moisture storage even during the months of July and September when the soil moisture of many locations have attained 250mm (100% saturation) in 1983. It is evident from Figure 3 that the soil moisture increases from less than 100mm to as high as 200mm and above in most of the locations during the months of July, August, September and October in both 1983 and 2003. It could be observed from Figure 4 that the highest soil moisture storage was recorded during the month of September. The soil moisture storage of virtually all places across the country reached their full storage capacity of 250mm (100% saturation) during the month of September. This is followed by the months of August, October and July with moisture storage of between 200mm and 250mm in both 1983 and 2003.

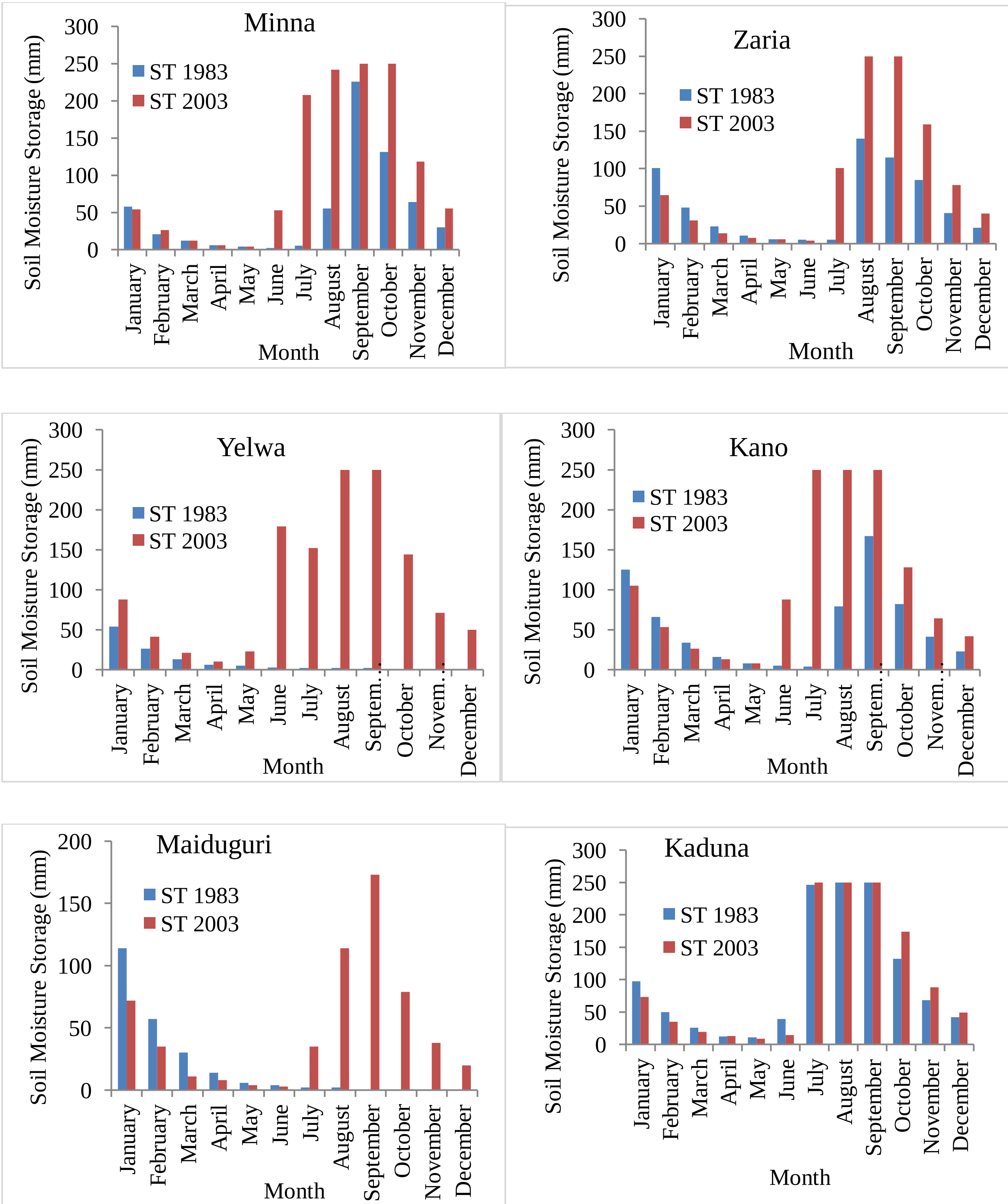


Figure 4. Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003
Source: Author's Computation

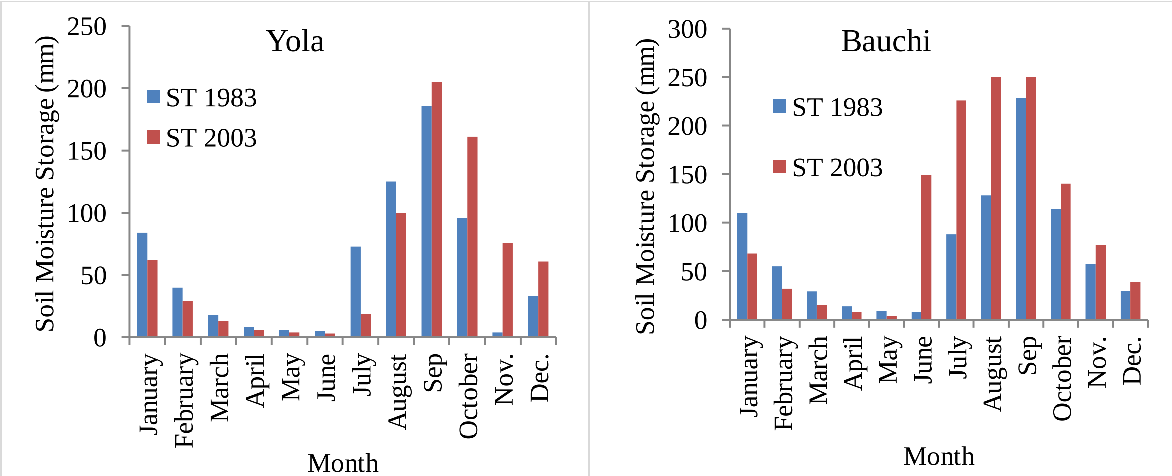


Figure 4. Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003. Source: Author's Computation

This monthly variations in soil moisture storage indicate the insufficient moisture in the soil for crop growth in most places in Nigeria from the months of January to April as well as October to December. The values of soil moisture storage across the country also indicate the commencement of growing season to be around April in most part of the Southern part of Nigeria and around June/July in most part of the North (see Figures 4). It is also important to note that the amount of moisture in the soil begins to decline from above 100mm in October to less than 60mm and as low as below 40mm between November and December in most places both 1983 and 2003. The values of monthly soil moisture storage across different locations in Nigeria make it possible to identify the months of July, August and September as the flood risk months in Nigeria. This is because virtually all places in Nigeria attained 100% moisture storage capacity. This information, if properly utilized can assist to minimize the incidences of flooding in Nigeria. It is evident that most locations across the country recorded soil moisture storage of above 50mm in the months of January in 1983 and 2003 (see Figure 4). This could be because of the low PE and APWL, which is an influence of the harmattan wind. The high soil moisture storage is not because there is high record of rainfall during the months of January, February and March but because there is low potential evapotranspiration during the months. The climatic water budgeting method assumes even if there is no rainfall, evapotranspiration will continue. The rate of PE is always low during the cool months. As such, the low PE will reduce the amount of water loss and more water in the soil. On the other hand, the rate of PE is always high during the warm months and this increases the rate and amount of water loss from the soil (Moreland, 1993). The monthly values of soil moisture storage at different locations in Nigeria will serve as a useful guide in understanding the level of soil moisture storage at different locations and at different time of the year in Nigeria. The temporal pattern of soil moisture storage in Nigeria will enable the farmers to plan the best time to commence the growing of their crops and to understand cessation of the growing season. The temporal pattern of the soil moisture in Nigeria as revealed by this study will not only be useful to agriculture rather; but alsoto the stakeholders in water resources management to design and forecast the best water management strategies. This will be crucial in = forestalling incidence of flooding especially during the months in which the soil of many places across Nigeria might have reached their water holding capacity. Those months with low soil moisture storage indicate the need for irrigation scheme across many places in Nigeria to facilitate all year round farming in.

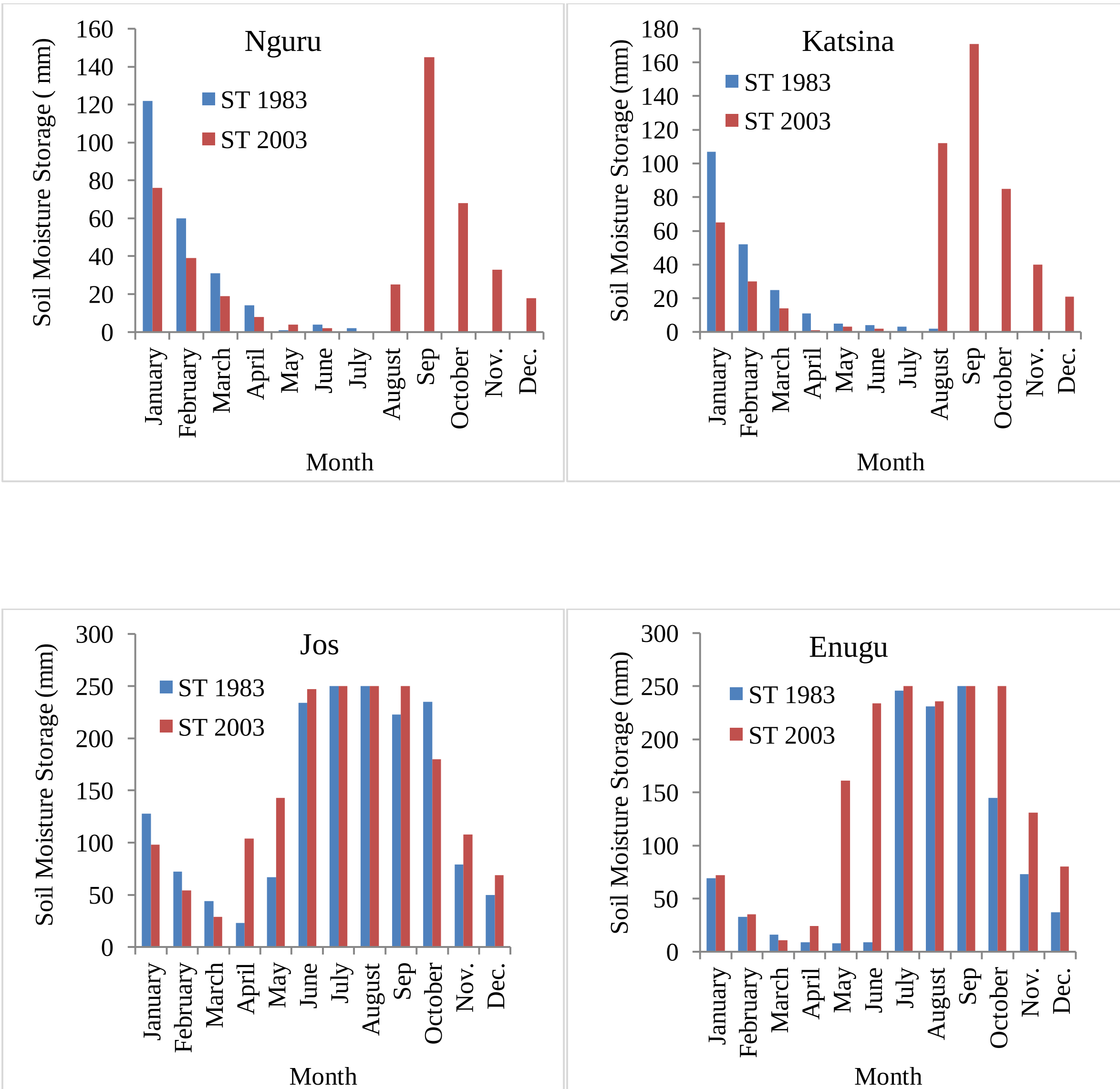


Figure 4 (continued). Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003

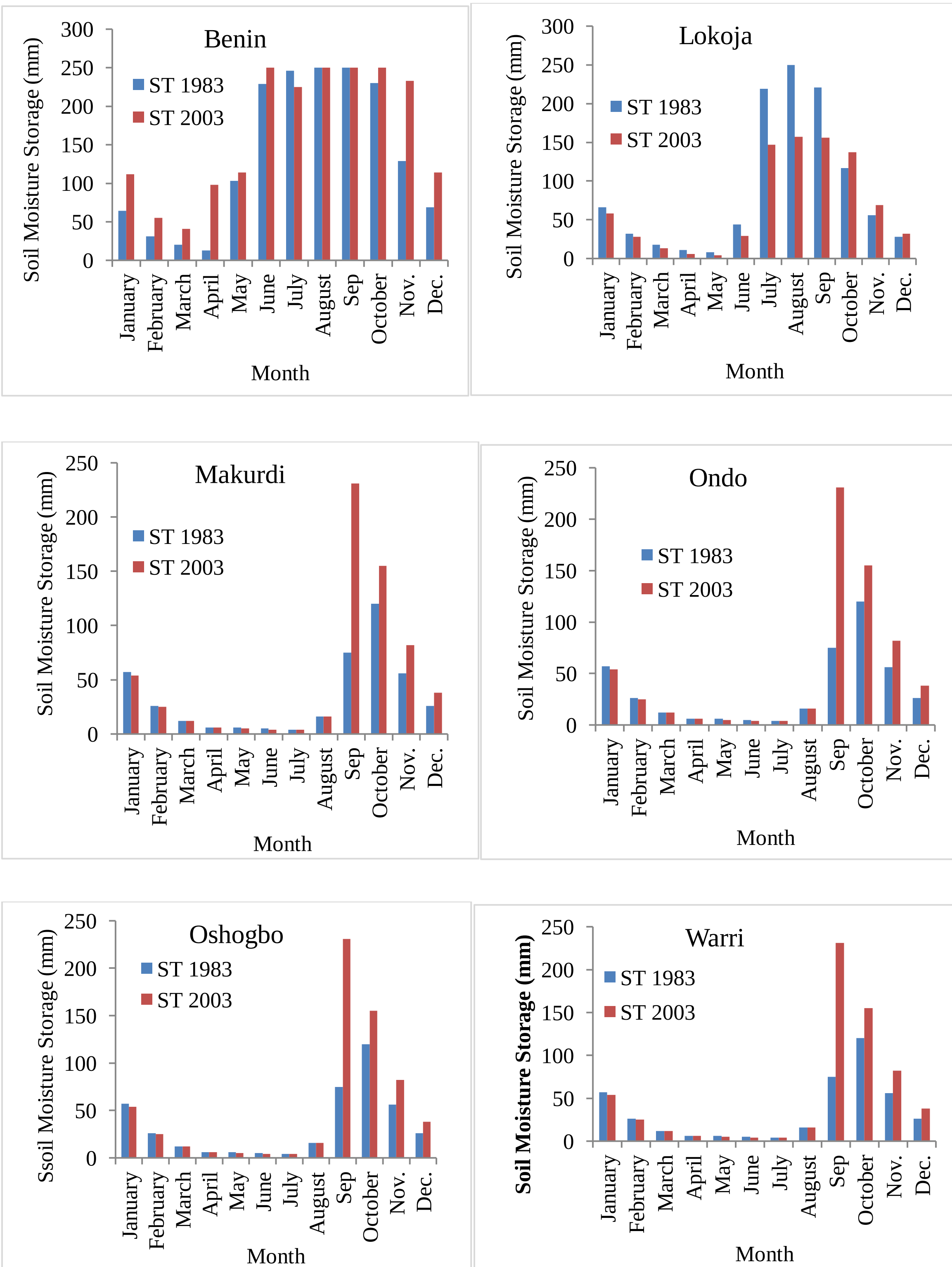


Figure 4 (continued). Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003

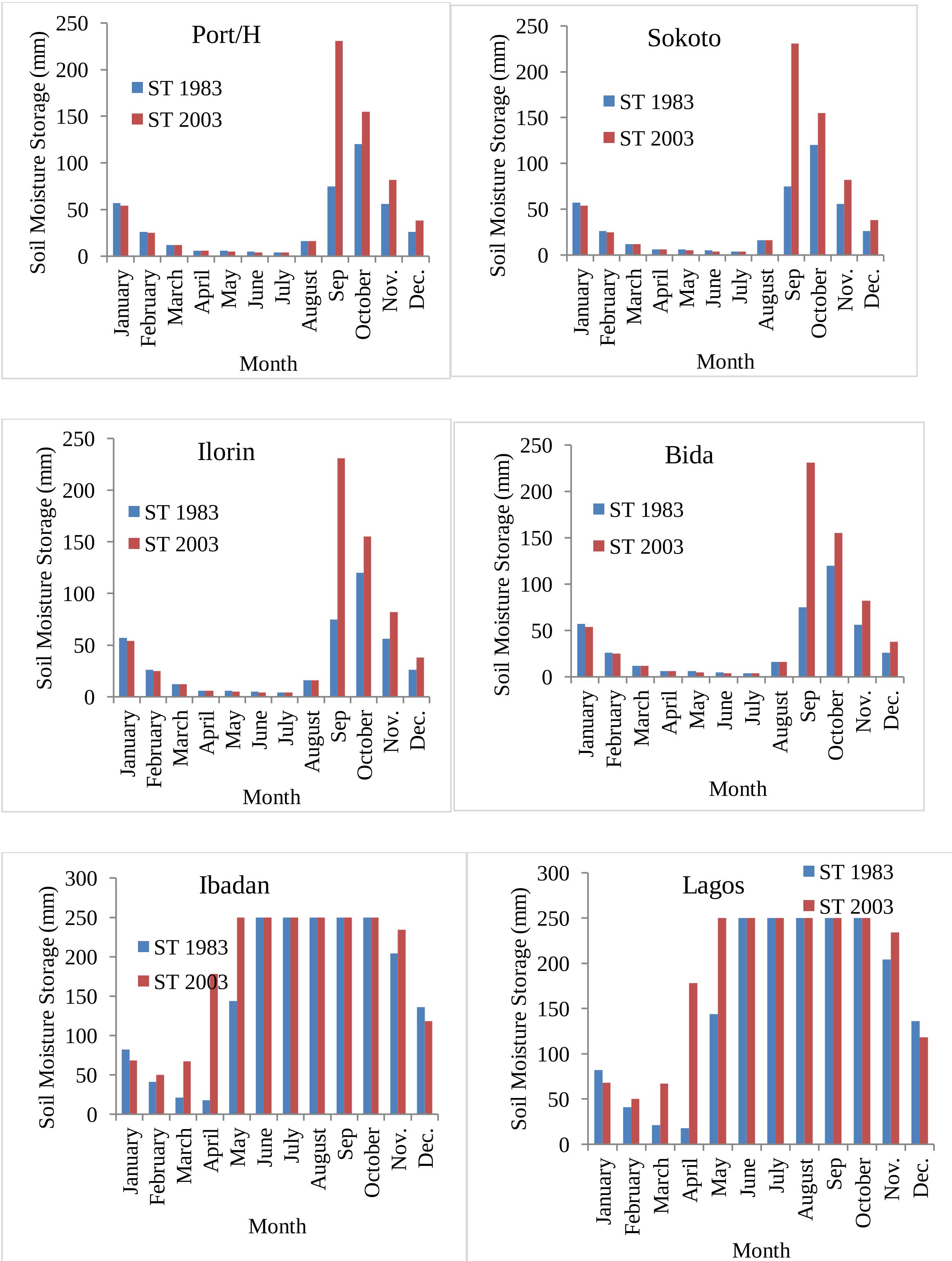


Figure 4 (continued). Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003

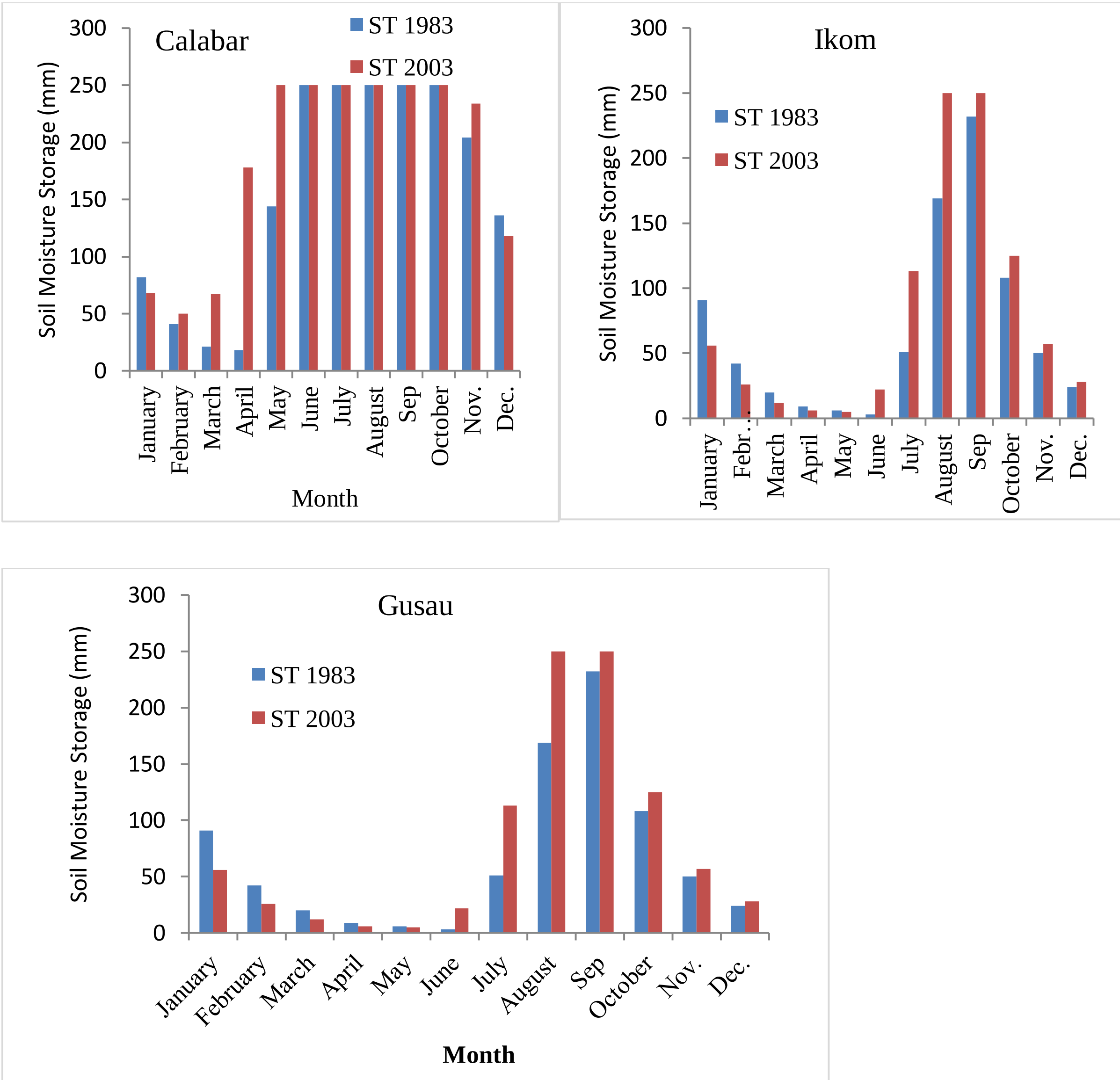


Figure 4 (continued). Monthly Variation of Soil Moisture Storage for the Individual Locations in Nigeria for 1983 and 2003

Variation between the Soil Moisture Storage of 1983 and 2003 in Nigeria

The results in Figure 3 show that there is variation between the soil moisture storage of 1983 and 2003 in Nigeria. The numbers of locations that attained soil moisture storage of 250mm in 2003 during the months of July, August and September are many compared to 1983. It is only in Kaduna and Jos states in the North of latitude 9° N that soil moisture storage attained 250mm (100%) in 1983. The soil moisture storage for 1983 and 2003 were subjected to pair t test and the result in Table 3 and Table 4 revealed that there is a significant difference between the soil moisture storage for 1983 and 2003 in Nigeria. With reference to Tables 3 and4, .000 is less than ∝ (0.05). Therefore, "paired sample t test reveals statistical difference between the soil moisture storage of 2003 (M=1299.56, s=515.45) and 1983 (M=1001.56, S=551.66) in Nigeria. t (26) =4.420, P= .000, ∝ 0.05. This means there is a significant difference in the soil moisture storage of 2003 and that of 1983 in Nigeria. The low soil moisture storage recorded in 1983 compared to 2003 in Nigeria could be attributed to the fact that the decade 1980s was bedeviled with drought of varied magnitudes. The year 2003 on the other hand, recorded high soil moisture storage across many locations in Nigeria because this year is described as a recovery year in Nigeria when there was more rainfall (Umar, 2013). This finding is in agreement with Kehinde (2017) which revealed that there is a significant different between the water balance indices of 1983 and 2003 and across different locations in Nigeria.

Table 3. Paired Sample Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ST 2003	1299.56	27	515.44	99.19
	ST 1983	1001.56	27	551.66	106.17

Source: Author's Computation

Table 4. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ST 2003-ST1983	298	350.36	67.43	159.4	436.59	4.42	26	0

Source: Author's Computation

Conclusion and recommendations

The study assessed the monthly soil moisture storage at different locations in Nigeria for 1983 and 2003. Based on the findings available, I concluded that soil moisture storage varies spatio-temporally and that the variations are function of the amount of the rainfall, potential evapotranspiration (PE) and the Accumulated Potential Water loss (APWL). The soil moisture storage increases from the north to the south. While the amount of soil moisture storage was very low from March to June in both years especially in the northern part of Nigeria, it was very high from July to September. The study suggests the need for more irrigation projects across Nigeria and expansion of the capacity of the existing ones to be more productive for efficient food productions across Nigeria. Government should also intensify efforts to create awareness about the likely incident of flood from the months of July to September when the soil moisture of different places across the country must have attained their full storage capacity in order to take proactive measures against flood occurrence. Irrigation agriculture should not be limited to only the Northern part of Nigeria. Rather, it should be extended to some other locations in the Southern part of Nigeria as well, because of rainfall variability and dry spells which truncate the length of the growing season in Nigeria.

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