Simulation of Soil Moisture Movement in Ghataprabha Representative Basin

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Abstract

In the recent past lot of efforts have been done on field measurement of soil physical properties and on the development of mathematical models to predict soil moisture movement and contaminant transport. The principle feature of field soils is their variability over many length and time scales. These kinds of variability in physical properties results in errors while modeling soil moisture movement and solute transport processes. A very large fraction of rainfall and irrigation water moves through unsaturated soil during the processes of infiltration, drainage, evaporation and the absorption of soil water by plant roots. Quantification of groundwater recharge is a complex function of hydrometeorology, soil, vegetation, physiographic characteristics and properties of geologic material within the paths of flow. Therefore, to quantify the groundwater recharge one of the simple methods is by estimating the soil moisture movement through the unsaturated zone. However, field estimation of soil moisture content require extensive investigations which is highly expensive and the scientists have developed alternative approaches to understand soil moisture movement using numerical techniques. SWIM is a physically based, isothermal, one dimensional model of water flow through the soil coupled with a simple crop water extraction model of the canopy and of the root system as an predetermined input. SWIM is driven by rainfall or irrigation and potential evaporation and so appears to be more appropriate than similar models if limited meteorological data is available. Therefore, in the present study field and laboratory investigations were carried out in the Ghataprabha basin at 10 locations using Guelph Permeameter (to determine the saturated hydraulic conductivity) and soil moisture retention characteristics using the Pressure Plate Apparatus. The field and laboratory data were used to simulate the soil moisture movement in Ghataprabha basin before and after irrigation. The model results showed good match between the observed and predicted soil moisture variations in the soil profile and also indicated the control of soil hydraulic properties in the distribution of moisture content.

Key words: Soil moisture, unsaturated zone, infiltration

Introduction

Hydrological processes involving soil-water interactions in the field, and particularly, the flow of water in the rooting zone of most crop plants, occur while the soil is in unsaturated condition. The ability of the soil to absorb, retain and transmit water gives rise to the notion of this zone behaving as a leaky reservoir. The water movements in the unsaturated zone, together with the water holding capacity, are very important for the water demand of the vegetation, as well as for the recharge of groundwater storage. A fair description of the flow in the unsaturated zone is crucial for predictions of groundwater recharge characteristics. Input at the soil surface is in the form of precipitation or irrigation out of which a part is absorbed and the other runs off. The water that infiltrates into the soil is later partitioned between that amount which returns to the atmosphere by evapotranspiration and which seeps downward and recharges the saturated zone. Soil Physicists, in the recent years have offered analytical solutions for describing water movement in the unsaturated zone and validated through several laboratory experiments. However, it becomes highly hypothetical if field situations are simulated under laboratory conditions and using mathematical formulations. Therefore, in the present study an attempt is made to simulate the soil moisture movement in the unsaturated zone by combining both field and numerical models.

Recharge to aquifers is considered as the main source of groundwater, while moisture in the soil has a big role on the plant growth and evapotranspiration processes and on the quantity of recharge of

groundwater to aquifers. Thus, prediction of soil moisture content and aquifer recharge has an important impact on water resources management. Therefore, in this study, a numerical model named 'SWIM' or 'Soil Water-Infiltration and Movement Model' is used to simulate soil moisture distribution and to estimate aquifer recharge under different land use/covers in parts of Ghataprabha catchment which is tributary of river Krishna. The model is based on finite difference method which solves Richard's equation for unsaturated flow. Input data to the model such as rainfall rate, evaporation, capillary head, hydraulic conductivity etc, are obtained from the monitoring agencies and also by measurements in the field and laboratory.
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The present study has been carried out to simulate the soil moisture movement in Ghataprabha sub basin, a tributary of river Krishna, using the SWIM model.

Description of the study area

The study area of Ghataprabha catchment lies between latitudes $15^0$50' and 16^0 40' N and longitude 74^0 08' and 74^0 30'E. The Ghataprabha river originates from the Western Ghats at an altitude of 884 m, flows eastwards for a length of 283 km before joining the Krishna. Tamraparni river is a tributary of river Ghataprabha joins the main stream at Daddi. A dam has been constructed at Hidkal (which is about 20-25 km from Daddi) in Hukkeri taluk (Belgaum district, Karnataka, India) to impound 2200 Mm^3 of water for supplying to adjoining taluks for irrigation purpose.

Geomorphology, Soil and Geology

Geomorphologically, the catchment is relatively flat and gently undulating with isolated hillocks intervened by valleys. The catchment is somewhat oval in shape. The relief of the basin varies between 682 m and 1039 m. Very steep contours are observed towards western side of the basin. The high basin relief observed in the catchment is an indication of higher potential energy available to move water and sediment downstream. a) Lateritic soils (Coarse shallow soil , 22.3 % and medium deep soil, 21.4%), Coarse shallow black soil (10 %) and Medium black soil (45.8%).

According to Munsell's system of color notation, soils in the upper catchment areas having dense forest cover are characterized by brown (7.5 YR-4/4) to dark reddish brown (5Y-3/3) color and light loam to heavy loam in texture. In areas covered by shrubs, soils are brown (5 YR- 4/4) in color. However, in the northern boundary of the catchment the soils are reddish brown (5YR-3/4) in nature with a medium loam texture. In the downstream of the catchment (near Daddi), color of the soil varies between yellowish brown (10 YR – 5/8) and reddish brown (5 YR – 4/3) with medium to heavy loam texture.

The geological formations found within the basins are (i) Deccan traps of Tertiary age; and (ii) sedimentary formations known as `Kaladgi group' comprising limestone, shale and quartzites. The spatial distribution of land use shows that 13.8 % is covered by forest, 35.05% is covered by shrubs, 8.35% covered by fallow lands and 42.8 % covered by Agriculture (Purandara et al, 1997).

Methodology

The present study involves modeling of soil moisture movement and solute transport in the red and black cotton soils of Ghataprabha sub-basin (up to dam site) using the SWIM Model.

Field Investigations – measurement of saturated hydraulic conductivity using Guelph Permeameter (Reynold et al, 1985) and soil sampling before and after the application of irrigation.

Laboratory Investigations – Determination of soil moisture content, soil satuarted hydraulic conductivity using Guelph permeameter and soil moisture retention characteristics using the Pressure Plate Apparatus.

Modelling of soil moisture movement using the SWIM model. Daily rainfall and evaporation data for available stations within the catchment were used for the study. Field observed and simulated moisture profiles were simulated before and after irrigation.

Soil Water Infiltration Movement Model (SWIM)

SWIM is an acronym that stands for Soil Water Infiltration and Movement (SWIM). SWIMv2.1 is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution of moisture content, solute transport, plant uptake and transpiration, soil evaporation, deep drainage and leaching. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e. g. precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model.

The governing partial differential equation (Richard's equation) applicable for one-dimensional flow in the unsaturated zone can be written as:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\mathrm{K}\left[\frac{\partial\psi}{\partial x} + \frac{dz}{dx}\right] + S \qquad \textbf{(1)}$$

where θ = volumetric water content (cm^3/cm^3)

t = time (h)

x = distance into the soil (cm soil)

K = Hydraulic conductivity (cm^2 water/cm soil/h)

Ψ = matric potential (cm water)

z = gravitational potential (cm); and

S = Sink strength (cm^3 water/cm^3 soil/h)

The model deals with a one-dimensional soil profile. For a vertical soil profile, this means that it may be vertically inhomogeneous, but must be horizontally uniform. This assumption has two consequences of importance in many common simulations. There is only one hydraulic conductivity function for each layer, so that any macropore, or bypass flow can only be accounted for in a limited way. Secondly, the calculated solute concentrations apply to the whole soil layer, which means that there is no concentration gradient from the bulk soil to near the root surface. The presence of such a concentration gradient may in reality affect the soil osmotic potential and hence water and solute uptake. The overall purpose of the model is to address issues relating to the soil water and solute balance. As such it is a research tool that can be integrated in laboratory and field studies concerned with soil water and solute transport (Verberg et al., 1996).

Input Data

Input data such as average monthly rainfall, evaporation, moisture content, soil hydraulic properties etc. are shown in table 1, 2 and 3.

Simulation of Soil Moisture Movement

In the present study, the Ghataprabha basin up to Daddi (upstream of Hidkal dam) is considered for the study. The catchment area of the Ghataprabha basin is divided into 10 micro-hydrological regions as shown below. Each micro-hydrological region is characterized by specific type of geology, soil and land use pattern. (i) Forests with coarse shallow soil and sedimentary rocks, (ii) Agricultural land with coarse shallow soil and sedimentary rocks, (iii) Shrubs with medium deep soil and basaltic rocks (iv) Agriculture land with medium deep soil and basaltic rocks (v) Forests with medium deep soil and basaltic rocks (vi) Shrubs with coarse shallow soil and basaltic rocks, (vii) Agriculture land with coarse shallow black soil and basaltic rocks, (vii) Barren land with coarse shallow black soil and basaltic rocks (viii) Barren land with medium deep soil and basaltic rocks, (ix) Agriculture land with medium deep soil and basaltic rocks.

The upper catchment is dominated by red shallow soil with high rainfall and downstream area is covered by black soil with moderate rainfall. The permeability of the red soil is significantly higher than the black soils. Soil moisture profiles were simulated under two soil regimes using SWIM model. Figures 3 & 4 represent the observed and simulated moisture profiles of the upstream (red soil) and downstream (black soil) regions of the study area. It is noted that both observed and simulated profiles follow a similar trend thereby strengthening the applicability of SWIM model for soil moisture modeling studies.

From the above study, it is noticed that the SWIM model predicts the moisture movement reasonably well. Therefore, further attempt was also made to simulate the moisture movement after the application of irrigation water in both red and black soils of the same locations. Figure 5 & 6 shows the observed and simulated moisture profiles immediately after the application of irrigation water. The results indicate that in the case of red soils there is decrease of moisture approximately up to 100 cm depth. However, beyond this depth, an increase in the moisture content observed. The increase of moisture content below 100 cm is attributed to the drastic change in soil hydraulic properties. In this zone soil is relatively finer and exhibited lower permeability (Tejaswini, 2000) and ponding of infiltrated water takes place. Therefore, due to capillary movement, ponded water moves upwards thereby increasing the moisture content in bottom layers. Similar study was conducted by Purandara et al (2005) in Malaprabha sub basin. Further, in the black soils, a reverse phenomenon is observed. The moisture is higher in the top layers, i.e. up to 60 cm and below there is a sudden decline in the moisture content. This is due to the lower hydraulic conductivity of black soils which inhibits the movement of water to bottom layers. In the top layer higher moisture is observed due to preferential flow paths developed due to swelling and cracking which is the typical characteristic of black soil. Therefore, in th case of black soil, physical properties of soil plays a significant role in maintaining the soil moisture status. Apart from this, the cropping pattern is also major factor which determine the rate of water flow (e.g. hydraulic conductivity).

Conclusions

Though the SWIM model predicted the soil moisture variation close to the field conditions, it is evident that, the soil profile consists of different layers with distinct physical characteristics and root activity. The thickness and physical characteristics of each layer must be specified for soil moisture simulations. The mathematical equations describing the soil processes are the same for all layers, but the outcome is specific to each layer in view of varying parameter values. Therefore, it is quite essential to have more representative set of soil data in order to predict the moisture movement under varying soil and land use conditions.

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References

B. K. Purandara and V. K. Choubey, 1997. Remote Sensing Application in Optimal use of Water Resources, Journal of Indian Water Resources Society; Vol. 17 (3), No. 2.

Purandara, B. K., N. Varadarajan, and C. P. Kumar. 2005. Modeling of Soil Moisture Movement and Solute Transport processes in an Agriculture Field – A Case Study

W. D. Reynolds and B. E. Elrick, 1985. ‘Measurement of field saturated hydraulic conductivity, Sorptivity and the conductivity – pressure head relationship using the Guelph Permeameter’. Proceedings, National Water Well Association conference on Characterization and monitoring of the vadose (unsaturated) zone, Denver, Colorado, November.

B. K.. Tejaswini, 2000. Assessment of Cumulative Watershed Effects in Ghataprabha Representative basin. M. Tech Dissertation, VTU, Belgaum.

Verburg Kirsten, Ross, P. J., and Bristow, K. L., 1996. ‘SWIMv2.1 User Manual, Divisional report No. 130. CSIRO, Australia.

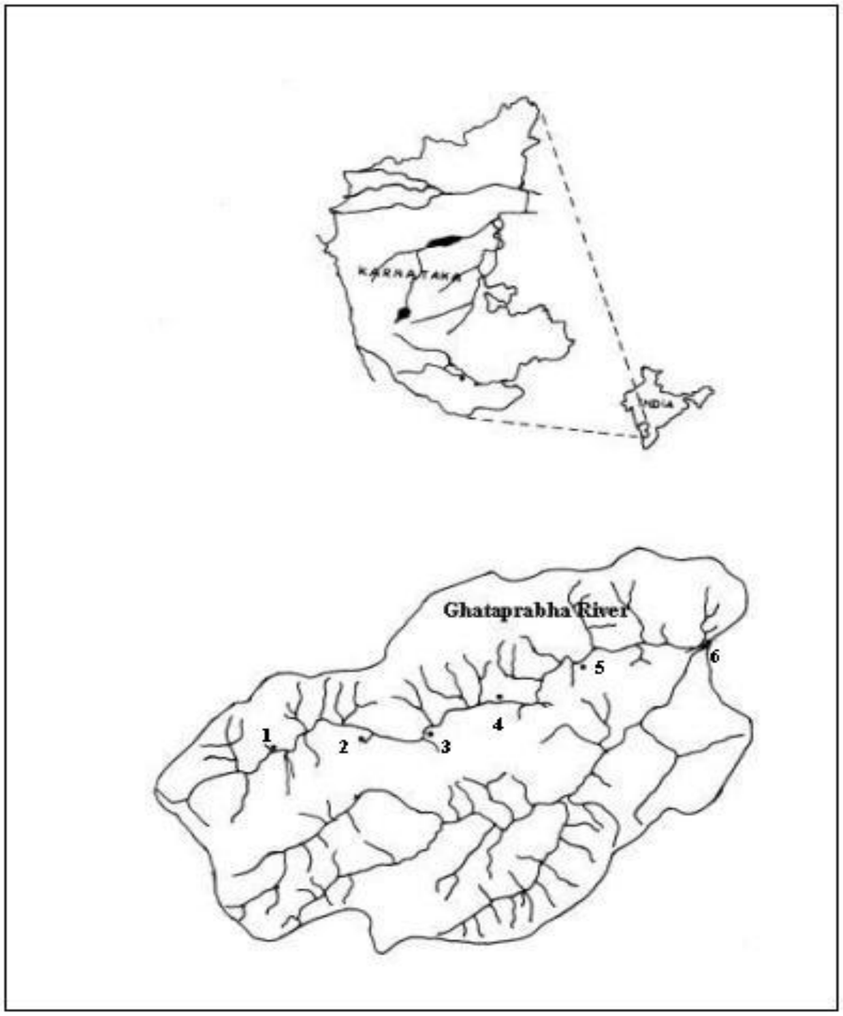

Figure 1: Ghataprabha Representative Basin with Water Sampling Locations

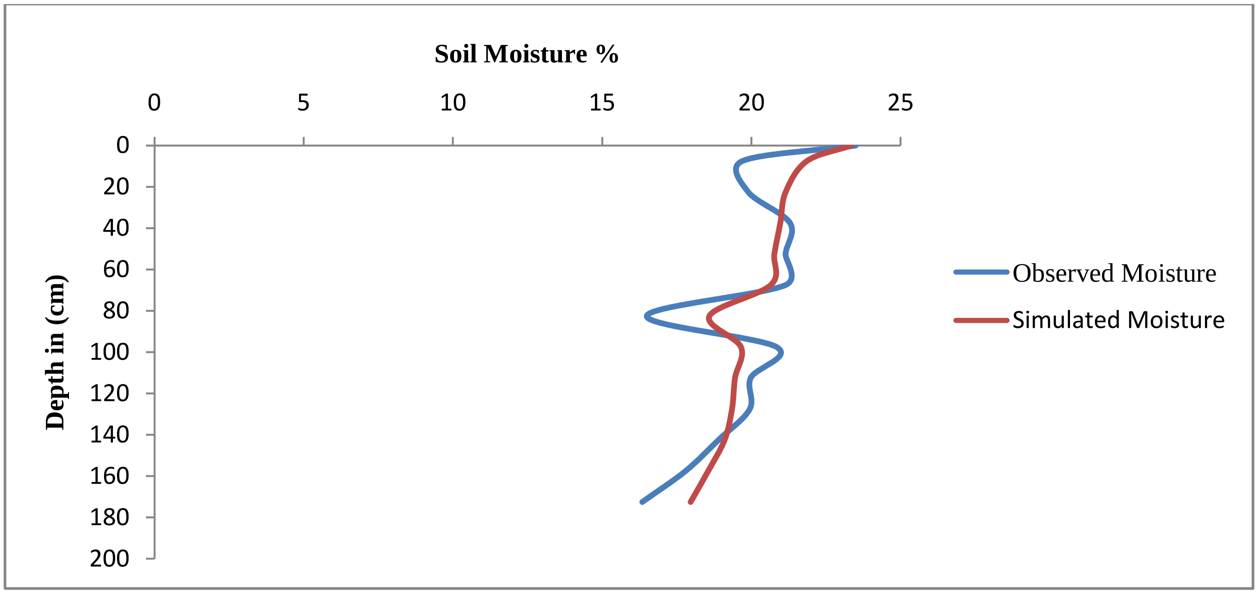

Figure 3: Observed and Simulated moisture profiles before the application of irrigation in Red soil

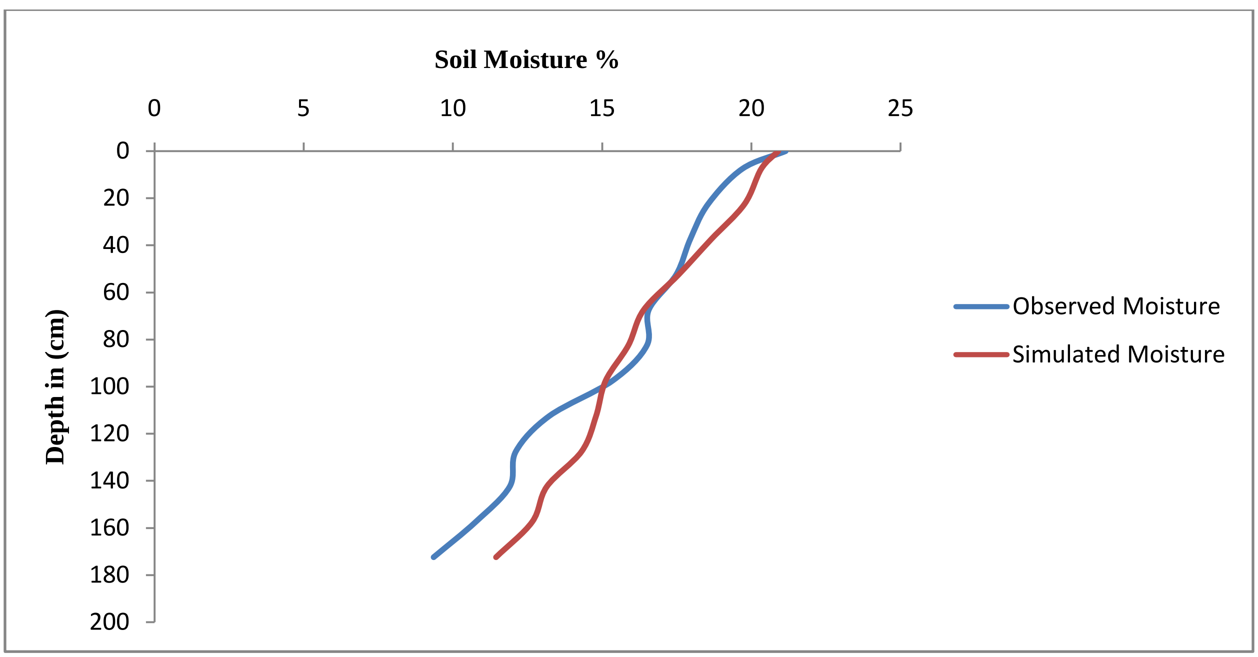

Figure 4: Observed and Simulated moisture profiles before the application of irrigation in Black soil

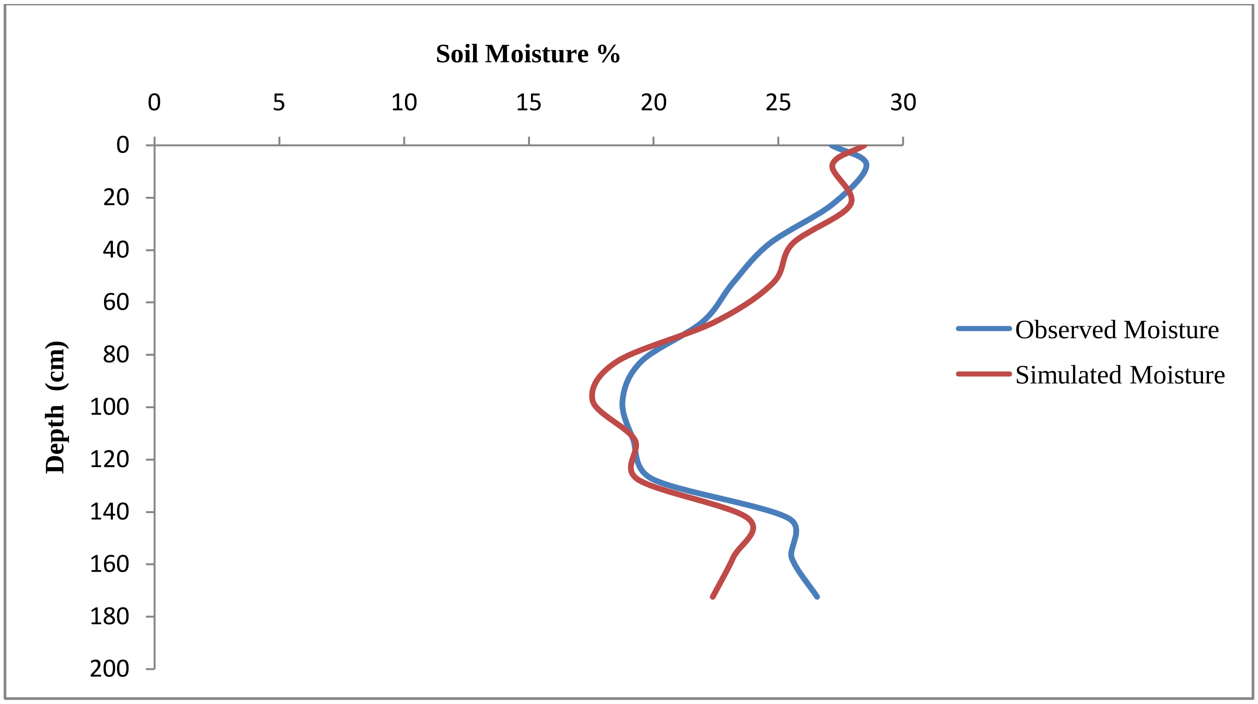

Figure 5: Observed and Simulated moisture profiles after the application of irrigation in Red soil

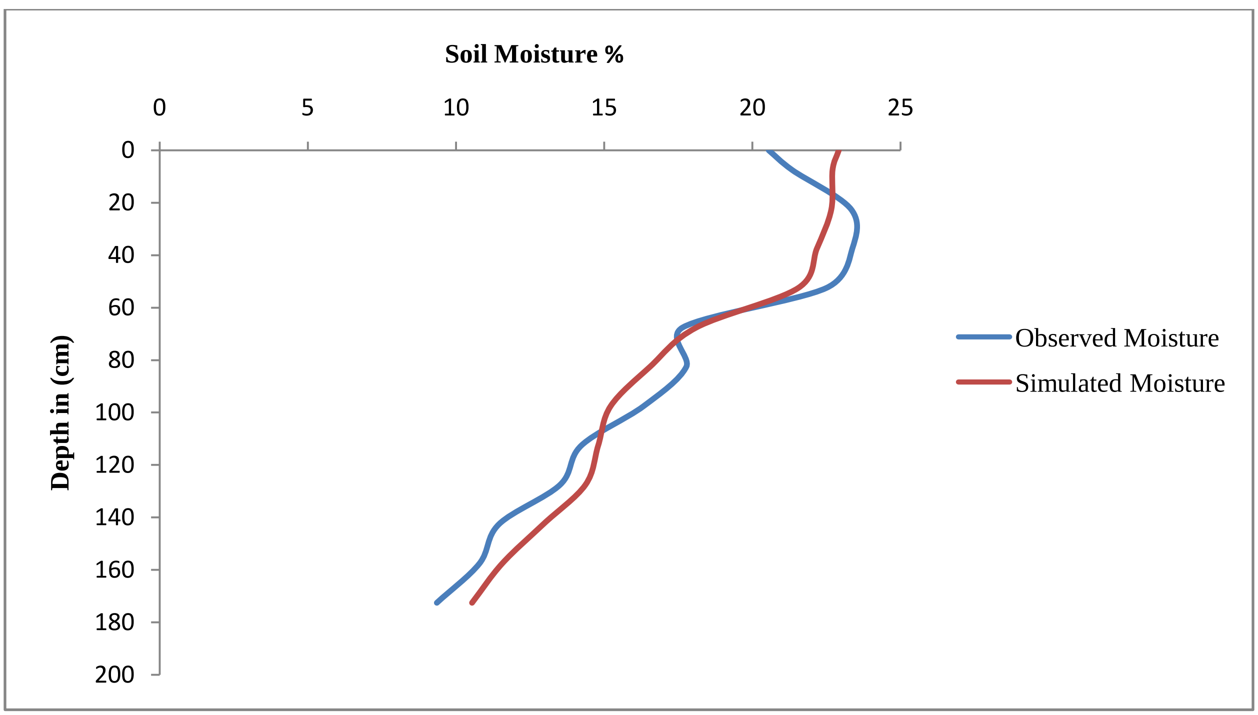

Figure 6: Observed and Simulated moisture profiles after the application of irrigation in black soil

Table 1: Average Monthly Rainfall in the Ghataprabha basin (mm)

Months	Average Rainfall (mm)	Average Evaporation (mm)
Jun	384.3	193.00
Jul	723.4	129.60
Aug	441.6	112.00
Sep	150.7	114.40
Oct	80.2	159.90
Nov	25.5	157.00
Dec	2.8	127.60
Jan	0.1	152.20
Feb	0.9	188.30
Mar	7.3	224.90
Apr	26.7	289.00
May	71.8	178.60

Table 2a: Soil Hydraulic properties Physical characteristics of soils in Ghataprabha catchment (%)

S.No.	Soil type	Saturated Moisture Content (%)	Residual Moisture Content (%)	Hydraulic Conductivity mm/hr	Van Genuchten Parameters	
					α	n
1	Red soil (top layer)	29.8	24.1	15.47	0.00323	1.545
2	Red soil (bottom layer)	27.7	12.4	13.94	0.00277	1.370
3	Black soil (top)	47.2	18.7	12.381	0.00180	1.33
4	Black soil (bottom)	53.3	7.3	6.567	0.00215	1.66

Table 2b. Soil moisture Retention characteristics (%)

Stations	Pressure in Bars								
	0	0.1	0.3	0.5	0.7	1.0	5.0	10	15
Red soil	39.9	33.7	30.7	25.3	24.24	20.77	20.09	19.20	18.81
Red soil	31.2	23.19	20.20	19.07	17.10	15.40	13.35	11.20	9.27
Black soil (top layer)	48.72	36.45	32.3	27.39	22.43	21.90	17.77	16.12	12.45
Black soil (bottom layer)	55.37	34.33	29.92	27.63	26.37	22.39	21.89	20.50	17.55