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Research Paper

Seasonal Variability Of Groundwater Levels, Horton Infiltration Constant And Soil Moisture Content In Coastal Aquifers Case Study-Kilifi, Kenya

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ABSTRACT: *Infiltration is important in determining the surface runoff, groundwater recharge, evapotranspiration, soil erosion, and transport of chemicals on surface and in subsurface waters. Kilifi County heavily depends on groundwater exploitation resulting to poor well drilling, overexploitation and salt water intrusion problems ; there is no monitoring data in place. This research employs the Horton infiltration model to determine infiltration parameters, the soil moisture probe to determine the soil moisture content and the dipper to measure the groundwater levels. Results reveal that; 56% of the boreholes had either; broken hand pumps, malfunctioning generators, had caved in, or had been abandoned. 172 boreholes and shallow wells identified, were predominantly in urban centres, 90% did not adhere to the environmental, safety and construction standards. Rainfall variability had little impact on the deep wells but groundwater levels in shallow wells increased in the wet season. Soil moisture content in Kilifi South was high pointing to the prevalent swampy clay soil. Results from double ring infiltrometer indicate that initial soil moisture content is critical in determining the rate of infiltration. The infiltration rate was lower in the wet season and high in dry season. The Horton decay constant (k) was equally higher during the dry season*

Keywords - *Groundwater levels, Horton constant, infiltration, seasonal variation, soil moisture,*

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I. INTRODUCTION

Soil infiltration refers to the ability of the soil to allow water to move into and through the soil profile. Infiltration rate is the rate at which the water actually infiltrates through the soil during a storm and it must be equal the infiltration capacity. Infiltration capacity is the maximum rate at which a soil in any given condition is capable of absorbing water. Infiltration is important in determining the surface runoff, groundwater recharge, evapotranspiration, soil erosion, and transport of chemicals in surface and subsurface waters. The rate and quantity of water which infiltrates into the ground is a function of soil type, soil moisture, soil permeability, ground cover, drainage conditions, depth to water table, and intensity and volume of precipitation. Most of the water stored in the ground comes from residual precipitation at the surface infiltrating into the top soil and percolating downwards through the porous layers. The longer term renewal of groundwater is brought about by infiltration of rainfall over a catchment area [1]. Initial soil water content is critical in determining the rate of infiltration and the rate at which the wetting front proceeds through the soil profile. The drier the soil is initially, the steeper the hydraulic gradient and the greater the available storage capacity; both these factors increase infiltration rate [2]. The wetting front proceeds more slowly in drier soils, because of the greater storage capacity [3]. The soil type helps to identify the size and number of capillaries through which water may flow into the ground, while moisture content helps to identify capillary potential and relative conductivity. For soil with low moisture content, capillary potential is high and conductivity is low. Soil moisture will increase soil conductivity, but decrease capillary potential, therefore, reduces the infiltration capacity of the soil. Horton's equation is the most popular empirical model for the simulation of infiltration and it is named after Robert E. Horton [4], who derived a semi-empirical formula that says that infiltration starts at a constant rate i_0, and is decreasing exponentially with time t.

Kilifi is classified as a semi-arid land in the coast of Kenya amongst other counties [5]. It is an administrative unit located in the Kenyan coast and it stretches 75 km along the Kenyan coast and for several tens of kilometres inland. The County relies heavily on groundwater for domestic and agricultural water supply due to- rapid population growth leading to poor well drilling, overexploitation and salt water intrusion. The River Sabaki is the only perennial river, originating in the central highlands. The other rivers and streams in the area are seasonal due to the low amount of rainfall, small catchment areas, and sandy soils which have high infiltration rates, low runoff and high evapo-transpiration rates. Some parts of Kilifi County especially on the western part experience 5-6 months of continuous dry weather. Sources of water in Kilifi includes; piped water, water from boreholes and shallow wells , pans, traditional river wells and rainfall harvested water in tanks.

These water resources are not adequate as most of the sources are saline and there is an increasing pressure from the rising population and industrial developments in the area.

Geologically Kilifi County is characterized by sedimentary rocks and the basement rocks, described according to the age of the rocks. Along the western side, basement rocks prevalent include; grits, sandstones, shale and limestone rocks. The metamophosised rocks include the; schist and gneiss and sedimentary rocks in the county are mainly sandstones [6]. The land rises gradually to 900 m on the south western side and it is divided into six physiographic regions which include the coastal plains, the foot plateau, the coastal range, the Nyika plateau, the plateau and the coastal uplands. The soils in the area vary in terms of depth, texture, physical and chemical properties due to different underlying rocks which range from well drained loamy sands to sandy clay texture [7]. The county has both the deep and shallow unconfined aquifers which are naturally recharged by rainfall, during the periods of high rainfall through the highly permeable sandy soils prevalent in the area.

Currently no groundwater level monitoring data exists in relation to the varying soil moisture conditions and infiltration rates. This research aims at establishing the seasonal variation of the soil moisture content which influences the soil infiltration rates and groundwater level fluctuations. This is important in managing the coastal aquifer that is faced with an ever increasing demand for the fresh groundwater resource that needs to be sustained. The study employs the in-situ experiments, the Horton infiltration model and the geospatial techniques to establish the soil moisture, the infiltration levels and the groundwater levels. The in-situ experiments included; the double ring infiltrometer for measuring soil infiltration rates, the soil moisture probe for measuring the soil moisture content and the dipper for measuring the groundwater levels.

1.1 Location of the Study Area.

Kilifi County is located in the coastal area of Kenya and it covers an area of 4779.2 square km. Its geographic coordinates are 3° .38’.00 to 3° .40’.00S latitudes and 39° .45’.00 to 39° .51’.00E longitudes. It is located at an elevation of 150 metres above the sea level. The District consists of 7 divisions: Bahari, Kikambala, Chonyi, Kaloleni, Bamba, Ganze and Vitengeni. **Figure 1** illustrates the map of the study area. The district has a strong industrial sector with the Mabati Rolling Mill, the Athi River cement factory, Cashew nut milling industry and Salt Processing factory that contribute to the region’s economy both in employment provision and income generation.

1.2 Climatic Conditions

Rainfall is bimodal; short rains occurring in October to December while long rains in March to June. Rainfall intensity varies from 400mm in the hinterland to 1300mm in the high potential areas in the coastal plains. Most of the divisions are located in the hinterland and experience less rainfall hence Kilifi County falls under the coastal semi arid areas. It has high temperature ranging from 21°to 35°C.

Figure 1: Map of Kilifi County.

II. RESEARCH METHODOLOGY

2.1 Field Experimentation

Ground water levels were measured using a dipper during the dry and wet season; the dry season data was collected in February and wet season was in June. Photographic recordings were taken to illustrate the present soil textural conditions surrounding the shallow wells and boreholes as they influence the infiltration process. A total of 172 boreholes and shallow wells along the coastal shore were identified using the GPS handset and there spatial distribution done. The groundwater level readings was carried out in 53 shallow wells and 23 boreholes as the rest could not be examined due to inaccessibility and the tight well coverings.

The double ring infiltrometer experimental set up was as seen in Figure 2. Six sites were examined to determine the infiltration rates. Soil moisture probe used to determine the soil moisture content.

Figure 2: Double ring infiltrometer experiment at the beginning and end of experiment

2.2 Methods of evaluating infiltration parameters and Horton decay constant k

Infiltration is the process by which water seeps into the ground through the surface of the earth [8; 9]. Horton's Equation [1] is the most popular empirical model for the simulation of infiltration and it is semi-empirical formula that says that infiltration starts at a constant rate i_0, and decreases exponentially with time t. After time t, the soil reaches the saturation level and the infiltration rate becomes contant i_c. The cumulative infiltration I is given by Equation [2]. The infiltration rate is given by:

$$i = i_c + (i_0 - i_c)e^{-kt} \qquad (1)$$

$$I = i_c t + \frac{i_0 - i_c}{k}[1 - e^{-kt}] \qquad (2)$$

Where I is the cumulative infiltration, i is the infiltration rate at time t; i_o is the initial infiltration rate, i_c is the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate; k is the decay constant specific to the soil. Using the data from the six sites where the infiltration tests were done, the infiltration rates and the decay constant k in the Horton infiltration model were determined based on research by [10]. In this method, simple regression model was applied to calculate the k value (Equation 3) as the slope of the line of best fit between lny and elapsed time (t). Rearranging equation (1) then, $\frac{i - i_c}{i_0 - i_c} = e^{-kt}$, Taking the Logarithm both sides, then, $\ln \frac{i - i_c}{i_0 - i_c} = -kt$, let $\ln y = \frac{i - i_c}{i_0 - i_c}$

Therefore $\ln y = -kt$ (3)

III. RESULTS AND DISCUSSIONS

3.1 Groundwater level measurements

A sectional survey of the different kinds of the shallow wells and boreholes that existed in the study area was as seen in Figure 3. Some boreholes and shallow wells were not constructed according to the recommended standards by the Water Resource Management Authority [11], For instance; about 70% of the shallow wells were uncovered or only had the local papyrus as a covering and were flooded during the rainy season. 56% of the boreholes were not functioning due to broken hand pumps, some had collapsed or had malfunctioning generators and some were abandoned. 1% of the boreholes were constructed next to the residential buildings which could easily compromise the residential structures. Research done by [12], indicates that in Africa, most rural areas are marked with broken down hand pumps and abandoned boreholes. Adekile and Olabode [13] give an approximation of 30% to 50% of installed facilities boreholes in Nigeria to be broken at any one time. Comparative studies are also seen in Malawi at 30% and Uganda at 20% [12] and this is attributed to poor drilling programs that neglect community sensitization and mobilization aspects. There is lack of ownership by the communities and due to the poverty condition they minimally contribute towards the capital costs.

Figure 3: Across-section of boreholes and swallow wells existing in Kilifi

It was also noted that the development support to social infrastructure was neglected and spare parts were not available. The collapsing boreholes and those that had dried up could be attributed to the lack of proper hydro-geological pre- installation studies being carried out before drilling the boreholes.

Only 3 % of the population in the poor agricultural small scale farming areas like in Chasimba had shallow wells. Long queues were observed during the field work where the women would queue for more than 8 hours just to fetch water from the dirty shallow well (Figure 3).The geospatial distribution of the 172 boreholes and shallow wells was as seen in Figure 4. It could be noted that most boreholes were predominant in the urban centres like Mtwapa, Mtepeni, and Tezo where there was a lot of human activities and most of the population could afford the cost of drilling. This agrees with research done by [14] which relates groundwater drilling and ownership to wealth status of households.

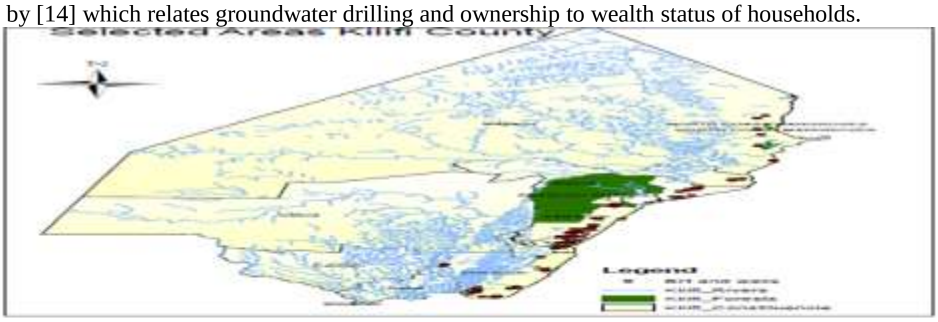

Figure 4: Geospatial distribution of the Boreholes and shallow wells in Kilifi

Most of the shallow wells and boreholes were located in the urban centres where the population density was high and most of them were privately owned. 90% of the boreholes and shallow wells especially the privately owned did not adhere to the set environmental, safety and construction standards as set by the Water Resource Management Authority [11]. This brings to attention the need to control the multiplicity of the privately owned boreholes as they pose a risk of land subsidence compounded with other issues like aquifer depletion, abandonment, health safety and environmental issues. Anwuri [15], suggests that in urban centres, before borehole installation, it is imperative to consider regulations like ; the prevailing regulatory controls and procedures, the issues of health, safety and environment; the effect of leaking sewers and other effluents; chemical storage facilities and the presence of underground facilities such as electric cables, tele-communication lines, oil and gas pipelines among others

3.2 Groundwater level measurements

The groundwater level geospatial map (Figure 5) reveals that most of the deep wells in Kilifi were located to the south (Mtwapa, Tezo) where the geology was mainly sandy clay and the coral sands. The shallow wells of up to 5m depth were observed in the North of the county which were marked with the sandy terrain and soft sandstones which are very highly permeable. The groundwater in the area was very saline and 60% of boreholes had been abandoned because of the high saline levels of up to 22600mg/l which is weigh above the recommended standard of 250mg/l. This result agrees with research done by [16] describing the geological formation and salt water intrusion problems prevalent in the study area.

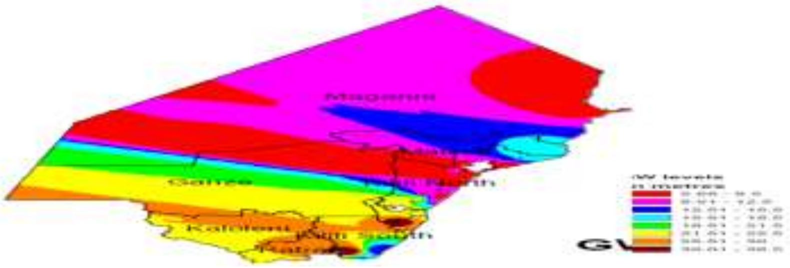

Figure 5: Geospatial distribution of the groundwater rest levels

3.3 Seasonal variation of the groundwater rest levels

Figure 6 and 7 show the groundwater rest levels measured from the ground surface both in the dry and the wet season. The values plotted represent the distance from the reference datum on the ground surface to the water rest levels. It was observed that in the boreholes that were deep (Figure 6), had very little impact of the rainfall to the groundwater levels except in the two sites (BH7 and BH8). This could be attributed to the loose sandy soils that are prevalent in these areas. This implies that rainfall was not the only factor influencing groundwater level fluctuations but also the soil structure, soil type vegetation cover and the human activities around the well. This agrees with research done by [17] which states that rain to some extent is not the only contributor to groundwater recharge. The lack of change in groundwater level fluctuation in the deep boreholes could be attributed partly to the high temperatures prevalent in the study area, given that the area is in a semi arid region and also, most of the recharge could have been lost due to absorption as the wetting front advanced through the deep soils of varying types and structures.

In the shallow wells (Figure 7) the water levels seemed to be increasing during the wet season and this could be because of the shallow water tables therefore most recharge reached the water table. Nyakundi et al.,[17] highlights that a major cause for low water levels during the dry season as high temperatures, low recharge and over extraction due to drought.

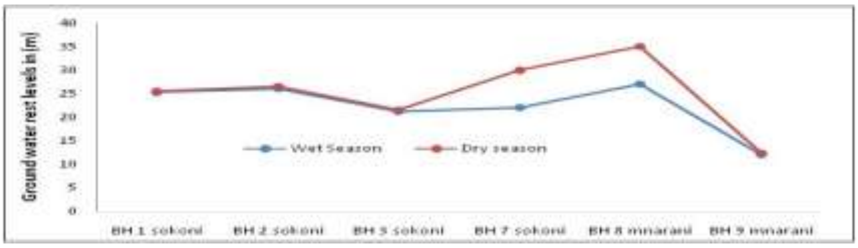

Figure 6: Seasonal Variation in groundwater rest levels in the boreholes

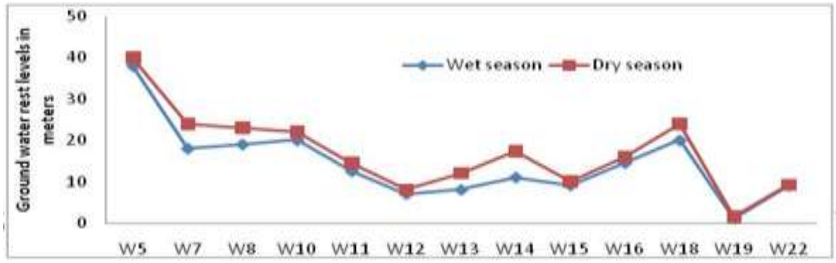

Figure 7: Seasonal variation in the groundwater rest levels in shallow wells

3.4 Soil Moisture Distribution

Research done by [18], indicates that infiltration rate is influenced by; soil type, soil moisture, soil permeability, ground cover, drainage conditions, depth to water table, and intensity and precipitation volume. The soil type helps to identify the size and number of capillaries through which water may flow into the ground, while moisture content helps to identify capillary potential and relative conductivity. Different types of soils were identified in the study area (Figure 8) and they were ranging from the coral stones in the North coast to the clay soils in Chasimba. The clay soils seemed to retain more moisture as it is clearly evident from the Figure 8.

Figure 8: The soil types identified in study area in Kilifi County

Soil moisture impacts infiltration by increasing the hydraulic conductivity which increases infiltration, it also reduces surface tension that draws moisture into the soil which reduces infiltration [19]. Antecedent or initial water content affects the moisture gradient of the soil at the wetting front, the available pore space to store water and the hydraulic conductivity of the soil. The geospatial soil moisture distribution (Figure 9) indicates that the soils in Kilifi South had more soil moisture content both in the dry and wet season indicating the presence of swampy clay soils that are prevalent in that area. The North coast soils retained less water and this could be attributed to the sandy terrain that dominates the area. This agrees with soil classification profile by [20] that indicates sandy soils retain less water.

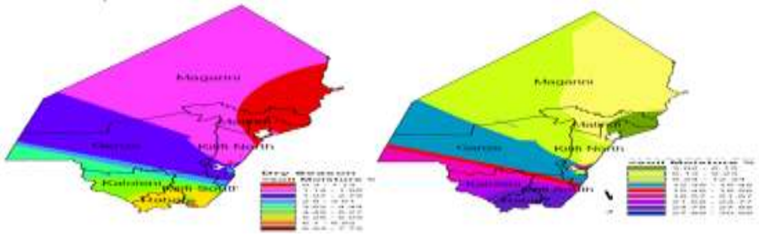

Figure 9: Geospatial distribution of the soil moisture content in Kilifi County

3.5 Seasonal variation in the soil moisture content

Initial water content is important in determining the rate of infiltration and the rate at which the wetting front proceeds through the soil profile. This was clearly observed in the study area (Figure 10), where the soil moisture content during the wet season was higher. The soils were already saturated before the start of the experiment and therefore the infiltration rate was low.

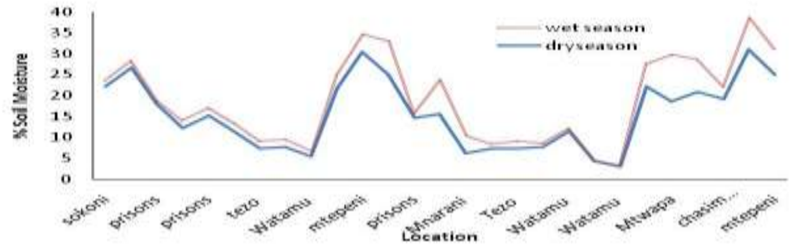

Figure 10: Seasonal variation of Soil Moisture content

3.6 Double Ring Soil Infiltration Tests

Research by [1] states that accurate determination of infiltration rates is essential for reliable prediction of surface runoff, hydraulic conductivity and ground water recharge. Results from this test (Figure 11) reveal that water infiltrates faster (higher infiltration rate) when the soil is dry, and when the soil becomes wet during the wet season, the infiltration rate decreases. Research by [21] suggests that soils with low moisture content (dry season), have a high capillary potential and conductivity is low. Soil moisture will increase soil conductivity, but decrease capillary potential, therefore, reduce the infiltration capacity and this was true for both the cumulative infiltration (Figure11a) and the infiltration rate (Figure 11b). Research by [2], reveals that the drier the soil is initially, the steeper the hydraulic gradient and the greater the available storage capacity; both factors increase infiltration rate The wetting front proceeds more slowly in drier soils, because of the greater storage capacity, which fills as the wetting front proceeds [3].

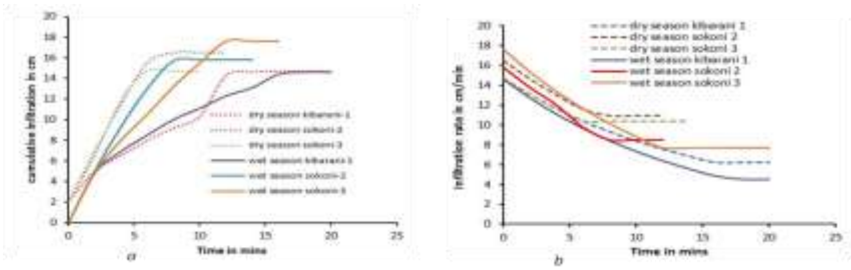

Figure 11; Seasonal variation in (a) Cumulative Frequency (b) Infiltration rates

3.7 Horton infiltration model results for decay constant (k)

Simple regression procedure was applied to determine the Horton infiltration model parameter (k) from the field data. This involved the determination of k value as the slope of the line of best fit between lny and elapsed time (t). It was observed that infiltration begins at some rate i_o and exponentially decreases until it reaches a constant i_c (Figure 12). The Horton decay constant (k) for the dry season was higher compared to the wet season implying that the same factors that affect the infiltration rate also affected the Horton decaying constant (k). Research done by[22] highlights that in the Horton's model, that the reduction in infiltration over time is strongly controlled by factors of soil surface, such as surface crusting, soil swelling and shrinkage phenomena, among others. Research by [23] reveals that as infiltration starts at a maximum value, the infiltration-capacity decreases rapidly at first as the result of the packing of the soil-surface by rain; swelling of the soil, thus closing openings and the in-washing of fine materials into the soil surface pores.

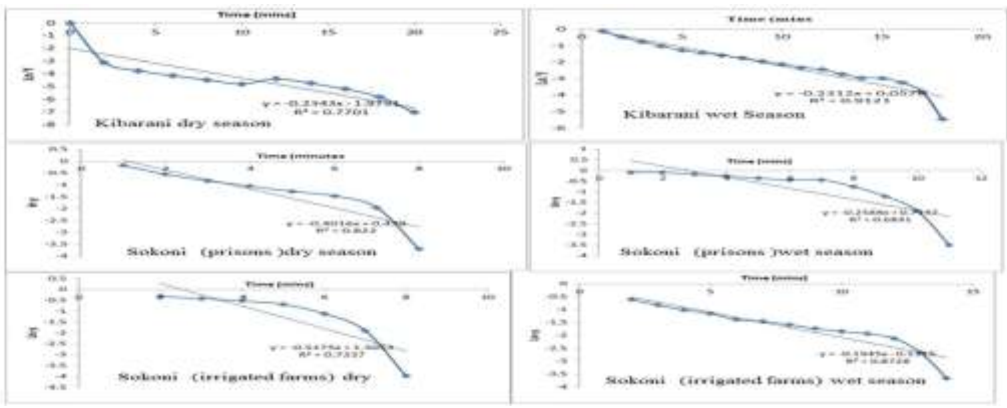

Figure 12: Horton infiltration model results from both dry and wet season from six sites

IV. CONCLUSIONS

It was observed that about 70% of the shallow wells were uncovered or only had the local papyrus as a covering and were flooded during the rainy season. 56% of the boreholes were not functioning due to broken hand pumps, some had collapsed or had malfunctioning generators and some were abandoned due to the salty water intrusion. 1% of the boreholes were constructed next to the residential buildings which could easily compromise the residential structures. The geospatial distribution of the 172 boreholes and shallow wells revealed that most boreholes were predominant in the urban centres where human activities were pre dominant and most of the population could afford the cost of drilling. 90% of the boreholes and shallow wells especially the private owned did not adhere to the set environmental, safety and construction standards as set by the Water Resource Management Authority. The seasonal variation in rainfall did not impact so much the groundwater levels in the deep boreholes but the shallow wells seemed to be affected by the rainfall season as there was an increase in the groundwater levels. Kilifi South had more soil moisture content both in the dry and wet season pointing to the swampy clay soil that is existent in that region. Kilifi North comparatively had less soil moisture content and, sandy soils were prevalent in that region. Results from double ring infiltrometer indicate that initial soil moisture content is critical in determining the rate of infiltration; during the wet season, the infiltration rate is lower since the soils are already saturated but in the dry season water infiltrates faster. The drier the soil is initially, the steeper the hydraulic gradient and the greater the available storage capacity The Horton Infiltration decay constant (k) is higher during the dry season than the wet season implying that the factors that affect the infiltration rate equally affect the decay constant (k).

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