# DETERMINATION OF DEEP PERCOLATIONS via SOIL MOISTURE APPROACH IN SAIGON RIVER BASIN, VIETNAM

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***Abstract*— *As a critical factor of the groundwater balance, the groundwater recharge rate plays an essential role in determining sustainable yields for groundwater resources, especially in overexploited aquifers. ~~Traditionally, due to the difficulty of measurement, groundwater recharge could be estimated based on lysimeter, unsaturated zone water balance, Darcy flux, water table fluctuation, tracer, and parameters optimization from groundwater modeling. However, soil profile somehow cannot be validated, and lead land recharge incorrectly equated with the sustainable yield of an aquifer. Hence, ~~T~~t~~he paper focused on describing deep percolation flow using Richard's function (Hydrus 1D). First, the field measurement was designed, and moisture sensors were installed in three locations in Saigon River Basin, Vietnam. Second, the daily deep percolation of 3 soil types is simulated using the Hydrus 1D model. The water retention parameters are calibrated and verified by field experimental data in the study area. Third, relationship~~p~~ of effective rainfall and land recharge is~~are~~ analyzed to detect the deep percolation functions for 3 soil types in the study area. Finally, the assessment water balance provides a better understanding of the deep percolation flow mechanism. The investigation gives an insight on deeper percolation as well as potential land recharge from rainfall utilizing soil moisture approach for developing groundwater modeling. The percolation ratio of sand clay loam, sand clay, and clay are estimated 0.33, 0.22, and 0.18, respectively. Henceforth, the deeper percolation procedure and results will be useful for further determining groundwater yields and disaster management as in the consecutive drought years.*

**Keywords— Deep percolation; Hydrus 1D; Soil moisture approach, Saigon River basin**

## I. INTRODUCTION

Since 1990s, under the pressure of social economic growth in the Ho Chi Minh City, the water resources are facing a critical shortage during current drought years. To meet rising water demand, the groundwater extraction is exploited excessive which cause dramatically drawdown to aquifers. In order to have well planned for sustainable socio development, groundwater recharge mechanism needs to be explored more intensively under transient condition. Although land recharge is one of important factor [1], investigation of land recharge somehow remains a challenging task.

Since 1960s, there are varied commonly methods applied to estimate natural groundwater recharge, e.g., i) soil water balance method [2-7], ii) zero flux plane method [8-12], iii) one-dimensional soil water flow model [13-17]; iv) infiltration test using single ring, double rings, the well permeameter [18, 19], v) inverse modeling technique [20-22], vi) groundwater level fluctuation method [6, 23, 24], vii) Chemical/ radioactive method[25-28]. However, these methods sometimes are difficult and expensive in the field test. Moreover, the water balance in unsaturated zone cannot be evaluated easily and lead incorrectly equated with the sustainable yield of an aquifer.

Along the development of technology, soil water content can be monitored via Arduino soil moisture sensor [29, 30]. This approach shows potential useful to validate soil profile under water movement process. Hence, the paper focused on describing deep percolation flow using Richard's function (Hydrus 1D) and observed soil moisture via field sensors. First, the field measurement system was designed and installed three locations in the Saigon Basin. Second, the daily deep percolation of 3 soil types (sand clay loam, sand clay, ~~clay~~and clay) are simulated using the Hydrus 1D model. The water retention parameters are calibrated and verified by field experimental data from Oct 2017 to August 2018 in the study area. Third, relationship effective rainfall and land recharge are analyzed to detect the deep percolation function for 3 soil types in the study area. Final, the assessment water balance provides a better understanding of the deep percolation flow mechanism.

These investigations gave an insight on deeper percolation as well as potential land recharge from rainfall utilizing soil moisture approach for developing groundwater modeling. Henceforth, the deeper percolation procedure and results will be useful for further determining groundwater yields and disaster management as in the consecutive drought years.

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## II. Study Area

Study area stretches from latitude 10.320 E to 11.201 E and from longitude 106.215 N to 107.024 N with an area of 6,640 $km^2$. It covers all area of Ho Chi Minh City and some districts of Dong Nai, Binh Phuoc, Binh Duong, Long An and Tay Ninh Province (Fig. 1). The area has a tropical climate, specifically a tropical wet and dry climate, with an average humidity of 75%. The year is divided into two distinct seasons. Mean annual rainfall is at 1,612 mm and mean annual temperature is at 27$^o$C. Terraced plain mainly characterizes the topography of the area with elevation varies from 0 MSL to 70 MSL. In the area, there are 3 major rivers as Sai Gon River, Vam Co Dong River, and Dong Nai River. Regarding soil type, the monitor soil sensors were set up in 3 locations, i.e., B1 is sand clay loam, B2 is sand clay, ~~B3~~and B3 is clay.

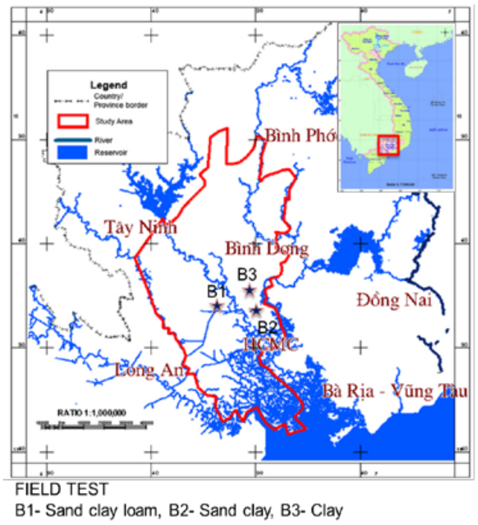


Fig. 1. Study area

## III. Theories And Procedures Used

The study began by installing soil moisture sensors in 3 field sites with automatic data collection. There soil samples were collected to calibrate soil moisture sensors in the lab. Then, the percolation flows are simulated using Richard's function (Hydrus 1D). The water retention parameters are calibrated and verified by observed soil moisture in the field. The performance of soil moisture simulation is justified due to statistic parameters and the regression. The water balance was accessed to give better understanding on percolation movement. Finally, the percolation is analyzed to find the ratio between land recharge and effective rainfall. The procedures of study are shown as Fig. 2.

### A. Field measurements

At field sites, the Arduino sensors were installed every meter in 5 meters depth. The soil moisture sensor monitored every 1-meter depth daily. The soil moisture of each soil type is calibrated with moisture measurement in the lab. Then, the measurements in three field sites are converted to soil moisture. The circuit includes Arduino board, soil moisture module, and soil moisture sensor (copper plate), automatic data transmit. The study approach is summarized and shown in Fig. 3.

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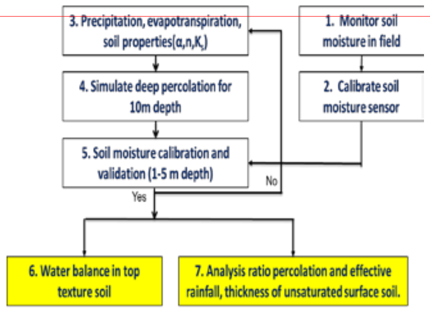


Fig. 2. Study procedures

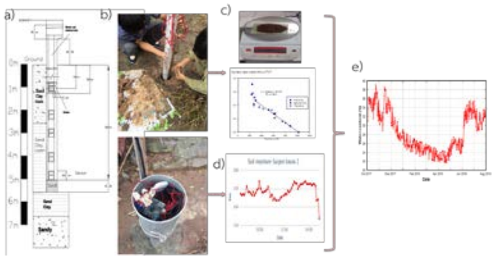


Fig. 3. Approch of field measurement (a: borelog design; b: inject sensor into soil; c: calibration soil moisture; d: field measurement data; e: monitor soil moisture)

### B. Percolation simulation theories

The governing flow equation for the uniform Darcian flow of water in a porous medium is adopted by the following modified form of the Richards' equation: (Simunek, Van Genuchten, and Sejna 2005)

$$\frac{\delta\theta}{\delta t} = \frac{\delta}{\delta x_i}\left[K\left(K_{ij}^{A}\frac{\delta h}{\delta x_j} + K_{iz}^{A}\right)\right] - S \quad (1)$$

θ is the volumetric water content, ($L^3L^{-3}$)

K is the hydraulic conductivity ($LT^{-1}$),

h is the pressures head (L)

S is a sink term [$T^{-1}$]

~~$x_i$ (i-1,2) are~~ $x_i$ (i-1,2) is the spatial coordinates [L], t is the time (T) and

z is the vertical ordinate (L)

$K^A_{ij}$ are components of a dimensionless anisotropy tensor $K^A$

K is the unsaturated hydraulic conductivity function [$LT^{-1}$] given by

$$K(h) = K_s S_e^{1/2}\left[1 - (1 - S_e^{1/m})^m\right]^2 \qquad (2)$$

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1 - |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \qquad (3)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (4)$$

m=1-1/n, n>1 (5)

$S_e$ is the effective water content

$\theta_r$ denote the residual water content

$\theta_s$ denote the saturated water content

$K_s$ is the saturated hydraulic conductivity

α is the inverse of the air-entry value (or bubbling pressure)

n is a pore-size distribution index

The percolation simulation applied rainfall and evaporation of study area from Oct 2017 to August 2018. The upper boundary condition is set as atmosphere condition. The bottom boundary condition is set as seepage condition. The initial retentions parameters ($\theta_r$, $\theta_s$, α , n, $K_s$) are referred from Rosetta program [31].

## IV. Results and Discussions

### A. Field measurement

In this experiment, the percolation rates at each depth w~~ereas~~ compared with effective rainfall. The effective rainfall defines as rainfall minus evaporation. Fig. 4 shows sample of field observed water content and effective rainfall (rainfall-evaporation) during Oct 2017- August 2018 at sand clay loam field site. The observed water content corresponded with effective rainfall. The soil moistures at 1 m depth are sensitive with rainfall event. The lower soil depth has less sensitive with rainfall events.

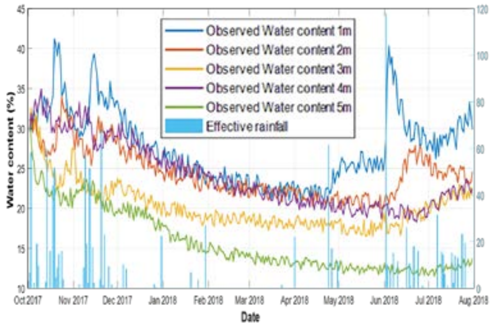


Fig. 4. Observed water content and effective rainfall during Oct 2017-August 2018 at sand clay loam field site

Fig. 5 shows soil moistures of 3 soil types at rainy season 2017 and dry season 2017. The difference of soil moisture in sand clay loam is the highest. ~~Clay shows t~~The ~~lowest~~ difference of ~~in~~ soil moisture in clay is the lowest. The soil moisture increases after rainy season and decreases after dry season. The measurement data show that modified soil moisture sensors give reliable value under natural condition. Then, the percolation and water balance analyses can apply the field soil moisture data via installed sensors.

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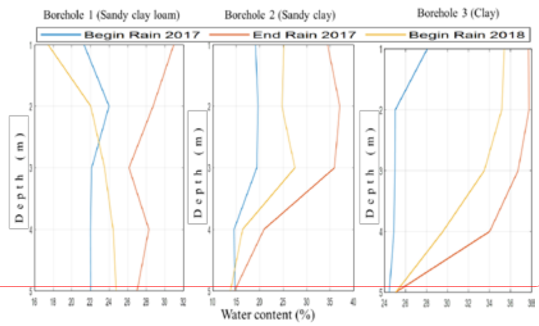


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Fig. 5. Soil moistures of 3 soil types in~~at~~ rainy season 2017 and dry season

2017

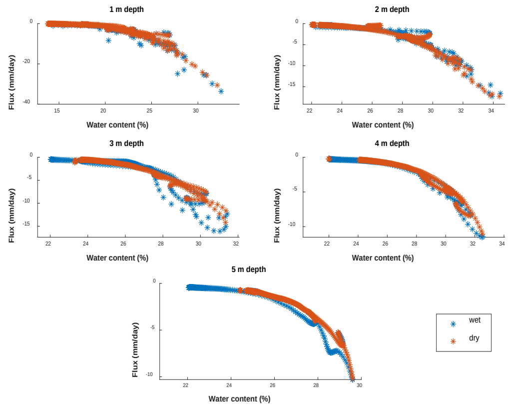


Fig. 6. The relationship between fluxes in filed test and water contents of sandy clay loam

Fig. 6 demonstrates the relationship between fluxes in filed test and water contents. The flux and soil moisture show closed relationship, especially in seasonal. The fluxes in wet season are higher than in dry season.

## *B. Calibration and verification of percolation simulation*

Retention parameter calibrations relied on performance statistics of observed soil moisture. In calibration step, the calculated soil moistures of three soil type match well with observed data. The maximum error (%) is 2.98 to 1.45. The minimum error (%) is 0. The mean error (%) is 0.66 to 1.16. The RMSE is 0.67 to 1.37. The R-square is 0.7 to 0.88. The Nash coefficient is 0.65 to 0.8. In verification step, the calculated soil moistures of three soil type are similar with observed data. The maximum error (%) is 4.68 to 1.35. The minimum error (%) is 0. The mean error (%) is 0.8 to 1.8. The RMSE is 0.83 to 1.81. The R-square is 0.65 to 0.8. The Nash coefficient is 0.62 to 0.8.

TABLE I shows the soil retention parameter values after calibration and verification. The soil retention parameters are proportional with percentage of sand. The α, n, K parameters decrease in deeper depths. The sand clay loam has highest hydraulic conductivity. The lowest hydraulic conductivity is clay.

TABLE I. SOIL RETENTION PARAMETERS AFTER CALIBRATION AND VERIFICATION

| | Depth | Sand (%) | Silt (%) | Clay (%) | Soil type | $\theta_r$ | $\theta_S$ | α (1/mm) | n (-) | K (mm/day) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Borehole 1** | 1m | 71.4 | 14.6 | 13.9 | Sandy loam | 0.065 | 0.41 | 0.0075 | 1.89 | 361 |
| | 2m | 67.5 | 8.5 | 24 | Sandy clay loam | 0.0605 | 0.3807 | 0.0029 | 1.6 | 124.4 |
| | 3m | 65.5 | 6.5 | 28 | Sandy clay loam | 0.0605 | 0.3807 | 0.00277 | 1.64 | 120.3 |
| | 4m | 63.2 | 16.4 | 20.4 | Sandy clay loam | 0.0644 | 0.3919 | 0.0029 | 1.48 | 114 |
| | 5m | 64.1 | 12.8 | 23.1 | Sandy clay loam | 0.0629 | 0.3807 | 0.0015 | 1.7 | 120 |
| **Borehole 2** | 1m | 50.2 | 10.4 | 39.4 | Sandy clay | 0.1 | 0.38 | 0.0035 | 1.65 | 55.8 |
| | 2m | 53 | 9.6 | 37.4 | Sandy clay | 0.1 | 0.38 | 0.0032 | 1.62 | 51 |
| | 3m | 54.5 | 7.5 | 38 | Sandy clay | 0.1 | 0.38 | 0.0031 | 1.65 | 45 |
| | 4m | 56 | 5.7 | 38.3 | Sandy clay | 0.1 | 0.38 | 0.0027 | 2.2 | 60 |
| | 5m | 61.3 | 4.6 | 34.1 | Sandy clay | 0.1 | 0.38 | 0.00025 | 2.1 | 65 |
| **Borehole 3** | 1m | 17.2 | 3.4 | 79.4 | Clay | 0.068 | 0.391 | 0.0015 | 1.29 | 15.6 |
| | 2m | 16.7 | 7 | 76.3 | Clay | 0.068 | 0.391 | 0.0012 | 1.25 | 17.6 |
| | 3m | 10.8 | 2 | 87.4 | Clay | 0.068 | 0.389 | 0.0008 | 1.25 | 18.1 |
| | 4m | 23.6 | 5.4 | 71 | Clay | 0.068 | 0.385 | 0.0006 | 1.26 | 24 |
| | 5m | 23.5 | 4.5 | 73 | Clay | 0.068 | 0.385 | 0.0004 | 1.75 | 27 |

## *C. Water balance analysis*

TABLE II shows total fluxes at three field sites from Oct 2017-August 2018. The fluxes in deeper depth are lower than in topsoil. The fluxes in lower depth also give a lag time compared with flux in upper depth (Fig. 7 as a sample). The percolation amount of sandy clay loam is the highest. In contrast, the clay has the lowest percolation. The gap between fluxes of two soil depth can be explained by the fluctuation water content in its depth.

TABLE II. TOTAL FLUXES AT THREE FIELD SITES FROM OCT 2017-AUGUST 2018.

| Soil type | Sand clay loam | Sand clay | Clay |
|---|---|---|---|
| **Total. Effective rainfall (mm)** | 2285.4 | 2285.4 | 2285.4 |
| **Total flux 1m (mm)** | 1849.09 | 1545.91 | 1174.2 |
| **Total flux 2m(mm)** | 1600.96 | 1328.26 | 964.38 |
| **Total flux 3m (mm)** | 1420.21 | 1218.19 | 809.21 |
| **Total flux 4m (mm)** | 1112.36 | 1176.35 | 577.81 |
| **Total flux 5m (mm)** | 988.17 | 525.47 | 421.58 |

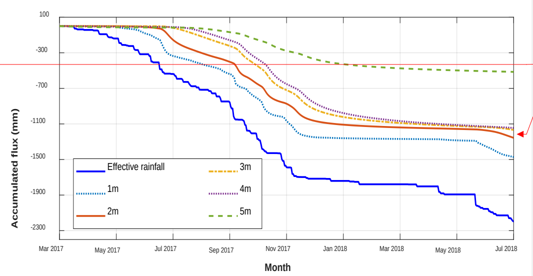


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Fig. 7. Accumulated flux at the field site of sandy clay loam

Fig. 8 shows water balance of 3 soil types during wet season. The difference of water content in clay during rainy season is the highest. Therefore, water was captured in upper soil layer and cannot reach to bottom layer at the same rate. While the delta water content in sand-clay loam and sand-clay are lower than clays. Thus, deep percolation amount of sand clay loam and sand-clay are higher than clay's. This experiment also reveals that grain size of soil and percentage of sand has strong relationship with percolation flux.

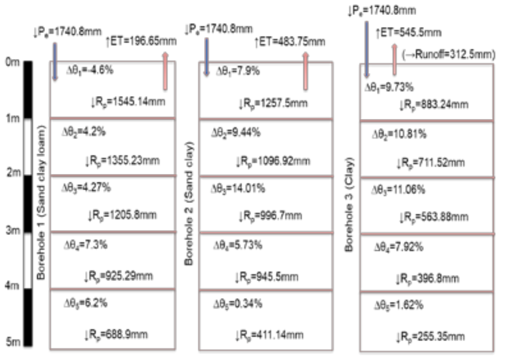
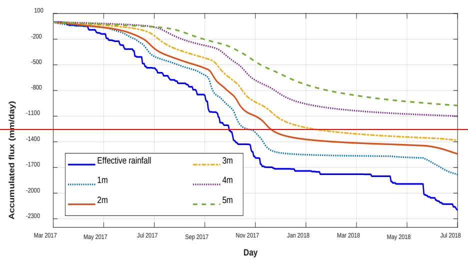



Fig. 8. Water balance of 3 soil types during wet season




Month (not day)

Fig. 7. Accumulated flux at the field site of sandy clay loam

Fig. 9 shows water balance of 3 soil types during dry season. The difference of water contents in upper soil depth is low. Hence, the rainfall did not infiltrate in dry season. While, the difference of water contents in lower soil depth is high. These phenomena can help to explain the lag time of fluxes in lower depth. The sandy clay loam shows the highest amount of percolation after lag time. In other side, sand clay and clay have similar amount of percolation after lag time.

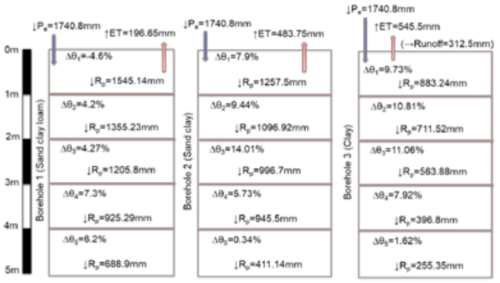



Fig. 8. Water balance of 3 soil types during wet season

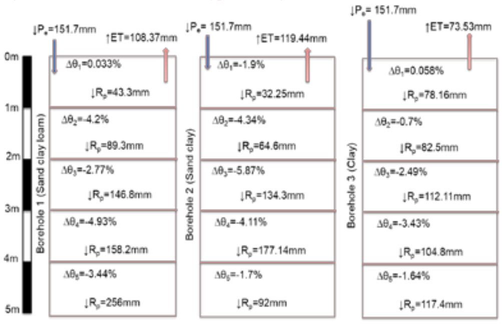



Fig. 9. Water balance of 3 soil types during dry season

## *D. Percolation rate ratio*

The percolation fluxes were compared with effective rainfall to find the percolation rate ratio in study area. The percolation rate ratios of three soil types decrease from top to bottom depth. The highest ratio is sand clay loam. The second ratio is sand clay. The lowest is clay. The ratio of sand clay loam from top to bottom is 0.8 to 0.33. The ratio of sand clay from top to bottom is 0.67 to 0.22. The ratio of clay from top to bottom rate is 0.5 to 0.18.

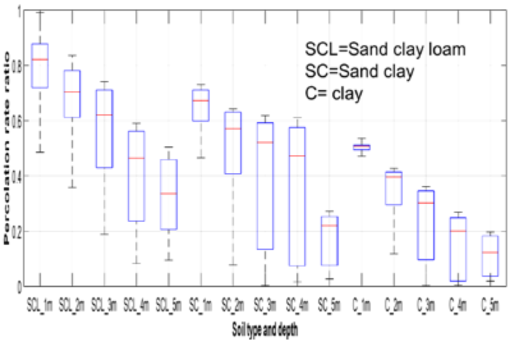



Fig. 10. Percolation rate ratios of 3 soil types

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## V. CONCLUSIONS

The percolation ratio is proportional with percentage of sand in soil (Fig. 11). The water was captured in upper clay layer and reach difficultly to bottom layer. While the water pass through sand clay loam and sandy clay more than clay. Under high evaporation, rainfall in dry season cannot infiltrate to soil. Hence, the percolation rate in dry season at 5 meter is from water of upper soil which absorbed during wet season.

The percolation ratio of sand clay loam, sand clay, and clay are 0.33, 0.22, and 0.18, respectively (Fig.12). The experiments are in concordance with the results of previous study [32], which also pointed out land recharge is limited to 27.6% of rainfall.

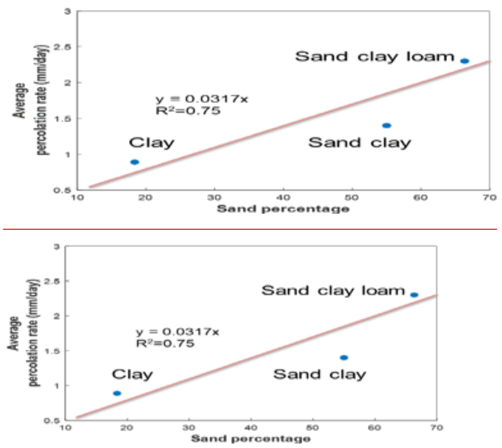


Fig. 11. Relationship between percolation rate and percentage of sand

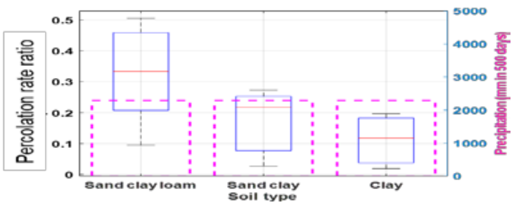


Fig. 12. Percolation rate at 5 meters of 3 soil types

These experiments presented an insights approach to estimate better deep percolation from effective rainfall via field soil moisture sensor. The approach gives better understanding mechanism of deep percolation. The approach has potential to help planning the water resources and disaster management more efficient in the consecutive drought years.

## ACKNOWLEDGMENT

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