FIELD SCALE PONDING INFILTRATION ASSESSMENT USING MODIFIED GREEN-AMPT APPROACH

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The Green-Ampt, GA infiltration concept has been used for decades to estimate the soil water infiltration capacity, but lacks the estimation of reliable hydraulic parameters, especially in field conditions for ponding irrigation. In this study, we have derived a solution for classical Green-Ampt model CGAM by taking valid hydraulic conductivity parameters and wetting front pressure head relating to van Genuchten model parameters and sorptive number in modified form of Green-Apmt model, GAMM. The infiltration experiments were conducted in the laboratory and field at different locations in 2018. The GAMM was calibrated and compared to Philip and CGAM for field application to study its performance in heterogeneous soil. The CGAM underestimated the cumulative infiltration, while GAMM gives reliable estimates. The infiltration rate was better estimated by CGAM when the proposed air entry head was incorporated for wetting front suction head estimation. We use Root mean squared error RMSE, Nash Sutcliff Efficiency NSE, and coefficient of determination $R^2$ for the Philip, CGAM and GAMM models comparison using measured and estimated values. It is concluded that the effective hydraulic conductivity will always be less than saturated hydraulic conductivity in field conditions. In GAMM taking modified air entry head and effective saturation performed better than CGAM, which showing its dependency on effective soil water saturation and sorptivity for field application. Effective utilisation of the GAMM model in field will give actual infiltration capacity of heterogeneous soil.

**Keywords:** Modified Green-Ampt model; Effective Hydraulic conductivity; Air Entry Head; Soil moisture sensors.

INTRODUCTION

Infiltration is the entry of water into soil profile with varying velocity. The soil characteristics that changes spatiotemporally determines the soil infiltration capacity and rates, such as soil moisture content, soil texture and structure, vegetation types and cover, soil water temperature, and porosity (Green and Ampt, 1911; Abu-Awwad, 1997; Jejurkar and Rajurkar, 2012; Yuan et al., 2013) and soil crust. The need for a model that could be used for multipurpose hydrogeological simulation, and a hybrid method is needed using multiscale approach for simulation. The field water infiltration and hydraulic conductivity assessment is also a complicated job for field scale irrigation estimation, to assess these variations in the field, various parametric infiltration models have been used.

The infiltration models performed differently under varying field conditions and double ring infiltrometer (DRI) sizes, (Jejurkar and Rajurkar, 2012) such as the soil porosity, organic matter, soil texture and structure, moisture content and capillary formation (Yuan et al., 2013). The field parameters i.e. soil suction, sorptivity, hydraulic conductivity and infiltration capacity have been related to geomorphological conditions of a watershed (Ravi et al., 1998; Duan et al., 2011). These parameters almost remains constant in homogenous soil and have uniform infiltration and hydraulic conductivity, but if the soil having different vertical layers will have varying hydraulic conductivity and infiltration (Philip, 1969; Shukla et al., 2003; Corradini et al., 2011). Just like other parameters, vegetation also has a significant role in the infiltration process (de Almeida et al., 2018). Therefore, to understand the vegetation response to infiltration processes, one must have a deep understanding of the vegetation dependent infiltration mechanisms. In another study, Ejurkar and Rajurkar, 2012 have mentioned that beside vegetation factor, there are also other essential parameters, i.e. moisture-holding capacity, evapotranspiration, aeration that need to be considered to understand the process of spatial infiltration variability in field conditions (Sharma et al., 1980). A number of infiltration tests were conducted for spatial variability assessment in a field conditions, using different models (Berndtsson, 1987; Razzaghi et al., 2016) and instruments (Merzougui and Gifford, 1987; Di Prima et al., 2017). It is more important to develop a model that represents the actual soil water infiltration process during ponding irrigation.

The infiltration variability was assessed on sandy soil in three different locations with 15 to 55% stoniness, varying soil moisture and vegetation during winter and summer (Gregory et al., 2005; Verbist et al., 2010, 2013; Ruggenthaler et al., 2016). There was no significant seasonal variations during infiltration (Wilcock and Essery, 1984).
A number of physical infiltration models have been used successfully for decades to simulate the solute transport and water flow in the vadose zone. The Green and Ampt modified infiltration model using effective hydraulic conductivity ($K_e$) as saturated hydraulic conductivity ($K_s$) in the original/classical GAM (Green and Ampt, 1911) or approximated to $K_s$ (Hammecke et al., 2003). The ratio of $K_e$ and $K_s$ changes with soil textures and antecedent moisture contents (Valiantzas, 2010; Stewart et al., 2013; Mohammadzadeh-Habili and Heidarpour, 2015) as well as with actual soil water saturation conditioning and air entrapped in the soil film (Ma et al., 2011). The GAM application for measuring field infiltration is more dependent on actual soil hydraulic properties. It does not follow the piston type distribution of soil moisture for field application (Ma et al., 2015).

In this study the effective hydraulic conductivity and absolute air entry head are used in the modified Green Ampt model, (Neuman, 1976; Wang et al., 2002; Ma et al., 2009). The concept of effective hydraulic conductivity for partially saturated flow in the field soils (DANE, J. H; TOPP, G C; CAMPBELL, G S; AL-AMOODI, L; DICK, 2002). The VG model parameters were evaluated by HYDRUS-1D software for an analytical solution (Ma et al., 2010, 2015).

When taking inlet pressure head $h_p$ as air entry head−$h_{ae}$, it overestimates the infiltration (Ma et al., 2009). While taking as complete air entry head (1/α), it best fits observed values, where the α is a Van Genuchten fitted parameter (Ma et al., 2015). The proposed Green-Ampt modified model GtAM was tested for infiltration estimation in varying field conditions, using modification for air entry head and effective hydraulic conductivity (Yates et al., 1992; Ma et al., 2015).

### MATERIALS AND METHODS

The double ring infiltrometer tests were conducted in the laboratory and field for infiltration estimation. The soil moisture conditions before and after trials at each site were evaluated at different depths using EC5 soil moisture sensors (Inc., 2018). The gravimetric method was also used to measure soil moisture and bulk density at different depths for the evaluation of the infiltration models parameters. The laser particle size analyser (Bettersize 2000, Bettersize Instruments Ltd, China) used for soil texture analysis gives a complete range of soil particle size. The saturated hydraulic conductivity was measured by a constant and falling head method in the laboratory (Reynolds and & Elrick, 2002; Moret-Fernández et al., 2017).

In the current study, a ½” automatic water level control valve (JUNY, JYN15, Wenzhou Junyoung Technology Co., Ltd, China) has been used to control the water level in the DRI inner and outer ring to the desired depth. The rate of water levels fall in a reservoir with time has been recorded to calculate the infiltration rate $i$ (cm/hr) and cumulative infiltration $I$ (cm) as $R = \Delta L/\Delta t$ for steady-state condition < 10% variation or a constant value of R for an applied head (H) as,

$$i = R \frac{A_e}{A_r}$$  \hspace{1cm} (1)

Where $i$ (cm/hr) is infiltration rate, $A_e$ ($L^2$) is the inner cross-sectional area of the water reservoir, and $A_r$ ($L^2$) is infiltration surface or inner ring cross-sectional area, $L$ ($L$) is water level fall in a reservoir, $t$ (T) is time.

### Site Selection and Sampling Techniques:

Yinchuan is a plain catchment located in the north of Ningxia (eastern part of Northwest China). The climate of Ningxia is arid to semi-arid according to Köppen–Geiger climate classification having annual mean temperature -0.7 to 9.9 °C and annual precipitation 289 mm/year with increasing trends from north to south 180 to 800 mm/year. Yinchuan’s annual average precipitation is 186.3 mm/year. The infiltration tests were conducted in the laboratory (School of Civil and Hydraulic Engineering, Ningxia University), and three different field sites between May and November 2018, where the two-stage sampling technique was used. During this technique, each Field (F) divided into sub-fields cited as location (L) with variations in vegetation cover, soil structure and texture, porosity, soil moisture content. The field tests were conducted in Yinchuan in Jinfeng county, Xixia county, and Yongning county.

The Van Genuchten model parameters were evaluated by using RETC computer code numerical solution (Ma et al., 2015). The best fit parameters were used in GAMM for the simulation of cumulative infiltration and infiltration rate. The soil moisture content was measured at different locations and depths during infiltration experiments using EC5 sensors in heterogeneous. The Figure (1) shows the change in soil moisture content of laboratory experiments at three different depths, where the silt loam soil was used having different initial moisture content and porosity.

The soil moisture content measured during four different trials having fine sandy loam soil at Yongning County at different depths in Figure (2). Where the change in soil moisture content is more in 10 cm depth, while the deep soil layers shows less change in moisture content specially at location 1, and 3 due to soil heterogeneity.

The soil moisture content measured at Jinfeng County at different depths is given in Figure (3). Where the soil at location 1 was sandy, that shows maximum change in
Infiltration assessment by using green-ampt

moisture content and heterogeneous soil at location 5 with minimum change in moisture content.

The Figure 4 shows the soil moisture content variation at Xixia County at six different locations. The minimum change was recorded at location 5, where the soil was saline sodic and more compact as compared to other locations. The maximum change in moisture content was observed at location 1 and 2 having uniform fine sandy loam soil and shallow water table.

The MATLAB and Excel programs used for Philip model parameters estimation using linear curve fitting technique and statistical models evaluation metrics of coefficient of determination ($R^2$), Adjusted $R^2$, Root Mean Squared Error (RMSE), Nash-Sutcliffe efficiency (NSE), Error sum of square (SSE), Mean, Median, Mode, Maximum, Minimum, and Geometric Mean.

The infiltration models of Philip, Classical Green-Ampt (GAM) and Green-Ampt modified model (GAMM) described below are used in this study. Field saturated hydraulic conductivity $K_{fs}$ comparatively less than true or complete saturated hydraulic conductivity $K_s$ (Warrick and Nielsen, 1980; Stephens et al., 1998), there for the saturated hydraulic conductivity measured by Bouwer (1986) method is used for the simulation of infiltration rate in the Green-Ampt model GAM.

Van Genuchten model parameters: The field-scale hydraulic conductivity $K_h$ variation mostly results of watershed characteristics such as soil heterogeneity (Reynolds and Elrick, 2002). Hence the quasi-state flow is acceptable in practice (Angulo-Jaramillo, 2016). The Van Genuchten parameters were estimated as (van Genuchten, 1980),

$$S_e = \left(\frac{\theta_e - \theta_r}{\theta_s - \theta_r}\right) = \frac{1}{\left(1 + (\alpha h)^n\right)^m}.$$  

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

Where $S_e$ is effective saturation, $\theta_e$ is actual, $\theta_r$ is residual, and $\theta_s$ is saturated water content ($L^3 L^{-3}$), and $n (> 0)$ is a dimensionless coefficient characterizing pore size distribution, Where $l$ is soil pore tortuosity factor, $K_s$ is
The soilially dry soil $S$ instead of van Genuchten applied water head, and $\Delta$ in uniform soil is given as,

$$I = \int_0^h K_s dh$$  \hspace{1cm} (8)

Where $h$ is the pressure head and $h_i$ is initial pressure head (cm) taken as negative here and $K_r$ is the relative hydraulic conductivity, $K(h)/K_s$. $K(h)$ is unsaturated hydraulic conductivity (cm hr$^{-1}$) measured by second-order polynomial fitting (Quadratic equation) (Whisler and Bouwer, 1970).

Green-Ampt Modified Model (GAMM): This modified form is comprised of two main concepts, the effective hydraulic conductivity $K_e$ instead of saturated hydraulic conductivity $K_s$ in Green-Ampt equation, and air entry head by taking sorptive number $\alpha'$ instead of van Genuchten $\alpha$. The soil hydraulic properties are used for the measurement of cumulative infiltration $I(t)$ (cm) and infiltration rate $i$ (cm/hr). The $I(t)$ (cm) into initially dry soil-derived analytically by Ma et al. (2015) incorporated in the classical Green-Ampt model (Green and Ampt, 1911).

$$t = \frac{I}{K_e - \frac{(\theta_s - \theta_i)(H_p - H_f)}{K_e} \ln \left[ 1 + \frac{I}{(\theta_s - \theta_i)(H_p - H_f)} \right]} \left[ 1 + \frac{I}{(\theta_s - \theta_i)(H_p - H_f)} \right]$$  \hspace{1cm} (9)

Where the cumulative infiltration $I$ (cm hr$^{-1}$) and wetting front advance is given as,

$$I = A \cdot Z_f$$  \hspace{1cm} (10)

Where $t$ is time (hour), $I$ is cumulative infiltration (cm), $H_p$ is ponding head (cm), $K_e$ is effective hydraulic conductivity (cm hr$^{-1}$), $H_f$ is wetting front negative pressure head (cm), $A$ is an increase in moisture content and $Z_f$ is the wetting front depth (cm). The $K_e$ and $H_f$ are calculated from van Genuchten retention function, and sorptive number of Elrick et al (1986) parameters as follows.

$$K_{e5} = \frac{(a+1)(\theta_{s5}-\theta_i)}{(a+2)(\theta_{s5}-\theta_i-\alpha(\theta_{s5}-\theta_i))} K_s$$  \hspace{1cm} (11)
We introduced $K_e$ using the concept of complete saturation avoiding entrapped air as follow.

$$K_e = \frac{(a+1)(\theta_s - \theta_i)}{(a+2)(\theta_s - \theta_i - a)} + 1$$  \hfill (12)

The Eq. (11) is modified for complete saturation and $K_s$ is replaced by 1.

$$H_f = H_p - \frac{(a+2)\theta_s - \theta_i - a(\theta_s - \theta_i)}{(a+1)(\theta_s - \theta_i)} \left[ \frac{2(1+\alpha)}{1+4a} \right] p + H_p$$  \hfill (13)

Where $\alpha$ is VG model parameter and $h_d$ is the absolute value of air entry suction ($cm^{-1}$) as, Ma et al., (2015) in Eq. (14),

$$\alpha = 1/h_d$$  \hfill (14)

While in Eq. (15) the proposed function for air entry head suction, the sorptive number $\alpha^*$ ($cm^{-1}$) is estimated as, (Bouwer, 1966; Elrick and Reynolds, 1992).

$$\alpha^* = 2(h_d^{-1})E$$  \hfill (15)

$$A = \frac{\theta_s - \theta_i - (\theta_s - \theta_i)a}{\alpha^*}$$  \hfill (16)

Where $a$, is, the shape coefficient of soil moisture profile, and $n$ is VG model water retention parameter used to calculate as,

$$a = n \frac{n}{2n+2}$$  \hfill (17)

For comparison with infiltration models, the above Eq. (9) transformed in sorptivity form by substituting Eq. (11 and 12), moreover, Eq. (17) into Eq. (13) gives,

$$H_I = H_p - \frac{K_s}{K_{es}} \left[ \frac{3n+2}{3n+1} h_d + H_p \right]$$  \hfill (18)

$$H_f = H_p - \frac{K_e}{K_{es}} \left[ \frac{3n+2}{3n+1} h_d + H_p \right]$$  \hfill (19)

Here the Ma et al. (2016), sorptivity function is reduced by eliminating soil water saturation function and $h_d$ in Eq. (20) taking the comparison between Eq. (18 and 19). The Eq. (16) is given in the form of effective soil hydraulic properties Eq. (21 and 22).

$$S^2 = 2K_s(\theta_s - \theta_i) \left[ \frac{3n+2}{3n+1} h_d + H_p \right]$$  \hfill (20)

$$S^2 = 2K_e(\theta_s - \theta_i) \left( H_p - H_f \right)$$  \hfill (21)

$$S^2 = 2K_{es}(\theta_s - \theta_i) \left( H_p - H_f \right)$$  \hfill (22)

Almost similar to the Fok (1975) equation, but $K_e$, $K_{es}$ is used instead of $K_s$. Substituting sorptivity $S^2$ instead of $\Delta h = H_p - H_f$ in the following GAMM.

$$t = \frac{l}{K_{es}} - \frac{s^2}{2K_{es}} \ln \left[ 1 + \frac{2K_{es}l}{s^2} \right]$$  \hfill (23)

$$t = \frac{l}{K_e} - \frac{s^2}{2K_e} \ln \left[ 1 + \frac{2K_e l}{s^2} \right]$$  \hfill (24)

The infiltration rate is calculated by using the classical Green-Ampt model with modification for wetting front suction head $S_f$. Eq. (26) (Green and Ampt, 1911).

$$i = K_{fs}(H_p + L_f + S_f)/L_f$$  \hfill (25)

Where $i$ is infiltration rate ($cm\ hr^{-1}$), $K_{fs}$ is field saturated hydraulic conductivity ($cm\ hr^{-1}$) measured by Bouwer Eq. (5), $L_f$ is the wetting front depth (cm). The wetting front suction head $S_f$ estimated as, (Bouwer, 1966):

$$S_f = h_d/2$$  \hfill (26)

Here the flow is restricted to one-dimensional by using DRI inner ring infiltration and the lateral flow divergence is avoided by using $L_f > d$.

**RESULT AND DISCUSSION**

GAMM was used to estimate the field infiltration in varying field conditions effectively. The GAMM estimated infiltration was then compared with the classical Green-Ampt and Philip infiltration models. A well-defined approach was used in deriving and modelling the proposed GAM model by considering the concept of soil hydraulic properties and avoiding the classical GAM concept of piston type distribution of soil moisture profile. The Ma et al., (2015) concept of infiltration for field application further evaluated by modification for $K_e$ and air entry head $h_d$, and found that the GAMM gives reasonable estimates to that of observed data by taking different soil hydraulic parameters. The effective hydraulic conductivity $K_{es}$ and $K_e$ Eq. (11 and 12) and $H_f$ wetting front pressure head Eq. (18 and 19) were estimated from the observed data. Ma et al., (2015) took the Brooks and Corey (1964) concept and used van Genuchten $\alpha$ parameter for $h_d$ air entry head calculation Eq. (14). While in our proposed method, the sorptive number $\alpha^*$ is used for air entry head Eq. (15). A total of 19 trials were conducted in three different location in Yinchuan and in the laboratory in Table (2). This concept of taking actual field soil hydraulic parameters evaluated for the goodness of fit using different statistical data obtained from experiments. The mean values are used in this study for cumulative infiltration $I$ (cm) and infiltration rate $i$ ($cm\ hr^{-1}$) estimation for observed and simulated data using different models, Table (3).

**Comparison of GAMM with CGAM and Philip**

Cumulative infiltration: The cumulative infiltration $I$ (cm) estimated by Philip model gives the best fit, using linear curve fitting technique by fitting parameter (S) and hydraulic conductivity (A) to that of observed mean data in Table 3 and Figure 5 having RMSE 0.077 (cm) and NSE is 1.

In GAMM the effective hydraulic conductivity $K_{es}$ and $K_e$ are measured by using Eq. 11 and 12, and air entry head $h_d$ is measured from Eq. 15 and 16. The field conditions always having more variability in soil, water content, porosity and vegetation, which requires the actual hydraulic parameters estimation that effect the 1D infiltration.

The cumulative infiltration $I$ (cm) is over estimated by taking $K_e$ in Eq. 24 given in Table (1) and Figure (5). While using Eq. 15 of $\alpha^*$ gives better estimates comparatively to that of Eq. 14 of $\alpha$ in most of the cases. The RMSE is dropped from 2.048 to 1.184 (cm), and NSE increased from 0.981 to 0.994. The cumulative infiltration estimated by GAMM using Eq. 24 performed better than CGAM, which have high RMSE 7.217 (cm) and less NSE 0.763 in Table 3 and Figure 5.
Table 2. Actual hydraulic properties of the soil that was investigated in the field are listed here.

<table>
<thead>
<tr>
<th>Site</th>
<th>$\theta_r$ (cm$^3$/cm$^3$)</th>
<th>$\theta_i$ (cm$^3$/cm$^3$)</th>
<th>$\theta_s$ (cm$^3$/cm$^3$)</th>
<th>$1/h_d$ (cm$^{-1}$)</th>
<th>$2 \times (h_d^{-1})$</th>
<th>n</th>
<th>$H_p$ (cm hr$^{-1}$)</th>
<th>Ks (cm hr$^{-1}$)</th>
<th>$Z_f$</th>
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</thead>
<tbody>
<tr>
<td>LT1</td>
<td>0.067</td>
<td>0.076</td>
<td>0.364</td>
<td>0.020</td>
<td>0.040</td>
<td>1.410</td>
<td>5.000</td>
<td>1.330</td>
<td>30.00</td>
</tr>
<tr>
<td>LT2</td>
<td>0.067</td>
<td>0.096</td>
<td>0.409</td>
<td>0.020</td>
<td>0.040</td>
<td>2.500</td>
<td>10.00</td>
<td>1.330</td>
<td>30.00</td>
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<tr>
<td>LT3</td>
<td>0.067</td>
<td>0.076</td>
<td>0.397</td>
<td>0.020</td>
<td>0.040</td>
<td>1.100</td>
<td>5.000</td>
<td>1.330</td>
<td>35.00</td>
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<tr>
<td>LT4</td>
<td>0.067</td>
<td>0.066</td>
<td>0.297</td>
<td>0.020</td>
<td>0.040</td>
<td>2.100</td>
<td>10.00</td>
<td>1.330</td>
<td>30.00</td>
</tr>
<tr>
<td>F1,L1</td>
<td>0.065</td>
<td>0.069</td>
<td>0.369</td>
<td>0.075</td>
<td>0.040</td>
<td>1.890</td>
<td>10.00</td>
<td>11.09</td>
<td>40.00</td>
</tr>
<tr>
<td>F1,L2</td>
<td>0.065</td>
<td>0.100</td>
<td>0.226</td>
<td>0.075</td>
<td>0.040</td>
<td>1.890</td>
<td>5.000</td>
<td>2.000</td>
<td>15.00</td>
</tr>
<tr>
<td>F1,L3</td>
<td>0.065</td>
<td>0.038</td>
<td>0.300</td>
<td>0.075</td>
<td>0.120</td>
<td>1.890</td>
<td>6.000</td>
<td>4.250</td>
<td>45.00</td>
</tr>
<tr>
<td>F1,L4</td>
<td>0.030</td>
<td>0.051</td>
<td>0.410</td>
<td>0.068</td>
<td>0.120</td>
<td>2.000</td>
<td>5.000</td>
<td>3.160</td>
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<tr>
<td>F2,L1</td>
<td>0.045</td>
<td>0.071</td>
<td>0.345</td>
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<td>10.00</td>
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<td>0.081</td>
<td>0.436</td>
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<td>5.000</td>
<td>14.27</td>
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<tr>
<td>F2,L3</td>
<td>0.065</td>
<td>0.079</td>
<td>0.400</td>
<td>0.075</td>
<td>0.120</td>
<td>1.890</td>
<td>5.000</td>
<td>6.850</td>
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<tr>
<td>F2,L4</td>
<td>0.065</td>
<td>0.088</td>
<td>0.354</td>
<td>0.075</td>
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<td>1.890</td>
<td>10.00</td>
<td>6.590</td>
<td>50.00</td>
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<tr>
<td>F2,L5</td>
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<td>0.082</td>
<td>0.358</td>
<td>0.020</td>
<td>0.040</td>
<td>2.530</td>
<td>10.00</td>
<td>1.160</td>
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</tr>
<tr>
<td>F3,L1</td>
<td>0.065</td>
<td>0.098</td>
<td>0.388</td>
<td>0.075</td>
<td>0.040</td>
<td>4.510</td>
<td>10.00</td>
<td>13.07</td>
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<tr>
<td>F3,L2</td>
<td>0.065</td>
<td>0.067</td>
<td>0.394</td>
<td>0.075</td>
<td>0.040</td>
<td>1.990</td>
<td>5.000</td>
<td>10.10</td>
<td>45.00</td>
</tr>
<tr>
<td>F3,L3</td>
<td>0.067</td>
<td>0.132</td>
<td>0.398</td>
<td>0.020</td>
<td>0.040</td>
<td>1.410</td>
<td>7.500</td>
<td>3.180</td>
<td>40.00</td>
</tr>
<tr>
<td>F3,L4</td>
<td>0.065</td>
<td>0.075</td>
<td>0.380</td>
<td>0.075</td>
<td>0.120</td>
<td>1.890</td>
<td>10.00</td>
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</tr>
<tr>
<td>F3,L5</td>
<td>0.067</td>
<td>0.081</td>
<td>0.379</td>
<td>0.020</td>
<td>0.040</td>
<td>1.410</td>
<td>5.000</td>
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<td>0.162</td>
<td>0.467</td>
<td>0.020</td>
<td>0.120</td>
<td>1.410</td>
<td>10.00</td>
<td>0.420</td>
<td>40.00</td>
</tr>
</tbody>
</table>

$\theta_r$, $\theta_i$ and $\theta_s$ are residual, initial and saturated soil moisture content, n and $h_d$ are empirical parameters of Van Genuchten (1980) and Elrick et al., (1989); $H_p$ is water pressure head; Ks is saturated hydraulic conductivity and $Z_f$ is wetting front depth measured from EC5 sensors.

When the effective hydraulic conductivity $K_{es}$ is used in Eq. 23, the cumulative infiltration ($I$) estimation is improved as compared to Eq. 24 and classical GAM. When taking the observed field soil moisture variation with soil pores capillary index for each soil texture in the Table. (1), and Figure. (5). The air entry head $h_d$ measured from Eq. 15 also gives best estimates of cumulative infiltration, and the RMSE is decreased from 2.125 to 0.812 (cm hr$^{-1}$) and NSE is increased from 0.979 to 0.997.

The Figure 5 shows the performance of GAMM using $\alpha$ and $\alpha^*$ for air entry head, and $K_e$ and $K_{es}$ for effective hydraulic conductivity estimation. The cumulative infiltration estimation is improved by using $\alpha^*$ and $K_{es}$ in the modified Green-Ampt model.

The Philip infiltration model fitting parameter S and GAMM $S^2$ both represent sorptivity. In GAMM this parameter is derived from Eq. (21 and 22) using the effective hydraulic conductivity $K_{es}$ and $K_e$, change in soil moisture $\Delta \theta$ with time and change in pressure head throughout the soil moisture profile $\Delta h$ explained early. These soil hydraulic conductivity parameters relate well the soil infiltration response in the changing field conditions as compared to the analytical and fitting method.

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Figure 5. observed and simulated (1:1) relationship of cumulative infiltration I (cm) using $\alpha$ L$^{-1}$ and $\alpha^*$ L$^{-1}$ for $h_d$ cm$^{-1}$ in hf (cm) calculation and effective hydraulic conductivity $K_{es}$ and $K_e$ cm hr$^{-1}$ in (Green-Ampt Modified Model).
Infiltration assessment by using green-ampt

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Mean, Standard Deviation, Median, Maximum, Minimum, Geometric Mean, Error Sum of Square, Coefficient of determination, Root mean squared Error, Nash Sutcliffe Model Efficiency.

Infiltration rate: The infiltration rate i (cm hr⁻¹) simulated by Philip model using linear curve fitting gives better goodness of fit RMSE 0.578 and NSE 0.994 as compared to Ma et al., (2015) air entry head concept in Eq. 25 in CGAM with RMSE 2.628 and NSE 0.886 given in Table 3 and Figure 6. The classical Green-Ampt model CGAM using field saturated hydraulic conductivity $K_s$ (cm hr⁻¹) and proposed air entry head $h_d$ measured by Eq. 15 gives the best fit for infiltration rate i (cm hr⁻¹) estimation with RMSE 0.046 and NSE 1. While using the Ma et al., (2015) air entry head Eq.14 resulted in poor estimates of infiltration rate. When using the $\alpha^*$ for air entry head estimation, it mostly relating the vadose zone soil structure and structure using DRI infiltration for $H_p > 0$ (Bouwer, 1966; Elrick and Reynolds, 1992).

Figure 6 shows the infiltration rate measured by Philip and Classical Green-Ampt model using the modified concept of air entry head in Eq. 15 for wetting front suction head estimation $S_f$ (cm). The modified form of CGAM performed best for infiltration rate estimation as compared to Ma et al., (2015) air entry head Eq. 14 and Philip model in Table 3. Field evaluation: The laboratory and field trials performed by using two different sized DRI of inner and outer ring 15-30 and 30-60 cm are having different ring depth and water head ranging from 5 to 10 cm. In the laboratory, classical GAM underestimated cumulative infiltration I (cm) in trail 1, 2, 3 and overestimated in trail 4 during the laboratory experiment, due to soil surface compaction and variation in soil moisture and porosity. The Gamm using Eq.24 and $h_d$ measured by Eq.14 and 15 overestimated while Eq. 23.
underestimated $I$ (cm) and best fit to observed data as compared to classical GAM given in Table 3 and Figure 5. During the Field 1 experiment in Yongning county, the classical GAM underestimated at L1 due to vertical soil heterogeneity and overestimated at L 2, 3 and 4 due to extreme soil dryness. The GAMM cumulative infiltration (cm) simulations are in best fit with little variations at some location, and performed better as compared to CGAM given in Table 3.

In the Field 2 Jinfeng County, the classical GAM underestimated the cumulative infiltration $I$ (cm) at location L 1, 4 and 5 and overestimated at L 2 and 3. While the cumulative infiltration (cm) simulated by GAMM Eq. 24 and 23 through Eq. 14 resulted in little underestimation at all location, while using Eq. 15 resulted in overestimation at location 2 only. The GAMM best fit simulations to that of observed cumulative infiltration (cm) as compared to classical GAM given in Table 3 and Figure 5.

The cumulative infiltration $I$ (cm) was over estimated by using the classical GAM at location 4 and underestimated at 1, 2, 3, 5 and 6 at field 3 Xixia County. The GAMM Eq. 24 and 23 at all location gives an excellent fit to that of observed $I$ (cm) given in Table 3 and Figure 5.

The Infiltration rate $i$ (cm hr$^{-1}$) was underestimated by Philip model during the laboratory and field experiments except at F1L2 where overestimation was observed. When the Ma et al., (2015) air entry head $h_d$ concept was used in GAM, it underestimated $i$ (cm hr$^{-1}$) in field except at F3L3 and F3L6, and in the laboratory it estimated well to that of observed data.

The GAMM better represents the actual soil hydraulic properties, and cumulative infiltration (cm). Moreover taking $\alpha^*$ as air entry head in classical Green-Ampt model for infiltration rate (cm/hr) estimation also explains well soil water infiltration in the laboratory and field. Experiments are needed for further authentication of this method specially in varying field conditions.

**Conclusions:** The Green and Ampt model was developed and tested in the current study taking the modified concept for field application in heterogeneous soil. The Ma et al., (2015) concept of air entry head $h_d$ taking $\alpha$ and effective hydraulic conductivity $K_e$ compared with modified concept for $h_d$ taking $\alpha^*$ and effective hydraulic conductivity $K_e$. The GAMM gives a better estimation for cumulative infiltration $I$ (cm) as compared to classical GAM and Ma et al., (2015) concept. For infiltration rate estimation the CGAM result the best fit when $\alpha^*$ was used as air entry head in wetting front pressure head $S_f$ estimation as compared to Philip model and Ma et al., (2015). The classical GAM underestimated infiltration capacity in silt loam soil (with or without vegetation), in loose sandy soil having trees F2L1, and loose grey sandy loam soil F2L4, while overestimated in compacted silt loam soil LT4, and grey fine sandy loam soil with grass or trees cover. The GAMM resulted in little overestimation of cumulative infiltration (cm) in silt loam soil, red fine sandy loam soil with compaction, and grey fine sandy loam soil with vegetation cover, and underestimation in vertically heterogeneous, sandy, and grey fine sandy loam soil without vegetation cover. The Most reliable estimates are given by GAMM using $Kes$ only relating $I$ (cm) to soil hydraulic characteristics with varying antecedent soil moisture. When
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using actual field characteristics of a watershed, also recommended for further field application and evaluation.

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Conflict of Interest: There is no conflict of interest

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