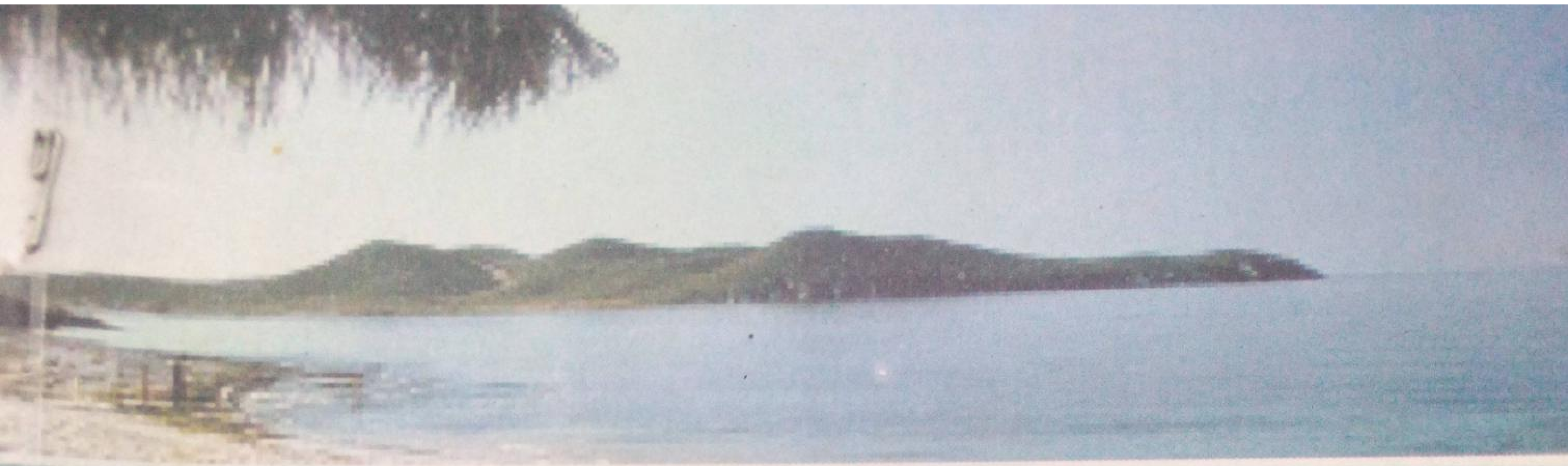

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Estimation of runoff from Chanchaga River Basin using soil-water balance approach

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Abstract

This paper presents the estimation of runoff in an ungauged watershed in Chanchaga River Basin in Guinea Savannah region using semi arid moisture balance technique (SAMBA). The SAMBA model is a single layer soil water balance model that estimates daily surface runoff using daily rainfall, evapotranspiration, vegetal cover and soil moisture deficit (SMD). The model estimate was validated with discharge measurements taken in 2009 and 2010 with a rectangular weir across a stream at the outlet of the basin. Annual runoff for the year 2009 was 167.7 mm, which is 14.5% of the annual rainfall of 1157.1 mm. Maximum runoff occurred on 1st September, coinciding with the high rainfall that occurred between 29th August and 1st September. Similar result was obtained for the year 2010. It was also found that SMD was as high as 49.8 mm during the dry season. The result is useful in understanding and management of water resources in the region.

Keywords. Runoff, Soil Moisture Deficit; Ungauged catchment; Guinea Savannah

INTRODUCTION

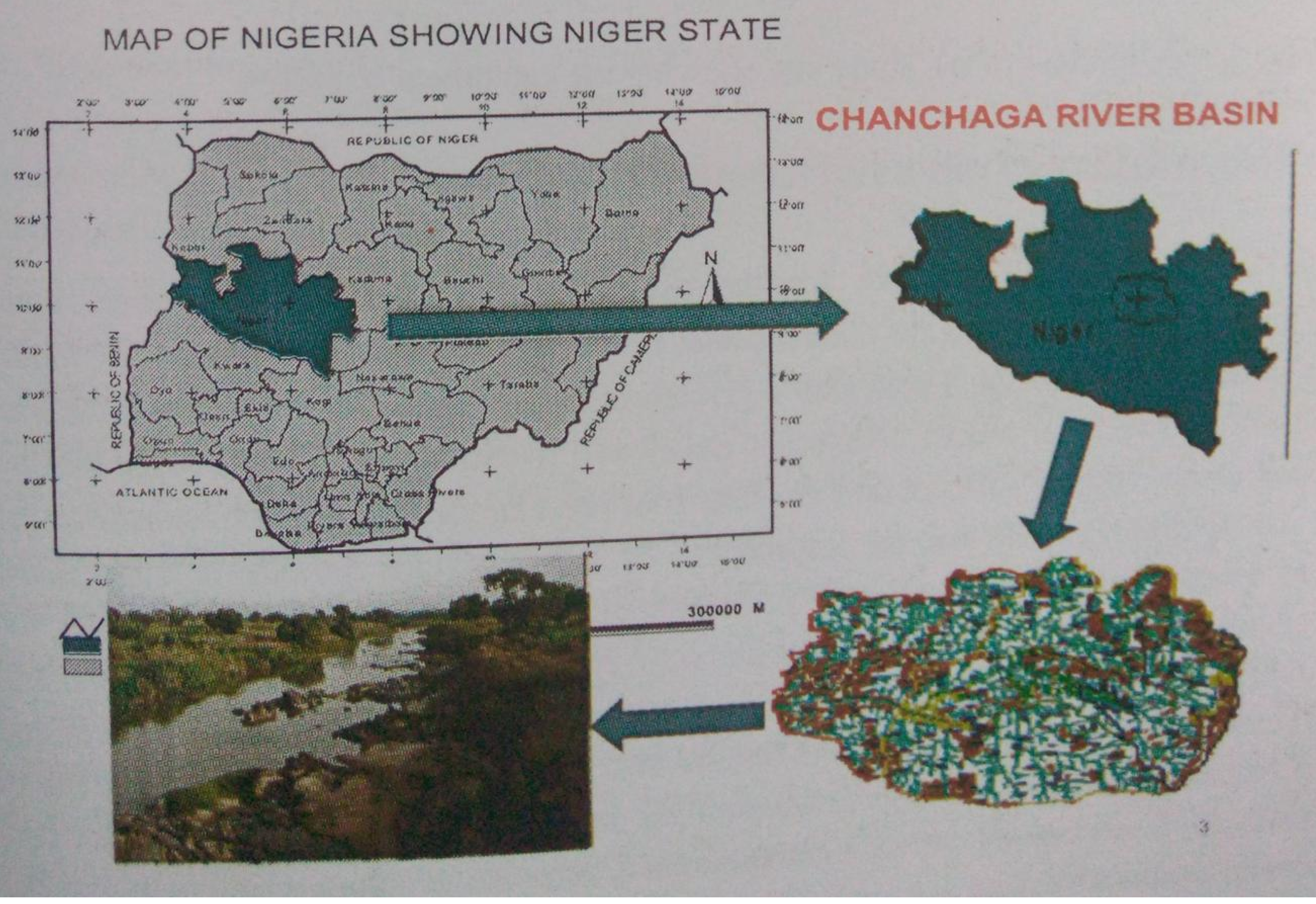
The excess water flowing on the soil surface after the infiltration, percolation, recharge, and interception have been satisfied is called runoff. In the water balance, runoff is a very significant component for its input in the water balance procedure. Surface runoff depends on many factors, among which are, surface gradient, soil characteristics, vegetation, rainfall intensity, and the soil moisture conditions, which is represented in this study by soil moisture deficit, SMD. The estimation of runoff of a catchment is required for various water resources projects. Once the demand of evapotranspiration, interception, infiltration, surface storage, surface detention, and channel retention are satisfied, runoff will occur. Based on this note, runoff is defined as the portion of precipitation that makes its way towards stream channel, es or ocean as surface or subsurface flow (Schwab, 1993). When all the factors affecting cipitation are kept constant, equal amount of precipitation will produce different amount runoff. This is actually dependent on the size of the watershed, the larger the size, the er the amount of runoff produced. Watershed can simply be defined as a topographical drained by a stream or a system of connecting streams such that all outflow is discharged ugh a single outlet. Perevia (1998) also defined watershed as the area to water course. topography or orientation of watershed defines its shape. Watershed either promotes or otes runoff. The topography of the watershed influences the mean travel time of a drop of er from its point of impact on the surface thereby influencing flood intensities to the point xit in the main stream.

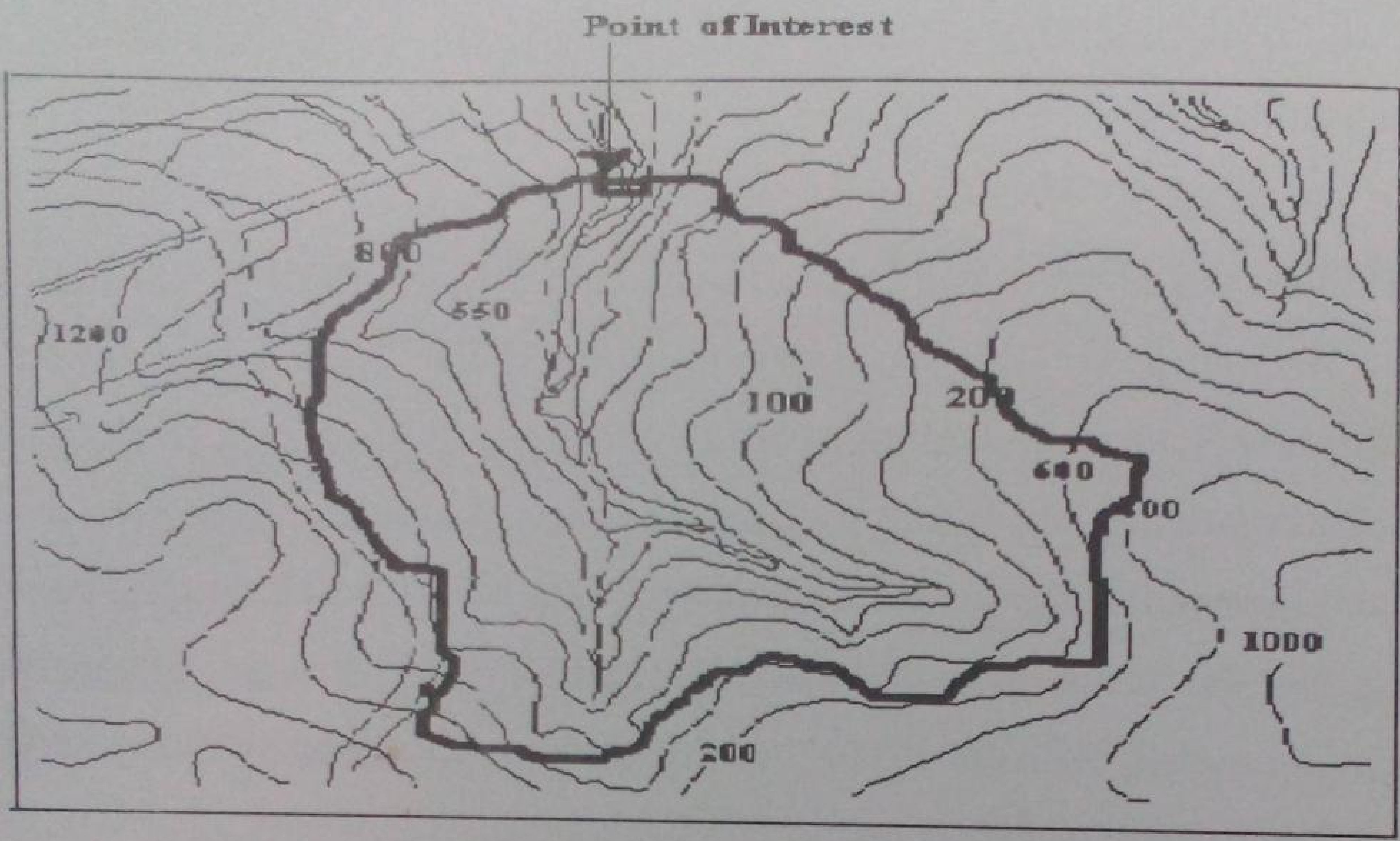
ous methods have commonly been used in the past for the estimation of surface runoff in catchment. These include the rational method and the Natural Resources Conservation ice (NRCS) method. The rational method is very simple in concept but relies on iderable judgment and experience to evaluate all factors properly. It is used primarily for l drainage areas (less than 20 ha). The NRCS method offers a more accurate oximation of runoff, particularly for areas larger than 8 ha. Another technique is the soil r balance methods account for all water entering and leaving the soil zone based on the tification of the individual physical processes (the inputs and outputs), without senting all the physical soil physics and their interactions which describe the movement ater within the soil (Eilers, 2002). This approach is based on fewer physical processes t is not subject to the uncertainties of the mechanisms of a full soil physics analysis. s (2002) and Rushton *et al*. (2006) among others, discussed the merits and demerits of oil water balance techniques over other methods such as empirical rainfall-recharge ssion, lysimeters, zero flux plane, and numerical solutions based on Darcy's law. fically, soil water balance method is favoured for semi-arid region because of its cal credibility at daily or less time scale, and its simplicity with less uncertainty in l variability in hydraulic soil properties. In addition, the technique is favoured because parameters are few. As the number of parameters increases, the level of data required arameter estimation increases. In semi-arid areas, the availability of complex nation (e.g. soil-vegetation system) is poor and there are financial and technical tions involved in gathering a large amount of data.

In this study, we have used a daily soil water balance (the Semi Arid Moisture Bala Accounting - SAMBA) to estimate the groundwater recharge and runoff in a small waters in Minna, Nigeria. Runoff from the outlet of the watershed was measured for different rair events. The field data were used to validate the SMABA estimates.

MATERIALS AND METHOD

The study area is the Chanchaga river basin located between Latitude 10°15′ and 10°45′N Longitude 6°15′ and 6°45′E (Fig. 1). The topography is shown in Fig. 2. The vegetation of area is classified as Guinea Savannah. Characteristic vegetation in the area includes sh with scattered shear butter and locust bean trees. The climate is characterized by wet and seasons. The wet season lasts between April and October with annual rainfall ranging betw 1000 mm to 1200 mm and the temperature between 20°C and 40°C. The nature of vegeta varies from one season to another with shrubs at the early period of the year showing what vegetation looks like when the soil moisture deficit, *SMD*, is high.





10°N6°E

Fig. 2: Topography of the study site showing the catchment boundary

THE MODEL AND ITS COMPUTATIONAL METHOD

There are various models available for the estimation of the runoff and some other hydrological components. There are conventional single layer model; the CROPWAT model which was developed by the Food and Agriculture Organization of the United Nations (Smith, 1992); a two layer model which was developed to estimate daily soil water balance for cropped or un-cropped surface; and the four root layer model (FRLM) developed by the Institute of Hydrology, UK for the estimation of soil moisture deficits in sites under permanent grass cover (Ragab *et al.*, 1997). The model used in this study is a single layer soil water balance model that incorporates the physical processes (rainfall, surface runoff, soil evaporation, crop transpiration, root growth, soil water distribution following rain event and potential recharge). It is termed SAMBA model and has been applied in various areas in northern Nigeria. Grema *et. al.* (1994) adopted the model for Maiduguri where a detailed field investigation was carried out for a complete rainy season and Nguru where daily rainfall and potential evaporation data are available for several years. Though there is difference in the vegetation between these two locations and the study area, the successes recorded in these two locations encouraged the application of this model to Guinea Savannah regions. The features of the model are presented in Fig. 3.

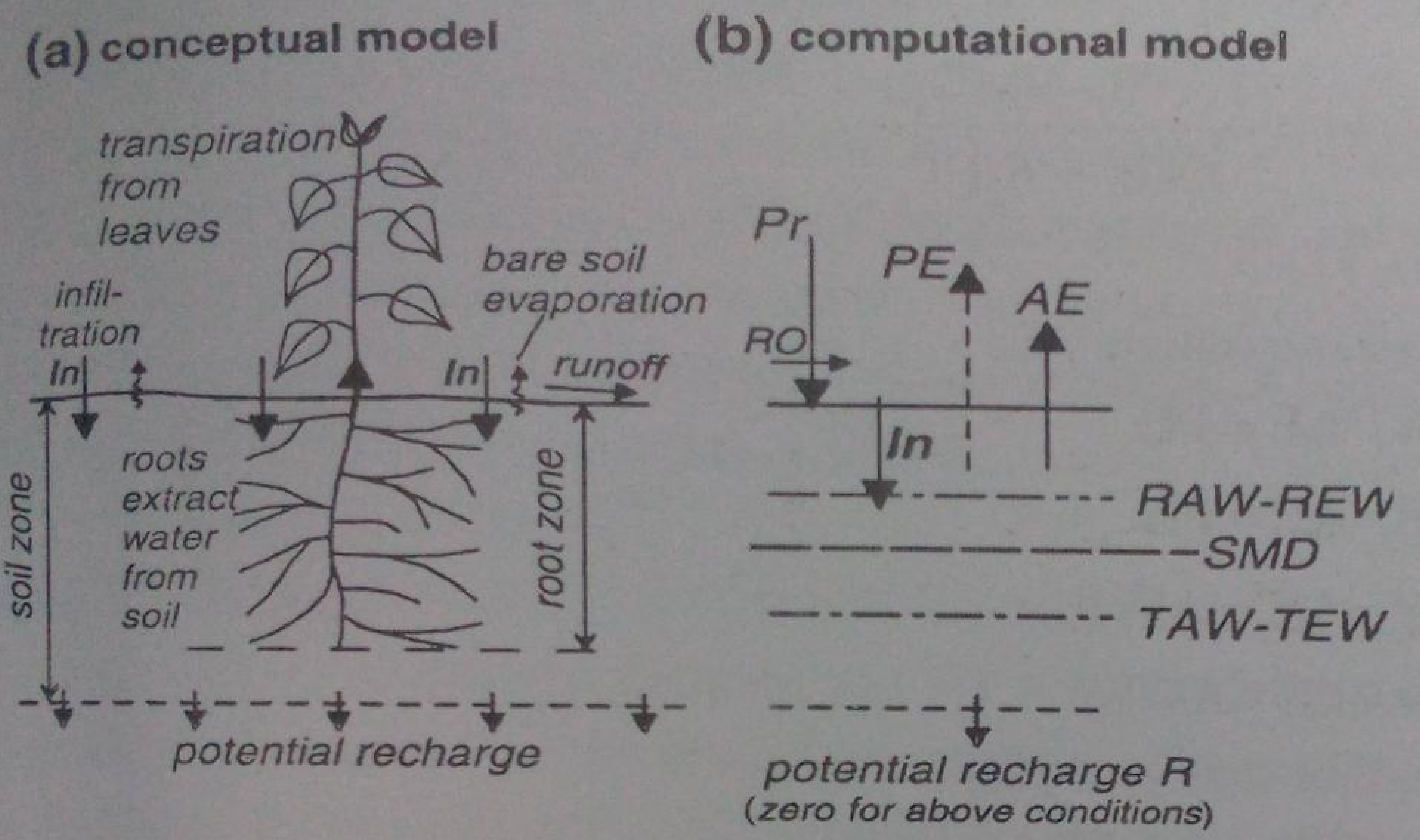


Fig. 3: Features of the model

The computational procedure (Senarath and Rushton, 1984; Rushton *et al*., 2006) on daily time step is summarised below.

(i) Get daily rainfall
(ii) Compute reference evapotranspiration (ET_o). The Blaney-Morin-Nigeria technique (Duru, 1984) was adopted for this study.
(iii) Use *SMD* at the driest season as initial soil moisture deficit - SMD
(iv) Compute runoff coefficient, using a runoff matrix
(v) Compute the Runoff = Rainfall * Runoff coefficient
(vi) Determine Available water for evaporation (AWE)
If SMDpr < 0, AWE = Rain – Runoff
(vii) Compute crop coefficient Kc using information on planting date and crop duration
(viii) Potential evapotranspiration = Kc * ETo
(ix) Determine root depth Zr based on growth stage
(x) Determine Total available water, TAW as:
TAW = max[(FC-WP)*1000*Zr, (FC-WP/2)*1000*Ze]

Ze is the soil evaporative surface

(xi) Readily available water, RAW = TAW * ρ (a constant between 0.2 and 0.7, Allen *et al.*, 1998)

(xii) Determine soil stress coefficient, ks as follows:

$$\text{If } SMDpr \geq TAW,\ ks = 0$$

$$\text{If } SMDpr > RAW,\ ks = \frac{TAW - SMDpr}{TAW - RAW}$$

$$\text{If } SMDpr \leq RAW,\ ks = 1$$

(xiii) Compute actual evapotranspiration, AE:

$$\text{If } SMDpr < RAW,\ AE = PE$$

$$\text{Else If } AWE \geq PE,\ AE = PE$$

$$\text{If } SMDpr \geq TAW,\ AE = AWE$$

$$\text{Else } AE = AWE + ks(PE - AWE)$$

(xiv) Determine the near surface storage (NSS)

$$\text{If } (AWE - AE) > SMDpr,\quad NSS = 0$$

$$\text{Else, } NSS = \max((AWE\text{-}AE)*NSSfactor,\ 0)$$

(xv) $\text{If } SMDpr \leq 0,\ SMD = AE - AWE + NSS$

$$\text{Else } SMD = SMDpr + RECHpr + AE - AWE + NSS$$

(xvi) Compute recharge:

$$\text{If } SMD < 0,\ Rech = -1 * SMD + NSS$$

$$\text{Else, } Rech = 0$$

where: SMD denotes soil moisture deficit at the end of day t, while SMDpr denotes previous day SMD.

Rech denotes recharge at the end of day t, while Rechpr denotes previous day recharge

NSS is near surface storage at the end of day t and NSSpr is the previous day NSS

NSSfactor is the storage fraction of near surface storage.

FIELD EXPERIMENT AND DATA COLLECTION

Hydrological data such as rainfall, evapotranspiration, and actual evapotranspiration, AE were all collected from a meteorological agency and used in the model for the purpose of the runoff estimation. Figure 4 shows the time series of the rainfall depth. Soil moisture deficit in the catchment was determined and used in the model and daily moisture content estimation of the soil in the catchment was carried out for the whole length of the study period. Field and laboratory tests were carried out to describe the soil characteristics, infiltration capacity of the soil, runoff, and particle size analysis of the soil. For the discharge measurement in the catchment, a wooden weir was mounted at the outlet of the basin considered and firmly braced at the downstream to withstand the built up pressure from the impounded water. The weir was buried into the soil at about 0.7 m and clay materials were used to brace the wooden weir by pressing to avoid water leaking through underneath and sideways. Record of water level above the weir crest was recorded. Measurements were taken on four days with appreciable rainfall. The weir discharge formula (equation 1) based on Larry (1993) was used to convert the recorded water level to discharge.

$$Q = 0.0184\,(b-0.2H)\,H^{3/2} \qquad (1)$$

where, Q = discharge in cm^3/s, b = crest width (cm)
H = head (difference between the crest and the water surface) at a point upstream usually 4 times the maximum head of the crest, k = constant. The resulting runoff peaks are labeled Q_1, Q_2, Q_3 and Q_4 for respective measurements for the years under study.

RESULTS AND DISCUSSION

Weekly record of rainfall depth for the year is presented in Fig. 4. The variation of rainfall with time is noisy. The highest rainfall depth, 150 mm, was in week 34. The seasonal variation of the collected data of Potential evaporation, PE, Actual evaporation, AE, and Reference evapotranspiration, ETo is presented in Fig. 5 with PE recording the highest values in most part of the season. Figure 6 shows the hydrographs obtained from the field measurements carried out. Figure 6a shows the hydrograph of the measurement made on 28th July, 2009 with effective rainfall depth of 28.6 mm. From the hydrograph, the runoff depth was 2.0 mm (volume of runoff was 1344.6 m^3) while the value obtained from SAMBA model on same date was 2.86 mm. However, on the 18th August, 2009 (Fig. 6b) the measured runoff depth was 1.2 mm as compared to 5.1 mm obtained from the SAMBA model. The runoff depth on the 17th September was 4.88 mm, while that of 21st September, 2009 was 19.89 mm respectively. The annual runoff was 168 mm, equivalent to 14.5% of the total annual rainfall of 1157 mm in the year. It was found that runoff estimated by the model is similar to the runoff obtained from field measurements in two occasions (Fig. 6) while the remaining two estimates differ by 21% and 24% respectively.