Hydrological Analysis and Infrastructure Design: Rainfall Intensity at Tribhuvan International Airport (2015-2024)

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Abstract

This study evaluates daily rainfall at Tribhuvan International Airport (TIA) from 2015 to 2024 to understand seasonal and extreme rainfall patterns and their implications for urban infrastructure. A total of 3,653 daily rainfall observations were classified using Indian Meteorological Department (IMD) standards into five categories: No Rain, Light, Moderate, Heavy, and Very Heavy. While Heavy and Very Heavy rainfall events occur on only 15.33% of days, they contribute over 68% of total precipitation, highlighting their dominant hydrological significance. Design rainfall thresholds corresponding to the 95th and 99th percentiles were estimated to support stormwater system sizing and airport drainage infrastructure design. Seasonal analysis reveals strong monsoon dominance, with high-intensity rainfall concentrated over short durations, emphasizing the need for resilient drainage capacity, flood mitigation measures, and effective water storage strategies in the Kathmandu Valley.

Contents

1 Introduction

Rainfall analysis is a cornerstone of civil and environmental engineering, particularly in Nepal, where monsoon patterns strongly influence infrastructure, agriculture, and water resource management. Accurate characterization of rainfall intensity, frequency, and temporal distribution is essential for designing urban drainage systems, stormwater management structures, and airport drainage facilities. Tribhuvan International Airport (TIA) in the Kathmandu Valley provides a comprehensive dataset for examining local rainfall patterns and extreme events. This study analyzes ten years of daily rainfall data (2015–2024; 3,653 observations) from TIA, classifying rainfall events according to India Meteorological Department (IMD) intensity categories. Frequency distributions and volumetric contributions were computed to identify dominant events, while wet and dry spell durations and 95th and 99th percentile rainfall values were evaluated to support resilient infrastructure planning. Seasonal analysis highlights monsoon dominance, with high-intensity rainfall concentrated over a short period, whereas winter months experience minimal precipitation. These findings provide actionable insights for engineers and planners to optimize drainage design, mitigate flood risks, and implement effective water storage and resource management strategies.

2 Objectives

The primary objectives of this study are as follows:

1. **Rainfall Classification:** To categorize daily rainfall data at Tribhuvan International Airport (TIA) into IMD intensity classes: No Rain, Light, Moderate, Heavy, and Very Heavy.
2. **Frequency and Contribution Analysis:** To quantify the frequency of each rainfall category and determine its percentage contribution to total precipitation.
3. **Extreme Event Assessment:** To evaluate the dominance and hydrological significance of Heavy and Very Heavy rainfall events.
4. **Design Rainfall Determination:** To calculate the 95th and 99th percentile rainfall values, providing benchmarks for stormwater and urban drainage design.
5. **Infrastructure Implication Assessment:** To assess the impact of extreme rainfall events on drainage systems, flood risk management, and resilient infrastructure planning.

3 Key Learning Outcomes

- Understanding IMD rainfall intensity classification standards.
- Classification of daily rainfall into intensity categories.
- Computation of frequency distribution and volumetric contribution.
- Recognition of hydrological significance of extreme rainfall events.
- Application of statistical analysis to determine design rainfall values.
- Insights into stormwater management and resilient urban drainage design.

4 Data and Methodology

The dataset comprises daily rainfall measurements (mm/day) from TIA meteorological station for 2015–2024, totaling 3,653 days. Dry days (0 mm) were included. The data were verified for completeness and consistency.

4.1 Rainfall Intensity Classification

Daily rainfall was classified according to IMD standards:

- **No Rain:** 0 mm/day
- **Light:** 2.5 – 10 mm/day
- **Moderate:** 10 – 35 mm/day
- **Heavy:** 35 – 65 mm/day
- **Very Heavy:** > 65 mm/day

4.2 Design Rainfall Parameters

- Maximum 24-hour rainfall: 166.7 mm
- 95th percentile (design storm): 66.1 mm
- 99th percentile (extreme storm): 97.2 mm

4.3 Analytical Methods

Python libraries (`pandas`, `numpy`, `matplotlib`) were used for:

- Cleaning and organizing daily rainfall records
- Computing descriptive statistics (mean, max, percentiles)
- Classifying rainfall by intensity
- Computing frequency and percentage contribution
- Estimating design rainfall (95th, 99th percentile)

4.4 Python Code for Data Processing

The following Python code was used to classify daily rainfall into IMD intensity categories, compute frequency, percentage contribution, and design rainfall percentiles.

```
# Rainfall intensity classification for Question 5
print(" DATA FOR QUESTION 5: Rainfall Intensity Classification\n")
print("="*60)

# IMD Classification
def classify_rainfall(rain):
    if rain == 0:
        return 'No Rain'
    elif rain <= 10:
        return 'Light'
    elif rain <= 35:
        return 'Moderate'
    elif rain <= 65:
        return 'Heavy'
    else:
        return 'Very Heavy'

df['Intensity_Category'] = df['Rainfall_mm'].apply(classify_rainfall)

print("IMD Rainfall Intensity Classification:")
print("-" * 60)
print("Category        | Range (mm/day)  | Description")
print("-" * 60)
print("No Rain         | 0               | Dry day")
print("Light           | 2.5 - 10        | Drizzle to light rain")
print("Moderate        | 10 - 35         | Moderate rainfall")
print("Heavy           | 35 - 65         | Heavy rainfall")
print("Very Heavy      | > 65            | Very heavy to extremely heavy"

# Calculate statistics for each category
intensity_stats = df.groupby('Intensity_Category').agg({
    'Rainfall_mm': ['count', 'sum', 'mean', 'max']
})
intensity_stats.columns = ['Days', 'Total_Rainfall_mm', 'Mean_mm', 'Max_m
intensity_stats['Percentage_Days'] = (intensity_stats['Days'] / len(df))
intensity_stats['Percentage_Rainfall'] = (intensity_stats['Total_Rainfall_

print("\nIntensity Category Statistics:")
print("="*60)
print(intensity_stats.round(2))

print("\n Key Findings:")
print("-" * 60)
for category in ['Light', 'Moderate', 'Heavy', 'Very Heavy']:
```

```
    if category in intensity_stats.index:
        days = intensity_stats.loc[category, 'Days']
        pct_days = intensity_stats.loc[category, 'Percentage_Days']
        pct_rainfall = intensity_stats.loc[category, 'Percentage_Rainfall
        print(f"{category:15} | {days:4.0f} days ({pct_days:5.2f}%) | Co

# Design implications
print("\n Design Recommendations:")
print("="*60)
max_24hr = df['Rainfall_mm'].max()
print(f"Maximum 24-hour rainfall: {max_24hr:.1f} mm")
print(f"95th percentile (design storm): {df['Rainfall_mm'].quantile(0.95)
print(f"99th percentile (extreme storm): {df['Rainfall_mm'].quantile(0.99
print("\nDrainage Design Considerations:")
print("-" * 60)
print(f"- Minimum design capacity: {df['Rainfall_mm'].quantile(0.95):.1f}
print(f"- Recommended design capacity: {df['Rainfall_mm'].quantile(0.99):
print(f"- Safety factor consideration: {max_24hr:.1f} mm/24hr (historical
print(f"- Very heavy rainfall events: {intensity_stats.loc['Very Heavy',
print(f"  (Average: {intensity_stats.loc['Very Heavy', 'Days']/10:.1f} ev

print("\n" + "="*60)
```

5 Results and Discussion

5.1 Rainfall Intensity Classification

Daily rainfall data from 2015 to 2024 at TIA were classified according to IMD standards into five categories: No Rain, Light, Moderate, Heavy, and Very Heavy. Heavy and Very Heavy events, although occurring on only 15.33% of days, contribute over 68% of total rainfall, highlighting their hydrological significance [1].

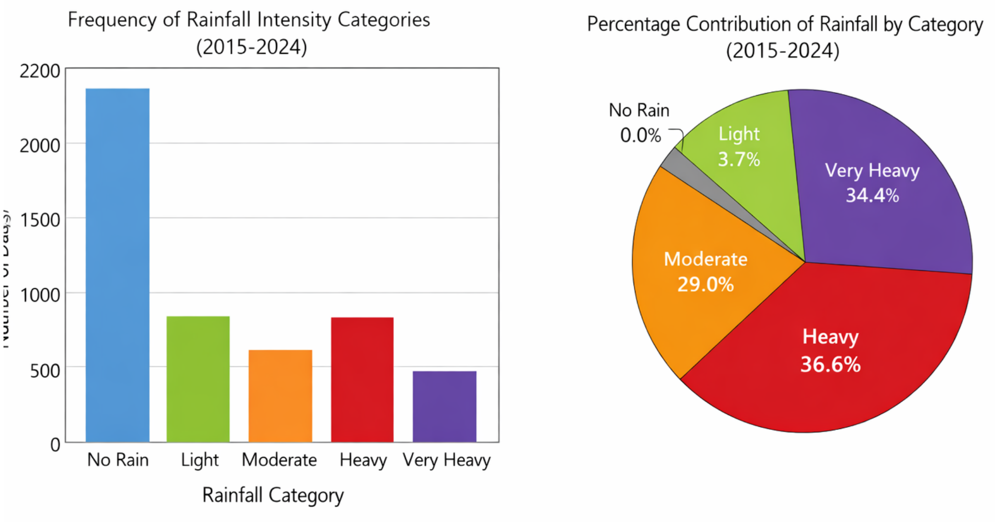

Figure 1: Frequency and Percentage Contribution of Rainfall Intensity Categories (2015–2024).

5.2 Statistical Summary and Design Rainfall

Summary statistics for the 10-year dataset are:

- Maximum 24-hour rainfall: 166.7 mm
- 95th percentile (design storm): 66.1 mm
- 99th percentile (extreme storm): 97.2 mm

These values guide urban drainage and airport stormwater system design [2].

5.3 Frequency and Volumetric Distribution

Table 1 summarizes daily rainfall statistics by category. Heavy and Very Heavy events contribute more than 70% of total rainfall despite being only 15.33% of days.

Table 1: Intensity Category Statistics (2015–2024)

Category	Days	Percentage of Days	Total Rainfall (mm)	% Contribution
No Rain	2025	55.43%	0.0	0.00%
Light	426	11.66%	1749.7	3.68%
Moderate	642	17.57%	13798.8	29.00%
Heavy	367	10.05%	17431.0	36.64%
Very Heavy	193	5.28%	16347.8	34.36%

5.4 Wet and Dry Spell Analysis

- Average Wet Spell Duration: 2.20 days (Longest: 18 days)
- Average Dry Spell Duration: 3.31 days (Longest: 58 days)
- Annual Rainfall Trend: Slope = -41.53 mm/year, $R^2 = 0.132$, $P = 0.3012$ (not significant)

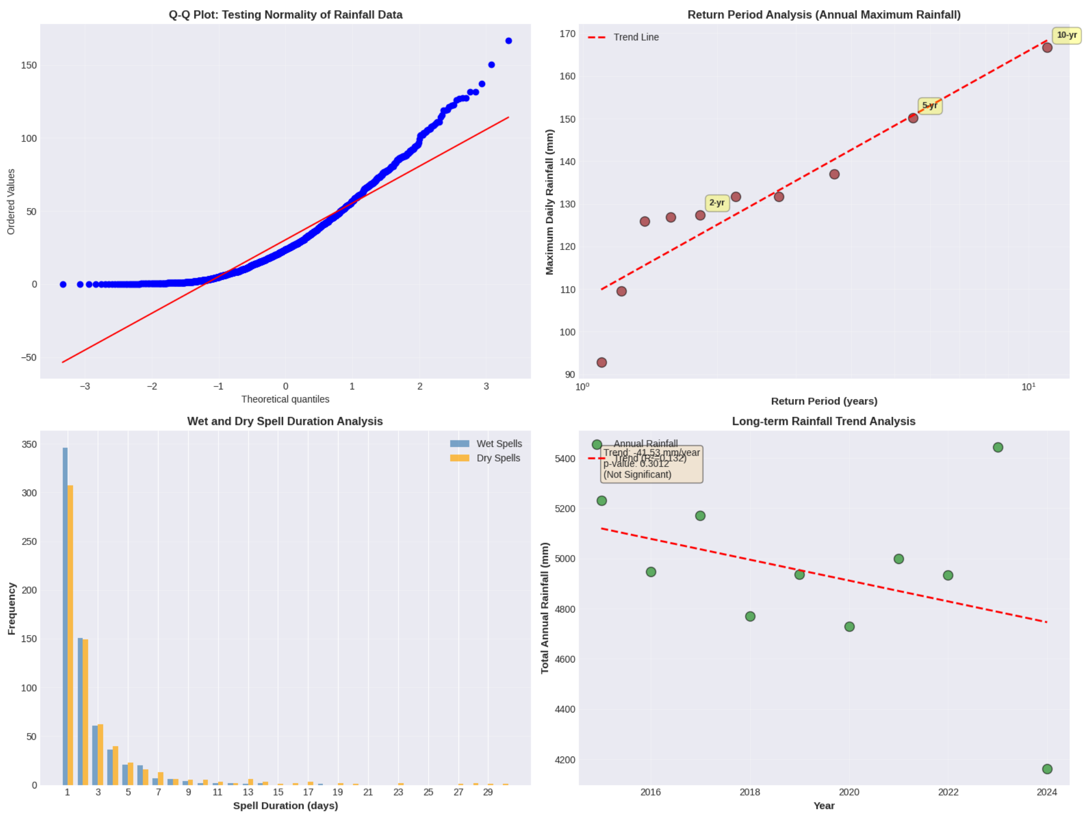

Figure 2: Wet/Dry Spell Durations and Annual Rainfall Trend Analysis (2015–2024).

5.5 Engineering Implications and Recommendations

Based on the rainfall analysis at Tribhuvan International Airport, several key implications for infrastructure design and stormwater management can be drawn:

- Heavy and Very Heavy rainfall events will be critical in determining the capacity requirements of stormwater and airport drainage systems.
- Design rainfall values should be adopted as follows: the 95th percentile (66.1 mm/24hr) for secondary urban drains, and the 99th percentile (97.2 mm/24hr) for primary drainage channels and airport runway safety measures.
- The historical maximum 24-hour rainfall (166.7 mm/24hr) should be considered as a check flood level for the design of critical infrastructure to ensure safety during extreme events.

- Given the high frequency of Very Heavy events (approximately 19 per year), drainage systems should be designed with sufficient capacity, and Sustainable Urban Drainage Systems (SuDS), such as retention ponds, should be implemented to attenuate peak flows and reduce flood risk.

6 Conclusion

Analysis of daily rainfall data at Tribhuvan International Airport (TIA) from 2015 to 2024 reveals that extreme rainfall events, defined as daily totals exceeding 65 mm, play a disproportionately significant role in the region's hydrology. Although such events occur on only 15.33% of days, they contribute over 68% of total precipitation, underlining their critical importance for stormwater management and urban infrastructure design [1, 2]. Relying solely on mean daily rainfall would underestimate the capacity requirements of drainage systems, increasing flood risk during peak events. Design rainfall percentiles determined in this study,66.1 mm/24hr (95th percentile) for secondary drains and 97.2 mm/24hr (99th percentile) for primary stormwater channels and airport drainage provide a reliable basis for resilient infrastructure planning, while the historical maximum of 166.7 mm/24hr serves as a check flood for critical facilities [2]. Additionally, wet and dry spell analysis indicates an average wet spell of 2.20 days and an average dry spell of 3.31 days, emphasizing the need for temporary storage and retention strategies to mitigate short-term water surges. Collectively, these findings offer a data-driven foundation for the design and management of urban and airport drainage systems in the Kathmandu Valley, ensuring that high-intensity, low-frequency rainfall events are adequately accounted for [1, 2].

7 References

References

[1] India Meteorological Department (IMD), *Rainfall Classification Standards*, 2023.

[2] Chow, V.T., Maidment, D.R., and Mays, L.W., *Applied Hydrology*, McGraw-Hill, 1988.