



Environmental rainfall baseline and climate-responsive stormwater planning for peri-urban residential development

Zul Janwar^{1,*}, Zulkarnain², Hajrah²

¹ Department of Environmental Engineering, Universitas Syekh Yusuf Al Makassar Gowa, Gowa, South Sulawesi 92111, Indonesia;

² Department of Biology, Faculty of Science and Technology, Universitas Islam Negeri Alauddin Makassar, Makassar, South Sulawesi 90222, Indonesia.

*Correspondence: zuljanwar6@gmail.com

Received Date: June 23, 2026

Revised Date: July 25, 2026

Accepted Date: August 17, 2026

ABSTRACT

Background: Peri-urban residential expansion in tropical Indonesia increasingly requires environmental baselines that connect routine climatic evidence with practical stormwater planning. This article develops a decadal rainfall baseline for the planned Sunville Residence area in Paccinongang, Somba Opu District, Gowa Regency, South Sulawesi, using a 2015-2024 monthly precipitation matrix extracted from NASA POWER data. **Methods:** The study applies descriptive climatology, interannual variability analysis, Schmidt-Ferguson wet-dry month classification, and Oldeman agroclimatic interpretation. Annual and monthly rainfall were summarized to identify seasonal concentration, wet and dry month structure, and planning-relevant hydrological implications. **Findings:** Mean annual rainfall reached 2,178.64 mm, with substantial interannual variability from 1,345.22 mm in 2019 to 2,955.56 mm in 2022. The rainfall regime was strongly seasonal, with December, January, February, November, and March forming the main wet-season core, while July to September represented the driest period. Using direct rainfall thresholds, the mean number of wet months was 7.3 and dry months was 3.2, producing a Schmidt-Ferguson Q value of 43.84%, which places the site in type C or moderately wet climate. Oldeman interpretation of the monthly climatological pattern indicates a C3-type agroclimate, characterized by approximately five wet months and four dry months. **Conclusion:** The baseline indicates that the site is not climatically dry; rather, its environmental risk is shaped by high wet-season water input, pronounced seasonality, and the possibility of rapid runoff if land conversion increases impervious cover. **Novelty/Originality of this article:** The article translates a project-level rainfall dataset into an international-style environmental planning approach by linking climate classification, peri-urban land conversion, and stormwater-sensitive design recommendations for a specific Indonesian residential development context.

KEYWORDS: environmental assessment; green infrastructure; oldeman; peri-urban development; rainfall baseline.

1. Introduction

Peri-urban residential development can substantially alter local hydrological processes by replacing open and permeable land with roofs, roads, compacted surfaces, and engineered drainage systems (Braud et al., 2013). Such land-cover changes reduce infiltration and can increase runoff even where rainfall itself does not exhibit a significant long-term increase (Sasongko et al., 2024). This issue is particularly relevant in tropical

Cite This Article:

Janwar, Z., Zulkarnain, & Hajrah. (2026). Environmental rainfall baseline and climate-responsive stormwater planning for peri-urban residential development. *EcoVision: Journal of Environmental Solutions*, 3(2), 201-215. <https://doi.org/10.61511/evojes.v3i1.2026.3894>

Copyright: © 2026 by the authors. This article is distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).



monsoonal environments, where rainfall is strongly concentrated within particular months and seasonal water surpluses may coincide with rapid urban expansion (Pramono et al., 2026). The present study focuses on the planned Sunville Residence development in Paccinongang Village, Somba Opu District, Gowa Regency, South Sulawesi, located within the rapidly developing Makassar metropolitan fringe. The site therefore provides a relevant case for examining how a project-level rainfall baseline can inform climate-responsive stormwater planning. The current manuscript identifies this location and its peri-urban development context as the empirical basis of the study.

Rainfall baseline analysis is important because annual rainfall totals alone may not adequately represent the hydrological conditions relevant to development planning (Darnkachatarn & Kajitani, 2024). Seasonal distribution, wet- and dry-month frequency, and interannual variability can influence runoff generation, construction-phase erosion, drainage performance, and the feasibility of infiltration- or storage-based measures (Brown et al., 2024). This is especially important where development increases impervious cover, because hydrological risk may rise through land-use change even without a statistically significant increase in rainfall (Ongaga et al., 2024). Accordingly, rainfall information should be interpreted not merely as descriptive climatic background but as an environmental baseline that can support early-stage stormwater planning (Darnkachatarn & Kajitani, 2024).

For this purpose, climatic classification can provide a practical interpretation of seasonal rainfall structure (Surya et al., 2021). The Schmidt–Ferguson classification describes the relative occurrence of wet and dry months, whereas the Oldeman system characterizes sequences of wet and dry conditions (Ridahwati, 2021). Although these classifications were originally developed mainly for climatological and agroclimatic interpretation, they can also help communicate whether a peri-urban site is dominated by wet-season surplus, dry-season limitation, or a mixed seasonal regime (Latos et al., 2021). In this study, they are used as planning-level interpretive tools rather than hydraulic design methods, complementing descriptive analysis of a 2015–2024 monthly rainfall dataset derived from NASA POWER. The current Methods similarly defines the analysis as an environmental baseline rather than a substitute for detailed hydrological and hydraulic design (Sanusi & Abdy, 2021).

Against this background, the study addresses the gap between project-level rainfall datasets and their practical interpretation for peri-urban stormwater planning. Specifically, it asks three research questions: 1) What is the decadal rainfall profile of the planned peri-urban residential development site? 2) How is the rainfall regime classified using Schmidt–Ferguson and Oldeman approaches? and 3) What planning-level implications does the observed rainfall regime have for climate-responsive stormwater management in peri-urban residential development? By addressing these questions, the study aims to translate routine rainfall information into a structured environmental baseline that supports early-stage assessment and stormwater-sensitive planning without extending the analysis beyond the limits of the available monthly rainfall data.

2. Methods

2.1 Research design and data source

This study used a descriptive quantitative design based on secondary climatic data. The analysis was developed from a monthly rainfall matrix for the period 2015–2024, obtained from NASA POWER and compiled for the planned Sunville Residence area in Paccinongang, Somba Opu District, Gowa Regency. NASA POWER provides solar and meteorological data derived from satellite observations and assimilation products for energy, infrastructure, and agroclimatology applications (Marzouk, 2021). For precipitation, the POWER system uses higher-resolution products derived from the Global Precipitation Measurement (GPM) mission and the Integrated Multi-satellitE Retrievals for GPM (IMERG), with a global 0.1° latitude by 0.1° longitude grid for relevant precipitation services (Marzouk, 2021). The use

of remotely sensed gridded rainfall is appropriate for baseline screening in areas where continuous station data may be limited, although project-level design should ideally be supported by local rain-gauge validation and design storm analysis.

2.2 Study area and period analysis

The study area was defined by the coordinates and administrative description in the project climate dataset: Paccinongang Village, Somba Opu District, Gowa Regency, South Sulawesi, Indonesia. The broader district is located in the southern part of the Makassar urban region and is influenced by monsoonal rainfall dynamics. The uploaded project file states that the rainfall matrix was used to characterize the initial climate condition of the planned residential development site. It also indicates that NASA-based climate data were used for multiple parameters, including rainfall, air temperature, relative humidity, wind speed, and surface wind direction, while the present article focuses on rainfall because precipitation is the most direct climatic driver of runoff, erosion, site drainage, and construction-phase sediment control. The period 2015-2024 was selected because a ten-year record provides a recent decadal baseline for environmental screening and satisfies the minimum temporal logic commonly used in local climate classification exercises, although it remains shorter than the thirty-year climatological normal recommended for formal climate-normal calculation (Apriyana et al., 2021).

2.3 Data processing and rainfall variability analysis

The data were organized into a year-by-month matrix containing twelve monthly rainfall values for each year. Annual rainfall was calculated as the sum of the 12 monthly totals. Monthly climatology was calculated as the arithmetic mean of the same month across the ten-year period. Interannual variability was summarized using minimum, maximum, mean, standard deviation, and coefficient of variation (Marzuki et al., 2025; Mehta et al., 2022). A linear regression diagnostic was applied to annual rainfall as an exploratory trend test, with year as the independent variable and annual rainfall as the dependent variable. Kendall tau was also calculated as a non-parametric indication of monotonic tendency. Because the record is only ten years, statistical trend results were interpreted cautiously and were not used to claim long-term climate change. The purpose of the trend diagnostic was to identify whether the decadal baseline showed an obvious directional tendency that should influence environmental interpretation (Marzuki et al., 2025; Mehta et al., 2022).

2.4 Schmidt-Ferguson climate classification

Schmidt-Ferguson classification was applied by categorizing each monthly rainfall value into three classes: dry month when rainfall is less than 60 mm, humid month when rainfall is 60-100 mm, and wet month when rainfall is greater than 100 mm. The Q value was then calculated as the ratio between the mean number of dry months and the mean number of wet months, multiplied by 100. The formula is expressed as follows: $Q = (M_d/M_f) \times 100$, where M_d is the average number of dry months and M_f is the average number of wet months. The resulting percentage was interpreted using the common Schmidt-Ferguson scale: type A very wet, type B wet, type C moderately wet, type D moderate, type E moderately dry, type F dry, type G very dry, and type H extremely dry. This method is useful for classifying the broad humidity character of a location, but it does not replace hydrological modeling for drainage design (Yasa et al., 2022).

$$Q = (M_d/M_f) \times 100 \quad (\text{Eq. 1})$$

2.5 Oldeman agroclimatic classification

Oldeman classification was applied using monthly climatological rainfall. In the Oldeman framework, a wet month is commonly defined as rainfall greater than 200 mm and a dry month as rainfall less than 100 mm. The classification emphasizes the number of consecutive wet and dry months because crop water availability depends not only on total rainfall but also on the continuity of rainfall across growing periods. Although the study site is intended for residential development, Oldeman classification is retained because the existing environmental context includes peri-urban land that may still perform agricultural and infiltration functions. The interpretation also helps identify the seasonal windows during which construction works, erosion control, soil exposure, and drainage maintenance require special attention. For example, wet-month sequences indicate periods when open soil and unfinished drainage are most vulnerable to erosion, while dry-month sequences indicate periods when dust, water scarcity, and vegetation establishment may require management (Grimm et al., 2024).

2.6 Stormwater planning interpretation

The study also translated rainfall findings into environmental planning implications using a stormwater-sensitive design lens. This translation was qualitative and evidence-based rather than a full hydraulic design exercise. The analysis considered how rainfall seasonality could affect runoff generation, detention needs, infiltration feasibility, maintenance timing, and the selection of blue-green infrastructure. The interpretation was informed by international literature on low-impact development, sustainable urban drainage systems, nature-based solutions, and green infrastructure (Alves et al., 2024; Palermo et al., 2023). The study did not calculate design rainfall intensity, peak discharge, or channel capacity because the uploaded rainfall dataset consisted of monthly totals rather than sub-daily or daily maximum rainfall. Therefore, the results should be understood as an environmental baseline and planning framework, not as a substitute for detailed hydrological and hydraulic design (Alves et al., 2024; Palermo et al., 2023).

3. Results and Discussion

3.1 Results

3.1.1 Annual rainfall variability

To characterize the climatic conditions relevant to residential development, annual rainfall variability was assessed over a ten-year period (2015–2024). The analysis considers both total annual rainfall and the monthly distribution of wet, humid, and dry conditions, as these indicators provide a more informative representation of water availability and seasonal rainfall patterns than annual totals alone. The classification of wet months (> 100 mm), humid months (60–100 mm), and dry months (< 60 mm) was used to identify the seasonal structure of rainfall at the study site. The resulting annual rainfall totals and monthly classifications are presented in Table 1.

Table 1. Annual rainfall and wet-dry month summary for the study site, 2015–2024

Year	Annual rainfall (mm)	Wet months (> 100 mm)	Humid months (60–100 mm)	Dry months (< 60 mm)
2015	1,822.21	6	0	6
2016	1,972.75	8	2	2
2017	2,160.48	8	1	3
2018	1,921.62	6	1	5
2019	1,345.22	5	0	7
2020	2,230.44	8	2	2
2021	2,809.98	8	4	0
2022	2,955.56	9	2	1
2023	1,745.94	7	2	3

2024	2,822.21	8	1	3
Mean	2,178.64	7.3	1.5	3.2

The ten-year rainfall matrix shows that the planned residential development site is located in a water-rich but seasonally structured environment. Mean annual rainfall for 2015-2024 was 2,178.64 mm, with a standard deviation of 530.90 mm and a coefficient of variation of approximately 24.37%. This level of variability is meaningful for environmental planning because a drainage system designed only around the average year may underperform during very wet years, while a construction and landscape plan designed only around dry-season convenience may fail to anticipate wet-season erosion and sedimentation. The wettest year in the record was 2022 with 2,955.56 mm, followed closely by 2024 with 2,822.21 mm and 2021 with 2,809.98 mm. The driest year was 2019 with 1,345.22 mm. The difference between the wettest and driest years reached 1,610.34 mm, demonstrating that the site can experience large year-to-year variation even within a short decadal window.

The temporal pattern of annual rainfall is further illustrated in Figure 1, which provides a visual comparison of rainfall fluctuations across the study period. The figure highlights the contrast between relatively wet and dry years and illustrates the non-uniform rainfall pattern that characterizes the study site. Such temporal variability is important for interpreting the site's hydrological conditions, particularly in relation to the planning of drainage infrastructure, erosion control, and other measures intended to maintain environmental resilience under differing rainfall conditions.

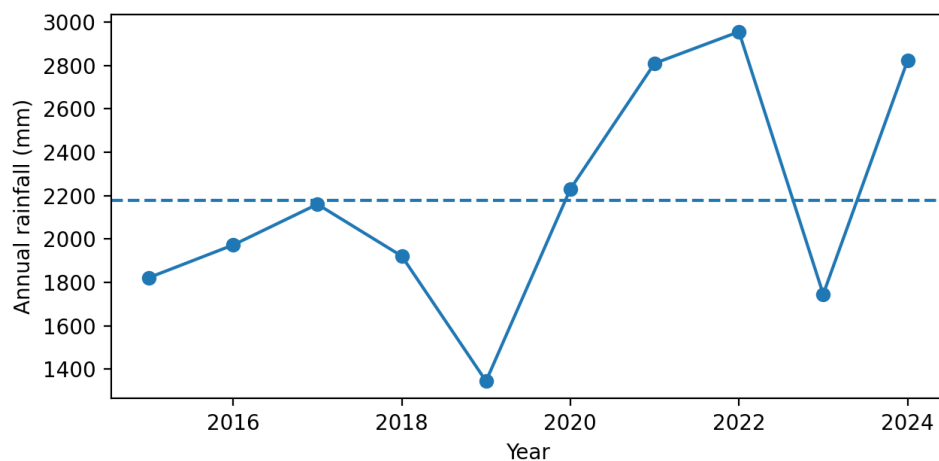


Fig. 1. Annual rainfall variability at the study site, 2015-2024

3.1.2 Exploratory trend diagnostics

Exploratory trend diagnostics showed a positive annual rainfall slope of approximately 90.53 mm per year over 2015-2024. However, this apparent increase was not statistically significant at the 0.05 level in the simple linear regression diagnostic ($p = 0.127$), and Kendall tau likewise did not indicate a statistically significant monotonic trend ($\tau = 0.378$; $p = 0.156$). These results should not be interpreted as evidence that rainfall is stable in the long term, because a ten-year sample is insufficient for robust climate-change detection. Rather, the result indicates that the project baseline is best interpreted as a recent variability profile. In planning terms, the absence of a significant decadal trend does not reduce the need for caution: urban hydrological risk can increase through land conversion alone, even when rainfall totals do not significantly increase (Ongaga et al., 2024).

3.1.3 Monthly rainfall climatology

The monthly rainfall climatology was further examined to identify the seasonal distribution and magnitude of rainfall variability throughout the year. Monthly mean

rainfall and standard deviation were calculated for each month during 2015–2024 and classified according to the Oldeman rainfall classification. This analysis provides a clearer basis for identifying the months with relatively high rainfall and greater variability, as well as the period of pronounced dry-season conditions, which are important for assessing seasonal water availability, drainage requirements, and environmental risks associated with residential development. The monthly rainfall characteristics and corresponding climatological classes are presented in Table 2.

Table 2. Monthly rainfall climatology and variability, 2015-2024

Month	Mean rainfall (mm)	Standard deviation (mm)	Climatological class
Jan	367.06	82.21	Oldeman wet
Feb	295.05	84.03	Oldeman wet
Mar	236.58	65.88	Oldeman wet
Apr	180.99	64.49	Oldeman moist
May	108.32	110.07	Oldeman moist
Jun	91.06	31.93	Oldeman dry
Jul	54.96	43.19	Oldeman dry
Aug	23.06	29.12	Oldeman dry
Sep	34.12	36.50	Oldeman dry
Oct	114.46	122.89	Oldeman moist
Nov	268.01	217.77	Oldeman wet
Dec	404.97	152.24	Oldeman wet

The seasonal pattern is clear. December had the highest mean monthly rainfall at 404.97 mm, followed by January at 367.06 mm, February at 295.05 mm, November at 268.01 mm, and March at 236.58 mm. These months form the main wet-season core. April remained high at 180.99 mm and October showed a transitional recovery at 114.46 mm. In contrast, August was the driest month with a mean of 23.06 mm, followed by September at 34.12 mm and July at 54.96 mm. The pattern indicates a monsoonal regime in which most annual water input occurs from November to March, with a low-rainfall window from July to September. Such seasonality is consistent with broader rainfall characteristics in parts of South Sulawesi and the Makassar region, where wet-season months are generally concentrated in the late and early parts of the calendar year (Hutauruk et al., 2026).

The monthly rainfall distribution is visualized in Figure 2 to further clarify the seasonal concentration and transition between wet and dry periods. The figure illustrates the pronounced contrast between the high-rainfall months at the beginning and end of the year and the substantially lower rainfall during the middle of the year. This visual pattern complements the monthly climatological statistics and facilitates interpretation of the timing and intensity of seasonal rainfall conditions relevant to water management and residential development planning.

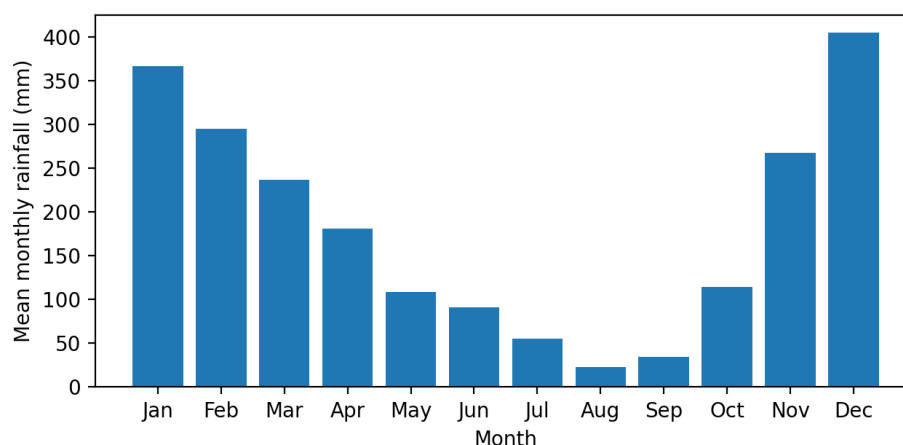


Fig. 2. Monthly rainfall climatology showing wet-season concentration and dry-season minimum

3.1.4 Schmidt-Ferguson classification result and Oldeman agroclimatic classification result

The Schmidt–Ferguson classification was applied to further characterize the rainfall regime of the study site by examining the relative frequency of wet and dry months over the 2015–2024 observation period. Unlike annual rainfall totals, which describe the overall amount of precipitation received, this classification emphasizes the seasonal distribution of rainfall and therefore provides additional information on the temporal structure of water availability. The frequency of wet and dry months is particularly relevant for environmental and residential development planning because prolonged wet periods may increase surface runoff, drainage demand, and erosion potential, whereas extended dry periods may affect soil moisture and landscape water requirements. Figure 3 presents the average number of wet and dry months identified during the study period, providing a visual basis for understanding the seasonal balance used in calculating the Schmidt–Ferguson climatic quotient (Q) and determining the corresponding climate type.

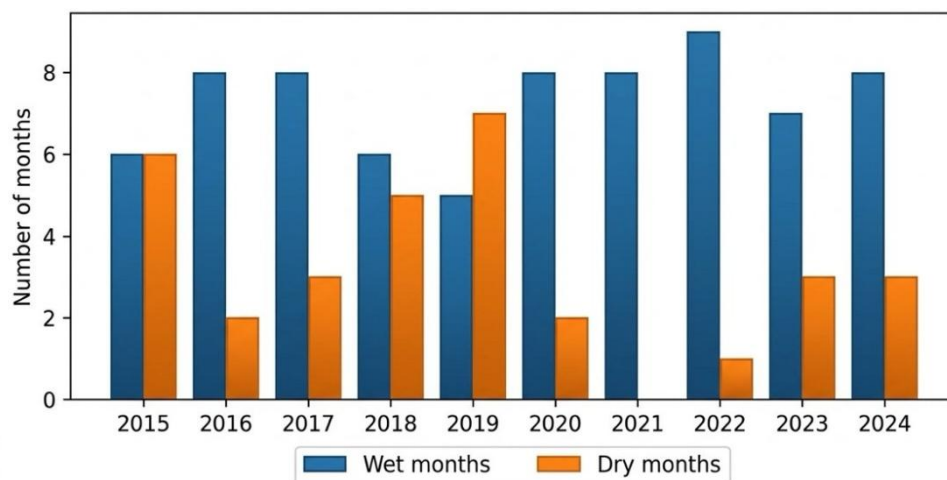


Fig. 3. Wet and dry month frequency used for Schmidt-Ferguson interpretation

The classification produced an average of 7.3 wet months and 3.2 dry months per year, resulting in a Q value of 43.84%. This places the site within climate type C, commonly interpreted as moderately wet or rather wet. The project classification table reported a Q value of 45.21%, which falls within the same type C interval; therefore, the small numerical difference does not alter the climatic classification. The type C classification indicates that the site should neither be treated as dry land where stormwater is a minor concern nor as continuously wet throughout the year. Instead, it represents a seasonally wet tropical environment in which rainfall management must address both wet-season water surplus and dry-season conditions. Such a rainfall regime supports an integrated planning approach that combines drainage capacity, runoff control, erosion prevention, and landscape management rather than relying solely on conventional drainage infrastructure (Ardana et al., 2025; Li et al., 2024).

The Oldeman interpretation of the monthly climatological pattern indicates approximately five wet months, using the greater-than-200 mm criterion, and four dry months, using the less-than-100 mm criterion. This places the area in a C3-type agroclimatic condition. In agricultural terms, C3 is generally associated with the possibility of one rice crop and two secondary crops, with caution for the second secondary crop because it may overlap with dry months. For environmental planning, the significance of C3 lies not in crop recommendation but in water-balance interpretation. The site has enough wet-season rainfall to create substantial surface water input, yet it also has a dry-season interval long enough to affect soil moisture, vegetation survival, and the reliability of shallow infiltration systems. Residential landscaping and green infrastructure should therefore be designed for both inundation tolerance and dry-season resilience (Wainwright et al., 2021).

Table 3. Climate classification results from the decadal rainfall baseline

Classification	Indicator	Result	Interpretation
Schmidt-Ferguson	Mean wet months; mean dry months; Q	Mf = 7.3; Md = 3.2; Q = 43.84%	Type C/moderately wet
Oldeman	Wet months > 200 mm; dry months < 100 mm	5 wet months; 4 dry months	C3 agroclimatic condition
Planning interpretation	Seasonality	Wet peak in Nov- Mar; dry minimum in Jul-Sep	Drainage, retention, erosion control, and dry-season landscape resilience must be integrated

3.2 Discussion

3.2.1 Rainfall variability and seasonal characteristics

The rainfall baseline demonstrates that the study area experiences substantial precipitation combined with pronounced interannual and seasonal variability, both of which are important for environmental assessment and stormwater planning. Mean annual rainfall during 2015–2024 was 2,178.64 mm, with a standard deviation of 530.90 mm and a coefficient of variation of 24.37%. Annual totals ranged from 1,345.22 mm in 2019 to 2,955.56 mm in 2022, producing a difference of 1,610.34 mm between the driest and wettest years. This broad range confirms that year-to-year rainfall conditions can differ considerably, meaning that reliance on mean annual rainfall alone may obscure hydrologically important variability and potentially underestimate wet-year runoff pressures, erosion risks, and drainage demands.

Although the annual rainfall series showed an exploratory positive slope of approximately 90.53 mm year⁻¹, the statistical tests did not confirm a significant temporal trend. Linear regression produced $p = 0.127$, while Kendall's tau yielded $\tau = 0.378$ with $p = 0.156$. Consequently, the apparent upward tendency should not be interpreted as evidence of a sustained increase in precipitation. Instead, the ten-year dataset is more appropriately used to characterize recent rainfall variability and seasonal behavior. This distinction is important because a decadal record provides a useful project-level environmental baseline for this rapidly developing peri-urban site, but it remains too short to support robust attribution of long-term climatic change. Accordingly, the numerical results should inform planning-level stormwater interpretation while maintaining caution regarding climate-trend conclusions (Grimm et al., 2024; Ridahwati, 2021).

3.2.2 Wet-season rainfall and stormwater implications

Monthly rainfall exhibits a pronounced wet-season concentration from November to March, indicating that a substantial proportion of annual precipitation occurs within a relatively short seasonal window. December recorded the highest mean monthly rainfall at 404.97 mm, followed by January (367.06 mm), February (295.05 mm), November (268.01 mm), and March (236.58 mm). This seasonal concentration has important implications for environmental management and stormwater planning at the proposed development site. First, construction activities involving exposed soil, excavation, grading, and unfinished drainage systems are likely to be most vulnerable to erosion, sediment mobilization, and surface runoff during these months. Accordingly, construction scheduling should account for the identified wet-season period, particularly for activities that disturb large areas of soil. Measures such as staged earthworks, temporary sediment barriers, rapid stabilization of disturbed surfaces, protected stockpiles, and post-rainfall inspections are therefore particularly relevant during November–March (Grimm et al., 2024; Ridahwati, 2021).

Second, the magnitude and concentration of wet-season rainfall support consideration of temporary storage, infiltration, retention, and safe conveyance measures within the site

to reduce uncontrolled runoff. However, these findings should be interpreted strictly as planning-level implications rather than hydraulic design specifications (Ongaga et al., 2024). The monthly NASA POWER dataset does not provide information on rainfall intensity, storm duration, peak discharge, or channel capacity required for drainage sizing. Consequently, monthly rainfall totals can support preliminary environmental planning and seasonal risk identification but cannot substitute for detailed hydrological and hydraulic analyses using higher-temporal-resolution rainfall data and site-specific drainage characteristics (Palermo et al., 2023).

3.2.3 Dry-season characteristics and climate classification

The rainfall regime also contains a clearly defined dry-season component. Mean monthly rainfall declined to 54.96 mm in July, 23.06 mm in August, and 34.12 mm in September, making July–September the driest period of the annual cycle. This pronounced seasonal contrast indicates that stormwater planning should not focus exclusively on the management of wet-season runoff. Vegetated and infiltration-based stormwater measures must also remain functional during substantially drier periods, when reduced rainfall may affect soil moisture, vegetation condition, and the performance of nature-based drainage components. Consequently, plant selection, soil characteristics, infiltration capacity, and maintenance requirements should be considered in relation to both seasonal extremes.

The climate classifications reinforce this interpretation. The Schmidt–Ferguson analysis produced an average of 7.3 wet months and 3.2 dry months, corresponding to $Q = 43.84\%$ and a Type C, moderately wet climate. The Oldeman analysis identified approximately five wet months and four dry months, corresponding to a C3 agroclimatic condition. Together, these classifications describe a seasonal rainfall regime characterized by substantial wet-season water input combined with a distinct dry-season interval (Öztürk et al., 2024). The relevance of these classifications to residential stormwater planning is not that they provide direct engineering design parameters. Rather, they offer an interpretable description of seasonal water availability and climatic structure. This information supports planning strategies that combine effective wet-season runoff control with the dry-season resilience of vegetated, infiltration-based, and other climate-responsive stormwater measures.

3.2.4 Implications for climate-responsive stormwater planning

The main planning implication of the rainfall baseline is the need to accommodate both high wet-season inputs and pronounced seasonal variability within the proposed residential development. The mean annual rainfall of more than 2,000 mm, together with a 24.37% coefficient of variation and the concentration of rainfall during November–March, indicates that stormwater management should not rely solely on rapid conveyance through conventional drainage systems. Instead, a more distributed approach to runoff management should be considered so that rainfall can be temporarily stored, infiltrated, reused, or conveyed in a controlled manner across the site.

Potential measures include detention facilities, rainwater harvesting systems, vegetated swales, permeable surfaces, and infiltration-based practices where local site conditions are suitable. These approaches are consistent with stormwater-sensitive and nature-based strategies that aim to reduce runoff volumes, delay peak flows, and improve the overall resilience of urban drainage systems (Zhang et al., 2023). Their application may also help integrate drainage functions with landscape and environmental objectives within peri-urban residential areas.

However, the rainfall baseline alone does not determine the appropriate dimensions, locations, capacities, or expected performance of these measures. Such design decisions require additional site-specific information, including soil permeability, topography, existing and proposed land cover, drainage-network capacity, runoff coefficients, groundwater conditions, and rainfall intensity characteristics (Zhou et al., 2024). Therefore,

the present findings should be used to guide early-stage planning and measure selection, while detailed hydrological and hydraulic analyses are still required before final engineering design and implementation.

3.2.5 Study limitation

This study has several limitations that should be considered when interpreting the findings. First, the rainfall analysis was based on a ten-year record covering 2015–2024. Although this period is useful for characterizing recent rainfall variability and establishing a project-level environmental baseline, it is shorter than the approximately 30-year period commonly used for formal climatological normals. Consequently, the observed interannual variability and trend diagnostics should not be interpreted as evidence of long-term climate change. The non-significant linear regression and Kendall's tau results therefore describe rainfall behavior only within the available decadal period (Kundzewicz & Robson, 2004).

Second, the rainfall dataset was obtained from NASA POWER and was not validated against concurrent observations from a representative local Meteorology, Climatology, and Geophysics Agency (*Badan Meteorologi, Klimatologi, dan Geofisika*, BMKG) ground-station rain gauge. Although gridded satellite- and reanalysis-based rainfall products are useful for environmental baseline screening, potential differences between NASA POWER estimates and local ground observations remain unquantified in this study (Urraca et al., 2018). This limitation is particularly important for site-specific engineering applications, because local rainfall bias may influence the estimation of design rainfall and runoff response. Accordingly, the NASA POWER dataset used here should be regarded as suitable for screening-level environmental assessment, while subsequent engineering studies should incorporate and, where possible, validate the rainfall series against local BMKG observations.

Third, the study relies on monthly rainfall totals, which are adequate for describing seasonal concentration, wet-dry month patterns, and recent interannual variability but cannot represent short-duration rainfall intensity, storm duration, extreme-event peaks, or temporal rainfall distributions that determine drainage performance (Rodrigues & Braga, 2021). In addition, the study did not quantitatively incorporate soil permeability, topography, land cover, imperviousness, groundwater conditions, runoff coefficients, drainage-network capacity, or downstream receiving conditions. Therefore, the results and proposed stormwater measures should be interpreted strictly as a planning-level (screening-level) assessment rather than a detailed hydrological or hydraulic design. The present analysis does not provide a basis for determining design discharge, detention volume, channel dimensions, or other engineering specifications, all of which require locally validated rainfall data together with detailed site-specific hydrological and hydraulic analysis (Prakasa & Utami, 2019).

3.2.6 Recommendations for future research

This study has several limitations that should be considered when interpreting the findings. First, the rainfall analysis was based on a ten-year record covering 2015–2024. Although this period is useful for characterizing recent rainfall variability and establishing a project-level environmental baseline, it is shorter than the approximately 30-year period commonly used for formal climatological normals. Consequently, the observed interannual variability and trend diagnostics should not be interpreted as evidence of long-term climate change. The non-significant linear regression and Kendall's tau results therefore describe rainfall behavior only within the available decadal period (Valdés-Pineda et al., 2016).

Second, the rainfall dataset was obtained from NASA POWER and was not validated against concurrent observations from a representative local BMKG ground-station rain gauge. Although gridded satellite- and reanalysis-based rainfall products are useful for environmental baseline screening, potential differences between NASA POWER estimates and local ground observations remain unquantified in this study. This limitation is

particularly important for site-specific engineering applications, because local rainfall bias may influence the estimation of design rainfall and runoff response. Accordingly, the NASA POWER dataset used here should be regarded as suitable for screening-level environmental assessment, while subsequent engineering studies should incorporate and, where possible, validate the rainfall series against local BMKG observations.

Third, the study relies on monthly rainfall totals, which are adequate for describing seasonal concentration, wet-dry month patterns, and recent interannual variability but cannot represent short-duration rainfall intensity, storm duration, extreme-event peaks, or temporal rainfall distributions that determine drainage performance. In addition, the study did not quantitatively incorporate soil permeability, topography, land cover, imperviousness, groundwater conditions, runoff coefficients, drainage-network capacity, or downstream receiving conditions. Therefore, the results and proposed stormwater measures should be interpreted strictly as a planning-level (screening-level) assessment rather than a detailed hydrological or hydraulic design. The present analysis does not provide a basis for determining design discharge, detention volume, channel dimensions, or other engineering specifications, all of which require locally validated rainfall data together with detailed site-specific hydrological and hydraulic analysis (Dharmayasa et al., 2022).

4. Conclusions

This study developed an environmental rainfall baseline for a planned peri-urban residential development in Paccinongang, Somba Opu District, Gowa Regency, using monthly rainfall data for 2015-2024. The analysis found a mean annual rainfall of 2,178.64 mm and strong seasonality, with the highest rainfall concentrated from November to March and the driest period occurring from July to September. The Schmidt-Ferguson classification places the site in type C, or a moderately wet climate, while the Oldeman interpretation indicates a C3 agroclimatic condition. These classifications show that the site has both wet-season water surplus and dry-season management needs.

The main environmental implication is that residential land conversion should be planned with stormwater sensitivity. Increased impervious cover can amplify runoff even if rainfall does not show a statistically significant upward trend. Therefore, the development should combine conventional drainage with distributed storage, infiltration, vegetated corridors, detention ponds, rainwater harvesting, erosion control, and a clear maintenance system. The rainfall baseline should be followed by detailed hydrological and hydraulic analysis using daily or sub-daily rainfall, local station validation, land-cover scenarios, runoff coefficients, soil infiltration testing, and drainage capacity assessment. The original contribution of this paper is the transformation of project-level rainfall data into an international-style environmental planning narrative that connects climate classification with practical stormwater design implications for peri-urban residential development in Indonesia.

Acknowledgment

The authors acknowledge PT Enviro Celebes Konsultan for providing access to the database and supporting information required for this study. Appreciation is extended to the Government of Gowa Regency for its support and facilitation during the research process. The authors further acknowledge the institutional support, coordination, and administrative assistance provided by LPPM Universitas Halu Oleo, Institut Kesehatan dan Teknologi Buton Raya, and Institut Teknologi dan Kesehatan Tri Tunas Nasional. The contributions of all parties have supported the development, analysis, and completion of this manuscript.

Author Contribution

Conceptualization, Z.J. and Z.; Methodology, H.; Software, H.; Validation, Z., H., and Z.J.; Formal Analysis, Z.; Investigation, H.; Resources, Z.J.; Data Curation, Z.J.; Writing – Original

Draft Preparation, Z.J.; Writing – Review & Editing, Z.; Visualization, H.; Supervision, Z.J.; Project Administration, Z.J.; and Funding Acquisition, Z.J.

Funding

This research received no external funding.

Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available.

Data Availability Statement

Not available.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this manuscript draft, the authors used generative AI assistance to improve English academic structure and to format the manuscript according to the IASSSF template. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Open Access

©2026. The authors. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: <http://creativecommons.org/licenses/by/4.0/>

References

- Alves, R. A., Santos, M. M. dos, Rudke, A. P., Francisquetti Venturin, P. R., & Martins, J. A. (2024). Site selection for nature-based solutions for stormwater management in urban areas: An approach combining GIS and multi-criteria analysis. *Journal of Environmental Management*, 359, 120999. <https://doi.org/10.1016/j.jenvman.2024.120999>
- Aprilia, A., Wahidin, A. B., & Abdurrahman, A. F. (2025). Integration of machine learning and NASA POWER dataset for predicting coffee production in Lampung. *Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat*, 22(1), 44. <https://doi.org/10.20527/flux.v22i1.20980>
- Apriyana, Y., Surmaini, E., Estiningtyas, W., Pramudia, A., Ramadhani, F., Suciantini, S., Susanti, E., Purnamayani, R., & Syahbuddin, H. (2021). The integrated cropping calendar information system: A coping mechanism to climate variability for sustainable agriculture in Indonesia. *Sustainability*, 13(11), 6495. <https://doi.org/10.3390/su13116495>
- Ardana, P. D. H., Pamungkas, T. H., & Putra, I. G. A. A. (2025). Rainwater harvesting for drought disaster prevention in Seraya Village, Karangasem Regency, Bali Province, Indonesia. *Journal of the Civil Engineering Forum*, 11(1), 57–68. <https://doi.org/10.22146/jcef.12545>

- Braud, I., Fletcher, T. D., & Andrieu, H. (2013). Hydrology of peri-urban catchments: Processes and modelling. *Journal of Hydrology*, 485, 1–4. <https://doi.org/10.1016/j.jhydrol.2013.02.045>
- Brown, C. J. M., Noble, B. F., & Munkittrick, K. R. (2024). Examination of recent hydroelectric dam projects in Canada for alignment of baseline studies, predictive modeling, and postdevelopment monitoring phases of aquatic environmental impact assessments. *Integrated Environmental Assessment and Management*, 20(3), 616–644. <https://doi.org/10.1002/ieam.4823>
- Darnkachatarn, S., & Kajitani, Y. (2024). Long-term flood exposure assessment using satellite-based land use change detection and inundation simulation: A 30-year case study of the Bangkok Metropolitan Region. *Journal of Flood Risk Management*, 17(3), e12997. <https://doi.org/10.1111/jfr3.12997>
- Dharmayasa, I. G. N. P., Simatupang, C. A., & Sinaga, D. M. (2022). NASA POWER's: An alternative rainfall data resources for hydrology research and planning activities in Bali Island, Indonesia. *Journal of Infrastructure Planning and Engineering*, 1(1), 1–7. <https://doi.org/10.22225/jipe.1.1.2022.1-7>
- Grimm, A. G., Tirpak, R. A., & Winston, R. J. (2024). Monitoring the impacts of rainfall characteristics on sediment loss from road construction sites. *Environmental Science and Pollution Research*, 31(22), 32428–32440. <https://doi.org/10.1007/s11356-024-33361-3>
- Hutauruk, R., Hadi, T. W., Muharsyah, R., & Yolanda, S. (2026). Determining monsoon onset dates in Makassar using rainfall anomalies and moisture source trajectory analysis (1991–2020). *Jurnal Meteorologi dan Geofisika*, 26(2), 171–179. <https://doi.org/10.31172/jmg.v26i2.1162>
- Kundzewicz, Z. W., & Robson, A. J. (2004). Change detection in hydrological records—A review of the methodology. *Hydrological Sciences Journal*, 49(1), 7–19. <https://doi.org/10.1623/hysj.49.1.7.53993>
- Latos, B., Lefort, T., Flatau, M. K., Flatau, P. J., Permana, D. S., Baranowski, D. B., Paski, J. A. I., Makmur, E., Sulystyo, E., Peyrillé, P., Feng, Z., Matthews, A. J., & Schmidt, J. M. (2021). Equatorial waves triggering extreme rainfall and floods in Southwest Sulawesi, Indonesia. *Monthly Weather Review*, 149(5), 1381–1401. <https://doi.org/10.1175/MWR-D-20-0262.1>
- Li, J., Zeng, J., Huang, G., & Chen, W. (2024). Urban flood mitigation strategies with coupled gray–green measures: A case study in Guangzhou City, China. *International Journal of Disaster Risk Science*, 15(3), 467–479. <https://doi.org/10.1007/s13753-024-00566-6>
- Marzouk, O. A. (2021). Assessment of global warming in Al Buraimi, Sultanate of Oman based on statistical analysis of NASA POWER data over 39 years, and testing the reliability of NASA POWER against meteorological measurements. *Heliyon*, 7(3), e06625. <https://doi.org/10.1016/j.heliyon.2021.e06625>
- Marzuki, M., Ramadhan, R., Yusnaini, H., Vonnisa, M., Muharsyah, R., Nugraha, Y., Sari, A. Y., & Eralajita, A. (2025). Long-term spatial-temporal variability, trends and extreme rainfall events over Indonesia based on 43 years of CHIRPS data. *International Journal of Climatology*, 45(14). <https://doi.org/10.1002/joc.70107>
- Mehta, P., Jangra, M. S., Bhardwaj, S. K., & Paul, S. (2022). Variability and time series trend analysis of rainfall in the mid-hill sub humid zone: A case study of Nauni. *Environmental Science and Pollution Research*, 29(53), 80466–80476. <https://doi.org/10.1007/s11356-022-21507-0>
- Ongaga, C. O., Makokha, M., Obiero, K., Kipkemai, I., & Diang'a, J. (2024). Urbanization and hydrological dynamics: A 22-year assessment of impervious surface changes and runoff in an urban watershed. *Frontiers in Water*, 6, 1455763. <https://doi.org/10.3389/frwa.2024.1455763>
- Öztürk, Ş., Yılmaz, K., Dinçer, A. E., & Kalpakçı, V. (2024). Effect of urbanization on surface runoff and performance of green roofs and permeable pavement for mitigating urban floods. *Natural Hazards*, 120(13), 12375–12399. <https://doi.org/10.1007/s11069-024-06688-w>

- Palermo, S. A., Turco, M., Pirouz, B., Presta, L., Falco, S., De Stefano, A., Frega, F., & Piro, P. (2023). Nature-based solutions for urban stormwater management: An overview. *IOP Conference Series: Earth and Environmental Science*, 1196(1), 012027. <https://doi.org/10.1088/1755-1315/1196/1/012027>
- Prakasa, A., & Utami, F. D. (2019). Sistem informasi radar cuaca terintegrasi BMKG. *Journal of Telecommunication, Electronics, and Control Engineering (JTECE)*, 1(2), 78–87. <https://doi.org/10.20895/jtece.v1i02.89>
- Pramono, I. B., Basuki, T. M., Santosa, B. H., Nugroho, H. Y. S. H., Pratiwi, Purwanto, E., & Narendra, B. H. (2026). Hydrological consequences of land use/land cover change in Indonesia: Impacts, trends, and disaster mitigation. *Trees, Forests and People*, 25, 101291. <https://doi.org/10.1016/j.tfp.2026.101291>
- Ridahwati, R. (2021). Changes in rainfall and climate classification in South Sulawesi. *Journal La Lifesci*, 2(5), 37–50. <https://doi.org/10.37899/journallalifesci.v2i5.524>
- Rodrigues, G. C., & Braga, R. P. (2021). Evaluation of NASA POWER reanalysis products to estimate daily weather variables in a hot summer Mediterranean climate. *Agronomy*, 11(6), 1207. <https://doi.org/10.3390/agronomy11061207>
- Sanusi, W., & Abdy, M. (2021). Model runtun waktu curah hujan Kabupaten Gowa. *Indonesian Journal of Fundamental Sciences*, 7(2), 92–100. <https://doi.org/10.26858/ijfs.v7i2.26278>
- Sasongko, I., Gai, A. M., & Azzizi, V. T. (2024). Spatiotemporal dynamics of land use and community perception in peri-urban environments: The case of the intermediate city in Indonesia. *Urban Science*, 8(3), 97. <https://doi.org/10.3390/urbansci8030097>
- Surya, B., Salim, A., Hernita, H., Suriani, S., Menne, F., & Rasyidi, E. S. (2021). Land use change, urban agglomeration, and urban sprawl: A sustainable development perspective of Makassar City, Indonesia. *Land*, 10(6), 556. <https://doi.org/10.3390/land10060556>
- Urraca, R., Huld, T., Gracia-Amillo, A., Martinez-de-Pison, F. J., Kaspar, F., & Sanz-Garcia, A. (2018). Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data. *Solar Energy*, 164, 339–354. <https://doi.org/10.1016/j.solener.2018.02.059>
- Valdés-Pineda, R., Pizarro, R., Valdés, J. B., Carrasco, J. F., García-Chevesich, P., & Olivares, C. (2016). Spatio-temporal trends of precipitation, its aggressiveness and concentration, along the Pacific coast of South America (36–49°S). *Hydrological Sciences Journal*, 61(11), 2110–2132. <https://doi.org/10.1080/02626667.2015.1085989>
- Wainwright, C. M., Black, E., & Allan, R. P. (2021). Future changes in wet and dry season characteristics in CMIP5 and CMIP6 simulations. *Journal of Hydrometeorology*, 22(9), 2339–2357. <https://doi.org/10.1175/JHM-D-21-0017.1>
- Wang, W., & Hocke, K. (2022). Atmospheric effects and precursors of rainfall over the Swiss Plateau. *Remote Sensing*, 14(12), 2938. <https://doi.org/10.3390/rs14122938>
- Wangwongchai, A., Waqas, M., Dechpichai, P., Hlaing, P. T., Ahmad, S., & Humphries, U. W. (2023). Imputation of missing daily rainfall data: A comparison between artificial intelligence and statistical techniques. *MethodsX*, 11, 102459. <https://doi.org/10.1016/j.mex.2023.102459>
- Yasa, I. W., Sulistiyono, H., Saadi, Y., & Hartana. (2022). Spatial climate forecasting for climatology disaster mitigation. *Environment and Ecology Research*, 10(6), 786–796. <https://doi.org/10.13189/eer.2022.100613>
- Zhang, C., Wang, J., Liu, J., Lv, Y., Chen, J., Yang, Z., & Zhang, N. (2023). Performance assessment for the integrated green-gray-blue infrastructure under extreme rainfall scenarios. *Frontiers in Ecology and Evolution*, 11, 1242492. <https://doi.org/10.3389/fevo.2023.1242492>
- Zhou, H., Liu, J., Ou, S., Gao, C., Zhou, Y., Shi, L., & Zhou, K. (2024). Impact of effective impervious surface disconnection on urban hydrographs: A multi-scenario modeling study at the catchment scale. *Journal of Hydrology*, 630, 130656. <https://doi.org/10.1016/j.jhydrol.2024.130656>

Biographies of Authors

Zul Janwar, Department of Environmental Engineering, Universitas Syekh Yusuf Al Makassar Gowa, Gowa, South Sulawesi 92111, Indonesia.

- Email: zuljanwar6@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Zulkarnain, Department of Biology, Faculty of Science and Technology, Universitas Islam Negeri Alauddin Makassar, Makassar, South Sulawesi 90222, Indonesia.

- Email: zulkarnainbio@uin-alauddin.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Hajrah, Department of Biology, Faculty of Science and Technology, Universitas Islam Negeri Alauddin Makassar, Makassar, South Sulawesi 90222, Indonesia.

- Email: hajrah.sukri@uin-alauddin.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A