# The source of rainfall and others reference

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**Abstract.** Rainfall plays a critical role in the hydrological cycle, affecting water availability, agriculture, and resource management. Understanding the sources of rainfall and the factors influencing its intensity and distribution is vital for addressing climate change and extreme weather events. This study aims to identify the primary sources of rainfall in Denpasar, assess the influence of meteorological, topographic, and human factors, and provide a comprehensive analysis supported by relevant literature. We employed both quantitative and qualitative approaches, analyzing rainfall data from meteorological stations (2021–2025), satellite-based atmospheric models, and a review of scientific journals and technical reports. Statistical analysis revealed that rainfall in the region is primarily driven by the monsoon cycle, local topography, and evaporation from surrounding water bodies. Human activities, particularly deforestation and urbanization, have been found to increase spatial rainfall variability. Furthermore, global climate models and regional studies indicate that climate change is amplifying the frequency of extreme rainfall events. The study concludes that both natural and anthropogenic factors shape rainfall patterns, with land-use change playing a significant role. Effective water resource management requires integrating meteorological data and evidence-based policies to mitigate climate change impacts.

## 1 Introduction

Rainfall is essential in the hydrological cycle, providing freshwater for ecosystems, agriculture, and human use. In tropical regions like Indonesia, particularly in Denpasar, Bali, rainfall patterns result from a complex interaction of atmospheric, geographic, and anthropogenic factors. Denpasar, located at 8.65°S latitude and 115.22°E longitude, experiences a tropical monsoon climate with distinct wet and dry seasons. Understanding the sources and variability of rainfall is crucial, especially in light of climate change, which intensifies extreme weather events such as floods and droughts. This study investigates the origins of rainfall in Denpasar, using data from 2021 to 2025, and analyzes the meteorological, topographic, and human factors influencing rainfall distribution. By integrating local meteorological data with global and regional climate studies, the research aims to provide actionable insights for sustainable water resource management, supporting efforts to mitigate the impacts of climate change on water availability and ecosystems.

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Previous studies have highlighted the role of the Asian-Australian monsoon system in driving rainfall in Indonesia, while local factors like topography and land-use changes add layers of complexity. This study builds on these foundations by incorporating recent data and satellite analyses to offer updated insights [1,2].

# 2 Literature Review

### Natural Sources of Rainfall

Rainfall in tropical regions primarily originates from convective processes driven by solar heating, evaporation from oceans, and atmospheric circulation patterns. In Indonesia, the Intertropical Convergence Zone (ITCZ) and the monsoon winds are key drivers. The wet season (November to March) is dominated by the northwest monsoon, bringing moist air from the Indian Ocean, while the dry season (April to October) features southeast trade winds from Australia [1].

Topography significantly influences rainfall distribution. Bali's mountainous interior creates orographic lift, enhancing precipitation on windward slopes [3]. Evaporation from surrounding seas, such as the Bali Sea and Indian Ocean, contributes to local moisture recycling [4].

## 2.1 Anthropogenic Influences

Forma Human activities, including urbanization and deforestation, alter land surfaces, affecting evapotranspiration and heat fluxes. Studies show that deforestation in monsoon regions reduces precipitation by disrupting moisture feedback loops [3,5]. In urban areas like Denpasar, the urban heat island effect can intensify convective storms, leading to uneven rainfall distribution [6].

## 2.2 Climate Change Impacts

Global climate models, such as those from the IPCC, predict increased rainfall intensity in Indonesia due to warming oceans and enhanced evaporation [6]. Regional assessments indicate a rise in extreme events, correlated with El Niño-Southern Oscillation (ENSO) variability [5]. In Bali, projections suggest longer dry spells interspersed with heavy rains [5,7].

# 3 Methods

## 3.1 Data Collection

Rainfall data were collected from the Ngurah Rai meteorological station in Denpasar, spanning monthly totals from January 2021 to October 2025 (with November and December 2025 data unavailable at the time of analysis). This station provides reliable ground-based measurements. Additional data sources included satellite observations from the Global Precipitation Measurement (GPM) mission and atmospheric reanalysis from ECMWF's ERA5 dataset, which were used to assess evaporation and wind patterns. A comprehensive literature review was conducted using databases such as PubMed, MDPI, and ResearchGate, focusing on keywords like "rainfall Bali," "monsoon Indonesia," and "climate change impacts" to supplement the data analysis.

### 3.2 Data Analysis

Quantitative analysis involved statistical processing using Python with libraries like Pandas and SciPy. Monthly rainfall was averaged across the period to identify seasonal patterns. Correlation analyses were performed to assess relationships with topographic elevation (using DEM data), vegetation cover (NDVI from Landsat), and urbanization metrics (land-use change from 2020-2025 maps). Qualitative synthesis integrated findings from references to contextualize results. Extreme events were defined as rainfall exceeding the 95th percentile (R95p).

## 4 Results

### 4.1 Rainfall Patterns in Denpasar (2021-2025)

The average annual rainfall in Denpasar during 2021-2025 was approximately 1,636 mm, with a pronounced wet season from November to March. Table 1 summarizes monthly averages derived from station data. Table 1 summarizes monthly averages derived from station data.

**Table 1.** The average annual Rainfall in Denpasar Bali 2021-2025

| Month | Average Rainfall (mm) | Standard Deviation (mm) | Rainy Days |
|---|---|---|---|
| January | 296 | 45 | 20 |
| February | 254 | 38 | 18 |
| March | 182 | 32 | 15 |
| April | 100 | 25 | 10 |
| May | 82 | 20 | 8 |
| June | 92 | 22 | 9 |
| July | 60 | 15 | 6 |
| August | 24 | 10 | 3 |
| September | 36 | 12 | 4 |
| October | 94 | 28 | 9 |
| November | 166 | 35 | 13 |
| December | 250 | 40 | 17 |

Peak rainfall occurs in January, driven by monsoon inflows. Dry months (June-September) show minimal precipitation, consistent with southeast trade winds [1,2].

### 4.2 Influencing Factors

Monsoon Cycle: Correlation analysis revealed a strong positive relationship ($r = 0.85$) between northwest monsoon strength (measured via wind anomalies) and wet-season rainfall. Topography: Areas with higher elevation (e.g., northern Denpasar outskirts) received 15-20% more rainfall due to orographic effects. Evaporation: Satellite data indicated that 40-50% of rainfall moisture originates from local evaporation from the Indian Ocean and Bali Strait [4]. Anthropogenic Activities: Urban expansion in Denpasar increased spatial variability, with deforested areas showing 10% lower average rainfall [8]. Extreme events rose by 25% from 2021 to 2025, aligned with climate change trends [5].

## 5 Discussion

The results affirm that natural factors like the monsoon and topography dominate rainfall sources in Denpasar, but human-induced changes amplify variability. Deforestation reduces evapotranspiration, echoing findings from large-scale studies, while urbanization exacerbates flood risks through altered runoff [6,8,9]. Climate models support the observed increase in extremes, urging adaptive strategies [5,7]. Limitations include reliance on station data, which may not capture micro-scale variations. Future research should incorporate higher-resolution models.

## 6 Conclusion

Rainfall in Denpasar is primarily sourced from monsoon interactions, topographic enhancement, and oceanic evaporation, modulated by anthropogenic factors. Climate change is intensifying extremes, necessitating integrated management. Recommendations include enhanced monitoring networks, reforestation, and policy frameworks for sustainable water use.

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