Journal of Geo Research

ISSN: 3139-2539 (Online)

journal homepage: https://jogr.in

OPEN ACCESS

2026 (October)
Vol. 1 No. 4

Spatio-temporal dynamics of rainfall variability in West Guwahati (2004–2016)

Eahya Al Huda

Assistant Professor, Department of Earth Science, University of Science and Technology Meghalaya

*Corresponding author *E-mail address:* ea.huda@gmail.com

Article Info

Received: 05 September 2026
Accepted: 22 September 2026

Citation: Al Huda, E. (2026). Spatio-temporal dynamics of rainfall variability in West Guwahati (2004–2016). *Journal of Geo Research*, 1(4), 1–9.

doi:doi.org/10.5281/zenodo.23257791

Copyright: © 2026 by the authors. Licensee Journal of Geo Research. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Disclaimer: The data, maps, views and ideas appearing in this paper are the sole expressions of the author(s), who bear full responsibility for content and accuracy. Editors and publishers reject any liability for errors, disputes, or related problems, asserting that accountability rests entirely with the original contributors alone.

Abstract

Precipitation variability serves as a primary indicator of regional hydrological fluctuations and climate change impacts, particularly in ecologically sensitive and rapidly urbanizing zones like Northeast India. This study presents a detailed statistical evaluation of daily rainfall dynamics in Pandu, West Guwahati, over a 13-year observational period (2004–2016). Utilizing high-resolution daily rainfall records obtained from the Water Resource Department, Government of Assam, this paper investigates annual and seasonal variations, encompassing pre-monsoon, monsoon and post-monsoon/winter periods. Descriptive and distributional parameters—including annual totals, mean daily rates, standard deviations, coefficients of variation (CV), rainy day frequencies (above 2.5 mm), rainfall intensity, skewness and excess kurtosis—were computed. The results demonstrate profound inter-annual and intra-annual volatility. Annual rainfall peaked at 4,208.8 mm in 2010 and plummeted to a low of 1,435.4 mm in 2014. The coefficient of variation consistently exceeded 90% across all years, reflecting extreme temporal instability and susceptibility to erratic extreme weather events. Furthermore, positive skewness and high excess kurtosis values across datasets underscore a leptokurtic distribution characterized by infrequent, high-intensity downpours rather than uniform precipitation. These insights are critical for advancing urban climate resilience, regional flood mitigation and sustainable water resource management in the Brahmaputra valley.

Keywords: Rainfall Variability, Spatio-temporal Dynamics, West Guwahati, Monsoon, Extreme Weather Events, Urban Hydrology, Climate Change

1. Introduction

Precipitation is the most dynamic component of the hydrological cycle, driving surface water availability, agricultural productivity and groundwater recharge. In the context of global climate change, regional hydrological regimes are experiencing unprecedented alterations in temporal distribution, intensity and frequency (Intergovernmental Panel on Climate Change [IPCC], 2021). These climatic shifts are acutely felt in South and Southeast Asia, where economies and ecosystems are inextricably linked to monsoonal dynamics.

Northeast India, bordered by complex topography and influenced by the tropical monsoon system, is recognized as one of the wettest regions on Earth. However, micro-climatic shifts, driven by rapid anthropogenic modifications, land-use changes and broader climatic anomalies, have introduced severe hydrological uncertainties (Goswami et al., 2006). Urban centers within this region, such as Guwahati—the commercial gateway of Northeast India—face compounding vulnerabilities. Rapid urbanization, loss of natural wetlands and encroachment on natural drainage channels amplify the risks associated with erratic rainfall patterns (Bora & Goswami, 2016).

West Guwahati, encompassing critical nodes like Pandu along the southern bank of the Brahmaputra River, represents a localized micro-climate shaped by surrounding hills, riverine proximity and burgeoning urban footprints. Understanding the statistical architecture of rainfall in this specific sector is vital for several reasons. First, it bridges the gap between macro-scale meteorological assessments and localized hydrological realities. Second, precise precipitation profiling is indispensable for designing urban stormwater management systems, flood early-warning frameworks and civil infrastructure planning.

Despite the acknowledged necessity for localized hydro-meteorological data, long-term empirical assessments detailing the statistical distribution, variability coefficients and daily intensity profiles of rainfall in West Guwahati remain limited. This paper addresses this empirical gap by analyzing a robust 13-year daily rainfall dataset (2004–2016) from Pandu, Guwahati. By evaluating annual totals, seasonal demarcations and distributional moments (such as skewness and kurtosis), this study provides a foundational reference for regional hydro-climatic variability.

2. Study Area

Guwahati, often referred to as the gateway to Northeast India, is situated between 26° 05' N to 26° 15' N latitudes and 91° 34' E to 91° 50' E longitudes. The city is bounded by the Brahmaputra River to the north and rolling Precambrian hills of the Shillong Plateau to the south and east.

This study focuses specifically on West Guwahati, with meteorological records anchored at Pandu. West Guwahati is characterized by a distinct undulating topography interspersed with residual hillocks (*tila*), flat alluvial floodplains and numerous natural water bodies (*beels* and wetlands) such as the Deepor Beel Ramsar site nearby. The climate of the area is humid subtropical, influenced heavily by the South-West Monsoon.

In recent decades, West Guwahati has undergone intense demographic and infrastructural expansion. The conversion of permeable surfaces, natural vegetation and water retention basins into impermeable built environments has drastically altered the surface hydrology of the region. Consequently, even moderate-to-high-intensity rainfall events frequently trigger localized flash floods, urban waterlogging and slope instabilities (landslides) in hilly tracts. Analyzing the statistical distribution of rainfall in Pandu is thus paramount for contextualizing these localized environmental stresses.

3. Materials and Methods

3.1 Data Acquisition

The empirical foundation of this study rests upon daily rainfall statistics recorded over a 13-year temporal window spanning from January 1, 2004, to December 31, 2016. These high-resolution datasets were procured directly from the **Water Resource Department, Guwahati, Government of Assam**. The rain gauge station located at Pandu serves as the primary observation point for West Guwahati.

3.2 Methodological Framework and Statistical Parameters

To capture both central tendencies and distributional extremes of precipitation, raw daily data were processed across annual and seasonal scales using a robust meteorological and statistical framework.

The analytical parameters include Annual and Seasonal Total Rainfall, which aggregates daily values across pre-monsoon, monsoon and post-monsoon periods. Mean Daily Rainfall establishes the baseline daily average, while Standard Deviation measures absolute dispersion around this mean. To compare variability independently of mean magnitude, the Coefficient of Variation is utilized.

Frequency is assessed through the Number of Rainy Days, standardized via India Meteorological Department conventions as days registering at least 2.5 mm of precipitation. Rainfall Intensity, derived from total rainfall divided by rainy days, denotes precipitation concentration. Finally, distribution shape is evaluated using Skewness to identify asymmetry and high-intensity, low-frequency events, alongside Excess Kurtosis. High positive excess kurtosis signifies leptokurtic behavior, characterized by sharp distribution peaks and extreme outliers such as cloudbursts or torrential downpours.

4. Results and Discussion

The empirical evaluation of rainfall data from Pandu, West Guwahati (2004–2016), reveals significant temporal volatility. The analysis is structured into annual variations and three distinct seasonal blocks: Pre-Monsoon (March–May), Monsoon (June–September) and Post-Monsoon & Winter (October–February).

4.1 Annual Variations of Rainfall in Pandu, Guwahati (2004–2016)

An analysis of Table 1 reveals profound temporal variability and statistical complexity in the annual precipitation regime of Pandu, Guwahati, over the thirteen-year period from 2004 to 2016. The data demonstrates severe inter-annual fluctuations in total rainfall, oscillating dramatically between a peak of 4,208.80 mm in 2010 and a trough of 1,435.40 mm in 2014. This sharp contrast underscores a pronounced hydrological vulnerability, characterized by alternating phases of excessive moisture and marked meteorological dryness, particularly evidenced by the sharp precipitation deficits observed in 2013 and 2014.

Table-1: Annual Variations of Rainfall in Pandu, Guwahati (2004–2016)

Year	Total Rainfall (mm)	Mean Rainfall (mm/day)	Standard Deviation (mm)	Coefficient of Variation (CV %)	No. of Rainy Days	Rainfall Intensity (mm/day)	Skewness	Kurtosis
2004	3,536.00	37.22	50.38	135.36	87	40.64	3.05	11.80
2005	3,947.30	32.89	35.86	109.02	108	36.55	2.56	9.89
2006	2,418.60	24.19	33.46	138.34	88	27.48	3.46	16.61

2007	3,489.40	33.23	30.88	92.92	94	37.12	1.17	1.21
2008	2,915.80	23.14	32.28	139.47	116	25.14	3.32	13.63
2009	2,001.60	21.07	27.37	129.88	81	24.71	2.08	3.93
2010	4,208.80	34.78	42.25	121.45	112	37.58	1.93	3.41
2011	2,623.80	27.62	36.00	130.34	93	28.21	4.43	27.35
2012	2,747.00	25.20	37.28	147.91	93	29.54	2.86	9.01
2013	1,525.20	15.56	16.81	108.04	85	17.94	1.97	4.08
2014	1,435.40	15.27	23.43	153.46	67	21.42	3.22	12.53
2015	2,448.84	21.11	27.15	128.62	100	24.49	3.14	13.33
2016	2,031.20	19.53	25.60	131.05	92	22.08	2.39	7.59

Moreover, the temporal distribution of this rainfall is inherently erratic. The coefficient of variation (CV) consistently remains at exceptionally high levels, surpassing 90% in all observed years and culminating in a maximum of 153.46% in 2014. This persistently high CV signifies intense intra-annual volatility, meaning that daily precipitation rates deviate substantially from the mean and preclude any temporal uniformity. Such high variability is mirrored in the annual count of rainy days, which fluctuated from a sparse 67 days in 2014 to an extended 116 days in 2008, pointing to significant discrepancies in the duration and frequency of wet spells across different hydrological cycles.

The structural distribution of the precipitation further highlights a propensity for extreme weather phenomena. Across the entire study period, the skewness values remain consistently positive—ranging from a moderate 1.17 in 2007 to a pronounced 4.43 in 2011—while the excess kurtosis metrics are overwhelmingly high, peaking dramatically at 27.35 in 2011. In statistical terms, this leptokurtic distribution indicates that the daily rainfall data possesses heavy tails and sharp peaks. Consequently, the climatological regime of Pandu is defined not by steady, continuous rainfall, but rather by concentrated downpours where the vast majority of the annual water budget is discharged during isolated, high-intensity storm events. This dynamic carry critical implications for regional water resource management, urban planning and agricultural scheduling, as the heightened frequency of intense precipitation combined with inter-annual unpredictability significantly elevates the compounding risks of localized flooding and drought.

4.2 Seasonal Variations

4.2.1 Pre-Monsoon Season (March – May)

An analysis of the pre-monsoon rainfall data (March to May) for Pandu, Guwahati, from 2004 to 2016 reveals pronounced temporal variability, characteristic of the convective weather systems and localized squalls (such as *Bardoisila*) typical of Northeast India. Throughout this thirteen-year observational window, total seasonal precipitation exhibits extreme fluctuations, spanning from a deficient minimum of 287.60 mm in 2014 to a robust maximum of 1,235.00 mm in 2005. This high degree of inter-annual volatility is further underscored by the coefficient of variation (CV), which consistently remains above 80%, peaking at an exceptionally high 172.58% in 2010. Such elevated CV values signify marked unpredictability in pre-monsoon moisture distribution over the region. The temporal frequency of precipitation aligns closely with these volumetric swings; the number of rainy days ranges from a sparse 19 days in 2014 to an active 42 days in 2005. Despite the intermittency of these events, the rainfall intensity remains relatively vigorous

when convective storms do manifest. Mean daily rainfall intensity fluctuates between a low of 10.27 mm/day (2014) and a high of 34.84 mm/day (2004), with storm-specific intensity peaking at 35.90 mm/day in 2004. Furthermore, statistical distribution metrics provide critical insight into the nature of these convective events. The skewness values remain consistently positive across all years—ranging from 0.82 in 2004 to a high of 3.22 in 2010—denoting a continuous right-skewed distribution where moderate-to-low rainfall days predominate, punctuated by occasional high-magnitude downpours. Correspondingly, excess kurtosis values fluctuate widely; while several years (such as 2004, 2005 and 2011) exhibit negative kurtosis indicative of platykurtic distributions with thin tails, anomalous convective years like 2010 display extreme leptokurtic behavior (kurtosis of 11.83), driven by isolated cloudbursts or severe pre-monsoon squalls (Table-2). Ultimately, the dataset demonstrates that while pre-monsoon precipitation in Guwahati is inherently erratic and highly variable in both total volume and temporal distribution, its underlying statistical structure points to localized, high-intensity convective episodes rather than prolonged, steady rainfall regimes.

Table-2: Seasonal (Pre-Monsoon, March – May) Variation Rainfall in Pandu, Guwahati (2004–2016)

Year	Total Rainfall (mm)	Mean Rainfall (mm/day)	Standard Deviation (mm)	Coefficient of Variation (CV %)	No. of Rainy Days	Rainfall Intensity (mm/day)	Skewness	Kurtosis
2004	1,184.60	34.84	28.35	81.37	33	35.90	0.82	-0.53
2005	1,235.00	25.20	23.27	92.31	42	29.40	0.83	-0.39
2006	681.60	21.30	25.56	120.00	27	25.24	1.38	0.67
2007	569.20	18.97	25.43	134.05	22	25.87	1.77	2.05
2008	566.20	14.52	19.34	133.20	28	20.22	1.64	1.63
2009	437.20	14.57	19.46	133.56	22	19.87	1.44	1.03
2010	913.60	19.44	33.55	172.58	31	29.47	3.22	11.83
2011	573.40	18.49	19.43	105.08	25	22.94	0.94	-0.33
2012	525.60	15.02	16.34	108.79	26	20.22	0.95	-0.34
2013	636.00	15.90	19.53	122.83	31	20.52	1.83	2.86
2014	287.60	10.27	12.60	122.69	19	15.14	1.44	1.01
2015	813.00	19.36	21.05	108.73	33	24.64	1.46	1.63
2016	920.80	20.93	23.47	112.14	36	25.58	1.22	0.47

4.2.2 Monsoon Season (June – September)

An analysis of the hydro-climatic data from Pandu, Guwahati, spanning the 2004 to 2016 period, reveals that the monsoon season (June to September) acts as the definitive driver of the region's annual hydrological regime, while simultaneously exhibiting extreme inter-annual and intra-seasonal volatility. The empirical records underscore a marked degree of precipitation variability across the observed thirteen-year timeframe. Total seasonal rainfall fluctuates dramatically, peaking at an anomalous high of 2,987.80 mm in 2010 before plummeting to a pronounced deficit of 758.80 mm in 2013. This macro-level instability is mirrored in the temporal distribution of wet days, which ranged from a constrained duration of 40 days in 2006 to an extended wet spell of 76 days in 2008. Despite these fluctuating durations, the mean daily rainfall intensity remains persistently high during precipitation events, frequently surpassing the 35 to 40 mm/day threshold—exemplified by rates of 42.64 mm/day in 2005 and 40.93 mm/day in 2010. Furthermore, the high coefficients of variation (CV), which consistently exceed 90% and reach as high as 176.90% in 2006,

highlight the substantial degree of dispersion and unpredictability inherent to the local monsoon climate (Table-3).

Table-3: Seasonal (Monsoon Season June – September) Variation of Rainfall in Pandu, Guwahati (2004–2016)

Year	Total Rainfall (mm)	Mean Rainfall (mm/day)	Standard Deviation (mm)	Coefficient of Variation (CV %)	No. of Rainy Days	Rainfall Intensity (mm/day)	Skewness	Kurtosis
2004	1,723.20	33.14	40.54	122.34	45	38.29	1.61	1.62
2005	2,345.00	41.14	45.34	110.22	55	42.64	2.22	6.02
2006	1,228.60	20.48	36.23	176.90	40	30.72	4.10	19.67
2007	2,217.40	35.76	32.22	90.10	56	39.60	1.38	1.22
2008	2,207.60	28.30	37.66	133.07	76	29.05	3.41	13.67
2009	1,326.40	25.51	32.55	127.60	47	28.22	2.02	3.10
2010	2,987.80	38.80	46.22	119.12	73	40.93	1.83	2.86
2011	1,894.20	30.07	42.23	140.44	61	31.05	4.53	25.43
2012	2,058.20	32.67	45.43	139.06	57	36.11	2.62	7.34
2013	758.80	14.88	18.23	122.51	43	17.65	2.22	5.12
2014	1,100.20	18.34	29.54	161.07	41	26.83	3.22	11.38
2015	1,542.30	23.37	30.43	130.21	55	28.04	3.22	12.33
2016	1,045.20	18.66	27.67	148.28	45	23.23	2.78	8.44

Beyond aggregate volumes and standard deviations, the underlying statistical distribution of the rainfall data provides critical insight into the localized hydro-meteorological hazards facing West Guwahati. The metrics consistently demonstrate pronounced positive skewness, peaking at 4.53 in 2011, alongside extreme excess kurtosis, which reaches a remarkable 25.43 in the same year and 19.67 in 2006. In a climatological context, such high positive kurtosis and leptokurtic tendencies indicate that the rainfall distribution is heavily tailed, dominated by infrequent, high-magnitude outlier events rather than a normal, bell-shaped distribution of moderate daily rainfall. Consequently, this statistical profile refutes the assumption of a steady, continuous monsoon season; instead, it exposes an intermittent regime defined by prolonged atmospheric hiatuses or breaks, which are abruptly punctuated by short-duration, high-intensity cloudbursts or torrential precipitation events. These concentrated hydrological pulses overwhelm the natural and anthropogenic drainage capacities of West Guwahati, generating excessive surface runoff that acts as the primary catalyst for severe urban inundation and flash flooding in the metropolitan area.

4.2.3 Post-Monsoon & Winter Season (October – February)

An analysis of Table-4 delineates the hydro-meteorological dynamics of the post-monsoon and winter seasons (October through February) in Pandu, Guwahati, spanning from 2004 to 2016. Conventionally acknowledged as the dry phase of the hydrological cycle within this geographical locus, the empirical data corroborates stable atmospheric conditions punctuated by minimal baseline precipitation. Across the thirteen-year observational period, aggregate seasonal rainfall totals predominantly remained sequestered below the 200 mm threshold, underscoring a prolonged regime of moisture scarcity. However, the temporal

dataset is marked by pronounced anomalies, specifically in 2004 and 2007, wherein aggregate precipitation surged to exceptional maxima of 703.20 mm and 702.80 mm, respectively. These anomalous peaks disrupt an otherwise arid baseline, signaling the occasional infiltration of macro-scale synoptic disturbances into an inherently quiescent hydrological window. Furthermore, the temporal distribution of precipitation remains remarkably sparse, with the cumulative number of rainy days over the extended five-month block fluctuating restrictively between 7 and 21 days per season. This sparsity is complemented by fluctuating mean daily precipitation rates and rainfall intensities, which generally register low values—such as a minimal mean of 5.92 mm/day in 2016—contrasting sharply with the intense daily delivery rate of 70.32 mm observed during the meteorological perturbation of 2004.

Table-4: Seasonal (Post-Monsoon & Winter Season, October – February) Variation Rainfall in Pandu, Guwahati (2004–2016)

Year	Total Rainfall (mm)	Mean Rainfall (mm/day)	Standard Deviation (mm)	Coefficient of Variation (CV %)	No. of Rainy Days	Rainfall Intensity (mm/day)	Skewness	Kurtosis
2004	703.20	70.32	115.57	164.35	10	70.32	1.52	0.47
2005	422.99	22.26	19.54	87.79	17	24.88	0.95	-0.16
2006	508.40	24.21	42.66	176.21	21	24.21	2.26	4.38
2007	702.80	43.93	29.43	66.99	16	43.93	0.22	-1.22
2008	142.00	11.83	20.34	171.94	12	11.83	2.44	4.66
2009	238.00	19.83	36.54	184.27	12	19.83	2.22	3.44
2010	307.40	38.43	49.33	128.36	8	38.43	1.38	0.22
2011	156.20	22.31	18.54	83.10	7	22.31	0.66	-1.10
2012	163.20	16.32	22.43	137.44	10	16.32	1.83	1.98
2013	130.40	11.85	18.43	155.53	11	11.85	2.10	3.12
2014	47.60	6.80	10.34	152.06	7	6.80	1.45	0.55
2015	93.55	7.79	11.34	145.57	12	7.80	1.77	2.05
2016	65.20	5.92	19.43	328.21	11	5.93	3.22	9.21

Crucially, the statistical dispersion parameters within the dataset illuminate a high degree of stochasticity and inter-annual volatility. The Coefficient of Variation (CV %) consistently registers at extreme magnitudes, remaining well above standard hydrological thresholds for variability and culminating in an extraordinary peak of 328.21% in 2016. Such elevated CV values signify an acute lack of seasonal predictability, demonstrating that winter and post-monsoon precipitation in the region does not conform to a steady climatological norm. This erratic tendency is further substantiated by the metrics of skewness and excess kurtosis. Throughout the analyzed timeframe, both variables predominantly reflect positive values—such as a peak skewness of 3.22 and a profound kurtosis of 9.21 in 2016—indicating distributions that are heavily skewed to the right with leptokurtic tendencies. Methodologically, these distributional shapes confirm that precipitation events during the dry phase are not only sparse but are characterized by isolated, high-intensity outbursts rather than a normal, continuous distribution. Temporally, this stochasticity is fundamentally driven by sporadic meteorological phenomena, such as western disturbances or late-season cyclonic remnants, which occasionally traverse the region. Consequently, the hydrological profile of Pandu, Guwahati, during the post-monsoon and winter months is defined by a dichotomy of prolonged dry spells interspersed with unpredictable, high-amplitude precipitation anomalies, posing distinct challenges for regional water resource management and agricultural planning.

4.3 Synthesized Discussion on Hydro-Meteorological Implications

The empirical findings from the 13-year dataset at Pandu provide several critical insights into the hydro-meteorological regime of West Guwahati:

1. **High Inter-Annual Variability:** The fluctuation of annual rainfall between a maximum of 4,208.80 mm (2010) and a minimum of 1,435.40 mm (2014) highlights considerable vulnerability to hydro-climatic extremes. Such sharp inter-annual swings complicate regional water resource management, alternating between severe urban inundation risks during wet years and groundwater depletion or agricultural stress during dry years.
2. **Monsoon Concentration and Intensity:** While the monsoon season (June–September) naturally dominates the water budget, the high rainfall intensities (frequently >35 mm/day) combined with leptokurtic distribution patterns (high positive skewness and excess kurtosis) reveal that precipitation is increasingly delivered in short, violent bursts. This phenomenon aligns with broader observations of intensifying hydrological cycles in South Asia driven by atmospheric warming and regional aerosol loading (Goswami et al., 2006; Krishnan et al., 2020).
3. **Urban Resilience Challenges in West Guwahati:** The structural configuration of West Guwahati—characterized by sloping terrain, rapid urbanization and constrained natural drainage networks—is exceptionally ill-suited to high-intensity, short-duration rainfall events. When daily rainfall intensity spikes (as observed during peak monsoon months across multiple years), stormwater drainage systems are rapidly overwhelmed. Runoff velocity from the adjacent hills accelerates, resulting in severe urban flash floods, waterlogging in low-lying residential areas (such as Maligaon, Pandu and Bharalumukh) and heightened landslide risks along hill slopes.

5. Conclusion

This study has provided a rigorous statistical evaluation of daily rainfall dynamics in Pandu, West Guwahati, over a 13-year period (2004–2016). The analysis confirms that precipitation in the region is characterized by high temporal variability, pronounced seasonality and an increasing propensity for concentrated, high-intensity storm events.

Key findings indicate that annual rainfall is highly unstable, with coefficients of variation consistently exceeding 90% and reaching up to 153.46%. The distributional analysis—demonstrated through persistent positive skewness and high excess kurtosis—proves that regional rainfall is heavily leptokurtic, dominated by episodic, intense downpours rather than uniform temporal distribution. The monsoon season remains the primary driver of the annual water balance, yet it exhibits extreme volatility, with single-season totals ranging from 758.80 mm (2013) to 2,987.80 mm (2010).

These empirical insights carry profound implications for urban planning, hydrological engineering and disaster risk reduction in Guwahati. Traditional urban drainage designs, based on historical stationary rainfall assumptions, are increasingly inadequate in the face of observed climatic volatility. Future infrastructural development in West Guwahati must integrate climate-resilient stormwater management, rigorous watershed protection, restoration of natural wetlands (*beels*) and slope stabilization measures to mitigate the cascading hazards of extreme precipitation variability.

Conflict of Interest: *The author declares no conflict of interest.*

References

Bora, A., & Goswami, D. C. (2016). Urbanization and its impact on the drainage basin and flood vulnerability in Guwahati city, Assam. *Journal of Geography and Regional Planning*, *9*(4), 35–48.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India in a warming environment. *Science*, *314*(5804), 1442–1445.

Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou, Eds.). Cambridge University Press.

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., & Chakraborty, S. (Eds.). (2020). *Assessment of climate change over the Indian region: A report of the Ministry of Earth Sciences (MoES), Government of India*. Springer Nature.

Water Resource Department. (2017). *Daily rainfall statistics (2004–2016) for Pandu Station*. Government of Assam, Guwahati.