COMPARISON OF INFILTRATION MODELS: A CASE OF FENTALE IRRIGATION SCHEME IN ETHIOPIA

By

Sileshi Hunduma Tuge

A Thesis Submitted to the Department of Water Resources Engineering, School of Civil and Architecture Engineering

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resources Engineering (Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

July, 2020

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Sileshi Hunduma Tuge have read and evaluated his thesis entitled "Evaluation of Most Commonly used Infiltration Models: Case of Fantalle Irrigation Scheme in Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering (Irrigation Engineering) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with my approval as thesis advisor.

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Date of submission: July, 2020

ADVISOR’S APPROVAL SHEET

To: Water Resource Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled “Comparison of Infiltration Models: A Case of Fentale Irrigation Scheme in Ethiopia’’ submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering (Irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by Sileshi Hunduma (ID. No PGR/18039/11), under my supervision and guidance. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Abdulkarim Bedewi Serur (PhD)	________________________	__________________
Name of Advisor/supervisor	Signature	Date

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ABBREVIATIONS AND ACRONOMS

Cm	Centimeters
D	Surface Detention
Ei	Error Ratio
GMER	Geometric Mean Error Ratio
GSDER	Geometric Standard Deviation Error Ratio
Hr	Hour
I	Cumulative Infiltration
i	Measured Infiltration Rate
i_c	Calculated Infiltration Rate
Ic	Calculated Cumulative Infiltration Depth
Im	Observed Cumulative Infiltration Depth
K	Hydraulic Conductivity
MAE	Mean Absolute Error
Min	Minute
NGO	None Governmental Office
OIDA	Oromia Irrigation Development Authority
Q_{max}	Maximum Discharge
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
S	Sorptivity
Z	Observed Infiltration Depth by cm

ABSTRACT

Good understanding on the soil characteristics and site-specific steady infiltration rate could help to increase the irrigation water use efficiency in irrigated agriculture. The broad aim of this study was to evaluate performance of most commonly used infiltration models (Kostiakov, Modified Kostiakov, Philips, and Horton) in estimating steady infiltration characteristics and to find the best fit infiltration model for Fentale irrigation scheme in Ethiopia. Infiltration measurements were taken on irrigation command area of Fentale Irrigation Scheme using double ring infiltrometer at selected six points of the study area. Statistical model performance evaluation criteria namely coefficient of determination (R^2), Root Mean Square Error (RMSE), Ei, GMER, and GSDER were used in addition to graphical observation technique to find the best fit infiltration model for the study area. Results revealed that Kostiakov's infiltration model's parameter such as the values of empirical constant 'a' and c were estimated in the range of 0.36-0.52 (in an average value of 0.42) and 5.84-28.01 in average 19.88 respectively. Modified Kostiakov's parameters like values of empirical constants 'a' was estimated in the range of 0.27-0.52 (with an average value of 0.36). Philip's infiltration model's parameters like Sorptivity 'S' was found in the ranges of 6.68-69.77 mm/min$^{0.5}$ (with an average value of 45.78 mm/min$^{0.5}$) while Horton's model's parameter such as constant 'k' was estimated in the range of 1.78-6.39 (with an average value of 3.93). Results showed that Modified Kostiakov's model provided the lowest mean value for RMSE of 0.13, GSDER of 1.10, the lowest value for Ei of 23%, and the highest value for R^2 of 0.99 as compared to Kostiakov's, Horton's, and Philip's models. This indicated that infiltration can be well-described by the Modified Kostiakov's model and gave a better fit to the measured cumulative infiltration depth and infiltration rate at the selected study area. Thus, the scheme administration is suggested to practice infiltration measurement with suitable model to enhance irrigation water use efficiency and reduce water losses in the scheme.

Keywords: *Infiltration Characteristics; Double Ring Infiltrometer; Commonly Used Infiltration Models; Models' Parameters Estimation and Prediction Capability*

1. INTRODUCTION

1.1. Background of the Study

Infiltration is defined as the process by which water passes through the soil surface and enters the sub soil, generally the root zone for application in irrigation. The groundwater reservoir is formed after the rain fall or other sources of water are percolated in the ground. Infiltration is caused by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity. The rate of infiltration is determined by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil (Rahimi et al., 2009).

Study of soil water infiltration is of great importance considering both aspects of intensity and the amount of infiltration in design, estimation of evapotranspiration, groundwater recharge, surface runoff, effective rainfall; flooding, irrigation scheduling, soil erosion and pollutants transport hydrologic cycle and implementation of all irrigation methods. The rate and cumulative infiltration amount are necessary to calculate the total water requirement for efficient irrigation system (Michael, 2007; Tesansis, 2006; Dagadu and Nimbalkar, 2012).

Amount of soil moisture and physical properties including soil texture and structure are the most important determinant factors of infiltration (Radcliffe and Rasmussen, 2000). Jagani et al. (2018) evaluated Kostiakov's and Philip's infiltration models on the soil of Dediapada, India and found values for RMSE of 0.123, GMER of 0.934, GSDER of 1.02 and R^2 of 0. 996 in case of Kostiakov model while RMSE of 0.112, GMER of 0.923, and GSDER of 1.01 and R^2 of 0.999 in Philip infiltration model. Depending upon their finding they have proposed as Philip infiltration Model was better to estimate infiltration characteristics of the study area.

Neshat and Parehkar (2007) evaluated the Kostiakov infiltration model on three types of soil texture namely clay, loam and clay loam they have got satisfactory results finding R^2 and RMSE values of 0.998 and 0.48 respectively. Finally, they inferred that Kostiakov infiltration model is found to be the best model to estimate cumulative infiltration and infiltration rate for all conditions. However, by increasing the time of infiltration, Kostiakov model had more errors and variations than other models. Empirical estimation models have fewer limits considering the assumptions which are related to soil surface and soil profile conditions.

According to Gorji et al. (2010) as cited in Philip (1957), the soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity play a paramount role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by protecting the soil from raindrop impact, which can close natural gaps between soil particles, loosening soil through root action and enhancing the presence of soil organism like termites, worms and small mammals that have a direct impact on soil bulk densities.

Fantale irrigation scheme was designed and constructed on Awash River and mainly located in Fantalle Woreda, East Shewa zone of the Oromia Regional State, and a limited part of Boset Woreda in the same zone and adjacent to some part of Fantalle district is also incorporated in the project (OIDA,2011). Infiltration is a key dynamic process which is used for scheduling, design, and management and optimization of irrigation system. The study conducted by Geleta (2011) on Fantalle Irrigation Scheme also showed the limitation of design construction quality and weak Seepage (infiltration or deep percolation. This research is therefore, tries to identify the hydrologic losses or water losses behind this failure and recommend possible solutions. Evaluating infiltration characteristics of Fentale irrigation scheme is necessary because of its large irrigation scheme and now a day it interconnected research institute and most demonstrations are undergoing.

1.2. Statement of the Problem

In different developing or underdeveloped countries, measurement of infiltration was not practiced successfully. There are several reasons for this: lack of awareness of measuring actual volume and rate of infiltration; lack of skill and knowledge of infiltration measurement and its role in water management practices. Considering the importance and economic benefit of irrigation and water management practices, a infiltration model may be selected to forecast amount of water infiltrated and available for serving the assessment and quantifying the amount of water needed for actual water requirement of the crops (Hasan, 2015).

In Fentale Irrigation Scheme, there were conflict between Upper and downstream user because of water scarcity and poor irrigation scheduling. Knowledge of infiltration characteristics helps to properly schedule irrigation scheduling, design, and management and optimization of irrigation system but till now infiltration not forecasted by suitable infiltration model. Farmers use water for irrigation simply as they want without knowing crop water requirement. Supply and demand not well matched because of misuse and poor irrigation management. Infiltration causes waterlogging and salinity of land in area high groundwater. In order to optimize and overcome the problem forecasting infiltration with suitable model is necessary models for the study area.

Fentale irrigation scheme was designed to irrigate net irrigation area 16000 ha but which only 3640 ha have been irrigated due to poor irrigation water management, high losses of water in 2019 (OIDA, 2011). This shows more study was necessary in order to improve water losses infiltration characteristics and its effect waterlogging, salinity and to keep sustainability of the Fentale irrigation scheme. So it was necessary to provide best infiltration model after evaluating most commonly used infiltration models to evaluate infiltration characteristics of the study area.

1.3. Research Objectives

1.3.1. General objective

The general objective of this study was to infiltration models in estimating steady infiltration characteristics and to find the best fit infiltration model for the study area of Fantalle irrigation scheme in Ethiopia.

1.3.2. Specific objectives

In order to meet the general objective of the study, the following specific objectives were set to:

- Estimate infiltration models parameters under sandy clay dominant soil condition of the study area
- Estimate cumulative and rate of infiltration using Kostiakov, modified Kostiakov, Philip, and Horton infiltration models
- Determine a proper model which forecast cumulative and rate infiltration values in the study area.

1.4. Research Questions

Therefore, the study was directed by the following research questions:

- What are the values of infiltration models parameters under the study area?
- Which model performs well in estimating accumulated and rate of infiltration in the Fantalle Irrigation Scheme soil characteristics?
- What are the performances of Horton's, Philip, and Kostiakov and Modified Kostiakov models in estimating cumulative depth of infiltration in the Fantalle Irrigation Scheme?

1.5. Significance of the Study

Detailed knowledge about soil characteristics and site-specific final steady infiltration rate could help to increase the irrigation water use efficiency, maximize the productivity of both land and water, managing water logging and salinity of land, and decrease water losses in irrigated agricultural scheme. So, comparing infiltration models in estimating infiltration characteristics of Fentale Irrigation Scheme is very important in order to use irrigation water effectively and efficiently.

1.6. Scope and Limitation of the Study

The study specifically focuses on evaluation of most commonly used infiltration models: case of Fentale irrigation scheme in Fantalle and Bosat Woreda. It was delimited to Fantale irrigation scheme which exist between 8° 50' and 9° 04' N latitude and 39° 41' and 39° 52' E longitude. Hence, the results and finding on the problem and improved situation were the reflection of the study area which may be difficult to replicate to other areas of the regions.

Soil survey input and output data of only November 2019 to April 2020 period was used for the analysis. The laboratory analysis limited with analysis of soil texture and initial soil moisture only. Sorptivity is calculated logarithmic function in Philip infiltration model not from soil laboratory. Hydraulic conductivity of the soil was limited due to availability of instruments and budget. All infiltration models parameters were calculated depend up on logarithmic function with Microsoft Excel.

1.7. Organization of the Thesis

The thesis was organized with five sections. Section one includes background, statement of the problem, objectives, research questions, significance and scope of the study. Section two presents literature review part. While section three focused on material, methods, and procedures followed; which includes description of the study areas, data collection methods and data analysis techniques. Section four contains the result and discussion of the research findings while section five includes conclusion and recommendation drawn from the findings of this thesis work.

2. LITERATURE REVIEW

2.1. Infiltration

Infiltration is defined as the process by which water passes through the soil surface and enters the sub soil, generally the root zone for application in irrigation. It is different from the percolation, because percolation is the movement of water within the soil strata. Patra (2008) states the ways of knowing the infiltration process can be easily understood through a simple analogy. Consider a small container covered with wire gauze, if water is poured in to the container a part of it will go into the container and a part over flows. Further the container can hold only affixed quantity and when it is fully no more flow into the container can take place. While this analogy is the highly simplified it emphasizes two important aspects: i). the maximum rate at which the ground can absorb water, the infiltration capacity and ii).the volume of water that the ground can hold, the field capacity since the infiltrated water may contribute to the groundwater discharge in addition to increasing the soil moisture (Gorji et al., 2010).

2.1.1. Infiltration rate

It is actually the prevailing rate at which the water is entering the given soil at any given instant of time. It is expressed in cm/hr (i.e. depth of water entering soil per unit time). It is evident that the rain water will inter the ground soil at full capacity rate (f) only during the period when rain fall rate exceed the infiltration capacity. When the rain intensity is less than the infiltration capacity the prevailing infiltration rate is approximately equal to the rainfall rate. Hence, the actual prevailing rate at which the water will enter the given soil at any given time is known as infiltration rate. If rain intensity (p) exceeds the infiltration capacity (f) the difference is called the excess rain fall rate (pe). This excess water is first of all accumulated on the ground as surface detention (D) and then flows over land into the streams (Dagadu and Nimbalkar, 2012).

Infiltration rate is controlled by the nature of the soil, by the plant and animal communities it supports, and by human influences. Where soil is absent and little-fractured bedrock is exposed, water cannot soak in and will run off rapidly. If soil is present, but is very fine-grained and clay rich, the pore spaces that water must pass through are extremely small; hence, water will infiltrate very slowly compared to sandy soils that readily soak up water. Some finer-grained soils have vertical cracks that form when the soil shrinks as it dries. These cracks allow water to enter more readily, but may close up after the soil is wetted (Strudley et al., 2012).

Several infiltration models (Philip, Kostiakov, Mezencey, Soil Conservation Services and Horton) have been developed to determine the soil infiltration rate and characteristics. These infiltration models have been thoroughly and comprehensively reviewed, presented and summarized. All models are not applicable to all types of soils because of the dependency of infiltration rate on soil texture. Several research studies have been conducted to estimate the parameters of infiltration models and to validate these models for different soil conditions (Nugroho, 2018; Umar et al., 2019).

Steep slopes in the headwaters of drainage basins tend to generate more runoff than do lowland areas. Mountain areas tend to receive more precipitation overall because they force air to be lifted and cooled. On gentle slopes, water may temporarily pond and later soaks in. But on steep mountainsides, water tends to move downward more rapidly. Soils tend to be thinner on steep slopes; limiting storage of water, and where bedrock is exposed, little infiltration can occur (Peng et al., 2004).

2.1.2. Infiltration capacity

The ground water stored in the underground soil depends mainly up on the number of voids present in the soil. This in turn does not depend up on the size of the soil particles but rather up on the arrangement, sorting, shape and degree of compaction. Therefore, different soil will have different number of voids and different capacity to absorb water. The maximum rate at which a soil in any given condition is capable of absorbing water is called the infiltration capacity. The infiltration capacity of a soil is high at the beginning of storm and has an exponential decay as the time elapses (Michael, 2007; Soufi, 2002). According to Thompson et al. (2010), the capability of formation to absorb water is known as infiltration capacity. It is not constant factor and only changes with time but also changes with location the value of infiltration capacity at any given time and a given location is the resultant effect of the interaction of various factors. Some of this factors change the value of infiltration capacity with the change of location and others change it from time to time at a given section. There are certain other factor like the vegetative cover which may change the value of infiltration capacity with both location and time (Garg, 2005).

According to Madan and Mimi (2009), the water infiltrates into the ground under the force of gravity and there exists a layer of soil near the surface having its interstitial spaces saturated if the thickness of these saturated soils.

According to Peng et al. (2004), the amount of soil moisture has an important effect on the infiltration capacity. The effects of soil moisture on infiltration capacity are two folds, as described below: i). In early winter or spring, the soil moisture content is generally high and the value of infiltration is low, while in summer season the soil moisture content is low and so the value of infiltration goes up. When the soil is dry the infiltration is more because of the following reason. When the water falls on the dry soil the upper surface becomes wet, while the lower part of this soil remains comparatively much dry. Thus, there exist a large difference of capillary potential between the surface of the soil and those below it. Due to these differences of capillary potential, downward force will act on the water which will be in addition to the normal force of gravity. Hence, the water will now move down ward with two forces and hence rapidly. As the time passes the lower surface of soil will also go on becoming wet, and these difference of capillary potential will go on reducing and hence the infiltration will go on falling, as the soil moisture content goes on increasing. ii).The second effect soil moisture on infiltration capacity is the reverse of the first. When the soil becomes hot, the colloids present in the soil swell immediately, which reduce the infiltration capacity during the initial period of the rain fall. This is one of the reasons as to why there is a rapid in infiltration during rain. Hence these factors are responsible for much of the typical seasonal variation in the values of infiltration as well as a part of the rapid decrease in infiltration capacity during rain.

Davis (2000) studied as the viscosity of water changes with temperature. Since the flow in the interstitial space of soil is nearly always laminar, the rate of infiltration will also change with viscosity. Hence, infiltration will change with temperature. This factor causes the value of infiltration capacity to be somewhat lower in winter and somewhat higher in summer.

Fetter (2001) stated that when rain fall over the soil; the soil automatically undergoes mechanical compaction. This compaction reduces the voids in fine textured soils like clay, and hence, reduces their infiltration capacity. According to his study a lot of effect can be produced in this matter on the exposed clay soils, which on compaction, become virtually impermeable; whereas, the infiltration capacity of a clean sandy soil is affected very little by rain compaction.

When a soil becomes very dry, the surface often contains many fine particles. When the rain falls, and the infiltration begins, these fines are taken down into the soil, and are deposited in the voids, thus reducing the infiltration capacity. This factor also reduces infiltration capacity during a rain (Patra, 2008).

2.2. Infiltration Management

According to Jagani et al. (2018), Management practices such as using diverse high-residue crops, maintaining residue on the soil surface, using cover crops, and managing equipment traffic to avoid compaction affect infiltration by minimizing surface crusting and compaction and increasing soil organic matter content and porosity. Unless the soil is protected by plant or residue cover, the direct impact of raindrops dislodges soil particles, resulting in runoff and erosion. The rainfall simulator more runoff occurs where there is less residue on the surface, increasing the risk of erosion. Dislodged soil particles fill in the surface pores, contributing to the development of a surface crust, which restricts the movement of water into the soil. Equipment use, especially on wet soils, and tillage can result in compaction.

2.2.1. Infiltration management strategies

According to Patra (2008), infiltration management strategies include: Increase the amount of plant cover, especially of plants that have positive effects on infiltration, Decrease the extent of compaction by avoiding intensive grazing and the use of machinery when the soils are wet, Decrease the formation of physical crusts by maintaining or improving the cover of plants or litter and thus reducing the impact of raindrops.

According Subramanya (2008), the pressure of dense vegetative cover over a soil; increase the infiltration capacity of that soil to considerable extent. In the presence of a vegetative cover, the rain will not fall directly on the soil, and hence not able to compact the soil. The vegetation cover also provides a layer of decaying organic matter, which promotes the activity of burrowing insects and animals, which in turn, produces spongy permeable soil structure. Both of these factors help in increasing the infiltration capacity, and hence the presence of vegetative cover causes the infiltration capacity to increase predominantly (Thompson et al., 2010).

2.3. Methods of Infiltration Measurement

There are three methods for determining the infiltration characteristics for any irrigation system design and water management practices. They are: a). Cylindrical infiltrometer method, b). Accumulation infiltration estimation from waterfront advance data, and b). Depletion of free water surface measurement in a large basin. Out of the above mentioned methods, cylindrical infiltrometer method is most commonly used. Cylindrical infiltrometer method offers the advantages over the other two avoiding the cumbersome procedure in collecting correct data from the field while estimating from waterfront advance data and there is necessity of considering the evaporation loss due to atmospheric influences on the large basin while measurement of water depletion is considered (Thompson et al., 2010).

2.3.1. Double ring infiltrometer

The cylindrical infiltrometer is comparatively reliable for measuring the infiltration rate and accumulated infiltration. Infiltration characteristics can be measured by using a metal cylindrical round shaped hollow drum driven to a certain length into the soil surface and then ponding this cylinder with water and simultaneously record the time required to deplete water and enter into the soil surface (Jagani et al., 2018).

The double ring infiltrometer, with inner and outer of diameters 30 cm and 60 cm respectively were most popular to measure infiltration. The double ring infiltrometer was driven concentrically into the soil surface about 10 cm and the total height of these two ring cylinders was 25 cm (Alizadeh, 2001; Darbandi et al., 2012).

2.3.2. Inflow out flow method

Infiltration is a component of the general mass balance hydrologic budget. There are several ways to estimate the volume and the rate of infiltration of water into a soil. The rigorous standard that fully couples groundwater to surface water through a non-homogeneous soil is the numerical solution of Richards' equation. A newer method that allows full groundwater and surface water coupling in homogeneous soil layers, and that is related to the Richards equation is the Finite water content vadose zone flow method. In the case of uniform initial soil water content and a deep well drained soil, there are some excellent approximate methods to solve for the infiltration flux for a single rainfall event. Infiltration is a component of the general mass balance hydrologic budget. There are several ways to estimate the volume and/or the rate of infiltration of water into a soil. The rigorous standard that fully couples groundwater to surface water through a non-homogeneous soil is the numerical solution of Richards' equation. A newer method that allows full groundwater and surface water coupling in homogeneous soil layers, and that is related to the Richards equation is the Finite water content vadose zone flow method. In the case of uniform initial soil water content and a deep well drained soil, there are some excellent approximate methods to solve for the infiltration flux for a single rainfall event. Among these are the Green and Ampt (1911) method. Beyond these methods there are a host of empirical methods such as, Soil Curve Statistical method, Horton's method, Philip that are little more than curve fitting exercises (Tesansis, 2006)

Given all the other variables and infiltration is the only unknown, simple algebra solves the infiltration question.

$$I = BI + P - E - T - ET - S - IA - R - BO \tag{2.0}$$

Where, I = infiltration, which can be measured as a volume or length, BI = the boundary input, which is essentially the output watershed from adjacent, directly connected impervious areas, BO = the boundary output, which is also related to surface runoff, R depending on where one chooses to define the exit point or points for the boundary output, P = precipitation, E = evaporation, T = transpiration, ET = evapotranspiration, S = the storage through either retention or detention areas, IA = the initial abstraction, which is the short term surface storage such as puddles or even possibly detention ponds depending on size, R = surface runoff.

2.4. Infiltration Models

When water falls on the ground, a small part of it is first, absorbed by the top layer of soil, so as to replenish the soil moisture deficiency, thereafter, excess water moves down ward. Where it is trapped in the voids, and becomes ground water. This process is occurred where the water enters the surface strata of the soil and moves down ward towards the water table, by means of infiltration, and percolation (Valiantze et al., 2009).

The rate of infiltration is influenced by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity (Subramanya, 2008). With consideration of the parameters infiltration can be represented by mathematical models

Different researcher proposed different types of infiltration models depending up on soil characteristics of the study area. The detail descriptions are presented in the subsequent section.

2.4.1. Kostiakov equation

According to Haneyeh and Hamidreza (2013), Kostiakov suggested the empirical model as below, to determine the amount of water infiltration in the soil:

$$I = ct^{a} \quad (2.1)$$

$$i = act^{a-1} \quad (2.2)$$

Where, I = infiltrated water since the beginning of infiltration by cm, i = infiltration rate (cm/hr), t = infiltration opportunity time (since the beginning) by minute, and a, c = empirical coefficients for different soils and their values are greater than 0 and between 0, 1 respectively.

Haneyeh and Hamidreza (2013) examined Kostiakov and Philip models accuracy and found that results of RMSE, GMER, GSDER and R^2 as 0.1337, 0.989, 1.42, 0.996 for Kostiakov respectively and RMSE, GMER, GSDER, R^2 0.392, 1.013, 1.34 and of 0.989 for Philip respectively. They concluded that Kostiakov model has a more appropriate performance than Philip model, in estimation of the amount of infiltration in Iran Marvdasht region, Fars province.

2.4.2. Modified kostiakov equation

A more general infiltration function is the extended form of the Kostiakov equation. One of the limitation of modified kostiakov is if the soil intake rate at long times approaches a zero value or if the irrigation event is short compared to the time required for the infiltration to reach a steady rate or its reliance on the zero final intake rates (Tegenu et al., 2018)

According to Davis (2000), Modified Kostiakov suggested the empirical model as below, to determine the amount of water infiltration in the soil:

$$I = kt^{a} + b \quad (2.3)$$

$$i = akt^{a-1} + i_o \quad (2.4)$$

Where, I = accumulated infiltration at time t (cm), io is basic infiltration (cm), t = elapsed time, (min/hr), a, c, and b are three characteristic constants. Values of a, k, and b can be calculated by the method suggested by Davis Values of a, k, and b are usually less than 1.

Egbadon and Indris (2007) evaluated Philip, Swartzendruber, Kostiakov and Modified Kostiakov infiltration models and they found that, Kostiakov model and Adjusted Kostiakov model have more compatibility with observed values.

Gorji et al. (2010) evaluated some infiltration models (modified kostiakov, Horton and Philip) and hydraulic parameters in Spanish agricultural research. They recommended Modified kostiakov model for the study area depending up on result found with highest R^2, RMSE of 0.994 and 0.23 respectively.

2.4.3. Philip equation

According to (Haneyeh and Hamidreza, 2013), Philip suggested the empirical model as below, to determine the amount of water infiltration in the soil:

$$I = \frac{S}{2} t^{0.5} + Kt \quad (2.5)$$

$$i = St^{-0.5} + K \quad (2.6)$$

Where, I = cumulative infiltration, i = infiltration rate and K = constant coefficient related to soil hydraulic conductivity (cm/Min), S = constant coefficient related to water absorbency which is a function of soil water suction ($mm/min^{0.5}$), t is time (min or hr).

Ellen (2006) compared Green-Ampt, Holtan and Philip equations with respective root mean squared errors (RMSE) of 0.15, 0.17, and 0.19 respectively and provided the first, second and third best estimates of infiltration rates, for observed infiltration data at the University of Maryland's Research.

Nugroho (2018) evaluated infiltration models for mineral soils with different land uses in Indonesia. The infiltration models evaluated were Green–Ampt, Kostiakov, Philip, and Horton. The results of the study indicate that there is no significant difference ($\alpha = 5\%$) in the infiltration rate among the five models of infiltration.

2.4.4. Horton equation

The Horton infiltration equation empirical and can be expressed as below (Gorji et al. (2010)

$$I = i_c t + \frac{io - ic}{K}(1 - e^{-\beta t}) \quad (2.7)$$

$$i = (i_0 - i_c)e^{-\beta t} + i_c \quad (2.8)$$

Where, i_0 = the initial infiltration rate in cm /min; i_c = constant infiltration rate in cm /min, t = time (min); and β = the infiltration decay factor.

According to Mohammadi and Refahi (2005), by applying the infiltration models (Philip (RMSE of 0.307 and R^2 of 0.912), Kostiakov (RMSE of 0.290 and R^2 of 0.910) in Agricultural research farm of Bahauddin plots with soil concluded that, Horton's model provided the lowest mean values for RMSE of 0.235 and highest mean values for R^2 of 0.94. This indicated that infiltration can be well-described by the Horton's model at the selected site. The importance and role of infiltration phenomenon in other soil factors, environmental and biological factors has caused that, the researchers always look for providing a suitable model and determination of its coefficients to explain it, quantitatively.

According to Mohammad (2018), comparative analysis on Novel infiltration model with Horton infiltration model, Horton infiltration model was selected depending up on the findings of Root Mean Square Error, coefficient of determination 0.8 and 0.9 respectively.

Vikas et al. (2018) assessment of Infiltration Models (Horton, Philip and Green-Ampt) under Different Conservation Agriculture Practices in India, by comparing the performance of different infiltration models, they recommended Horton infiltration Model. Higher values of coefficient of determination and lower value of RMSE, MAE are indicating better performance of the model. Magnitude of R^2 ranged between 82-96%, RMSE between 0.32-1.19, MAE between 0.25-0.83.

According to Umar et al. (2019) estimation of infiltration models parameters and their comparison to simulate the onsite soil infiltration characteristics in Agricultural Research Farm of Bahauddin Zakariya University, Multan, Pakistan, and the value of infiltration capacity at onset of infiltration was obtained as 1.744 to 3.491 cm/min for all the five points. The analysis showed that the infiltration models using the estimated parameters have satisfactory prediction capability at all the five points. Depending up on results Horton's model provided the lowest mean values for RMSE (0.235) and highest mean values for ME (94%); and the lowest mean values for MPD (0.127). This indicated that infiltration can be well-described by the Horton's model.

Table 2.1: Infiltration models and their coefficients

Coefficients	Infiltration equation	Model name
a, c	$I = ct^a$ and $i = act^{a-1}$	Kostiakov
k, a ,b	$I = kt^a+b$ and $i= akt^{a-1}+i_o$	Modified Kostiakov
K	$i = St^{-0.5} + K$ and $I = \frac{S}{2}t^{0.5} + Kt$	Philip
e, k	$i= (i_0 - i_c)e^{-\beta t} + i_c$ and $I = i_c t + \frac{io-ic}{K}(1-e^{-\beta t})$	Horton

Where, I = the accumulated infiltration (cm), i = infiltration rate (cm/hr), a, k, β and b = constant parameters, e = decay logarithm, i_o = basic infiltration (cm/hr), i_c = constant infiltration (cm/hr), t = elapsed time (hr) and S = Sorptivity (mm/min).

2.2. Parameters Used to Assess Accuracy

According to Vanger et al. (2001) and Tietje and Hennings (2006), the minimum value of Root Mean Square Error (RMSE) is equal with zero and whatever the amount is less, it is more appropriate. RMSE value indicates that the estimated parameters have been estimated how high or low. If GMER value is equal with 1 then, the measured and estimated values are completely overlapped. If Geometric Mean Error Ratio (GMER) is less than 1 then, the estimated values are less than measured values and if GMER is higher than 1 then, the estimated values are greater than measured values. Also, if Geometric Standard Deviation (GSDER) value is equal with 1 then, the measured and estimated values are completely overlapped and increasing GSDER of 1 indicates increasing distance between estimated and measured values. Therefore, it is most appropriate that, GMER to be close to 1 and GSDER value also to be small that means not much bigger than 1 (Vikas et al., 2018).

Tietje and Hennings (2006) recommended the formula to assess the accuracy of the models, some parameters such as Root Mean Square Error (RMSE), Geometric Mean Error Ratio (GMER) and Geometric Standard Deviation of Error Ratio (GSDER) during their study on accuracy of the saturated hydraulic conductivity prediction by pedotrasfer function compared to the variability within FAO textual classes which is calculable using following equations.

$$\text{RMSE} = [\sum_{i=1}^{n} \frac{(\text{AIa}-\text{AIc})2}{n}]^{0.5} \quad (2.9)$$

$$\text{GMER} = \exp[\frac{1}{\text{n}} \sum_{i=1}^{n} \ln(\text{Ei})] \quad (2.10)$$

$$\text{GSDER} = \exp[(\frac{1}{n} \sum_{i=1}^{n}[\ln(\text{Ei})\text{-}\ln(\text{GMER})]^{2})^{0.5}] \quad (2.11)$$

$$\text{R}^2 = 1\text{-}\sum_{\text{i}=1}^{\text{n}} \frac{(\text{AIa}-\text{AIc})2}{(\text{AIa}-\text{AIa av})2} \quad (2.12)$$

$$\text{Ei} = \sum_{\text{i}=1}^{\text{n}} \frac{\text{AIa}-\text{AIc}}{\text{AIa}} *100 \quad (2.13)$$

Where, AI_a = the actual or observed accumulated infiltration, Ei = error ratio, GMER = Geometric Mean Error Ratio, n = number of samples, RMSE = Root Mean Square Error, GSDER = Geometric Standard Deviation Error Ratio, AI_c = calculated accumulated infiltration by the model, i = the number of data, R^2 = coefficient determination are estimated and measured values in each soil moisture.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1.Fentale irrigation scheme

The study was conducted on Fentale Irrigation Scheme which is located about 200km from Addis Ababa and 85 km from Adama town on Asphalt road. Particular project area is located in Oromia region, East Shoa zone, Boset Woreda (Kawa and Huluko) for about 30-40 km to east of (Fentale) Metehara town. Generally, both woredas are low land with agro-ecological zone characterized by low annual precipitation and high temperature and geographically in the main rift-valley system in east Showa zone (OIDA, 2011).

The command area is situated west of Metehara town and it is bound to the foot slopes of mount Fantalle on the north, Lake Beseka on the east, Rift valley escarpment on the west and rocky land (young lava flow) on the south. More precisely it falls in between 8° 50' and 9° 04' N latitude and 39°41' and 39° 52' E longitude. The study has cover gross area of about 6,000 hectares. The altitude ranging of study area is from 970 to 1020 m above sea level (OIDA, 2011).

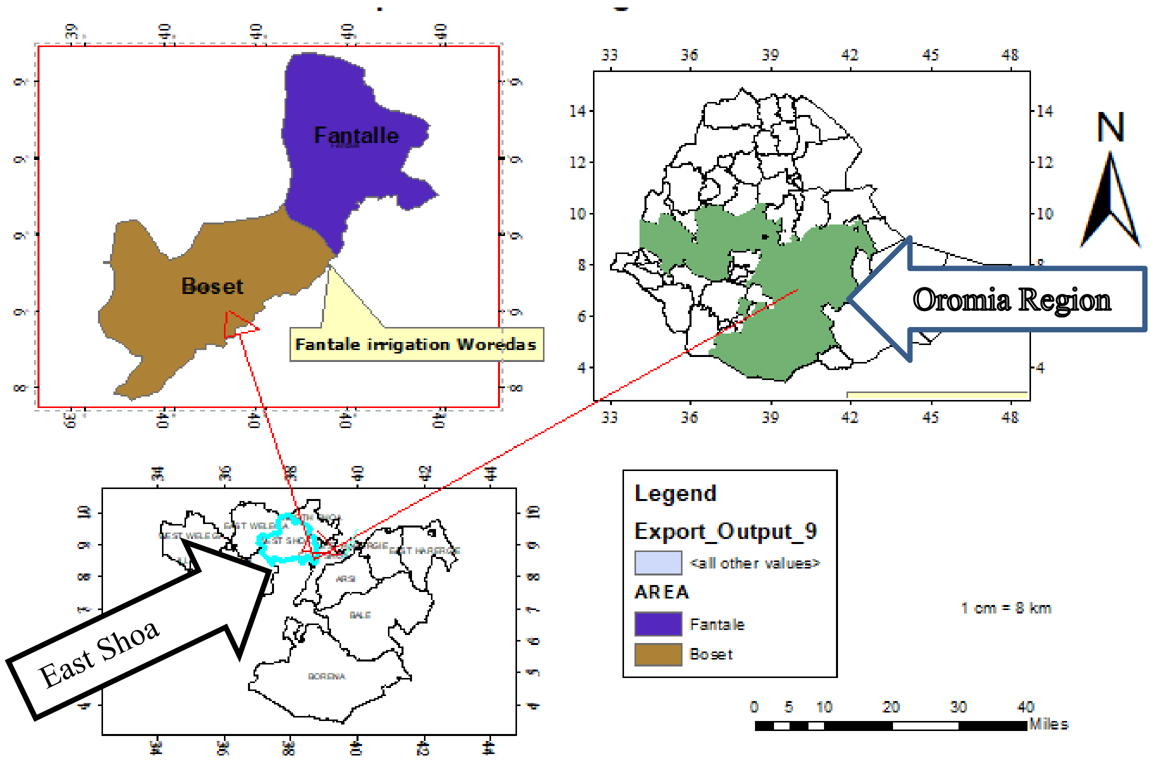


Figure 3. 1: Location Map of the Study Area

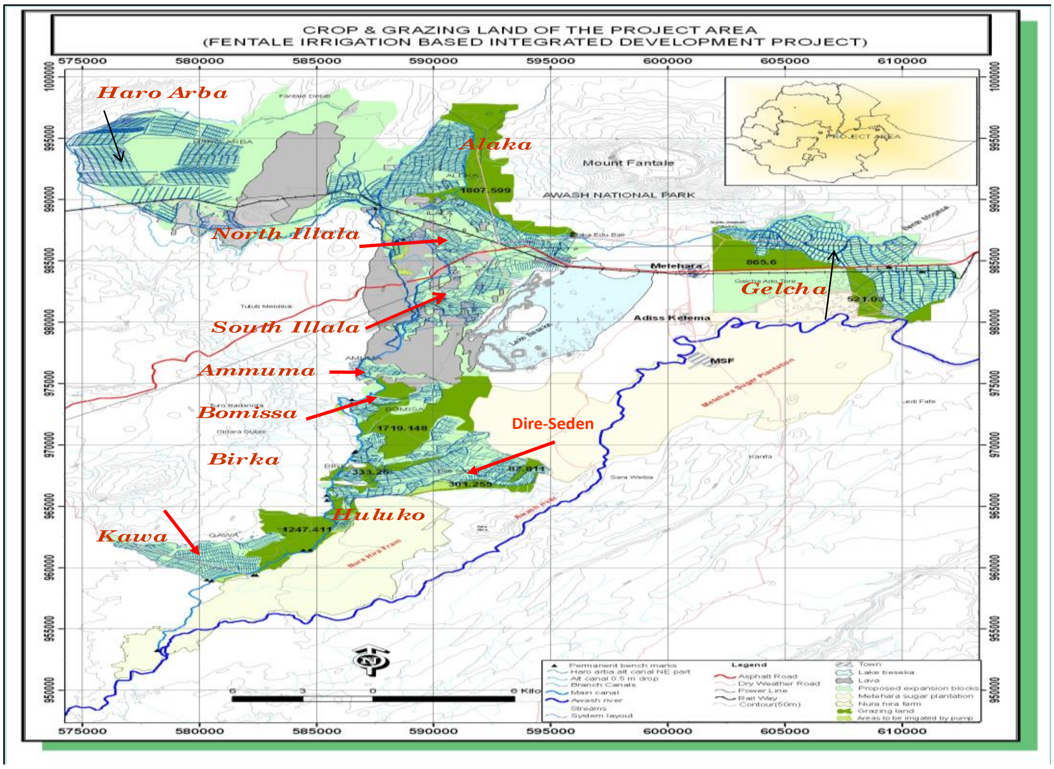


Figure 3. 2: Boundary of Irrigation Area for Fentale Irrigation Scheme.

3.1.2. Climate

The mean monthly minimum and maximum temperature in the project area varies from 10 °C to 38.3 °C respectively. The mean minimum temperature is recorded in December and the maximum is recorded in May. May and June are the hottest months of the year. Annual rainfall in the project area is about 500 mm. Mean monthly rainfall varies from 4.8 mm to 124 mm. The highest rainfall occurs in July and August; while the lowest rainfall occurs in December. Mean monthly relative humidity varies from 32% to 49%.

3.1.3.The command area

The command areas of the project are scattered along the main canal and divided as south and north blocks. Hence, the areas that establish under south block are Kawa, Huluko, Burka Direseden, Bomisa, Ammuma and South Ilala. Similarly under North block are North Ilala, Alaka, Gelcha and Haro-arba. Consequently, the areas that are on the first block are found between headwork and asphalt Road (on Djibouti to Addis Ababa Highway) and the area of the second Block are under Mountain Sebebor and Fantalle including the area between the highway and Railway and beyond Rail way both right and left side of the main and branch canals. Therefore, in all Command areas irrigation water through whole canal system can flow by gravity except Kawa Kebele command area, which is irrigated by pump.

3.1.4. Water source and diversion

The water source for the whole command area of the scheme is the Awash River. Irrigation water for abstraction was raised by weir at the headwork of the scheme and conveyed through conveyance main canal of 49.3 km and eleven (11) blocks canal with pertinent structures and pump including electro mechanical equipment for Kawa command area (OIDA, 2011).

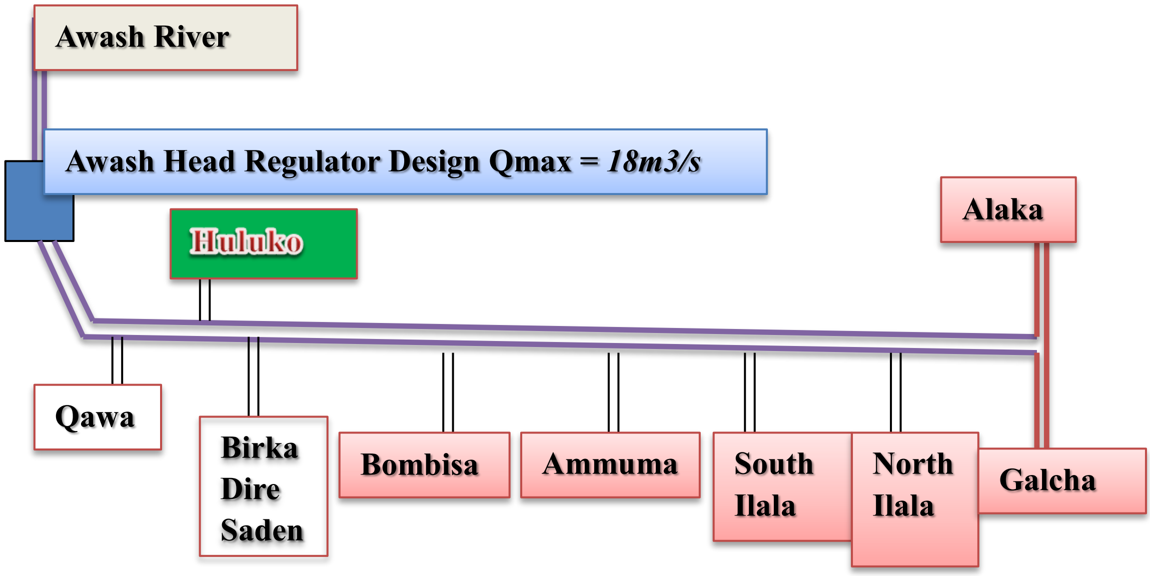


Figure 3. 3: Fentale Irrigation Scheme Diagram

3.2. Materials Used

The instruments used during present study were described as below with their purpose: Double infiltrometer was used to measure amount of water infiltrated. Plastic Hammer was used to driven double infiltrometer in to ground level, Water container used to store water where Jar used to simulate water from container and stop watch to catch time. Sponge was used to prevent soil erosion during simulation water to double infiltrometer and driving plate (flat wood) to protect the steel from hammer pressure. In addition to the materials list previous the following were used in laboratory to determine initial soil moisture and soil texture. Core Sampler was used to carry soil during determination initial soil moisture where cylinder used to carry the mixture of soil with water during texture determination and the height of soil settled in the cylinder measured by ruler. Shellby is the type of cylinder which used for took sample from field and Excluder was used to remove soil sample from shellby. In order to get the weight of wet soil and dry soil Electrical weighing Balance was used. Electrical Oven dry is the electrical machine which used to dry wet soil at 105 °C.

3.3. Determination of Soil Texture and Initial Soil Moisture

Soil texture refers to the relative proportion of particles or it is the relative percentage by weight of the three soils separates like sand, silt and clay or simply refers to the size of soil particles (Kostiakov, 2002). Soil sample was taken from sampling point-1 to point-6 and the soil texture of the study area were determined by triangular soil profile after calculating percentage of clay, silt and sand. Depending up on laboratory result and percentage calculation of clay, silt and sand the soil texture of the study area determined. A total of 18 soil samples (that means three rounds from each point) were collected from six selected points at 30 cm depth of soil. The samples were taken from the field by shellby sampler from each point and removed from shellby by Excluder. The soil samples were balanced before oven dry and put in oven dry for 24 hr with 105 ^{O}C. These soil samples were analyzed a civil department soil laboratory of Adama Science and Technology University. Soil texture of each point was determined by measuring the settlement of soil at 1min, 3hr and 24hr in the cylinder and the percentage of clay, sand and silt calculated respectively.

Initial soil moisture of each point was determined in Civil Department, Adama Science and Technology University of soil laboratory auger sampling method as follow:

- Say weight of container is $W_{1,}$
- Weight of the container + wet soil equal to $W_{2,}$
- Weight of Container + dry soil equal to W_3,
- Weight of the soil moisture was calculated by subtracting W_2 - W_3 equal to Ww and, Weight of dry soil equal to ws = w_3-Ww then the percentage of initial soil moisture is Ww divide by Ws multiply by 100 as shown table 50, 51, and 52.

3.4. Experimental Setup and Measurement

Six infiltrometers were installed randomly lengthwise with distances 5, 5, 10, 10, 10 and 9km across command area of the scheme with three rounds. The depth of infiltrated water to soil and all measurements of infiltrate waters are in cm. The geographical location of each point (point-1, point-2, point-3, point-4, point-5, and point-6) was depending up on the Chainages of design document of canal and collocutor. The infiltration was measured according to the layout shown in the figure below.

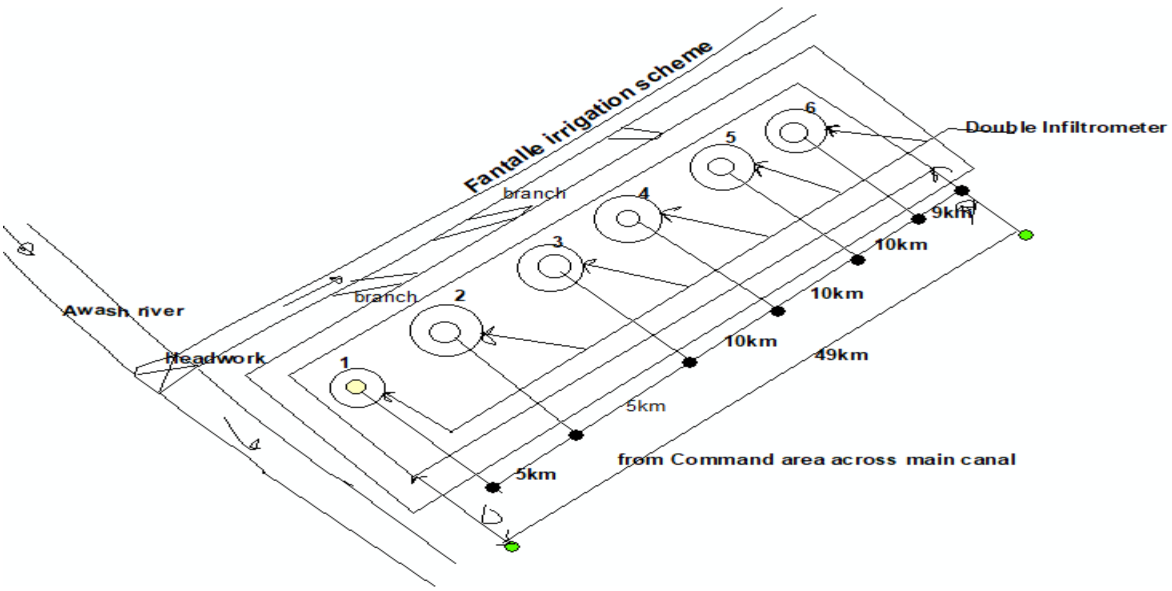


Figure 3. 4: Field layout with the locations of the infiltrometers

The double ring infiltrometer, with inner and outer of diameters 30 cm and 60 cm respectively were installed to measure field infiltration. The double ring infiltrometer was driven concentrically into the soil surface about 10 cm and the total height of these two ring cylinders was 25 cm. The inner and the outer cylinders were both ponded with water. The Inner and outer cylinder were filled at the same time and used as a buffer pond to avoid the lateral movement of water from and to the inner cylinder. The cylinders were driven into the soil by a light weight hammer striking on top of a wooden block placing on top of the cylinders to avoid the damage at the edge of the cylinders (Jagani et al., 2018). The readings or depth of water infiltrated were taken at an interval of 5, 10, 15, 30, 60, 90, 120 and 150 min. An average infiltration head of 15 cm was maintained during these time intervals. Similarly, infiltration measurement was made at each selected point (Point-1 to Point-6). The experiment has been continued until the steady state infiltration rate was reached. After reaching the steady state infiltration rate, the experiment was stopped and the infiltration rate, cm/min, and cumulative infiltration depth, cm, were calculated.

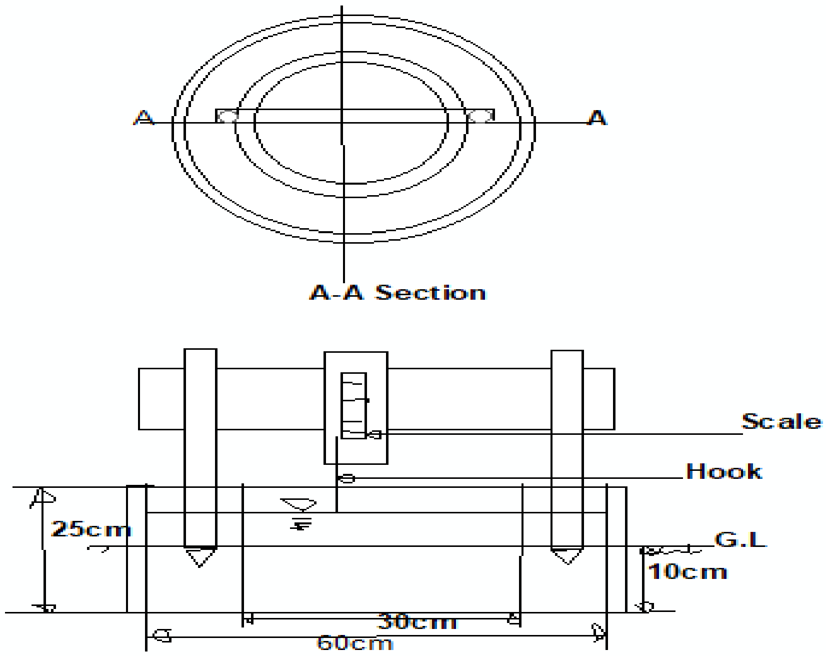


Figure 3. 5: Plan and cross-sectional views of a cylindrical infiltrometer

3.4.1. Procedures

In order to measure infiltration the procedure were followed: Water levels in the inner and the outer cylinders were kept approximately same to keep up the water pressures same between the inner and outer cylinders and avoids the lateral water movement due to difference in height between the inner and the outer cylinders. The water levels of the inner cylinder were read by a ruler whose sharp and pointed head end was just touching water level for initial water height reading and the tail end was set with a scale to read the difference after a predetermined time when a depletion of water height was there by adjusting the pointed head again touching the deplete water surface (Hasan, 2015).

The difference between initial and the final readings were the height of water that infiltrated during the predetermined time. This height divide by time was the one what was define as the infiltration rate. Here times were recorded as minutes but they were converted into hours for calculation purposes and express the infiltration rate as cm/hr.. At the initial stages, time versus depletion of water recordings were taken frequently, refill of water were done as quickly as possible so that the pace of infiltration could be kept constant. The raw data or depth of infiltrated water was collected using double infiltrometer from the field across command area of the scheme (Hasan, 2015).

Secondary sources were kept by the responsible bodies or officials at irrigation project, Journal, Woreda Agricultural offices, Irrigation offices at Regional, Zonal and Centeral levels were collected as much as possible. Furthermore, Research Centers and NGO's of the agricultural sectors were periodically to gather further information. Climatic data of irrigation project was collected from the nearby weather station. The design document of the irrigation scheme was collected from respective Oromia Design and Supervise Enterprise and OIDA.

3.5. Determination of Infiltration Models Parameters

Several models that simplify the concepts involved in the infiltration process had been developed for field applications. Model calibration is determination of the model parameters, such that observed values closely checked whether it match the simulated value or not. In practice, this was most often done by trial and error adjustment of parameters, but automatic parameter estimation may also be used. In the present study, most commonly used infiltration models such as Horton, Philip, Kostiakov and Modified Kostiakov models were selected for evaluation. The field data were used to evaluate these infiltration models and to obtain numerical values of the model's parameters. To determine these parameters the logarithmic function is used.

3.5.1. Kostiakov model

Kostiakov proposed a simple empirical infiltration model based on the data observed in the field. The model relates the infiltration to as a power function as described in Equation (2.1) Equation (2.2).

To determine these parameters (c and a), the logs of both observed infiltration (Z) and time (t) were taken. The Log (I) was plotted against the log (t) for all the six points that give a straight line. The slope of the plotted line gave values of parameter c and the intercept gave the value of log (a). The value of a was estimated by taking anti-loga.

3.5.2. Modified Kostiakov model

The relationship of accumulated infiltration (I) with respect to time (t) can be mathematically defined by the equation(2.3) and (2.4) previously and Values of a, k, and b can be calculated by the method suggested by Valiantze et al., 2009. The steps were described below: Plot the values of y and t, Select a pair of points of (t_1, y_1) and (t_2, y_2) from this plot, selection of the points on the plotted line should be near the extremities of the line to cover a wide range of interpolated values and calculate a third value for time t_3 using the values of t_1 and t_2 from the procedure followed in the previous section, then agreement of measured and calculated was checked.

3.5.3. Philip model

Philip proposed an empirical model for infiltration by truncating the series of solution from a pounded surface. The parameters of resulting Equation (2.5) and (2.6) determined using following steps: The estimation of S and K values was made by fitting the infiltration rate, (cm/min), and data against the transformed time ($1/2t^{0.5}$) by the least square regression for all data points. The resulting plot gives the straight line. The slope of the straight line gives the value of S and intercept as the value of K.

3.5.4. Horton model

Horton derived the relationship using the work and energy principle for estimation of infiltration rates. The relationship cumulative and rate infiltration Horton model discussed in equation (2.7) and (2.8).

The parameters of Horton's model such as f_o and k are determined by subtracting the value of f_c from experimental values of fp. The natural log of resulting values ln ($\mathbf{f_0 - f_c}$) is plotted as a function of time (t). The resulting graph was a straight line and slope of the line gave the value of k. The base value for parameters k was equal to a negative slope and the initial infiltration capacity (f_o) was calculated using the $f_0 - f_c = e^{\text{intercept}}$. The estimated values of infiltration model's parameters were incorporated to the model equations for all the three models to simulate cumulative infiltration depth for each point. The field data were compared with the model's simulated data to evaluate the capability of the model to simulate cumulative infiltration.

3.6. Infiltration Models Performance Evaluation

For estimation and evaluation of infiltration models, it is necessary to define the statistical criteria by which models are evaluated. To judge the estimated accuracy of the model, the following statistical indices are used for quantifying the best fit infiltration model.

The RMSE provides a measure of the deviation of predicted values from measured data and has frequently been used as a means of evaluating the accuracy of hydrologic models. The minimum value of RMSE is equal with zero and whatever the amount is less, it is more appropriate and which help to select the best model. The RMSE is calculated as follows:

$$\text{RMSE} = [\sum_{i=1}^{n} \frac{(\text{Aia}-\text{AIc})2}{n}]^{0.5} \quad (2.9)$$

Where, AI_a is the actual or observed cumulative infiltration, n is number of samples, RMSE is Root Mean Square Error, AI_c calculated cumulative infiltration by the model, n is the number of measurements.

The correlation coefficient of the computed infiltration data and the observed ones in these models are consistent in most cases. R^2 exceeds 0.8 except for a few simulation results, which means that the trends of simulated data agree with the observed ones, but the degree of similarity of these two sets is not clear (Wang et al., 2007). Predicted values of infiltration rate were plotted versus observed values and a coefficient of determination (R^2) was calculated for each model according to the equation.

$$R^2 = 1\text{-}\sum_{\text{i}=1}^{\text{n}} \frac{(\text{AIa}-\text{AIc})2}{(\text{AIa}-\text{AIa av})2} \quad (2.12)$$

Several approaches had been used by different researchers for selection of suitable models for the experimental fields. Model validation was test the model to see whether it is capable of making sufficiently accurate predictions. This involves application of calibrated model, without changing the parameters for another period, other than the calibration period. Minimizing the difference between the observed and simulated values was one of the simplest approaches to find the best fit infiltration model (Tietje and Hennings, 2006).

If GMER value is equal with 1 then, the measured and estimated values are completely overlapped. If GMER is less than 1 then, the estimated values are less than measured values and if GMER is higher than 1 then, the estimated values are greater than measured values. Also, if GSDER value is equal with 1 then, the measured and estimated values are completely overlapped and increasing GSDER of 1 indicates increasing distance between estimated and measured values. Therefore, it is most appropriate that, GMER to be close to 1 and GSDER value also to be small that means not much bigger than 1. GMER, GSDER, Ei calculated as follow:

$$\text{GMER} = \exp[\frac{1}{\text{n}} \sum_{i=1}^{n} \ln(\text{ei})] \quad (2.10)$$

$$\text{GSDER} = \exp[(\frac{\mathbf{1}}{\boldsymbol{n}} \sum_{i=1}^{n} [\ln(\text{ei})\text{-}\ln(\text{GMER})]^{2})^{0.5}] \quad (2.11)$$

$$\text{Error ratio(Er)} = \sum_{i=1}^{n} \frac{\text{A}I\text{a}-\text{AI}c}{\text{AIa}} *100 \quad (2.13)$$

The model was selected depending on values of above parameters and Model performances

3.7. Data Analysis and Interpretation

The Horton, Philip, Kostiakov and modified Kostiakov models were tested if it suits the local soil condition and if it can be represented for the cumulative infiltration and infiltration rate. The relationship of cumulative infiltration (I) with respect to time t can be mathematically defined by the equations(2.9 to 2.13) were analyzed depending up on values of Root Mean Square Error (RMSE), Geometric Mean Error Ratio (GMER) and Geometric Standard Deviation of Error Ratio (GSDER). Collected data were analyzed using Microsoft Excel software.

3.8. Methodological Framework of the Study

The methodological framework that was used in this study was outlined in Figure 3.6. The details of the data collection methods, mathematical equations and method of analysis used to understand the performance of most commonly used infiltration Models in estimating infiltration processes of Fantalle irrigation scheme are specified. More specifically understanding infiltration models constants, calibration, validation and selection of best model which calculate infiltration rate and cumulative infiltration have been done. Brief description of the methods used in this study is presented below.

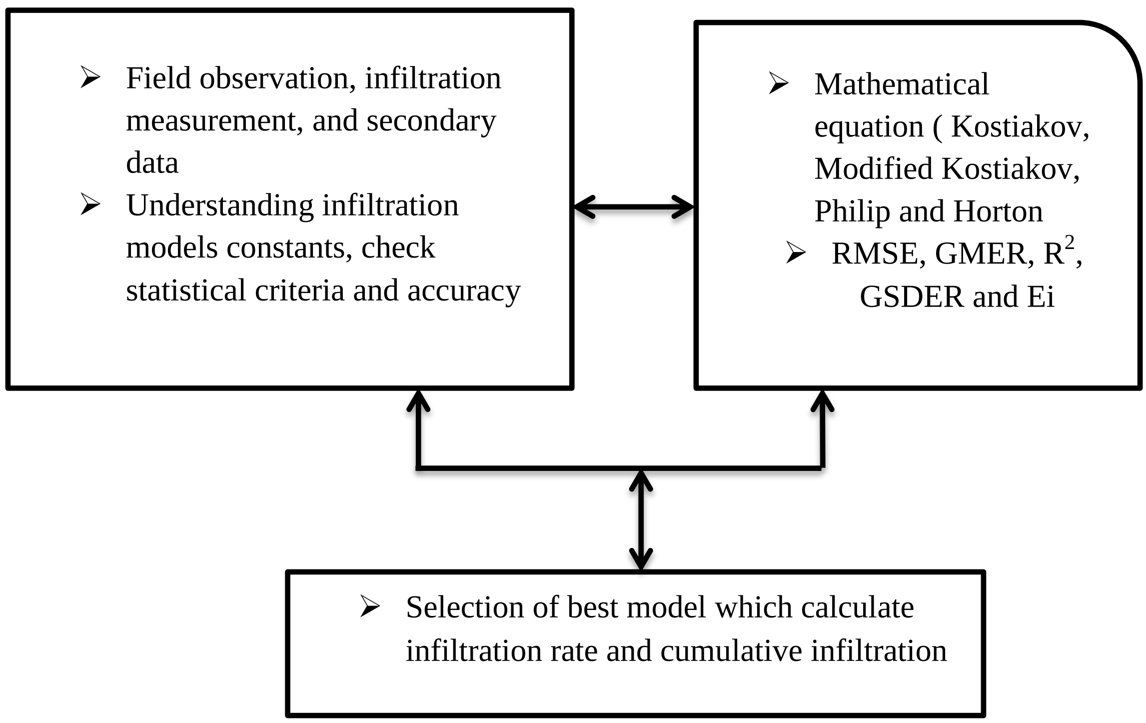


Figure 3. 6: Methodological framework of the study

4. RESULTS AND DISCUSIONS

All data collected were analyzed, interpreted and discussed in tables and graph method presented in the following subsection:

4.1. Determination of Soil Texture and Soil Sampling

Soil properties of the experimental site showed little variability among the six selected points (Table 4.1). Soil textures were predominantly sandy clay having clay fraction of 32.61%-44.89% and sandy fraction of 47.06%-58.33%. Soil textural class was determined by seeing the triangular textural class of soil. Similarly, the initial soil moisture was ranged from 4.43%- 10.39%. The initial soil moisture was different at each sampling point in the same textural class. The result showed us the moisture depends on the irrigation scheduling and condition of each sampling point. The result showed that initial soil moisture of the study area was low. Overall analysis indicated that these points had homogenous soil and similar soil surface conditions.

Table 4. 1: Soil textural classes and initial soil moisture at 30 cm soil depth

Sampling point	Clay (%)	Sand (%)	Silt (%)	Initial Moisture (%)	Textural class
1	36.11	58.33	5.56	6.85	Sandy clay
2	41.18	47.06	11.77	10.39	Sandy clay
3	32.61	47.83	19.57	6.85	Sandy clay loam
4	40.00	48.89	11.11	7.50	Sandy clay
5	44.89	51.02	4.08	6.99	Sandy clay
6	40.98	49.18	9.84	4.43	Sandy clay
Average	39.30	50.39	10.32	7.17	

4.2. Measured Infiltration

Measured average infiltration depth, cumulative infiltration depth and infiltration rates (cm/hr) from the study area were presented in tables (4.1-4.5) and annex of figure 2.1. Observed infiltration depth which presented in table 4.2 showed that at the beginning infiltration capacity was high. As time increased it become decreased and at the middle again increased but, it become decreased and steady or constant. This process was done due to soil characteristics and attraction forces (capillary action and gravity).

Table 4. 2: Average field measured infiltration depth in (cm) for all sampling points

Time (Min)	SP-1	SP-2	SP-3	SP-4	SP-5	SP-6
5	1.83	4.00	6.50	6.53	6.83	7.47
10	1.53	2.50	2.37	5.13	6.23	6.53
15	0.97	1.80	1.27	4.63	5.26	5.17
30	0.87	2.90	2.20	5.20	6.36	5.67
60	0.73	5.40	1.83	6.17	5.50	4.27
90	0.58	3.57	1.67	6.00	2.93	3.20
120	0.50	2.30	1.50	3.20	2.00	2.10
150	0.50	2.30	1.50	3.20	2.00	2.10

Note that, SP-1 = sample at point-1, SP-2 sample at point-2, SP-3 = sample at point-3, SP-4 = sample at point-4, SP-5 = sample at point-5 and SP-6 = sample at point-6.

Table 4.3: Average observed infiltration depth (Im), cumulative infiltration (Im), infiltration rate (i) for sampling point 1and 2.

	SP-1			SP-2		
Time (Min)	Zm (cm)	Im (cm)	i (cm/hr)	Zm (cm)	Im (cm)	i (cm/hr)
5	1.83	1.83	21.96	4.00	4.00	48.00
10	1.53	3.36	18.36	2.50	6.50	30.00
15	0.97	4.33	11.64	1.80	8.30	21.60
30	0.87	5.20	3.48	2.90	11.20	11.60
60	0.73	5.93	1.46	4.93	16.13	9.87
90	0.58	6.52	1.16	3.57	19.70	7.13
120	0.50	7.02	1.00	2.30	22.00	4.60
150	0.50	7.52	1.00	2.30	24.30	4.60

Where, Zm = observed infiltration depth, Im = observed cumulative infiltration depth and i = measured infiltration rate

Table 4. 4: Average field observed infiltration depth (Zm), cumulative infiltration (Im), infiltration rate (i) for sampling point 3 and 4.

	SP-3			SP-4		
Time (Min)	Zm (cm)	Im (cm)	i (cm/hr)	Zm (cm)	Im (cm)	i (cm/hr)
5	6.50	6.50	78.00	6.53	6.53	78.36
10	2.37	8.87	28.44	5.13	11.66	61.56
15	1.27	10.14	15.24	4.63	16.29	55.56
30	2.20	12.34	8.80	5.20	21.49	20.80
60	1.83	14.17	3.67	6.17	27.66	12.34
90	1.67	15.84	3.33	6.00	33.66	12.00
120	1.55	17.39	3.10	3.23	36.89	6.40
150	1.55	18.94	3.10	3.23	40.12	6.40

Table 4. 5: Average observed infiltration depth (Zm), cumulative infiltration (Im), infiltration rate (i) for sampling point 5 and 6.

	SP-5			SP-6		
Time (Min)	Zm (cm)	Im (cm)	i (cm/hr)	Zm (cm)	Im (cm)	i (cm/hr)
5	6.83	6.83	82.00	7.47	7.47	89.60
10	6.23	13.07	74.80	6.53	14.00	78.40
15	5.27	18.33	63.20	5.17	19.17	62.00
30	6.37	24.70	25.47	5.67	24.83	22.67
60	5.50	30.20	11.00	4.27	29.10	8.53
90	2.93	33.13	5.87	3.20	32.30	6.40
120	2.00	35.13	4.00	2.10	34.40	4.20
150	2.00	37.13	4.00	2.10	36.50	4.20

As shown in the above table 4.5 of all points' infiltration rate was decreased as time increased and almost constant, where cumulative infiltration increased. The measured infiltration depth at 15-30 min increased again because of soil particle elasticity and infiltration by capillary action as time increased.

4.3. Determination of Infiltration Models Parameters

The infiltration models and its parameters were presented in Table 4.6 and the performance of four the models in terms of coefficient of determination is given in table 4.6 below for each models.

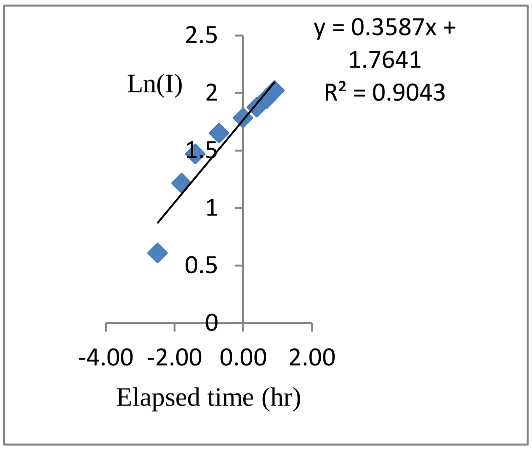
Table 4. 6: Parameters of Kostiakov, Modified Kostiakov Philip, and Horton's equations for all six sampling points

Sampling Points	Kostiakov		Modified Kostiakov			Phillips		Horton	
	A	C	a	K	b	S	K	K	e
1	0.36	5.84	0.29	0.51	0.61	6.46	1.23	3.56	2.71
2	0.52	15.78	0.52	0.49	1.82	30.14	6.34	1.80	2.71
3	0.29	14.42	0.27	0.21	0.38	47.75	19.32	6.39	2.71
4	0.50	27.41	0.43	0.20	1.76	55.94	11.96	6.39	2.71
5	0.45	28.01	0.35	0.14	3.12	64.63	16.64	2.69	2.71
6	0.42	27.83	0.32	0.12	3.18	69.77	19.93	2.75	2.71
Mean	0.42	19.88	0.36	0.28	1.81	45.78	12.57	3.93	2.71
standard deviation	0.09	9.27	0.09	0.18	1.19	23.78	7.54	1.99	

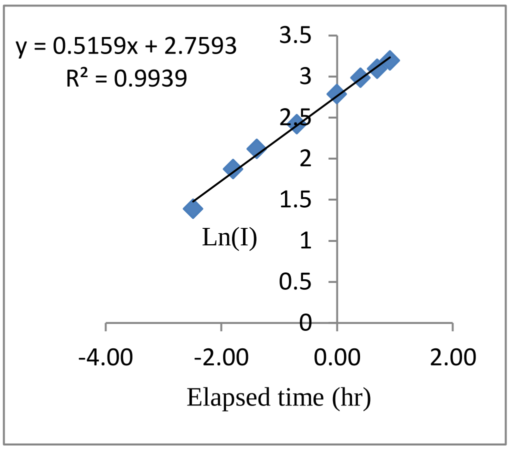
Estimated parameters for the four infiltration models (Kostiakov, Phillip, Horton and Modified Kostiakov) parameters depend up on field measured data and summarized in above table 4.6. Kostiakov's infiltration model's parameter such as the values of empirical constant 'a' and c was estimated in the range of 0.29-0.52, 5.84-28.83 in an average 0.42 and 19.88 respectively. The Philip's infiltration model parameter was not in the range for all the six points when compared with other models. Similarly, Horton's model's parameter such as constant 'k' was determined in the range of 1.79-6.39 with an average 3.93. The values of infiltration capacity at the beginning of infiltration 'b' was obtained as 0.38- to 3.18 with an average 1.81 for all the six points. Modified Kostiakov's parameters such as values of empirical constants 'a' were estimated in the range of 0.27-0.52 with an average 0.36. Similarly the values of infiltration decay constant 'k' were estimated in the range of 0.2-0.51 with an average 0.28. The values of infiltration decay constant 'k' were in accordance to the theory of infiltration that described the values to be positive and always less than unity. All parameters constants of modified Kostiakov were laid in the range so it was the best than others. While the values of model infiltration parameters have no physical meaning, these values reflected the effects of soil physical properties on infiltration as well as surface conditions and soil moisture contents. The estimated values of these infiltration models' parameters can be used for developing the infiltration equation for the study area after verification.

4.3.1. Kostiakov model

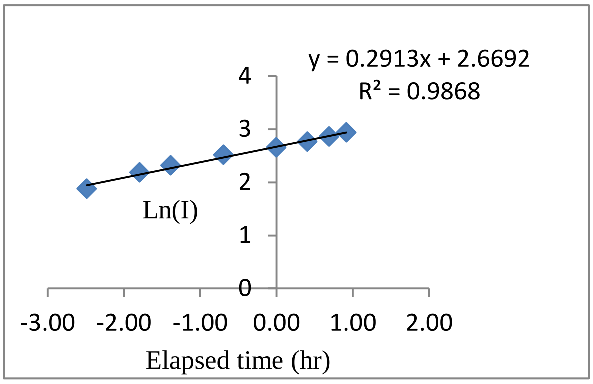
The measurement was taken from field by Double infiltrometer. Infiltration rate and cumulative infiltration was calculated depending on field data at different range of time were presented in table 4.3 and annex of figures 2.2 to 2.7. The developed Kostiakov model was depend on the figure 4.1 and figure 4.2 which is presented as follows.



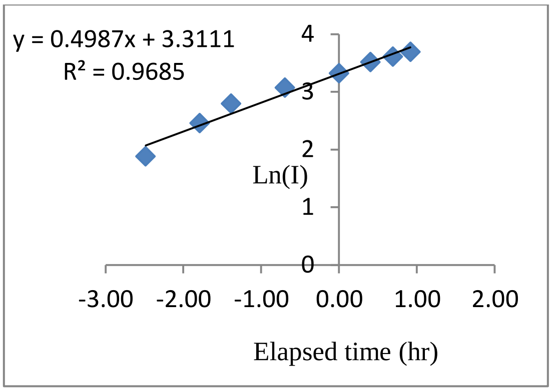
a.SP-1



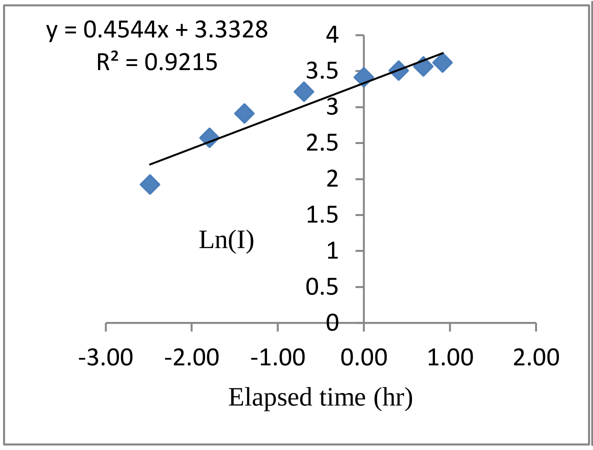
b. SP-2



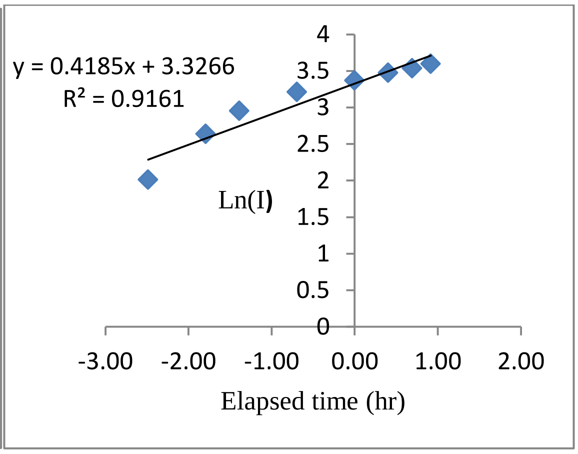
c. SP-3



d. SP-4



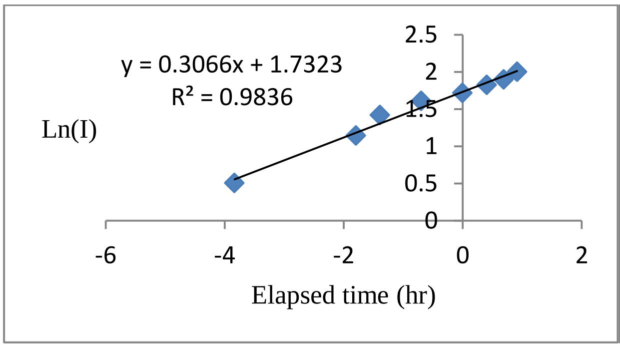
e. SP-5



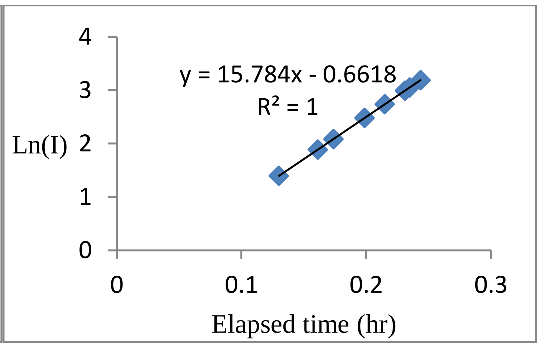
f. SP-6

Figure 4. 1: Ln (I) versus Ln (t) plot for Kostiakov Model parameters

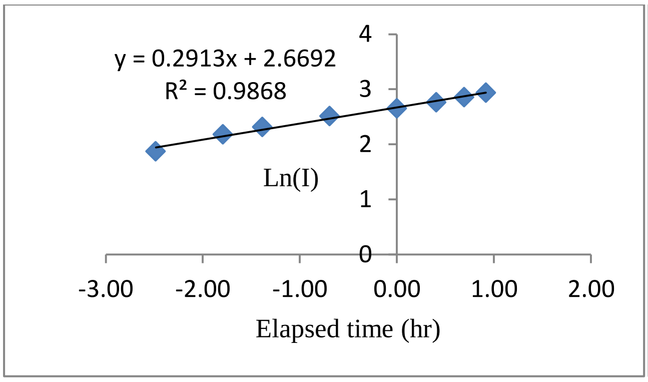
After calculation was done the following log scale found.

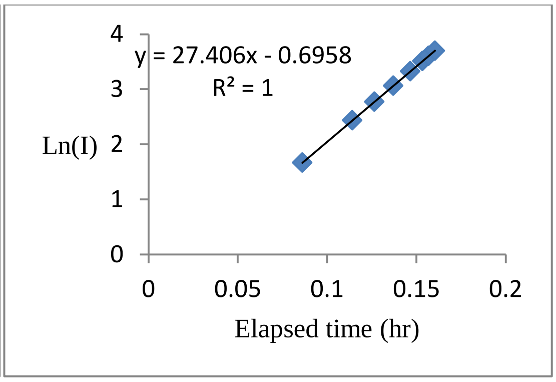


a. SP-1



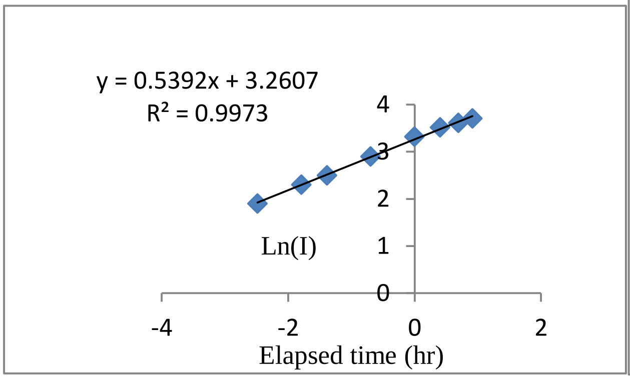
b. SP-2

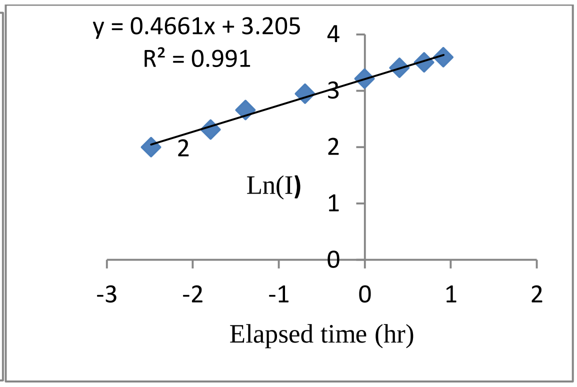




c. SP-3

d. SP-4





e. SP-5

f. SP-6

Figure 4. 2: calculated Ln (I) versus Ln (t) plot for Kostiakov Model parameters

comparison of calculated and average field measured accumulated and infiltration rate of kostiakov model.

Table 4. 7: Comparison of calculated and observed cumulative and rate infiltration Kostiakov model for sampling point-1

Time(min)	Ic (cm)	Im (cm)	ic (cm/hr)	i (cm/hr)
5	1.66	1.83	20.31	21.96
10	3.14	3.37	17.80	18.36
15	4.13	4.33	11.12	11.64
30	4.99	5.20	3.32	3.48
60	5.57	5.93	1.4	1.46
90	6.21	6.52	1.11	1.16
120	6.67	7.02	0.95	1.00
150	7.40	7.52	0.95	1.00

Where, I_m = measured cumulative infiltration, I_c = calculated cumulative infiltration, i = measured infiltration rate and i_c = calculated infiltration rate

Table 4.7 showed that calculated infiltration rate was almost similar with observed infiltration rate and as time increases both infiltration rates decreased and constant. Hence, calculate values lay below measured cumulative infiltrations, calculated cumulative infiltration depth have almost best agreement with measured cumulative infiltration depth of sampling point-1. Graphically the comparison observed and calculated infiltration rate and cumulative infiltration Kostiakov model for sampling point-1 presented in the annex of figure 2.2.

Table 4.8: Comparison of observed and calculated cumulative and rate infiltration Kostiakov model for sampling point-2

Time(min)	Ic (cm)	Im (cm)	i_c (cm/hr	i (cm/hr)
5	4.02	4.00	47.96	48.00
10	6.58	6.50	15.02	15.00
15	8.04	8.30	7.39	7.20
30	11.90	11.20	5.73	5.80
60	15.39	16.13	4.89	4.93
90	19.81	19.70	2.16	2.38
120	21.08	22.02	1.09	1.16
150	24.17	24.32	1.09	1.16

Table 4.8 showed that calculated infiltration rate was almost similar with measured infiltration rate and as time increases both infiltration rates decreased and constant but in the ranges of 5-10 min, 10-15 min calculated infiltration rate laid above the measured. Hence, calculate values lay below measured cumulative infiltrations, calculated cumulative infiltration depth have almost best agreement with measured cumulative infiltration depth of sampling point-2. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Kostiakov model for point-2 discussed in the annex figure 2.3.

Table 4. 9: Comparison of observed and calculated cumulative and rate infiltration Kostiakov model for sampling point-3

Time(min)	Zc (cm)	Zm (cm)	fpc (cm/hr	fp (cm/hr)
5	5.13	6.50	76.25	78.00
10	6.87	8.87	23.00	14.20
15	7.28	10.13	5.03	5.07
30	11.47	12.33	4.15	4.40
60	12.82	14.17	1.37	1.83
90	15.98	15.83	1.16	1.11
120	17.82	17.38	0.65	0.78
150	19.85	18.88	0.65	0.78

Table 4.9 showed that calculated cumulative infiltration was in the ranges of 5-10 min where calculated infiltration rate lay above the observed. Hence, calculated values lays above the measured rate infiltrations it doesn’t exist in reality. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Kostiakov model for sampling point-3 presented in the annex of figure 2.3.

Table 4.10: Comparison of observed and calculated cumulative and infiltration Kostiakov model for sampling point-4

Time(min)	Ic (cm)	I_m (cm)	i_c (cm/hr	i (cm/hr)
5	5.29	6.53	77.65	78.40
10	11.41	11.67	60.57	61.60
15	16.03	16.30	54.80	55.60
30	21.39	21.50	20.25	20.80
60	27.79	27.67	12.29	12.33
90	33.56	33.60	11.35	11.87
120	36.86	36.83	6.42	6.47
150	40.47	40.05	6.42	6.47

Table 4.10 showed that calculated values lays below observed cumulative infiltrations, calculated cumulative infiltration depth have almost best agreement with measured cumulative infiltration depth of sampling point-4. Calculated and measured almost overlapped. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Kostiakov model for sampling point-4 presented in the annex of figure 2.4.

Table 4.11: Comparison of observed and calculated cumulative infiltration rate Kostiakov model for sampling point-5

Time(min)	I_c (cm)	I_m (cm)	i_c (cm/hr	i (cm/hr)
5	5.08	6.83	75.22	82.00
10	11.12	13.07	58.34	74.80
15	15.77	18.33	52.67	63.20
30	21.17	24.70	19.03	25.47
60	27.65	30.20	11.42	11.00
90	33.53	33.13	8.94	5.87
120	36.91	35.13	5.88	4.00
150	40.61	37.13	5.88	4.00

Table 4.11 showed that calculated and observed infiltration rate decreased and steady but, in the ranges of 60-90 min, 90-120min, and 120-150 min calculated infiltration rate positioned above the measured. Hence, calculated cumulative values positioned below measured cumulative infiltrations, calculated cumulative infiltration depth have almost best agreement with measured cumulative infiltration depth of sampling point-5. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Kostiakov model for point-5 presented in the annex of figure 2.5.

Table 4.12: Comparison of observed and calculated cumulative and infiltration rate Kostiakov model for point-6

Time(min)	I_c (cm)	I_m (cm)	i_c (cm/hr	i (cm/hr)
5	5.79	7.47	72.69	89.60
10	10.06	14.00	55.95	78.40
15	14.21	19.17	50.35	62.00
30	19.04	24.80	17.63	22.67
60	24.83	29.10	10.42	8.53
90	30.07	32.30	8.09	6.40
120	33.08	34.40	5.25	4.20
150	36.38	36.50	5.25	4.20

Table 4.12 showed that calculated infiltration rate in the ranges of 60-90 min, 90-120 min, and 120-150 min lay above the observed. Generally calculated cumulative values lay below observed cumulative infiltrations, calculated cumulative infiltration depth have almost best agreement with measured cumulative infiltration depth of sampling point-6. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Kostiakov model for sampling point-6 presented in the annex of figure 2.5.

Graphically the comparison average observed, average calculated infiltration rate and average accumulated infiltration depth for Fantalle irrigation scheme using Kostiakov model shown below:

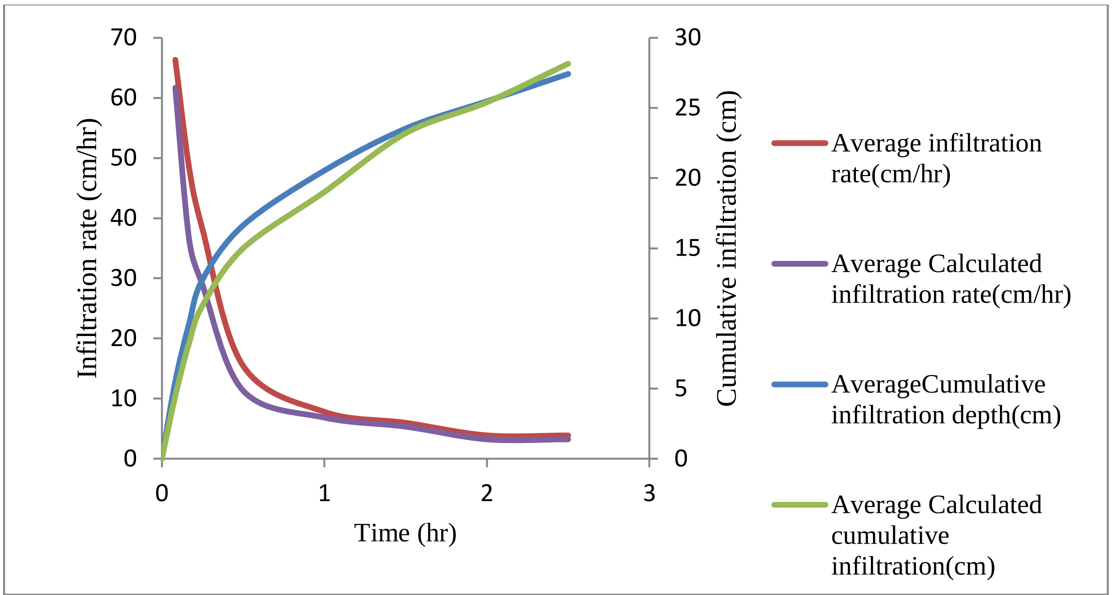
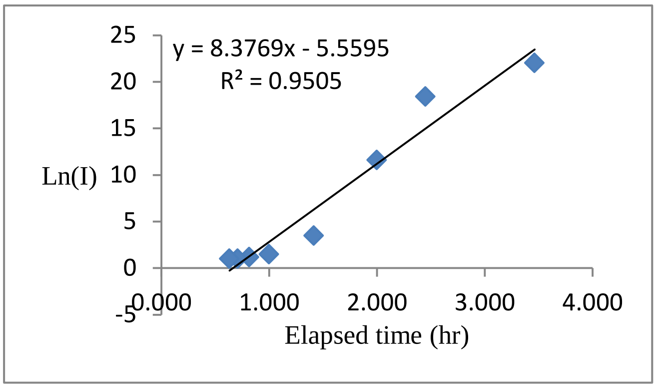


Figure 4. 3: Comparison of average observed and calculated cumulative and rate infiltration Kostiakov model for Fantalle irrigation scheme.

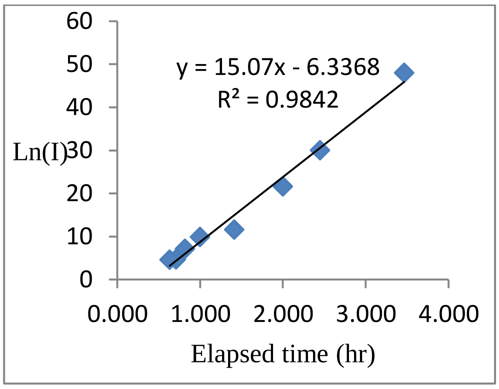
Generally, figure 4.3 showed that the average calculated infiltration rate of Kostiakov model was almost similar with measured infiltration rate and as time increases both infiltration rates decreased and become steady. Calculated infiltration rate positioned below the measured. Hence, calculated values lay below average measured cumulative infiltrations, average calculated cumulative infiltration depth have almost best agreement with average measured cumulative infiltration depth of study area.

4.3.2. Philip model

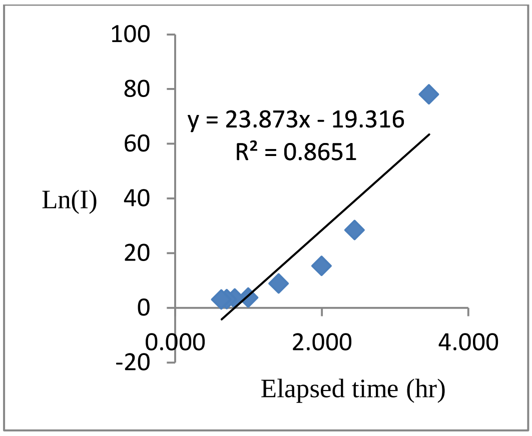
The measurement was taken from field by Double infiltrometer. Philip infiltration rate and cumulative infiltration was calculated depend up on field data at different range of time presented in the annex of table 1.8. The developed equation was depend on the figure 4.3 and figure 4.4 presented below



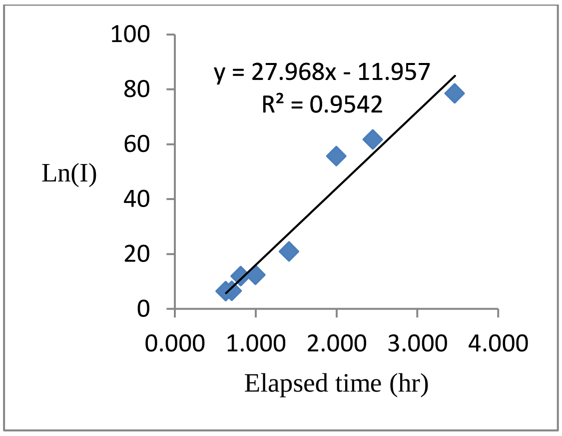
a. SP-1



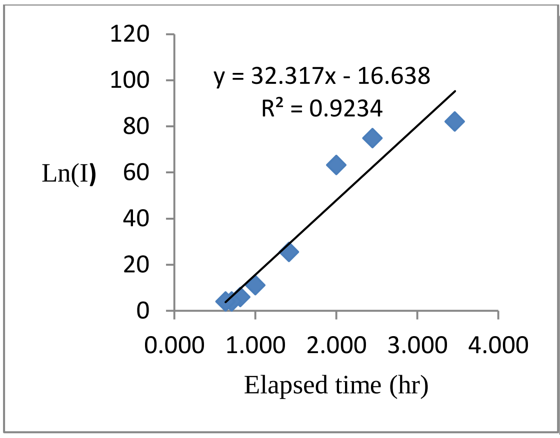
b. SP-2



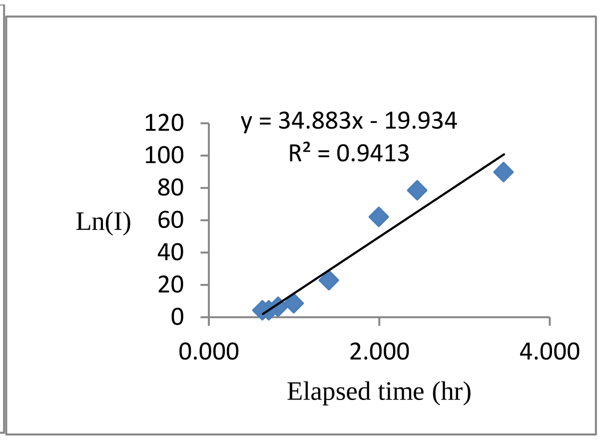
c. SP-3



d. SP-4



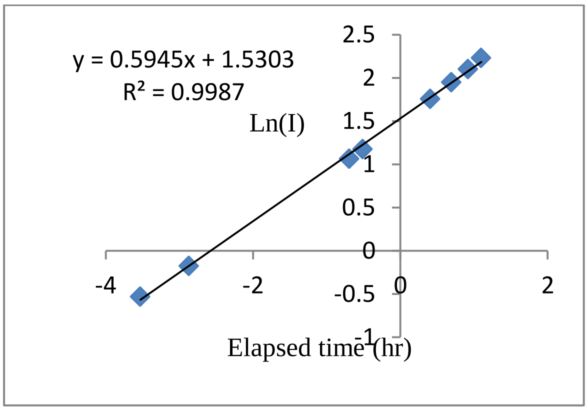
e. SP-5



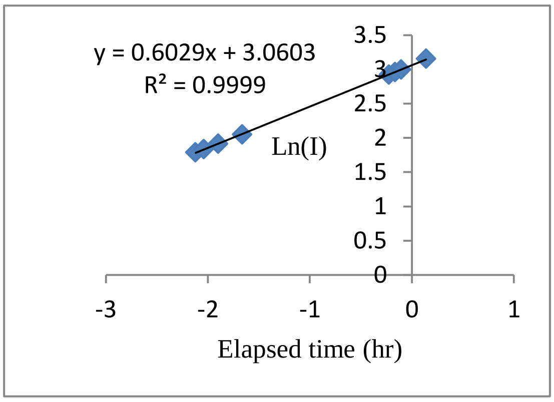
f. SP-6

Figure 4. 4: Ln (I) versus Ln (t) plot for Philip Model parameters

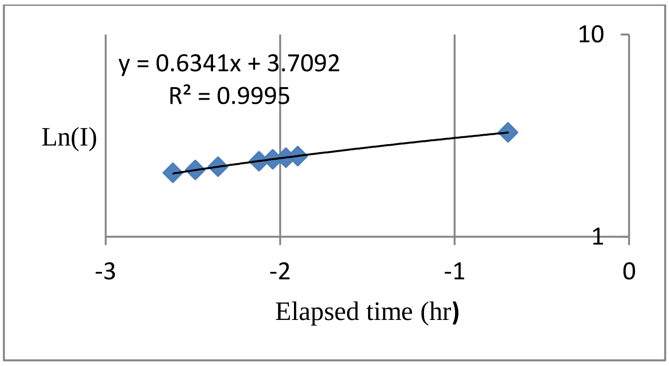
Calculation was done by changing only time of developed formula for each sampling point. After calculation the figure 4.3 presented as below:



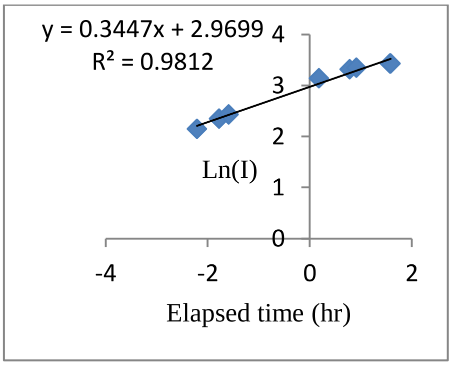
a.SP-1



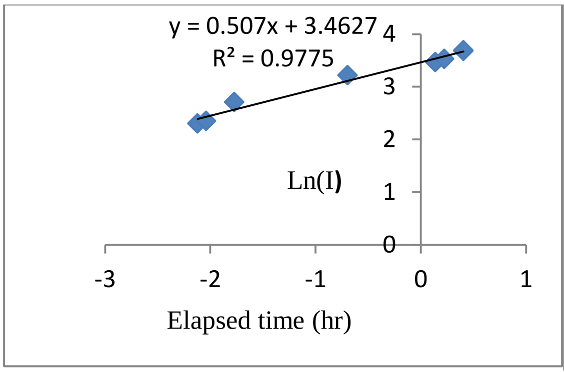
b. SP-2

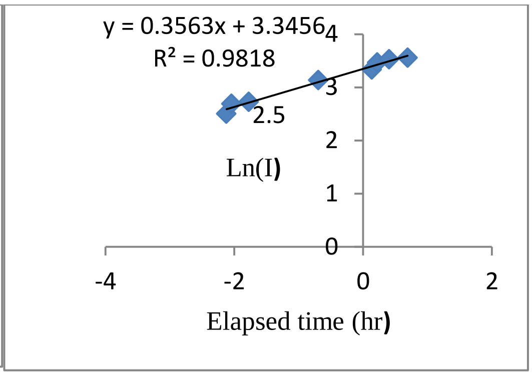


c. SP-3



d. SP-4





e. SP-5 f. SP-6

Figure 4. 5: Calculated Ln (I) versus Ln (t) plot for Philip Model parameters

Comparison of observed and calculated accumulated infiltration and infiltration rate Philip model

The observed infiltration rate and cumulative infiltration were compared with calculated infiltration rate and accumulated infiltration depth by Philip infiltration model presented figure 4.4 and table 4.13 for all points.

Table 4.13: Comparison of observed and calculated cumulative and rate infiltration Philip model for sampling point-1

Time (Min)	I_m (cm)	I_c (cm)	i_c (cm/hr)	i (cm/hr)
5	1.83	0.59	20.09	22.00
10	3.37	0.84	14.79	18.40
15	4.33	2.89	5.79	11.60
30	5.20	3.24	5.40	3.47
60	5.93	5.80	3.87	1.47
90	6.52	7.03	3.51	1.17
120	7.02	8.18	3.27	1.00
150	7.52	9.29	3.27	1.00

Where, I_m = measured cumulative infiltration, I_c = calculated cumulative infiltration, i = measured infiltration rate and i_c is calculated infiltration rate.

Table 4.13 showed that comparison of calculated infiltration rate and measured infiltration rate of Philip model. As time increases both infiltration rates decreased and constant but, as time increased calculated infiltration rate lays above the measured infiltration. Hence, calculated values placed above the measured cumulative infiltrations, calculated cumulative infiltration depths have lowest agreement with observed cumulative infiltration depth of sampling point-1. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration of Philip model for point-1 presented in the annex figure 2.8.

Table 4.14: Comparison of observed and calculated cumulative and rate infiltration Philip model for sampling point-2

Time (Min)	I_m (cm)	I_c (cm)	i (cm/hr)	i_c (cm/hr)
5	4.00	5.98	48.00	41.32
10	6.50	6.26	30.00	36.29
15	8.30	7.32	21.60	23.80
30	11.20	10.82	11.60	14.98
60	16.13	17.12	9.90	8.73
90	19.7	19.28	7.10	7.42
120	22.02	20.82	4.60	3.19
150	24.32	23.45	4.60	3.19

Table 4.14 showed that in the ranges of 5-10 min, 10-15min, 15-30, and 60-90 min calculated infiltration rate lay above the measured. Hence, calculated values lay below measured cumulative infiltrations, calculated cumulative infiltration depth have good agreement with measured cumulative infiltration depth of sampling point-2. Graphically the comparison observed and calculated infiltration rate and cumulative infiltration Philip model for sampling point-2 presented in the annex figure 2.9.

Table 4.15: Comparison of observed and calculated cumulative and rate infiltration Philip model for sampling point-3

Time (Min)	Im (cm)	Ic (cm)	i (cm/hr)	Ic (cm/hr)
5	6.50	5.81	78.00	75.55
10	8.87	8.50	28.40	28.43
15	10.13	10.59	15.20	14.45
30	12.33	12.14	8.80	8.25
60	14.17	14.54	3.67	3.45
90	15.83	15.89	3.33	3.14
120	17.38	17.20	3.10	3.04
150	18.88	18.87	3.10	3.04

Table 4.15 showed that comparison of calculated infiltration rate and measured infiltration rate of Philip infiltration model. As time increases both infiltration rates decreased and become constant. It was concluded that calculated infiltration of Philip have good agreement with measured infiltration. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Philip model for sampling point-3 presented in the annex figure 2.10.

Table 4.16: Comparison of observed and calculated cumulative and rate infiltration of Philip model for sampling point-4

Time (Min)	i (cm/hr)	I_c (cm/hr)	I_m (cm)	I_c (cm)
5	78.40	77.99	6.53	8.58
10	61.60	61.50	11.67	10.45
15	55.60	55.43	16.30	11.36
30	20.80	19.19	21.50	23.03
60	12.33	12.52	27.67	27.54
90	11.87	11.35	33.60	28.38
120	6.47	6.36	36.83	30.86
150	6.43	6.30	40.05	30.86

Table 4.16 showed that comparison of calculated infiltration rate and measured infiltration rate of Philip infiltration model. As time increases both infiltration rates decreased and constant but in the beginning time calculated infiltration rate positioned above the measured and have little agreement. Calculated cumulative infiltration depth doesn't have agreement with measured cumulative infiltration depth of sampling point-4. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Philip model for point-4 presented in the annex of figure 2.11.

Table 4.17: Comparison of observed and calculated cumulative and rate infiltration of Philip model for sampling point-5

Time (Min)	i (cm/hr)	i_c (cm/hr)	I_m (cm)	I_c (cm)
5	82.00	76.65	6.83	10.00
10	74.80	72.99	13.07	10.50
15	63.20	61.74	18.33	15.00
30	25.47	29.07	24.70	25.00
60	11.00	13.50	30.20	32.00
90	5.87	12.27	33.13	34.00
120	4.00	9.75	35.13	39.50
150	4.00	9.75	37.13	40.00

Table 4.17 showed that comparison of calculated infiltration rate and measured infiltration rate of Philip infiltration model. As time increases both infiltration rates decreased and constant but calculated infiltration rate lays above the measured. In addition to that, calculate cumulative infiltration depth of Philip model values lays above measured cumulative infiltrations which do not exist in reality. Graphically the comparison observed, calculated infiltration rate and accumulated infiltration Kostiakov model for sampling point-5 presented in the annex of figure 2.12.

Table 4.18: Comparison of observed and calculated cumulative and rate infiltration of Philip model for sampling point-6

Time (Min)	i (cm/hr)	i_c (cm/hr)	I_m (cm)	I_c (cm)
5	82.00	80.76	6.83	7.35
10	74.80	76.81	13.07	14.70
15	63.20	64.67	18.33	15.22
30	25.47	29.39	24.70	23.00
60	11.00	8.00	30.20	28.00
90	5.87	6.40	33.13	32.00
120	4.00	4.51	35.13	34.00
150	4.00	4.50	37.13	35.00

Table 4.18 showed that calculated infiltration rate have little agreed with measured infiltration rate and as time increases both infiltration rates decreased and constant. Measured cumulative infiltrations have good agreement with calculated cumulative infiltration depth of Philip infiltration model at sampling point-6. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Philip model for point-6 presented in the annex of figure 2.13.

Graphically the comparison average observed, average calculated infiltration rate and average accumulated infiltration depth for Fantalle irrigation scheme using of Philip model presented below:

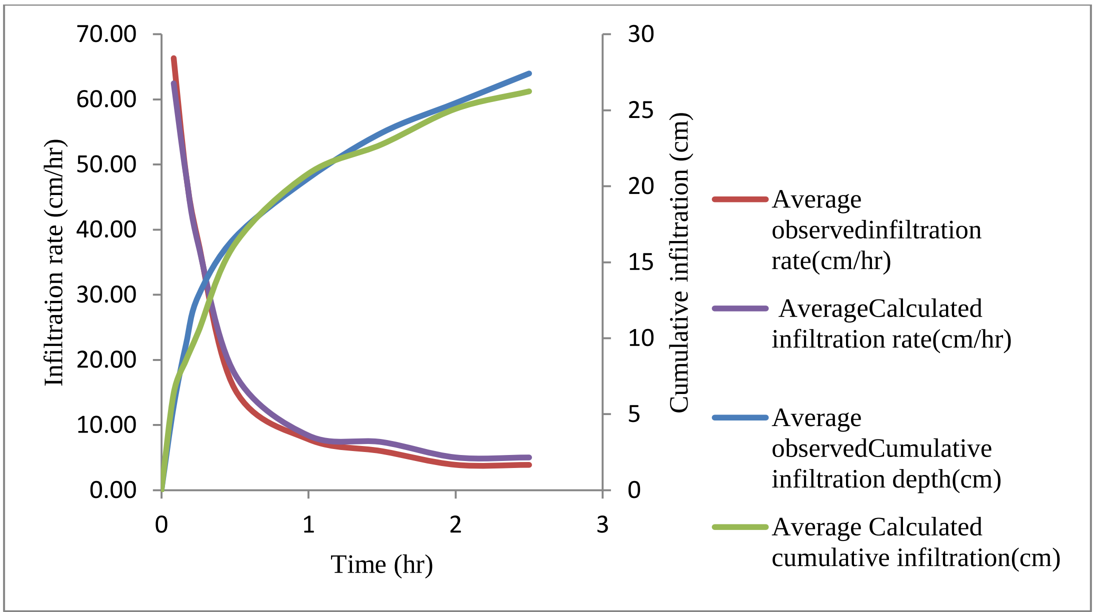
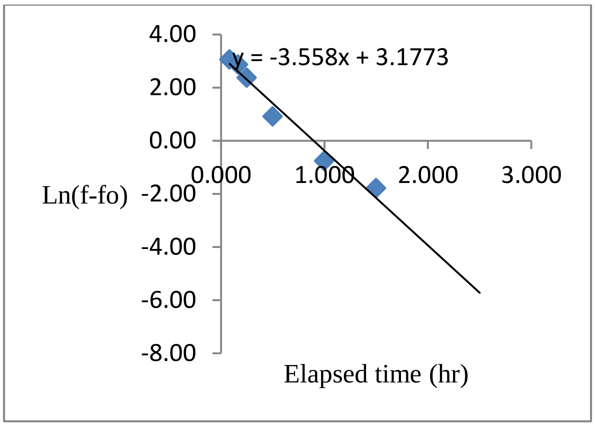


Figure 4.6: Comparison of average observed and average calculated infiltration rate and accumulated infiltration of Philip model for Fantalle irrigation scheme.

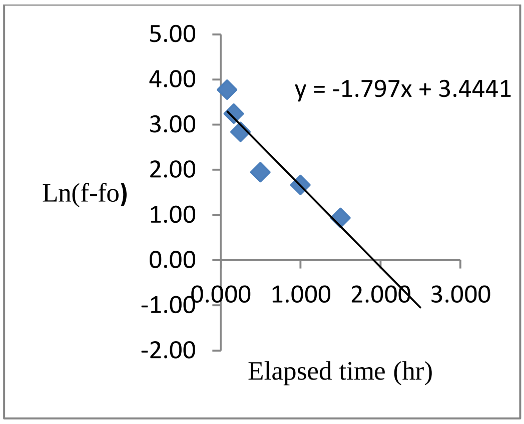
The figure 4.6 showed that the average calculated infiltration rate laid above the average observed infiltration rate and similarly cumulative infiltration depth laid above observed at the time ranges 10,15,30 minutes for Philip's model Fantalle irrigation scheme.

4.3.3. Horton model

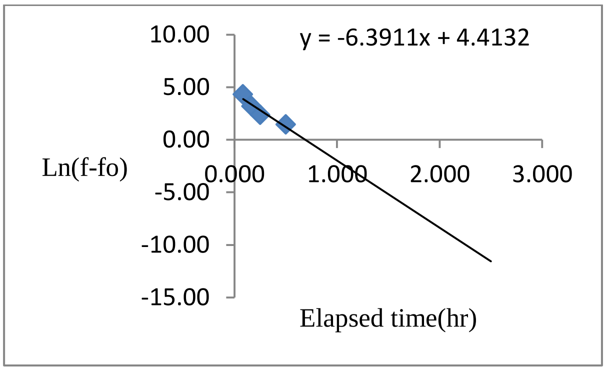
Horton infiltration rate and accumulated infiltration was calculated depend up on field data at different range of time presented in the annex of tables 1.9. Determination parameters and developed equation depend on the following figures 4.7 and 4.8.



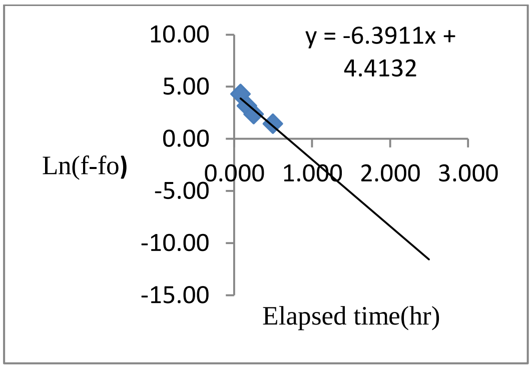
a. SP-1



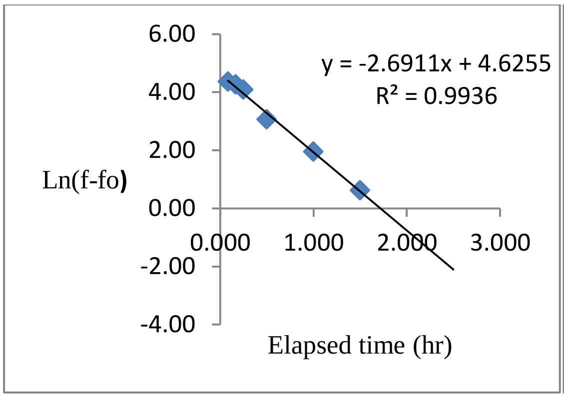
b. SP-2

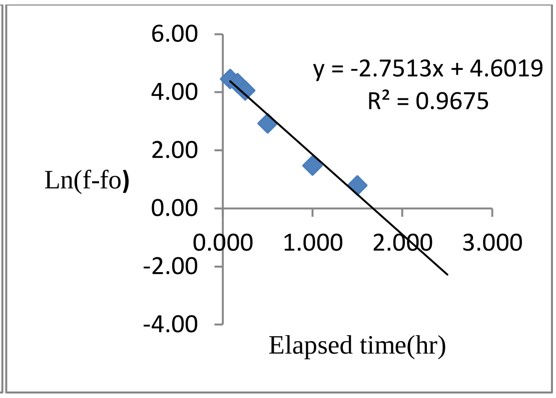


c. SP-3



d. SP-4



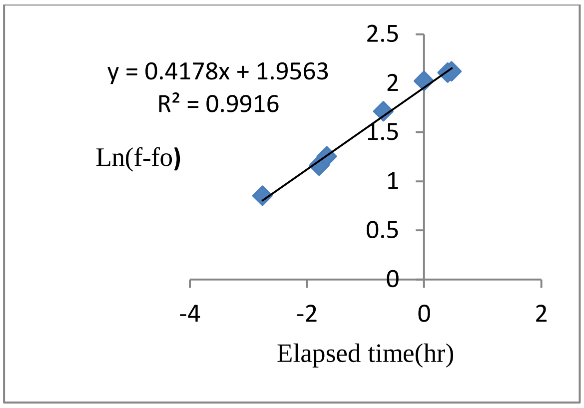


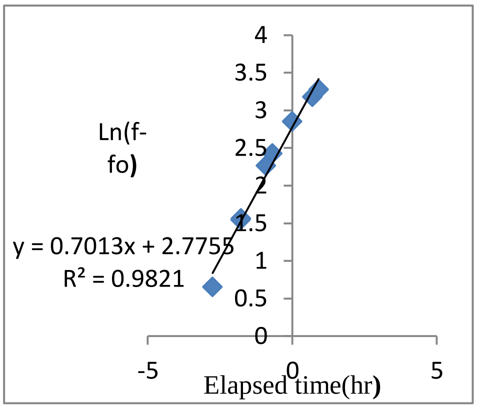
e. SP-5

f. SP-6

Figure 4. 7: Ln (I) versus Ln (t) plot for Horton Model parameters

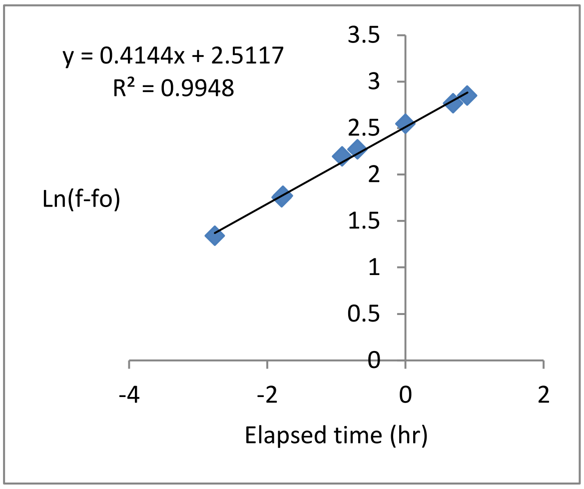
After calculation was done the following figure were formulated with high coefficient of determination. The graphs presented below;

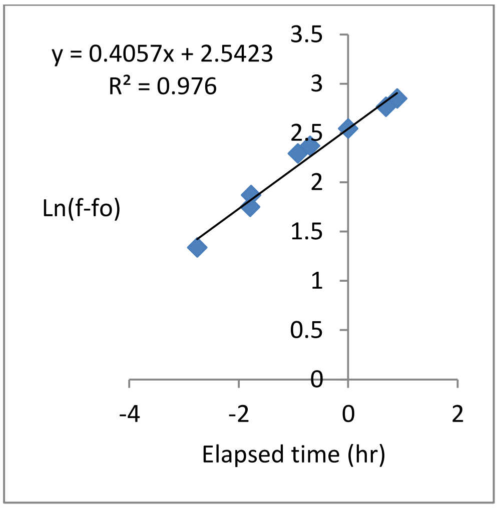




a. SP-1

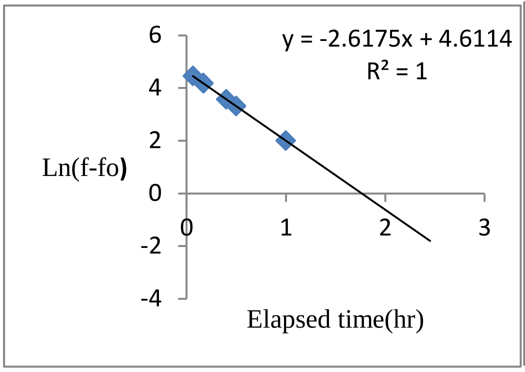
b. SP-2

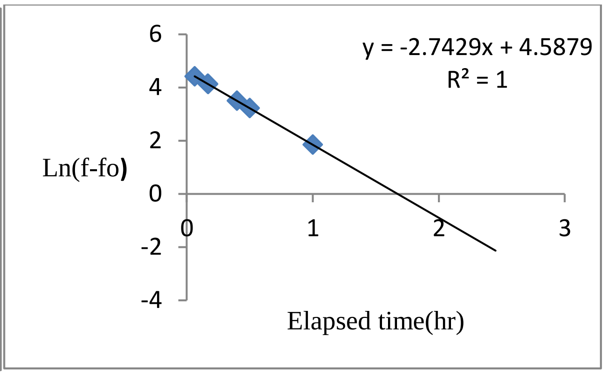




c. SP-3

d. SP-4





e. SP-5 f. SP-6

Figure 4. 8: calculated Ln (I) versus Ln (t) plot for Horton Model parameters

comparison of observed and calculated cumulative infiltration and infiltration rate of Horton model

The observed infiltration rate and cumulative infiltration were compared with calculated infiltration rate and accumulated infiltration depth by Horton infiltration model presented below graphically and by table 4.19 for each point.

Table 4.19: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative and calculated cumulative Horton model for sampling point-1

Time (Min)	i (cm/hr)	i_c (cm/hr)	I_m (cm)	I_c (cm)
0	0.00	0.00	0.00	0.00
5	22.00	19.97	1.83	1.42
10	18.40	14.15	3.37	3.18
15	11.60	13.01	4.33	3.67
30	3.47	4.56	5.20	5.23
60	1.47	2.03	5.93	6.71
90	1.17	1.68	6.52	7.56
120	1.00	1.12	7.02	8.22
150	1.00	1.08	7.52	8.33

Table 4.19 showed that comparison of calculated infiltration rate and measured infiltration rate of Horton infiltration model for sampling point-1. As time increases both infiltration rates decreased and constant but calculate infiltration rate values lays above measured infiltrations rate. Calculated cumulative infiltration depths have low agreement with measured cumulative infiltration depth of sampling point-1. Graphically the comparison observed, calculated infiltration rate and cumulative infiltration of Horton model for sampling point-1 presented in the annex figure 2.14.

Table 4.20: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative and calculated cumulative of Horton model for sampling point-2

Time (min)	i (cm/hr)	i_c (cm/hr)	Im (cm)	Ic (cm)
5	48.00	32.26	4.00	1.93
10	30.00	27.59	6.50	4.90
15	21.60	25.00	8.30	5.78
30	11.60	12.73	11.20	9.64
60	9.87	10.25	16.13	15.32
90	7.13	7.77	19.70	18.53
120	4.60	5.46	22.02	24.02
150	4.60	5.46	24.32	26.57

Table 4.20 showed that calculated infiltration has little agreement with measured infiltration rate and as time increases both infiltration rates decreased and become constant. Hence, calculated values lays below measured cumulative infiltrations, calculated cumulative infiltration depth have better agreement with measured cumulative infiltration depth of sampling point-2. Graphically the comparison observed, calculated infiltration rate and accumulated infiltration of Horton model for sampling point-2 presented in the annex of figure 2.15.

Table 4.21: Comparison of observed and calculated cumulative and calculated infiltration rate of Horton model for sampling point-3

Time(Min)	I_c (cm)	I_m (cm)	i_c (cm/hr)	i (cm/hr)
0	0.00	0.00	0.00	0.00
5	4.43	4.00	57.49	48.00
10	8.05	6.50	31.26	30.00
15	8.56	8.30	25.01	21.60
30	12.99	11.20	9.47	11.60
60	13.77	16.13	6.47	9.87
90	15.82	19.70	3.24	7.13
120	18.94	22.02	3.10	4.63
150	20.34	24.32	3.10	4.60

Table 4.21 showed that the comparison of calculated infiltration rate and measured infiltration rate of Horton infiltration model for sampling point-3. As time increases both infiltration rates decreased and become constant. Calculated values lays below measured cumulative infiltration so calculated cumulative infiltration depth have good agreement with measured cumulative infiltration depth of sampling point-3. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Horton model for sampling point-3 presented in the annex of figure 2.16.

Table 4.22: Comparison of observed and calculated cumulative and calculated infiltration rate Horton model for sampling point-4

Time (min)	I_c (cm)	I_m (cm)	i_c (cm/hr)	i (cm/hr)
5	6.43	6.50	77.29	78.40
10	11.57	11.70	64.44	61.60
15	14.57	16.30	60.74	55.60
630	20.93	21.50	25.13	20.80
60	27.64	27.70	15.57	12.30
90	32.33	33.60	9.23	11.90
120	36.65	36.80	6.52	6.47
150	44.95	40.10	6.51	6.47

Table 4.22 showed that the comparison of calculated infiltration rate and measured infiltration rate of Horton infiltration model for sampling point-4. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have best agreement with measured cumulative infiltration depth of sampling point-4. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Horton model for sampling point-4 presented in the annex of figure 2.17.

Table 4.23: Comparison of observed and calculated cumulative and calculated infiltration rate of Horton model for sampling point-5

Time (min)	I_c (cm)	I_m (cm)	i_c (cm/hr)	i (cm/hr)
0	0.00	0.00	0.00	0.00
5	6.11	6.83	89.25	82.00
10	14.22	13.07	69.05	74.80
15	16.45	18.33	65.48	63.20
30	25.00	24.70	30.32	25.47
60	29.00	30.20	13.00	11.00
90	35.00	33.13	9.12	5.87
120	40.00	35.13	4.17	4.00
150	41.00	37.13	4.17	4.00

Table 4.23 showed that the comparison of calculated infiltration rate and observed infiltration rate of Horton infiltration model for sampling point-5. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays above measured cumulative infiltration so calculated cumulative infiltration depth have low agreement with measured cumulative infiltration depth of sampling point-5. Graphically the comparison observed and calculated infiltration rate and cumulative infiltration Horton model for sampling point-5 presented in the annex of figure 2.18.

Table 4.24: Comparison of observed and calculated cumulative and calculated infiltration rate of Horton model for sampling point-6

Time (hr)	I_c (cm)	I_m (cm)	i_c (cm/hr)	i (cm/hr)
5	5.96	7.47	86.81	89.60
10	13.81	14.00	66.42	78.40
15	17.03	19.17	61.86	62.00
30	25.48	24.83	30.01	22.67
60	28.76	29.10	10.14	8.53
90	37.62	32.30	7.53	6.40
120	43.97	34.40	4.32	4.20
150	45.97	36.50	4.32	4.20

Table 4.24 showed that the comparison of calculated infiltration rate and measured infiltration rate of Horton infiltration model for sampling point-6. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays above measured cumulative infiltration so calculated cumulative infiltration depth have lowest agreement with measured cumulative infiltration depth of sampling point-6. Most of time such reality was not exists in the nature. Graphically the comparison observed and calculated infiltration rate and accumulated infiltration Horton model for sampling point-6 presented in the annex of figure 2.19.

Graphically the comparison average observed, average calculated infiltration rate and average accumulated infiltration depth for Fantalle irrigation scheme using Horton model presented below:

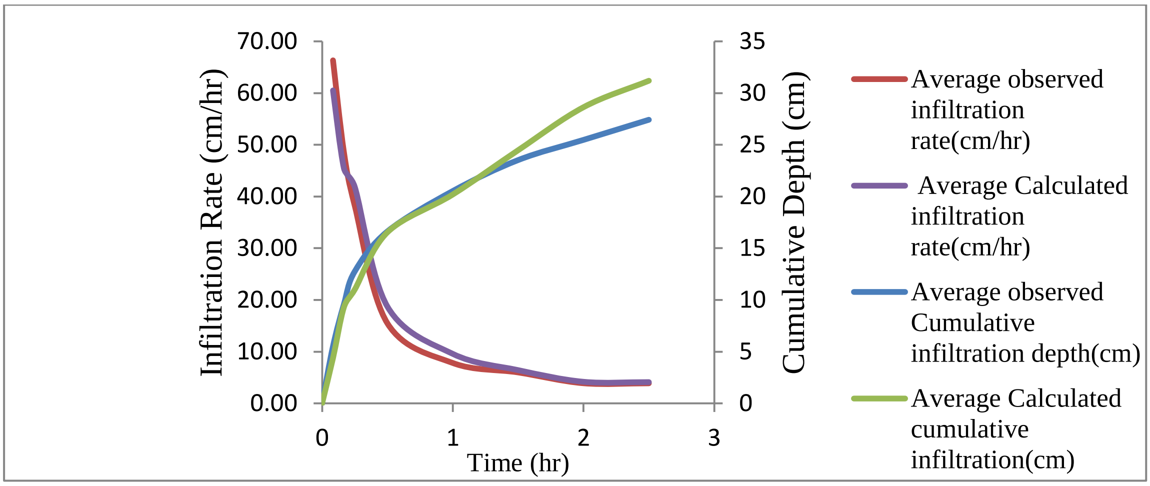


Figure 4. 9: comparison of average observed and calculated infiltration rate cumulative infiltration of Horton model for Fantalle irrigation scheme.

The Figure 4.9 showed that as time increases the average calculated infiltration become to laid above the observed infiltration rate and almost constant. Similarly average calculated cumulative infiltration lay above and close agreement to observed cumulative infiltration depth.

4.3.4. Modified Kostiakov model

Modified Kostiakov infiltration rate and accumulated infiltration was calculated depend up on field data at different range of time presented in the annex tables 1.1 to 1.6.

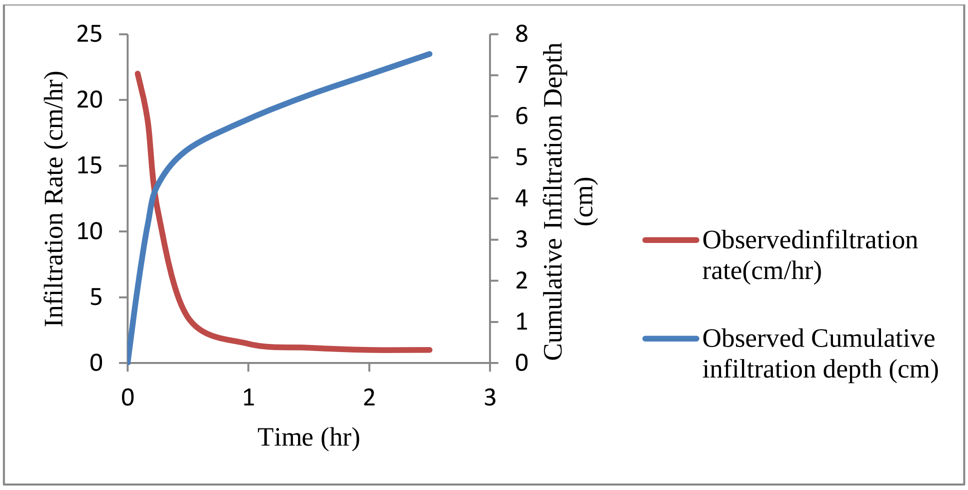


Figure 4. 10: The plot of observed infiltration rate (cm/hr) and observed cumulative infiltration (cm) of sampling point-1

Following the above steps t_3 was calculated as follow depending upon the graph plotted on figure 4.8.

$t_3 = \sqrt{t1 * t2}$ by referencing Hasan, (2015)

$t_3 = \sqrt{5 * 150} = 27.38613 \approx 27.4\ min$

Values of t_1 and t_2 are available from the plotted line and that has been described in steps above. The corresponding value of accumulated infiltration Z_3 = 5.055 cm when t_3 = 27.4 minutes. Value of b can be calculated by formula used in regression analysis. The formula can be listed as follows (presented to Figure 4.10):

$$b = \frac{(Z1 * Z2 - (Z3)2}{(Z1 + Z2 - 2Z3)}$$

$$b = \frac{(7.51667 * 1.833 - (5.055)\text{^}2)}{(7.51667 + 1.833 + (2 * 5.055))} = -0.6051$$

From equation 2.3 rearranging the formula and taking log both side

$Z = kt^a + f_o t$

$Log(Z) = log(kt^a) + log(f_o t)$

$Log(Z) = Log(K) + alog(t) + log(f_o t)$ taking $f_o t = b$

$Log(Z-b) = log(k) + alog(t)$ (4.1)

Then by developing equations by substitution value of b and t in the above equation

At t = 5min, log (1.833+0.605) = logk+0.699a = Log (k) +0.699a = 0.387 (4.2)

At t =10min, log (k) +a = 0.599 (4.3)

At t =15min, log (k) +1.18a = 0.693 (4.4)

At t = 30min, log (k) +1.477a = 0.764 (4.5)

At t = 60min, log (k) +1.778a = 0.815 (4.6)

At t = 90min, log (k) +1.954a = 0.853 (4.7)

At t =120min, log (k) +2.079a = 0.882 (4.8)

At t =150min, log (k) +2.176a = 0.910 (4.9)

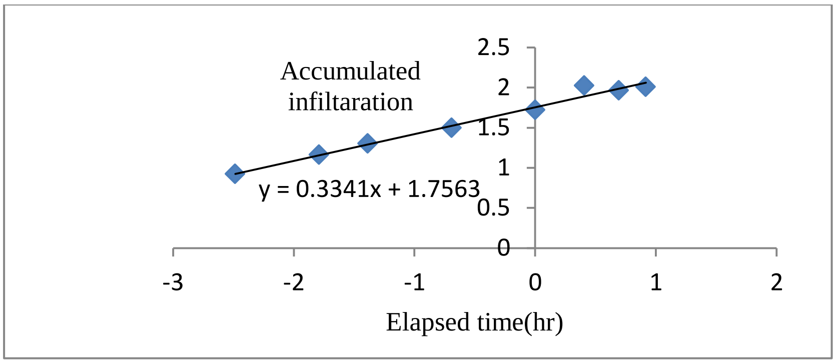


Figure 4. 11: Accumulated infiltration versus time in log scale for sampling point-1

Adding equations 4.2 to 4.5

4logk+4.356a = 2.443 (4.10)

Adding equation from 4.6 to 4.9

4logk+7.987a = 3.46 (4.11)

Solving Equations (4.10) and (4.11), the value of a becomes 0.286 .The value of log (k) = -0.294

Now substituting the values of a, b, and k in equation for individual elapsed times

Log (I-b) = log (k) +alog (t)

I_{5min} = antilog (log (k) +a log (t)) +b

Using the above formula accumulated infiltration was calculated as follow

At t = 5min, I_{5min}= 2.513

At t = 10mn, I_{10min} =3.196

At t =15min, I_{15min}= 3.675

At t = 30min, I_{30min}= 4.463

At t = 60 min, I_{60min}= 5.596

At t = 90min, I_{90min} = 7.568

At t = 120min, I_{120min} = 7.131

At t =150min, I_{150min} = 7.454

Methods of estimating Modified Kostiakov models parameters follows similar step shown in point-1 for other points. The methods of estimation parameters for each point depend up on the observed values of the cumulative infiltration (I) in cm and their corresponding time t in minute for infiltrometer 2, 3, 4, 5, and 6 (presented in the annex of tables 1.10 and calculated cumulative infiltration Modified Kostiakov calculations in annex of calculations 4.5).

Comparison of observed and calculated accumulated infiltration and infiltration rate Modified Kostiakov model

The observed infiltration rate and cumulative infiltration were compared with calculated infiltration rate and accumulated infiltration depth by Modified Kostiakov infiltration model presented in the table 4.25 for each point.

Table 4.25: Comparison of observed and calculated cumulative infiltration and infiltration rate of Modified Kostiakov model for point-1

Time (Min)	Im (cm)	I_c (cm)	i (cm/hr)	i_c (cm/hr)
0	0.00	0.00	0.00	0.00
5	1.83	2.51	22.00	20.01
10	3.37	3.20	18.40	18.08
15	4.33	3.67	11.60	11.09
30	5.20	4.46	3.47	3.31
60	5.93	5.60	1.47	2.63
90	6.52	7.01	1.17	1.97
120	7.02	7.13	1.00	1.60
150	7.52	7.45	1.00	1.60

Table 4.25 showed that the comparison of calculated infiltration rate and measured infiltration rate of Modified infiltration model for sampling point-1. As time increases both infiltration rates decreased and become steady. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have good agreement with measured cumulative infiltration depth of sampling point-1. Graphically the comparison observed, calculated infiltration rate and cumulative infiltration of Modified Kostiakov model for sampling point-1 presented in the annex of figure 2.20.

Table 4.26: Comparison of observed and calculated cumulative infiltration and infiltration rate Modified Kostiakov model for point-2

Time (min)	Im (cm)	Ic (cm)	i (cm/hr)	i_c (cm/hr)
0	0.00	0.00	0.00	0.00
5	4.00	2.95	48.00	31.02
10	6.50	4.00	30.00	28.62
15	8.30	7.99	21.60	24.06
30	11.20	12.00	11.60	12.51
60	16.13	17.60	9.87	8.07
90	19.70	19.18	7.13	2.03
120	22.02	22.55	4.60	1.95
150	24.32	25.54	4.60	1.95

Table 4.26 showed that calculated cumulative value lays below observed cumulative infiltration. It was summarized as calculated cumulative infiltration depth has best agreement with observed cumulative infiltration depth of sampling point-2. Graphically the comparison observed, calculated infiltration rate and accumulated infiltration of Modified Kostiakov model for sampling point-2 presented in the annex of figure 2.21.

Table 4.27: Comparison of observed and calculated cumulative infiltration and infiltration rate of Modified Kostiakov model for point-3

Time (min)	I_m (cm)	I_c (cm)	i (cm/hr)	i_c (cm/hr)
0	0.00	0.00	0.00	0.00
5	6.50	7.14	78.00	72.17
10	8.87	8.70	28.40	63.36
15	10.13	9.77	15.20	30.71
30	12.33	11.88	8.80	10.67
60	14.17	14.43	3.67	6.01
90	15.83	16.16	3.33	4.03
120	17.38	17.51	3.10	2.16
150	18.93	18.30	3.10	2.16

Table 4.27 showed that the comparison of calculated infiltration rate and measured infiltration rate of Modified infiltration model for sampling point-3. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have satisfactory agreement with measured cumulative infiltration depth of sampling point-3. Graphically the comparison observed, calculated infiltration rate and cumulative infiltration of Modified Kostiakov model for sampling point-3 discussed in the annex of figure 2.22.

Table 4.28: Comparison of observed and observed cumulative infiltration and calculated infiltration rate Modified Kostiakov model for point-4

Time (min)	Im (cm)	Ic (cm)	i (cm/hr)	ic (cm/hr)
5	6.53	8.04	78.40	78.24
10	11.67	11.70	61.60	47.94
15	16.30	15.96	55.60	25.41
30	21.50	20.10	20.80	11.33
60	27.67	27.27	12.33	8.02
90	33.60	32.10	11.87	7.60
120	36.83	37.32	6.47	6.27
150	40.07	41.37	6.47	6.27

Table 4.28 showed that the comparison of calculated infiltration rate and measured infiltration rate of Modified infiltration model for sampling point-4. As time increases both infiltration rates decreased and become steady. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have very good agreement with measured cumulative infiltration depth of sampling point-4. Graphically the comparison observed, calculated infiltration rate and accumulated infiltration of Modified Kostiakov model for sampling point-4 discussed in the annex of figure 2.23.

Table 4.29: Comparison of observed and calculated cumulative infiltration and infiltration rate Modified Kostiakov model for point -5

Time (min)	I_m (cm)	I_c (cm)	i (cm/hr)	ic (cm/hr)
0	0.00	0.00	0.00	0.00
5	6.83	6.07	82.00	81.42
10	13.07	13.48	74.80	76.46
15	18.33	17.07	63.20	64.52
30	24.70	23.28	25.47	21.71
60	30.20	29.00	11.00	10.75
90	33.13	32.76	5.87	5.04
120	35.13	36.57	4.00	3.58
150	37.13	39.92	4.00	3.58

Table 4.29 showed that the comparison of calculated infiltration rate and measured infiltration rate of Modified infiltration model for sampling point-5. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have best or almost overlapped agreement with measured cumulative infiltration depth of sampling point-5. Graphically the comparison observed, calculated infiltration rate and cumulative infiltration of Modified Kostiakov model for sampling point-5 discussed in the annex of figure 2.24.

Table 4.30: Comparison of observed and calculated cumulative infiltration and infiltration rate Modified Kostiakov model for point -6

Time (min)	I_m (cm)	I_c (cm)	i (cm/hr)	i_c (cm/hr)
0	0.00	0.00	0.00	0.00
5	6.83	10.54	82.00	81.62
10	13.37	14.00	78.40	77.89
15	18.53	16.47	62.00	61.07
30	24.20	21.34	22.67	21.85
60	28.47	27.52	8.53	8.13
90	31.67	31.82	6.40	6.38
120	33.77	32.54	4.20	4.05
150	35.87	38.13	4.20	4.05

Table 4.30 showed that the comparison of calculated infiltration rate and observed infiltration rate of Modified infiltration model for sampling point-6. As time increases both infiltration rates decreased and become constant. Calculated cumulative value lays below measured cumulative infiltration so calculated cumulative infiltration depth have best agreement with measured cumulative infiltration depth and overlapped infiltration rate of sampling point-6. Graphically the comparison observed, calculated infiltration rate and accumulated infiltration of Modified Kostiakov model for sampling point-6 discussed in the annex of figure 2.25.

Graphically the comparison average observed, average calculated infiltration rate and average accumulated infiltration depth for Fentale irrigation scheme using Horton model shown below:

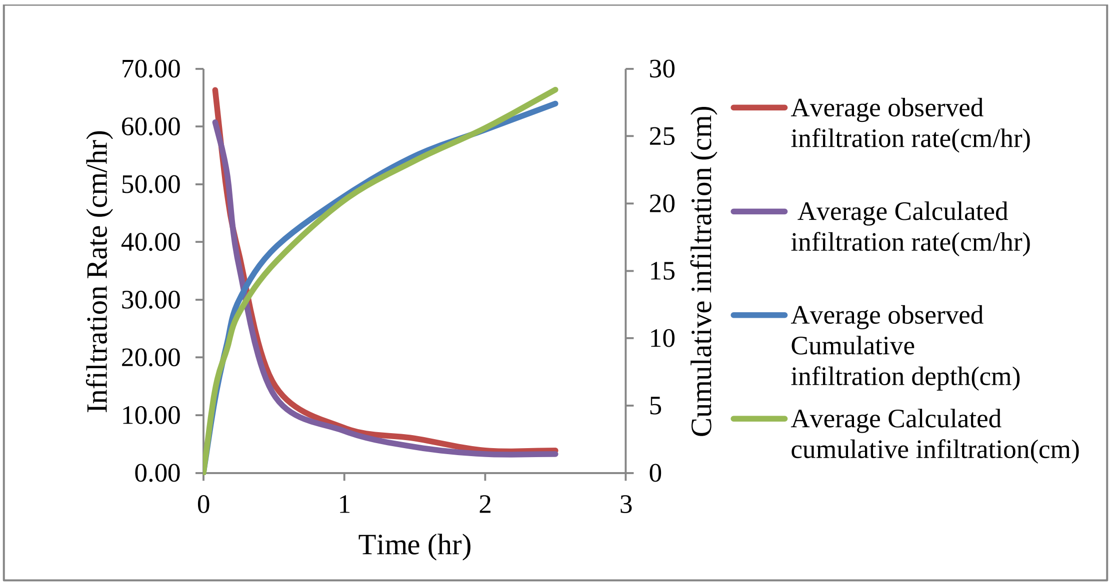


Figure 4.12: Comparison of average observed, average calculated infiltration rate and accumulated infiltration Modified Kostiakov model for Fentale irrigation scheme.

The figure 4.12 showed that the average calculated infiltration rate was laid almost below the observed infiltration rate and similarly the average calculated cumulative infiltration depth laid below the average observed cumulative infiltration depth. These approaches have best agreement which exists in reality.

Generally the comparison of average observed and calculated infiltration rate and average cumulative infiltration depth of four models their similarly were discussed in table 4.31 and table 4.32.

Table 4.31: Comparison of average observed and calculated cumulative infiltration using four models for Fantalle irrigation scheme.

Time(min)	Kostiakov		Phillip		Horton		Modified Kostiakov	
	I_m	I_c	I_m	I_c	I_m	I_c	I_m	I_c
v5	5.53	4.494	5.53	6.385	5.53	4.38	5.53	6.21
10	9.58	8.199	9.58	8.542	9.58	9.29	9.58	9.18
15	12.76	10.91	12.76	10.40	12.76	11.01	12.76	11.82
30	16.63	14.99	16.63	16.21	16.63	16.54	16.63	15.51
60	20.53	19.01	20.53	20.83	20.53	20.20	20.53	20.24
90	23.53	23.19	23.53	22.76	23.53	24.48	23.53	23.17
120	25.48	25.4	25.48	25.09	25.48	28.63	25.48	25.60
150	27.42	28.15	27.42	26.24	27.42	31.19	27.42	28.45

The infiltration rate (cm/hr) and the cumulative infiltration (cm) were plotted with respect to time as presented in Figure 2.1 and figure 4.11for six points. The calculated infiltration rate by Kostiakov's, Philip's, Horton's and Modified Kostiakov's models were compared with the observed values as shown in Figure 4.5, figure 4.6, figure 4.7, and Figure 4.8. The calculated average cumulative infiltration by Kostiakov's, Modified Kostiakov's, Horton's and Philip's model was compared with the average observed values as shown in table 1.7, table 1.8,table 1.9 and table respectively. Graphically the comparison average observed cumulative infiltration, and average calculated cumulative infiltration depth for Fantalle irrigation scheme using Kostiakov, Modified Kostiakov, Philip, and Horton models shown in figure 4.9.

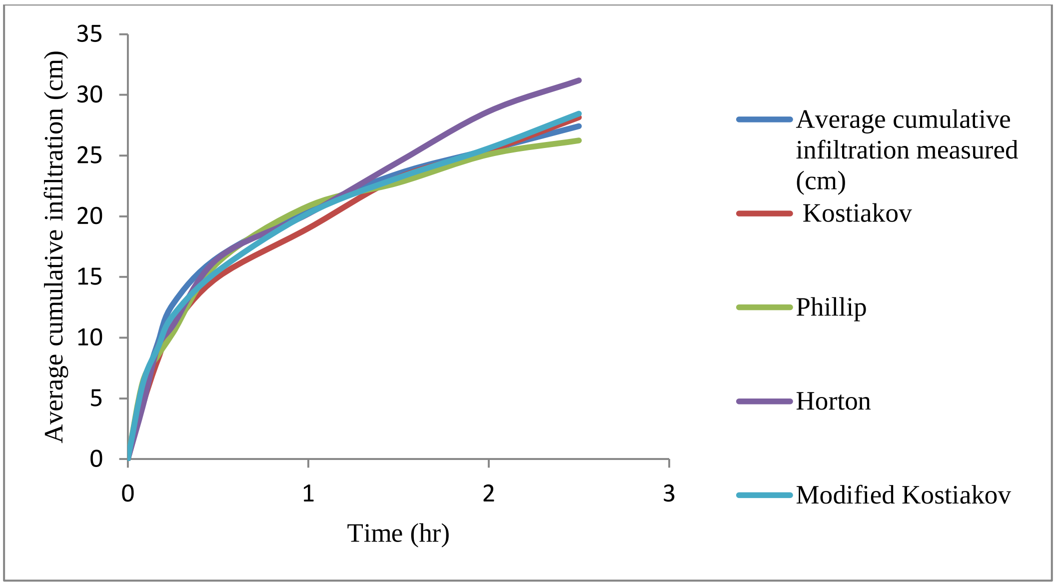


Figure 4. 13: Average measured and calculated cumulative infiltration of the study area.

Figure 4.13 compared the calculated average cumulative infiltration with average observed cumulative infiltration depth. According to the result calculated value of Kostiakov, Modified Kostiakov, and Philip laid below observed cumulative infiltration. But, Modified Kostiakov was the best infiltration described cumulative infiltration than others.

Table 4.32: Comparison of average measured and calculated infiltration rate using four models for Fantalle irrigation scheme.

Time	Kostiakov		Phillip	Horton	Modified Kostiakov			
(min)	i	i_c	i	i_c	I	i_c	i	i_c
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	66.33	61.68	66.33	62.47	66.33	60.51	66.33	60.75
10	48.60	36.72	48.60	48.46	48.60	45.48	48.60	52.06
15	38.20	28.93	38.20	37.77	38.20	41.85	38.20	36.14
30	15.47	11.34	15.47	17.81	15.47	18.70	15.47	13.56
60	7.81	6.85	7.81	8.38	7.811	9.58	7.81	7.27
90	5.98	5.35	5.98	7.38	5.98	6.43	5.98	4.51
120	3.88	3.24	3.89	5.02	3.89	4.18	3.88	3.27
150	3.88	3.24	3.88	5.02	3.88	4.18	3.88	3.27

Graphically the comparison average observed infiltration rate, and average calculated infiltration rate for Fantalle irrigation scheme using Kostiakov, Modified Kostiakov, Philip, and Horton models shown below:

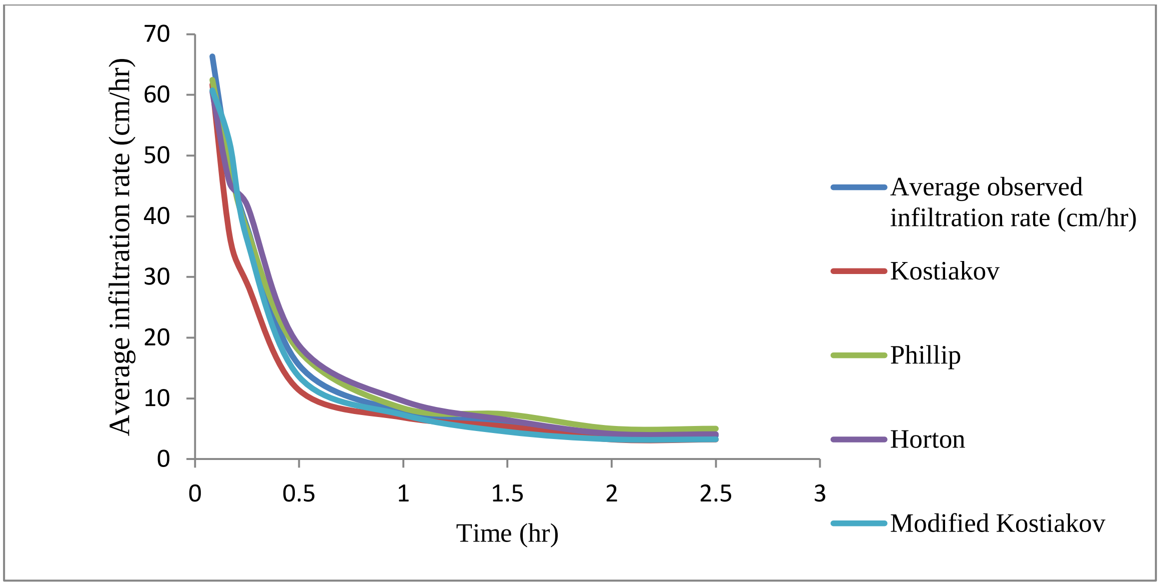


Figure 4.14: Average observed infiltration rate for Fantalle irrigation scheme.

Generally, the figure 4.l4 compared average observed infiltration rate with average calculated infiltration rate. The values of average calculated cumulative infiltration depth of Kostiakov and Modified Kostiakov laid below average observed cumulative infiltration depth. This shows that Modified Kostiakov well described infiltration rate of the study area.

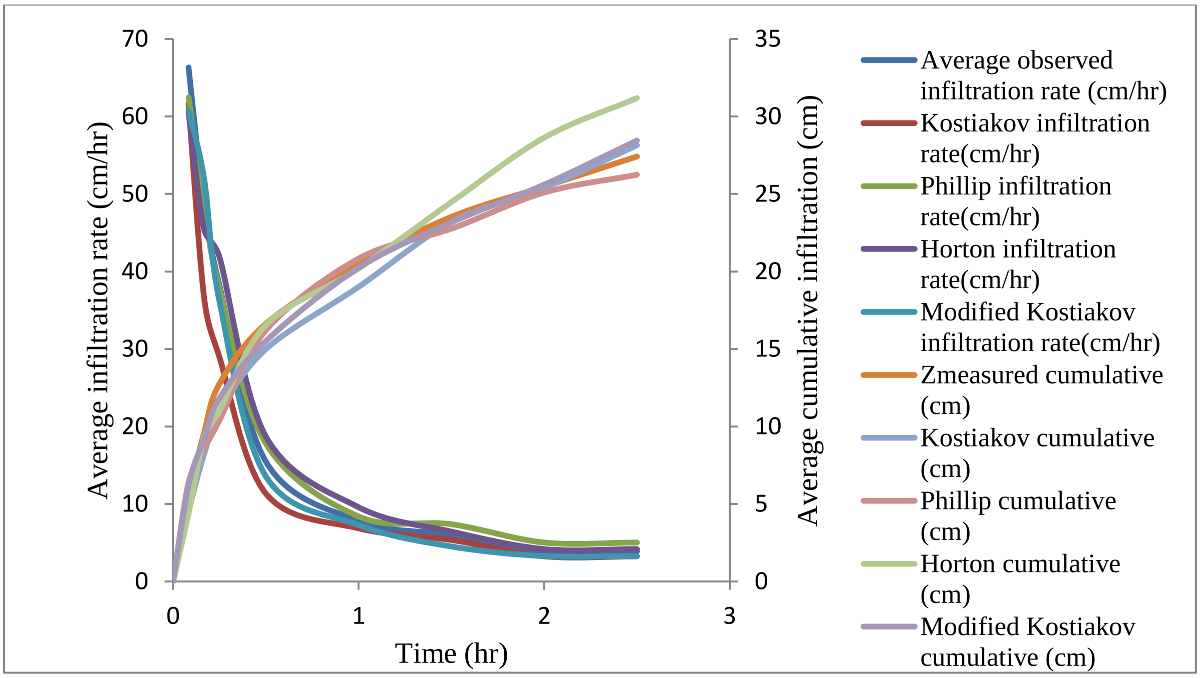


Figure 4. 15: Average observed and calculated cumulative infiltration and infiltration rate for Fantalle irrigation scheme.

Generally the graphical comparison of observed infiltration rate and calculated infiltration rate were needed to select the suitable model for Fantalle Irrigation Scheme. Figure 4.10 showed that observed and calculated value of infiltration rate for each models were almost close to each other but the calculated value of Horton, Philip were laid above the observed. The values of Kostiakov, Modified Kostiakov calculated lays below the observed infiltration rate. In reality the calculated cannot be greater than the observed. Modified Kostiakov was the best model which predicted close agreement to the observed ones for all points. When we rank four models by comparing the calculated with observed Modified Kostiakov was first, Kostiakov the second, Horton the third and Philip the fourth.

4.4. Infiltration Models Performance Evaluation

The suitable model was selected depend up on values of performance indices such as RMSE, GMER, GSDER, Ei and R^2 for the four infiltration models (Kostiakov's, Philip's, Horton's and Modified Kostiakov's) showed accurate fits (Table 4.35, 4.36, 4.37, 4.38). All the models have good capabilities for prediction of cumulative infiltration depth at the selected points except Phillip model. The RMSE values were found in the range of 0.12 to 0.93, 0.09 to 8.16, 0.01 to 3.36 and 0.04 to 0.13 for Kostiakov's, Philip's, Horton's and Modified Kostiakov's infiltration models, respectively for all the six points whereas the average values of RMSE were calculated as 0.54 for Kostiakov's, 2.76 for Philip's, 0.85 for Horton's and 0.13 for Modified Kostiakov's models. The values of RMSE were found in close agreement as reported by Vikas et al., (2018). Similarly, Vanger et al., (2001) and Tietje and Hennings, (2006) found RMSE, Ei and R^2 values in the range of 0.03 to 1.19, 0.25 to 0.83 and 0.82 to 0.96 with an average value of 0.82, lowest and highest respectively and reported that the model can successfully be used for prediction of infiltration rate. The Ei values were observed from 3.3% to 43% for Kostiakov's with an average 29%, 3.5% to 98% for Phillip's with an average 40%, 7.5% to 89% for Horton's with an average 43% and 12.2% to 47% for Modified Kostiakov's model with an average 23%. All values of Ei were found to be in the acceptable range since the average percent were less than 0.5. Since, the least Ei was selected Modified Kostiakov model was the most acceptable. R^2 values also showed the satisfactory prediction by the infiltration models for all the selected points. Since the highest R^2 was selected Modified Kostiakov was the most acceptable. Similarly, the comparison between observed and predicted cumulative infiltration depths for four tested models further verified the prediction capability of these infiltration models (annex of tables 1.11). Evaluated four models (Kostiakov, Philip, Horton and Modified Kostiakov) and demonstrated that all four models provided similar fits to the numerical results in terms of infiltration rates but depend up on model performances Modified Kostiakov was suitable for Fantalle irrigation Scheme (presented Table 4.33,4.35,4.36,4.37,4.38 and figure 4.11).

Table 4.33: The values of performance kostiakov model for Fantalle irrigation scheme.

Sampling Points	Kostiakov					
	RMSE	GMER	GSDER	Ei	R^2	Cal R^2
1	0.50	0.05	2.08	0.43	0.90	0.98
2	0.38	0.10	2.08	0.40	0.99	1.00
3	0.93	0.04	2.08	0.35	0.99	0.99
4	0.41	0.00	2.07	0.03	0.97	1.00
5	0.91	0.00	2.07	0.17	0.92	0.99
6	0.12	0.36	1.00	0.36	0.91	0.99
Mean	0.54	0.09	1.90	0.29	0.95	0.99
Standard Deviation	0.32	0.14	0.44	0.16	0.04	0.01

Table 4.34: Values of the performance of Philip model for Fantalle irrigation scheme.

Sampling Points	Philips					
	RMSE	GMER	GSDER	Ei	R^2	cal R^2
1	0.09	0.35	1.00	0.04	0.95	0.99
2	0.35	1.00	0.03	0.98	0.98	0.99
3	2.29	0.44	1.00	0.44	0.87	0.99
4	8.16	0.23	1.00	0.23	0.95	0.98
5	2.64	0.23	1.00	0.39	0.92	0.98
6	3.01	0.35	1.00	0.35	0.94	0.98
Mean	2.76	0.44	0.84	0.40	0.94	0.99
Standard Deviation	2.91	0.29	0.39	0.32	0.04	0.01

Table 4.35: Values of the performance of Horton model for Fantalle irrigation scheme.

Sampling Points	Horton					
	RMSE	GMER	GSDER	Ei	R^2	Cal R^2
1	0.15	0.05	2.08	0.39	0.97	0.95
2	0.01	2.08	0.11	0.89	0.88	0.98
3	0.01	0.01	1.33	0.08	0.89	0.99
4	3.36	0.06	1.34	0.46	0.89	0.84
5	0.73	0.04	1.34	0.30	0.99	1.00
6	0.73	0.06	1.34	0.45	0.97	1.00
Mean	0.85	0.38	1.26	0.43	0.93	0.962
Standard Deviation	1.27	0.83	0.64	0.27	0.05	0.062

Table 4.36: Values of the performance of Modified kostiakov model for Fantalle Irrigation scheme.

Sampling Points	Modified Kostiakov					
	RMSE	GMER	GSDER	Ei	R^2	cal R^2
1	0.12	0.02	1.66	0.12	0.90	0.98
2	0.04	0.48	1.00	0.47	0.99	0.99
3	0.23	0.14	1.00	0.14	0.99	0.99
4	0.11	0.14	1.00	0.13	0.97	0.99
5	0.13	0.14	1.00	0.14	0.92	0.99
6	0.12	0.36	1.00	0.34	0.91	0.99
Mean	0.13	0.21	1.10	0.23	0.95	0.99
standard deviation	0.06	0.17	0.27	0.15	0.04	0.01

Where, RMSE = Root Mean Square Error, GMER = Geometric Mean Error Ratio, GSDER = Geometric Standard Deviation Error Ratio, Ei = Error ratio, R^2 = Coefficient of Determination and Cal R^2 = Calculated Coefficient of Determination.

Depending up on the above tables the Modified Kostiakov's model provided the lowest mean values for RMSE, highest mean values for R^2, lowest mean values for Ei. Infiltration can be well-described by the Modified Kostiakov's model at the selected site. Evaluated the six infiltration models on relatively course-textured and almost homogenous soil and reported that Modified Kostiakov's model performance was most realistic. Kostiakov's gave a very good representation of infiltration when compared with the Horton's and Phillip model. It could be concluded that Modified Kostiakov's model differed most as compared to the other three models. These results also ranked Modified Kostiakov's model in the 1st with an average RMSE = 0.13, GMER = 0.21, GSDER = 1.10, Ei = 23%, R^2 = 0.99 and calculated R^2 = 0.99, Kostiakov's model in the 2nd with an average RMSE = 0.54, GMER = 0.09, GSDER = 1.90, Ei = 29%, R^2 = 0.95 and calculated R^2 = 0.99, Horton's in the 3rd with an average RMSE = 0.85, GMER = 0.38, GSDER = 1.26, Ei = 43%, R^2 = 0.93 and calculated R^2 = 0.96 and Phillip's model in the fourth positions with an average RMSE = 2.76, GMER = 0.44, GSDER = 0.84, Ei = 40%, R^2 = 0.94 and calculated R^2 = 0.99. Overall analysis based on the other research studies such as Vikas et al., (2018), Vanger et al., (2001). So indicated that findings of the present study were satisfactory, and Modified Kostiakov's model can be used to predict the infiltration depth at the study area most precisely. Overall analysis showed that these infiltration models using the estimated parameters have satisfactory prediction capability at all the selected points because the model performance indicators were in acceptable limits as discussed in the above section.

5. CONCLUSION AND RECOMMENDATIONS

Results of this study attempt made to identify the most suitable model to calculate infiltration rate and cumulative infiltration of the irrigation project by giving great emphasis to Models parameters and accuracy. In this section, conclusion and recommendations on these results are presented.

5.1. Conclusion

Based on the evaluation of the most commonly used infiltration models, all the models show good agreement with the measured cumulative infiltration depths in the field using the estimated model's parameters except Philip model. The acceptable ranges of model performance indicators such as RMSE values were found in the range of 0.12 to 0.93, 0.09 to 8.16, 0.01 to 3.36 and 0.04 to 0.13 for Kostiakov's, Philip's, Horton's and Modified Kostiakov's infiltration models, respectively for all the six points whereas the average values of RMSE were calculated as 0.54 for Kostiakov's, 2.76 for Philip's, 0.85 for Horton's and 0.13 for Modified Kostiakov's models. Ei of 23%, R^2 of 0.95 and calculated $R^2$of 0.99 for modified kostiakov, Ei of 29%, R^2 of 0.95 and calculated R^2 of 0.99 for Kostiakov, Ei of 43%, R^2 of 0.93 and calculated R^2 of 0.96 for Horton and Ei of 40%, R^2 of 0.94 and calculated R^2 of 0.99 indicated that the evaluated infiltration models realistically simulate cumulative infiltration depth under the field conditions of the study area.

It was also analyzed that Modified Kostiakov's model gave the best fit to the observed cumulative infiltration depth than the Kostiakov's, Horton's and Philip's models. Application of these infiltration models under verified field conditions leads to simulate the cumulative infiltration depth.

Finally, Modified Kostiakov model could successfully be used for simulating infiltration data needed in planning irrigation project and also required for management of soil and water resources of the study area.

5.2. Recommendation

- Modified Kostiakov infiltration Model was the best described cumulative infiltration and infiltration rate of Fantalle Irrigation Scheme. So, it is recommendable to use modified Kostiakov infiltration.
- Community awareness should be created to develop sense of measuring cumulative infiltration and infiltration rate and ways of minimize factors affecting infiltration of the irrigation area.
- Sorptivity and hydraulic conductivity of soil which were determined by logarithmic function. Thus, the use of various models and Sorptivity is restricted and this problem needs to be considered in these sorts of studies.
- It is suggested that in the future there is a need to evaluate the parameters of infiltration models and the relationship among them, accurately and for the calibration of infiltration models under different conditions.

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ANNEXES

1. ANNEX OF TABLES

Table 1.1: Field measured accumulated infiltration and infiltration rate of sampling point-1

Time (Min)	Average measured infiltration rate(cm)	Cumulative infiltration depth (cm)	Incremental depth of infiltration (cm)	Time interval (min)	Observed infiltration rate (cm/hr)
5	1.83	1.83	1.83	5	22.00
10	1.53	3.37	1.53	5	18.40
15	0.97	4.33	0.97	5	11.60
30	0.87	5.20	0.87	15	3.47
60	0.73	5.93	0.73	30	1.47
90	0.58	6.52	0.58	30	1.17
120	0.50	7.02	0.50	30	1.00
150	0.50	7.52	0.50	30	1.00

Table 1.2: Field measured accumulated infiltration and infiltration rate of sampling point-2

Time (Min)	Average measured infiltration depth (cm)	Cumulative infiltration depth (cm)	Incremental depth of infiltration(cm)	infiltration rate (cm/hr)
5	4.00	4.00	4.00	48.00
10	2.50	6.50	2.50	30.00
15	1.80	8.30	1.80	21.60
30	2.90	11.20	2.90	11.60
60	4.93	16.13	4.93	9.87
90	3.57	19.70	3.57	7.13
120	2.32	22.02	2.32	4.60
150	2.30	24.32	2.30	4.60

Table 1.3: Field measured accumulated infiltration and infiltration rate of point-3

Time (Min)	Average measured infiltration depth (cm)	Cumulative infiltration depth (cm)	Incremental depth infiltration(cm)	Interval of time	Observed infiltration rate cm/hr
5	6.5	6.5	6.50	5	78.00
10	2.37	8.87	2.37	5	28.40
15	1.27	10.13	1.27	5	15.20
30	2.2	12.33	2.20	15	8.80
60	1.83	14.17	1.83	30	3.67
90	1.67	15.83	1.67	30	3.33
120	1.55	17.38	1.55	30	3.10
150	1.50	18.88	1.50	30	3.10

Table 1.4: Field measured accumulated infiltration and infiltration rate of point-4

Time (Min)	Average measured infiltration depth (cm)	Cumulative infiltration depth (cm)	Incremental depth of infiltration(cm)	Time interval (min)	Observed infiltration rate (cm/hr)
5	6.53	6.53	6.53	5	78.40
10	5.13	11.67	5.13	5	61.60
15	4.63	16.3	4.63	5	55.60
30	5.20	21.5	5.20	15	20.80
60	6.17	27.67	6.17	30	12.33
90	5.93	33.6	5.93	30	11.87
120	3.23	36.83	3.23	30	6.47
150	3.23	40.07	3.23	30	6.47

Table 1.5: Field measured accumulated infiltration and infiltration rate of point-5

Time (Min)	Average measured infiltration depth (cm)	Cumulative infiltration depth (cm)	Incremental depth of infiltration(cm)	Time interval (min)	Observed infiltration rate (cm/hr)
5	6.83	6.83	6.83	5	82.00
10	6.23	13.07	6.23	5	74.80
15	5.27	18.33	5.27	5	63.20
30	6.37	24.70	6.37	15	25.47
60	5.50	30.20	5.50	30	11.00
90	2.93	33.13	2.93	30	5.87
120	2.00	35.13	2.00	30	4.00
150	2.00	37.13	2.00	30	4.00

Table 1.6: Field measured accumulated infiltration and infiltration rate of point-6

Time (Min)	Average measured infiltration depth (cm)	Cumulative infiltration depth (cm)	Incremental depth of infiltration(cm)	Time interval	Observed infiltration rate (cm/hr)
5	7.47	7.47	7.47	5	89.60
10	6.53	14.00	6.53	5	78.40
15	5.17	19.17	5.17	5	62.00
30	5.67	24.83	5.67	15	22.67
60	4.27	29.10	4.27	30	8.53
90	3.20	32.30	3.20	30	6.40
120	2.10	34.40	2.10	30	4.20
150	2.10	36.50	2.10	30	4.20

Table 1.7: Comparison of average observed and calculated cumulative infiltration and average calculated infiltration rate of Kostiakov model for study area.

Time (hr)	Average Cumulative infiltration depth(cm)	Average infiltration rate(cm/hr)	Average Calculated cumulative infiltration(cm)	Average Calculated infiltration rate(cm/hr)
0	0.00	0.00	0.00	0.00
5	5.53	66.33	4.49	61.68
10	9.58	48.6	8.19	36.72
15	12.76	38.2	10.91	28.93
30	16.63	15.47	14.99	11.34
60	20.53	7.81	19.01	6.85
90	23.53	5.98	23.19	5.35
120	25.48	3.89	25.40	3.23
150	27.42	3.88	28.15	3.23

Table 1.8: Comparison of average observed and calculated cumulative infiltration and average calculated infiltration rate of Philip model for study area.

Time (min)	Average measured infiltration (cm)	Average observed Cumulative infiltration depth(cm)	Average observed infiltration rate(cm/hr)	Average Calculated cumulative infiltration(cm)	Average Calculated infiltration rate(cm/hr)
0	0.00	0.00	0.00	0.00	0.00
5	5.53	5.53	66.33	6.38	62.47
10	4.05	9.58	48.6	8.54	48.46
15	3.18	12.76	38.2	10.40	37.77
30	3.87	16.63	15.47	16.21	17.81
60	3.91	20.53	7.81	20.83	8.38
90	2.99	23.53	5.98	22.76	7.38
120	1.95	25.48	3.89	25.09	5.03
150	1.95	27.42	3.88	26.24	5.02

Table 1.9: Comparison of average observed and calculated cumulative infiltration and average calculated infiltration rate of Horton model for study area.

Time (min)	Average measured infiltration (cm)	Average observed Cumulative infiltration depth(cm)	Average observed infiltration rate(cm/hr)	Average Calculated cumulative infiltration(cm)	Average Calculated infiltration rate(cm/hr)
0	0.00	0.00	0.00	0.00	0.00
5	5.53	5.53	66.33	4.38	60.51
10	4.05	9.58	48.6	9.29	45.48
15	3.18	12.76	38.2	11.01	41.85
30	3.87	16.63	15.47	16.54	18.70
60	3.91	20.53	7.81	20.20	9.58
90	2.99	23.53	5.98	24.48	6.43
120	1.95	25.48	3.89	28.63	4.18
150	1.95	27.42	3.88	31.19	4.11

Table 1.10: Comparison of average observed and calculated cumulative infiltration and average calculated infiltration rate of Modified Kostiakov model for study area.

Time(min)	Average measured infiltration (cm)	Average observed Cumulative infiltration depth(cm)	Average observed infiltration rate(cm/hr)	Average Calculated cumulative infiltration(cm)	Average Calculated infiltration rate(cm/hr)
0	0.00	0.00	0.00	0.00	0.00
5	5.53	5.53	66.33	6.21	60.75
10	4.05	9.58	48.60	9.18	52.06
15	3.18	12.76	38.20	11.82	36.14
30	3.87	16.63	15.47	15.51	13.56
60	3.91	20.53	7.81	20.24	7.27
90	2.99	23.53	5.98	23.17	4.51
120	1.95	25.48	3.89	25.60	3.27
150	1.95	27.42	3.88	28.45	3.27

Table 1.11: Comparison of average observed and calculated cumulative infiltration depth using four models for Fantalle irrigation scheme.

Time(min)	Kostiakov		Phillip		Horton		Modified Kostiakov	
	I_m	I_c	I_m	I_c	I_m	I_c	I_m	I_c
5	5.53	4.494	5.53	6.385	5.53	4.38	5.53	6.21
10	9.58	8.199	9.58	8.542	9.58	9.29	9.58	9.18
15	12.76	10.91	12.76	10.4	12.76	11.01	12.76	11.82
30	16.63	14.99	16.63	16.21	16.63	16.54	16.63	15.51
60	20.53	19.01	20.53	20.83	20.53	20.2	20.53	20.24
90	23.53	23.19	23.53	22.76	23.53	24.48	23.53	23.17
120	25.48	25.4	25.48	25.09	25.48	28.63	25.48	25.6
150	27.42	28.15	27.42	26.24	27.42	31.19	27.42	28.45

Im = Average Measured cumulative infiltration depth Ic = average calculated cumulative infiltration depth

Table 1.12: Determination of initial soil moisture for point-1 and point-2

No	Particulars	Sample one				sample two			
		A	B	C	average	D	E	F	Average
1	Container No	P1	P12	P13		P21	P22	P23	
2	Weight of the container = w1	29	29	29	29	29	30	18	25.67
3	Weight of the container + wet soil = w2	65	74	63	67.33	48	53	43	48
4	weight of container + dry soil = w3	59	68	58	61.67	45	49	38	44
5	weight of the moisture = w2-W3 = ww	6	6	5	5.67	3	4	5	4
6	Weight of dry soil = ws = w3-Ww	53	62	53	56	42	45	33	40
7	Moisture content = W (%)	11.32	9.68	9.43	10.14	7.14	8.89	15.15	10.39

Table 1.13: Determination of initial soil moisture for sampling point-3 and point-4

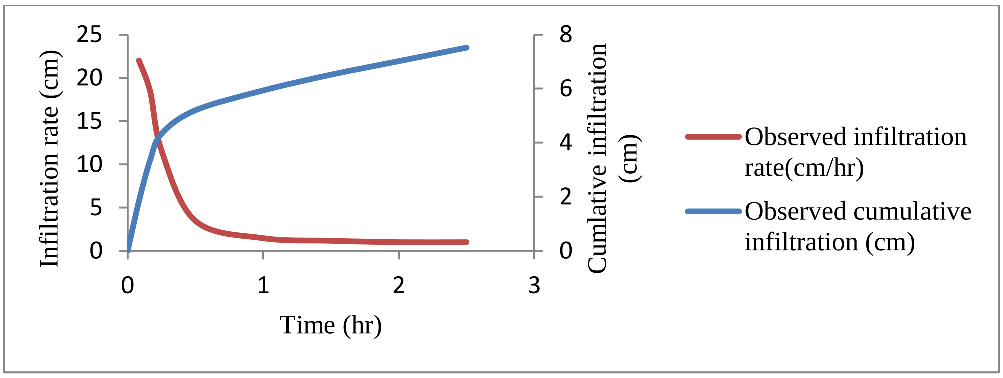
No	Particulars	Sample three				sample four			
		A	B	C	Average	D	E	F	Average
1	Container No	P31	P32	P33		P41	P42	P43	
2	Weight of the container=w1	18	30	29	25.67	30	30	30	30
3	Weight of the container + wet soil =w2	52	46	52	50	60	50	57	55.67
4	weight of container+ dry soil=w3	49	43	49	47	55	48	53	52
5	weight of the moisture = w2-W3 = ww	3	3	3	3	5	2	4	3.67
6	Weight of dry soil= ws= w3-Ww	46	40	46	44	50	46	49	48.33
7	Moisture content = W (%)	6.52	7.5	6.52	6.85	10	4.35	8.16	7.50

Table 1.14: Determination of initial soil moisture for sampling point-5 and point-6

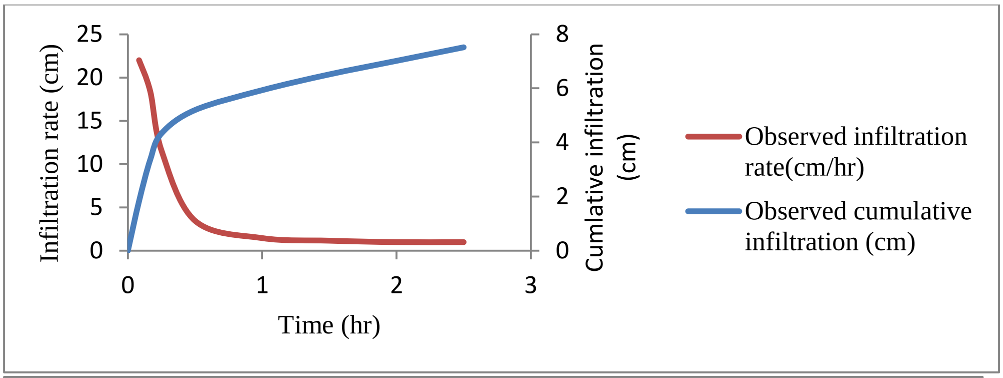
No	Particulars	Sample five				sample six			
		A	B	C	Average	D	E	F	Average
1	Container No	P51	P52	P53		P61	P62	P63	
2	Weight of the Container = w1	19	29	29	25.67	29	30	29	29.33
3	Weight of the container + wet soil = w2	48	72	58	59.33	55	62	53	56.67
4	weight of container+ dry soil = w3	45	67	55	55.67	53	58	52	54.33
5	weight of the moisture = w2-W3 = ww	3	5	3	3.67	2	4	1	2.33
6	Weight of dry soil = ws = w3-Ww	42	62	52	52	51	54	51	52
7	Moisture content = W (%)	7.14	8.1	5.77	6.99	3.92	7.41	1.96	4.43

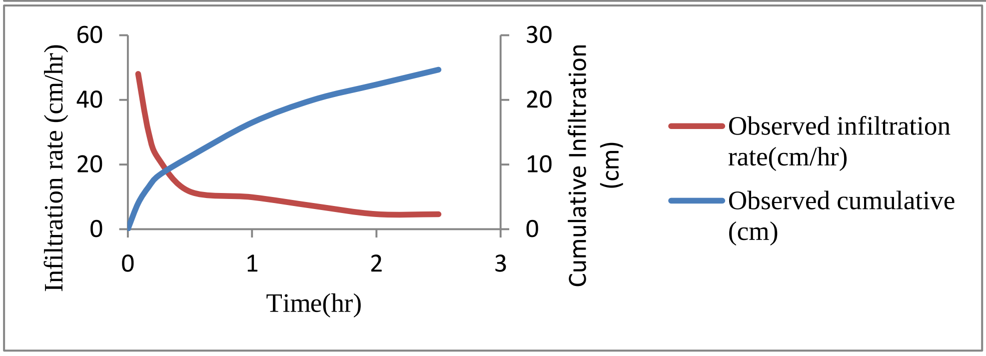
2. ANNEX OF FIGURES

Graphically the observed infiltration rate and accumulated infiltration with respect to time of different ranges were presented as follow:

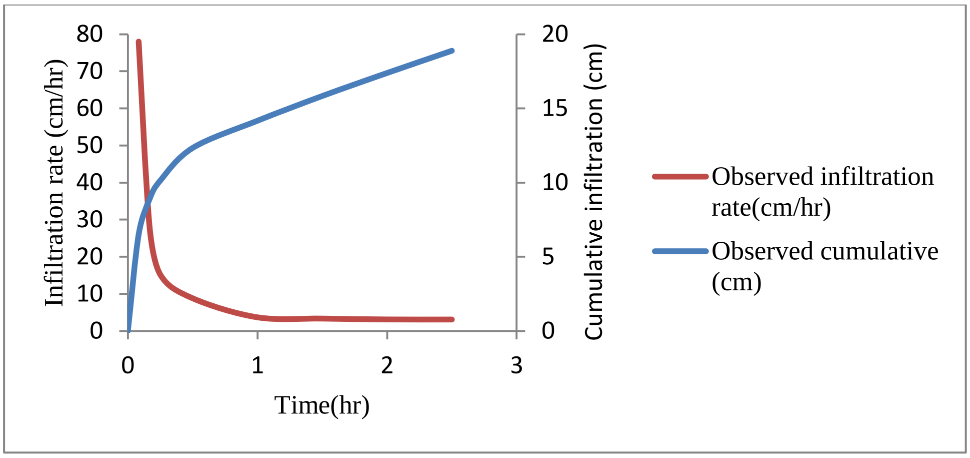


a. SP-1

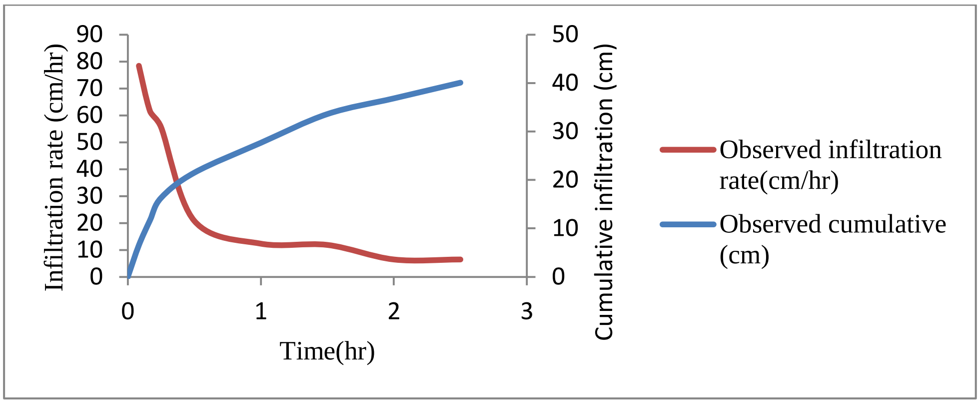




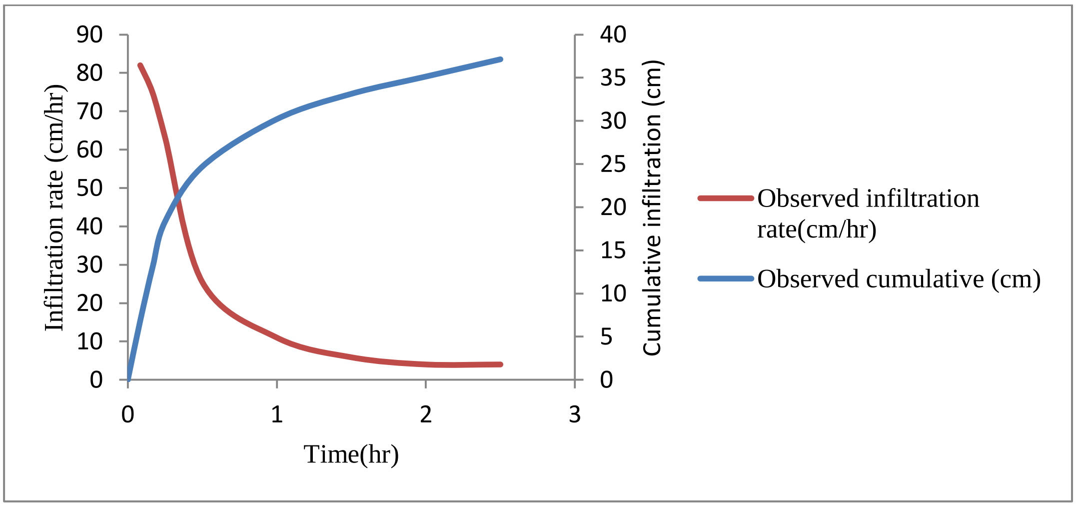
b. SP-2



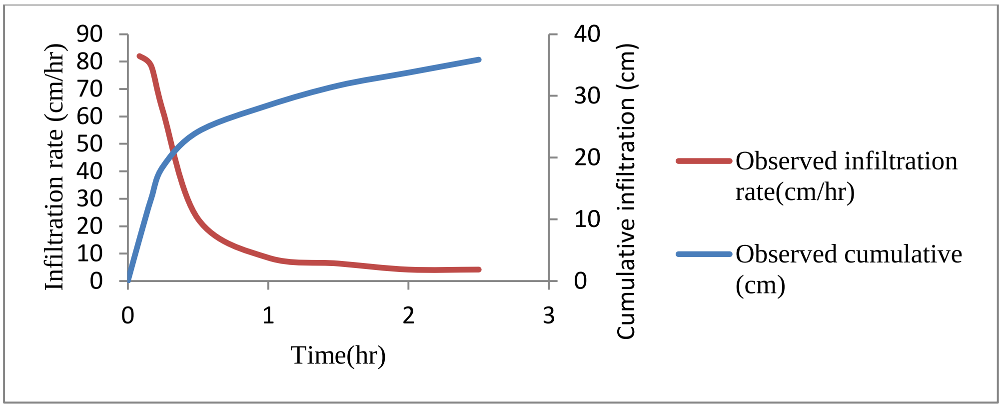
c. SP-3



e. SP-4



f. SP-5



g. SP-6

Figure 2.1: Observed infiltration rate and cumulative infiltration depth for six sampling points.

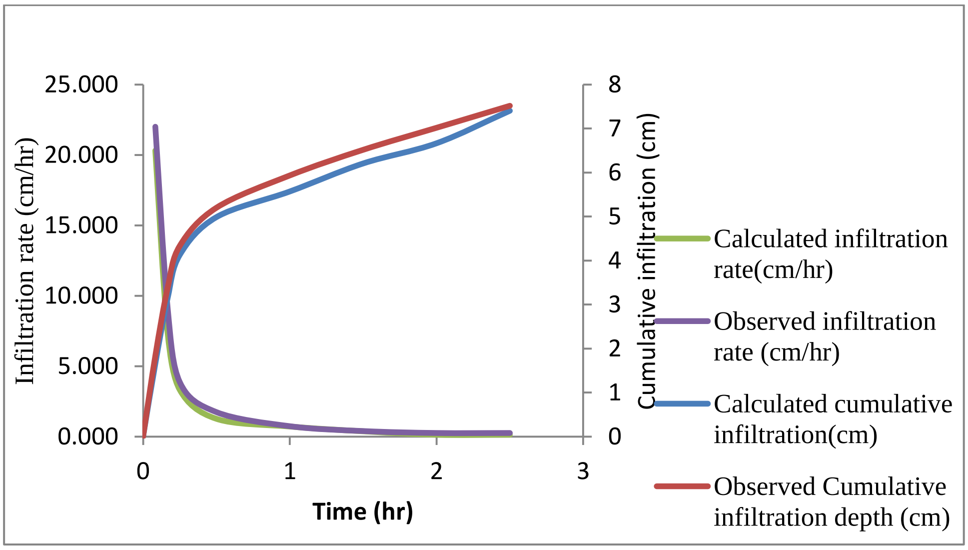


Figure 2.2: Comparison of observed and calculated infiltration rate and cumulative infiltration of Kostiakov model for sampling point-1

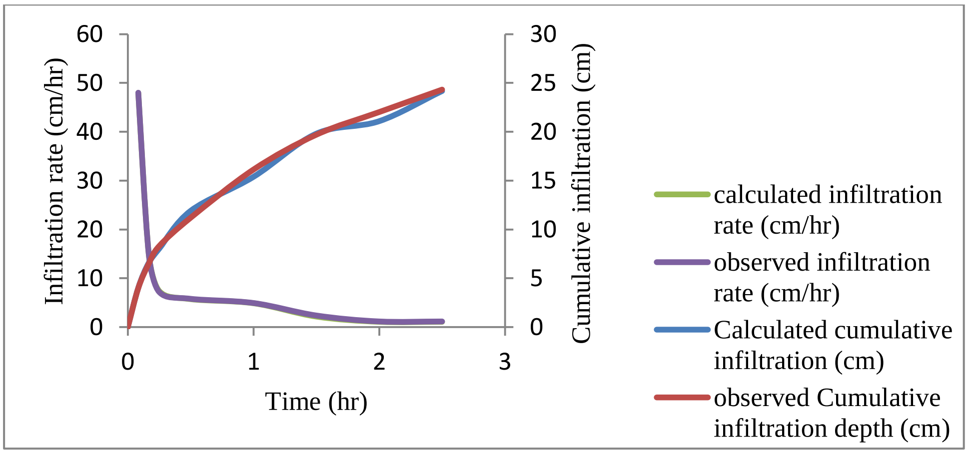


Figure 2.3: Comparison of observed and calculated infiltration rate and cumulative infiltration of Kostiakov model for sampling point-2

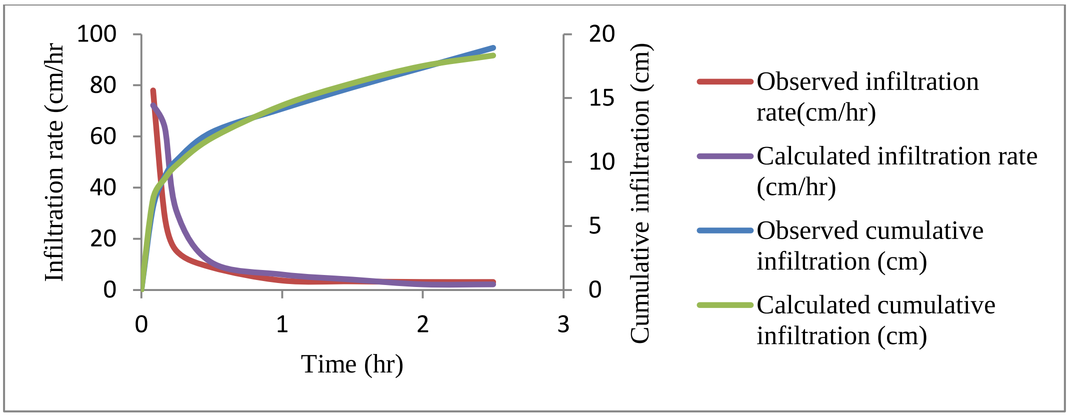


Figure 2.4: Comparison of observed infiltration rate and calculated cumulative infiltration Kostiakov model for sampling point-3

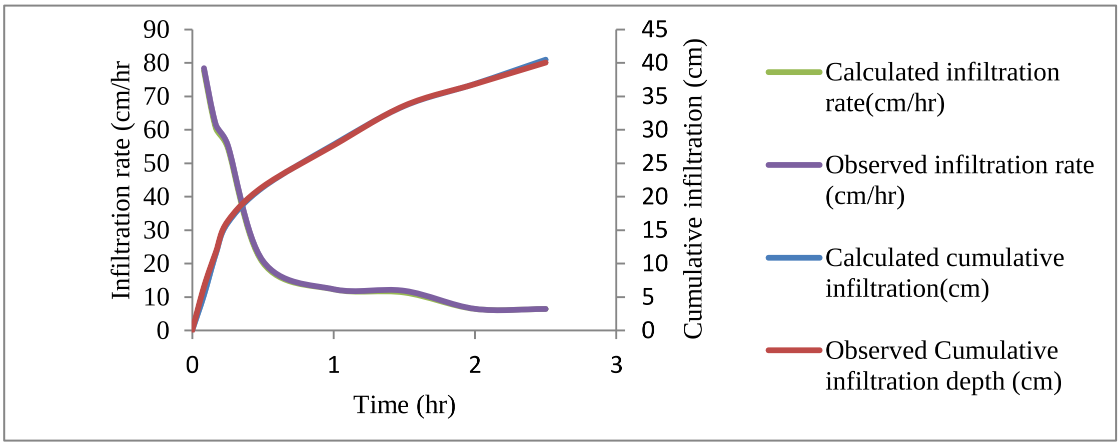


Figure 2.5: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Kostiakov model for sampling point-4

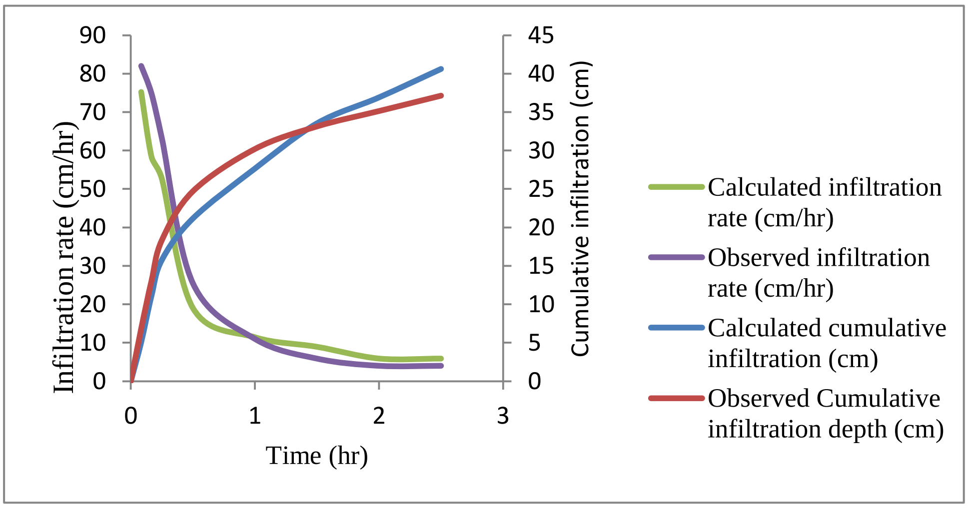


Figure 2.6: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Kostiakov model for sampling point-5

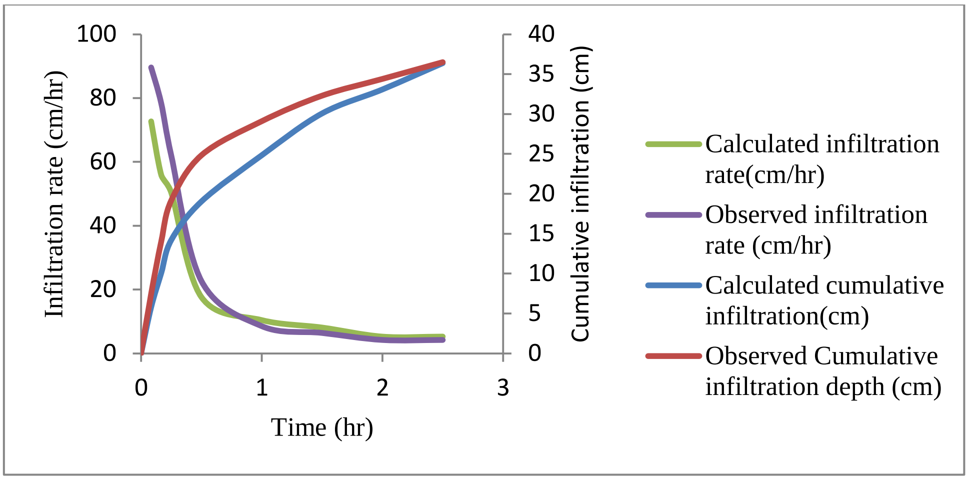


Figure 2.7: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Kostiakov model for sampling point-6

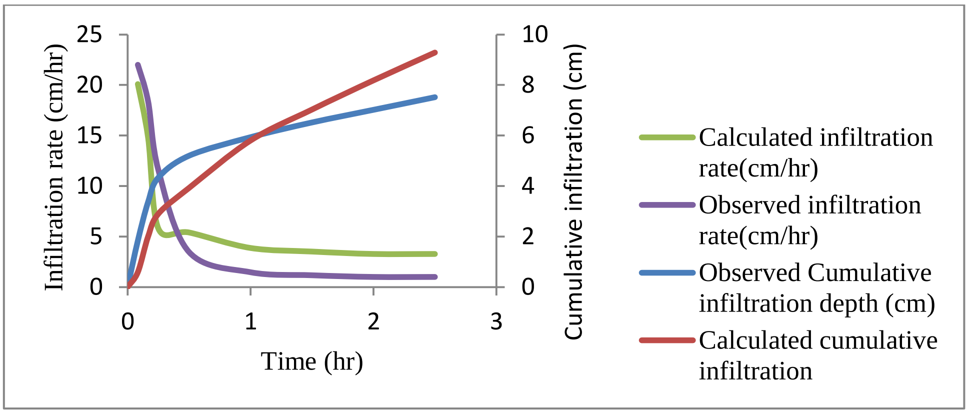


Figure 2.8: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Philip infiltration for point-1

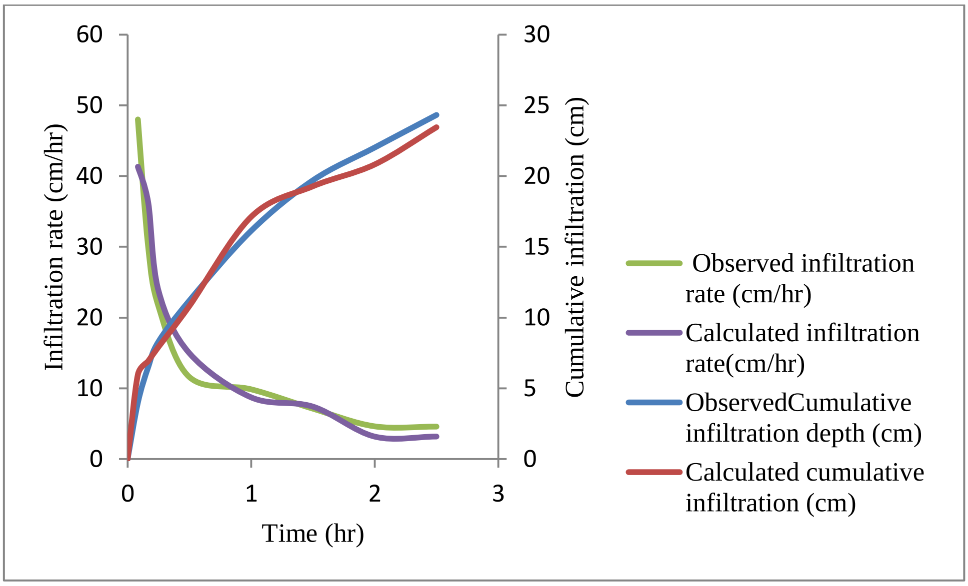


Figure 2.9: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Philip infiltration for point-2

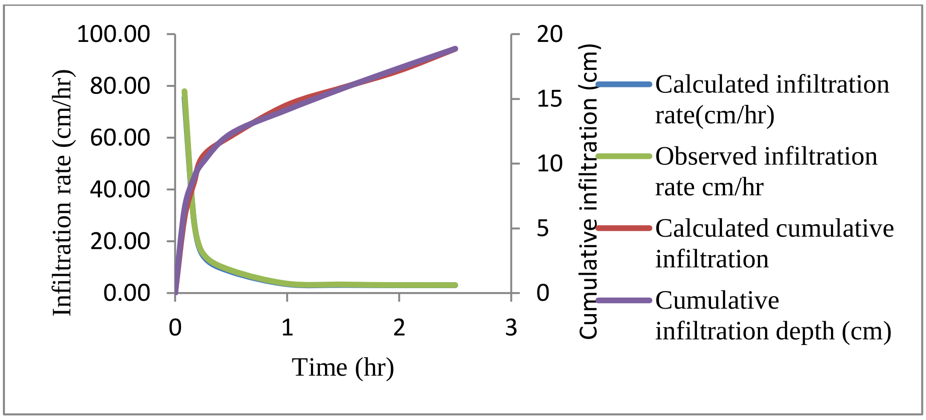


Figure 2.10: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration accumulated Philip infiltration for point-3

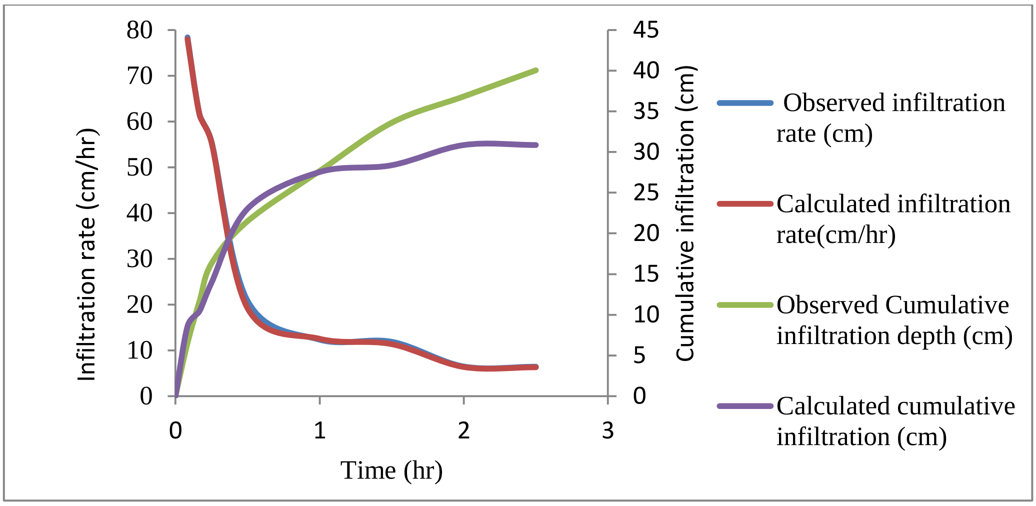


Figure 2.11: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration accumulated Philip infiltration for point-4

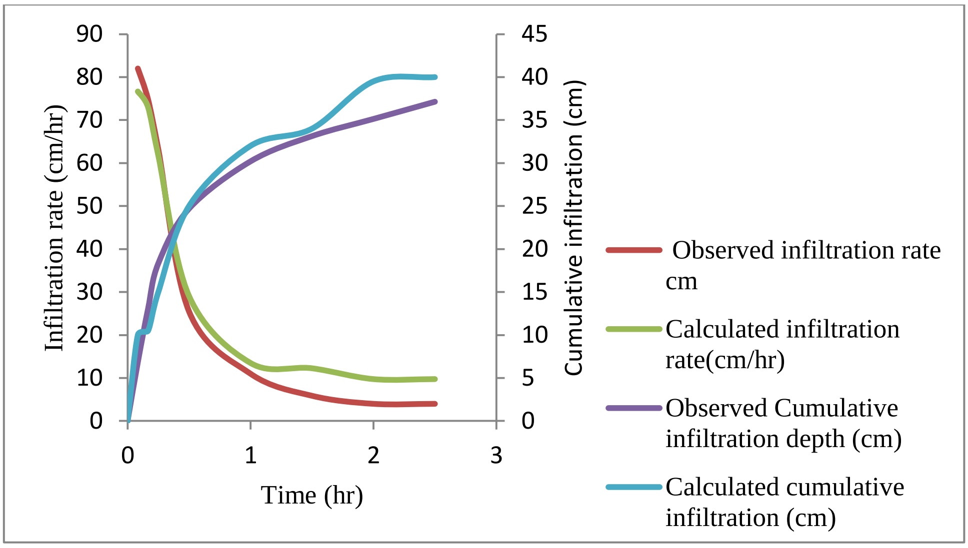


Figure 2.12: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration accumulated Philip infiltration for point-4.

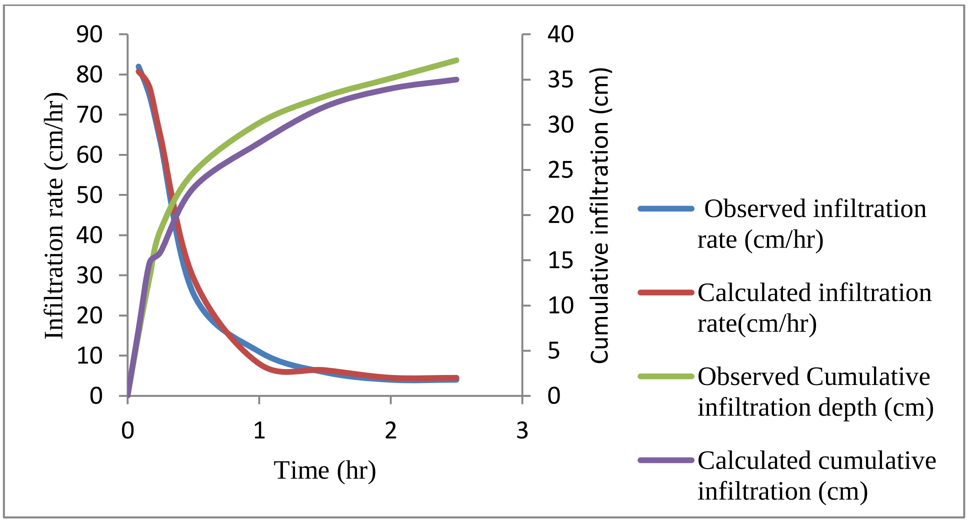


Figure 2.13: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Philip infiltration for point-6

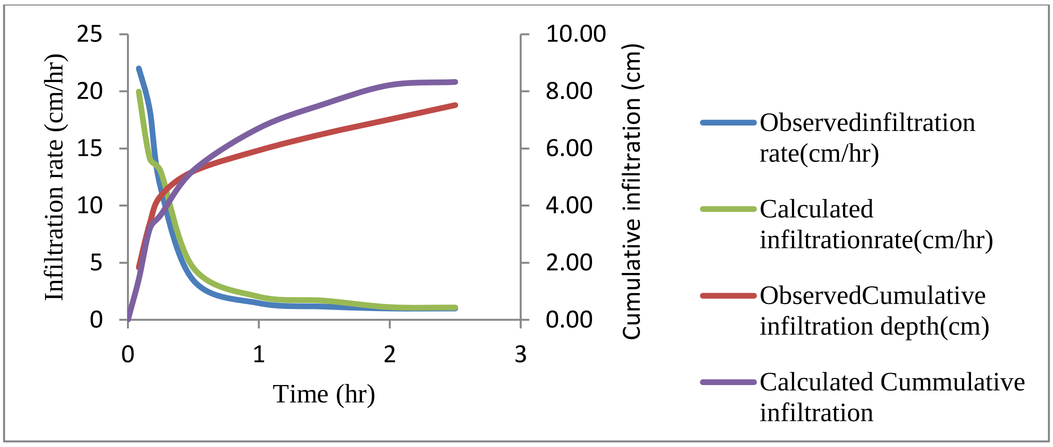


Figure 2.14: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Horton infiltration for point-1

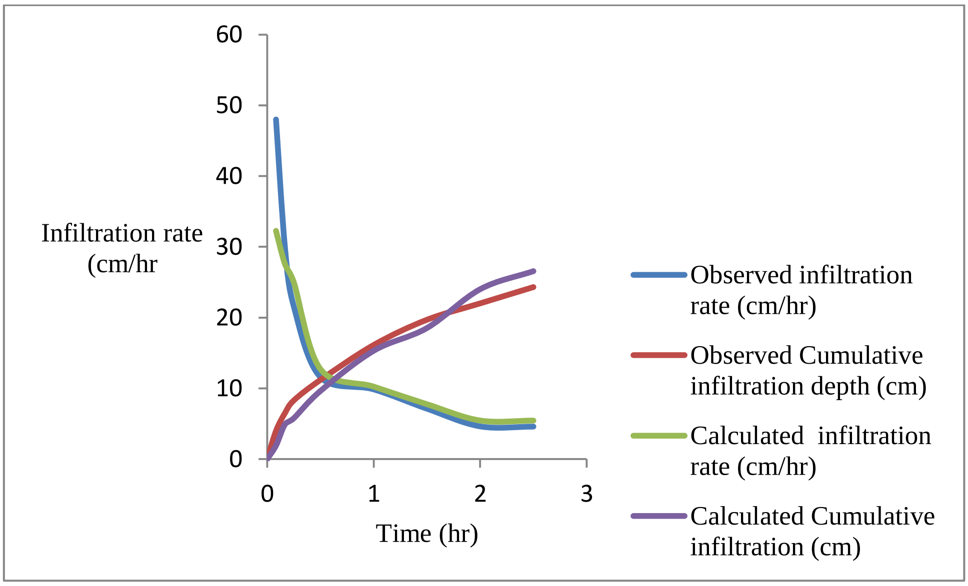


Figure 2.15: Graphical comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Horton infiltration for sampling point-2

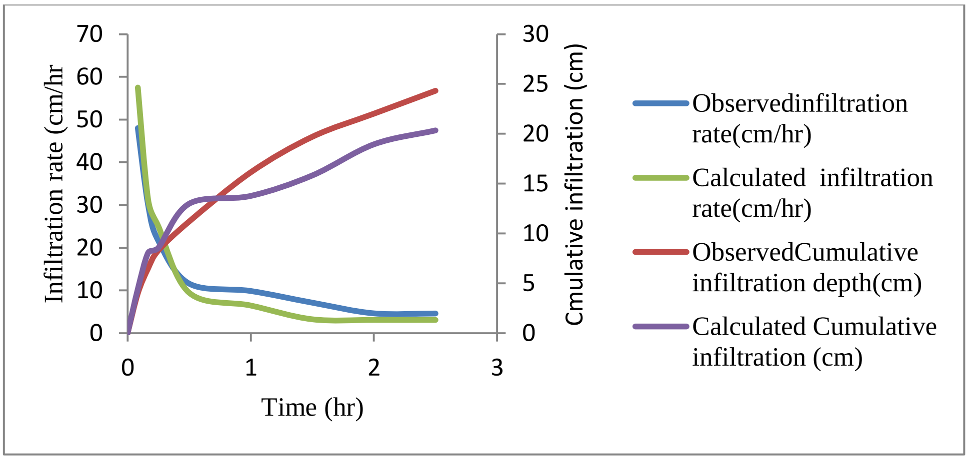


Figure 2.16: Comparison of observed infiltration rate, calculated infiltration rate, observed cumulative infiltration and calculated cumulative infiltration Horton infiltration for point-3

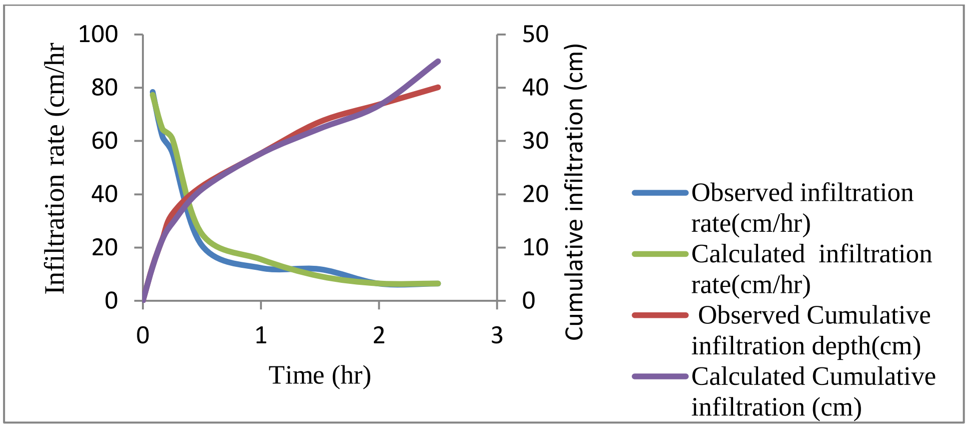


Figure 2.17: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Horton infiltration for point-4

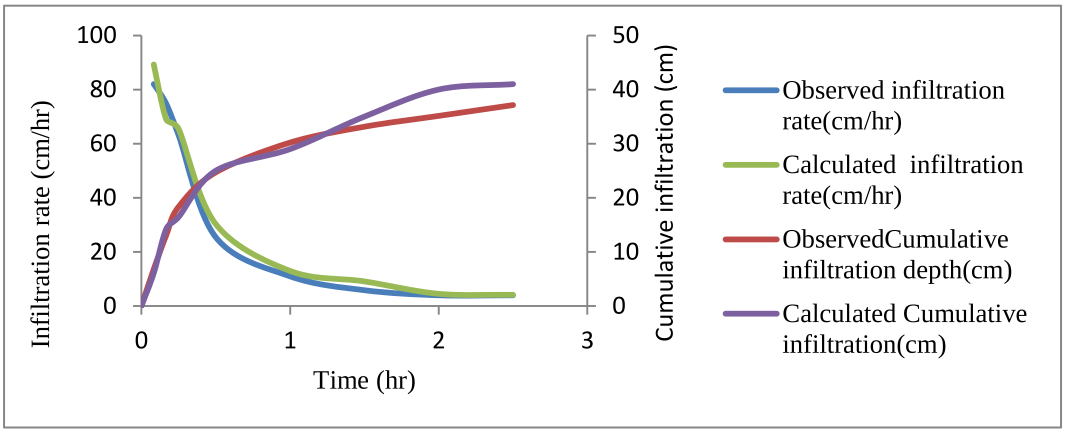


Figure 2.18: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Horton infiltration for point-5

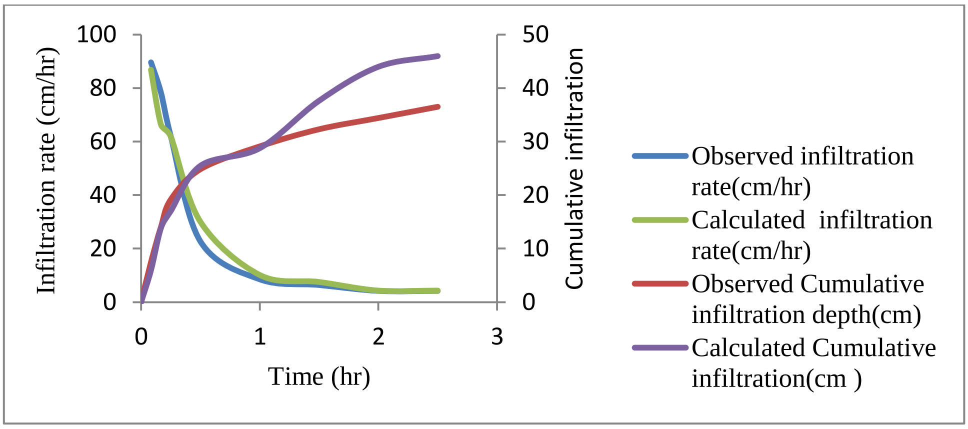


Figure 2.19: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Horton infiltration for point-6

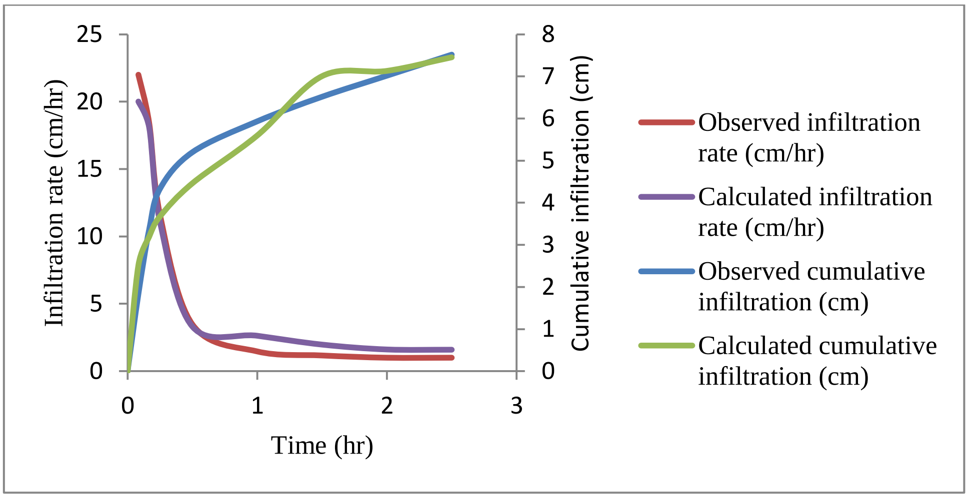


Figure 2.20: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for point-1

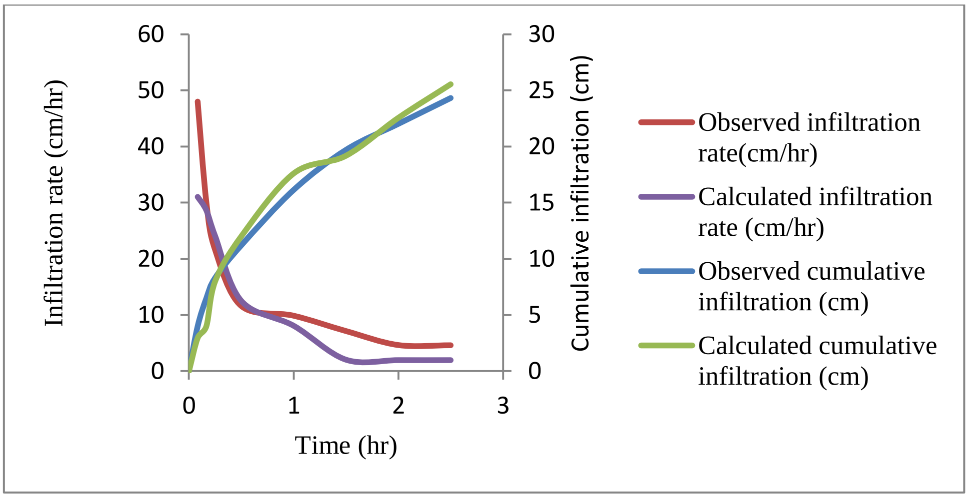


Figure 2.21: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for point-2

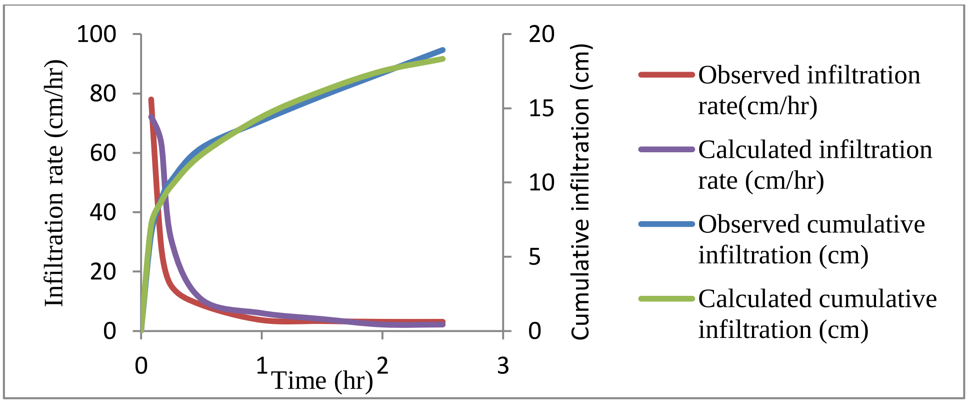


Figure 2.22: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for point-3

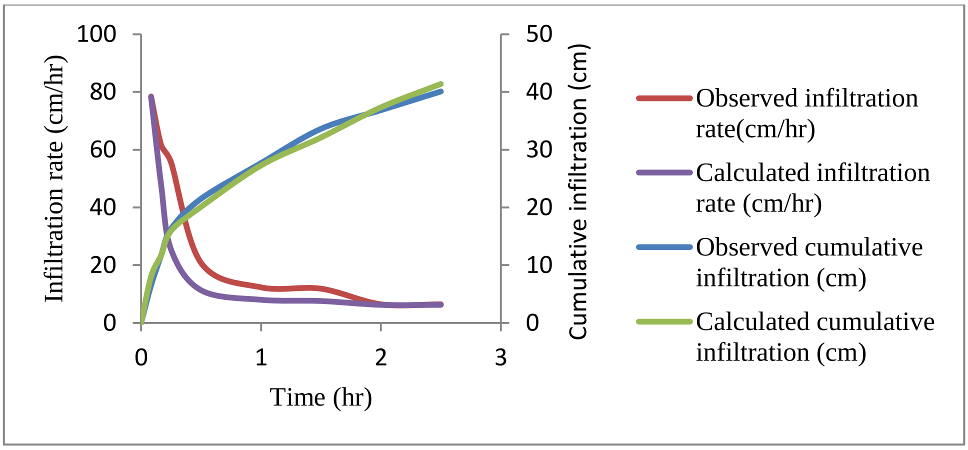


Figure 2.23: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for point-4

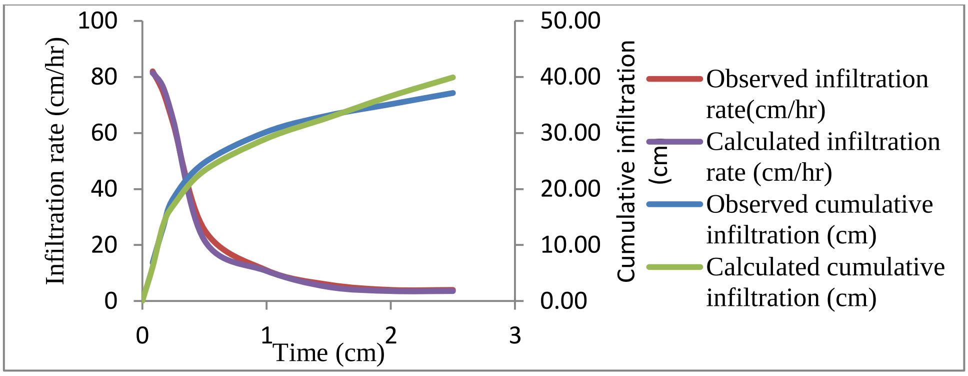


Figure 2.24: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for sampling point-5

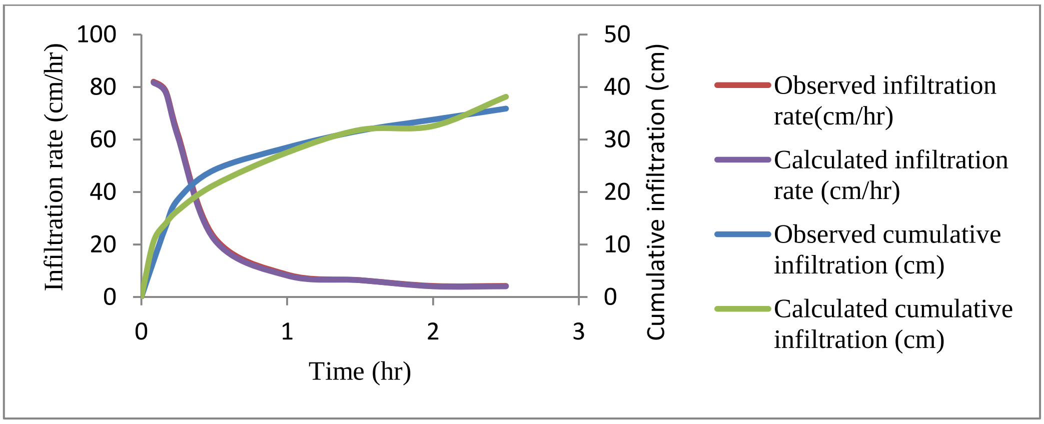


Figure 2.25: Comparison of observed infiltration rate, calculated infiltration rate, measured cumulative infiltration and calculated cumulative infiltration Modified Kostiakov infiltration for sampling point-6.

3. ANNEX OF PHOTOS

Figure 3.1: Photos taken during field infiltration measurements

Figure 3.2: Initial soil moisture and textural class laboratory determination by photo in Civil Department Adama Science and Technology University Soil laboratory.

4. LIST OF CALCULATIONS

4.1. Derived Formula for Kostiakov Model

The developed Kostiakov model to calculate cumulative infiltration depth (I) and infiltration rate (i) for points 1, 2, 3, 4, 5, 6 were found to be:

I = 0.3587t^5.835 and i = 2.093t^4.835 for sampling point-1

I = 0.5159t^15.784 and i = 8.1431t^14.784 for sampling point-2

I = 0.2913t^14.424 and i = 4.2018t^13.424 for sampling point-3

I = 0.4987t^27.406 and i =13.67t^26.406 for sampling point-4

I = 0.4544t^28.007 and i =12.72638t^27.007 for sampling point-5

I = 0.4185t^27.834 and i = 11.648t^27.834 for sampling point-6

This derivation was done by substituting the models parameters listed table 4.6.

4.2. Developed Formula for Philip Model

The derived Philip model to predict or calculate cumulative infiltration depth (Z) and infiltration rate (fp) for points 1, 2, 3, 4, 5, 6 were found to be:

$I =3.23t^{0.5}+1.23t$ and $i = 3.23t^{-0.5}+1.23$

$I=15.07t^{0.5}-6.3368t$ and $i = 15.07t^{-0.5}-6.3368$

$I=23.873t^{0.5}-19.316t$ and $i = 23.873t^{-0.5}-19.316$

$I =27.968t^{0.5}-11.957t$ and $i = 27.968t^{-0.5}-11.957$

$I =32.317t^{0.5}-16.638t$ and $i = 32.317t^{-0.5}-16.638$

$I = 34.883t^{0.5}-19.934t$ and $i = 34.883t^{-0.5}-19.934$ respectively.

This derivation was done by substituting the constants listed table 4.6.

4.3. Developed Formula for Horton Model

The derived Horton model to predict or calculate cumulative infiltration depth (I) and infiltration rate (i) for points 1, 2, 3, 4, 5, 6 were found to be:

$I = t+6.75(1-e^{-3.558t})$ and $i = 1+23.75e^{-3.558t}$

$I = 4.6t+15.24(1-e^{-1.797t})$ and $i = 4.6+30.987e^{-1.797t}$

$I = 3.1t+12.74319(1-e^{-6.3911t)}$, and $i= 3.1+81.429e^{-6.3911t}$

$I = 6.5t+29.0259(1-e^{-3.6778t})$ and $i = 6.5+106.7516e^{-3.6778t}$

$I = 4t+38.33276(1-e^{-2.6255t})$ and $i = 4+100.6235e^{-2.6255t}$

$I = 4.2t+35.723(1-e^{-2.7513t})$ and $i = 4.2+98.28367e^{-2.7513t}$ respectively. This derivation was done by substituting the constants listed table 4.6.

4.4. Developed Modified Kostiakov

The derived Horton model to calculate cumulative infiltration depth (I) and infiltration rate (i) for points 1, 2, 3, 4, 5, 6 were found to be:

$I = antilog\ (0.294+0.286t)-0.605$ and $i = 0.145t^{-0.714}-0.605$

$I = antilog\ (-0.31+0.518t) +1.82$ and $i =0.254t^{-0.482}+1.82$

$I = antilog\ (0.685+0.273t) - 0.375$ and $i= 0.149t^{-0.28}-0.375$

$I = antilog\ (0.7+0.429t) - 1.758$ and $i = 0.098t^{-0.51}-1.758$

$I = antilog\ (0.869+0.351t) - 3.12$ and $i = 0.047t^{-0.649}+3.12$

$I = antilog\ (0.911+0.324t) +3.18$ and $i = 0.03985t^{-0.676}+3.18$ respectively. This derivation was done by substituting the constants listed table 4.6.

4.5. Modified Kostiakov Calculation

Following the same step accumulated infiltration that was calculated for sampling point-1 above accumulated infiltration for sampling point-2 was calculated presented as follows:

From equation Value of b = 1.82 can be calculated by formula used in regression analysis.

At t = 5min, $\log(4+1.82) = \log(k) +0.699a$

$$\log(k) +0.699a=0.765 \quad (4.12)$$

At t = 10, $\log(k) +a = 0.920$ (4.13)

At t = 15min, $\log(k) +1.18a = 1.005$ (4.14)

At t = 30min, $\log(k) +1.477a = 1.115$ (4.15)

At t = 60min, $\log(k) +1.778a = 1.254$ (4.16)

At t = 90min, $\log(k) +1.954a = 1.333$ (4.17)

At t = 120min, $\log(k) +2.079a = 1.377$ (4.18)

At t = 150min, $\log(k) +2.176a = 1.417$ (4.19)

Table 4.2 showed that calculated values of the accumulated infiltration in cm and their corresponding time t in minute for infiltrometers 1and 2. These values are used to plot the cumulative infiltration.

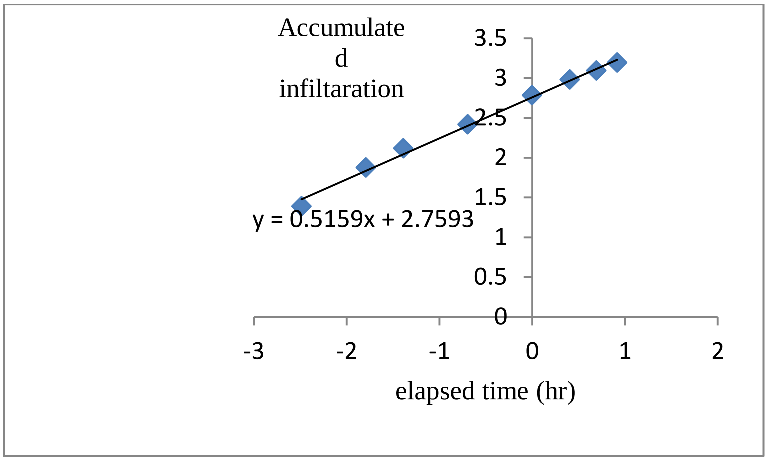


Figure 4.5.1.: Accumulated infiltration versus time in log scale for point-2.

Adding equations 4.12 to 4.15 and 4.16 to 4.19 found equation presented below

$4\log(k) + 4.356a = 3.805$ (4.20)

$4\log(k) + 7.987a = 5.378$ (4.21)

Solving Equations (4.20) and (4.21), the value of a and k becomes 0.518 and 0.490 respectively. The value of log (k) = -0.310

Now substituting the values of a, b, and k in equation for individual elapsed times

$\text{Log}(I-b) = \log(k) + a\log(t)$

At t = 5min, $I_{5min} = 2.947$

At t = 10min, $I_{10min} = 3.434$

At t = 15min, $I_{15min} = 5.894$

At t = 30min, $I_{30min} = 10.067$

At t = 60min, $I_{60min} = 15.202$

At t = 90 min, $I_{90min} = 19.178$

At t = 120min, $I_{120min} = 22.554$

At t = 150min, $I_{150min} = 25.543$

Following the same step accumulated infiltration that was calculated for point-1and 2 above accumulated infiltration for point-3 was calculated as follow:

From the equation Value of b = 0.376 can be calculated by formula used in regression analysis.

At t = 5min, log (6.5+0.375) = log (k) +0.699a

Log (k) +0.699a = 0.837 (4.22)

At t = 10min, log (k) +a = 0.966 (4.23)

At t = 15min, log (k) +1.18a = 1.022 (4.24)

At t = 30min, log (k) +1.477a = 1.104 (4.25)

At t = 60min, log (k) +1.778a = 1.163 (4.26)

At t = 90min, log (k) +1.954a = 1.22 (4.27)

At t = 120min, log (k) +2.079a = 1.25 (4.28)

At t = 150min, log (k) +2.176a = 1.286 (4.29)

The same is represented in Table 4 for Infiltrometer 3 and 4. These values are used to plot the accumulated infiltration.

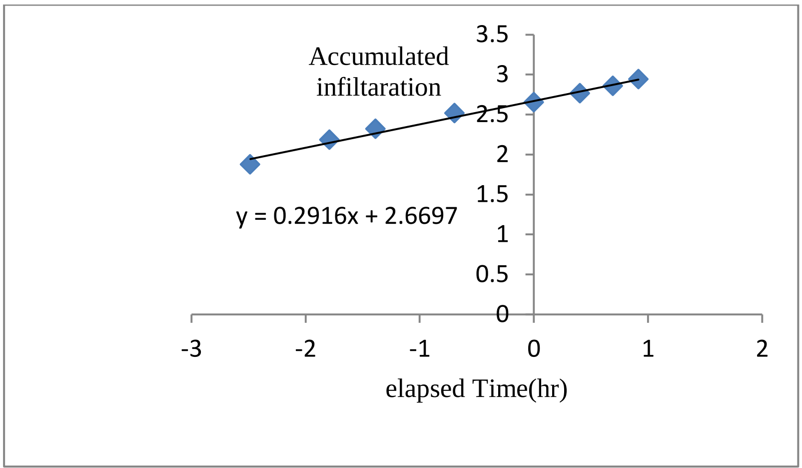


Figure 4.5.2: Accumulated infiltration versus time in log scale point-3.

Adding equations 4.22- 4.25 and 4.26 to 4.29

4log (k) +4.356a = 3.929 (4.30)

4log (k) +7.987a= 4.919 (4.31)

Solving Equations (4.30) and (4.31), the value of a and k becomes 0.273 and 0.2067 respectively. The value of log (k) = - 0.685

Now substituting the values of a, b, and k in equation for individual elapsed times

Log (I -b) = log (k) +alog (t)

At t = 5min, I_{5min} = 7.138

A t = 10min, I_{10min} = 8.703

At t = 15min, I_{15min} = 9.765

At t = 30min, I_{30min} = 11.877

At t = 60min, I_{60min} = 14.429

At t = 90min, I_{90min} = 16.161

At t = 120min, I_{120min} = 17.513

At t = 150min, I_{150min} = 18.638

Following the same step accumulated infiltration that was calculated for point-1, 2 and 3 above accumulated infiltration for point-4 was calculated as follow:

From the equation Value of b = 1.758 can be calculated by formula used in regression analysis.

At t = 5min, log (6.53+1.758) = Log (k) +0.699a

$$\text{Log}(k) + 0.699a = 0.918 \quad (4.32)$$

At t = 10min, Log (k) +a = 1.128 (4.33)

At t = 15min, Log (k) +1.18a = 1.1256 (4.34)

At t = 30min, Log (k) +1.477a = 1.366 (4.35)

At t = 60min, Log (k) +1.778a = 1.469 (4.36)

At t = 90min, Log (k) +1.954a = 1.549 (4.37)

At t = 120min, Log (k) +2.079a = 1.587 (4.38)

At t= 150min, Log (k) +2.176a = 1.622 (4.39)

The same is represented in Table 4.3 for infiltrometer 3 and 4. These values are used to plot the cumulative infiltration.

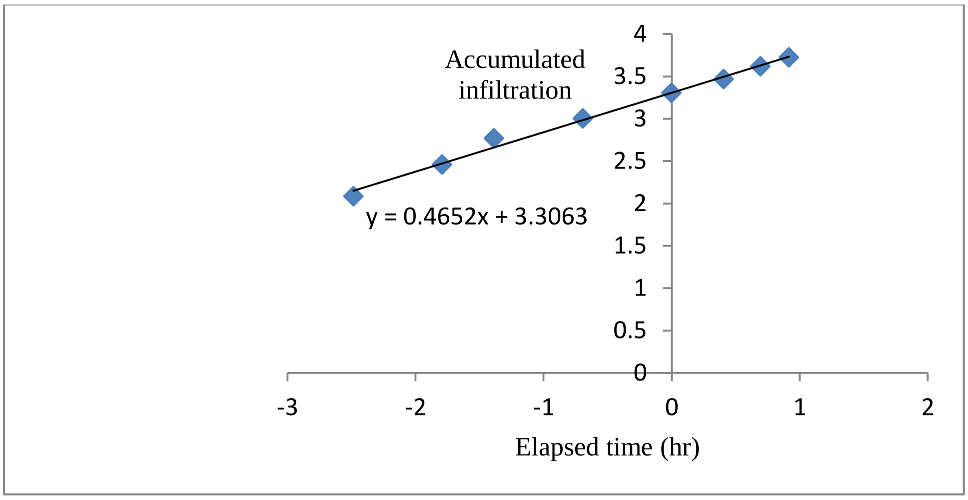


Figure 4.5.3: Accumulated infiltration versus time in log scale point-4

Adding equations 4.32-4.35 and 4.36-4.39

4log (k) +4.356a = 4.667 (4.40)

4log (k) +7.987a= 6.227 (4.41)

Solving Equations (4.40) and (4.41), the value of a and k becomes 0.429 and 0.20 respectively. The value of log (k) = - 0.70

Now substituting the values of a, b, and k in equation for individual elapsed times:

Log (I-b) = log (k) +alog (t)

At t = 5min, I_{5min}= 8.239

At t = 10min, I_{10min} = 11.701

At t= =15min, I_{15min} = 14.319

At t = 30min, I_{30min} = 19.801

At t = 60min, I_{60min} = 27.266

At t = 90min, I_{90min} = 32.102

At t = 120min, I_{120min} = 37.316

At t = 150min, I_{150min} = 41.373

Following the same step accumulated infiltration that was calculated for point-1, 2, 3 and 4 above accumulated infiltration for point-5 was calculated as follow:

From the equation Value of b = 3.12 can be calculated by formula used in regression analysis.

At t = 5min, log (6.53+3.12) = log (k) +0.699a

Log (k) +0.699a = 1.007 (4.42)

At t = 10min, log (k) +a = 1.215 (4.43)

At t = 15min, log (k) +1.18a = 1.336 (4.44)

At t = 30min, log (k) +1.477a = 1.447 (4.45)

At t = 60min, log (k) +1.778a = 1.525 (4.46)

At t = 90min, log (k) +1.954a = 1.562 (4.47)

At t = 120min, log (k) logk+2.079a = 1.585 (4.48)

At t = 150min, log (k) +2.176a = 1.607 (4.49)

Table 5 showed the average values of accumulated infiltration, infiltration rate vs. time for Infiltrometer 5 and 6. These values are used to plot the accumulated infiltration.

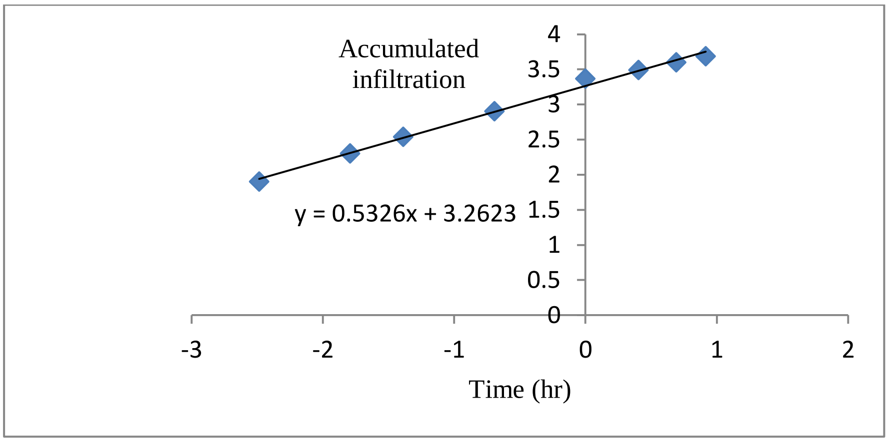


Figure 4.5.4: Accumulated infiltration versus time in log scale

Adding equations 4.32-4.35 and 4.36-4.39

4 log (k) +4.356a = 4.667 (4.50)

4 log (k) +7.987a= 6.279 (4.51)

Solving Equations (3.50) and (3.51), the value of a and k becomes 0.351 and 0.135 respectively. The value of log (k) = - 0.8697

Now substituting the values of a, b, and k in equation for individual elapsed times

Log (I-b) = log (k) +alog (t)

At t = 5min, I_{5min} = 6.071

At t = 10min, I_{10min} = 13.476

At t = 15min, I_{15min} = 16.075

At t = 30min, I_{30min} = 21.282

At t = 60min, I_{60min} = 28.003

At t = 90min, I_{90min} = 32.760

At t = 120min, I_{120min} = 36.574

At t = 150min, I_{150min} = 39.916

Following the same step accumulated infiltration that was calculated for point-1, 2, 3, 4 and 5 above accumulated infiltration for point-6 was calculated as follow:

From the equation Value of b = 3.18 can be calculated by formula used in regression analysis.

At t = 5min, log (6.53+3.18) = log (k) +0.699a

Log (k) +0.699a = 1.027 (4.52)

At t = 10min, log (k) +a = 1.235 (4.53)

At t = 15min, log (k) +1.18a = 1.349 (4.54)

At t = 30min, log (k) +1.477a = 1.447 (4.55)

At t = 60min, log (k) +1.778a = 1.509 (3.56)

At t = 90min, log (k) +1.954a = 1.55 (4.57)

At t = 120min, log (k) +2.079a = 1.575 (4.58)

At t = 150min, log (k) logk+2.176a = 1.599 (4.59)

Table 4 shows the average values of accumulated infiltration, infiltration rate vs. time for Infiltrometer 5 and 6. These values are used to plot the accumulated infiltration.

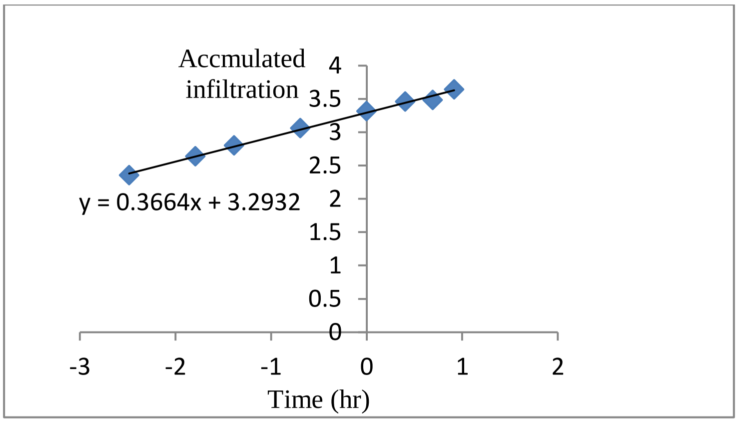


Figure 4.5.5: Accumulated infiltration versus time in log scale

Adding equations 3452-4.35 and 4.56 to 4.59

$$4 \log(k) + 4.356a = 5.058 \quad (4.60)$$

$$4 \log(k) + 7.987a = 6.233 \quad (4.61)$$

Solving Equations (3.60) and (3.61), the value of a and k becomes 0.323 and 0.123 respectively. The value of log (k) = - 0.911

Now substituting the values of a, b, and k in equation for individual elapsed times

Log (I-b = log (k) +alog (t)

At t = 5min, I_{5min} = 10.544

At t = 10min, I_{10min} = 13.999

At t = 15min, I_{15min} = 16.468

At t = 30min, I_{30min} = 21.342

At t = 60min, I_{60min} = 27.515

At t = 90min, I_{90min} = 31.822

At t = 120min, I_{120min} = 35.243

At t = 150min, I_{150min} = 38.127