



Regular Article

Assessment and Mapping of Climate Shocks Vulnerability of Odisha, India: A PCA Approach

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Abstract Climate shocks affect all walks of life, including livelihood, standard of living, critical infrastructure, health, productivity of agriculture, wealth, and socio-economic conditions of the different social groups. Climate change-induced extreme events such as floods, droughts, heatwaves, tropical cyclones, and inundations are increasing in frequency and severity and are likely to increase in the future. Therefore, climate shocks can vary across space, time, and person; therefore, their impact can be on the entire economy, one sector, or a specific region. The effect of climate shocks varies from country to country and region to region, and it is observed that developing and less developed regions are subject to more losses and severity than the developed regions. This study, therefore, makes a modest attempt to analyse the historical trends of climate shocks, loss, and damage caused by these events over the period 2001-2021. By addressing the major gaps and uncertainties in existing literature, this study assessed the vulnerability of districts of Odisha using principal component analysis, and then districts were ranked and mapped accordingly to determine the severity of vulnerability. It is observed that tribal-dominated districts like Malkangiri, Kalahandi, and Raygada are highly vulnerable to climate shocks. The findings provide necessary inputs for policymakers and livelihood losers to develop appropriate adaptation strategies. Major policy prescriptions were derived for interventions to lessen vulnerability.

Keywords: vulnerability, PCA, climate shocks, mapping, district vulnerability, climate change

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1. INTRODUCTION

Climate change is a continuous, long-term change in different weather-related events beyond normal atmospheric conditions, which include rising temperatures and extreme events such as floods and cyclones. Variation in climatic conditions and its associated effects create transitory and permanent climatic instabilities that have concomitant negative effects on the environment as well as on human society. Climate change-induced changes can lead to the degradation of environmental quality and have enormous indirect impacts (Endalew & Sen, 2020). Climate change can affect all walks of life, such as livelihood, standard of living, critical infrastructure, health, productivity of agriculture, wealth, and socio-economic conditions of the suppressed ones (Ngoma et al., 2023; Jeganathan et al., 2021). However, shocks can be climatic or non-climatic (economic, land, and demographic pressure, price, and income). Climate shocks are, riskier and create sudden havoc, resulting in multidimensional vulnerability (Das, 2021). Climate shocks (i.e., such as earthquakes, cyclones, droughts, floods, locust plagues, epidemics, strong winds, inundation, heat waves, and hurricanes) are exogenous in nature and involve a high degree of unexpected risks (Martin & Bargawi, 2005; De Young et al., 2012; Asmamaw et al., 2019; Ngoma et al., 2023). Specifically, climate shocks are extreme natural events that outweigh the capacity of individual households to cope with and overburden households' socio-economically (Anderson, 2000). Intergovernmental Panel on Climate Change (IPCC) reports reveal that climate change-induced extreme events such as floods, droughts, heatwaves, tropical cyclones, and inundations are increasing in frequency and severity, and are likely to increase in the future. (Field, 2012; IPCC, 2012; Collins et al., 2019; Kumar et al., 2021).

Climate shocks can vary across space, time, and person; therefore, their impact can be on the entire economy, one sector or, a specific region. Over the years, climate-induced geophysical disasters killed almost 1.3 million people between 1998 and 2017 and left 4.4 billion injured, homeless, or displaced (Jeganathan et al., 2021). Each year, climate shocks create vulnerability in different corners of the world, resulting in hunger and poverty. The degree of vulnerability and loss from climate shocks depends on the geographical settings, roles of different sectors, livelihood strategies, socio-demographic features, economic capabilities, and infrastructural facilities (Dash & Das, 2025) of that region (Wallace, 2017; Sen et al., 2023).

The effect of climate shocks varies from country to country, and developing countries are subject to more losses and severity than developed countries (Mendelsohn et al., 2006; Stern, 2006; Toya & Skidmore, 2007). So far as India is highly categorized as a country vulnerable to climate shocks because of its fragile landmass, geographical divide, and physical features (INCCA, 2010; Datta & Behera, 2022). India has a long stretch of coastline of approximately 7516 km, of which 5400 km are along the mainland, including 72 districts touching the coast and 24 districts lying within 100 km of the coastline, which are highly prone to the effects of climate shocks (Mohapatra, 2015). In central India, floods and waterlogging are regular events that affect millions of lives (Pandey et al., 2010). High floods and unpredicted rainfall have resulted in barren agricultural land, which is challenging the food security provisions of

the country, as these lands were earlier used to produce 59 percent of the country's total foodgrains country (Srivastava et al., 1994). The northern part of India is vulnerable to multiple hydrometeorological climate shocks, such as, landslides, recurring flash floods, cloud bursts, rockfalls, and the mudflow. The wide river stretches and the existence of mountains creates a vulnerable situation, and people dependent on agriculture suffer huge losses and stress due to their geographic location (Maikhuri et al., 2017; Khandekar et al., 2019).

In eastern India, several vulnerability studies have been conducted on climate shocks, focusing only on coastal districts (Sahoo & Bhaskaran, 2018). For instance, Odisha is a large state in eastern India that is continuously vulnerable to a series of natural calamities throughout the years. As livelihood losses and damage to rural agricultural households are regular affairs due to climate shocks, very few studies have been conducted on this (Naik et al., 2024). Therefore, this study assessed the vulnerability to climate shocks in Odisha based on the IPCC definition. Earlier studies have ignored climatic variables and extreme climatic events as indicators of vulnerability, given equal weights to all indicators, and have also ignored the role of infrastructural availability in reducing the vulnerability of a specific locality. Therefore, a modest attempt has been made to overcome these gaps in previous studies. The first part of the study focuses on the historical background of climate shocks with a glimpse of loss and damage caused by extreme events, and the second part focuses on the assessment of the district-wise vulnerability of Odisha. The findings provide necessary inputs for policymakers and livelihood losers to develop appropriate adaptation strategies. By addressing the major gaps and uncertainties in previous studies, therefore the objectives of this study is to (a) understand the exposure of the study area to different extreme climate events and weather variability (b) assess the loss and damage in the study area caused by climate shocks and (c) assess the vulnerability of Odisha at the district level to climate shocks. The important contribution of the study is that Odisha is highly exposed to frequent natural hazards and understanding the regional vulnerability at district level is important as decentralised preparation and planning can be done to reduce vulnerability. The study is specific to a coastal state of India and helpful in understanding the district level vulnerabilities to climate shocks.

2. STUDY AREA

This study was conducted in the State of Odisha, India. A geographical map of the study area is shown in Figure 1. Odisha, with 480 km. of long coastline and six coastal districts, represents itself as the worst-victimised state of India to witness extreme events, and it is a hub of cyclones and floods. The state is located between 17049' and 22036' North latitudes and 81036' and 87018' East longitudes. Odisha is bestowed with rich natural resources, but its geographical location and features make it the most vulnerable state to climate shocks. During the period 1891–2021, “Odisha has been lashed with over 100 tropical cyclones, and 314 cyclones crossed the eastern coastline. In the last two decades, the state has confronted

10 cyclones, and the frequency is on the rise and highest among the states on the coast of India” (Government of Odisha, 2021). Over the years, Odisha witnessed uneven distribution and erratic rainfall in nature, which creates floods and droughts and affects agricultural households every year (Government of Odisha, 2021).

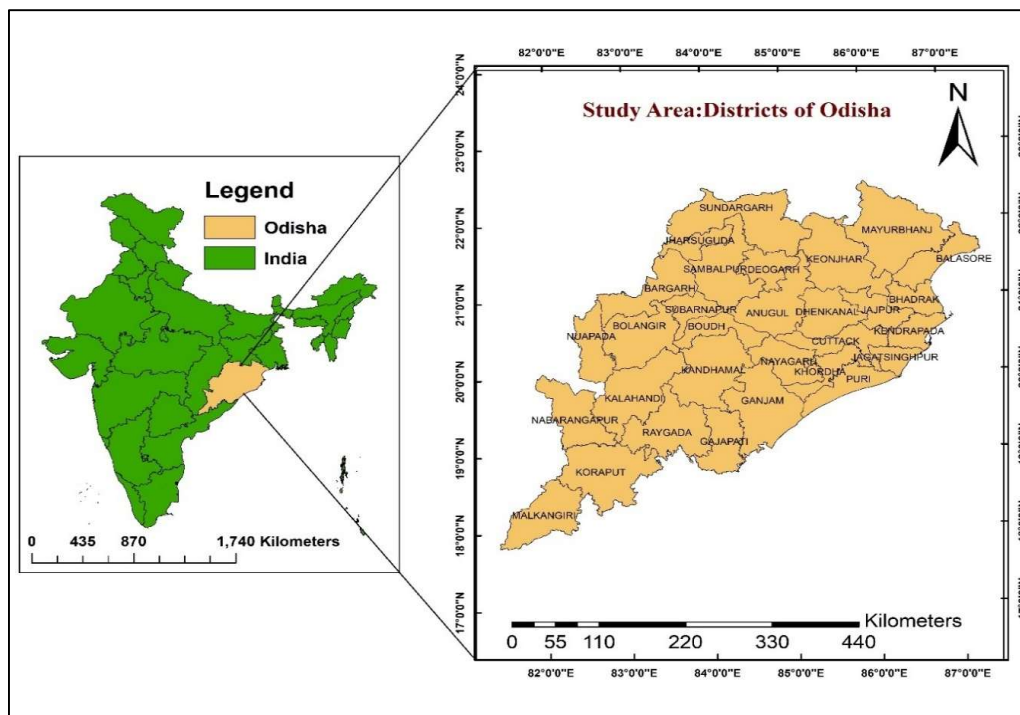


Figure 1. Map of the study area showing India and part of the eastern India (i.e., Odisha)

Table 1 presents the climate shocks and extreme climatic events that occurred in Odisha. During the last five decades, the state has witnessed 33 years of flooding, 22 years of drought, and 13 years of tropical cyclone events. These natural calamities, which are sometimes severe in nature, have devastated the lives and livelihood of Odisha. More specifically, over the last 53 years the state has encountered natural calamities for forty-seven years. Farmers are the most victimized and suffer huge losses (Dash et al., 2024). The extreme events in the last fifty-three years show that it is essential to further detail their consequences and vulnerability on a regional basis. Therefore, the current study makes a modest attempt to address the issues of district-wise vulnerability to climate shocks and its overall implications in Odisha.

3. OVERVIEWS ON CLIMATE SHOCKS VULNERABILITY

Over the past few decades, there has been a growing body of literature on vulnerability from multiple aspects, which vary considerably in place, time, and person (Reed et al., 2013; Dintwa, 2019). Normally, vulnerability is portrayed as a susceptibility to be harmed by the negative impact of climate shocks, and literature has widely accepted the IPCC definition (third assessment report) as "vulnerability is the degree to which a system is susceptible to and is unable to cope with adverse effects of climate change" (McCarthy et al., 2001).

According to the IPCC (2007) report, "vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its ability to cope, that is adaptive capacity. Therefore, the vulnerability of a system depends on three principal factors, :exposure to a shock (physical, social, and ecological), sensitivity to different grounds, and the strength and capacity of that region to cope with these adverse impacts (Bucherie et al., 2022; Raju et al., 2017; Adger, 2006), which is known as the adaptive capacity of a region. Exposure and sensitivity have a positive relationship with vulnerability, whereas adaptive capacity has a negative relationship. This study considers vulnerability a function of exposure, sensitivity, and adaptive capacity to climate stimuli as per the IPCC definition.

Although vulnerability assessment started in the 1970s, social science effectively assessed it in the 1980s (Brooks, 2003; Sahana et al., 2021). Researchers have pointed out that vulnerability assessment can be a focal point, starting point, or end point of any extreme climate consequences (Kelly & Adger, 2000). Vulnerability assessment and analysis generally provide a framework for interpreting the physical, social, institutional, economic, demographic, ecological, and biological impacts of climate shocks (Zarafshani et al., 2016), which ultimately leads the path towards effective measures and policies for mitigation and adaptation strategies (Corobov et al., 2013; Sen et al., 2023). Despite the increasing literature on vulnerability assessment for climate shocks, this study highlights vulnerability assessment on a regional basis, that is district-level vulnerability assessment. Moreover, the key research gap is that this study emphasizes the catastrophic situation faced by the eastern region of India. Odisha, which is home to climate shock, is vulnerable to multiple aspects. Therefore, vulnerability assessment, along with highlighting the role of detrimental attributes in the degree of vulnerability, is the core objective of this paper, as stated earlier. Existing literature focuses on socioeconomic indicators (Raju et al., 2017; Baig et al., 2021; Tanir et al., 2024), hydrological indicators (Shah et al., 2020), agricultural indicators (Corobov et al., 2013; Sridevi et al., 2014; Murthy et al., 2015), and environmental indicators (Sen & Nag, 2024) of vulnerability. These studies considered these attributes but did not emphasize the principal factors. The lack of determining indicators in the existing literature is imputed in this study. Table 1 shows the indicators considered for the vulnerability study, focusing on all the 30 districts of Odisha.

4. LOSS AND DAMAGE CAUSED BY CLIMATE SHOCKS IN ODISHA

Odisha, being an eastern seaboard state of India, encounters multiple climate shocks each and every alternative year. Taking into account its geo-physical location, river system, and livelihood option, Odisha seems vulnerable and bears heavy loss and damage due to climate shocks. Loss and damage can be caused by multiple climate shocks, such as submergence, gusting wind during a cyclonic storm, erratic rainfall, hailstorms, floods, cold waves, hit waves, tsunamis, etc. Climate shocks and their disastrous impact damage each corner of the state differently. Therefore, this study presents a district-wise regional picture of loss and damage estimates from 2001 to 2021 (Table 2).

Table 1. Series of Climate shocks and rainfall pattern from 1970 to 2023 in Odisha

Year	Normal Rainfall (mm)	Actual Rainfall (mm)	Deviation from Normal		Climate Shocks	Year	Normal Rainfall (mm)	Actual Rainfall (mm)	Deviation from Normal		Climate Shocks
			In mm	In %					In mm	In %	
1970	1502.5	1660.2	157.7	10.5	Flood	1997	1502.5	1493.0	-9.5	-0.6	Drought
1971	1502.5	1791.5	289.0	19.2	Cyclone, Flood	1998	1502.5	1277.5	-225.0	-15.0	Drought
1972	1502.5	1177.1	-325.4	-21.7	Flood, Drought	1999	1502.5	1435.7	-66.8	-4.4	Super Cyclone
1973	1502.5	1360.1	-142.4	-9.5	Flood	2000	1502.5	1035.1	-467.4	-31.1	Drought
1974	1502.5	951.2	-551.3	-36.7	Drought, Flood	2001	1482.2	1616.2	134.0	9.0	Flood
1975	1502.5	1325.6	-176.9	-11.8	Flood	2002	1482.2	1007.8	-474.4	-32.0	Drought
1976	1502.5	1012.5	-490.0	-32.6	Drought	2003	1482.2	1663.5	181.3	12.2	Flood
1977	1502.5	1326.9	-175.6	-11.7	Flood	2004	1482.2	1273.6	-208.6	-14.0	Flood
1978	1502.5	1261.3	-241.2	-16.1	Cyclone	2005	1451.2	1519.5	68.3	4.7	Flood
1979	1502.5	950.7	-551.8	-36.7	Drought	2006	1451.2	1682.8	231.6	16.0	Flood
1980	1502.5	1321.7	-180.8	-12.0	Flood, Drought	2007	1451.2	1591.5	140.3	9.7	Flood
1981	1502.5	1187.4	-315.1	-21.0	Flood, Drought	2008	1451.2	1523.6	72.4	5.0	Flood
1982	1502.5	1179.9	-322.6	-21.5	Flood, Drought, Cyclone	2009	1451.2	1362.6	-88.6	-6.1	Flood, Drought
1983	1502.5	1374.1	-128.4	-8.5	.....	2010	1451.2	1293.0	-158.2	-10.9	Flood, Drought, Cyclonic storm
1984	1502.5	1302.8	-199.7	-13.3	Drought	2011	1451.2	1338.1	-113.1	-7.8	Drought & Flood
1985	1502.5	1606.8	104.3	6.9	Flood	2012	1451.2	1384.1	-67.1	-4.6	Drought & Flood
1986	1502.5	1566.1	63.6	4.2	Flood	2013	1451.2	1653.1	201.9	13.9	Severe Cyclonic Storm, Flood
1987	1502.5	1040.8	-461.7	-30.7	Drought	2014	1451.2	1608.7	157.5	10.9	Severe Cyclonic Storm, Flood
1988	1502.5	1270.5	-232.0	-15.4	.....	2015	1451.2	1224.8	-226.4	-15.6	Drought, Flood
1989	1502.5	1283.9	-218.6	-14.5	Severe Cyclone	2016	1451.2	1283.1	-168.1	-11.6	Drought, Flood
1990	1502.5	1865.8	363.3	24.2	Flood	2017	1451.2	1336.4	-114.8	-7.9	Flood, Drought
1991	1502.5	1465.7	-36.8	-2.4		2018	1451.2	1643.3	192.1	13.2	Cyclonic Storm
1992	1502.5	1344.1	-158.4	-10.5	Flood & Drought	2019	1451.2	1627.8	176.6	12.2	Severe Cyclonic Storm
1993	1502.5	1421.6	-80.9	-5.4	.....	2020	1451.2	1627.4	176.2	12.1	Severe Cyclonic storm and heavy flood
1994	1502.5	1700.2	197.7	13.2	Flood	2021	1451.2	1444.3	-6.9	-0.5	Drought, Cyclonic storm
1995	1502.5	1588.0	85.5	5.7	Severe Cyclone	2022	1451.2	1430.9	-20.3	-1.4	Flood
1996	1502.5	990.1	-512.4	-34.1	Drought	2023	1451.2	1386.5	-64.7	-4.5	Flood, Drought

Source: IMD Pune, Odisha Agricultural Statistics, SRC Reports, GoO.

Table 2. District wise loss and damage due to climate shocks during 2001-2021

Districts	Total Property loss (in lakhs)	Sand cast (in hec.)	Crop area damaged (In hec.)	House damage (in nos.)	Cowshed Damaged (in nos.)	Life stock loss (in nos.)	Human loss (in nos.)	Crop loss (in Rupees)
Angul	35164.21	4679.51	86148.98	27329	6	6024	14	6986000
Balangir	4712.52	17970.67	243820.19	82442	208	220	20	1065200
Balasore	480215.29	167	349312.5	128049	370	25626	70	0
Bargarh	2826.35	17338.92	378596.8	71066	120	17188	7	104858480
Bhadrak	16375.57	397.05	464527.4	74517	2570	7822	46	285400000
Boudh	2090.39	2788.82	57563.95	15875	1	45	1	21538140
Cuttack	44230.77	1859.054	414297.1	189489	28996	1240487	142	481325000
Deogarh	1541.01	895.08	28382.201	8088	1	0	2	347000
Dhenkanal	5136.9	2030.13	62657.73	21586	45	4529	8	0
Gajapati	10964.53	3219.54	143041.6	88050	38	7744	67	592952000
Ganjam	0	1552.4	484854.33	234597	35491	31796	53	0
Jagatsinghpur	27133.215	4465.1	267041.7	398000	25213	99857	18	200065400
Jajpur	44207.1	5318.73	688687.05	174719	9506	45863	44	14003046.69
Jharsuguda	8047.33	1387.18	85130.75	9389	0	2	1	0
Kalahandi	18149.185	33437	113481.2	57646	99	243	17	0
Kandhamal	4109.4	1255	36892.85	16730	17	50	22	2887200
Kendrapada	27264.71	4612.5	570699.7	219438	10425	15644	52	256026183
Keonjhar	0	157.52	27208.9	23597	10	5	29	0
Khordha	41343.97	770.836	286874.27	216008	16836	1326973	19	33315000
Koraput	9813.79	3017.94	82407.3	28376	64	199	19	0
Malkangir	54.99	2166.331	13960.16	12842	63	1433	14	0
Maurbhanj	323.03	29.26	270654.411	37590	452	11	49	0
Nabarangpur	4280.15	3913.15	107933.33	7551	13	1361	17	84996000
Nayagarh	491.22	1614.948	193787.7	43770	2177	20089	25	562980
Nuapada	3173.32	2869.88	225615.76	14803	0	2607	1	5915563
Puri	27524.5	448.964	461707.5	437073	47799	2685357	77	447500000
Rayagada	2335.25	6567.8	11713002	36499	121	17987	35	0
Sambalpur	5088.03	3066.635	64928.22	40331	0	9	22	0
Subarnapur	3802.52	15204.62	116099.4	92911	95	271	3	0
Sundargarh	6104.8	491.49	75974.24	5489	12	0	1	0

Source: Compiled from Government of Odisha Reports

The extent of loss and damage can be split into house damage, crop loss, livestock loss, fishery loss, loss of handloom sector, damage of infrastructure (road, public building, irrigation sector, school, hospital, electricity, damage to drinking water system) and human loss. Recurring natural calamities slow down the developmental process and make the state socio-economically backward. In Table 2, this study has incorporated both economic and non-economic losses as per the availability of data in SRC annual reports. Economic losses include total property loss, area of sand casted, crop area damaged, house damage, cowshed damage, and crop loss. Similarly, human and livestock loss represent non-economic loss.

5. METHOD AND MATERIAL

5.1 Data

This study collected data from secondary sources. To determine the dry year, wet year, and weather variability of the state, rainfall data (1901–2023) were collected from IMD, Pune. To find a regional picture of climate shock vulnerability, Principal Component Analysis (PCA) was used to assign weights and rank all 30 districts accordingly. For these 44 indicators, data were collected from various Government of Odisha (GoO) reports (Table 3). The data sources for each variable are listed in Table 3 for each component.

5.2 Selection of the Indicators

Following a set of studies and data availability, 44 indicators were selected based on eight major representative indicators. Under the IPCC's three components of vulnerability, exposure, sensitivity, and adaptive capacity are considered under which the eight major indicators are fitted. The exposure part consists of a set of extreme climatic event indicators and climatic variable indicators, that is frequency of drought, flood, and cyclones in the last 21 years, deviation in rainfall, and minimum and maximum temperatures of the last 21 years.

Under the agriculture activities component, the net area sown and population involved in agriculture are included, as they are directly related to vulnerability (Ravindranath et al., 2011). On the other hand, the area cultivated under High Yielding Varieties (HYV) cereals, cropping intensity, net irrigated area, and proportion of fertilizer consumption per thousand hectares are included which are indirectly related to the degree of vulnerability.

Under sensitivity, another major component is the vulnerable groups of the population, which increases vulnerability to climate shocks and positively correlates with the degree of vulnerability. Considering this aspect, this study identified five vulnerable groups: percentage of scheduled caste population to total population, percentage of scheduled tribe population to total population, population below 15 years of age, percentage of female population involved in agriculture, and elderly population.

Table 3. Components and indicators of vulnerability with direction of relation

<i>Components of Vulnerability</i>	<i>Major indicators</i>	<i>Indicators</i>	<i>Description of indicators</i>	<i>Relationship with vulnerability</i>
Exposure	Extreme climatic events	Frequency of floods from 2001-2021	Frequency of flood increase the vulnerability of flood prone region Source: Makondo, C.C., et al (2014)	+
		Frequency of cyclones from 2001-2021	Frequency of cyclone caused widespread losses in coastal region and vulnerability. Source: Makondo, C.C., et al (2014)	+
		Frequency of droughts from 2001-2021	Frequency of drought lead to increased vulnerability. Source: Makondo, C.C., et al (2014)	+
	Climatic variables	Minimum temperature variability from 2001-2021	Variability of minimum temperature reflects the changing temperature and possible risk and uncertainty. Source: Makondo, C.C., et al (2014)	+
		Maximum temperature variability from 2001-2021	Variability of maximum temperature reflects the changing temperature and possible risk and uncertainty. Source: Makondo, C.C., et al (2014)	+
		Variability in rainfall from 2001-2021	Rainfall variability indicates instable weather conditions which affect agriculture sector and thereby the economy leading to vulnerability. Source: Paltasingh., et. al (2012), Das (2021) Makondo, C.C., et al (2014)	+
	Demographic	Sex Ratio	Due to uneven distribution of resources, poor asset ownership and social beliefs females are highly vulnerable to climate shocks. Source: Adeola, O. et al (2024) and Cutter (1996)	+
		Density of population	High density of population in a region causes higher loss and damage to climate shocks and high vulnerability. Source: A. Jurgilevich et al. (2023) and Zou & Yoshino, (2017)	+
		Literacy rate	Literate population can easily access climate related information and understand the information and therefore literacy reduce the vulnerability to climate shocks. Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003)	-
		Percentage of disabled population	Disabled population are disproportionately affected by climate change and shocks accordingly lead to vulnerability. Source: Kosanic et al (2022) and Wu, T. (2021)	+
Sensitivity	Unemployment Rate	Unemployment Rate	Unemployment rate lead to vulnerability as unemployed person face resource constraint during extreme climate shocks. Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003)	+
		Percentage of rural population	Percentage of population living in rural areas are highly vulnerable to climate shocks due to their poor standard of living, kutcha houses and sole dependence on agriculture for their livelihood. Source: Roy et al (2024) and: Cutter, Mitchell, and Scott (2000)	+
		Area cultivated under HYV Cereals	Area cultivated under high yielding varieties are generally resilient to climate shocks. Source: Swami and Parthasarathy (2021),	-
	Agricultural activities	Cropping Intensity	High cropping intensity implies farmers use land more effectively and less vulnerable. Source: Sridevi et al., 2014; Jamshidi et al.,2019	-
		Net Area Sown	More use of land area means larger amount of loss in climate shocks. Increasing use of chemicals exhaust the potential capacity of the soil and cause increasing soil degradation during climate shocks.	+

		Net Irrigated Area	Source: Sridevi et al., 2014; Jamshidi et al.,2019 Irrigated area are less vulnerable to extreme climatic events.	-
		Population involved in agriculture	Source: Yusuf & Francisco, 2009 Proportion of population directly or indirectly involved in agriculture for their livelihood are more vulnerable to climate shocks.	+
		Fertilizer Consumption	Source: Swami and Parthasarathy (2021), Fertiliser used (Kg/000Ha.) in gives more production and increase plants health and growth which causes less vulnerability.	-
	Vulnerable group	SC Population	Source: Swami and Parthasarathy (2021), Percentage of Scheduled Caste (SC) and Scheduled Tribe (ST) population to total population are those groups who are deprived of opportunities and face inequality in every sphere of the society. Poor standard of living makes them vulnerable to climate shocks.	+
		ST Population	Source: Sridevi et al., 2014; Malakar & Mishra, 2016	+
		Population Below 15 Year	Percentage of children below fifteen years are generally dependent population and are vulnerable accordingly.	+
		Female population involved in agriculture	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) Percentage of female population involved in agriculture (Cultivators and agricultural workers) lead to vulnerability to climate shocks.	+
		Elderly population	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) Number population above 65 years old / total number population are the elderly population who face issues of limited income, lack of mobility and they are normally depend on others and highly vulnerable to climate shocks.	+
Adaptive Capacity	Economic capability	Poverty Head count ratio	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) Population proportion below the poverty threshold are more vulnerable in the region.	+
		Livestock	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) Livestock is a source of adaptation and reduce vulnerability.	-
		Crop insurance	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) ; Swami and Parthasarathy (2021), Farmers insured under crop insurance generally get recovery amount against loss and damage due to climate shocks.	-
		MSME Units	Source: Swain (2014) Presence of Micro Small and Medium Enterprises strengthens the earning capacity and better economic outcome against climate shocks.	-
		Households with electricity facilities	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) Households with electricity facilities can access climate warning messages, store food products and can irrigate their agricultural field during climate shocks.	-
		Per capita income	Source: Boer, R. et al (2015) Higher per capita income can make individuals financially stronger and less vulnerable to climate shocks.	-
	Education infrastructure	Dropout rate at Secondary level	Source: Cutter, S. L., Boruff, B. J., & Shirley, L. W. (2003) and Wu, T. (2021) High dropout rate indicates low level of educational attainment and more vulnerability.	+
		Gross Enrolment Ratio	Source: N. W. Feinstein & K. J. Mach (2019) Higher enrolment indicates better educational infrastructure and low vulnerability.	-

	Secondary Level Number of schools per ten thousand population	Source: N. W. Feinstein & K. J. Mach (2019) Number of schools indicates educational infrastructure and negatively associated with vulnerability.	-
Health infrastructure	Institutional births	Source: N. W. Feinstein & K. J. Mach (2019) Institutional birth generally reflects the availability of health infrastructure in a region and less vulnerability to climate shocks.	-
	Community healthcare centre per ten thousand population	Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024) Again, CHC and PHC nearby availability reflects the availability of health infrastructure in a region and better coping mechanism during climate shocks.	-
	Primary Healthcare Centre per ten thousand population	Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024)	-
	Bed Availability per ten thousand population	Hospital bed availability is important aspect to less vulnerability during climate shocks. Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024)	-
	Health Insurance Facilities	Health insurance provides access to healthcare facilities during any unforeseen events including climate shocks. Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024)	-
	Drinking water facilities	Clean drinking water availability during climate shocks is another indicator of adaptation. Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024)	-
	Sanitation facilities	Availability of sanitation facilities reduce vulnerability to climate shock. Source: Lugten E, and Hariharan N. (2022); Zeynep Or and Anna-Veera Seppänen (2024)	-
Physical/ Institutional capability	Density of Post office per 1k sq. k.m.	Post offices act as reliable institution for communication, micro insurance and great facilitator of financial inclusion and during climate shocks can provided different types of services. Source: Taken from RBI and World bank	-
	Density of Bank Branches per 1k sq. k.m.	Bank branches also facilitate financial inclusion and farmers and other affected section can get smooth financial services during climate shocks. Source: Taken from RBI and World bank	-
	Credit Deposit Ratio	Credit deposit ratio is an indicator of the financial assets mobilization in an area and shows the resilience of the area to climate shocks. Source: Taken from RBI and World bank	-
	Railway route length Density	Availability of railway facilitate promotes transportation facilities, good supply chain and enhance capacity of people commute and cope during climate shock. Source: Wu, T. (2021)	-
	District Road density	Road facilities can help climate shocks affected people in accessing market, take shorter hours to avail health facilities and make easy availability of food during climate shocks. Source: Wu, T. (2021)	-

Age has been identified in the literature as a determining factor for vulnerability. During the climate shock period, it was difficult to move these groups from one place to another. The evacuation process and mobility of this group are difficult (Chakraborty et al., 2020).

Where exposure and sensitivity aggravate vulnerability, adaptive capacity minimizes vulnerability. Adaptive capacity generally stands against the vulnerability to climate shocks by strengthening the system or enhancing available opportunities. In this study, adaptive capacity contains twenty-one indicators under five major indicators as representative of vulnerability. Table 3 shows a list of 44 indicators included under vulnerability, along with their subclassification under eight major components and subsequent incorporation into three components: exposure, sensitivity, and adaptation, along with the sign that represents the direction of the relationship with vulnerability.

5.3 Methodological Framework

This study assessed the vulnerability of Odisha at the district level, and then districts are ranked and mapped by constructing a climate vulnerability index through PCA. Studies on vulnerability assessment focused on assigning weights in two different ways i.e. equal weights or unequal weights to different indicators. As different indicators contribute differently to vulnerability, to get relative weights of different indicators, PCA has been used. A set of 44 indicators are used here to construct vulnerability index. As vulnerability is a dynamic concept, its periodic assessment of a region holds significant and the vulnerability assessment at the district level gives a micro level perspective to understand the dynamics of vulnerability. Therefore, the study makes a modest attempt to understand vulnerability to climate shocks using a standardised index approach using PCA as shown in Figure 2.

As more than 50 percent of farmers depend on agriculture in Odisha and suffer from scant rainfall and irregular monsoons, it is necessary to study the weather variability of the state and its exposure to climate shocks before vulnerability assessment. We constructed a weather variability index using rainfall data (1901-2023) collected from the IMD in Pune. This weather variability index represents a particular year that is a drought year, flood year, or normal year. After obtaining the composite score, ArcMap GIS was used to map the vulnerability severity of different districts. The detailed methodology and analysis of the weather variability index are discussed in the respective analysis section. Owing to the continuous occurrence of climate shocks, the districts of Odisha face loss and damage under different heads (i.e., property loss, sand cast in agriculture fields, crop area damaged by the cultivated field, house damage, cowshed damage, soil erosion, livestock loss, human loss, and wealth loss). This study also tries to estimate the losses (economic and non-economic) suffered by the districts of Odisha from 2001 to 2021.

5.3.1 Methodological Framework for Vulnerability Assessment Using PCA Approach

After the selection of 44 indicators, the normalization technique or linear scaling technique was applied to a comparable data set (OECD, 2008; Swami & Parthasarathy, 2021; Ajtai et al., 2023). Because all the data are in different units, this standardization was applied to treat

them equally and for further use. The normalized data values varied between 0 and 1. Before normalization this study defined the relationship between the indicators and vulnerability. If vulnerability increases with the increase in the value of the indicators, then they share a positive relationship with vulnerability and vice versa (Table 4). Indicators related to vulnerability were defined according to the available literature. Normalization was performed using equation (1) for a positive functional relationship and equation (2) for a negative functional relationship (Nasrollahi et al., 2018; Kim et al., 2021; Ajtai et al., 2023).

$$Xi = \frac{Xi - MinXi}{MaxXi - MinXi} \tag{1}$$

$$Xi = \frac{MaxXi - Xi}{MaxXi - MinXi} \tag{2}$$

Here, Xi is the indicator, which is normalized using equations (1) and (2), X represents the value of the indicators, $MinXi$ represents the minimum value of the indicator i , and $MaxXi$ represents the maximum value of the indicator i and i stands for the indicator identifier.

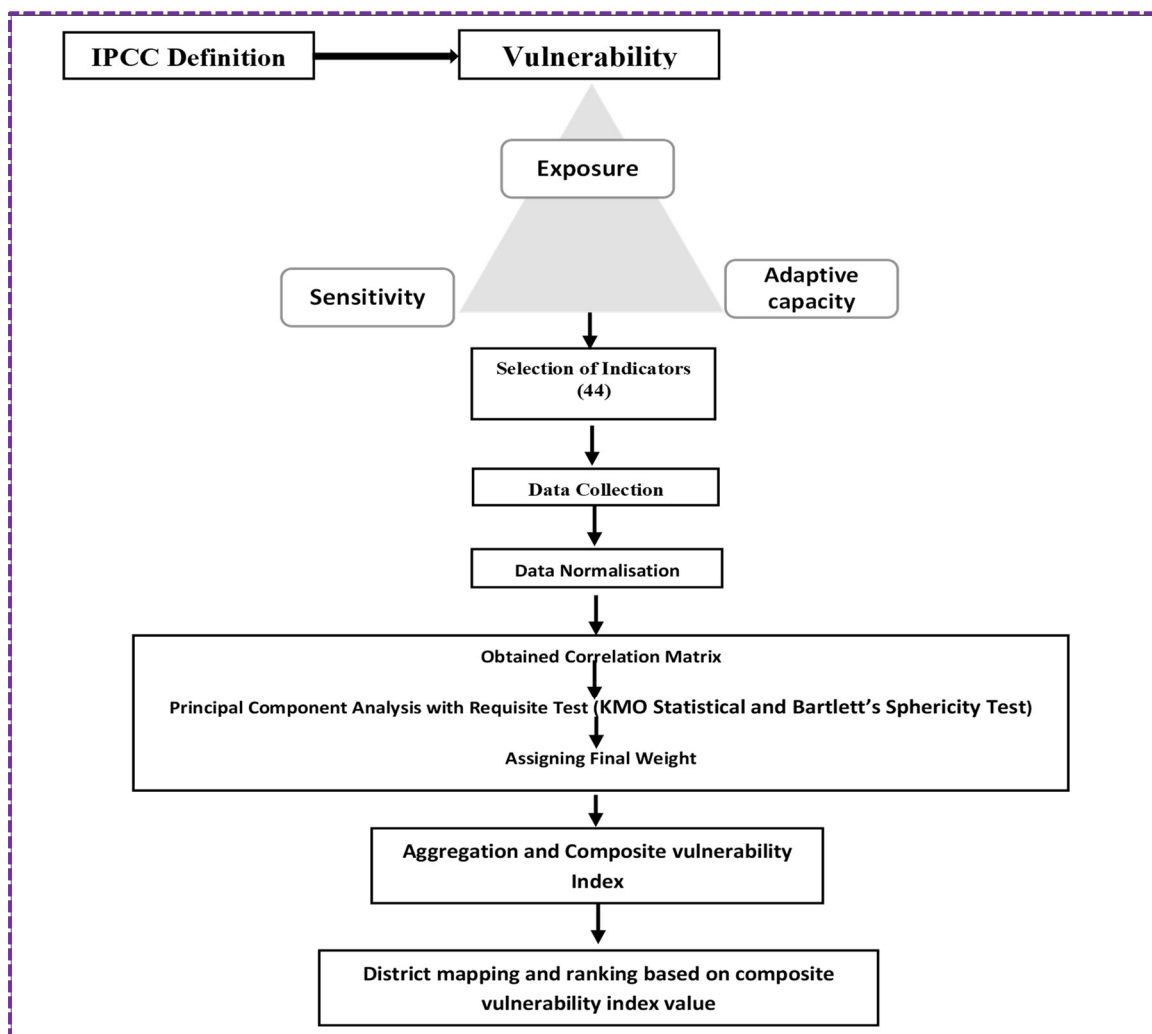


Figure 2. A flow chart of the methodological framework followed to construct vulnerability index

5.3.2 Calculating Weights Through PCA

The IPCC defines two types of vulnerability assessments: contextual vulnerability and outcome vulnerability. Contextual vulnerability draws a qualitative picture of vulnerability, while outcome vulnerability makes it comprehensive and reduces it from a larger to a smaller size (bird's-eye view). This study used indicators, an index-based approach, which is a well-known outcome-based method for vulnerability assessment (Pearson et al., 2008; Ravindranath et al., 2011; Jamshidi et al., 2019).

After normalizing of the dataset, assigning weights is a crucial task. Before that, PCA with correlation was run to check whether there was any association between the variables. To obtain a fair and reliable share of indicators of vulnerability to climate shocks, each indicator was treated according to its relative weight. This study used PCA, as in previous studies (Goel & Garg, 2018; Jamshidi et al., 2019; Tripathi & Singal, 2019; Ajtai et al., 2023). The indicators with eigenvalues greater than 1 were extracted, and weights were assigned using the component loading matrix (Appendix 1). First, extracted component-loading matrix squared and sum of square loading for each component is obtained which is called explained variance. From the explained variance total variance is obtained. Then component weight is obtained by dividing explained variance by total variance. Weights were assigned after squared loading matrix was scaled into unit sums, where we get the domain weight. Then domain weight is multiplied by weight score of the concerned variables to obtain weight score. From weight score of all variables, we get total weight. The PCA results along with the component loading matrix and final weights obtained as per the above procedure is shown in Appendix 1 and Appendix 2. Final weight for each indicator is obtained by dividing the weight score by total weight. Final weight score was assigned using Equation (3):

$$Wf_i = \frac{Ws_i}{\sum Ws_i} \quad (3)$$

Where Wf is the final weight of the indicators, Ws is the derived weight score, and Tw is the total weight of the components.

After deriving the total weight for the indicators, the weights are multiplied by the normalized dataset of the respective districts. Subsequently, the final composite vulnerability is constructed. After obtaining a composite value for all districts of Odisha, they were mapped and ranked accordingly. The aggregation and construction of composite vulnerability indices for the 30 districts of Odisha were performed by using equation (4):

$$CVi = \sum_{i=1}^{44} WiNVi \quad (4)$$

Where CVi is the composite vulnerability index of a district, NVi is the normalized value of the indicators i and Wi is the final weight assigned normalized indicator i .

6. RESULTS AND DISCUSSION

6.1 Weather Variability Index and Categorization of Drought and Flood Years

As we have seen in (Table 1), the historical background of natural events that have occurred in the state from 1970 to 2021 presents a clear picture that almost every year one shock hits Odisha. This study determines the weather variability in the state, particularly defining a year as a dry or wet year. Both annual and monsoon rainfall data from 1901 to 2023 were used in this study from 1901 to 2023 for constructing weather variability index. Deviations in rainfall from normal rainfall reflect weather variability. Scanty or excess rainfall destroys livelihood system by creating unexpected havoc and vulnerability. Therefore, given the historical and continuous extreme weather and climate events in the region, the weather variability index in annual and monsoon rainfall is constructed for better understanding.

Both annual and monsoon rainfall data were used to construct the weather variability index. First, we identified a dry year or wet year by the following Equation (5) and (6) (Pant & Kumar, 1997; Das, 2021):

$$Ria \geq Rma + Sda \text{ or } Ria \leq Rma - Sda \quad (5)$$

$$Ris \geq Rms + Sds \text{ or } Ris \leq Rms - Sds \quad (6)$$

Where, Ria is the annual rainfall in year i , Rma is the long-term mean annual rainfall and Sda is the standard deviation of the annual rainfall. Similarly, Ris is the monsoon rainfall in year i , Rms is the long term mean monsoon rainfall and Sds is the standard deviation of the monsoon rainfall. When actual rainfall is less than the normal plus standard deviation then the period is called dry and if actual rainfall is greater than normal plus standard deviation then it is called wet period. The long-term time series departure of rainfall is calculated by transforming departure in rainfall, long term standard deviation rainfall and long term mean rainfall. Therefore, the transferred annual and monsoon rainfall is calculated using Equations (7) and (8):

$$TNa = \frac{Ria - Rma}{Sda} \quad (7)$$

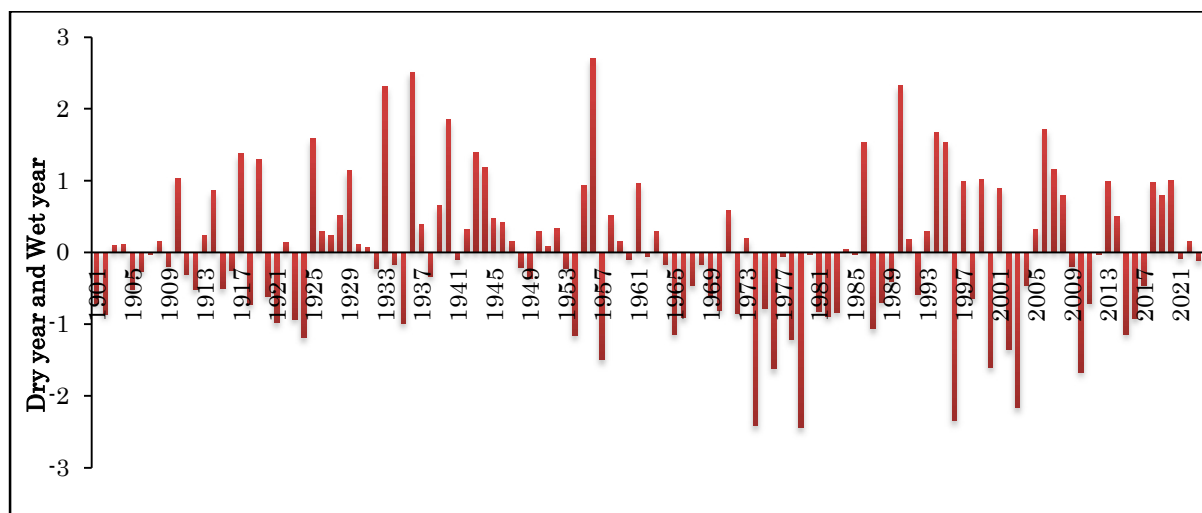
$$TNs = \frac{Ris - Rms}{Sds} \quad (8)$$

Where here TNa and TNs are the transferred and normalized annual and monsoon rainfall respectively. The transferred series had a mean of zero, and a standard deviation of 1. "The year with below-normal actual or monsoon rainfall quantity is designated as a drought year and the excess as the flood year." The result revealed that there were 15 wet years and 108 dry years when we considered annual rainfall. Similarly, in the case of monsoon rainfall, out of one hundred twenty-three years, this study found thirteen wet years and one hundred thirteen dry years. Although most of the years encountered severe cyclonic storms and heavy

flooding, the other months consisted of days with less rainfall. In a relative sense, the state is wet for three to four months, but is affected by scanty rainfall during the rest of the year. The normalized transferred values of annual and monsoon rainfall were categorized into different classes (normal, moderate, severe, and extreme). The scales of the transferred values are as follows:

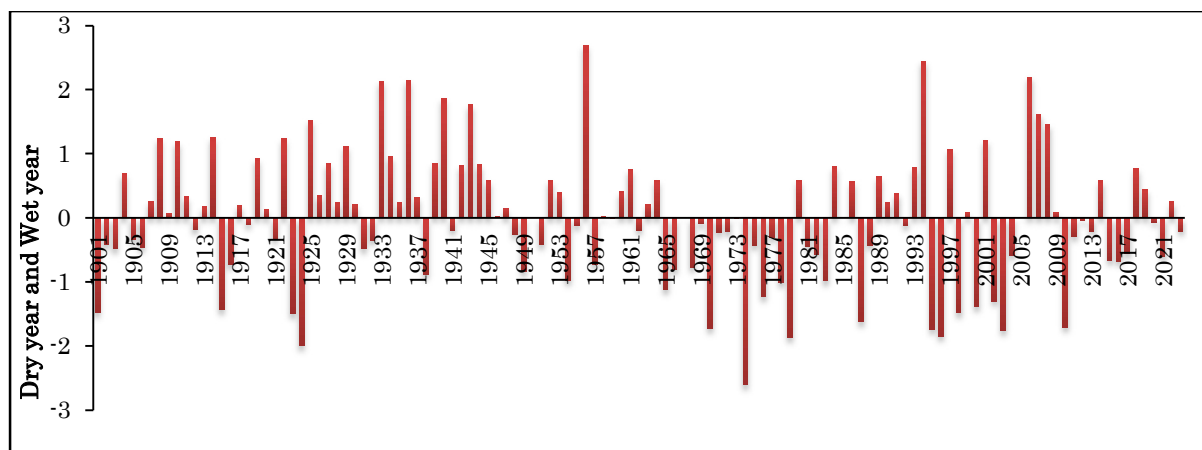
- (-0.99 to 0.99) - Normal
- -1.0 (+1.0) to -1.49 (+1.49) - Moderate drought (or flood)
- -1.5 (+1.5) to -1.99 (+1.99) - Severe drought (or flood)
- Values below (or above)-2.0 (+2.0) - Extreme drought (or flood)

Figures 3 and 4 represent normalised or departure annual and monsoon rainfall of one hundred twenty-three years. It reveals the dry year and wet year on the basis of annual rainfall. Figure 3 shows that there are four years of extreme drought and flood, six years of severe flood, three years of severe drought, nine years of moderate flood, and eight years of moderate drought. Similarly, Figure 4 defines dry and wet years along with weather variability by emphasizing monsoon rainfall. Monsoon rainfall generally takes into account the rainfall data in the months of June, July, August, and September. This period is a very crucial period for the farmers and other livelihood options that depend on rainfall distribution. Figure 4 clarifies that there are five years of extreme flood, one year of extreme drought, four years of severe flood, eight years of severe drought, eight years of moderate flood, and nine years of moderate drought.



Source: Author’s Calculation

Figure 3. Weather index for drought and flood years and its trend in Odisha (Annual rainfall)



Source: Author’s Calculation

Figure 4. Weather variability index for drought and flood years and its trend in Odisha (Monsoon rainfall)

6.2 Vulnerability Assessment and Ranking of the Districts on the Basis of Climate Shocks

This study assessed vulnerability to climate shocks by ranking the districts of Odisha. The dataset was examined to determine if it was appropriate for PCA dimension reduction before PCA is conducted. First, the correlation was checked among the variables because PCA strongly sets when there is an association among the variables. Both the Kaiser-Meyer-Olkin (KMO) statistic and Bartlett’s test were verified using SPSS software. The KMO generally verifies collinearity and relationship among the variables. The value of this index varies from zero to one. When the value is greater than 0.5 or equal to 0.5, the dataset is suitable for running PCA. This study verifies that KMO index is 0.574, and Bartlett’s sphericity test is significant at the 1% level. The significance level of the correlation is examined by matrix by considering its identity matrix as a null hypothesis.

After running the PCA, 12 principal components with eigenvalue greater than 1 were extracted. After rotating the matrix and assigning the final weight, as discussed in the methodology section, the districts were ranked and mapped (see Table 4). Among all indicators, the highest weight assigned to the literacy rate, which is a major component of vulnerability assessment, belongs to the socio-demographic category. According various studies (Muttarak & Lutz, 2014; Mabhuye, 2024) literacy rate is indirectly related to vulnerability. Literacy can directly influence skills, knowledge, and risk perception, and people can easily cope with climate shock. In contrast, the illiterate sections are highly sensitive to climate shocks. Among the 44 indicators, the lowest weight was assigned to the gross enrolment ratio at the secondary level. This is also indirectly related to vulnerability but is still part of the assessment. This study also assessed the district’s vulnerability at the subsection level based on exposure, sensitivity, and adaptive capacity (Table 4), where rank one represents the highly vulnerable district, and vulnerability decreases when the index value decreases. A detail of the vulnerability mapping based on their severity for different districts of Odisha is presented in Figure 4, which consists of four different parts as they

represent the vulnerability of the exposure index, sensitivity index, adaptive capacity index, and overall vulnerability of the district.

Table 4. Vulnerability of districts to climate shocks and their ranks

Districts	Exposure		Sensitivity		Adaptive Capacity		Vulnerability	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Angul	0.0467	17	0.2283	25	0.1760	22	0.4511	22
Balangir	0.0337	23	0.2675	11	0.1884	20	0.4896	16
Balasore	0.0657	5	0.2447	16	0.1516	29	0.4621	21
Bargarh	0.0194	29	0.2324	21	0.1958	14	0.4476	23
Bhadrak	0.0667	4	0.2633	12	0.1894	19	0.5194	13
Boudh	0.0371	21	0.2586	13	0.2363	5	0.5320	11
Cuttack	0.0578	8	0.1912	29	0.1736	23	0.4226	26
Deogarh	0.0319	25	0.2568	15	0.2187	8	0.5073	14
Dhenkanal	0.0481	14	0.2294	23	0.2107	10	0.4882	17
Gajapati	0.0339	22	0.2900	9	0.2515	3	0.5754	5
Ganjam	0.0821	1	0.2585	14	0.1788	21	0.5194	12
Jagatsinghpur	0.0464	18	0.2237	26	0.1601	26	0.4302	24
Jajpur	0.0688	3	0.2389	18	0.1897	18	0.4974	15
Jharsuguda	0.0109	30	0.2039	27	0.1704	25	0.3852	29
Kalahandi	0.0468	16	0.2979	7	0.2085	12	0.5531	9
Kandhamal	0.0532	10	0.3033	6	0.2172	9	0.5737	6
Kendrapada	0.0561	9	0.2417	17	0.1898	17	0.4877	18
Keonjhar	0.0501	13	0.2800	10	0.2054	13	0.5355	10
Khordha	0.0511	11	0.1915	28	0.1343	30	0.3769	30
Koraput	0.0617	6	0.3070	4	0.2286	7	0.5973	4
Malkangir	0.0408	20	0.3675	1	0.2823	1	0.6906	1
Maurbhanj	0.0751	2	0.2910	8	0.1926	16	0.5587	7
Nabarangpur	0.0446	19	0.3252	3	0.2601	2	0.6300	3
Nayagarh	0.0468	15	0.2375	19	0.1937	15	0.4780	19
Nuapada	0.0206	28	0.3054	5	0.2312	6	0.5572	8
Puri	0.0609	7	0.1871	30	0.1712	24	0.4191	27
Rayagada	0.0509	12	0.3414	2	0.2415	4	0.6338	2
Sambalpur	0.0281	26	0.2301	22	0.1570	28	0.4151	28
Subarnapur	0.0272	27	0.2291	24	0.2099	11	0.4662	20
Sundargarh	0.0331	24	0.2358	20	0.1586	27	0.4275	25

Source: Author's own interpretation

6.2.1 Assessment of Exposure

Among the three vulnerability indicators, exposure consists of two major indicators: extreme climatic events and climate variables. Six indicators, including the frequency of cyclones, floods, droughts, and variations in these shocks, indicate that the state is highly exposed to a number of extreme events. The final weight from the exposure shows that the state is more vulnerable to the frequency of cyclones, followed by the frequency of floods. Based on the exposure index results, Ganjam, Mayurbhanj, and Jajpur are the top districts that are highly exposed to the occurrence of climate shocks. These districts are adjacent to coastal and coastal districts. Districts in and near coastal regions are vulnerable to various extreme events (Hazra et al., 2022; Padhan & Madheswaran, 2023). Therefore, the probability of risk is higher than that in the other districts of Odisha. Jharsuguda is the least vulnerable ranked district in the exposure index with a value of 0.0109. This district is

located at the end of western Odisha and exists in the Northern Plateau. Hence, the probability that a district will be affected by extreme climatic events is lower.

6.2.2 Assessment of Sensitivity

As shown in both Table 3 and Figure 3, a district is sensitive, based of 17 indicators. Three major indicators as socio-demographic features, agricultural activities, and vulnerable groups, jointly formed this component. In socio-demographic features, population density has the highest weight because the denser the population of a district, the higher the chances of exploitation of resources, dependence on finite resources, and loss and damage to climate shocks in comparison to other regions (Raju et al., 2017). In the case of agricultural activities, the major indicator is the area under high-yielding varieties attaining the highest weight. Moreover, all indicators are important in the case of Odisha because of its significant dependence on agriculture. Under vulnerable groups, there are four indicators, such as SC population, ST population, and age groups below 15 and above sixty-five age groups. It also includes the female population dependent on agriculture for their livelihood, which is considered a vulnerable group to climate shocks due to a lack of coping capacity (Khandekar et al., 2019; Maja et al., 2023).

In the sensitivity index, Malkangir ranked as the district most sensitive to climate shocks, followed by Rayagada, Nabarangpur, and Koraput. The major reason for this is the low literacy rate, high percentage of underprivileged group of people, dependency on agriculture with less irrigation facilities and the backwardness of socio-demographic indicators. Nabarangpur is the least literate state, followed by Malkangir, according to the 2011 census. The dominance of the tribal population, hilly mountain region, and poor literacy rate, make these districts highly vulnerable to the sensitive index. Again, the results ranked Puri, followed by Cuttack and Khordha, as the least vulnerable districts in exposure index due to better infrastructure facilities and high literacy rates. Developed socio-economic characteristics, a high literacy rate (Khordha is the highest literate district), and access to well-developed resources are the reasons for this.

6.2.3 Assessment of Adaptive Capacity

The adaptive capacity of the districts is assessed on the basis of a set of major indicators: economic capability, education infrastructure, health infrastructure, and institutional capabilities. Under these determining major indicators, twenty-one major indicators are there that play a significant role in determining the adaptive capacity of a district. These indicators are cover almost all the available infrastructural facilities and capabilities of the districts. Among all districts, Malkangiri is ranked first in the adaptive capacity index, followed by Nabarangpur and Gajapati. Although these districts are tribal-dominated districts, the availability of Micro, Small, and Medium Enterprises (MSME) units and livestock is high in comparison to other districts. These districts perform well in adaptive capacity, but their high score in exposure and sensitivity indices makes them highly vulnerable overall. These districts ranked well in adaptive capacity however, in a relative sense, the index values were higher in case sensitivity, exposure, and overall vulnerability assessment. These high index

values outweigh the adaptive capacity index values. However, adaptive capacity is a crucial and sensitive component of vulnerability, which varies from group to group. A high score of adaptive capacity does not mean that the inhabitants of that district are coping easily, and low-adaptive districts are always lagging behind in adaptation (Abagat et al.2017). Therefore, further intervention should be conducted in this regard, and household investigation is required to provide a regional picture.

A detail of the vulnerability mapping based on their severity for different districts of Odisha is presented in Figure 5 which consists of four different parts as they represent the vulnerability of the exposure index, sensitivity index, adaptive capacity index and overall vulnerability of the district.

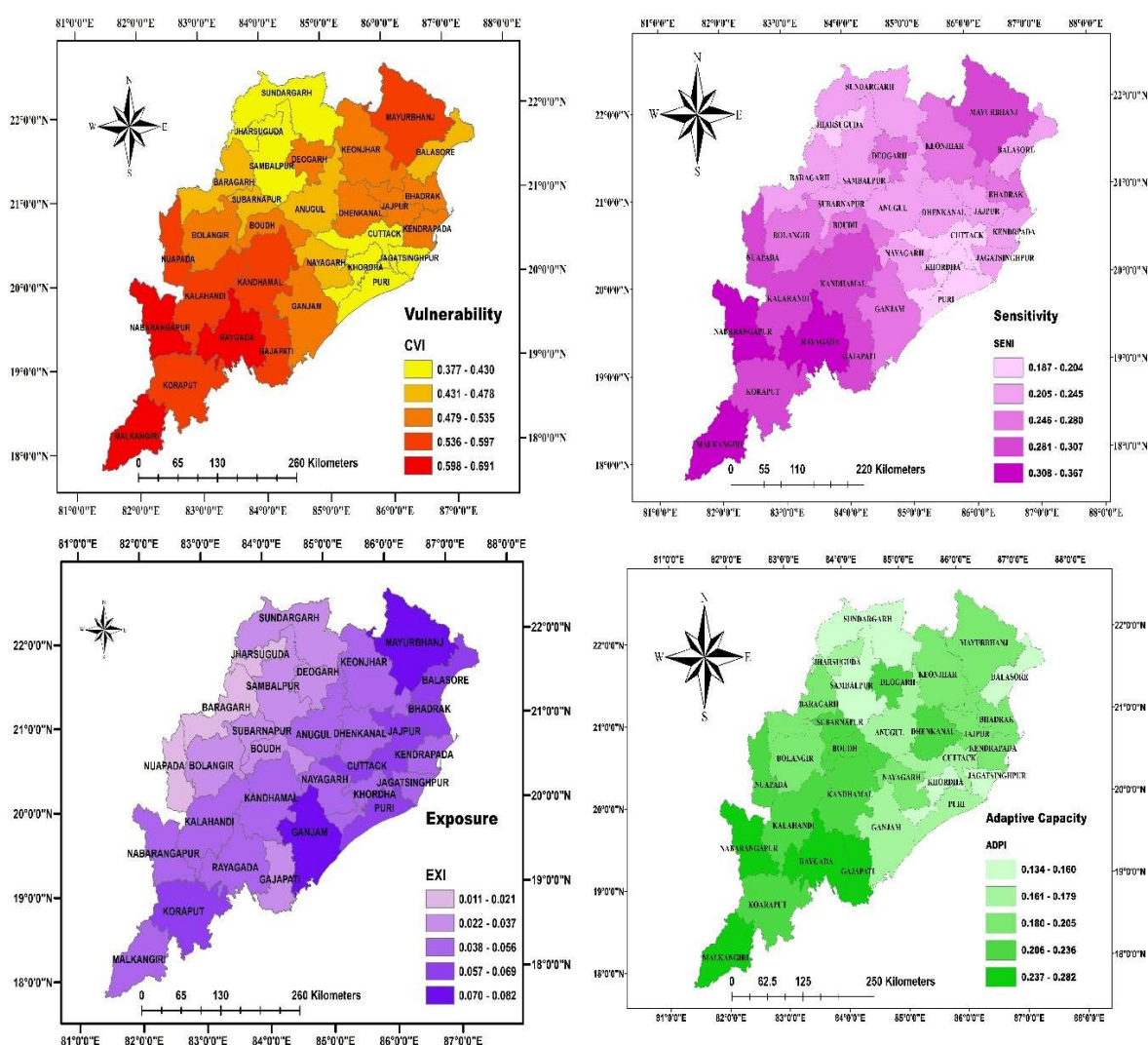
6.2.4 Overall Climate Vulnerability Assessment

Overall, stressing on three major components, the climate vulnerability index values ranked high values for the Malkangir district with a score of 0.6906 due to high sensitivity and exposure to vulnerable indicators. Raygada is the second vulnerable district, followed by Nabarangpur, Koraput, Gajapati, Kandhamal, Mayurbhanj, Nuapada, and Kalahandi. These districts are highly dense by tribal population, have a low literacy rate, heavily depend on agriculture, have low health infrastructure and low road density for which these districts are more vulnerable in comparison to other districts of Odisha. Coastal districts of Odisha though experience more climate shocks in the form of cyclones and floods are relatively less vulnerable due to better adaptive capacity in the form of better infrastructure, socio-economic factors, diversified livelihoods and concentration of MSMEs. Khordha is the least vulnerable district due to a better standard of living, civilised atmosphere, the availability of resources, and critical infrastructure. Further, districts such as Jharsuguda, Sundergarh, and Sambalpur located in the western Odisha are relatively less vulnerable due to better infrastructure and concentration of industries. In the northern Odisha Mayurbhanj is more vulnerable due to low infrastructural facilities, and low level of economic activities.

7. CONCLUSION AND POLICY SUGGESTIONS

This study observed that tribal-dominated districts like Malkangiri, Kalahandi, Raygada are highly vulnerable to climate shocks due to shortage of educational and health infrastructure and therefore requires better educational infrastructural facilities. The districts coming under high vulnerability are also those districts where per capita income is low and that lacks critical infrastructure and therefore for better standard of living and, critical infrastructure targeted policy intervention is required. Moreover, there is a dire need for financial support and government intervention to cope with this vulnerability. Frequency of cyclonic events, literacy rate, headcount ratio of exposure, sensitivity, and adaptive capacity, are majorly contributing to the level of vulnerability. In terms of exposure, coastal districts and coastal adjoining districts are highly vulnerable to climate shocks due to their geographic location and existence. Exposure parameters such as increased droughts, floods, and heavy

dependence on agriculture, along with a low concentration of infrastructural facilities, are the leading cause of the high vulnerability of a district. Districts that are sensitive to climate shocks have scored the lowest rank in literacy rate and fall under the backward region of Odisha and therefore proper provisioning of education facilities in those regions are required. For this, adaptation capacity like infrastructural facilities, opening of hospitals and road connectivity should be highly promoted to strengthen the backbone of the state and boost farmers and other livelihood that are vulnerable to climate shocks. However, from the weather variability index, it is evident that most of the years are interpreted as dry years. Although these years were experienced severe cyclonic storms and heavy flooding, the rest of the months consisted of days of scanty rainfall. In a relative sense, the state is wet for three to four months but affected by scanty rainfall during the rest of the year.



Source: Generated by author using Arc map10.8 software

Figure 5. The degree of vulnerability, exposure, sensitivity and adaptive capacity of districts of Odisha to climate shocks

Therefore, planned and innovative blueprint should be incorporated for physical, health, and educational infrastructure, along with the promotion of economic capabilities to reduce the vulnerability of various regions of Odisha. A targeted infrastructure development policy, along with the promotion of developmental activities for widening economic activities in vulnerable districts need to be implemented to lessen vulnerability to climate shocks. Moreover, training facilities for adaptation, financial provision for farmers, highly developed coping strategies, promoting community-based indigenous coping strategies, promotion of and introducing specific policies to uplift vulnerable tribal groups should be incorporated.

DECLARATION ON CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Appendix-1

Extracted Principal Components to Construct Composite Vulnerability Index

Principal Components	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total (Eigenvalue)	% of Variance	Cumulative %	Total (Eigenvalue)	% of Variance	Cumulative %	Total (Eigenvalue)	% of Variance	Cumulative %
PC1	12.774	29.033	29.033	12.774	29.033	29.033	10.389	23.612	23.612
PC2	4.525	10.284	39.316	4.525	10.284	39.316	3.753	8.530	32.142
PC3	4.166	9.469	48.786	4.166	9.469	48.786	3.689	8.385	40.527
PC4	3.679	8.360	57.146	3.679	8.360	57.146	3.561	8.094	48.621
PC5	2.880	6.546	63.693	2.880	6.546	63.693	2.810	6.385	55.006
PC6	2.079	4.726	68.419	2.079	4.726	68.419	2.396	5.445	60.451
PC7	1.831	4.160	72.579	1.831	4.160	72.579	2.231	5.071	65.522
PC8	1.701	3.866	76.445	1.701	3.866	76.445	2.165	4.921	70.443
PC9	1.434	3.258	79.704	1.434	3.258	79.704	2.091	4.752	75.195
PC10	1.192	2.709	82.413	1.192	2.709	82.413	1.877	4.266	79.461
PC11	1.076	2.445	84.858	1.076	2.445	84.858	1.744	3.965	83.426
PC12	1.006	2.286	87.144	1.006	2.286	87.144	1.636	3.718	87.144

Appendix-2

Component Matrix

Indicators	Principal Components												Final Weight
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	
Frequency of floods from 2001-2021	-.184	-.161	.430	-.100	.029	.481	-.195	-.411	.035	.245	-.007	-.095	0.0163
Frequency of cyclones from 2001-2021	-.415	-.134	.811	-.163	.026	-.151	-.114	.042	-.061	.086	-.052	-.040	0.0463
Frequency of droughts from 2001-2021	.025	-.383	-.606	.140	-.453	.063	.059	.048	-.075	-.128	-.113	-.308	0.0067
Minimum temperature variability from 2001-2021	.747	-.031	-.075	.212	.205	.132	.026	-.363	-.127	.239	.118	.100	0.0093
Maximum temperature variability from 2001-2021	.734	.016	-.081	.258	.413	.056	.049	-.336	.059	.139	.006	.073	0.0080

Variability in rainfall from 2001-2021	-.139	-.185	.109	.268	-.272	-.713	.228	.101	.144	.220	-.101	.216	0.0359
Sex Ratio	.162	-.067	.671	.094	.043	-.380	.022	.149	.228	.028	.093	.044	0.0317
Density of population	-.834	-.156	.373	.077	.244	.078	-.084	.044	.009	-.026	.033	.022	0.0489
Literacy rate	.915	-.094	-.019	.131	.138	-.138	.031	.002	.092	-.078	.184	.072	0.0590
Percentage of disabled population	-.375	.399	-.389	-.037	.026	-.138	-.383	-.002	-.106	.282	.359	.117	0.0091
Unemployment Rate	-.392	.246	.044	-.237	-.222	.235	.069	-.365	.525	-.187	-.049	.121	0.0194
Percentage of rural population	.435	.349	.427	.422	-.363	.281	-.047	.028	-.251	-.015	.001	.015	0.0125
Area cultivated under HYV Cereals	-.055	.721	-.083	-.346	.448	.073	.216	.166	.028	.110	.082	-.120	0.0366
Cropping Intensity	.365	-.641	-.366	.094	.131	-.001	-.199	.031	-.017	.049	-.270	.090	0.0289
Net Area Sown	.247	-.716	.048	.175	-.359	-.185	.004	-.228	.008	.065	-.047	.281	0.0361
Net Irrigated Area	.547	-.040	-.359	-.301	.163	.423	.038	-.038	.064	.132	-.048	.063	0.0126
Population involved in agriculture	.304	.137	.168	.227	-.441	.448	-.165	.215	.466	.161	-.050	-.026	0.0153
Fertilizer Consumption	.156	.378	.152	-.465	-.091	.042	.361	.171	.003	.438	-.026	.366	0.0135
SC Population	-.398	.366	-.010	.631	.132	.049	.041	-.114	-.284	.148	-.268	-.032	0.0280
ST Population	.875	-.215	-.109	-.273	.129	-.079	-.136	.058	.049	-.072	.033	-.084	0.0539
Population Below 15 Year	.811	.027	.354	.206	.257	-.027	.004	-.026	.105	.043	.041	-.104	0.0463
Female population involved in agriculture	.838	.086	-.051	.348	-.197	-.020	.134	.159	-.030	-.039	.024	-.064	0.0494
Elderly population	-.759	.349	.195	.120	-.218	.041	-.131	-.068	-.127	-.130	-.009	.111	0.0405
Head count ratio	.902	-.119	.236	-.003	.241	.000	-.085	.001	.003	-.027	.026	-.077	0.0572
Livestock	-.174	.546	-.299	.399	.272	-.005	.292	.070	.304	-.096	-.045	-.154	0.0210
Crop insurance	.326	.372	.093	-.479	.142	-.151	-.138	-.154	.052	-.449	.055	.225	0.0142
MSME Units	.257	.812	.007	.262	.007	-.166	-.035	.064	-.179	-.169	-.007	.127	0.0464

Households with electricity facilities	.644	-.248	.244	-.378	-.185	.170	-.063	.254	-.276	.050	.112	-.007	0.0054
Per capita income	.232	.191	.234	.635	-.133	.143	-.339	.146	.146	-.034	.317	.184	0.0284
Dropout rate at Secondary level	.469	.019	.243	.270	.393	-.100	-.082	.174	.090	.225	-.247	-.203	0.0043
Gross Enrolment Ratio Secondary Level	-.739	.224	-.065	.234	.123	-.086	-.176	.191	.152	.196	-.240	-.167	0.0041
Number of schools per ten thousand population	-.346	-.284	-.160	.430	.291	-.102	.309	-.410	.200	.068	.111	.102	0.0118
Institutional births	.682	-.070	.257	-.206	.219	-.159	.275	.221	.081	-.114	-.029	-.083	0.0053
Community healthcare centre per ten thousand population	-.500	-.377	.050	.302	.207	.160	.343	.019	-.153	-.038	.204	.035	0.0083
Primary Healthcare Centre per ten thousand population	-.510	-.215	-.021	.008	-.013	.118	.501	.124	-.247	.119	.437	-.167	0.0134
Bed Availability per ten thousand population	.118	-.153	.323	.156	.049	.498	.419	.312	-.102	-.186	-.253	.325	0.0175
Health Insurance Facilities	.043	-.407	-.354	.052	.214	.134	-.298	.520	.268	.098	.229	.083	0.0190
Drinking water facilities	.279	.288	-.039	-.596	-.282	-.109	.027	-.110	-.028	.368	-.154	-.027	0.0095
Sanitation facilities	.661	.060	.344	.070	.430	-.008	-.222	-.171	-.237	-.050	-.069	-.005	0.0130
Density of Post office per 1k sq. k.m.	.767	.198	-.499	-.098	-.099	-.116	.141	-.129	.032	-.026	.020	-.030	0.0175
Density of Bank Branches per 1k sq. k.m.	.742	.171	-.157	.149	-.311	-.104	-.035	.034	-.249	-.016	-.117	-.008	0.0044
Credit Deposit Ratio	.011	-.128	.663	-.192	-.263	-.107	.130	-.219	.106	-.030	.130	-.384	0.0104
Railway route length Density	.569	.305	-.042	.294	-.508	-.085	.008	-.127	.018	.098	.200	-.135	0.0181
District Road density	.773	.140	.119	.103	-.255	.156	.311	-.037	.194	.003	-.013	-.036	0.0068