International Journal of Research and Review
Volume 11; Issue: 3; March 2024
Website: www.ijrrjournal.com
Research Paper *E-ISSN: 2349-9788; P-ISSN: 2454-2237*

Impact of Infiltrability on Flooding in Thiaroye, Dakar, Senegal

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DOI: https://doi.org/10.52403/ijrr.20240316

ABSTRACT

For a long time, the drinking water supply to the Dakar region was provided by the Thiaroye boreholes. But the advance of the salt wedge has led the state authorities to order a halt to these drillings. This disconnection has not only led to a decrease in drinking water production in the area, but it has also encouraged the recurrence of flooding due to the rise of the water table. The objective of this work is to study the impact of infiltability on floods in Thiaroye. For the determination of infiltration capacity, the Horton model was used. The evolution of infiltration as a function of rainfall according to the wetness of sandy clay soils shows that the wetter the soil, the lower the infiltration, the greater the return time, the lower the infiltration for the same duration. The submersion time, which corresponds to the beginning of the runoff, arrives instantaneously after the onset of the downpour and after calculation, the value of the runoff is 14.16 mm on 30 mm rain; a runoff coefficient of 47.2%. The calculated runoff coefficients are around 0.50 and depend on the intensity and duration of the rainfall.

Keywords: Infiltrability, Thiaroye, flow, humidity

INTRODUCTION

For a long time, soil sealing was considered to be the main cause of flooding in urban areas [1],[2]. Indeed, this leads to an increase in runoff coefficients and consequently in runoff volumes. In this article, we will discuss the influence of soil infiltrability in floods in Thiaroye, Senegal. The Thiaroye area is characterized by uncontrolled urbanization that has seen spontaneous neighborhoods erect in marshy areas, which cannot be built on because of their flood prone [3]. It has regular and non-regular neighbourhoods that suffer from a lack of sanitation, pollution and, to a greater and more publicised degree, flooding. Since the heavy rains recorded in 2005, the district commune of Thiaroye has suffered from persistent flooding, forcing thousands of inhabitants to relocate [4][5]. A hydrological and hydrogeological study of the basin has been undertaken to help investigate the causes of these floods. It consisted of a modelling of infiltration using the relation of Horton (1933).

MATERIALS & METHODS

Location of the study area

Thiaroye is bounded to the south-west by a piezometric ridge that separates it from the subbasaltic aquifer located at the head of the peninsula, to the west by the oceanic boundary, to the south-east by the tertiary marl bedrock that outcrops from Mbao and to the north-east by the Tanma depression that separates it from the northern coastal aquifer (Figure 1) [6]. The Quaternary sands aquifer of Thiaroye is a sandy reservoir resting on impermeable clay-marl formations that constitute it.

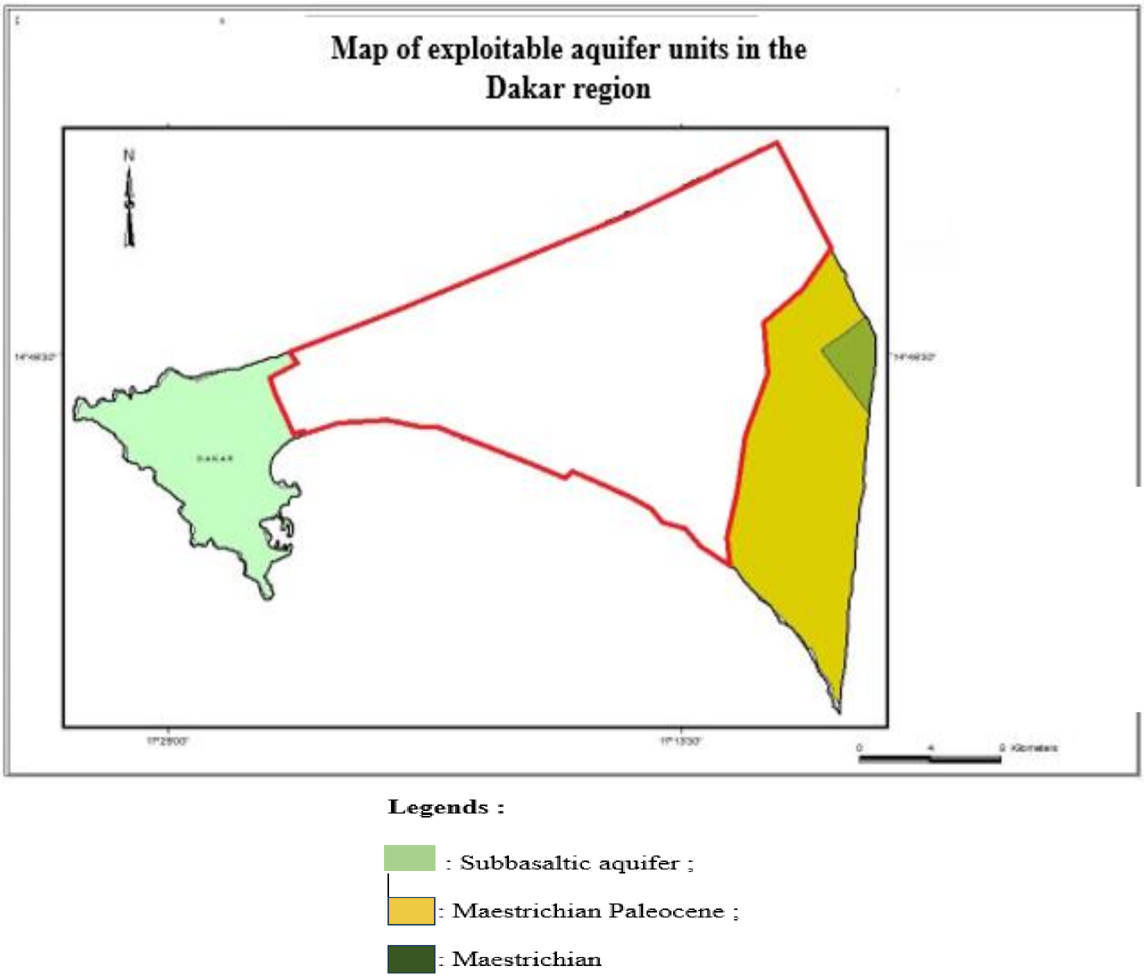


Figure 1: Location of the water table in the study area [9]

METHODS

Soil Infiltrability Testing

The infiltration capacity of a soil can be expressed by several models (Philip, Green – Ampt and Horton). Horton's (1933) Empirical Relationship [10],[11],[12].

Horton's (1933) model is expressed as follows:

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

i(t) is the capacity or rate of infiltration at time t in mm/h. It depends on the feeding regime, moisture condition and soil properties;

i_0 is the initial infiltration capacity depending on the soil type in mm/h. This is the maximum flow of water that the soil is able to absorb through its surface;

i_f is the final infiltration capacity in mm/h. It tends towards a limit which is the hydraulic conductivity at saturation (Ks);

t is the time elapsed since the start of the shower in hours;

k is an empirical constant, a function of the nature of the soil (in h^{-1}).

Estimation of cumulative infiltration after time t;

Cumulative infiltration I is the total volume of water infiltrated during a given period of time [13],[14]. It is equal to the integral over

time of the infiltration rate or regime. I is given in mm.
From Horton's empirical formula, I is deduced after a period of time.

$$I(t)=\int_0^t i_0+(i_0-i_f)\times e^{(-kt)}dt \qquad (2)$$

After integration, formula (2) becomes:

$$I(t)=i_f\times t+\frac{1}{k}(i_0-i_f)\times\left[1-e^{(-kt)}\right] \qquad (3)$$

RESULTS & DISCUSSIONS

Calculation of the amount of water infiltrated after a few minutes of rain

The results of the infiltration calculation after a few minutes of rain are reported in Table 1
Table 1: Wave of water infiltrated after a few minutes of rain depending on the state of the sandy clay soil.

Time (mn)	Blade of infiltrated water (mm)		
	Isolated rain: Wet soil i_0 = 50 mm/h i_f = 15 mm/h	**Rains close together: Very moist soil i_0 = 20 mm/h i_f = 10 mm/h**	**Saturated soil: i_0 = 8 mm/h i_f = 8 mm/h**
5	2,7	1,4	0,4
10	4,2	2,4	0,6
15	5,3	3,3	0,7
20	6,2	4,1	0,8
30	7,9	5,8	1,1
1 hour	13 mm	11 mm	2 mm

The values 13, 11 and 2 mm represent the cumulative infiltration after one hour of rain as a function of soil moisture states.

Figure 2 shows the evolution of infiltration as a function of rainfall according to the state of wetness of the clay-sandy soils.

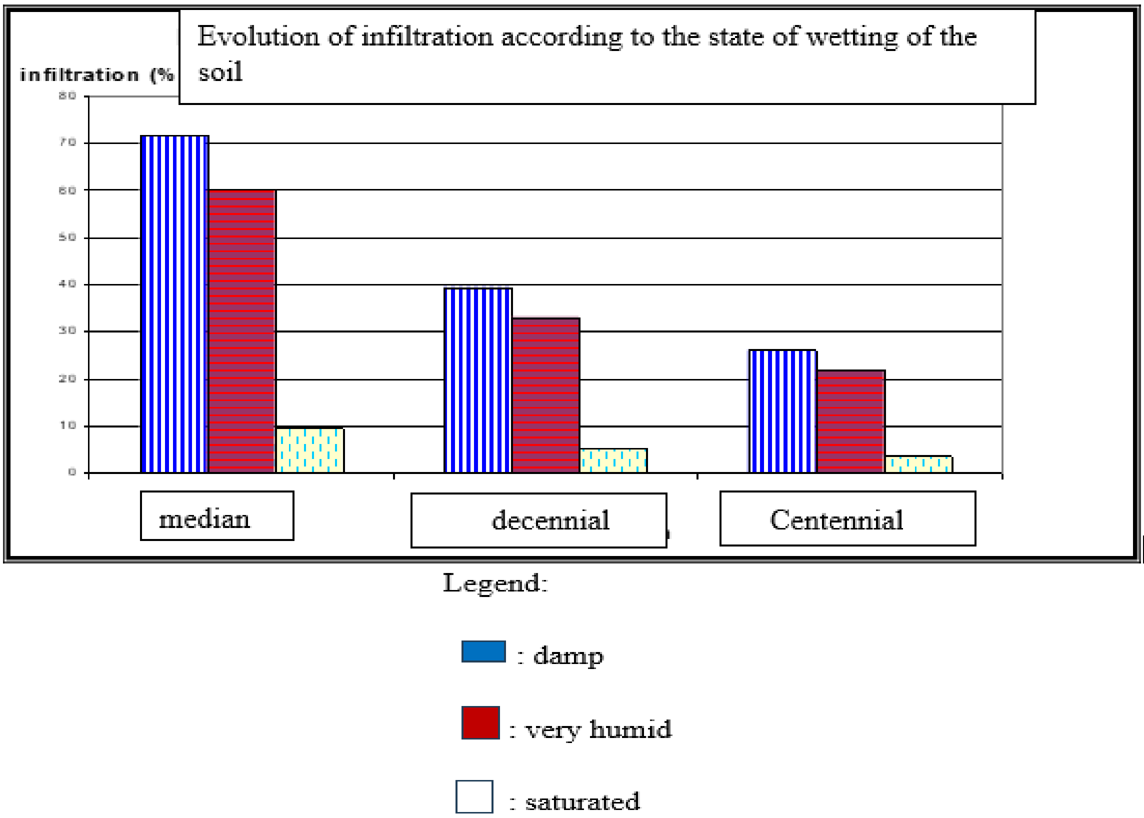


Figure 2 : Evolution of infiltration as a function of rainfall according to the state of wetness of sandy clay soils

These results show how infiltration evolves with soil moisture and rainfall intensities:

- The wetter the soil, the lower the infiltration ;
- The longer the return time, the lower the infiltration for the same duration.

This also means that infiltration decreases with the speed of the rainfall and its duration. Infiltration and runoff vary in opposite directions. If the infiltration is low, then the runoff is significant.

If we neglect the losses (evaporation and interception), we can say that where infiltration is close to 70%, runoff would tend towards 30%; and vice versa.

Comparison of infiltration rate and rainfall intensity

Several scenarios can occur depending on the range of average precipitation intensities (10, 20, 30, 40, 50 and 60 mm/h), the wetness states of the soil and consequently the initial and final infiltration capacities (i0 and if). A comparison is made with a variable average rainfall intensity (I) (30 to 150 mm/h) by varying the nature of the soils.

First case: Sandy clay soil: i0 = 50 mm/h; if = 15 mm/h and I = 30 mm/h

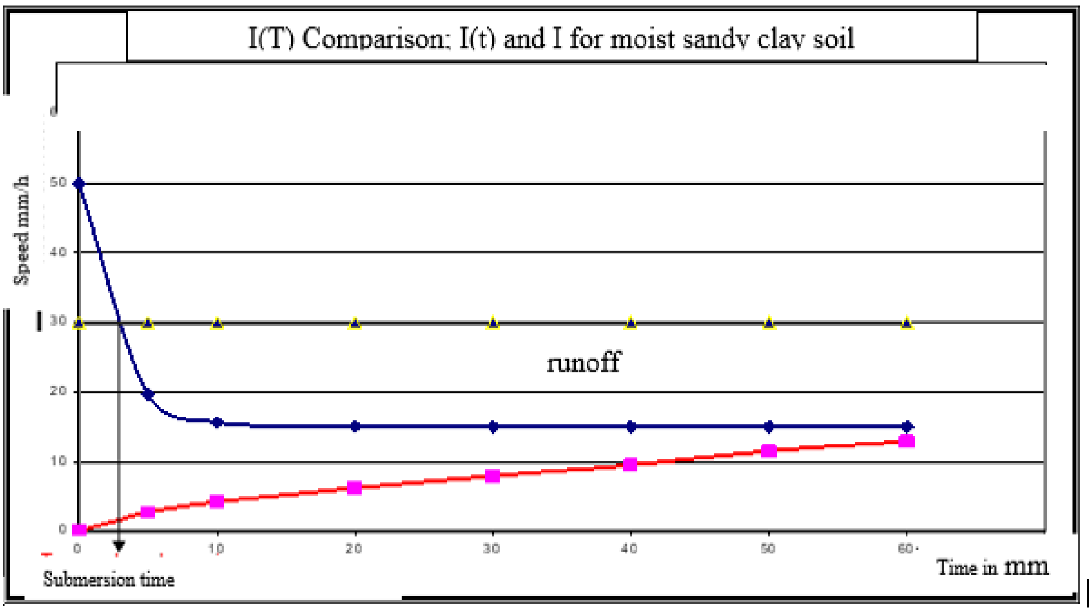
This case occurs when the soil is quite moist, as is the case after a few days of actual rainfall. For rainfall, an average intensity of 30 mm/h was chosen because this scenario occurs in most cases in August and September, in the heart of the rainy season when the intensities are less strong while the duration of the showers is more than 1 hour.

Table 2 shows the results of the infiltration test on moist sandy clay soils.

Table 2: The infiltration test on moist sandy clay soils.

Time (mn)	**0**	**5**	**10**	**20**	**30**	**40**	**50**	**60**
Infiltration rate (mm/h)	50	19.7	15.6	15.1	15.0	15	15.0	15

Figure 3 superimposes the changes in the infiltration rate, the cumulative infiltration and the average rainfall intensity, which is constant.



: Infiltration rate ; : Cumulative infiltration ; : Average Rainfall Intensity

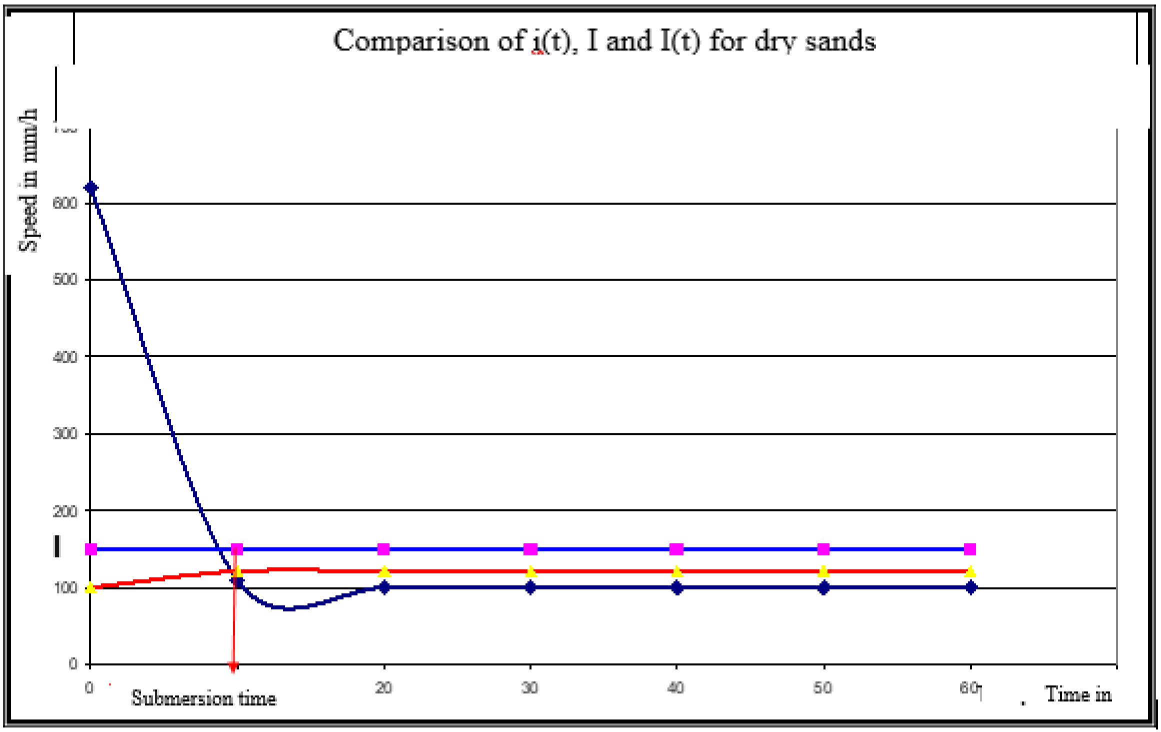
Figure 3: Comparison of soil infiltration and average rainfall intensity on moist sandy clay soil

The submersion time, which corresponds to the beginning of the runoff, arrives instantly after the start of the shower. This happens when the cumulative intensity is not at its maximum. Infiltration, which is very low for these types of soils, then occurs simultaneously with runoff. In one hour it is only 13 mm.
Runoff can be estimated as follows :

$$R = I - \int_{3}^{60} 15 + 35 \times e^{(-0,201t)} dt \quad (4)$$

After calculation, the runoff value is 14.16 mm over 30 mm rain; i.e. a runoff coefficient of 47.2%.
This is the most common case in which the average intensity of the rainfall exceeds the infiltration capacity of the soil. As the soils in this area are sandy clay, saturation occurs very quickly, helped by the rise of the very shallow water table.
In addition, daily rainfall of two or more consecutive days is of paramount importance in the infiltration process. Indeed, they do not facilitate the drying of the floors and increase their humidity; This constantly reduces the infiltrability of the soil. The case of sandy soils may be different.

Second case : i_0 = 620 mm/h; i_f = 100 mm/h and I = 150 mm/h
These infiltration values are for dry sands. Since the values of the infiltration rates on wet sand do not have the values, the value of the average rainfall intensity is increased.
Figure 4 superimposes the changes in the infiltration rate, the cumulative infiltration and the average rainfall intensity, which is constant.



: Infiltration rate i(t); Cumulative infiltration: ;
Average Rainfall Intensity:

Figure 4 : Comparison of soil infiltration, cumulative intensity, and average rainfall intensity on dry sandy soil.

In this second case, three steps are addressed :
At the onset of the downpour, the infiltration capacity of the soil is higher than the average intensity of the rainfall. The rain can then infiltrate completely;After about 10 minutes, the infiltration rate is equal to the average intensity of the rainfall: the submersion

threshold is reached. This is the end of infiltration and the beginning of runoff. At the same time, the cumulative intensity reaches its maximum (122 mm);

- Beyond 10 minutes, the average intensity of rain becomes greater than the infiltrability. The water can no longer infiltrate, so it flows over the surface to the low points.
- After one hour of rain, the runoff coefficient would be 44.5% for a k parameter of $1mn^{-1.}$

From these comparisons, two flow modes can be combined: These are:

- Flow due to exceeding the infiltration capacity of the soil (hortonian flow). It occurs when the intensity of the rain is greater than the rate of infiltration. This is the case for sandy clay soils;
- Flow on saturated soil. This is the case with sands.

It appears that the soils in Thiaroye behave differently with regard to rainfall. Sandy clay soils have low infiltrability and are more prone to flooding. The calculated runoff coefficients are around 0.50 and depend on the intensity and duration of the rainfall. However, these values are obtained without taking into account fairly influential parameters such as waterproofing coefficients (urbanization), basin shape parameters and rainfall variability. To integrate all these parameters into the flow process over an urban basin, it is useful to use modelling.

CONCLUSION

- The assessment of the risk of flooding, the measures to be taken to reduce the impacts, require reflections and studies carried out on the entire basin concerned. It would require studies on :
- Spatial and temporal variability of rainfall;
- Spatial variability of soils;
- The piezometry of the water table.

These studies would assess flow, infiltration and evaporation. This is why, with the complexity of the phenomenon and its specificity as far as Thiaroye is concerned, it is necessary to bring together research in meteorology, hydrology, pedology and hydrogeology to better understand the process of water transfers in the soil and the exchanges between the soil, the water table and the atmosphere.

In this regard, it would be interesting to integrate the results of infiltrability tests on several types of soil to see their share of responsibility for surface flows.

Rain has so far been identified as the main cause of flooding; which is trivial. However, given the permanent nature of these rainfall, even excess rainfall could not be the sole cause. Indeed, there are other factors whose influences aggravate the phenomenon and prolong its duration. These are :

- The shutdown of many boreholes;
- Soils, their very low infiltrability in places and their unsuitability for urbanization;

In this regard, it would be interesting to continue the infiltration tests started on dry ground, to see what it would look like on wet and even very humid ground.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Saidou NDAO, Famara Seydi BA, Papa Babacar Diop THIOUNE. Impact of infiltrability on flooding in Thiaroye, Dakar, Senegal. *International Journal of Research and Review*. 2024; 11(3): 124-130. DOI: *https://doi.org/10.52403/ijrr.20240316*

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