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A Comparative Study of Infiltration Capacity on Various Land Covers in the PT Semen Padang Industrial Area

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ABSTRACT

Changes in land cover within industrial areas have the potential to reduce soil infiltration capacity and increase the risk of surface runoff and flooding. This study aims to analyze and compare infiltration capacities across various land cover types within the industrial area of PT Semen Padang. Infiltration measurements were conducted using the double-ring infiltrometer method on several land cover types, namely greenbelt areas, open land, and developed areas. The data obtained were analyzed using the Horton model approach to determine initial and constant infiltration rates. The results indicate that greenbelt areas exhibit the highest infiltration capacity, with an average constant infiltration rate of 183.3 mm/h, followed by open land at 74 mm/h, while built-up areas showed the lowest rate at 35.9 mm/h. These differences are influenced by soil density, organic matter content, and vegetation root activity. These findings indicate that an increase in built-up surface area significantly reduces the soil's ability to infiltrate water, thereby potentially increasing surface runoff. This study recommends the implementation of green infrastructure and the conservation of vegetated land to support sustainable stormwater management in industrial areas.

Keywords: *Infiltration capacity; Greenbelt area; Open area; Developed area.*

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INTRODUCTION

Land-use changes resulting from human activities, such as industrial development and urban expansion, lead to an increase in impermeable surfaces. This condition can reduce natural infiltration zones, thereby significantly altering hydrological characteristics and disrupting the balance of the water cycle at the watershed scale ([1], [2]. Changes in land cover from naturally vegetated areas to impervious surfaces directly result in increased surface runoff and reduced groundwater recharge rates [3], [4]. In water resources engineering studies, infiltration capacity serves as a key parameter determining the distribution of precipitation between runoff and infiltration [5]. A decrease in infiltration capacity not only increases the risk of flooding and waterlogging in an area—particularly in the downstream regions of river basins—but also reduces groundwater availability during the dry season [6], [7]. Therefore, accurately identifying the infiltration characteristics of various land cover types plays a crucial role in planning Sustainable Urban Drainage Systems (SUDS).

Infiltration rates and capacity are highly dependent on the physical characteristics of the soil, such as texture, porosity, and structure, which are directly influenced by the type of land cover

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above it [8], [9]. Previous studies have demonstrated that areas with dense vegetation cover have significantly higher infiltration capacity compared to open land; this is because plant root systems can increase soil porosity and enhance hydraulic conductivity [10], [11], [12]

The PT Semen Padang industrial complex in Indarung, Padang, Indonesia, represents a complex hydrological ecosystem characterized by unique interactions between climatic factors and anthropogenic activities. As the oldest cement producer in Indonesia, this 1,214-hectare area is located in a wet tropical zone with annual rainfall exceeding 4,500 mm and a frequency of up to 110 rainy days per year, with peak intensity generally occurring in November [13]. Geomorphologically, the area extends from lowlands to hills with dominant soil types consisting of Ultisols, Oxisols, and Inceptisols [14]. Extreme heterogeneity in land cover—ranging from industrial infrastructure and open-pit mining sites to reclamation areas and buffer forests—creates spatial variability in hydrological responses [15]. Furthermore, soil physical conditions are threatened by mechanical compaction caused by heavy machinery and soil crusting due to cement dust deposition that clogs soil surface pores; this hinders the infiltration process, thereby significantly reducing infiltration capacity [16].

Although many studies have evaluated infiltration capacity across various land-use types in general, comparative studies that specifically quantify infiltration variability within densely active heavy industrial zones—particularly the cement industry—remain very limited. The majority of the current literature focuses more on runoff water quality in industrial areas, but neglects the aspect of its micro-hydrological quantity [17], [18]. The lack of empirical data on the specific infiltration capacity of each land cover type within the PT Semen Padang area poses a major challenge in designing precise hydrological infrastructure, such as infiltration wells, retention ponds, or Sustainable Urban Drainage Systems that align with local characteristics.

To address this gap, this study evaluated differences in infiltration capacity across various land cover types in the industrial area of PT Semen Padang. Through in-situ testing and infiltration modeling, the results of this study are expected to provide a comprehensive scientific basis for industrial management and policymakers in formulating strategies for surface runoff management, flood risk mitigation, and sustainable groundwater conservation in industrial areas.

MATERIAL AND METHOD

1. Research Location and Sampling

This study employed a field-based experimental investigation using a double-ring infiltrometer to analyze the comparative infiltration characteristics of various land cover types in the industrial area of PT Semen Padang.

Soil samples were collected from the three dominant land-cover types in the industrial area, which were classified as: vegetated greenbelts, open areas, and office and residential zones. The testing was conducted at eight observation points at each study site using a grid system to ensure spatial representativeness, as shown in the following figure:

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Figure 1: Sampling and testing locations

Soil sampling was conducted using the purposive sampling method at a depth of 0–30 cm, which is the active zone in the surface infiltration process. The samples collected included undisturbed samples for laboratory infiltration testing, as well as disturbed samples for the analysis of soil physical properties as supporting parameters.

2. Infiltration Measurement

Infiltration measurements were conducted in situ using a double-ring infiltrometer in accordance with Indonesian National Standard (SNI) 7752:2012, in which the infiltration rate was determined based on the volume of water added at a constant rate at specific time intervals. Prior to testing, the soil surface was cleared of litter, loose rocks, and surface organic material without disturbing the natural soil structure. The infiltrometer rings were installed concentrically and driven vertically into the soil to a specific depth in accordance with the test procedure. Subsequently, water was introduced into the outer and inner rings to maintain a relatively constant water level during observation.

Measurements were taken by recording the volume of water added to the inner ring at specific time intervals until the infiltration rate showed a constant trend. The instantaneous infiltration rate was calculated based on the volume of water infiltrating per unit area of the inner ring over the observation time interval. The equation used to calculate the infiltration rate is presented as follows:

$$f = \frac{\Delta h}{\Delta t} \quad (1)$$

f is the infiltration rate (mm/min), *Δh* is the drop in water level over a given interval (mm), and Δt is the time required for water at a height of Δh to infiltrate into the soil. The infiltration capacity is calculated based on the results of processing data from the infiltration rate table using the Horton method. The Horton equation is a mathematical model that describes the soil infiltration rate as a function of time, as shown in Equation 2.

$$f = f_c + (f_o - f_c)e^{-kt} \quad (2)$$

f_c is the constant infiltration rate (mm/min), f_o is the initial infiltration rate, *e* is the exponential constant, and *t* is time (minutes). To determine the unknown parameters in the Horton equation, the equation must be compared with a linear equation of the form $y = mx + cy = f$, as shown by the following equation.

$$m = -\frac{1}{k \log e} \quad (3)$$

$$x = \log(f - f_c) \quad (4)$$

Dan

$$c = \frac{1}{k \log e} \log(f_o - f_c) \quad (5)$$

The value of the constant k in Horton’s formula (Equation 2) can be determined based on Equations 3, 4, and 5, that is:

$$k = -\frac{1}{m \log e} = -\frac{1}{m \log 2{,}718} = -\frac{1}{0{,}434\, m} \quad (6)$$

di mana m adalah gradien yang diperoleh dari grafik linier hubungan antara waktu dan log $(f - f_c)$.

Next, the cumulative infiltration is calculated by integrating Horton's equation, and becomes:

$$F(t) = f_c t + \frac{(f_0 - f_c)}{k}(1 - e^{-kt}) \quad (7)$$

RESULTS AND DISCUSSION

1. Infiltration Rate

The infiltration rate is a critical parameter that represents the soil matrix’s capacity to absorb precipitation per unit of time. The resulting infiltration curve not only illustrates the temporal dynamics of the decline in absorption rate but also quantifies the volume of water

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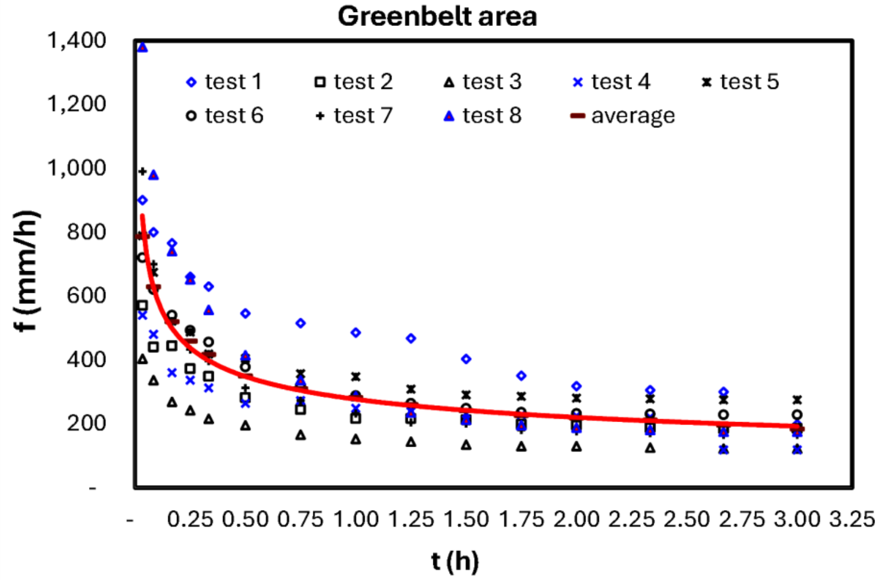
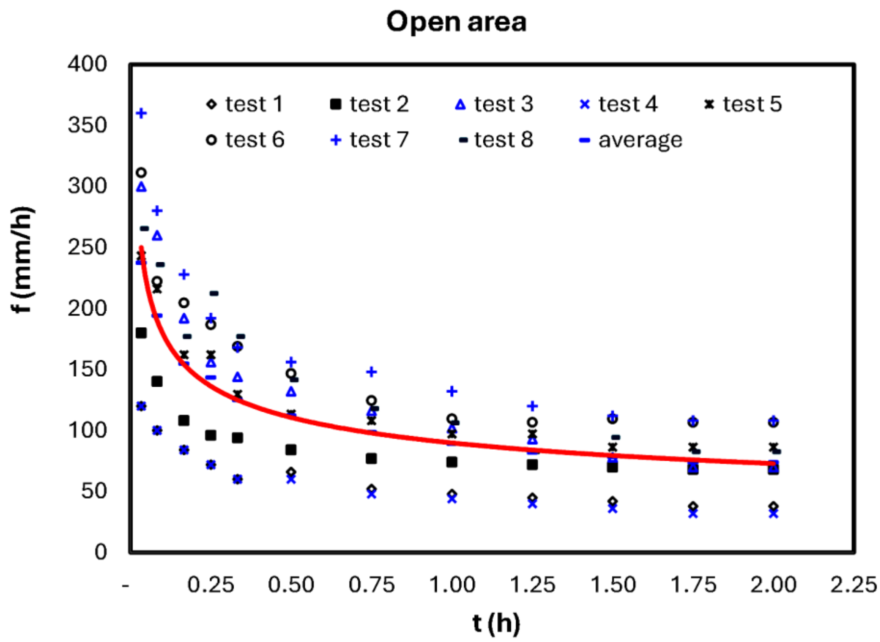
infiltrating during each observation interval. Figure 2 presents infiltration rate profiles for three different land cover types, where each profile is constructed based on data from eight field measurement points using a double-ring infiltrometer, along with the spatial average values for each location.





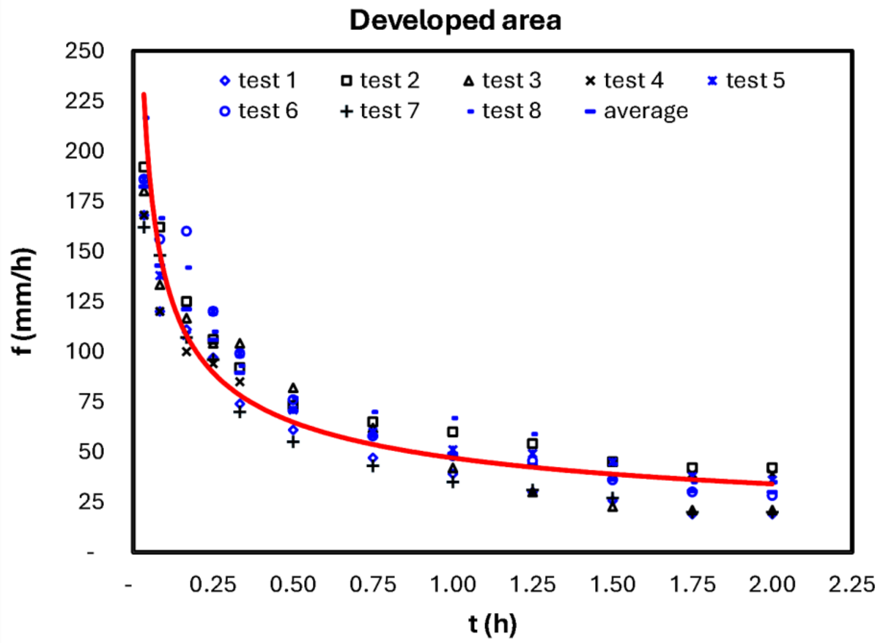


Figure 2: Sampling and testing locations

The results of the curve analysis (Figure 2) indicate significant differences in infiltration rate characteristics among the three land cover types in the PT Semen Padang industrial area. The vegetated greenbelt area exhibits relatively higher initial and steady-state infiltration rates compared to open areas and built-up areas (offices and residential areas). This indicates that the presence of vegetation plays a role in increasing soil porosity and aggregate stability, thereby improving infiltration capacity.

In contrast, open areas exhibited lower infiltration rates and a faster decline toward steady-state conditions, likely influenced by the lack of vegetation cover and potential soil surface compaction. The lowest infiltration rates were identified in built-up areas (office and residential zones), which generally exhibit higher levels of compaction. These differences confirm that changes in land cover in industrial areas directly influence soil hydrological response, particularly in controlling the amount of water that can infiltrate into the soil profile

In comparison, vegetated land cover (green belts) exhibited the best infiltration performance, characterized by a gentler decline in the infiltration rate and higher constant infiltration values. Meanwhile, built-up areas (offices and residential areas) showed the lowest infiltration capacity due to the dominance of compacted surfaces and reduced effective pore space. Open areas are in an intermediate condition but tend to be vulnerable to surface runoff. These findings indicate that the presence of green belts in industrial areas serves as an effective hydrological mitigation element in reducing potential runoff and increasing groundwater recharge.

2. **Infiltration Capacity**

Infiltration capacity was estimated using the Horton model (Equation 2) to accurately quantify the soil's hydraulic parameters. The analysis was based on the infiltration rate curve (Figure 2), which illustrates the functional relationship between infiltration capacity and time. This approach allows for the precise identification of water absorption dynamics and the determination of a constant infiltration rate throughout the observation period.

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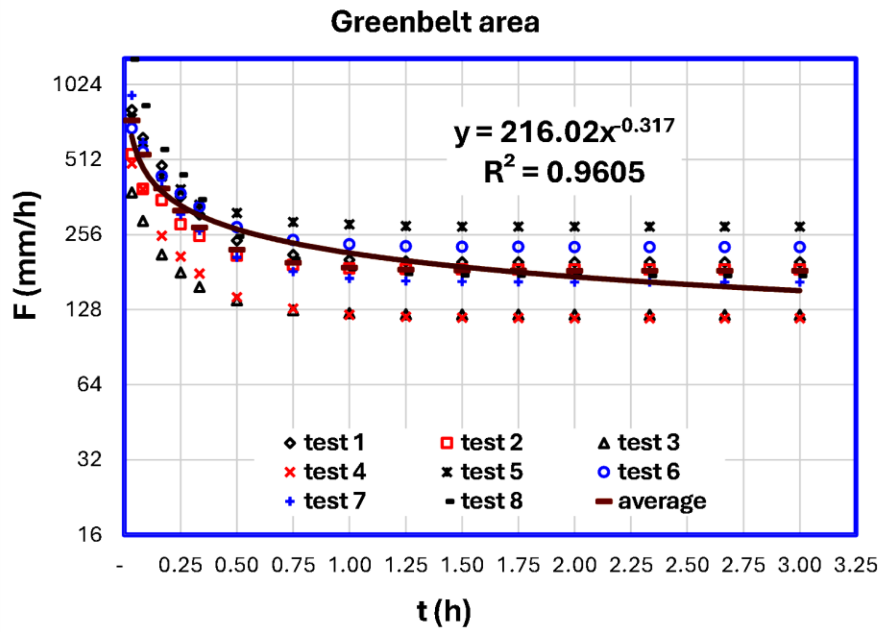

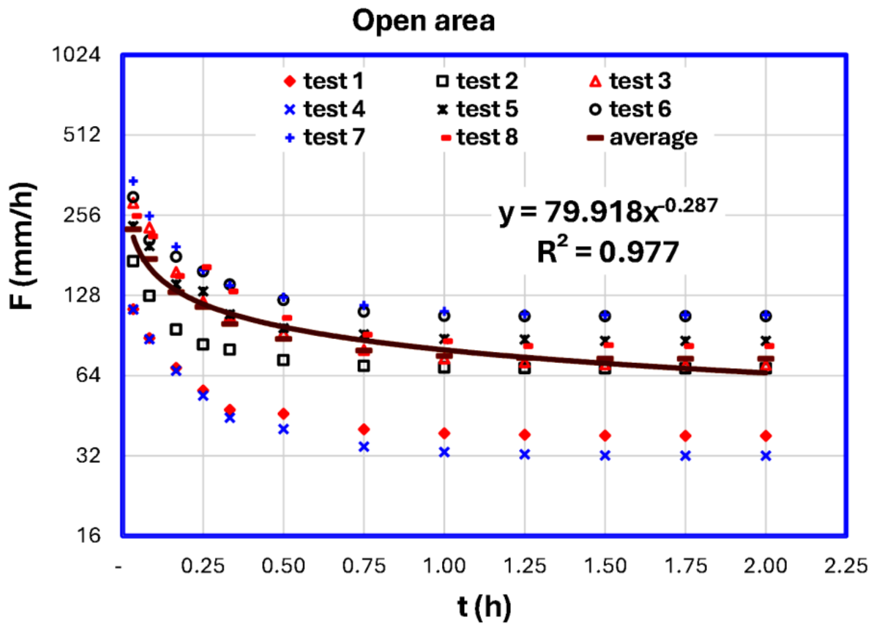

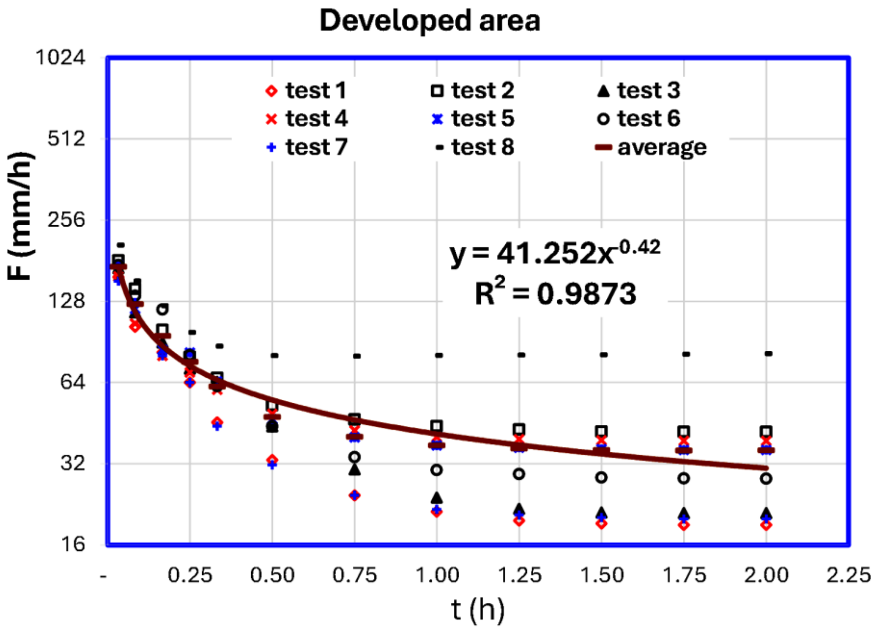

Figure 3: Infiltration capacity

The infiltration capacity curve modeled using the Horton equation shows an exponential decline from the initial infiltration rate (f_0) to the steady-state infiltration rate (f_c) across all land cover types in the PT Semen Padang industrial area. The greenbelt area exhibits a higher f_0 value (average 733 mm/h) and a more gradual decline until reaching an average f_c of 183 mm/h, with a relatively small decay constant (k). This pattern indicates soil capacity to sustain infiltration during the rainy season, supported by a crumbly soil structure and high organic matter content. Conversely, in open and built-up areas, the Horton curve shows a sharp decline in the early phase of the observation, marked by a larger k value and a lower f_c These conditions reflect how quickly the soil reaches saturation due to compaction and the accumulation of fine cement particles filling the soil pores, thereby limiting infiltration capacity.

The Horton infiltration model demonstrated high predictive performance across all observation sites, with coefficient of determination (R^2) values consistently exceeding 0.90. This indicates the model's robustness in capturing infiltration dynamics within the PT Semen Padang area. Hydrologically, the steep decay of the infiltration curves in built-up areas signifies a rapid loss of soil absorptive capacity, suggesting a heightened potential for surface runoff during high-intensity, short-duration rainfall events. Consequently, these findings necessitate a strategic refinement of the local drainage system to manage increased peak flows

A comparison of the infiltration capacities of alluvial and non-alluvial soils was analyzed using a comparative curve presented in a single graph, allowing the differences in infiltration capacity patterns to be observed more clearly (Figure 4).

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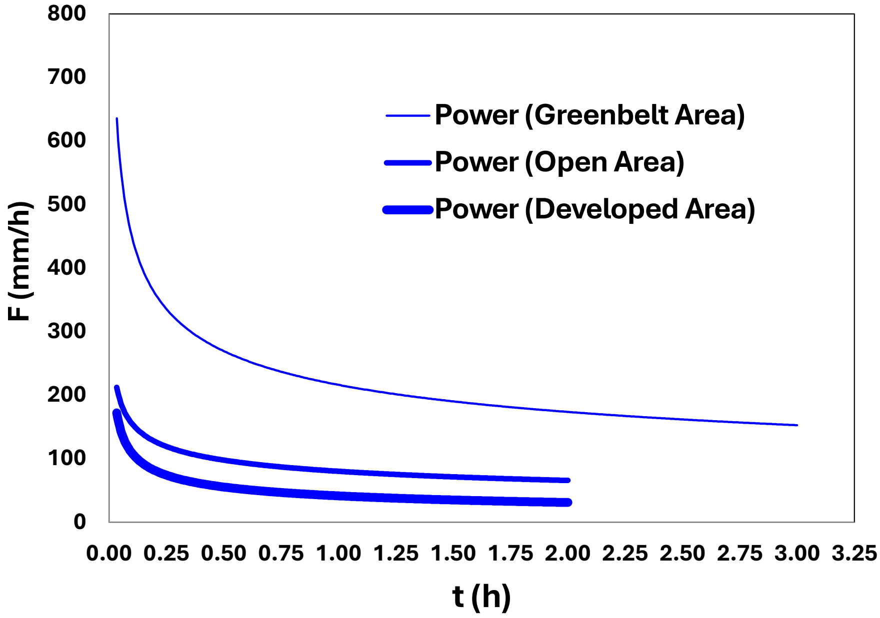

Figure 4: The comparison of infiltration capacity among various land covers

Infiltration capacity profiles vary significantly by land cover type, with greenbelts exhibiting the highest infiltration rates compared to open spaces and built-up areas. Built-up areas reach steady-state conditions the fastest at minimum values, reflecting extreme infiltration barriers due to surface impermeability. Hydrologically, this transition from natural vegetation to built structures results in a substantial degradation of infiltration capacity, which exponentially increases surface runoff volume and vulnerability to urban flooding.

3. Cumulative infiltration

The total volume of water that infiltrated into the soil profile during the observation period was quantified as cumulative infiltration, which was derived through mathematical integration of the Horton model's infiltration rate function (Equation 7).

Table 1: Cumulative infiltration for three types of land cover

Land cover types	f_o mm/jam	f_c mm/jam	k	F(t)	
				t=1 h	t = constan
Greenbelt Area	733.0	183.3	2.852	364.9	742.5
Open Area	226.6	74.0	2.127	137.2	218.7
Developed Area	172.0	35.9	2.193	91.0	133.1

The high cumulative infiltration in greenbelts effectively reduces surface runoff and replenishes groundwater reserves, while moderate values in open areas indicate that infiltration capacity is beginning to be limited due to soil compaction. Conversely, low infiltration in developed areas leads to a drastic increase in surface runoff volume, thereby increasing the risk of flooding in urban areas.

CONCLUSION

Variability in Infiltration Capacity: There are significant differences in steady-state infiltration capacity among land cover types, with greenbelts (183.3 mm/h) performing best compared to open land (74 mm/h) and developed areas (35.9 mm/h) due to differences in soil density and surface layer conditions. Hydrological Implications: The conversion of vegetated land to built-up surfaces drastically reduces infiltration capacity, which potentially increases the runoff coefficient and heightens the risk of flooding in industrial areas. Management Recommendations: Sustainable stormwater management strategies should prioritize the maintenance of greenbelt areas and the implementation of green infrastructure to offset the impacts of land imperviousness resulting from changes in industrial areas.

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