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Spatial Variability of Soil Moisture Deficit in Semi-Arid Region of Nigeria

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Abstract: Soil Moisture Deficit (SMD) in selected areas of the semi arid region of Nigeria was estimated and its spatial variation with rainfall investigated. The method applied used Rainfall, Evapotranspiration, Runoff Coefficients and Root Constants to estimate SMD on a daily time step over a period of 3 consecutive years (2001-2003). When the predicted daily SMD results were examined, the major variations were associated with prevailing rainfall events. As expected, seasonal variations in daily SMD occurred, with the months of January and February recording the maximum value of 123 mm. The range of the daily results was found to vary from 123 mm in January to 11 mm in August for Sokoto, 6 mm (August) in Maiduguri and 3 mm (August) at Kano. Minimum daily SMD (zero) occurred in several days in the months of July, August and September. Among the 3 locations studied in the region, Kano was found to have a better distribution of the daily SMD. The estimated maximum daily SMD is about 17% higher when compared with similar results quoted in literature.

Key words: Soil moisture deficit, variability, semi arid, Nigeria

INTRODUCTION

In Northern-Nigeria, large quantities of commercial fertilizers, pesticides and herbicides are applied to agricultural lands to increase crop production. During major rainfall events, petrochemical and agrochemical contaminants are carried in runoff and infiltration water into drinking water sources thereby increasing the health risk for human, livestock and aquatic organisms. According to Jury (1989) and Mallants *et al*. (1996) proper management of shallow aquifers and such surface environment is based on an accurate quantification of the controlling transport processes operating in the soil. It is also a known fact that the amount of water that may be extracted from an aquifer without causing deflation is primarily dependent upon the ground water recharge. The amount of moisture that will actually reach the water table depends upon the rate and duration of rainfall (P1), SMD balance process, the water table depth and soil type (Kumer, 1993). Among these parameters the SMD variation is one of the most difficult to estimate.

It is a known fact that the rate of flooding after heavy rain increases sharply once the effect of spare moisture capacity in the root zone of vegetation had been eliminated. Grindley (1967) suggested that simple forecasts of date of restitution of soils to field capacity and resumption of appreciable runoff might be obtained by projecting average rainfall and runoff from the date of known SMD. That will provide the drainage engineer an objective assessment of the degree of urgency with which attention should be paid to flood warning systems. Also, in the semi arid area where surface water resources are limited, the water engineer may estimate, with given probability, the rate of depletion of reservoir or forecast the date of restoration of reservoirs to full capacity. Based on such data, the risk of not imposing restriction on draft or relaxing them may be assessed. Much literature exists on the water resources, pattern of rainfall, evaporation and drought events, but not so much has been written about spatial variability of soil moisture deficit, which affects many aspects of water resources planning. Therefore, a quantitative assessment of SMD variation is important for optimal operation of ground and surface water resources and flood warning systems. Thus, the purpose of this study is to provide scientific information on SMD variability in the region.

MATERIALS AND METHODS

Study area: Figure 1 is a location map containing the seven stations used in this study. The semi arid region lies within latitudes 10 and 14°N and longitude 3 and 15°E. The region has great potentials for large-scale economic development due to bountiful resources including farmlands and minerals (Adelana *et al*., 2003).

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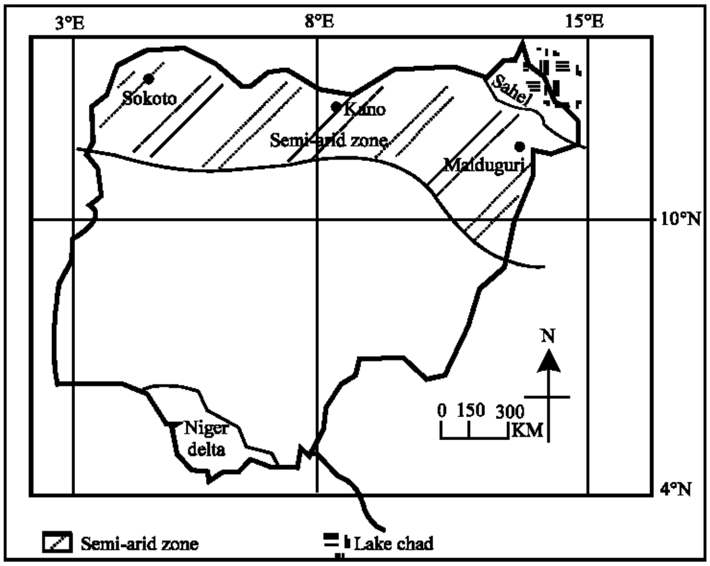

Fig. 1: Map of study area. Source: Ndubuisi (2007)

Three stations were selected in such a way that the major geological formations (superficial deposits) were represented (Adelena *et al*., 2003; Bumb *et al*., 1991). The selection was also based on available and reliability of input data that was obtained from the Nigerian Meteorological Agency. Thus, we had data from three model application sites: (Sokoto, Kano and Maiduguri) which were employed. The assumption here is that each station represents the three major meteorological stations of the region.

SMD can be estimated through *in situ* measurement of soil moisture at the field and also by laboratory experiments on unsaturated soil columns (Nyberg, 1996; Mallants *et al*., 1996; Jury, 1989). However, for this to be achieved, multitude of locations has to be sampled if a reasonable level of accuracy is required. But the need to be able to compute SMD rapidly and accurately remains undisputed. In Nigeria and perhaps in other developing countries, there is the added need to compute SMD variation from those meteorological parameters that can be easily measured. Grindley (1967) suggested that estimates of SMD are basically obtained by taking the difference between rainfall (P1) and evaporation. Mallants *et al*. (1996) emphasized that spatial variability of SMD, as point input cannot be evaluated solely by water balance consideration. In a similar study, Nyberg (1996) reported that SMD variation in a specific soil layer depends on several factors such as slope, drainage, runoff and evaporation. Therefore, in assessing SMD it is necessary to take into account the effect of vegetations and the manner/extent to which actual evaporation rate fall below the potential rate when moisture supply becomes limited.

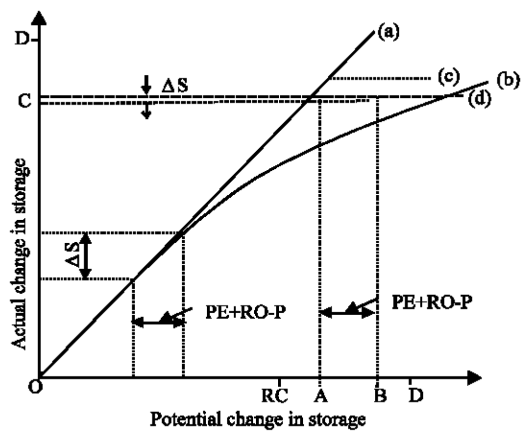

Fig. 2: Drying curves for a vegetated soil after Rushton and Ward (1979)

Duru (1984) and Fapohunda and Ude (1992) showed that any model that is easy to apply and requires a minimum of the commonly available meteorological parameters is to be preferred over a more complex and sophisticated model with comparable accuracy of prediction. Therefore, for reasons of reliability and cost effectiveness an SMD Model (Ndubuisi, 2005) which has these simple characteristics was adopted.

Theoretical concept: The availability of soil water between field capacity and permanent wilting point has been a controversial issue among different researchers. Three different hypotheses which at one time or the other have won popular acceptance are represented in Fig. 2. The actual amount of water extracted from the soil as, related to the evaporative demand of the atmosphere is shown in the figure. For example, Veihmayer and Hendrickson (1949) proposed an Equal Availability-Curve (a) which claimed that soil water is equally available throughout the defined limits of soil wetness. Richards and Wadleigh (1952) used field evidence to support a totally different hypothesis that soil water availability to plant decreased with soil wetness (Gradually decreasing availability-curve (b). Penman (1949) modified this hypothesis and proposed an equal availability followed by decreasing availability, which he called the critical point Root Constant (RC). This concept is shown graphically by curve (c). Rushton and Ward (1979) modified Penman's hypothesis by suggesting that the equally available stage is followed by a sudden and very high decreasing availability stage. This concept is represented by curve (d). The Rushton and Ward (1979) proposal has undergone modifications because it is easy to incorporate in a computer program (Odigie and Anyaeche, 1991; Ndubuisi, 2005).

Basically, the mode of computation depends on the state of the soil moisture deficit along the drying process. Estimation is carried out on one-day time step and priority for satisfying evaporative demand is from rainfall. Within the range of variation in SMD, computations are made for the following 4 states:

A $SMD = 0$
B $0 < SMD < RC$
C $RC < SMD < D$
D $SMD > D$

Where:
RC = Root Constant.
D = Maximum Soil Moisture Deficit.

RESULTS AND DISCUSSION

Some of the results generated by the SMD model are presented in Fig. 3 (a-c) and Table 1. Rainfall (mm) data have also been incorporated in the figures to present an overall picture of the spatial variability. In order to reduce the volume of results, these figures contain only the 3 year average daily estimates corresponding to effective rainy season (May to October). Generally, the results show that a typical hydrological year in the region is characterized by a high SMD during the months of January and February (Table 1) followed by a low (recession) in June to early September. The major influencing factor controlling SMD variation in the area is Rainfall. The months of January and February recorded the maximum value of 123 mm day^{-1}. The range of the daily results was found to vary from 123 mm in January to 11 mm in August for Sokoto, 6 mm (August) in Maiduguri; and 3 mm (August) at Kano. Minimum daily SMD (zero) occurred in the months of July, August and September. Among the 3 application sites used for the region, Kano was found to have a better distribution of the daily SMD. This can be explained by the relatively higher rainfall events.

The average maximum daily SMD from this investigation (123 mm) is about 17% higher than 105 mm reported in literature by Agboola (1979) and Mbagiorgu (1999). This can be explained by the fact that the use of computer simulation technique has lead to an improvement in the representation of the actual field behavior. The increase in SMD can also be attributed to

Table 1: Summary of average daily SMD (mm)

	Kano			Maiduguri			Sokoto		
Month	2001	2002	2003	2001	2002	2003	2001	2002	2003
Jan	122.78	122.80	122.80	122.78	122.78	122.78	122.78	122.80	122.80
Feb	122.78	122.80	122.80	122.78	122.78	122.78	122.78	122.80	122.80
Mar	122.78	122.80	122.80	122.78	122.78	122.78	122.78	122.80	122.80
Apr	119.95	122.80	122.80	122.78	122.78	122.78	119.19	107.35	122.80
May	93.69	122.80	120.91	120.31	122.78	122.78	99.28	94.39	122.80
Jun	33.67	114.24	40.23	81.49	105.14	88.66	83.94	72.15	91.76
Jul	14.59	24.65	16.55	64.37	73.55	55.52	30.46	31.83	28.71
Aug	2.19	3.87	2.27	13.17	15.76	4.80	7.04	5.76	4.51
Sep	10.12	10.65	14.07	20.48	66.19	26.28	22.78	7.18	23.07
Oct	35.33	52.31	60.88	34.86	114.61	80.51	64.82	52.31	61.46
Nov	35.33	117.38	65.01	35.33	133.40	78.26	64.82	116.42	65.01
Dec	35.33	117.38	65.01	35.33	133.40	78.26	64.82	116.42	65.01
Total	2749.52	3056.48	2879.13	2897.46	3257.96	3029.19	2926.48	2974.21	2956.52

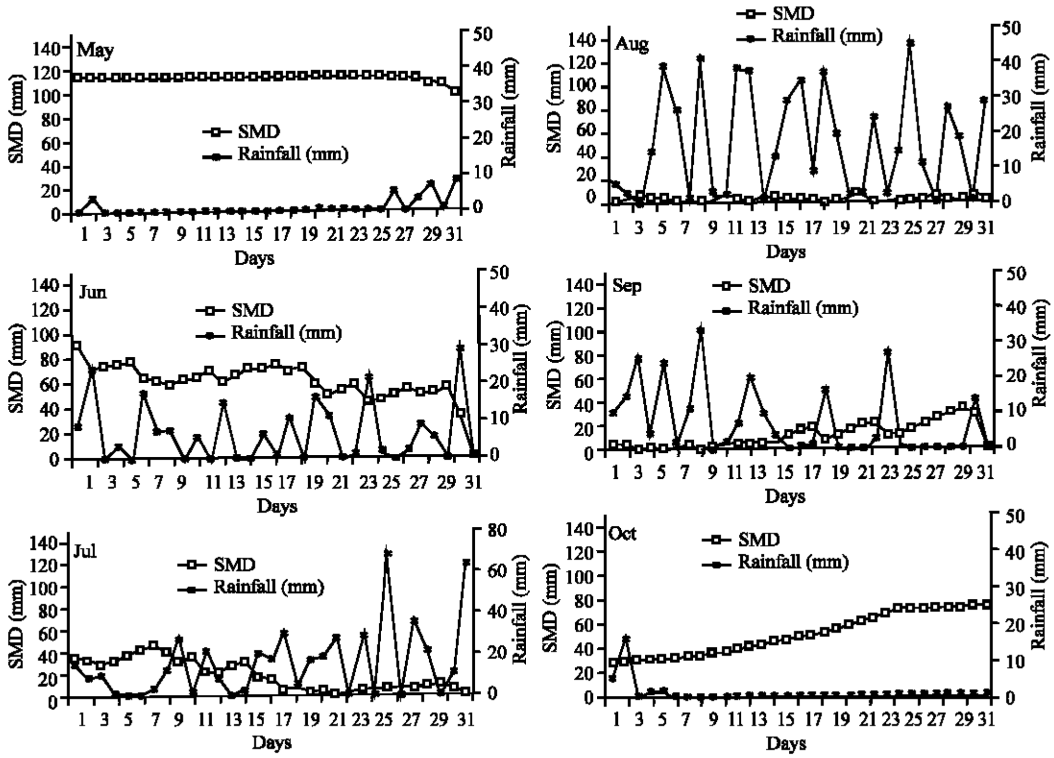

Fig. 3a: Variation of estimated average daily SMD with rainfall in Maiduguri

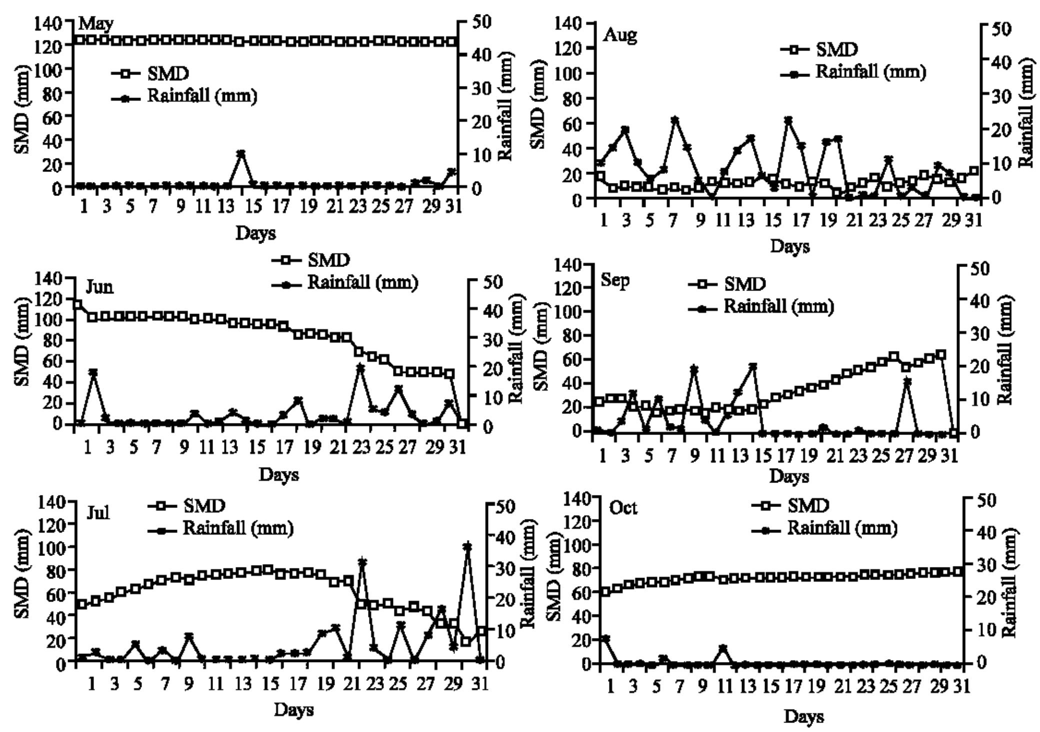

Fig. 3b: Variation of estimated average daily SMD with rainfall in Kano

other ecological problems such as global warming. Thus, the results of this investigation can be used as input in prediction of groundwater recharge and also as preliminary scientific information for forecasting. For example, according to Grindley (1967), the risk of flooding after heavy rainfall increases with the elimination of

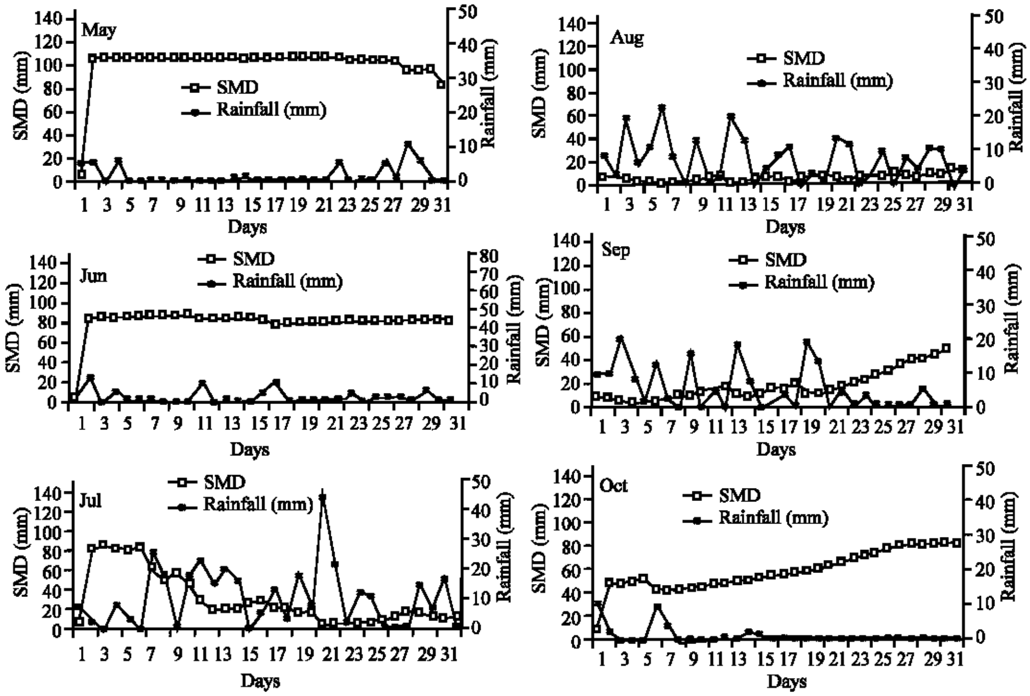

Fig. 3c: Variation of estimated average daily SMD with rainfall in Sokoto

SMD. Therefore, from Fig. 3, flooding can occur between 17th July and 13th August in Kano area and 2nd-8th September in Maiduguri the potential dates for Sokoto are 21st-26th July and 3rd-5th of September.

CONCLUSION

A modified form of Soil Moisture Deficit model was applied to representative sites within the arid zone of Northern-Nigeria. Variability of the estimated SMD was found to be large. The mean daily results were compared with rainfall data. Among the sites, Kano was found to have a better distribution than Maiduguri and Sokoto. The results can be used for prediction of groundwater recharge and also as basis for preliminary forecasting of flooding events in the area.

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