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Exponential Concept Modeling for Rainfall Duration Forecasting at SMAN1 Sukapura

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Abstract

This study aims to predict rainfall duration using an exponential approach based on applied mathematics. Data were obtained from three rainfall events with different characteristics that were observed directly at SMAN 1 Sukapura. The research method used an applied observational quantitative study of a cross-sectional nature. The modeling results show that the decay constant value varies between rainfall events, reflecting differences in the rate of intensity decline after reaching its peak. The predicted time of rainfall cessation differed by 4–6 minutes from the field observations. Evaluation of the model's accuracy using Mean Absolute Percentage Error (MAPE) yielded values of 1.32%, 2.10%, and 3.64%, all of which were below the 10% threshold. These findings indicate that the exponential model is capable of quantitatively representing the decay pattern of rainfall intensity with excellent accuracy but has limitations in representing fluctuations in rainfall intensity.

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INTRODUCTION

Mathematics is a fundamental science that is very important in the development of science, technology, and even trade in today's world. Mathematics is a unique science, which can be described as an essential linguistic activity that can enhance human thinking skills and form the basis for ideas, processes, and reasoning (Qadry et al., 2021). In its application, mathematics functions not only as a tool for calculation but also as a medium for modeling, analyzing, and solving various real-world problems through applied mathematics and mathematical modeling. Mathematics is often considered a science that only studies numbers and logic, but in reality, many human activities in everyday life are closely related to mathematics. Various real-world problems, such as time planning, distance measurement, financial management, and weather data calculation, can be presented in the form of mathematical models so that they can be processed systematically and objectively. Mathematics plays an important role in various activities in everyday life and forms the basis for studying other sciences (Nuraita et al., 2024). Through applied mathematics and modeling, abstract concepts can be converted into mathematical representations that help us understand patterns, predict events, and determine optimal solutions. Therefore, mathematics not only serves as a calculation tool but can also be used to model real phenomena and solve everyday problems more effectively (Banerjee & Bhat, 2025).

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Mathematics has several branches, including algebra, geometry, combinatorics, number theory, and calculus, each of which plays an important role in explaining various phenomena in the real world. One important concept in mathematics is the exponential function, which is used to understand the dynamics of change in a quantity when the rate of change is proportional to the value of the quantity itself (Siller et al., 2022). In hydrometeorology, this exponential characteristic is relevant to the phenomenon of rain. The process of rainfall, from the initial formation phase to its weakening, is influenced by physical mechanisms such as the growth and decay of raindrops and changes in water vapor content in the atmosphere, where changes in rainfall intensity at a given time are greatly influenced by previous rainfall intensity. As a result, rainfall intensity tends to increase or decrease rapidly in a short period of time, forming an exponential change pattern. Therefore, the use of exponential models is an important basis in modeling and forecasting rainfall over time, especially in modeling studies such as rainfall and hydrometeorology (Permata et al., 2024).

Global and regional climate change is the result of increased concentrations of greenhouse gases in the atmosphere. Carbon dioxide traps heat from the sun at the Earth's surface, causing global temperatures to rise and leading to changes in rainfall patterns, both in terms of intensity and duration. This phenomenon causes rainfall to become increasingly unpredictable and potentially extreme, especially in mountainous areas (Prayoga & Ahdika, 2021). The uncertainty of rainfall has implications for the disruption of community activities, especially in the education sector. SMAN 1 Sukapura is a school located in a mountainous area with unpredictable rainfall characteristics. The unpredictable rainfall conditions often cause students and teachers to be late, delay learning activities, and prevent school activities from being carried out. The relatively long travel distance, inadequate road infrastructure, and steep terrain increase safety risks during heavy rain, leading to increased student absenteeism and parental concerns (Lassa et al., 2023). These problems indicate that the main challenge is not the high rainfall but the lack of accurate and easily understandable information about the duration of rainfall. Uncertainty in predicting rainfall remains an obstacle due to the complex and nonlinear nature of the atmosphere, limiting the accuracy of forecasts and complicating the planning and decision-making processes in various sectors (Calvo-Olivera et al., 2024).

One way to avoid problems caused by uncertainty about rainfall is to know the weather conditions for today and the coming days. In Indonesia, weather forecasts are provided by the website of the Meteorology, Climatology, and Geophysics Agency (BMKG), which is responsible for providing weather information based on available meteorological data (Wele et al., 2020). Through this information, homeroom teachers can send reminders via WhatsApp groups so that students can prepare for their departure to and return from school. However, the information on the BMKG website generally only provides information on the time of rainfall, not information on the duration of rainfall. This problem can be overcome through an applied mathematical approach by modeling rainfall as a temporal process that considers variations in intensity over the duration of rainfall. Various studies show that rainfall events generally have an intensity pattern that increases towards a certain peak, followed by a phase of decreasing intensity that reflects the decay characteristics at the end of the rainfall event. Probability distribution-based approaches and density function analysis enable the quantitative characterization of single-peak rainfall patterns, allowing the temporal dynamics of rainfall to be represented and compared objectively with meteorological observation data

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(Gaona et al., 2024). In addition to the probability distribution approach, an exponential function-based hydrological model has also been developed to simulate the relationship between rainfall and surface runoff response. Research results show that a relatively simple but exponential-based model formulation is capable of providing a competitive representation of the relationship between rainfall and hydrological response, particularly in capturing the dynamics of the hydrological system in response to rainfall events (Lee & Noh, 2023). In another approach, exponential function-based modeling is effectively used to analyze rainfall data, particularly in representing asymmetric rainfall distribution patterns that contain extreme events. The exponential approach utilizes the characteristics of continuous decay functions so that the variability and complexity of rainfall data can be modeled quantitatively through an exponential probability distribution framework (Alrweili, 2024). Thus, the concept of this exponential model is able to describe the variation in rainfall intensity that increases until it reaches its peak, then gradually decreases, and shows an exponential decay pattern after the peak intensity phase is reached (Ramesh et al., 2022). Based on this, this study aims to predict rainfall duration based on rainfall intensity observations at specific times using an exponential model as an effort to overcome problems related to weather conditions at SMAN 1 Sukapura.

METHOD

This study uses an applied observational quantitative study based on applied mathematics to model the dynamics of rainfall intensity changes over time. Observations focus on the relationship between accumulated rainfall height and time variables, with the aim of determining the rainfall intensity decay constant (k) and determining the theoretical time of rainfall cessation (t_{stop}) through exponential modeling.

The research design is cross-sectional, in which each rainfall event is defined as a single, independent observation unit, representing atmospheric conditions at a specific time. This design is relevant for event-based rainfall studies, which allow analysis to be conducted within a single rainfall cycle, from the onset of the event to the natural decline and cessation of rainfall intensity (Zhu et al., 2024).

Data collection was conducted in the field at SMAN 1 Sukapura during three different rainfall events, namely:

1. November 5, 2025, 9:00–9:30 a.m. WIB
2. November 6, 2025, 12:00–12:21 p.m. WIB
3. November 7, 2025, 12:12–12:34 p.m. WIB

Rainfall measurements were taken using a simple rain gauge made from a 1500 mL plastic bottle, which was used to measure the height of rainwater accumulated during rainfall events. The use of a simple rain gauge has several limitations, including relatively low measurement scale resolution, potential errors due to rainwater splashes, and the influence of wind, which can affect the accuracy of rainwater collection (Krüger et al., 2024). Nevertheless, simple rain gauges are still considered adequate for small-scale research and analysis of relative patterns of rainfall intensity changes over time and are widely used in hydrological studies based on simple field observations (Dervos & Baltas, 2024). In addition to rain gauges, stopwatches are used to record observation times in minutes, while writing instruments and calculators are used for recording and processing observation data.

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The research procedure began with placing the rain gauge in an open location free from obstacles in the surrounding area to minimize interference with the rainwater collection process. When it starts to rain, time measurement begins by activating a stopwatch as a temporal reference. The height of rainwater collected in the rain gauge is measured and recorded periodically at certain time intervals until the rain naturally stops. The rainfall height data obtained is then used to calculate the rainfall intensity at each observation time using the following equation:

$$r_{(t)} = \frac{\Delta h}{\Delta t} \times 10$$

Where $r_{(t)}$ represents the rainfall intensity at a given time in units of $(mm/minute)$, Δh indicates the change in measured rainfall height between two consecutive observation times in units of (cm), while Δt represents the observation time interval in units of $(minute)$.

Based on all rainfall intensity data obtained, the maximum rainfall intensity value (r_0) is set as the initial condition for analysis. Next, the rainfall intensity decrease phase is modeled using an exponential function based on the concept of natural decay, which is an approach that states that the rate of change of a quantity over time is directly proportional to the quantity itself (Bartolomeo et al., 2021; Nasution et al., 2023). Mathematically, the model is expressed as:

$$\frac{dr}{dt} = -kr_{(t)}$$

With a general solution:

$$r_{(t)} = r_0 e^{-kt}$$

Where $\frac{dr}{dt}$ represents the rate of change of rainfall intensity over time with units $(mm/minute^2)$, k is the rainfall intensity decay constant $(minute^{-1})$, $r_{(t)}$ represents the rainfall intensity at time $(mm/minute)$, r_0 is the highest rainfall intensity $(mm/minute)$, t represents the time interval between the initial intensity r_0 and the intensity at time $r_{(t)}$ $(minute)$, and e is the exponential number with a value close to ≈ 2.718281828.

Based on this equation, the constant of decay of rainfall intensity (k) is calculated using the following equation:

$$k = \frac{1}{t} ln \left(\frac{r_0}{r_{(t)}}\right)$$

The decay constant value is determined based on several rainfall intensity data points observed during the decline phase. These values are summed and divided by the amount of data to obtain the decay constant value k, which represents the characteristic rate of rainfall intensity decay in each rainfall event.

Next, (t_{stop}) is determined by assuming that rainfall ends when the rainfall intensity decreases to a certain value, such as $r_{(t)} = 0.1\ mm/minute$ (Cai et al., 2025). The t_{stop} value is then derived analytically based on the exponential decay model and formulated as follows:

$$t_{stop} = \frac{1}{k} ln \left(\frac{r_0}{r_{(t)}}\right)$$

The results (t_{stop}) obtained through modeling were then compared with the rainfall cessation times observed directly in the field. This served as the basis for assessing the level of suitability and representativeness of the exponential model in relation to the observed rainfall phenomena.

The observation data was compiled in a table representing the relationship between observation time and rainfall height, then transformed into rainfall intensity data. The accuracy level of the exponential model was validated using the Mean Absolute Percentage Error (MAPE) indicator as formulated in the study (Aini et al., 2022):

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n} \left|\frac{t_i^{obs} - t_i^{model}}{t_i^{obs}}\right|$$

Where t_i^{obs} denotes the observed rainfall intensity time and t_i^{model} represents the predicted rainfall intensity time. MAPE is used as a measure to evaluate model performance. MAPE was chosen based on its ability to present the error rate in an easily interpretable percentage form and its independence from the data scale, making it relevant for regression analysis and model prediction. With these characteristics, MAPE is considered suitable for comparing model performance on data sets with different value ranges (Nuha, 2024). Furthermore, MAPE values are classified into several categories as shown in the following table.

Table 1 MAPE Categories

MAPE value	Criteria
< 10%	Very Good
10% - 20%	Good
20% - 50%	Enough
> 50%	Bad

Research Results and Discussion

This study is based on three rainfall events observed with different characteristics. The analysis focuses on the phase of rainfall intensity decrease, which is modeled using an exponential model to predict the time of rainfall cessation. The main parameters analyzed include maximum rainfall intensity (r_0), rainfall intensity decay constant (k), theoretical rainfall cessation time (t_{stop}), and prediction error rate evaluated using Mean Absolute Percentage Error (MAPE).

Table 2 Observation Data 1

Time ($minute$)	Height (cm)	Rainfall Intensity ($mm/minute$)
0	0	0
5	0.1	0.2
10	0.5	0.8
15	1	1
20	1.7	1.4
25	2.3	1.2
30	2.6	0.6

Based on Table 2, in the first observation, the rainfall intensity reached its maximum value at the 20th minute with a peak intensity of $r_0 = 1.4\, mm/minute$. The decay constant calculation resulted in a value of $k = 0.0578\, minute^{-1}$, so that the theoretical time of rainfall cessation predicted based on the model occurred at the 65th

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minute. However, based on actual rainfall observation data, the rain stopped at the 71st minute. Thus, there is a 6-minute difference between the modeling results and the actual conditions. Model validation using MAPE produced a value of 1.32%, indicating that the exponential decay model was able to represent the pattern of rainfall intensity decline in this observation with a good level of accuracy. These results indicate that the assumption of a monotonic decrease in rainfall intensity is relatively fulfilled. The exponential decay pattern in this observation is presented in the following graph.

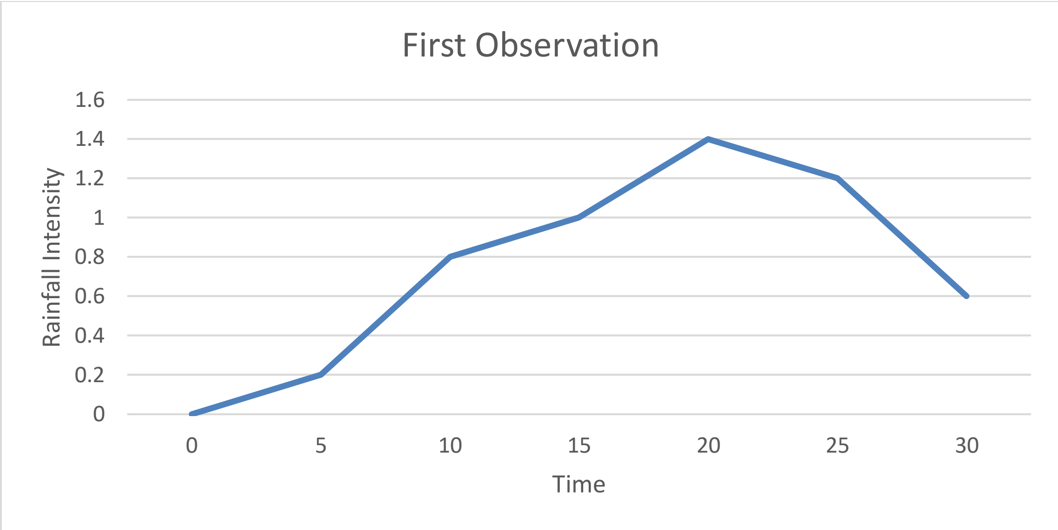

Figure 1

Table 3 Observation Data 2

Time ($minute$)	Height (cm)	Rainfall Intensity ($mm/minute$)
0	0	0
3	0.3	1
6	1	2.3
9	1.7	2.3
12	2.4	2.3
15	2.9	1.6
18	3.3	1.3
21	3.4	0.3

Based on Table 3, in the second observation, the rainfall intensity reached its maximum value at the 12th minute, resulting in an initial intensity value of $r_0 = 2.3\, mm/minute$. The model parameter calculation resulted in a value of $k = 0.1475\, minute^{-1}$, which produced a theoretical prediction of the time of rainfall cessation at the 33rd minute. However, based on field observations, the rain stopped at the 41st minute. Thus, there is a relatively larger difference between the predicted time of rainfall cessation and the observation results compared to the first observation. The MAPE value of 2.10% is relatively low, but it still indicates that the variation in rainfall intensity after reaching its peak does not fully follow the ideal exponential decay pattern. The exponential decay pattern in the second observation is shown in the following graph.

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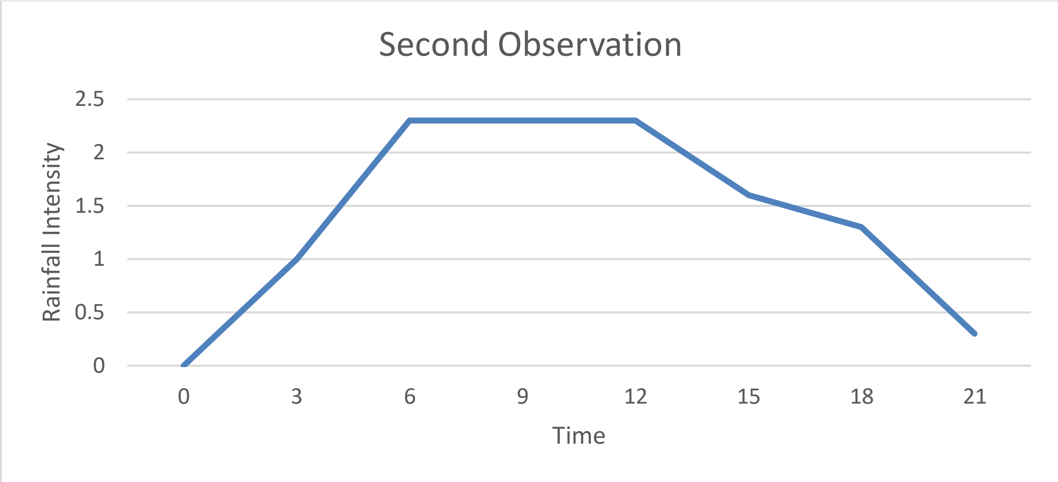

Figure 2

Table 4 Observation Data 3

Time ($minute$)	**Height** (cm)	**Rainfall Intensity** ($mm/minute$)
0	0	0
11	0.3	0.27
22	0.5	0.18

Based on Table 3, in the third observation, the rainfall intensity reached its maximum value at the 11th minute with an initial intensity of $r_0 = 0.27\ mm/minute$. The calculation results show a value of $k = 0.0369\ minute^{-1}$, so that the theoretical time of rainfall cessation is predicted to occur at the 37th minute. However, based on the observation data, the rainfall stopped at the 33rd minute, resulting in a time difference of 4 minutes, where the prediction tends to be slower than the actual condition. Nevertheless, the MAPE value of 3.64% is still below the tolerance limit of 10%, indicating that the exponential model performs adequately in predicting the duration of rainfall in this observation, even though the amount of data after the maximum intensity is relatively limited. The exponential decay pattern in the third observation is shown in the following graph.

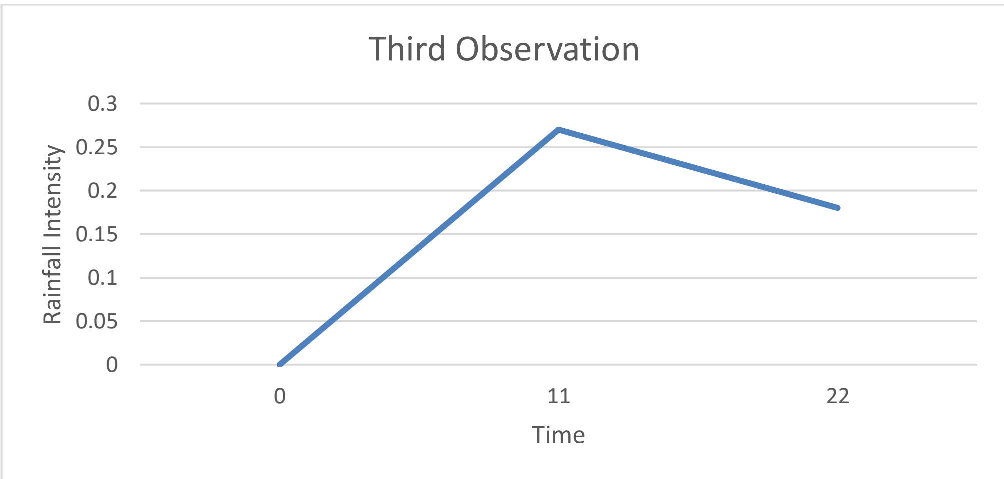

Figure 3

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The results of this study indicate that the rainfall intensity decay constant (k) varies between observations, reflecting differences in the rate of decline in rainfall intensity after reaching its maximum value. The variability in k values indicates that rainfall characteristics are not vary between events. This finding is in line with the results of Creaco (2025) study, which states that rainfall patterns generally show heterogeneity. In addition, Zhang & Qian (2025) report that the temporal distribution of rainfall intensity in various types of rainfall events shows significant differences, particularly in the intensity structure during the rainfall event.

The highest k value obtained in the second observation indicates that rainfall events with higher peak intensity tend to experience a faster decline in intensity. This pattern is consistent with the characteristics of high-intensity rainfall, which generally exhibits a sharp decay phase when modeled using an exponential approach, as reported in a study by Alrweili (2024). Conversely, in the third observation, although the peak intensity was relatively high, the resulting k value was the smallest, reflecting a slower rate of decline in rainfall intensity.

Exponential models tend to show lower accuracy when rainfall intensity fluctuates significantly after reaching its peak value, or when the observation period is relatively short. This condition is in line with the findings in a study of stochastic rainfall modeling, which reported that simple mathematical models have limitations in representing the complex dynamics of rainfall, as reported by Onof & Wang (2020).

However, the MAPE values obtained from the three models in this study were below 10%, indicating a relatively high and consistent level of model accuracy. These findings differ from the results of Irwan et al. (2023), who applied an exponential decay model and reported MAPE values that varied between observations. This difference shows that although the exponential model is effective as an initial approach in rainfall intensity modeling, the application of more complex methods is still necessary to represent fluctuating rainfall patterns and produce more realistic predictions.

Based on these results and discussions, it is clear that the exponential concept is quite effective in representing natural phenomena quantitatively. Meanwhile, in mathematical modeling, it can be used as an additional reference so that it can be developed to be more complex and accurate when the data obtained does not show a high level of variability or patterns that do not fully meet the assumptions of exponential decay. These findings have important implications for mathematics learning, namely that students can learn exponential concepts through everyday life, making learning more contextual and meaningful. Thus, students can understand that exponential models are not just formulas but tools for analyzing and predicting natural phenomena such as rainfall and realize the importance of mathematics in everyday life. In addition, the process of data processing, modeling, and application encourages the development of students' critical thinking and analytical skills.

CONCLUSION

This study shows that the exponential model can be used to predict the duration of ongoing rainfall at SMAN 1 Sukapura. This model is able to describe the decrease in

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rainfall intensity over time through a decay constant (k). Calculations for several rainfall events show that the exponential model can represent rainfall patterns systematically and accurately.

This study has several limitations, namely that the rainfall data used is still limited, so that the decay constant (k) is greatly influenced by changing atmospheric conditions, such as clouds, temperature, wind, and humidity. The exponential model applied assumes a relatively simple rainfall pattern. Meanwhile, rainfall phenomena in actual conditions can show more complex temporal variations and dynamics. The calculation process was done manually, so there is the potential for errors in the calculations. Further research could use more diverse rainfall data and longer observation periods to make the modeling results more accurate. The exponential model could also be developed using other methods to describe more complex rainfall patterns. In addition, computer-based calculations or applications could be developed to make the calculation process faster and more practical.

In the context of mathematics education, this study shows that exponential functions are not only abstract concepts, but can also be used to model real phenomena. This model can be used as a learning project so that students can learn exponential functions through contextual problems such as rainfall in the surrounding environment. Thus, exponential models become examples of the application of mathematics in everyday life to help students gain a deeper understanding of exponential material.

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