Research Paper

Climate and disaster risk assessment for sustainable coastal tourism: a study of puri in odisha

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ABSTRACT

Background: Coastal tourism contributes to regional development, but due to climatic changes and frequent occurrences of hydro- meteorological risks, coastal tourism is becoming a matter of concern in sustenance. On the Bay of Bengal coast of India, tourists are becoming increasingly exposed to the effects of cyclones, storm surges, excessive rainfall, floods, erosion, and sea level rise. Puri (Odisha) is a case that is critical because of a significant tourist inflow and concentrated coastal development in the area of hazardous activity.
Objective: To conduct an integrated climate and disaster risk assessment for sustainable coastal tourism in Puri by profiling hazards, tourism exposure, ecological buffering, preparedness using an evidence-based framework.
Methods: The secondary-data method of a quantitative design was used with the official datasets (XLS). It was tested using the Hazard-Exposure-Vulnerability-Risk (HEVR) framework, which analyzed the long-term monitoring of temperature changes (1901-2021), indicators of disaster losses (cyclones, heavy rainfall, floods), tourism pressure tendencies, ecological resilience (forest/tree cover), and preparedness proxies (cyclone shelters). The check was done by descriptive and comparative trend analysis.
Results: Odisha has also exhibited continuous warming, with the mean annual temperature increasing between 25.03 °C (1910s) and 25.86 °C (2010s-2020s), with the highest of annual maximum temperatures concentrated since 2009. Records on disasters reveal that there are high-impact years periodically with sharp increases in the loss of housing, livestock, and crops, which represent long-term vulnerability to cyclones and floods. Puri has minimal ecological protection (forest cover 5.95% of geographical area), that is more susceptible to storm surge, inundation, and erosion. Even though Odisha cyclone shelter cover is relatively high, the vulnerability of tourism is high because of the localized coastal development and planning loopholes.
Conclusion: Risk-informed coastal tourism planning is essential for Puri, prioritising hazard zoning, ecosystem restoration, climate-resilient infrastructure, and strengthened governance to ensure long-term sustainability.

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1. INTRODUCTION

Coastal tourism is acknowledged as an effective tool of regional development as it generates employment, improves destination image, and boosts related sectors, namely transport, hospitality, handicrafts, and local trade. Nevertheless, the expansion of tourism in climate-dependent coastal areas is now confronting compound vulnerability due to climate and disaster risks such as cyclones, storm surges, sea-level rise [1], rising seawater levels, erosion of coastal zones, and depletion of ecosystems [2] [3]. These threats are very pertinent to the Bay of Bengal coastlines of India, where cyclones, with high intensity, quite often visit, creating hydrometeorological disasters that act as factors disturbing tourism systems there and thus posing risks on long-term sustainability [4], [5]. In this regard, an assessment of climate and disaster risk also becomes crucial to ensure that tourism development is both resilient and low-carbon and ecologically sensitive [6].

The State of Odisha fits well in such an assessment as it has great tourism potential and high hazard exposure. One of the popular pilgrimage cum beach tourism spots in India is Puri, which represents a heavy influx of tourists all over the year, and substantial dependence on tourism-based infrastructure, in particular, tourism services [7]. Tourist statistics show that there has been clear growth in visitor numbers at the state and destination levels, inducing demand and fostering investment in tourism circuits on the coast. Growing tourism pressure not only increases environmental burden on beaches, dunes, coastal vegetation, and water quality [8], but also increases infrastructure exposure in hazard-prone areas. Interaction between development pressure and climate stress. Thus, Puri is a good case example of presenting risk-informed sustainable tourism planning [9].

An important risk factor in coastal Odisha is the return of tropical cyclones with their associated storm surges. Multi-hazard mapping methods indicated that cyclone strength [10], [11], wind exposure, the height of storm surge, amount of heavy rain, and inundation levels resulting from flooding all combine to produce highly variable risk patterns along the Odisha coast [12]. Coastal vulnerability studies of Odisha empirically also validate that the impact of floods does not depend on only the magnitude but varies characteristically with other settlement-related and livelihood dependent set up, as well as preparedness to withstand such disaster underscoring the need for integrated vulnerability indices for planning [13], [14]. District level estimates also show that Puri continues to be one of the most vulnerable coastal districts with low-lying land, and people and critical infrastructure are concentrated near the coast [15], [16]. Evidence from disaster loss records also underscores that cyclones, flooding, and extreme precipitation are still causing significant economic and infrastructure losses, which negatively impact coastal service delivery, including on the activities of the tourism sector.

Besides episodic instances, long-term instability of the shoreline also challenges the sustainability management of Puri's coastal tourist resources. Remote sensing studies conducted on the coast of Puri indicate that erosion accretion cycles of various intensities have taken place over several decades, accelerating during years of harshest cyclones as well as degradation due to anthropogenic activities such as the construction of coastal engineering structures and unregulated growth [17]. The applicability of integrated coastal zone management and ecosystem-based adaptation strategies is supported by the fact that books on vulnerability frameworks applied to Odisha also identify both floods along a coast and erosion as existing risks [18]. Further, projections of sea-level rise for the Odisha coast already show that there are increasing long-term (30–50-year) risks to coastal settlements, tourist-area infrastructure, and biophysical buffers, which makes it hard not to scale up adaptation plannin.

Governance and preparedness also affect tourism vulnerability. It has been suggested that risk reduction investment, planning integration, and co-operation among stakeholders are lacking in the disaster-affected destinations to still be vulnerable [19]. Though month-term resilience in Odisha has been enhanced through greater availability of cyclone shelters and disaster preparedness, it is necessary that the planning process for tourism development integrates, as well, systematically hazard zoning and infrastructure resilience with ecosystem conservation and community engagement [20], [21]. Thus, this research conducts a climate and disaster risk profiling of sustainable coastal tourism in Puri (Hazard Exposure; factors driving Vulnerability; resilient strategies based on evidence), contributing to the safer and more sustainable development of destinations.

1.1. Need for the Study

Puri's coastal tourism economy is expanding rapidly, yet it remains highly exposed to cyclones, floods, storm surges, shoreline erosion, and climate variability. A climate and disaster risk assessment is required to identify hazard hotspots, vulnerability drivers, and resilience strategies to support sustainable, safe, and climate-adaptive coastal tourism development.

1.2. Research Gap

Most Odisha-focused studies examine cyclones, flooding, or shoreline change separately, while tourism studies largely emphasise growth and visitor trends. Limited research integrates climate hazards, disaster loss records, long-term climate indicators, and tourism infrastructure exposure specifically for Puri. Hence, an integrated risk framework for sustainable coastal tourism remains underdeveloped.

2. RELATED WORK

The systems of coastal tourism are now being realised as very susceptible to the climate fluctuations and also risks of disasters, especially in the cyclone-prone areas. Emphasized that the weaknesses of sustainable coastal tourism in India include gaps in governance, poor involvement of the people, and insufficient integration of environmental protection measures, which include the high-risk areas in the coastal region. Such structural constraints increase the vulnerability of the destination in spite of the economic potential of tourism. Majoring on the disaster risk, created the Tourism Disaster Vulnerability Framework that shows that the tourism exposure depends not merely on the intensity of hazards but also on the planning failures, the lack of individual investments dedicated to risk mitigation, and the degradation of the environment. Their framework offers a conceptual approach to the vulnerability of tourism due not only to physical hazards, but also to other things [2].

To the Odisha coast, reported having an assessment involving multiple hazards using the GIS method and noted that the Odisha state experiences the greatest exposure to cyclones along the east coast of India due to the escalation in cyclone intensity and storm surges in the Bay of Bengal. Their results highlighted the necessity of combined coastal vulnerability indices, which involved physical, social, and environmental parameters [6]. Instead of looking at the instability of the shorelines in general, a few studies have considered a specific shoreline around Puri. Describe the faster process of coastal erosion at the Mahanadi delta and the Puri coast, and attribute the erosion to severe cyclonic events and uncontrolled erosion development. Such geomorphological transformations pose a direct threat to tourism infrastructure and beach-based livelihoods [5], [8].

Planning and resilience. Made the argument that integrated urban planning, ecosystem protection, and climate-resilient infrastructure are the key to coastal tourism sustainability. To supplement this [1] suggested the idea of disaster-resilient eco-communities in the city of Puri, with special attention paid to the community-based practices and restoring the ecology as the key elements of risk management.

On the whole, the literature shows that it is believed that the Puri coastal tourism susceptibility is a confluence of climatic warming, repeated hydro-meteorological risks, ecological deficiency, and governance restrictions, thus considering the need to incorporate a neighborhood climate and catastrophe risk evaluation.

3. METHODOLOGY

3.1. Study Design

This study used a quantitative secondary data-based approach to assess climate and disaster risk dimensions, of importance for sustainable coastal tourism in Puri, Odisha. The research has incorporated variability in long-term climate, historical impacts of disasters, indicators of ecological resilience, and patterns of growth in tourism within an evidence-based framework for risk assessment [2], [6].

3.2. Study Area

The study was conducted in the Puri district situated on Odisha's coastal plain along the Bay of Bengal. Puri, a globally known pilgrimage/bathing tourism destination, is considered as hot spot of beach tourism activities, and the tourism infrastructure and assets exist near the sea, which also intensifies the exposure of hotels, public amenities, and transport services to coastal hazards [18]. The district is extremely susceptible to tropical cyclones, storm surges, heavy precipitation, coastal flooding, and erosion, while these hazards continuously damage livelihoods and infrastructure, leading to direct challenges for the sustenance of tourism [6], [8], [22].

3.3. Data Sources

All analyses used official secondary data that have been made available by Govt on CSV/XLS formats. of Odisha and the Central Govt. Climate variation Analysis of the Odisha time series data for annual and seasonal mean temperature (1901–2021) with positive, negative, and average temperature indices was conducted as per the published sources. Cyclonic storm, heavy rainfall, flood, and associated disaster exposures were assessed based on state-level damage records due to cyclonic storms (North Eastern states not considered), heavy rain, and flood, along with multi-purpose cyclone shelters as a proxy indicator of preparedness. We quantified tourism pressure based on the India Tourism Statistics data and related tourism indicators. Environmental resilience was measured based on forest (Odisha;district-wise) and tree cover data, and the government records of eco -tourism projects sanctioned.

3.4. Analytical Framework and Procedure

The study was guided by the Hazard–Exposure–Vulnerability–Risk framework. The hazards were characterized by disaster damage records and long-term climate indices, and the exposure was measured as time-varying tourism activity and population density. Vulnerability was mirrored with ecological buffer indicators and preparedness infrastructure in a way similar to that in coastal vulnerability literature. Governing and planning capacity are factors in tourism disaster vulnerability; therefore, institutional preparedness indicators were considered with interpretation [2].

3.5. Data Analysis

After the collection of these datasets, they were straightforwardly analyzed through descriptive and comparative examination, percentage shares, inter-annual fluctuation, and long-term pattern interpretation. Also cross-referenced the outcomes with climate, disaster, and tourism databases to identify undertaking risk signals that may be useful for sustainable coastal-led resilient planning along Puri [6], [13].

4. RESULTS AND DISCUSSION

As shown in Table 1, the Key indicators of the baseline state. Odisha is one of the largest states in India, both in terms of geographical area and population. The majority of its inhabitants are domiciled as rural population, which signifies that agriculture dominates livelihoods, with thick dependence on natural resources. The sizable tribal population also indicates varied patterns of vulnerability owing to socio-economic and geographical marginality.

Table 1. Odisha State Profile Indicators (2013 Forest Bulletin)

Particulars	Specifications
Geographical Area	155,707 sq km
Population (as per Census 2011)	41.97 million
Population (as per Census 2011) - Urban	7.00 million (16.68%)
Population (as per Census 2011) - Rural	34.97 million (83.32%)
Population (as per Census 2011) - Tribal	9.59 million (22.85%)
Average Population Density	270 per sq km
Livestock population (as per 18th Livestock Census)	23.06 million
No. of Districts (as per Census 2001)	30
No. of Districts (as per Census 2001) - No. of Tribal Districts	12
Forest Cover within Green Wash - Very Dense Forest	6,780 sq km
Forest Cover within Green Wash - Moderately Dense Forest	19,646 sq km
Forest Cover within Green Wash - Open Forest	17,555 sq km
Forest Cover within Green Wash - Sub Total	43,981 sq km
Forest Cover outside Green Wash - Very Dense Forest	262 sq km
Forest Cover outside Green Wash - Moderately Dense Forest	1,652 sq km
Forest Cover outside Green Wash - Open Forest	4,452 sq km
Forest Cover outside Green Wash - Sub Total	6,366 sq km
Total Forest Cover	50,347 sq km
Tree Cover	4,013sq km
Total Forest & Tree Cover	54,360 sq km
Total Forest & Tree Cover - Per Capita Forest & Tree Cover	0.129 ha
Total Forest & Tree Cover - Of the State's Geographical Area	34.91%
Total Forest & Tree Cover - Of India's Forest & Tree Cover	6.89%
Growing Stock - Growing Stock in Recorded Forest Area	235.77 million cum
Growing Stock - Growing Stock in TOF	74.49 million cum
Growing Stock - Growing Stock in Agroforestry	65.19 million cum
Growing Stock - Growing Stock in Urban Area	3.61 million cum
Recorded Forest Area - Reserved Forest	26,329 sq km
Recorded Forest Area - Protected Forest	15,525 sq km
Recorded Forest Area - Unclassed Forest	16,282 sq km
Recorded Forest Area - Total	58,136 sq km
Recorded Forest Area - Of the State's Geographical Area	37.34%
Recorded Forest Area - Of India's Forest Area	7.53%

As shown in Table 2 and Figure 1, there is marked spatial variation of forest cover in the state of Odisha. The highest forest cover is experienced in Kandhamal (66.96%), followed by Gajapati (57.13%) and Sambalpur (50.44%). The forest cover changes are also differentiated. Kandhamal (-98) and Gajapati (-16) now have less, but Malkangiri (+135) and Sundargarh (+96) have more. In combination, they demonstrate district-level variation in ecological buffering capacity and resistance that is relevant to climate risk planning.

Table 2. Top Ten Districts in Odisha Ranked by Forest Cover Percentage of Geographical Area(GA) (2013)

District	Percent of GA	Change
Khandamal	66.96	-98
Gajpati	57.13	-16

Sambalpur	50.44	49
Deogarh	46.77	34
Rayagada	44.3	17
Nayagarh	43.24	17
Sundargarh	42.71	96
Angul	42.38	35
Boudh	40.77	8
Malkangir	40.08	135

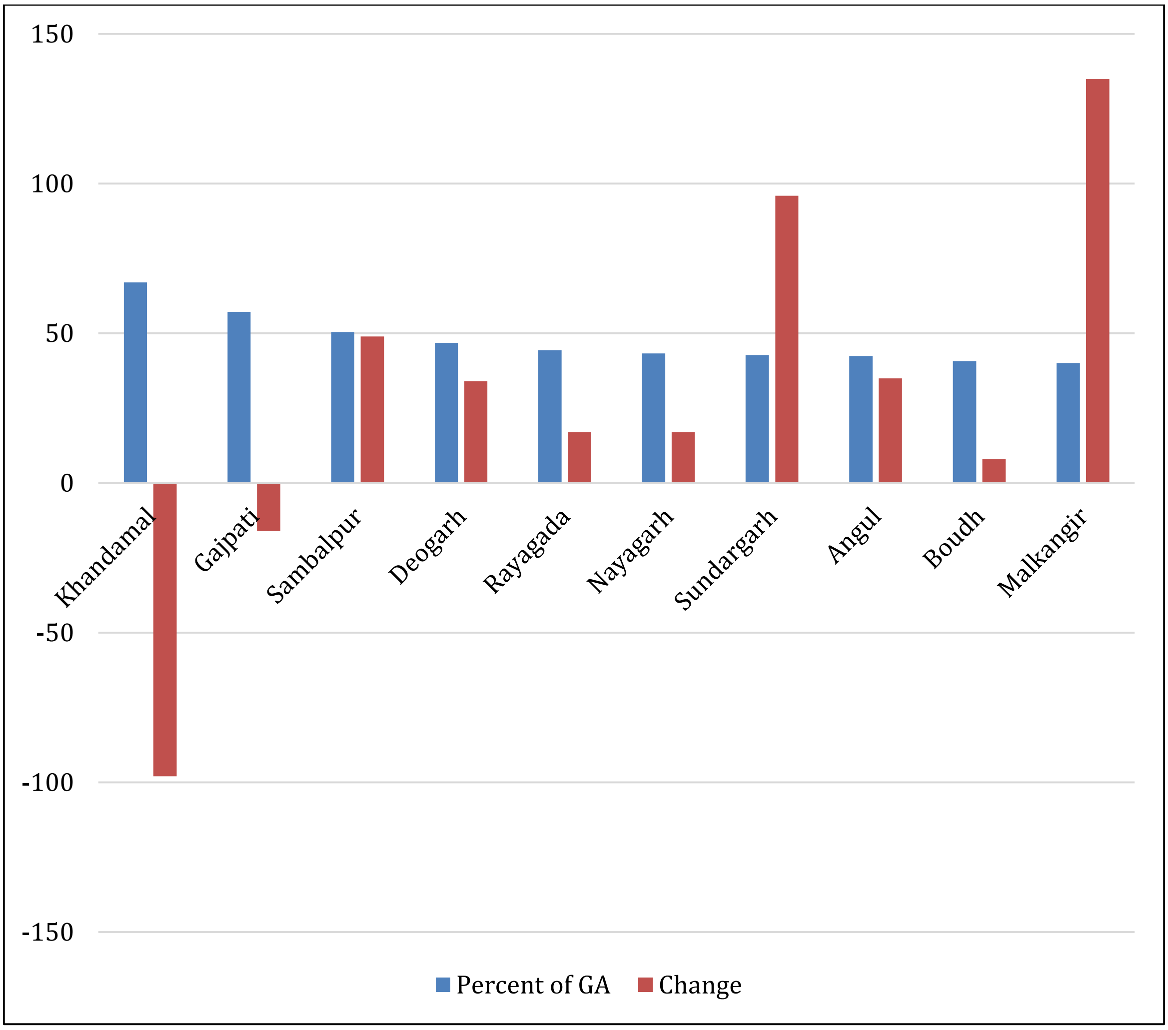

Figure 1. Top Ten Districts in Odisha Ranked by Forest Cover Percentage of Geographical Area(GA) (2013)

As shown in Table 3 and Figure 2, that Puri district possesses an extremely low forest, its total actual forest area is 207, and the percentage of GA under forest is only 5.95 in the year 2013. It is lower than that from most of the forest-dominant districts in Odisha, indicating little ecological buffering to coastal hazards. However, the positive change (+107) is an improvement over the last evaluation, indicating some rebound in forest extent. Despite the addition of this surplus 55 million hectares, the forest is still not at a level that offers strong climate resilience.

Table 3. District-Level Forest Cover Composition and Percent Coverage for Puri District, Odisha (2013)

District	2013 Year	Percent of GA	Change
Puri	207	5.95	107

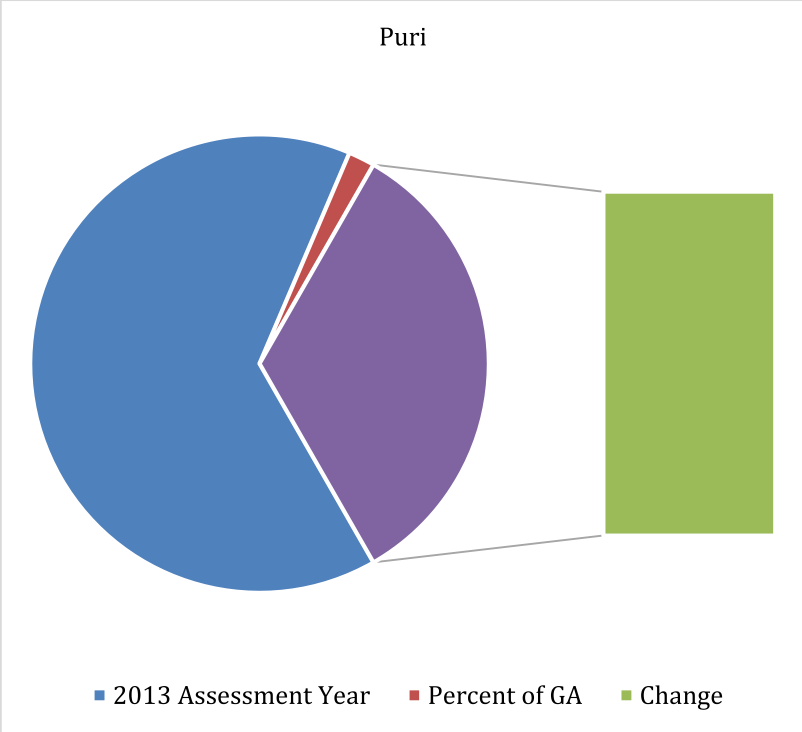

Figure 2. District-Level Forest Cover Composition And Percent Coverage For Puri District, Odisha (2013)

As shown in Table 4 and Figure 3, The long-term (1910 to 2020) warming trend of Odisha. The annual mean temperature is increasing by the decade, from 25.03°C in the 1910s to ~25.86°C (2010–2020s), indicating lasting climate warming. The seasonal rises are maximum during winter (Jan–Feb: 20.29°C to 21.11°C) and post-monsoon (Oct–Dec: 22.55°C to 23.71°C). The monsoon season (Jun–Sep) is also on a warming trend and reached 28.41°C in the 2020s.

Table 4. Decadal Mean Annual and Seasonal Temperature Trends in Odisha During 1901–2020

Year	Annual	Jan-Feb	Mar-May	Jun-Sep	Oct-Dec
1910	25.031	20.294	27.110	27.704	22.551
1920	25.181	20.296	27.505	27.78	22.646
1930	25.103	20.227	27.288	27.690	22.717
1940	25.131	20.047	27.391	27.848	22.646
1950	25.267	20.45	27.55	27.7889	22.825
1960	25.247	20.397	27.368	27.845	22.893
1970	25.172	20.080	27.413	27.714	22.932
1980	25.346	20.46	27.464	27.938	23.032
1990	25.427	20.604	27.454	28.017	23.166
2000	25.669	20.848	27.836	28.084	23.503
2010	25.857	20.96	28.067	28.32	23.631
2020	25.855	21.11	27.775	28.405	23.705

As shown in Table 5 and Figure 4, the warmest years in Odisha are found to be confined mostly during the last period (2009–2021), pointing towards intensified warming during recent years of the 21st century. The highest annual mean temperature is in 2016 (26.2°C), followed by 2009 (26.05°C) and 2017 (26.04°C). The majority of the listed years are higher than 25.9°C, indicating a continual above average thermal state. This clustering of extreme warm years indicates growing climate stress, which might influence coastal comfort, ecosystem stability, and seasonality of tourism.

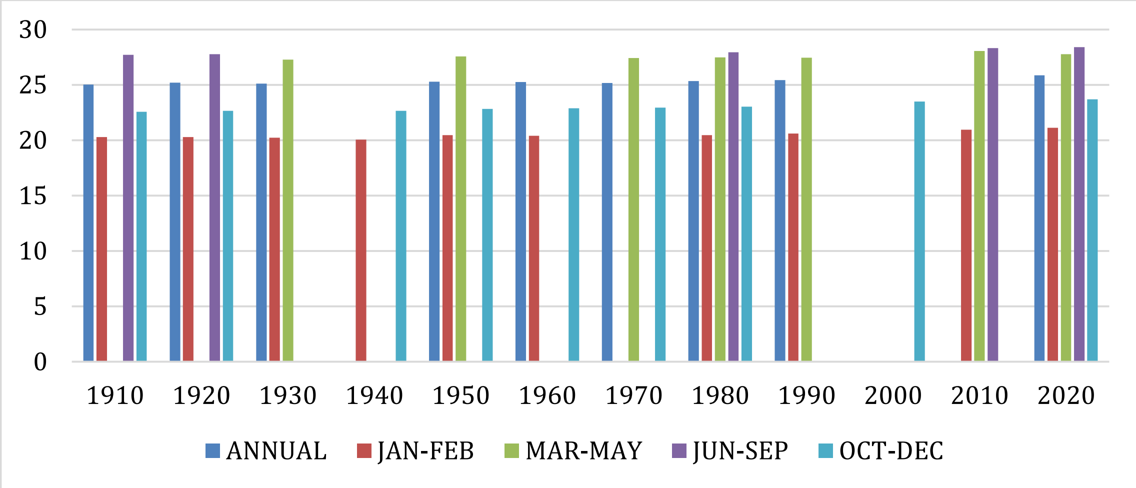

Figure 3. Decadal Mean Annual and Seasonal Temperature Trends in Odisha During 1901–2020

Table 5. Top Warmest Years in Odisha Based on Annual Mean Temperature Values (1901–2021 Series)

Year	Annual
2009	26.05
2010	26.03
2015	25.92
2016	26.2
2017	26.04
2018	25.9
2019	25.86
2020	25.78
2021	25.93

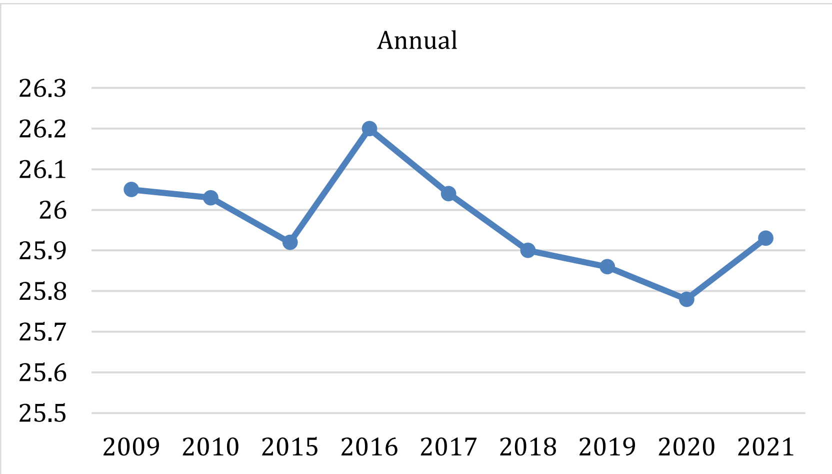

Figure 4. The Top Warmest Years in Odisha Based on Annual Mean Temperature Values (1901–2021 Series)

As shown in Table 6, illustrates massive losses in Odisha in terms of disasters because of cyclones, heavy rainfall, and floods in the period between 2015-16 and 2018-19. Although reported human casualties were not high in 2015-16 (5) and 2016-2017 (3), the increase in mortality in 2018-19 (102) showed a massive event impact. Housing damage increased sharply as high as 62,341 houses/huts in 2018-19. There was also an increase in the number of cattle (lost in 4,812), which increased steeply. Destruction of crops increased to 3.9 lakh ha, and this indicates high susceptibility to livelihood.

Table 6. State-Level Disaster Loss Indicators for Odisha From Cyclones, Heavy Rainfall, Floods, and Allied Hazards

Year	No.
2015-16 - Lives lost	5
2015-16 - Houses/huts	839
2016-17 - lives lost	3
2017-18 - lives lost	8
2017-18 - Cattle lost	399
2017-18 - Houses/huts	562
2017-18 - Crops area (in lakh ha.)	0.42
2018-19 (as on 11.12.18) - lives lost	102
2018-19 (as on 11.12.18) - Cattle lost	4812
2018-19 (as on 11.12.18) - Houses/huts	62341
2018-19 (as on 11.12.18) - Crops area (in lakh ha.)	3.9

As shown in Table 7 and Figure 5, points to the presence of major disparities in cyclone preparedness infrastructures between coastal states of NCRMP (2015). The states with the largest number of multi-purpose cyclone shelters include Odisha (316), Andhra Pradesh (219), and West Bengal (146), as the priority given to the disaster risk sector in high cyclone areas is high. However, other states like Goa (11), Karnataka (10), and Kerala (17) registered low coverage of shelter, whereas the state of Maharashtra had no coverage of shelter. All in all, the capacity to evacuate and the safety capacity are relatively high, as evidenced by the large network of shelters in Odisha.

Table 7. State-Wise Distribution of Multi-Purpose Cyclone Shelters Constructed Under the National Cyclone Risk Mitigation Programme (NCRMP) 2015

State	Number of Shelters Constructed
Andhra Pradesh	219
Odisha	316
Goa	11
Gujarat	76
Karnataka	10
Maharashtra	-
Kerala	17
West Bengal	146

As shown in Table 8 and Figure 6, reveals that the number of foreign tourists who arrived in India dropped significantly between 2019 and 202021, indicating the high number of tourists who were affected by the COVID-19 travel restrictions. The biggest source markets in 2019 were Bangladesh (2.58 million) and the USA (1.51 million). But the number of arrivals decreased significantly in 2020, and it only partially recovered in 2021. The USA presented a rather better recovery (429,860 in 2021) than Bangladesh (240,554). In general, it can be concluded that the trend shows a slow growth in international tourism and weak responses to external shocks.

Table 8. Eco-Tourism Projects Sanctioned for Odisha under the Ministry of Tourism (2013–14 To 2015–16), Including the Number of Projects and the Sanctioned Amount

State	2013-14	2013-14 Amt. Sanctioned	2014-15	2014-15 Amt. Sanctioned	2015-16	2015-16 Amt. Sanctioned
Odisha	12	65.43	4	114.88	0	0

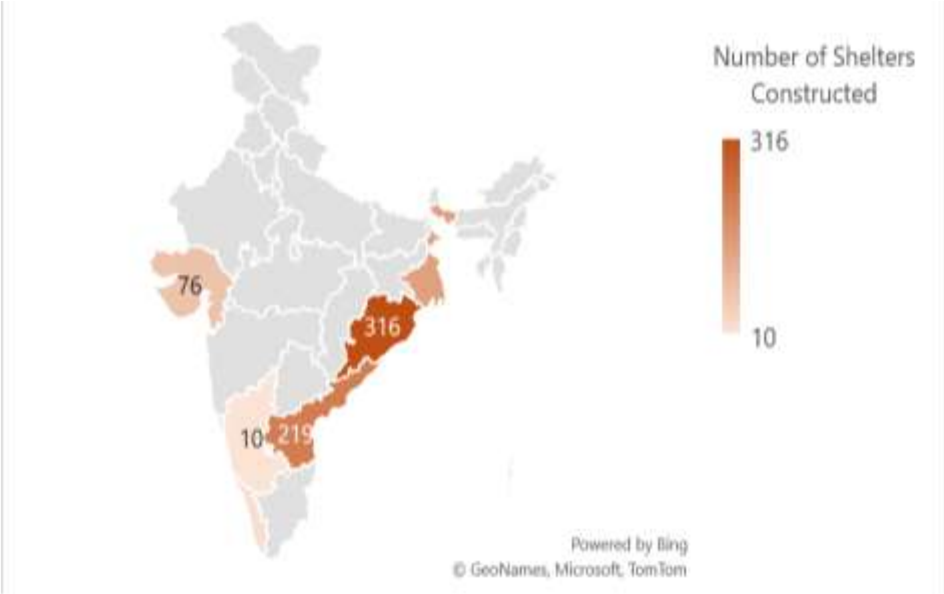

Figure 5. State-Wise Distribution of Multi-Purpose Cyclone Shelters Constructed Under the National Cyclone Risk Mitigation Programme (NCRMP) 2015

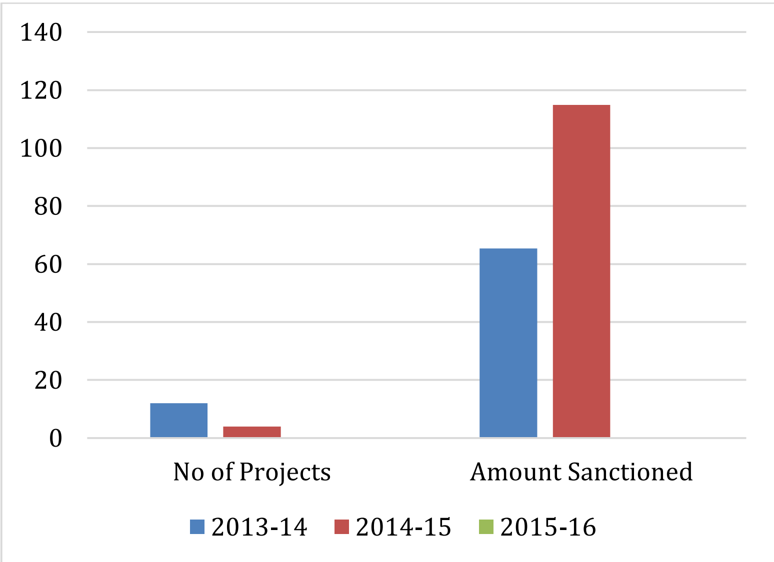

Figure 6. Eco-Tourism Projects Sanctioned for Odisha under the Ministry of Tourism (2013–14 To 2015–16), Including the Number of Projects and the Sanctioned Amount Discussion

An integrated climate disaster risk approach to sustainable coastal tourism in Puri, Odisha is presented through the convergence of evidence from long-term climate signals, ecological carrying capacity, loss records of disasters, preparation infrastructure, and tourism patterns. The findings help confirm that, in the long-term, Odisha state is undergoing warming wherein the warmest years are grouped over a recent time, similar to what was reported for regional climate distresses potentially impacting visitor comfort, ecosystem balance, and destination season. Disaster loss profile also indicates that cyclones, heavy rainfall, and flooding continue to be the high-impact hazards in coastal Odisha, leading to a sudden increase in housing and crop damage during severe years an exposure which have direct bearing on tourism service continuity and destination safety perception [6], [13].

Critical is the environmental fragility of Puri, having a very low forest cover (5.95% of GA) that acts as a natural barrier for protection from storm surge, coastal flooding, and erosion. This aligns with the geospatial reports about the highly vulnerable and shoreline instability along the Puri–Konark stretch, due to extensive cyclonic activity in addition to unrestricted development on the coast leading to erosional and environmental degradation [7], [11], [13]. Projections of the rise of sea level for the Chilika–Puri coast also indicate that long-term risk to tourist infrastructure and coastal settlement exist and preventive adaptation and zoning reform should be considered [21], [22], [23].

While cyclone shelter availability makes Odisha relatively better prepared, vulnerability related to tourism is not entirely mitigated since risk is arising as a result of the interaction between hazard intensity, huge concentration of exposure near the coast, and governance gaps in integrated planning [2], [24]. The funding trend for eco-tourism projects shows the policy emphasis on sustainability, although interruptions indicate that continuous investment is required in NBIs and resilience-based infrastructures [25]. The results generally encourage a risk-informed tourism development framework for Puri with an emphasis on hazard zoning, ecosystem restoration, resilient infrastructure, and coordinated coastal governance.

5. CONCLUSION

Measured risks posed by climate and disasters towards sustainable coastline tourism in Puri, Odisha. Analyzing the integrated body of secondary evidence that focused on warming climate, disaster losses, ecological buffering structure, preparedness infrastructure facilities for minimizing damage due to extreme events/ calamity and tourism dynamics. The findings reveal a strong long-term warming trend in Odisha , and warm years of excessive magnitude are clustered after 2009, signifying an increased climate stress. Disaster reports show sustained high exposure to cyclones, floods, and heavy rains, with a spike in the magnitude of losses in housing, livestock, and crops. Puri's extremely low forest cover indicates a poor natural shield against coastal calamities. Collectively, results provide evidence in support of risk-informed tourism planning via hazard zoning, ecosystem restoration approaches, resilient infrastructure, and enhanced governance.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Dr. Malini Prava Sethi	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

There is no conflict of interest in this research.

Informed Consent

There was no requirement for consent as the data was gathered based on secondary data.

Ethical Approval

There was no requirement for consent as the data was gathered based on secondary data.

Data Availability

The data available at the Govt. of Odisha portal is;

- https://dot.odisha.gov.in/en/publication/activity-report .

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