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HEAVY RAINFALL RESILIENCE: ADOPTION OF CLIMATE SMART AGRICULTURE AMONG MARGINAL FARMERS IN A SUB-BASIN OF INDIA

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Highlights:
- a significant issue for marginal farmers in sustainable agriculture is identified as heavy rainfall;
- 42 years of data from eight grid points analyzed;
- defined criteria for heavy, extreme, and rare rainfall;
- identified 58 agriculturally vulnerable communities;
- cashew nuts, coriander (most susceptible), sugarcane, sweet potatoes, turmeric are the primary crops grown in this region;
- Integrated Pest Management, shifting crop seasons, Meghdoot projections are suggested as Climate smart practices;
- suggested biochar from biomass breakdown as a part of emission reduction;
- 33 farmers from 7 villages used these techniques with minimal losses in their second harvest season;
- 44% of the farmers support biochar kilns as a supporting and income generating practice which is a part of social entrepreneurship.

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Abstract. Heavy rainfall is a significant challenge for marginal farmers in the aspect of sustainable agriculture. This research analyzed data from eight grid points over 42 years to determine rainfall criteria: 50.91 mm to 79.65 mm for heavy rain, 76.95 mm to 101.21 mm for extreme rain, and 101.21 mm for rare 24-hour occurrences. The vulnerability mapping found 58 agriculturally susceptible communities. Research shows cashew nuts, coriander, sugarcane, sweet potatoes, and turmeric are the five main crops in the 58 most susceptible villages to heavy rainfall. These villages contain a greater number of marginal farmers. The DELPHI method revealed that coriander is the most susceptible crop. In this study, climate-smart agricultural practices such as Integrated Pest Management methods, shifting crop seasons, and Meghdoot application projections are used to minimize the damages caused by heavy rainfall. This includes protecting crops before heavy rainfall and monitoring them after heavy rainfall. For emission reduction as one of the pillars of Climate Smart Agriculture, biochar from biomass breakdown without oxygen is suggested. A poll found that 44% of respondents would use social entrepreneurship for biochar kilns. As, a result 33 farmers from 7 villages used the suggested Integrated Pest Management Technique and Meghdoot to harvest their second season with minimum losses.

Keywords: heavy rainfall, marginal farmers, climate smart agriculture, coriander crop, sustainable agriculture.

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1. Introduction

India's marginal farmers face significant challenges due to heavy rainfall, which can lead to crop losses and economic hardship. The adoption of climate-smart agriculture (CSA) practices, such as conservation tillage and integrated nutrient management, is vital for enhancing resilience and ensuring sustainable agricultural practices (Ma & Rahut, 2024; Tyagi & Haritash, 2024). Recent studies emphasize the importance of these practices in mitigating the adverse effects of extreme weather events and improving crop yields (Tyagi & Haritash, 2024). This research explores how marginal farmers in India are adapting to heavy rainfall through CSA, aiming to inform policies and support frameworks that strengthen agricultural resilience and sustainability.

In India as a whole, both the annual and monsoon rainfall trends are increasing; however, there have been more extreme and heavy rainfall years recently (Mohanty et al., 2023; Morning AG Clips, 2019). Heavy rainfall may have a detrimental impact on the production of crops. Heavy rainfall may result in direct physical harm to crops, hinder planting and harvesting timing, and root development, and lead to oxygen deprivation and nutrient depletion (Pandey, 2024). Rainfall is generally advantageous for agricultural cultivation, although extreme deviations from the optimal average rainfall may result in substantial issues, ranging from waterlogged crops to decreased yields (Guo & Chen, 2022). To mitigate the impacts of heavy rainfall on agriculture, farmers need to adopt appropriate strategies. This could include Climate-Smart Agriculture which is supported by its three pillars such as increased production, enhanced resilience and reduced emissions (Ghimire et al., 2022; Ishtiaque et al., 2024). Another aspect of climate smart agriculture is the promotion of sustainability. Sustainability in agriculture involves using resources efficiently and minimizing negative environmental impacts (United Nations, 2023). Although climate-smart agriculture (CSA) has the potential to enhance food security in South Asia, the widespread adoption of CSA methods and technology remains limited (Yale E360, 2019). The implementation of CSA often necessitates investment in novel technology, infrastructure, and training. Financial constraints might provide a substantial obstacle (Bhattacharyya et al., 2020). Insufficient policies or a lack of cooperation between government agencies and non-government entities might function as obstacles (Giles et al., 2021). Climate variability: The unpredictability of climate conditions poses difficulties in accurately forecasting results and adjusting CSA procedures appropriately (StudyIQ, 2024). CSA necessitates an all-encompassing strategy that takes into account the whole of the agricultural system. Disjointed methods may impede successful adjustment (Giles et al., 2021). Successful implementation of CSA requires collaboration among government departments, corporate parties, and foreign assistance groups (Tankha et al., 2019). To summarize, addressing these obstacles requires tailoring strategies to individual locations, using a bottom-up approach. Collaboration among relevant parties is crucial for improving food security and strengthening the resilience of the system in response to climate change.

2. Study area

The Paravanar river basin showed in Figure 1 is located in the Cuddalore district of Tamil Nadu, India, between the Vellar and Pennnaiyar river basins to the north and south, respectively. The basin size is 879.462 sq. km., with the geographic coordinates of Latitude: 11º27′00″ to 11º43′00″ N and Longitude: 79º23′00 to 79º47′00″ E. It has two main tanks, Wallajah Tank and Perumal Eri, in addition to a number of smaller streams and rain-fed tanks. The taluks of Chidambaram, Cuddalore, Panruti, and Virudhachalam are enclosed by the river basin area. Recent research underlines the Paravanar River Basin's notable shift under the influence of climate change. The basin's temperature increased and extreme weather incidents such as floods and heavy rainfall have become more frequent (National Water Mission, 2024). The Paravanar Basin's typical annual rainfall, according to the National Water Mission, is roughly 1197.70 mm; monsoon season brings highest precipitation. But the fluctuation in monsoon patterns has resulted in more frequent floods and flooding, therefore influencing the agricultural output of the area (Asian Development Bank, 2019). This area is renowned for being naturally cyclonic, with rainfall primarily resulting from the North East Monsoon and low pressure in the Bay of Bengal. There is 1200 mm of rainfall in a given year. The Paravanar river rises 100 meters above mean sea level in the highland's northwest of the Neyveli lignite corporate region, or the restricted forest close to Semmakottai and Ammeri villages. The Paravanar River Basin represents a significant agricultural region in India. According to the Paravanar Basin Report published by the National Water Mission, Government of India (Asian Development Bank, 2019), the agricultural area within this basin expanded from 357 square kilometres to 456 square kilometres between 2004 and 2015. However, data on agricultural yields from the Ministry of Agriculture and Farmers Welfare, Government of India (Ministry of Agriculture and Farmers Welfare, 2020), indicates a decline in crop productivity. Furthermore, Kowshika and Sankar (2020) identified that the study area, which was previously classified as the Most Efficient cropping zone for coriander from 2006 to 2010, has transitioned to a highly inefficient cropping zone for coriander post-2015. Therefore, this location has been selected as the focus of the study to investigate the underlying causes of the decline in agricultural production. More than 40 crops are cultivated in this region, in which cashew nut, coriander, sugarcane, sweet potato and turmeric are the primary crops. Consequently, there was a notable decline in the productivity and production patterns of the primary rainfed crops in this region (Kowshika & Sankar, 2020). This research presents a temporal analysis of the Tamil Nadu state from 2001 to 2005 and 2011 to 2015. The aim is to determine the changes in cropping zones by using the relative spread index and relative yield index. The study area, Cuddalore district, has seen a significant transition from being a highly efficient cropping zone to a most inefficient cropping zone. The number of harvests also declined, which had an adverse effect on the region's food supplies.

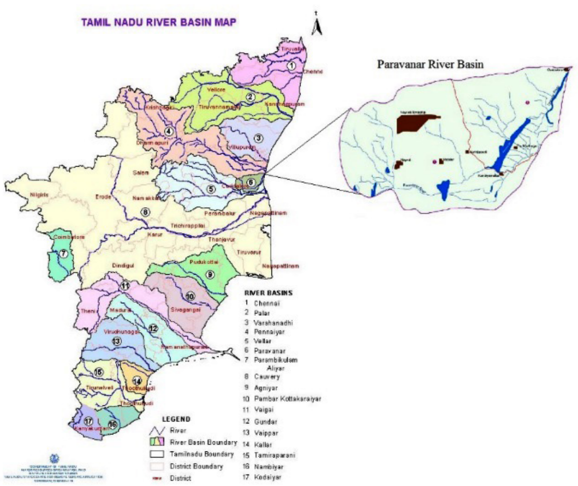


Figure 1. Index map of Paravanar River Basin

3. Materials and methods

The study's approach is categorized into five primary classifications. The initial category involves mapping villages at risk of heavy rainfall. The primary task is to identify the magnitude that significantly impacts the region. The best possible distribution is determined using the easy fit software. The heavy rainfall event thresholds are computed based on the best fit distribution and experts survey. Subsequently, the frequency of precipitation is determined by employing the inverse function in MATLAB. The second part is the agricultural vulnerability map on the aspect of heavy rainfall. It is developed by ArcGIS weighted overlay analysis, taking into- account elements such as number of HR events, slope, drainage density, soil, and geomorphology. The next step is to select the primary crops in the vulnerable villages. This analysis uses the Delphi technique to identify the most vulnerable crop. Five primary crops in that region are considered for this analysis. They are cashew nut, coriander, sugarcane, sweet potato and turmeric.

The study includes climate smart agriculture (CSA) for heavy rainfall as the next category to address the decreasing cultivation of the most vulnerable crop. It is based on the three pillars called increased productivity, enhanced resilience and reduced emission. Also, social entrepreneurship is incorporated with the process of emission reduction so that it can also be an income generation. It is found that, despite its potential, climate-smart agriculture (CSA) has not been extensively embraced among small farmers (Ishtiaque et al., 2024). Sustainable farming techniques and technology, which have been shown beneficial, are facing challenges in acquiring pace. Several obstacles hinder the implementation of climate smart agriculture practices, including insufficient organisational capabilities, poor targeted incentives, limited post-adoption monitoring, and disparities in the sharing of knowledge (Ishtiaque et al., 2024). Hence, the investigation concludes with the revival of crop cultivation, which is challenging due to farmers' emotional detachment from researchers. A target group of agriculturalists, former IT professionals, and influential farmers is selected from 150 samples. The implementation focuses on recommended CSA and the Meghdoot application for precipitation forecasts. The overall methodology is explained in the flow chart in Figure 2.

Figure 2. Methodology flow chart

Table 1. Goodness of fit using easy fit software

Goodness of Fit	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared		Overall Rank
		Statistic	Rank	Statistic	Rank	Statistic	Rank	
1	Gamma	0.18083	1	1336.7	3	941.59	1	5
2	Log-Pearson 3	0.13416	2	0.19361	1	0.221	3	6
3	Gen. Extreme Value	0.19406	3	291.46	2	1058.7	2	7

4. Results and discussion

Statistical Analysis for estimation of heavy rainfall: Effective flood control, agricultural planning, disaster readiness, and water resource management all depend on an awareness of the magnitude of heavy rainfall in the Paravanar River Basin. Accurate rainfall data guides agricultural decisions, helps forecast flood events, construct resilient infrastructure, create early warning systems, and sustainably manage water resources (National Water Mission, 2024; Asian Development Bank, 2019). For the marginal farmers in the area, who depend on exact weather data to protect their livelihoods and guarantee sustainable farming methods, estimating the magnitude of heavy rainfall is particularly crucial. IMD's heavy rainfall threshold is affecting marginal farmers. Heavy rainfall magnitude and return period are calculated using Easy Fit software, Agromet software, and MATLAB. The "return period" is a statistical notion used to estimate the probability of a given event, including heavy rainfall. It is stated as the mean interval of time between events of a given magnitude or intensity. The easy fit software analyzes historical rainfall data to identify the best-fitting distribution for rainfall events. Validation is conducted via observational surveys and expert reviews. The analysis utilizes MERRA2 Rainfall data spanning 40 years, from 1981 to 2021, which has been validated with rain gauge data for heavy rainfall event criteria and is shown in Table 2. The gamma distribution is determined to be the most suitable match. The research area is divided into 8 grid points, and the goodness of fit for one grid point is shown in the Table 1. The shape parameter is 0.3793 and the scale parameter is 8.9945. The collected data showed a 24-hour rainfall of 101.21 mm, which falls within the top 20% of the distribution and is considered a rare event in this study. The range of 76.95 mm to 101.21 mm is classified as extreme rainfall, representing

Table 2. Difference between the MERRA2 and rain gauge data

Date	Day	Vanamadevi Anicut			Parangipettai			Panruti			Cuddalore		
		Rain Gauge	Merra2 Data	Difference	Rain Gauge	Merra2 Data	Difference	Rain Gauge	Merra2 Data	Difference	Rain Gauge	Merra2 Data	Difference
1981 October	15	60	55.9	4.1	61	66.52	–5.52	70	72.44	–2.44	72	75.66	–3.66
1985 November	9	59	60.24	–1.24	61	62.51	–1.51	63	68.86	–5.86	56	63.97	–7.97
1986 November	29	73	76.94	–3.94	75	77.8	–2.8	72	74.25	–2.25	57	58.32	–1.32
1996 December	13	62	51	11	50	51.57	–1.57	51	53.33	–2.33	59	59.59	–0.59
	14	57	57	0	60	51.57	8.43	58	56.66	1.34	60	60.3	–0.3
1997 December	10	54	56.44	–2.44	60	58.62	1.38	66	70.66	–4.66	59	51.58	7.42
1998 November	29	60	54.77	5.23	65	64.7	0.3	59	63	–4	58	62.61	–4.61
2004 November	5	53	51.24	1.76	55	51	4	52	56.2	–4.2	61	56.88	4.12
	6	70	71.76	–1.76	70	66	4	68	75.18	–7.18	68	64.2	3.8
2005 November	5	68	70.24	–2.24	60	67.72	–7.72	67	72.85	–5.85	72	73.36	–1.36
	6	61	65.21	–4.21	57	56.51	0.49	66	70.15	–4.15	65	70.21	–5.21
	7	65	64.18	0.82	55	55.17	–0.17	54	55.96	–1.96	66	66.89	–0.89
2007 December	14	70	71.24	–1.24	76	76.72	–0.72	60	64	–4	53	53.38	–0.38
2008 December	9	60	65.85	–5.85	66	67.69	–1.69	64	59.9	4.1	64	67.2	–3.2
2009 November	9	58	59.51	–1.51	57	60.39	–3.39	54	55.54	–1.54	66	61.7	4.3
2010 November	30	58	57.21	0.79	52	57.51	–5.51	54	60.36	–6.36	59	63.5	–4.5
2012 December	31	61	61.24	–0.24	64	68.86	–4.86	65	65.64	–0.64	56	62.4	–6.4
2015 November	15	63	52.31	10.69	65	65.6	–0.6	59	61.15	–2.15	59	60.02	–1.02
2019 November	30	52	54.55	–2.55	57	56.49	0.51	55	59.08	–4.08	53	51.53	1.47
2020 December	3	70	71.21	–1.21	74	76.6	–2.6	71	72.5	–1.5	70	67.61	2.39
Average				0.298			–0.9775			–2.9855			–0.8955

the top 20% to 40% of the gamma distribution. Additionally, the range of 50.91 mm to 79.65 mm is categorized as heavy rainfall, representing the top 40% to 60% of the gamma distribution. Table 3 displays the frequency of occurrences that occurred during a 40-year period categorized as heavy, extreme, and rare rainfall events. Observational surveys were conducted with a sample size of 55 after rainfall occurrences on November 26, 2020, and November 29, 2021. If rainfall exceeds 80 mm, cashew nut and sugarcane crops will not experience significant losses, while turmeric and sweet potato yields will decrease by 50% per hectare due to water ponding and pest attacks. Coriander crops will be completely lost. Expert reviews conducted by agricultural engineers, water resource engineers, and farmers with over 15 years of experience have determined that rainfall exceeding 50 mm does not significantly affect the crop yield of cashew nut and sugarcane. However, the yield of sweet potato and turmeric is reduced by 30% under these conditions. The sweet potato crop will be harvested in November. The heavy rainfall is causing water to accumulate, leading to the sweet potatoes rotting. Turmeric will be at the rhizome growth stage during the post-monsoon season, making it susceptible to water stagnation and insect attacks that may damage the crop. The coriander crop is mostly affected by heavy rainfall that hits its leaves, causing the plant to bend over and making it more susceptible to insect attacks.

An observational investigation is being done to determine the threshold of heavy rainfall that impacts the crop. A sample of 150 individuals was selected, consisting of village heads, agriculturalists, water resource engineers, and farmers. The study was undertaken in December 2019 to assess the effects of the 50 mm rainfall on November 30, 2019, and in December 2021 to evaluate the effects of the 83 mm rainfall on November 29, 2021. The selected blocks for the survey are Mel Bhuvanagiri, Vanamadevi, and Parangipettai.

Table 3. Breakdown of heavy, extreme, and rare events for each grid point in Paravanar River Basin for the period 1981–2020

Grid points	Heavy	Very heavy	Extremely heavy
1	30	5	3
2	29	6	4
3	41	8	3
4	28	7	2
5	30	6	4
6	26	3	2
7	29	9	5
8	21	3	2

Frequency analysis is conducted to determine the recurrence interval of heavy, extreme, and rare rainfall occurrences. The return period was determined based on the expressed α and β values for three rainfall categories: top 40%–60%, 20%–40%, and <20%. The calculation was performed using the gamma inverse function in Matlab. The return period of heavy rainfall is estimated as 3 years, extreme rainfall as 3.5 years, and rare rainfall as 4 years.

Heavy rainfall susceptibility mapping is carried out in ArcGIS by overlaying village borders with the number of heavy rainfall occurrences at various grid locations and result is shown in Figure 3.

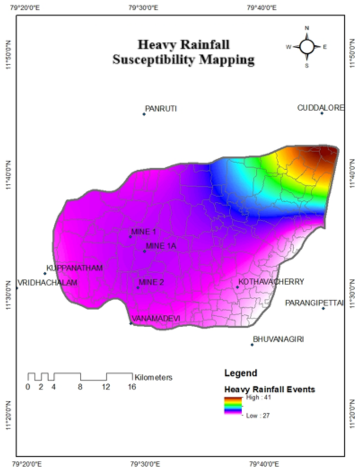


Figure 3. Heavy rainfall susceptibility mapping

Identification of Vulnerable Villages: The damages result from both the volume of rainfall and geomorphological causes, as well as human activities (Thirumurugan & Krishnaveni, 2019). The five thematic layers–heavy rainfall distribution, slope, drainage density, soil, and geomorphology–represent several elements that could lead to vulnerability to heavy rainfall. Every layer offers particular information that clarifies the interactions among several components of the terrain to affect the influence of heavy rainfall. Heavy rainfall distribution maps geographical variability and precipitation intensity, therefore emphasising places with more rainfall. With steeper slopes producing faster runoff and greater erosion rates, the slope layer shows the land surface gradient, therefore influencing water flow speed and direction. The layer of drainage density shows the water channel network, therefore highlighting places with more flood potential. Influencing water absorption and retention, the soil layer offers details on soil kinds and features including infiltration and water-holding capacities, therefore affecting water absorption and retention. Finally, the layer of geomorphology explains the physical characteristics and geological formations influencing the terrain, hence influencing water transport and storage. Through combined analysis of these thematic levels, researchers can acquire a thorough knowledge of the elements causing the vulnerability of the area for heavy rainfall and create focused mitigating and adapting plans. The input criteria raster was weighted, with a 100% impact compared to the other criterion. The values were rounded to the closest whole number, resulting in a total sum of 100. The weighted overlay tools were adjusted to a specified scale (default 1 to 6) to assign weights to the input data in the raster and combine them. Each class within the individual layer was awarded a rating on a scale of 1 to 6 based on its potential danger level for flood, as shown in Table 4. The most susceptible areas for each input criteria were reassigned to a higher value of 6. The weights supplied to the input raster in the weighted overlay tool must total 100%.

The layers were scaled by an appropriate multiplier, and the resultant values were aggregated for each cell. The weighted overlay process assumed that places with higher values in the output raster were considered highly vulnerable due to the presence of more favorable characteristics. The weightage was determined by expert reviews conducted by engineers from the Public Works Department, as well as hydrology and flood experts. Heavy Rainfall Distribution is given the highest weightage because it directly affects flooding and waterlogging. Slope and geomorphology then follow since they affect landscape stability and water flow. Although they are crucial for water absorption and flow control, soil and drainage density are given slightly less weight to represent their complementary contributions to reducing consequences of heavy rainfall. The survey questionnaire was carried out at the farm level in the research region to give weights to each parameter class for the multi-criteria analysis. Therefore, distinct weight was provided to each thematic layer based on expert knowledge and comprehension of their effect. The theme layers were transformed into raster grids and combined using GIS. The cell size was set at 30 metres by 30 metres. The vulnerability map was created by overlaying the borders of villages. Figure 4 displays the vulnerability map, indicating that 58 villages in the study area are vulnerable to heavy rainfall in terms of agriculture. Within the framework of the weighted overlay analysis, more favorable characteristics denote attributes that heighten an area's vulnerability to heavy rainfall and its consequences, including flooding, erosion, and waterlogging. These characteristics encompass higher precipitation levels, resulting in heightened vulnerability to flooding and water logging; inclined terrains, which facilitate rapid runoff and enhanced erosion; specific geomorphological attributes, such as valleys and depressions, that readily collect water; soil types with diminished infiltration rates that exacerbate surface runoff; and increased drainage density, signifying regions where water flow is concentrated, thereby amplifying the risk of waterlogging if the drainage system is compromised. Collectively, these attributes assist in identifying areas that are more vulnerable to the detrimental impacts of heavy rainfall.

Table 4. Scale and weightages of thematic layers

Sl. No	Thematic layer	Class	Scale value	% of influence
1.	Heavy Rainfall (mm)	40–41	6	30
		38–39	5	
		36–37	4	
		34–35	3	
		31–33	2	
		27–30	1	
2.	Slope (%)	>10	6	20
		2–10	5	
		0.5–2	4	
		0–0.5	3	
3.	Drainage Density km/km^2	0.1–0.2	6	15
		0.2–0.6	5	
		0.6–1.0	4	
		1.0–1.4	3	
4.	Soil	Waterbody	6	15
		Clay	5	
		Clayey loam	4	
		Sandy loam	3	
5.	Geomor-phology	Brackish water creek, lake and shallow alluvial plain	6	20
		Beach ridge and coastal plain	5	
		Channel Bars	4	
		Paleo Channel	3	
		Burried channel and buried pediplain	2	
		Upland	1	

Identification of Primary Crops: A field survey was carried out in the vulnerable villages to determine the crops that are most susceptible to Heavy Rainfall. A total of 22 villages were selected from the 58 vulnerable villages for the purpose of this study. A questionnaire was used to collect data from 50 individuals, with at least two individuals being included from each village. After conducting extensive research, it has been determined that the main crops grown in this region are cashew nut, coriander, sugarcane, sweet potato, and turmeric.

Most Vulnerable Crop Selection: This research used a mixed methods approach to measure risk in a new way which is shown in Table 5. The score-based risk assessment method was used (Hegazi & Fouda, 2023), along with the DELPHI methodology for expert discussions (Grisham, 2009). The outcome relied on evaluations from specialists and recommendations from risk assessment for mitigating hazards. The methodology offers a comprehensive and expert approach to evaluating and reducing risks. Three tables with scores ranging from 0.5 to 5 will be provided to the people (M & K G, 2023). Although the Delphi method is useful for obtaining professional agreement, it has many main drawbacks for determining which most vulnerable crops should be subjected to heavy rainfall. Given its iterative character and several rounds of input needed, it takes time. The approach also mostly depends on the availability and will of professionals to regularly engage. Subjectivity can affect results even with best attempts towards unanimous approval. Furthermore, doing a Delphi

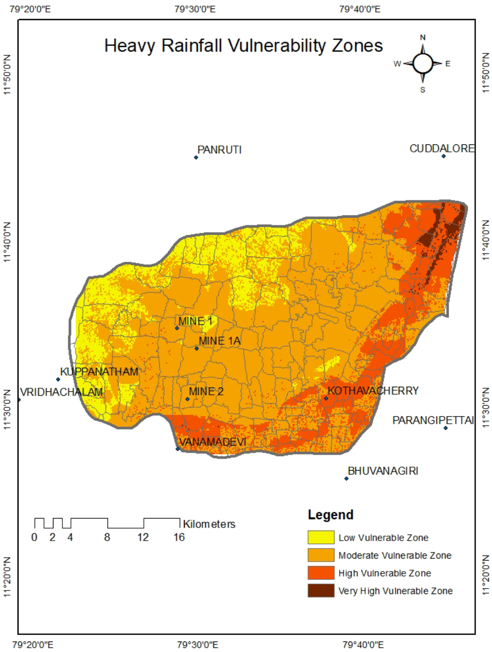
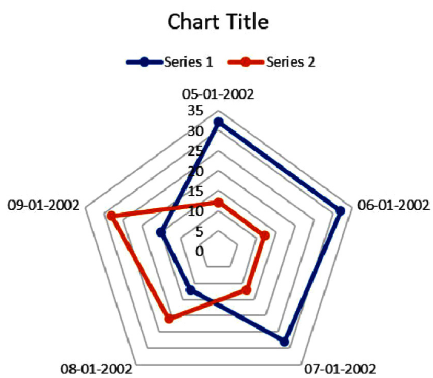
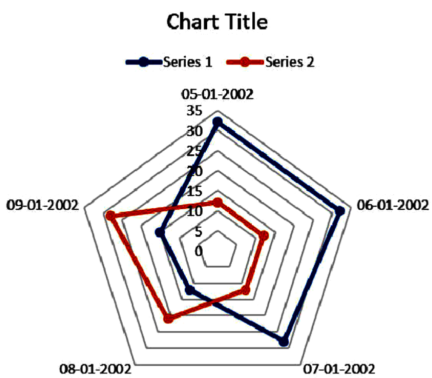


Figure 4. Heavy rainfall vulnerability map

survey calls for large time, money, and logistical support in addition. These restrictions draw attention to the requirement of giving great thought while applying the Delphi technique to guarantee its efficiency in spotting vulnerable crops with heavy rainfall. Table 1 displays the categorization of scores according to the frequency of heavy rainfall. Table 2 categorizes scores by the loss percentage caused by heavy rainfall, whereas Table 3 categorizes scores by the vulnerability of areas to heavy rainfall. This part of our study has been published (M & K G, 2023). The final magnitude of the risk assessment is determined by summing up the scores from all three tables. The Delphi technique involves three rounds of questionnaire surveys, refining the questionnaire based on prior responses. This study is conducted by a group of agricultural engineers, water resource managers, and farmers. The total number of respondents are 165 in which 20 are agricultural engineers and water resource managers residing in the study region and the remaining are farmers with a mixture of male, female, farmers with more than 15 years of experience and young farmers. Multiple surveys were conducted using the same sampling technique known as cluster sampling, which

Table 5. Mean of scores for the selected crops





Risk Elements	Risk No.	Cashew Nut				Coriander				Sugarcane				Sweet Potato				Turmeric				Mean	Risk Evaluation	Response
		A	B	C	Total	A	B	C	Total	A	B	C	Total	A	B	C	Total	A	B	C	Total			
Loss of crops	R1	2	2	1	5	4	5	5	14	3	2	1	6	3	3	3	9	4	3	3	10	8.8	Trigger	Crop management strategies
Damaged or spoiled crops	R2	3	2	2	7	5	5	5	15	3	3	2	8	3	4	3	10	4	4	3	11	10.2	Trigger	Crop management strategies
Soil erosion	R3	2	3	1	6	3	4	4	11	3	4	3	10	2	1	1	4	4	3	2	9	8	Trigger	Soil management strategies
Nutrient loss	R4	2	2	1	5	4	4	4	12	2	3	2	7	4	2	1	7	3	3	1	7	7.6	Secondary	Share knowledge
Water logging	R5	4	2	2	8	4	4	3	11	4	4	4	12	4	4	3	11	5	4	4	13	11	Trigger	Proper drainage
Leaching of nutrients	R6	3	1	1	5	3	3	3	9	3	3	2	8	4	2	1	7	3	2	2	7	7.2	Residual	Share knowledge
Restricted root growth	R7	1	1	1	3	4	4	3	11	3	3	2	8	4	3	2	9	4	2	3	9	8	Residual	Share knowledge
Loss of matured crops	R8	4	3	4	11	5	5	5	15	3	2	1	6	4	3	2	9	4	3	2	9	10	Trigger	Crop management strategies

15	14.5	14	13.5	13	12.5	12	11.5	11	10.5	10	9.5	9	8.5	8	7.5	7	6.5	6	5.5	5	4.5	4	3.5	3

Extreme Very High High Moderate Low Negligible involves selecting locations and then respondents within those areas. Cluster sampling is a method of sampling based on geographical proximity. The primary crops such as cashew nut, coriander, sugarcane, sweet potato and turmeric were considered for this study. Coriander is identified as the most vulnerable crop.

The main causes of the vulnerability of Coriander for heavy rainfall include damaged crops, loss of matured crops, and crop loss as a whole. Waterlogging brought on by heavy rainfall influences the root system and general plant health, therefore affecting growth and yield, which is addressed as damaged crops. Moreover, too much moisture might encourage the spread of fungal infections, so influencing crop quality and output, which influences the matured crops. Total crop loss results from the combination of crop damage and lost matured crops. These elements make coriander more vulnerable than other crops to the effects of heavy rainfall.

Reduced crop yields result in diminished income for farmers, hindering their ability to sustain livelihoods and invest in essential agricultural inputs. The financial strain lead to heightened debt and poverty levels in the community. The stress associated with crop failure result in food insecurity, which adversely impacts the health and well-being of families. Furthermore, migration patterns shifted, as certain families relocate to areas less susceptible to high intensity rainfall and water logging in pursuit of more stable agricultural conditions.

The broader implications underscore the necessity for effective adaptation strategies and support systems to assist farming communities in addressing the challenges associated with heavy rainfall and climate change.

Climate Smart Agriculture for Heavy Rainfall: Climate-smart agriculture is crucial for India and the G20 countries' Sustainable Development Goals (SDGs) (G-20 Agriculture Ministers' meeting, 2024). It involves sustainable intensification of agriculture, resilience to climate change impacts, and reduced emissions (World Bank, 2024). There are two types of measures formulated for Climate Smart Agriculture for Heavy Rainfall. There are measures taken to prevent damage before heavy rainfall and actions to reduce the impact after heavy rainfall. Various measures have been suggested to achieve the desired research objective. These include using crop covers, adjusting the crop season according to rainfall patterns and utilizing the Meghdoot application. Additionally, connecting drainage ditches, providing support to plants with extra sticks, and applying mulch around the crop roots are recommended. Some mitigation measures include implementing the Integrated Pest Management Technique, regularly monitoring for signs of mold, removing wet mulch, spreading salt, and avoiding stepping into waterlogged areas.

Integrated Pest Management Plan: Coriander crop yield more with honey bee pollination, so the pesticide should not repel honey bees. Carbendazim and mancozeb are the pesticides, Imidacloprid, acetamiprid and monostrophos are the insecticides and Sulphur and propiconazole is the fungicide. The majorly used pesticides, insecticides, and fungicides in the study region are the above. The central insecticide board and the registration committee has not recommended any use of pesticide to coriander crop. Also, imidacloprid and acetamiprid is highly lethal to honey bees. These show the lack of awareness among the farmers. From the questionnaire, Sulphur is yielding more when compared to propiconazole. Hence, it is recommended to use a combination of carbendazim and mancozeb as pesticide, monostrophos as insecticide and Sulphur as fungicide.

Linking social entrepreneurship with climate-smart agriculture: Furthermore, it is recommended to explore additional strategies, such as promoting social entrepreneurship through biochar production, to further enhance the effectiveness of Climate Smart Agriculture. Social Entrepreneurship is one of the ways which can provide socio-economic benefits (K G & M, 2019). Biochar is a form of charcoal produced through the thermal decomposition of biomass, without the presence of oxygen (Mohan et al., 2018). It is recommended for use in emission reduction efforts. The farmers are provided with social entrepreneurship insights through the establishment of a biochar kiln that focuses on group collaboration.

Proposing and fostering awareness of field practices to achieve increased resilience. Neighborhood citizen groups are asked to participate in the hearing phases and contribute their views on how to develop the Community Supported Agriculture (CSA) program to maximize its added benefits.

Kilns may be constructed manually in close proximity to the crops. Various kinds of kilns are available, although it is recommended to utilize brick kilns or cone-shaped kilns (Anand et al., 2022). Brick kilns are now operational in the vicinity of the research area. Charcoal manufacture from Prosopis Juliflora and brick making are present in this area, making farmers knowledgeable about kiln building. It is advisable to utilize cone-shaped kilns since they are more cost-effective than brick kilns. Social Entrepreneurship involves identifying social issues and using entrepreneurial strategies, processes, and activities to bring about social transformation (K G & M, 2019). A collective of farmers has the capacity to own a kiln and produce biochar. Excess biochar production may be marketed to create a small-scale enterprise for generating cash. The price of biochar varies from Rs. 50 to Rs. 150 as of September 12, 2023. Many individuals have experience working in fuel wood kilns and are familiar with brick kilns due to the prevalence of brick kilns in the area. A survey questionnaire was administered to 150 farmers in at-risk areas to assess their inclination towards social entrepreneurship via biochar production. 48% quickly accept the social entrepreneurship strategy, 36% are willing to execute after seeing one successful attempt, and 16% are not willing to implement which is shown in Figure 5.

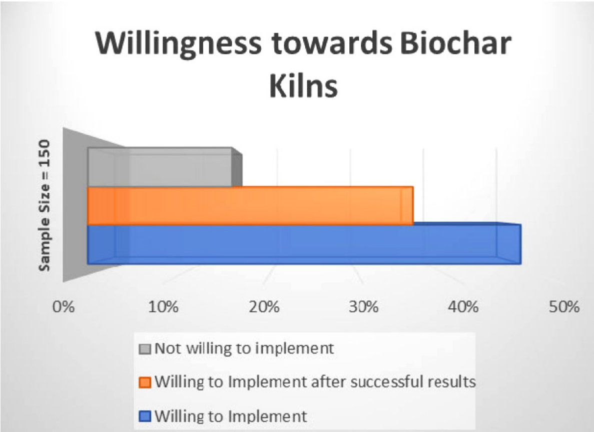


Figure 5. Willingness towards social entrepreneurship using biochar kilns

Adoption of Climate Smart Agriculture for Heavy Rainfall among Marginal Farmers: The implementation process involves determining the target population, gaining the reliability of the Meghdoot Application by using 2022 as the testing period, implementing the precautionary measures using the predictions from Meghdoot Application and implementing the mitigation measures such as Integrated Pest Management technique and crop coverings respectively. This group consisted of 19 individuals in which 5 individuals involved completely in agriculture and 6 individuals who transitioned to agriculture in 2003. The remaining 8 individuals currently own farmland and have secured employment outside of agriculture, making them financially stable and influential in their towns. The individuals who are economically strong from Kurinjipadi, Mel Bhuvanagiri, and Parangipettai were more receptive to climate-smart adaptation approaches compared to indigenous farmers. Out of 19 farmers, 2 are semi-medium-scale with 2–4 hectares of land. 2 farmers are small-scale with 1–2 hectares, while the remaining 15 are marginal farmers with less than 1 hectare. Farmers from seven villages have accepted the implementation of CSA along with meghdoot. The Meghdoot app is tested and the results from the application is shown to the farmers from September to December 2022 (Figure 6). The comparison of the Meghdoot app prediction with the real time data is shown to the farmers during September to December 2022. During testing, rainfall exceeding 10 mm is considered damaging for coriander. From September to December 2023, if the predicted rainfall exceeds 10 mm, farmers are advised to take preventive measures like using covers, mulching, and improving drainage. The red lines (01.09.2022, 20.10.2022, and 22.10.2022) represent the dates used to determine the extent of rainfall affecting the coriander crop. The implementation has been completed in seven villages: Kothavacheri, Ellaikudi, Sirupalaiyur, B.Kolakudi, Seeyapadi, Manjakollai, and B.Odaiyur (Figure 7).

The rainfall which was predicted by Meghdoot application is shown in Table 6 which was used as the data by the farmers during the implementation. Historical data shows that the highest rainfall occurs in November and December. To ensure timely harvest, farmers are insisted to start sowing in September and implement post-rain recovery procedures promptly after rainfall. Proposed measures include implementing Integrated Pest Management (IPM), using mulch to prevent soil erosion, and employing effective drainage techniques. Only three farmers opted for crop covers, which cost approximately Rs.15 per square foot. Post-rain recovery protocols involve monitoring for mold,

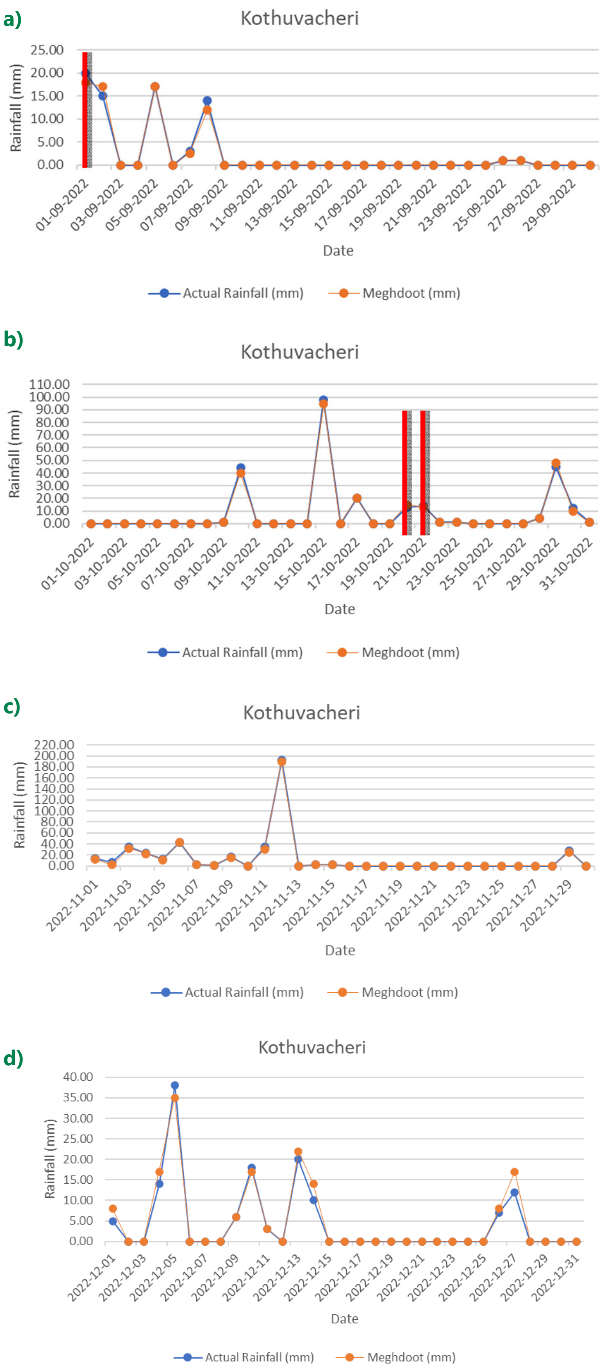


Figure 6. Comparison of Meghdoot application with the real time rain gauge rainfall data: a) September 2022; b) October 2022; c) November 2022; d) December 2022

Table 6. Rainfall predicted by Meghdoot application during 2023 (implementation period)

Rain prediction from Meghdoot (available before 5 days)							
September	Rain (mm)	October	Rain (mm)	November	Rain (mm)	December	Rain (mm)
16-Sep	10.3	07-Oct	11.2	02-Nov	11	01-Dec	13
29-Sep	11	21-Oct	13	04-Nov	11.1	03-Dec	10
30-Sep	10.6	29-Oct	10.5	09-Nov	13.9	04-Dec	175
		30-Oct	17.2	17-Nov	13	05-Dec	13.7
		31-Oct	24.6	25-Nov	14.7		
				27-Nov	14.7		

removing moist mulch, spreading salt, and avoiding stepping on waterlogged areas.

33 farmers successfully harvested the second season with minimal losses using pest management and Meghdoot. A survey revealed that 9% of the farmers had no significant losses, 54.54% had losses under Rs. 5000 which is marginal loss, and 36% had losses under Rs. 8000 which is minimal loss. The results are shown in Figure 8. After the successful revival of coriander cultivation, a survey showed that 78% were ready to implement IPM with Meghdoot, 4% were willing to implement IPM with Meghdoot and Cover, and 18% were willing to use cover with subsidies.

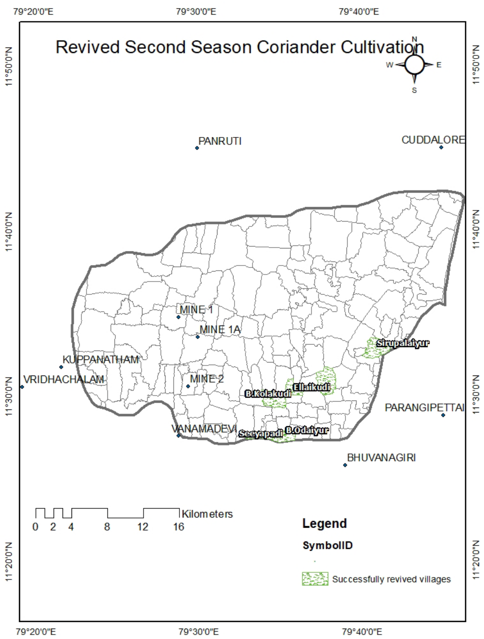


Figure 7. Villages with successful implementation of CSA for Heavy Rainfall

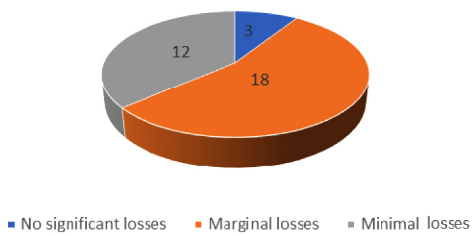


Figure 8. Losses after implementation of CSA

5. Conclusions

The Easy fit software determined the Gamma distribution as the best option for analyzing eight data points. This analysis used data from eight grid points over 42 years, resulting in rainfall criteria of 50.91 mm to 79.65 mm for heavy rain, 76.95 mm to 101.21 mm for extreme rain, and a threshold of 101.21 mm for rare events within a 24-hour period. The return period for heavy rainfall was found to be 3 years. Vulnerability mapping identified 58 highly vulnerable villages in the aspect of agriculture. After conducting research, it has been determined that the five primary crops in the 58 most vulnerable villages to heavy rainfall are cashew nuts, coriander, sugarcane, sweet potatoes, and turmeric. Through the utilisation of the Delphi technique, it has been determined that coriander is the crop with the highest susceptibility. One approach to address heavy rainfall in Climate Smart Agriculture involves implementing IPM strategies, adjusting crop seasons, and taking preventive measures based on predictions from the Meghdoot application. Climate-smart agriculture (CSA) comprises three fundamental components: the increase of production from agriculture, the enhancement of resilience, and the reduction of greenhouse gas emissions. The pillars directly address the issues associated with heavy rainfall in multiple ways: CSA practices, including conservation tillage and integrated pest management, enhance soil structure and fertility, resulting in more resilient crops that are less vulnerable to waterlogging and nutrient leaching from heavy rainfall. Resilience is improved in farming systems through CSA by encouraging preponing the seeding time. These practices mitigate the effects of heavy rainfall by decreasing the likelihood of complete crop failure. Emissions reduction is interconnected with heavy rainfall; practices such as enhanced water management and decreased reliance on chemical fertilizers can mitigate the environmental impact of agriculture. The combination of all the three pillars make the agriculture sustainable. This also includes protecting crops and closely monitoring them after periods of heavy rainfall. IPM covers one of the three pillars of CSA by focusing on controlling pests, specifically aphids in this region. Pesticides like carbendazim and mancozeb are used without harming honey bees, which are crucial for coriander production. Other insecticides like imidacloprid, acetamiprid, and monostrophos are also utilized. As an enhancement to CSA biochar making is insisted. Biochar, a type of charcoal produced through biomass decomposition without oxygen, is recommended for emission reduction efforts. A questionnaire survey shows that 44% of respondents are willing to implement social entrepreneurship towards biochar kiln. 33 farmers from 7 villages achieved a successful second season harvest with minimal losses by utilizing pest management and Meghdoot. A survey indicated that 9% of the farmers experienced no significant losses, 54.54% had losses below Rs. 5000, and 36% had losses below Rs. 8000. Following the successful revival of coriander cultivation, a survey revealed that 78% were willing to adopt IPM with Meghdoot, 4% were open to implementing IPM with Meghdoot and Cover, and 18% were interested in using cover with subsidies.

Future Scope

By means of the Climate Smart Agricultural Practices, this study effectively brought back coriander cultivation. This study can be further expanded by longitudinal studies spanning several geographical areas and varied agricultural environments enable evaluation of the consistency and generalisability of the results. Second, a more complete knowledge of vulnerability elements might result from combining qualitative observations from farmers with quantitative data from remote sensing and geographic information systems (GIS). Furthermore, by means of cooperative development and testing of adaptable agricultural techniques with farming communities, the suggested solutions can be refined and validated. Finally, including feedback systems and ongoing monitoring helps to guarantee that the strategy stays relevant and efficient for different agricultural societies and allows iterative developments.

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Author contributions

AKG executed the field research and analysis whereas KM supervised the work.

Disclosure statement

The authors declare that there is no conflicts of interest.

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