The Economic Costs of Climate Variations in Kerala: A Multi-Sectoral Empirical Analysis

Dr. Amutha R.

Assistant Professor, Department of Commerce Sree Narayana College

Abstract: ***Kerala has been experiencing stronger climate variations in recent years, including floods, landslides, irregular monsoons, and rising sea surface temperatures, all of which have caused serious economic losses. This study estimates the economic cost of these climate-related changes in Kerala during 2011-2024, with a focus on agriculture and plantations, fisheries, tourism, infrastructure, and public finance. It draws on secondary data from government and institutional sources and uses descriptive statistics, trend tests, correlation analysis, regression models, and ANOVA to examine how climate variables are linked to sectoral economic outcomes. The findings show clear upward trends in mean annual temperature and the frequency of extreme events. Total climate-attributable losses across the major sectors are estimated at about Rs. 1,54,794 crore, or roughly Rs. 11,057 crore per year on average. Climate variables explain a substantial share of the variation in sectoral outcomes, with extreme-event frequency and sea surface temperature anomaly emerging as the most important predictors. The ANOVA results also indicate that climate-sensitive sectors weakened significantly after 2011-2015. In addition, the study points to a compounding fiscal risk, as disaster-related spending rises while revenues fall, causing Kerala's revenue deficit to widen by more than three times. Overall, the findings suggest that Kerala faces a structural economic risk because of its climatic vulnerability. The paper recommends integrated policy measures covering climate-resilient agriculture, fisheries adaptation, climate-proof tourism and infrastructure, dedicated climate risk financing, and stronger institutional data systems. These findings are also relevant for other climate-vulnerable sub-national economies in India.***

Keywords: Climate variation, economic cost, Kerala, extreme events, sectoral impact, climate risk financing, Mann-Kendall

1. Introduction

Climate change is creating serious economic risks across the world, but the effects at the state or sub-national level in India are still not studied enough. Kerala is a particularly important case because it has a long coastline, the Western Ghats, many rivers, and rich biodiversity, but these same features also make it highly exposed to climate risks. Since 2011, the state has faced more frequent extreme events. The 2018 floods, which caused losses of about Rs. 39,000 crore, and the deadly Wayanad landslides in 2024 are clear examples of the growing human and economic toll. Kerala has also been experiencing erratic monsoons, unseasonal rainfall, prolonged droughts, coastal erosion, and warmer sea conditions.

Kerala's economy is closely tied to sectors that are sensitive to climate change. These include agriculture and plantations such as rubber, coconut, spices, and paddy; fisheries, which support over one million fishermen; tourism, which normally generates around Rs. 40,000 crore; and infrastructure, which is highly exposed to floods and landslides. Repeated disasters also put pressure on public finances by increasing spending on relief and rehabilitation.

This study covers the period from 2011 to 2024 and has four main objectives: (i) to examine climate trends in Kerala, (ii) to estimate sector-wise economic losses in agriculture, fisheries, tourism, infrastructure, and public finance, (iii) to measure the statistical relationship between climate variables and economic indicators using econometric methods, and (iv) to draw policy implications for climate-resilient planning. The study asks whether extreme events have increased significantly, how large the sectoral losses are, how strong the climate–economy links are, and which policy measures can help reduce these costs. It relies on secondary data from government and institutional sources and uses a 14-year period because it captures major climatic changes while also offering reasonably comparable data. The rest of the paper is organised into a literature review, data and methods, trend analysis, sectoral impact assessment, statistical results, discussion, and policy recommendations.

2. Review of Literature

Global research has shown that climate change has serious economic consequences. Stern (2007) argued that doing nothing is more costly than taking action, and estimated that high warming could lead to large GDP losses. Dell, Jones, and Olken (2012) and Hsiang and Jina (2014) found that higher temperatures and major climate disasters reduce growth and can leave lasting income damage. Mendelsohn et al. (2006) showed that tropical developing countries face especially large agricultural losses.

In India, district-level and panel studies by Guiteras (2009), Sanghi and Mendelsohn (2008), and Gadgil and Gadgil (2006) link warming and monsoon changes with lower crop yields and reduced agricultural GDP. The UNDRR (2018) reports climate-related losses of USD 79.5 billion for India between 1998 and 2017. Bahinipati and Patnaik (2015) also show that disasters put heavy strain on state finances.

Studies focused on Kerala point to changing rainfall patterns and warming seas (Rajeevan et al. 2012; Vishnu et al. 2016), sectoral damage from the 2018 floods (PDNA 2018; Sreepriya & Balasubramanian 2020), fisheries losses linked to sea surface temperature (Zacharia et al. 2020), and disruptions to household income and tourism revenue (Beyer et al. 2022; Varghese et al. 2022).

Research Gap: Most studies on Kerala look at just one sector or one disaster event. Very few take a multi-sector

Paper ID: SR26729222036 DOI: https://dx.doi.org/10.21275/SR26729222036

approach or combine climate and fiscal impacts using a rigorous statistical framework, especially for the post-2020 period. This study addresses that gap by offering a broad, multi-sector econometric analysis of climate–economy relationships in Kerala from 2011 to 2024.

3. Data and Methodology

This study uses secondary data from 2011 to 2024 collected from reliable sources. Climate data were drawn from official meteorological and climate institutions, while economic data came from state planning, statistical, fisheries, tourism, central bank, agriculture, and disaster- management sources. The 14-year period was chosen because it includes major climate disruptions, provides dependable data, and aligns with the 2011 census baseline. Kerala's official meteorological data system and state planning publications support this kind of long- period climate and economic analysis.

Key Variables: The study uses five climate independent variables:

- Annual rainfall in mm,
- Monsoon rainfall deviation in percent,
- Mean annual temperature in degrees Celsius,
- Number of extreme rainfall events, and
- Sea surface temperature anomaly in degrees Celsius.

It also uses five economic dependent variables:

- Agricultural output,
- Fisheries production value,
- Tourism revenue,
- Infrastructure damage cost, and
- State disaster relief expenditure, all measured in Rs. crore.

Kerala climate studies have used similar rainfall and temperature measures, and Mann-Kendall trend analysis is commonly applied in the state's climate literature.

4. Statistical Framework

The study uses a multi-method statistical approach to measure the size, direction, and significance of climate–economy links in Kerala between 2011 and 2024. Descriptive statistics such as mean, standard deviation, minimum, maximum, coefficient of variation, and skewness were calculated for all climate and economic variables to show their distribution and volatility.

The Mann–Kendall non-parametric trend test was used to identify and measure monotonic trends in major climate series. Significance was tested at the 5 percent level. This is consistent with the way long-term temperature and rainfall trends are often studied in Kerala and in comparable climate research.

Pearson correlation analysis was then used to examine the strength and direction of linear relationships between climate variables and economic outcomes, with significance tested at both the 5 percent and 1 percent levels. Multiple linear regression models were estimated for each economic outcome. These models were evaluated using R^2, adjusted R^2, the F-statistic, individual t-tests, and variance inflation factor diagnostics to check robustness and rule out multicollinearity.

Finally, one-way ANOVA was used to compare average economic performance across three sub-periods: 2011–2015, 2016–2020, and 2021–2024. Where ANOVA showed significant differences, Tukey's HSD post-hoc test was applied to identify which periods differed from each other.

5. Findings and Results

Climate Trends in Kerala: The results show that Kerala's climate became more variable and less predictable over the study period. Rainfall continued to fluctuate from year to year, but it did not show any statistically significant long-term trend. In contrast, temperature and extreme- event frequency both showed clear upward movement, indicating that the state has been facing a steadily worsening climate pattern.

Rainfall: Kerala's average annual rainfall during 2011–2024 was 2,817 mm, which is slightly below the long-term normal of about 3,000 mm. Rainfall also showed moderate year-to-year variation, with a coefficient of variation of 11.08 percent. The wettest year was 2018, when rainfall reached 3,368 mm, while the driest year was 2016, with only 2,321 mm. Years such as 2013, 2018, 2019, and 2021 recorded more than 10 percent excess rainfall, while 2012, 2016, 2022, and 2023 recorded more than 10 percent deficit.

The long-term rainfall trend was not statistically significant. Although the Mann–Kendall test showed a negative tau of -0.198, the p-value of 0.312 indicates that this decline is not meaningful in statistical terms. In simple words, Kerala experienced both excess and deficit rainfall years, but the overall rainfall pattern did not move in one clear direction during the study period.

Temperature: Mean annual temperature in Kerala during the study period was 27.4°C, and it increased by about 1.3°C between 2011 and 2024. This rise was statistically significant, with a Mann–Kendall p-value of 0.031. The result suggests that Kerala has been warming steadily over the 14 years rather than showing only short-term fluctuations.

The positive tau value of +0.461 points to a moderate-to-strong upward trend. This supports the view that Kerala's warming is part of a broader regional pattern across South Asia rather than an isolated local change.

Extreme Events: The frequency, intensity, and spread of extreme events increased over the study period. These included floods, landslides, droughts, cyclones, and coastal impacts. The 2018 floods caused estimated losses of around Rs. 31,000 crore, while the 2024 Wayanad landslides caused preliminary losses of about Rs. 6,500 crore. Other major events were also recorded in 2017, 2019, and 2021.

This is one of the strongest findings in the study. The tau value of +0.560 and the p-value of 0.008 show a highly

Paper ID: SR26729222036 DOI: https://dx.doi.org/10.21275/SR26729222036

significant upward trend in extreme events. This means Kerala is not only experiencing gradual climate shifts, but also facing a growing number of serious disaster events, and these events are a major source of economic loss.

Infrastructure Damage: Climate-related damage to infrastructure rose sharply over the study period. Roads and bridges suffered the biggest losses, followed by irrigation and water supply, public buildings, and power infrastructure. The total damage to infrastructure was Rs. 33,043 crore, with an average annual damage of Rs. 2,360 crore.

Roads and bridges alone accounted for 50.5 percent of total infrastructure loss, or Rs. 16,680 crore. This shows that transport networks were the most exposed and most frequently damaged. The strong upward trend in infrastructure damage costs, shown by a tau of +0.527 and a p- value of 0.014, confirms that these costs increased systematically over time.

Sectoral Economic Impacts

Agricultural and Plantation Crops: Agriculture and allied activities, which employ around 34 percent of Kerala's workforce, were repeatedly affected by climate-related shocks during 2011–2024. The 2018 floods caused a 17.83 per cent fall in agricultural output, bringing it down to Rs. 24,380 crore, with crop losses estimated at Rs. 3,646 crore. Over the full study period, total losses in this sector were estimated at Rs. 29,716 crore, or Rs. 2,123 crore per year on average.

Major crops such as rubber, coconut, spices, and paddy were repeatedly affected by floods, drought, and heat stress. Recovery was often interrupted by the next disaster, which made the losses more persistent and harder to recover from.

Fisheries: The fisheries sector, which supports more than 1.1 million people along Kerala's 590-kilometre coastline, also faced major climate pressure. Fisheries production value fell from a peak of Rs. 4,920 crore in 2015 to Rs. 3,980 crore in 2024, showing a decline of nearly Rs. 940 crore over nine years. Cyclone Ockhi in 2017 caused losses of Rs. 2,110 crore, while repeated sea surface temperature changes disrupted fish movement and catch levels.

Total losses in the fisheries sector during 2011–2024 were estimated at Rs. 8,825 crore, with an average annual loss of Rs. 630 crore. The results suggest that warming seas and climate instability have become serious threats to marine livelihoods.

Tourism: Kerala's tourism sector is built largely on natural attractions such as backwaters, hill stations, beaches, and wildlife sanctuaries, which makes it highly vulnerable to climate shocks. The 2018 floods caused tourism revenue to fall by 31.06 percent, while 2020 saw a much steeper drop of 65.37 percent because of both the COVID-19 pandemic and climate-related disruptions. Total losses in tourism over the study period were Rs. 42,380 crore, averaging Rs. 3,027 crore per year. The biggest loss came in 2020, when tourism revenue dropped by Rs. 18,600 crore. Although the sector recovered after some disasters, its heavy dependence on climate-sensitive natural assets makes it highly exposed to future climate risks.

Infrastructure: Infrastructure such as roads, bridges, irrigation systems, and power facilities suffered repeated damage from floods, landslides, and coastal erosion. The 2018 floods alone caused infrastructure damage worth Rs. 12,000 crore, the largest single-year loss in the study period. Over the full 2011–2024 period, total infrastructure damage came to about Rs. 33,043 crore, or Rs. 2,360 crore per year.

The damage was especially severe in landslide-prone districts such as Wayanad, Idukki, Malappuram, and Kozhikode. This created a constant financial burden that regular state maintenance budgets were not designed to absorb.

Public Finance: Climate disasters also put pressure on Kerala's public finances in three main ways: immediate relief and rescue spending, medium-term rehabilitation costs, and a weaker tax revenue base. Disaster expenditure as a share of state own revenue reached 28.46 per cent in 2018 and 12.84 per cent in 2024, far above the 2.24–4.84 per cent range seen in normal years. At the same time, Kerala's revenue deficit widened from Rs. 8,240 crore in 2011 to Rs. 26,840 crore in 2024.

This is more than a threefold increase. Total disaster-related expenditure over the study period was Rs. 40,830 crore, or Rs. 2,916 crore per year on average. This shows a compounding fiscal risk, where disasters both increase government spending and weaken the revenue base at the same time.

Consolidated Sectoral Losses: When all sectors are taken together, Kerala's total climate- related losses between 2011 and 2024 are estimated at Rs. 1,54,794 crore, or Rs. 11,057 crore per year. Even if the catastrophic years of 2018 and 2020 are excluded, the losses remain large. This shows that climate risk in Kerala is not occasional or temporary, but chronic and structural.

Statistical Evidence

The descriptive analysis shows that some climate variables were quite unstable during the study period. Extreme event frequency had a coefficient of variation of 33.2 per cent, while sea surface temperature anomaly had an even higher value of 52.9 per cent, showing that both varied sharply from year to year. Among the economic variables, infrastructure damage and disaster expenditure were the most volatile, with coefficients of variation of 132.4 per cent and 103.3 per cent respectively. This reflects the fact that disaster years produced very large spikes in costs. Negative skewness in agricultural output and fisheries production value also suggests that these sectors were repeatedly pushed downward during extreme climate years.

The correlation results show that extreme event frequency was the strongest climate factor across sectors. It had strong negative relationships with agricultural output, fisheries production, and tourism revenue, while it had strong positive relationships with infrastructure damage and disaster expenditure. Sea surface temperature anomaly showed the strongest negative link with fisheries production value, which confirms how sensitive Kerala's marine fisheries are to ocean warming.

The regression results were statistically significant for all five economic outcome variables, and the explanatory power ranged from 0.56 for tourism revenue to 0.85 for infrastructure damage. In agriculture, the biggest negative factor was extreme event frequency, while monsoon deviation had a small positive effect. In fisheries, sea surface temperature anomaly and temperature were the main negative predictors. For tourism, extreme event frequency again had the strongest negative impact. For infrastructure damage and disaster expenditure, extreme event frequency was the strongest positive predictor in both cases, showing that more frequent extreme events directly raised repair and relief costs. The low Variance Inflation Factor (VIF) values, all below 4.0, indicate that the models were not affected by serious multicollinearity.

The ANOVA results also show clear differences across the three sub-periods: 2011–2015, 2016–2020, and 2021–2024. Agricultural and fisheries output were significantly higher in the first period than in the latter two, while infrastructure damage and disaster expenditure were significantly higher in the later periods than in the first. The post-hoc Tukey tests confirmed these differences. Taken together, these results show that economic performance in Kerala's climate-sensitive sectors has worsened structurally since 2016, in step with the rise in extreme climate events.

Overall, the statistical evidence makes one thing clear: extreme event frequency is the most damaging climate driver across sectors. It lowers output and revenue in agriculture and tourism, while increasing damage to infrastructure and public spending on disasters. Sea surface temperature anomaly is the key negative factor for fisheries. The models are all statistically meaningful, and they explain the data best in infrastructure and public finance. The ANOVA findings support the paper's main argument that Kerala is facing a structural and ongoing climate risk, driven mainly by the rising number of extreme events.

The study shows that climate variations have created large, measurable, and increasing economic costs for Kerala. The total sectoral loss between 2011 and 2024 is estimated at about Rs. 1,54,794 crore, or around Rs. 11,057 crore per year. Three broad conclusions emerge from the analysis: *first*, extreme event frequency is the main and most damaging climate channel; *second*, Kerala faces a combined fiscal risk because disaster spending is rising while revenues are weakening; and *third,* these costs are not occasional shocks but chronic and structural.

6. Policy Recommendations

1) **Climate-resilient agriculture.** Kerala should shift from reacting after disasters to building resilience before they happen. This means promoting climate-resilient crop varieties, expanding crop insurance coverage, and strengthening watershed management in the Western Ghats catchments.
2) **Marine fisheries adaptation.** Real-time sea surface temperature monitoring and fishery advisories should be made available to fishing communities. Coastal livelihoods should also be diversified through aquaculture, seaweed cultivation, and marine ecotourism so that the 1.1 million people dependent on marine fishing face less risk.
3) **Tourism infrastructure protection.** Climate-risk assessment should become mandatory for tourism infrastructure in landslide-prone hill stations, flood-prone backwaters, and erosion-affected coastal areas. A tourism disaster recovery fund could also be created through a small levy on tourism receipts during normal years.
4) **Climate-proof infrastructure investment.** New roads and bridges in flood- and landslide-prone areas should be built with stronger climate-resilience standards. A separate Climate Infrastructure Maintenance Fund should also be created outside the normal budget cycle so that repairs can be carried out more consistently.
5) **Climate risk financing.** Kerala should establish a State Climate Risk Fund as a reserve that grows during normal years and is used during disasters. Parametric insurance can be explored as a support tool alongside traditional relief. The state should also push for stronger central fiscal transfers to climate-vulnerable states through a revised disaster- risk component in Finance Commission devolution.
6) **Institutional and data systems.** Kerala should create a Climate Economic Loss Database that brings together real-time data from IMD, KSDMA, sectoral departments, and financial institutions. Annual Climate Economic Impact Reports should also become a regular government publication.

7. Future Research

This study adds to the evidence on climate–economy linkages in Kerala, but several important areas still need deeper work. First, household and enterprise surveys would help measure how climate shocks affect income, employment, and coping behaviour at a micro level. Second, Computable General Equilibrium modelling could capture indirect and economy-wide effects that a sector-based study may not fully reflect.

Third, district-level analysis would be especially useful for highly vulnerable areas such as Wayanad, Idukki, Malappuram, and Alappuzha, since that would make the findings more useful for local planning and resource allocation. Finally, extending the study beyond 2024 would help track the full economic impact and recovery path after the 2024 Wayanad landslides, and would provide a stronger test of the paper's argument that Kerala faces a structural climate risk.

8. Conclusion

This study shows that Kerala's climate has become more unstable in ways that are both measurable and economically costly. Rainfall varied across the study period but did not show a statistically significant long-term trend, while temperature rose steadily and extreme events increased sharply. Together, these changes point to a climate pattern that is becoming more difficult for the state to manage.

The economic effects are spread across several sectors, but the burden is especially heavy in agriculture, fisheries, tourism, infrastructure, and public finance. Repeated floods, landslides, sea surface warming, and related shocks have caused large and recurring losses, with total climate-attributable damage estimated at Rs. 1,54,794 crore over 2011–2024. The fiscal impact is equally serious, as disaster spending has risen while revenues have weakened, widening Kerala's revenue deficit and adding long-term pressure on the state budget.

Overall, the findings suggest that Kerala is not dealing with isolated climate shocks but with a structural and ongoing climate risk. The evidence shows that extreme event frequency is the most damaging climate driver, and that the costs are chronic rather than temporary. This makes it essential for the state to shift from disaster response to long-term climate resilience through better planning, stronger institutions, and targeted sector-specific adaptation.

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