Empirical Rainfall Threshold Determination for Flooding in Sorsogon Province

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ABSTRACT

This study, titled "Empirical Rainfall Threshold Determination for Flooding in Sorsogon Province," aimed to identify rainfall thresholds that could trigger flooding in the province. Sorsogon, located in the Bicol Region of the Philippines, is highly susceptible to flooding due to its topography, coastal location, and exposure to multiple weather systems such as tropical cyclones, shearlines, and monsoons. Using both descriptive and evaluative research designs, the study analyzed historical rainfall data from the PAGASA Synoptic Station in Juban, complemented by satellite rainfall estimates from the Global Satellite Mapping of Precipitation (GSMaP). Bias correction techniques were applied to improve the accuracy of satellite-derived rainfall data.

Results revealed that rainfall thresholds for flooding varied among municipalities: 70–80 mm for Magallanes and Juban, 80–90 mm for Sorsogon City and Irosin, and 90–100 mm for Castilla and Bulan. Tropical cyclones and shearlines were identified as the dominant weather systems causing flooding across the province.

Findings from this research support the integration of localized rainfall thresholds into flood early warning systems, enabling communities and disaster management offices to anticipate flood events more effectively. The results contribute to broader disaster risk reduction and climate resilience efforts aligned with Sustainable Development Goals 11 and 13.

Keywords: Empirical rainfall threshold, Flooding, Sorsogon Province, GSMaP, Bias Correction, Tropical Cyclone, Shearline, Disaster Risk Reduction, Early Warning System.

INTRODUCTION

Sorsogon Province, located in the Bicol Region of the Philippines, is highly exposed to extreme weather systems such as tropical cyclones, shearlines, monsoons, and the intertropical convergence zone [1]. Its coastal lowlands and river basins make it one of the most flood-prone provinces in Southern Luzon. According to the 2020 Census, Sorsogon has a population of 828,655 [2], with 19,348 families identified as being at high to very high risk of flooding [3].

Understanding the relationship between rainfall and flooding is essential since rainfall intensity and duration largely determine the potential for flooding. Identifying the specific amount of rainfall that can trigger flooding, known as the rainfall threshold, is vital for disaster preparedness and early warning. Reference [4] emphasized that rainfall thresholds serve as important parameters in operational flood forecasting and risk reduction planning.

This study aims to determine empirical rainfall thresholds for flooding in Sorsogon Province by analyzing historical rainfall and flood data from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) and local disaster management offices. Establishing these thresholds will enhance flood prediction, improve early warning systems, and support proactive disaster risk reduction efforts.

The study contributes to broader climate resilience objectives by aligning with Sustainable Development Goals (SDGs) 11 and 13, which advocate for sustainable cities and strengthened adaptive capacity to climate-related hazards [5].

Several studies have highlighted the significance of rainfall thresholds in flood forecasting and hydrological modeling. Reference [6] discussed rainfall–runoff processes in flood prediction, while [7] applied Bayesian methods in flood frequency analysis. [8] proposed regionalization methods for defining homogeneous hydrological areas, and [9] emphasized the spatial variability of rainfall thresholds. These works underscore the need for localized rainfall threshold determination, especially for provinces like Sorsogon that experience frequent and damaging floods.

METHODOLOGY

The study employed both descriptive and evaluative research designs to determine rainfall thresholds that trigger flooding in Sorsogon Province. The descriptive design analyzed historical rainfall, climatic data, and geographic features to understand flood susceptibility, while the evaluative design examined the relationship between rainfall amounts and flood occurrences.

A combination of quantitative and qualitative methods was employed. Historical data on flood events from 2017–2024 were collected from the Sorsogon Provincial and Municipal Disaster Risk Reduction and Management Offices (PDRRMO and MDRRMOs). Meteorological data, including rainfall, temperature, humidity, and tropical cyclone occurrences, were obtained from the PAGASA Juban Synoptic Station. To supplement ground observations, satellite rainfall data from the Global Satellite Mapping of Precipitation (GSMaP) by the Japan Aerospace Exploration Agency (JAXA-EORC) were utilized. GSMaP provides quasi–real-time global precipitation estimates derived from geostationary and low-earth orbit satellites, with a spatial resolution of 0.1° and temporal resolution of one hour [10].

Since only one ground station is available in the province, a bias correction method was applied to adjust GSMaP satellite estimates and align them with observed rainfall values. One widely used bias correction approach involved the application of a Correction Factor (CF), which adjusted satellite-based rainfall estimates based on observed ground data. The CF was computed as follows [11]

Correction Factor (CF) = *(Ground Observation)/ (GSMAP Satellite estimate)* (Eq. 1)

A Correction Factor (CF) greater than 1 indicated that the satellite estimate was lower than the observed rainfall, while a CF less than 1 suggested that the satellite estimate is higher. The Derived Rainfall for other cities and municipalities was then obtained using the corrected GSMaP data, as expressed in Equation 2:

Derived Rainfall = *Satellite Rainfall Estimate X Correction Factor (CF)* (Eq.2) {Corrected Values}

This process produced adjusted hourly rainfall data for each study area. The rainfall values that corresponded to documented flood events were then analyzed to determine the threshold rainfall linked to the onset of flooding. Descriptive statistical methods such as mean, mode, and percentage analysis were used to summarize rainfall patterns and identify consistent threshold values. In addition, geographic and climatic factors including slope, soil type, and land cover were examined to provide a clearer understanding of flood behavior within the province.

RESULTS AND DISCUSSION

A. Flood Susceptibility Context of Sorsogon

1.) *Geographical and Climatic Features of Sorsogon Province:* This chapter presents the findings and analysis of the study on flood susceptibility in Sorsogon Province, focusing on the cities and municipalities most at risk of flooding. According to the flood susceptibility assessments by the Provincial Disaster Risk Reduction and Management Office (PDRRMO), as shown in Fig. 1, the municipalities most vulnerable to flooding are Sorsogon City, Bulan, Irosin, Castilla, Magallanes, and Juban. These areas are especially at risk due to their proximity to river systems, coastal regions, and low-lying areas, making them prone to significant flooding during heavy rainfall and tropical cyclones [12],[13].

Sorsogon Province, located at the southernmost tip of Luzon in the Bicol Region, covers about 197,334 hectares and is characterized by a varied topography of mountains, valleys, plains, and coastal lowlands that strongly influence its flood susceptibility [14]. Mountainous areas such as Mount Bulusan (1,560 m) and Mount Bintacan (820 m) act as watersheds feeding river systems, while about 34% of the province consists of low-lying terrain

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with slopes of 0–8%, making it highly prone to flooding [15] Major rivers, including the Cadac-an in Juban and Irosin and those traversing Castilla, Magallanes, and Sorsogon City, frequently overflow during heavy rains. Coastal towns like Bulan and Magallanes experience both riverine and coastal flooding, often worsened by storm surges from the Pacific Ocean and Sorsogon Bay. Rapid urbanization in Sorsogon City further intensifies flood hazards due to reduced infiltration and drainage obstruction. Soil and land cover also contribute to flood risks: clayey and alluvial soils in lowlands hinder water absorption, while upland sandy loam soils promote infiltration. Deforestation, agricultural expansion, and impervious urban surfaces have diminished vegetation cover and natural drainage, increasing surface runoff and flood vulnerability [16].

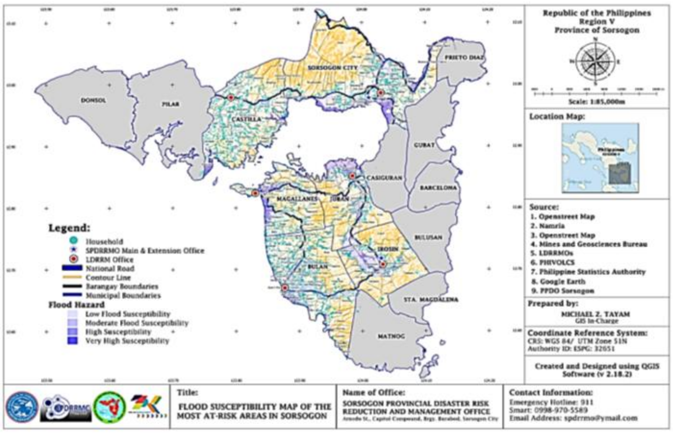

Fig. 1 Flood Susceptibility Map of Most At-Risk Areas in Sorsogon Province

The climate of Sorsogon plays a major role in determining the province’s vulnerability to flooding. Based on the PAGASA Modified Coronas Climate Classification, most areas belong to Climate Type II, which has no dry season and experiences peak rainfall from December to February due to the Northeast Monsoon [17]. The eastern and southern parts, including Donsol, Pilar, Castilla, and portions of Magallanes, Bulan, and Matnog, fall under Climate Type IV, which has evenly distributed rainfall throughout the year. These conditions result in persistently wet environments that promote moisture buildup and frequent flooding, especially in low-lying and poorly drained areas [18].

Rainfall records from the PAGASA Juban Synoptic Station show that precipitation exceeds 2,500 millimeters annually, with the highest values in November, December, and January. As presented in Fig. 2, the peak months coincide with the active shear line and the Northeast Monsoon, which enhance rainfall. The overlap of monsoon rains and tropical cyclone activity significantly heightens flood risks across the province.

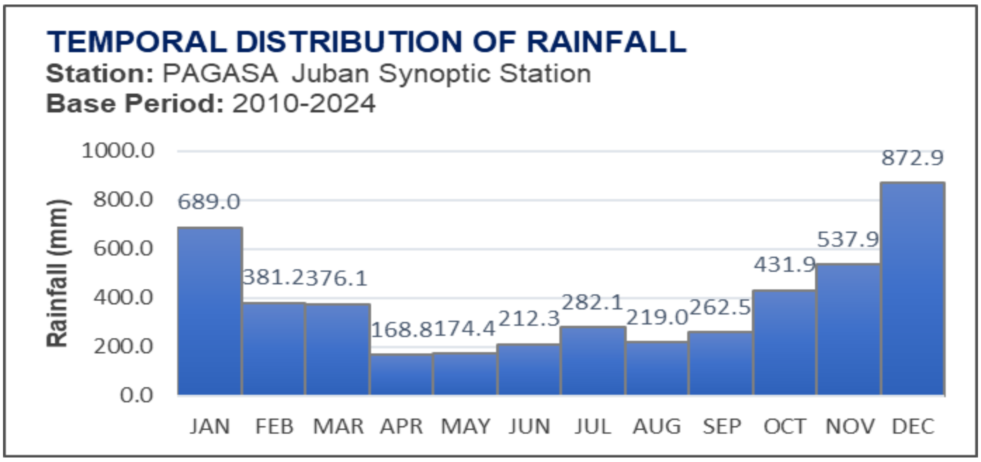

Fig. 2 Temporal Distribution of Rainfall in Sorsogon Province

From 2010 to 2022, PAGASA Synoptic Station data (Table 1) showed mean temperatures ranged from 25.3 to 28.3 degrees Celsius, while relative humidity averaged 86 percent and reached up to 90 percent from November to January. These conditions favor prolonged soil saturation and slow drying, increasing the likelihood of flooding.

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TABLE I AVERAGE MONTHLY TEMPERATURES AND RELATIVE HUMIDITY IN SORSOGON (2010–2022), PAGASA JUBAN SYNOPTIC STATION

Month	Maximum Temp. (°C)	Minimum Temp.(°C)	Mean Temp. (°C)	RH (%)
January	28.5	22.6	25.3	89
February	29.0	22.2	25.4	88
March	29.9	22.7	26.0	86
April	31.3	23.1	27.1	85
May	32.7	23.9	28.2	83
June	32.5	24.3	28.3	84
July	31.7	24.2	27.8	85
August	31.8	24.5	28.1	84
September	31.8	24.3	27.9	86
October	31.2	23.8	27.4	87
November	30.4	23.7	26.9	89
December	29.3	23.5	26.4	90

Tropical Cyclone: Similar to other areas in the Bicol Region, Sorsogon is frequently visited by tropical cyclones, particularly in the last quarter of the year (Fig 3). Over a

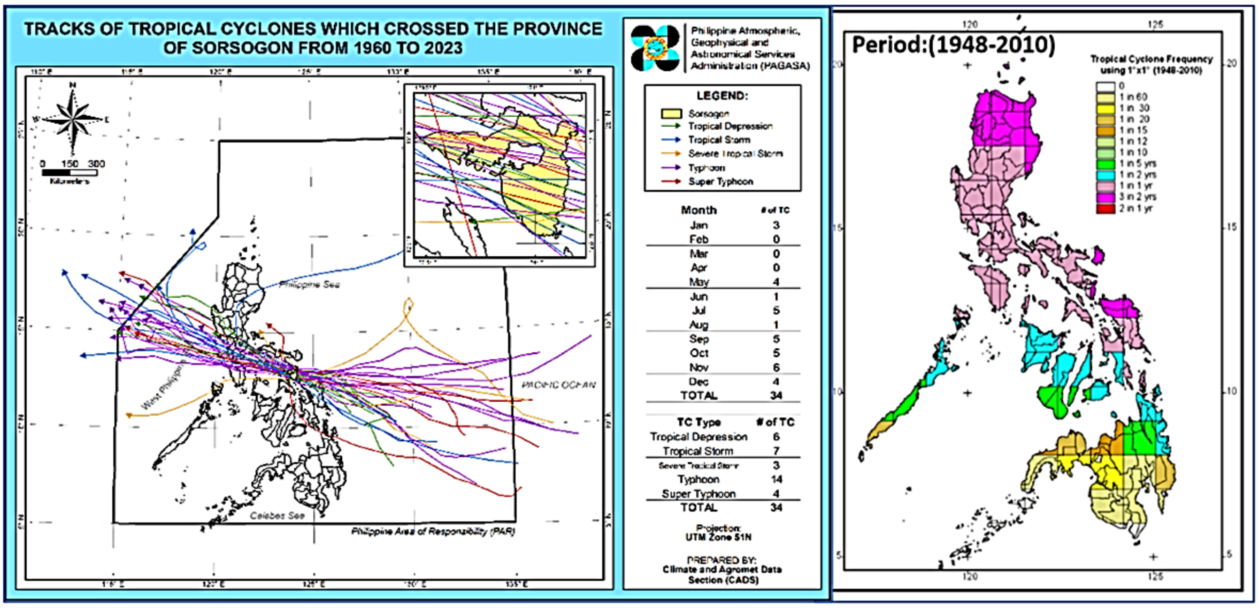

Fig. 3 Tracks of Tropical Cyclone which Directly Crossed the Province of Sorsogon from Year 1960-2023 and the Tropical Cyclone Frequency

64-year period, 34 tropical cyclones directly hit the province: 4 super typhoons, 14 typhoons, 3 severe tropical storms, 12 tropical storms, and 6 tropical depressions. Most of these cyclones occurred in November, while no direct cyclones passed through in February, March, or April. Even when cyclones did not directly cross the land, they still brought substantial rainfall, significantly affecting the area.

B. Weather Systems that Caused Flooding in Sorsogon Province

Flooding in Sorsogon Province is influenced by multiple weather systems that affect the frequency, duration, and severity of rainfall events. Table 2 presents the percentage and frequency distribution of weather systems that caused flooding in selected high-risk cities and municipalities from 2017 to 2024. Tropical cyclones are identified as the leading cause of flooding, particularly in Bulan and Irosin, where they account for 62.5 percent of incidents. Magallanes, Juban, Castilla, and Sorsogon City follow with 46.7, 46.2, 42.9, and 41.7 percent, respectively. These systems produce heavy and sustained rainfall, with slow-moving cyclones resulting in prolonged inundation. Their interaction with other weather systems often amplifies rainfall and leads to extended flooding episodes.

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TABLE II SUMMARY OF PERCENTAGE AND FREQUENCY DISTRIBUTION OF WEATHER SYSTEMS THAT CAUSED FLOODING IN SORSOGON FROM YEAR 2017-2024

City/ Mun.	Weather Systems				Distribution
	Tropical Cyclone	Shearline	LPA	Monsoons/ Thunderstorms	
Bulan	5	3	0	0	Frequency
	62.5%	37.5%	0.0%	0.0%	Percentage
Sorsogon City	5	6	0	1	Frequency
	41.7%	50.0%	0.0%	8.3%	Percentage
Irosin	5	3	0	0	Frequency
	62.5%	37.5%	0.0%	0.0%	Percentage
Castilla	3	4	0	0	Frequency
	42.9%	57.1%	0.0%	0.0%	Percentage
Magallanes	7	5	1	2	Frequency
	46.7%	33.3%	6.7%	13.3%	Percentage
Juban	6	4	1	2	Frequency
	46.2%	30.8%	7.7%	15.4%	Percentage

Cyclones frequently affect Sorsogon during the last quarter of the year. Even without making direct landfall, these systems often bring intense rainfall that leads to widespread flooding. Figures 4 and 5 illustrate the tracks of significant cyclones that impacted the province from 2017 to 2024. Among these, Tropical Depression Usman (December 25–30, 2018) with maximum sustained winds of 55 kph and gustiness of 65 kph, which made landfall in Borongan, Eastern Samar, and Severe Tropical Storm Kristine (October 20–28, 2024) with maximum sustained winds of 95 kph and gustiness of 115 kph, which made landfall in Divilacan, Isabela, exemplify the severe rainfall and flooding impacts experienced in Sorsogon despite their distant landfall points [19].

Shearline events significantly contributed to flooding in Sorsogon, especially during the Northeast Monsoon (Nov -Feb). Table 2 shows they caused over half the floods in

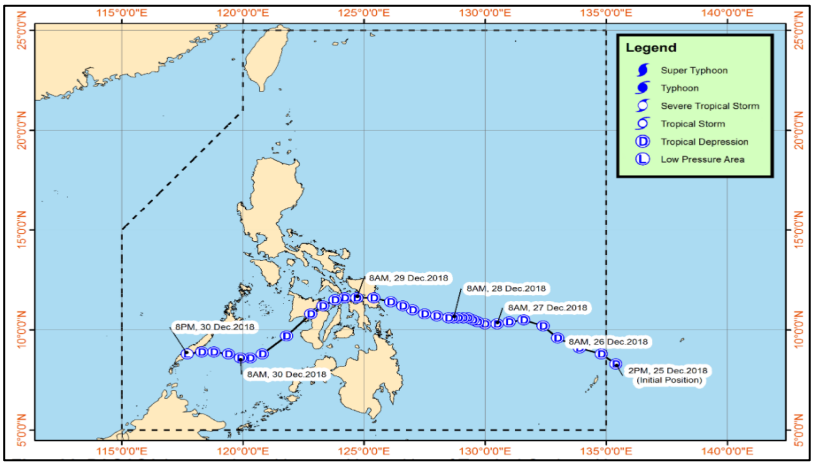

Fig. 4 Track of Tropical Depression Usman (December 25-30, 2018)

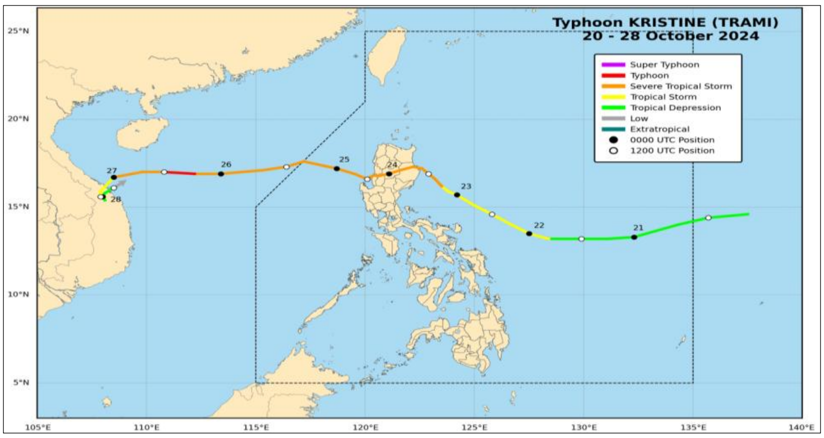

Fig. 5 Track of Severe Tropical Storm Kristine (October 20-28, 2024)

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Castilla (57.1%) and Sorsogon City (50.0%), and affected Bulan, Irosin, Magallanes, and Juban. Shearlines form when cold monsoon air meets warm Pacific air, triggering prolonged rain. Figures 6 and 7 illustrates satellite images of notable past shearline events that caused widespread flooding.

Flooding in Castilla and Sorsogon City is worsened by low elevation, poor drainage, and urbanization, which slow runoff. Unlike cyclones, shearlines last longer, allowing rain to accumulate. Reference [20] noted that cold surge winds, cyclones, and LPAs interacting with the monsoon intensify rainfall. While LPAs and thunderstorms cause localized floods, shearline events lead to widespread flooding.

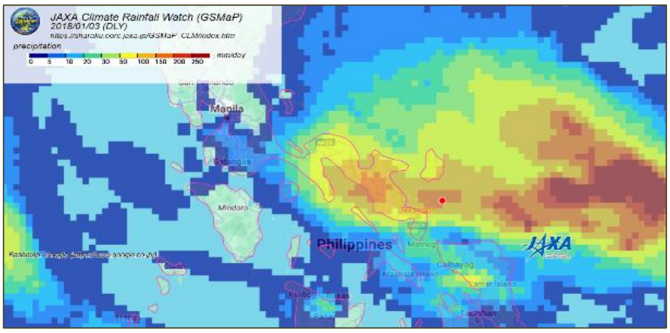

Fig. 6 JAXA GSMaP Satellite Image of January 1-3, 2018 Shearline Event

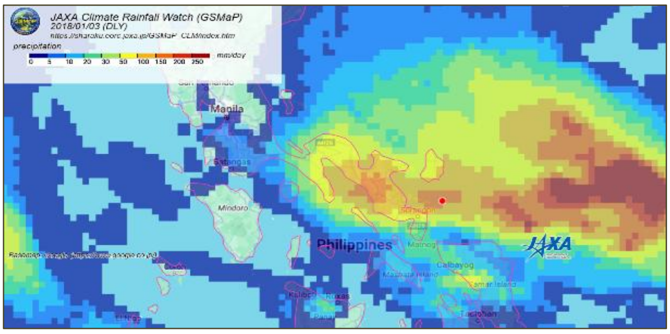

Fig. 7 JAXA GSMaP Satellite Image of December 24-25, 2024 Shearline Event

C. Rainfall Threshold that will Trigger Flooding in Sorsogon Province

The analysis revealed that the amount of rainfall plays a critical role in triggering flooding across Sorsogon Province. Using a combination of ground-based and satellite-derived rainfall data, threshold values were established for the six most flood-prone areas, namely Sorsogon City, Bulan, Irosin, Castilla, Magallanes, and Juban, based on rainfall amounts observed during actual flooding events from 2017 to 2024. The accumulated rainfall associated with the onset of flooding was analyzed and summarized to determine the rainfall levels that most frequently preceded flood occurrences.

Table 3 presents the suggested rainfall thresholds for flooding across the study areas. The findings indicate that flooding in Magallanes and Juban generally begins when accumulated rainfall reaches between 70 and 80 millimeters, while Sorsogon City and Irosin experience flooding at 80 to 90 millimeters. The highest thresholds were observed in Castilla and Bulan, ranging from 90 to 100 millimeters, which can already cause widespread inundation, particularly in low-lying coastal barangays.

TABLE III SUGGESTED RAINFALL THRESHOLD FOR FLOODING IN SORSOGON

City/ Municipality	Rainfall Threshold (Antecedent rainfall Amount in Millimeter)
Magallanes	70-80mm
Juban	70-80mm
Sorsogon City	80-90mm
Irosin	80-90mm
Bulan	90-100mm
Castilla	90-100mm

A conservative approach was applied in selecting these threshold values, ensuring that they were slightly lower than the calculated averages to enhance precautionary measures. This approach recognizes that flooding can still occur under lower rainfall totals depending on factors such as rainfall intensity, soil saturation, slope, topography, and drainage capacity. In Bulan, for instance, even slightly exceeding the 90 millimeter mark can lead to widespread flooding across its coastal areas. Adopting lower thresholds therefore provides an additional margin of safety and supports more effective disaster preparedness.

Beyond these conservative levels, continuous and heavy rainfall is expected to intensify flooding, expanding its effects from highly susceptible areas to include moderately to highly susceptible barangays. Flooding may occur at rainfall ranges of 81 to 100 millimeters in Magallanes and Juban, 91 to 110 millimeters in Sorsogon City and Irosin, and 101 to 120 millimeters in Bulan and Castilla. When rainfall exceeds these values, floodwaters can reach even low-lying and moderately susceptible areas, resulting in widespread inundation during extreme rainfall events.

Identifying rainfall thresholds for flooding in Sorsogon is vital for disaster risk reduction and management. The findings offer valuable guidance for local government units, disaster agencies, and communities in implementing proactive measures. Integrating these threshold values into early warning systems can improve the timing of evacuations, flood control operations, and overall preparedness. The combined use of ground-based observations and satellite data also enhances prediction accuracy, particularly in areas with limited monitoring stations. Establishing conservative thresholds ensures readiness, recognizing that floods may occur even below estimated levels due to the complex interaction of hydrological and geographical factors.

The concept of rainfall thresholds as early indicators of flooding supports previous studies on hydrometeorological hazards and flood forecasting. Reference [21], [22] emphasized the importance of defining region-specific rainfall thresholds since variations in terrain, soil type, and drainage capacity influence flood response. The application of bias correction methods, as demonstrated in the Bacon-Manito Geothermal Project, further validated the reliability of satellite-derived rainfall estimates for flood risk assessment. By aligning with these established methodologies, this study contributes to the growing body of research on flood prediction and disaster preparedness and provides a localized framework tailored to the unique hydrological and climatic characteristics of Sorsogon Province.

CONCLUSION

The study successfully established empirical rainfall thresholds that can serve as reliable indicators for potential flooding in Sorsogon Province. Results confirmed that rainfall accumulation between 70 mm and 100 mm is sufficient to trigger flooding in various municipalities, depending on local topography and drainage capacity. Tropical cyclones and shearlines were identified as the primary weather systems responsible for most flood events from 2017 to 2024.

The integration of ground-based and satellite rainfall data, adjusted through bias correction, provided a more accurate representation of rainfall distribution and intensity across Sorsogon. The derived thresholds can enhance local early warning systems, guide emergency response operations, and inform land-use and infrastructure planning to mitigate flood impacts.

RECOMMENDATION

It is recommended that the identified rainfall thresholds be integrated into the operational protocols of local disaster risk reduction and management offices to strengthen early warning systems and facilitate timely evacuation and response. Continuous calibration of these thresholds is necessary to reflect evolving climate patterns and land-use changes. Expanding rainfall monitoring networks across Sorsogon will also improve data reliability and spatial coverage. Furthermore, awareness campaigns and capacity-building activities should be conducted to familiarize communities with rainfall-based flood advisories. Integrating rainfall threshold data into local development and land-use planning will help reduce vulnerability and promote sustainable resilience against flooding.

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