# Philip Model Capability to Estimate Infiltration for Solis of Aba, Abia State

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## Abstract

The capability of Philip's infiltration model in simulating water infiltration on the soils of Aba, Abia state. Nigeria was evaluated. Field measurements of infiltration were conducted in five different locations using a double ring infiltrometer. Each test lasted for 150 minutes. The lowest cumulative infiltration obtained was 18cm at Eziama while the highest, 31cm occurred at Abayi Umungasi. Philip's infiltration model was then applied on the field data in order to determine the soils' infiltration parameters and also to simulate the model equations for the soils. Sorptivity values 'Sp' ranged from 0.457 cms$^{-1/2}$ - 2.734cms$^{-1/2}$ while transmissivity values (Ap) ranged from 0.076 cm/s to 0.142 cm/s,. Sp and Ap values were substituted into the model equation in order to simulate specific Infiltration equations for each location. Simulated infiltration rate equations obtained include: $0.457t^{1/2} + 0.102t$, $1.322t^{1/2} + 0.076t$, $2.708t^{1/2} + 0.142t$ , $0.691t^{1/2} + 0.135t$, $1.708t^{1/2} + 0.142t$ . The filed data showed close relationship when they were compared with the simulated data. The result shows that Philip's model was able to estimate water infiltration depths for Aba soils.

**Keywords:** Aba North, Philip's model, parameters, Irrigation, Sorptivity.

## 1 Introduction

Final steady infiltration rate of a soil is the maximum rate at which water enters into the soil.  Since measuring the final infiltration rate is time consuming, several models have been proposed to determine this parameter. Infiltration equations are presented as basic, physical and empirical models [1]. Empirical models such as those of kostiakov's, Horton's and other physical models are used to estimate final soil infiltration rate though the values for each model parameter, have been observed to be different due to the fact that the parameters  are soil dependent [2].  The ability of the model to estimate infiltration rate has been examined by many researchers. [3] suggested that Horton's

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model give an acceptable and accurate estimate of final infiltration rate under given soil textures conditions. However complicated factors that influence the final infiltration rate are the major reason for the different applicability of the models.

## 1.1 Theoretical Framework

The Philip's two term model is a truncated power series solution developed by [4]. During the initial stages of infiltration, the first term of the model equation (sorptivity) dominates the process. Sorptivity is a function of the soil's suction which is important for knowing soil hydraulic properties. The parameter is defined as physical quantity that shows the capacity of a porous medium for capillary uptake and release of water into the soil. This parameter can be estimated by defining the relationship between soil hydraulic and other available measured properties, which can be used to estimate hydraulic parameter [**5**].

There are several approaches for selection of suitable model. One of the simplest approaches in minimizing the differences between observed and predicted data is to find the best model. [6] used the coefficient of determination ($R^{2)}$) to compare infiltration models. [7] examined the suitability of infiltration models with the coefficient of efficiency. [8] and [9] used both the coefficient of determination ($R^2$) and the Mean Root Square Error (MRSE) to select the best infiltration model. [10] used Absolute mean difference and coefficient of determination to compare Kostiakov's and Philip's models.

Philip's (1957) model [11], is an infinite-series solution to solve non-linear partial differential Richards's equation under given soil condition which describes transient fluid flow in a porous medium. For cumulative infiltration, the general form of the Philip's model is expressed in powers of the square-root of time as:

$$I = St^{1/2} + At \qquad\qquad (1)$$

I is the cumulative infiltration (L)**,** S is the sorptivity ($LT^{1/2}$), t is the time of infiltration (T) and A is a parameter with dimension of the saturated hydraulic conductivity ($LT^{-1}$) and is equal to transmissivity ($LT^1$).

The rate of infiltration is determined by differentiating (eqn) 1. i.e

$$dI/dt = 1/2\ St^{-1/} + A \qquad\qquad (2)$$

The constant of A and S may be determined by plotting the graph of dI/dt against $t^{-1/2.}$. Where A (gravity factor) = intercept and S (Sorptivity factor) = slope

During the initial stages of infiltration when the first-term of the model dominates the process, infiltration proceeds at almost the same rate as absorption or horizontal infiltration while the gravity components, represented by second-term of the model is negligible. As infiltration continues, the second-term becomes progressively more important until it dominates the infiltration process.

## 1.2 Location

Aba is a strategic commercial city in Abia state with many economic and agricultural activities. It is located within latitude $7^o10'E$ and longitude $5^027'N$, and has an average population density of 3000 people per square kilometer [12]. Aba enjoys a lot of rainy

days. The rainy season occurs between March and October. Its vegetation is characterized by tropical rain forest.

## 2 Methodology

A double ring infiltrometer cylinder of sizes 15/30cm was used to measure the infiltration rate of the soils at different locations within Aba metropolis. In accordance with [13], [14], [15] method the inner ring was first driven into the ground, then the outer ring was placed centrically around the inner ring and then also driven into the ground. The two were driven into the ground to a depth of about 10cm. 2cm of sand layer was spread at the bottom of the inner ring to minimize soil surface disturbance when pouring water into the ring compartments. To ensure vertical flow in the inner ring, the outer ring was first filled with water so that the soil profile around the inner ring would be wet and water levels of the two rings were maintained at the same level. Cumulative infiltration of the soils were read off with using a rule inserted into the inner ring. Repeated readings of the water levels in the inner ring were taken at intervals of 5, 10, 15 and 30mins respectively. Each experiment lasted for 150mins. A ponding level of 5cm was maintained throughout the experiments.

The constants 'A' and 'S' were then determined by plotting cumulative infiltration (I) against $t^{1/2}$ as given in eqn. (1). The values of the estimated constants were then incorporated into the model equation to simulate cumulative infiltration depth for each location. The capability of the model to stimulate cumulative infiltration was evaluated by comparing the field data with the model's stimulated data.

## 3 Results

Table 1: Field measured infiltration depth ($i_f$)

| Time(s) | Eziama High.Sch $I_f$ (cm) | Abayi Umungasi $I_f$ (cm) | Eziama Community $I_f$ (cm) | Umuocham $I_f$ (cm) | Faulks Road $I_f$ (cm) |
|---|---|---|---|---|---|
| 5 | 1.40 | 2.10 | 3.00 | 6.00 | 5.50 |
| 10 | 2.50 | 3.60 | 5.00 | 8.60 | 6.40 |
| 15 | 3.50 | 4.60 | 7.00 | 11.20 | 8.60 |
| 20 | 4.50 | 5.60 | 9.00 | 14.40 | 10.70 |
| 25 | 5.40 | 6.50 | 10.20 | 16.70 | 11.90 |
| 30 | 6.10 | 7.40 | 11.50 | 18.60 | 12.80 |
| 40 | 7.00 | 7.90 | 12.80 | 21.60 | 15.60 |
| 50 | 9.00 | 11.50 | 14.00 | 26.80 | 18.80 |
| 60 | 10.00 | 13.60 | 15.50 | 30.10 | 20.50 |
| 75 | 12.30 | 15.60 | 16.40 | 34.40 | 24.60 |
| 90 | 13.50 | 18.80 | 17.60 | 37.00 | 35.40 |
| 120 | 17.50 | 24.50 | 19.00 | 45.50 | 43.10 |
| 150 | 18.00 | 31.50 | 22.40 | 56.00 | 45.72 |

Table 2: Summary of the simulated model parameter

| Location | Ap | Sp | I | $R^2$ |
|---|---|---|---|---|
| Eziama High School | 0.102 | 0.457 | $0.457t^{1/2} + 0.102t$ | 0.83 |
| Eziama 1 | 0.076 | 1.322 | $1.322t^{1/2} + 0.076t$ | 0.89 |
| Umuocham | 0.142 | 2.708 | $2.708t^{1/2} + 0.142t$ | 0.98 |
| Abayi Umungasi | 0.135 | 0.691 | $0.691t^{1/2} + 0.135t$ | 0.91 |
| Faulks | 0.142 | 1.708 | $1.708t^{1/2} + 0.142t$ | 0.98 |

Table 3: Comparison between field data and model simulated data

| | Eziama High.Sch | | Abayi Umungasi | | Eziama Community | | Umuocham | | Faulks | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time(s) | $I_f$ (cm) | $I_s$(cm) | $I_f$ (cm) | $I_s$(cm) | $I_f$(cm) | $I_s$(cm) | $I_f$ (cm) | $I_s$(cm) | $I_f$ (cm) | $I_s$(cm) |
| 5 | 1.40 | 1.50 | 2.10 | 2.22 | 3.00 | 3.34 | 6.00 | 6.78 | 5.50 | 4.53 |
| 10 | 2.50 | 2.50 | 3.60 | 3.53 | 5.00 | 4.94 | 8.60 | 9.98 | 6.40 | 6.82 |
| 15 | 3.50 | 3.30 | 4.60 | 4.69 | 7.00 | 6.26 | 11.20 | 12.61 | 8.60 | 8.75 |
| 20 | 4.50 | 4.10 | 5.60 | 5.79 | 9.00 | 7.43 | 14.40 | 14.95 | 10.70 | 10.48 |
| 25 | 5.40 | 4.80 | 6.50 | 6.84 | 10.20 | 8.51 | 16.70 | 17.09 | 11.90 | 12.09 |
| 30 | 6.10 | 5.60 | 7.40 | 7.44 | 11.50 | 9.53 | 18.60 | 19.10 | 12.80 | 13.61 |
| 40 | 7.00 | 6.10 | 7.90 | 7.84 | 12.80 | 11.40 | 21.60 | 22.80 | 15.60 | 16.48 |
| 50 | 9.00 | 8.30 | 11.50 | 11.64 | 14.00 | 13.15 | 26.80 | 26.25 | 18.80 | 19.18 |
| 60 | 10.00 | 9.70 | 13.60 | 13.46 | 15.50 | 14.81 | 30.10 | 29.51 | 20.50 | 21.75 |
| 75 | 12.30 | 10.60 | 15.60 | 16.12 | 16.40 | 17.15 | 34.40 | 34.10 | 24.60 | 25.44 |
| 90 | 13.50 | 13.50 | 18.80 | 18.71 | 17.60 | 19.39 | 37.00 | 38.48 | 35.40 | 35.75 |
| 120 | 17.50 | 17.40 | 24.50 | 23.77 | 19.00 | 23.60 | 45.50 | 46.69 | 43.10 | 42.21 |
| 150 | 18.00 | 20.90 | 31.50 | 28.72 | 22.40 | 27.60 | 56.00 | 54.47 | 45.72 | 46.10 |

$I_s$ = simulated cumulated infiltration, $I_f$ = Field measured cumulated infiltration

## 4 Discussion

Table 1 shows the average field measured cumulative infiltration depths for each location. There are variations in the infiltration depths at different times across the locations, for example in the first 60 mins, cumulative infiltration ranged from 10.0cm (Eziama high school premises) to 30.10cm (Umuocham). While at 120 mins it ranged from 17.5cm to 45.5cm respectively. This may be attributed to the fact that infiltration is dependent upon soil characteristics.

Table 2 shows the obtained estimated values for the model parameters. The values for transmisivity 'Ap' ranged from 0.076 to 0.142 cms$^{-1}$, while that of the sorptivity 'Sp' ranged from 0.457 cms$^{-1/2}$ to 2.734cms$^{-1/2}$. [16] in their evaluation and determination of soil infiltration model coefficients for Sanandaj soils obtained a range of 0.066 – 0.187cm$^{-1}$ for transmissivity and a range of 0.759 - 1.69cm min$^{-1/2}$ for sorptivity values. [17] also evaluated the performance of infiltration models for the soils of Zaria, Kaduna State, and obtained transmissivity values ranging from 0.078 - 0.155 cms$^{-1/2}$ .

Table 3 compared the field data with the model simulated data. It was observed that the two sets of data show close relationship with each other except for the soil of Eziama community, which showed a slight difference. However the coefficient of determination ($r^2$) for both the field data and the simulated data from each location is greater than 0.8.

($r^2 > 0.8$). This implies that the model was able to simulate water infiltration and model equation for the soils of Aba North.

## 5  Conclusion

This study evaluated the performance of Philip's infiltration models on the soils of Aba North. Field measurements of water infiltration were made on five locations within the study area using a double ring infiltrometer. The lowest cumulative infiltration obtained was 18cm while the highest, 31cm occurred at Abayi Umungasi. Philip's infiltration model was then applied on the field data in order to determine the soils' infiltration parameters and also to simulate the model equations for the soils. Transmissivity values (Ap) ranged from 0.076 cms$^{-1}$ – 0.142 cms$^{-1}$, while that of the Sorptivity 'Sp' ranged from 0.457 cms$^{-1/2}$ - 2.734cms$^{-1/2}$. Infiltration equations simulated include $1.322t^{1/2} + 0.076t$., $691t^{1/2} + 0.135t$ , $2.708t^{1/2} + 0.142t$ , $0.457t^{1/2} + 0.102t$ and $2.734t^{1/2} + 0.084t$ . The filed data were compared with the simulated data for each of the locations. The two sets of data showed close relationship. This shows that Philip's model was able to estimate water infiltration depths for these soils

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