

Climate change vulnerability in a tropical region based on environmental and socio-economic factors

S. Sarun · A. Ghermandi · A. M. Sheela  · J. Justus · P. Vineetha

Received: 12 January 2018 / Accepted: 30 October 2018 / Published online: 16 November 2018
© Springer Nature Switzerland AG 2018

Abstract The understanding of the regional and local dimensions of vulnerability due to climate change is essential to develop appropriate and targeted adaptation efforts. We assessed the local dimensions of vulnerability in the tropical state of Kerala, India, using a purposefully developed vulnerability index, which accounts for both environmental and socio-economic factors. The large extents of coastal wetlands and lagoons and high concentration of mangrove forests make the state environmentally vulnerable. Low human development index, large population of socially deprived groups, which are dependent on the primary sector, and high population density make the state vulnerable from a socio-economic point of view. The present study investigates climate change vulnerability at the district level in the State of Kerala relying on a purposefully developed composite vulnerability index that encompasses both socio-economic and environmental factors. The Kerala coast contains the socio-economically and ecologically most

vulnerable regions, as demonstrated by a composite vulnerability index.

Keywords Climate change · Vulnerability · Environmental vulnerability index · Socio-economic vulnerability index · Composite vulnerability index · Map · Tropical region

Introduction

The risk of adverse impacts of climate change to human and natural systems is the result of the interaction between the presence of physical, climate-related hazards (e.g., extreme weather events, droughts, floods, sea level rise), and the vulnerability of the local human and natural systems (Oppenheimer et al. 2014). Climate change vulnerability is the degree to which a system is susceptible to be adversely affected by climate change. It is a

S. Sarun (✉)
Department of Geography, University College, University of Kerala, Thiruvananthapuram, Kerala, India
e-mail: savithdse@gmail.com

A. Ghermandi
Department of Natural Resources and Environmental Management, Faculty of Management, University of Haifa, Haifa, Israel
e-mail: aghermand@univ.haifa.ac.il

A. M. Sheela
Kerala State Pollution Control Board, Thiruvananthapuram, Kerala, India

e-mail: sheelaamoses@gmail.com

J. Justus
St. Xavier's College, Thumba, Thiruvananthapuram, India
e-mail: justusjosephvm@gmail.com

P. Vineetha
Centre for Geo-information Science and Technology, University of Kerala, Thiruvananthapuram, Kerala, India
e-mail: geo.vineetha@gmail.com

function of the exposure of human and social-ecological systems to hazardous climatic events, as well as the sensitivity to that exposure, as reflected by the ability to cope with or, in the long run, adjust itself and adapt to ongoing and, possibly, future changes (Hahn et al. 2009). Climate vulnerability is a multi-dimensional concept that embraces considerations across the social, economic, environmental, institutional, and cultural systems (IPCC 2012). Climate change risk is often enhanced by the loss of biodiversity and the ecosystem services it supports as well as the concomitant presence of multiple stressors in a specific region (Oppenheimer et al. 2014). A full understanding of current vulnerability is necessary for developing strategies to adapt to future climate change (Olmos 2001). This involves the need for identification, quantification, and prioritization of vulnerabilities in ecosystems and/or particular geographic areas.

Climate vulnerability and exposure are largely determined by socio-economic pathways and societal conditions. Within the range of climate change studies, the most vulnerable populations are considered to be those who are most exposed to hazard and have limited adaptive capacity, either because of the lack of resources (e.g., financial resources), access to adaptation technologies, or lack of human and social capital (e.g., lack of know-how and appropriate governance structures) (Turner et al. 2003; Schröter et al. 2005; Vogel and O'Brien 2006). This includes, for instance, sectors of the population that are heavily dependent on subsistence activities involving extracting natural resources and have less resilience to climate shocks (Bohle et al. 1994). It is well understood that poor people in the poorest countries are the most vulnerable to the impacts of anthropogenic climate change (Stern et al. 2006).

Climate change vulnerability assessments often rely on composite indexes, such as the livelihood vulnerability index (LVI) (Hahn et al. 2009), in the attempt to explicitly and transparently incorporate multiple criteria in complex decision-making environments. Climate vulnerability assessments may play an important role in (1) understanding current vulnerability; (2) identifying the factors that render some districts more vulnerable than others; (3) inform and facilitate the decision-making process, in a transparent and replicable way; and (4) selecting and evaluating adaptation strategies and practices, possibly through the engagement of all relevant stakeholders, including the most vulnerable communities and populations in the national- or local-level

planning. Vulnerability assessment typically includes three components: exposure to climate change, sensitivity to its effects, and adaptive capacity to cope with the effects (IPCC 2012). Vulnerability assessments typically attempt to quantify the three components by identifying appropriate indicators and combining them into indices. Subsequently, the components are then often combined into an integrated index of vulnerability. The indicators used for the components include usually both the biophysical (environmental) and socio-economic dimensions (Yohe and Tol 2002; Metzger and Schröter 2006; Eakin and Luers 2006; Gbetibouo et al. 2010; cf. Iglesias et al. 2011). Thus, a common method to quantify vulnerability to climate change is by using a set or composite of proxy indicators. Indicators can, for example, be used to link biophysical and economic attributes of systems to vulnerability outcomes via a quantitative function. However, identifying and constructing appropriate indicators for vulnerability assessments is highly challenging (Downing and Patwardhan 2005; OECD 2008).

The number of climate vulnerability assessment studies that encompass the multi-dimensionality of both socio-economic and environmental factors in their analysis is still limited. The IPCC's Working Group II contribution to the IPCC's Fifth Assessment Report recognizes five criteria to identify key climate vulnerabilities: (1) exposure of a society, community, or social-ecological systems to climatic hazard; (2) importance of the vulnerable system; (3) limited ability of societal or ecological systems to cope with or adapt to climatic changes; (4) persistence of vulnerable conditions and degree of irreversibility of consequences; and (5) susceptibility to the effect of cumulative stressors.

The purpose of this study is to provide a multi-dimensional assessment of climate vulnerability in the State of Kerala in India. Kerala State is located in the South of India, a region that is understood to be among the most vulnerable to climatic changes. Various studies show that there is a change in climate of the state for the past few decades. Wassmann et al. (2009) observed that several areas in the South of India are already approaching critical levels to increased heat stress during the susceptible stages of rice cultivation. Previous studies observed that changes in seasonal precipitation in Kerala point towards vulnerability to increasing probability of water scarcity in the pre-monsoon time, delaying monsoon onset and floods (Pal and Al-Tabbaa 2009; Monirul and Mirza 2011). Compared to

other states in India, Kerala was found to be highly sensitive to climate-induced food insecurity, and reduced freshwater availability, in spite of showing relatively low inequality and high social and human capital (as reflected in literacy rates, particularly for women, birth and infant mortality rates, and life expectancy) (Brenkert and Malone 2005). Moreover, previous research on the climate-related risks in India has shown associations between high temperature and mortality (McMichael et al. 2008) as well as correlations between rainfall and malaria prevalence (Devi and Jauhari 2006; Dev and Dash 2007; Laneri et al. 2010).

The present study investigates climate change vulnerability at the district level in the State of Kerala relying on a purposely developed composite vulnerability index that encompasses both socio-economic and environmental factors. The index is designed to account for the local socio-economic, environmental, and cultural context. Given the climate vulnerability of the state as observed in previous studies, it is essential to understand the spatial variations in vulnerability and its drivers in order to develop appropriate and targeted adaptation efforts.

Study area

Kerala State comprises a narrow strip of land with an area of 38,863 km², extending between north latitudes 8°17'30" and 12°27'40" and east longitudes 74°51'57" and 77°24'47" (Soman 1997). The location of Kerala is given in Fig. 1. The Western Ghats lie on the east and the Arabian Sea on the west. The width of the state ranges from 11 km to a maximum of 124 km. Kerala has a diversified geological structure with coast line, mangroves, high mountains, and sandy beaches. The state is classified into five physiographical zones: mountain peaks above 1800 m, the highlands at altitudes of 600–1800 m, the midlands at altitudes of 300–600 m, the low lands at 10–300 m, and the coastal plains and lagoons below 10 m. Mountains and peaks above 1800 m within Western Ghats constitute only 0.64% of the area of the state, the highlands occupy 20.35%, the midlands occupy 8.44%, the low lands occupy 54.17%, and the coastal plains and lagoons constitute 16.4%. Kerala constitutes only 1.18% of the total area of India, but accounts for about 3.1% of the Indian's population. The density of population is 859 persons/km², which is three times higher than in the rest of India. Kerala is divided into

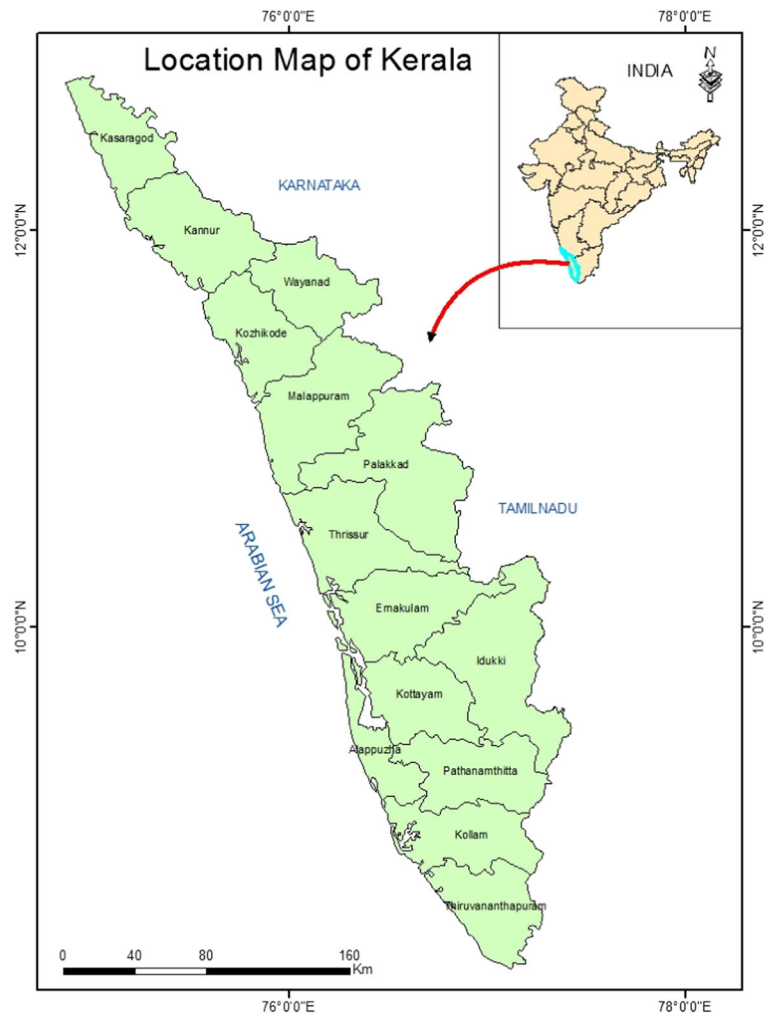
14 districts and its basic characteristics are given in Table 1.

According to the Indian Meteorological Department, during the last 43 years, the mean maximum temperature has risen by about 0.8 °C, the minimum by 0.2 °C, and the average by 0.6 °C over Kerala (27.3–27.9 °C), which is a clear upward trend in surface air temperature (SAPCC). The increase in annual maximum temperature was 0.72 °C, with a 0.22 °C increase in minimum and 0.47 °C increase in mean annual temperature across Kerala overall a period of 54 years from 1956 to 2009 (Rao Prasada et al. 2008). The mean temperature increased from 27 °C in 1956 to 27.9 °C in 2009 across Kerala. Widening difference between maximum and minimum temperature was also noticed due to increase in temperature range from 8.3 °C to 8.6 °C. According to Rao et al. (2008), the increases in maximum and minimum temperature were 0.64 °C and 0.23 °C, respectively. Rainfall of Kerala has shown a decreasing (SAPCC) trend in the last 100 years. There is an increasing trend of extreme rainfall and at the same time an overall decrease in annual precipitation in the state for 1954–2003 (Pal and Al-Tabbaa 2009). The southwest monsoon rainfall showed a decreasing trend while precipitation increased in post-monsoon season (Krishnakumar et al. 2009). The southwest and northeast monsoon rainfall at Kozhikode since 1980 is given in Fig. 2. Onset of Indian summer monsoon from 1870 to 2009 is given in Fig. 3. Historic sea level rise in Kochi coast is given in Fig. 4.

Materials and methods

The underlying assumption of the proposed methodology is that climate change vulnerability is created by the susceptibility of existing socio-economic factors as well as environmental factors of a region to climate change hazards. The most important challenge is to determine the regional specific parameters with respect to socio-economic and environmental factors. The composite vulnerability index in this study was constructed on a Geographic Information System (GIS) platform, which involves the estimation of an environmental vulnerability and a socio-economic vulnerability index based on the assessment of individual index with relative ranking methods and weights. Each district is placed into classes according to their relative environmental and socio-economic vulnerability. The indicators are assigned

Fig. 1 Location of the State of Kerala and administrative subdivisions



different weights to avoid the uncertainty of equal weighting, given the diversity of indicators used (Deressa et al. 2009).

The criteria for indicator selection for this study are based on the peculiar circumstances of the State of Kerala in terms of climate change vulnerability profile. The first methodological step deals with the identification of nine key environmental and socio-economic variables covering important aspects related to climate change vulnerability in the context of Kerala (Table 1). The key climate vulnerabilities have been identified as per the IPCC's Working Group II contribution to the IPCC's Fifth Assessment Report.

Lagoons, dense forests, Shola forests, coastal wetlands, and sand beaches are important vulnerable systems and susceptible to the effect of cumulative stressors. Coastal wetlands and lagoons and sand

beaches are prone to sea level rise, and dense forests are exposed to fire during intense summer. In the coastal areas, the vertical rise in the water column due to sea level rise and the limitations of landward margins may result in water logging, ultimately destruction of mangroves and associated fauna (MoEF 2004). In the higher altitude, Shola forest may be reduced and species composition may be changed (Chandrasekhara 2004). The dense forests are the most vulnerable region to projected climate changes (Ravindranath et al. 2006). Hence, the extent of these ecosystems has been identified as a key climate vulnerability. The relative extent of the ecosystems was measured in each district. Districts with larger extents are considered here as more vulnerable to climate change than other areas (Table 2). The socio-economic variables human development index, population dependent on primary sector (agricultural and

Table 1 Physiography and land use in different districts of Kerala

Category	Population per 100 km ²	%High	%Medium	%Low
Thiruvananthapuram (TVPM)	162,046	26.2	68.3	5.2
Kollam (KLM)	111,846	43.8	41.9	14.8
Pathanamthitta (PTA)	48,293	71.1	27.0	1.8
Alappuzha (ALPA)	157,065	0	20.2	79.9
Kottaya (KTM)	94,819	23.1	58.5	18.1
Idukki (IDK)	27,100	96.3	3.6	0
Emakulam (EKM)	112,000	6.9	51.9	19.6
Thrissur (TSR)	106,523	32.4	50.9	15.3
Palakkad (PLKD)	64,266	65.1	34.9	0
Malappuram (MLPM)	119,539	16.9	80.0	2.9
Kozhikode (KKD)	134,669	26.6	57.2	15.4
Wayanad (WND)	42,570	99.8	0	0
Kannur (KNR)	86,720	40.9	53.6	4.9
Kasargod (KGD)	67,960	51.7	37.2	9.6

fisheries sectors), socially deprived classes, and population density have also been included.

The second step was to assign weights to each indicator of every district based on vulnerability importance to the particular phenomenon. Weights have been assigned based on various reports, namely, Census Report 2011, State Environment Report, State Wetlands Atlas, Human Development Report 2005, and State Economic Review. The composite climate change vulnerability index was also tested by applying different normalization methods and using different weighting factors for the selected indicators. The main features of the results did not change, which confirms the robustness of the index.

In the environmental vulnerability index, the ranking was given to each variable as 2, 4, 6, and 8 based on degree of vulnerability. The rank value 2 indicates that the district is least vulnerable, 4 for medium, 6 to high, and rank value 8 indicates that it is very vulnerable to climate change. Moreover, in each district, these rank values also vary based on exposure of these variables to climate change risk. For example, rank 8 has been assigned to the lagoons of Alappuzha where the extent of lagoons is very high. But only rank 2 is given to the lagoons of Malappuram because the extent of lagoons is much lower. Accordingly, ranking changes with each district and variables when the criteria changes.

The individual shares of population density, population depending on primary sectors and socially deprived

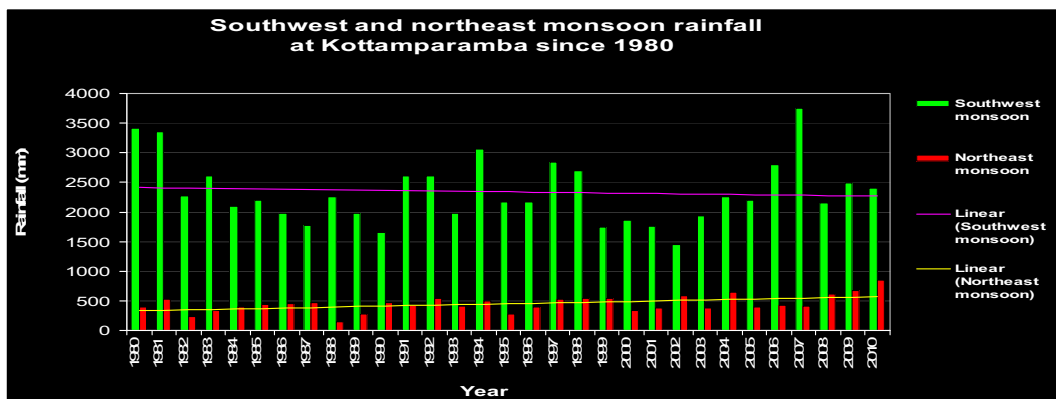


Fig. 2 Southwest and northeast monsoon rainfall at Kozhikode since 1980 (Kerala State Action Plan on Climate Change 2014)

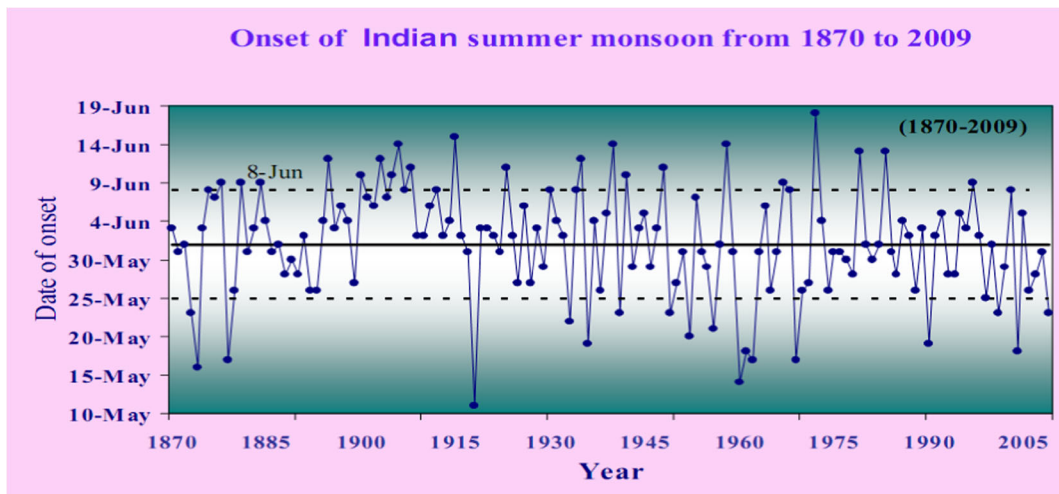


Fig. 3 Onset of Indian summer monsoon from 1870 to 2009 (Kerala State Action Plan on Climate Change 2014)

classes, have been calculated as percentages. Weighing for the socio-economic variables relied on expert judgment, where 4 was assigned to the variable most affected by climate change, i.e., population density, 3 to population dependent to the primary sector, 2 to socially deprived section, and 1 to the human development index. Socio-economic and environmental vulnerability indexes were developed by cumulating the corresponding values of each of the variables. Accordingly, separate district-wide maps of socio-economic and environmental vulnerability have been developed.

A composite climate change vulnerability index has finally been developed using simple additive weighting from environmental and socio-economic vulnerability indexes. A weight of 0.70 was given to socio-economic vulnerability and 0.30 to environmental vulnerability (Yusuf and Francisco 2009). Based on composite vulnerability index, 14 districts are clustered into four classes which are characterized by very high, high, medium, and low vulnerability.

In order to confirm the above results, Cluster analysis was conducted using SPSS Chicago 16.0 software. The classification of districts have been done using Cluster

analysis. Cluster analysis is an exploratory data analysis tool for classifying problems, the objective being to sort monitoring points into groups such that the degree of association is strong between members of the same cluster, while weak between the members of different clusters (Sheela et al. 2012) The Euclidian distance method and Ward's method were used for the analysis.

Results and discussion

Vulnerability profile of Kerala

Kerala State's unique geographical location, weather patterns, and high population density make it vulnerable to severe natural as well as human-induced disasters, and the state is considered as one of most multi-hazard prone states in the country (<http://documents.gov.in/KL/16344.pdf>). The increasing vulnerabilities due to a variety of factors such as rapid urbanization, environmental degradation, growing population, and climate change compound the disaster risks in the state (Kerala State

Fig. 4 Historic sea level rise in Kochi coast (Kerala State Action Plan on Climate Change 2014)

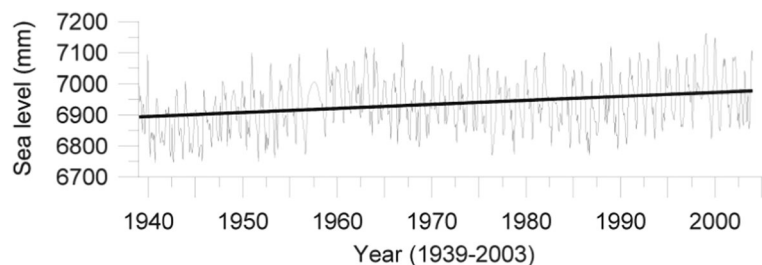
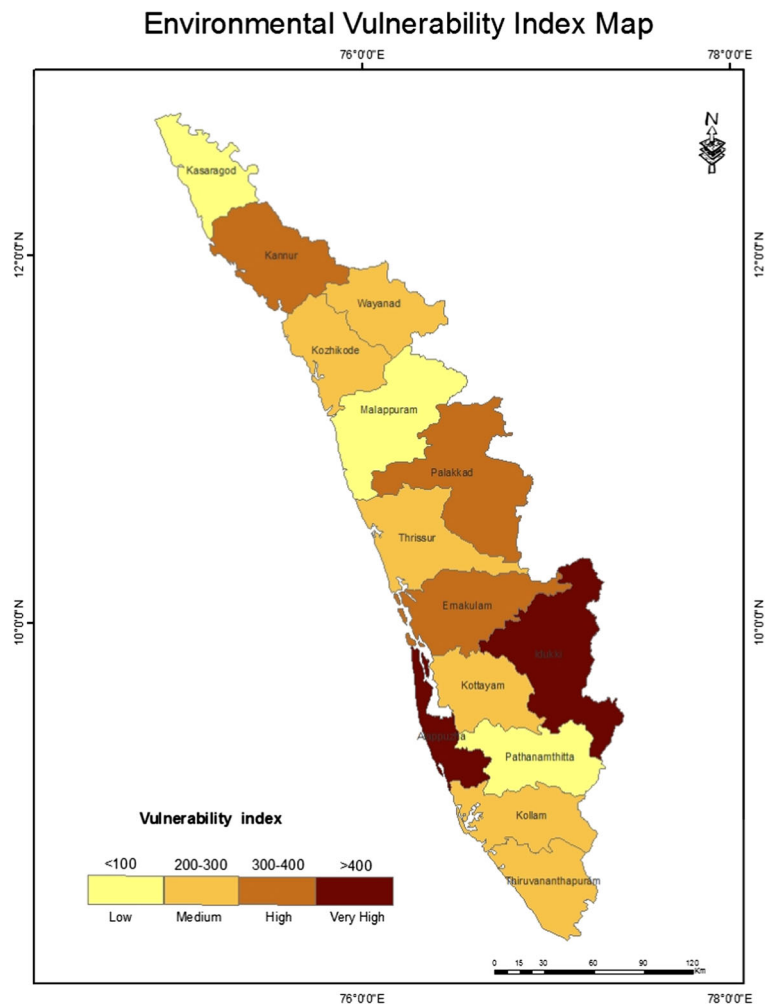


Table 2 Assignment of weights for environmental factors

Districts	Coastal wetlands		Lagoons		Sand beach		Dense forest		Mangrove forest		Shola forest)	
	In percentage of land cover	Weight	In percentage of land cover	Weight	In percentage of land cover	Weight	In percentage of land cover	Weight	In percentage of land cover	Weight	In percentage of land cover	Weight
Kasargod	2 (2)	2	2 (2)	2	14 (2)	2	0	0	5 (2)	2	0	0
Kannur	1 (2)	2	3 (2)	2	20 (6)	6	1 (2)	2	45 (4)	4	0	0
Wayanad	0	0	0	0	0	0	10 (4)	4	0	0	30 (8)	8
Kozhikode	1 (2)	2	0	0	24 (4)	4	2 (2)	2	18 (6)	6	0	0
Malappuram	3 (2)	2	2 (2)	2	12 (6)	6	10 (4)	4	1 (2)	2	0	0
Palaghat	0	0	0	0	0	0	19 (6)	6	0	0	30 (8)	8
Thrissur	1 (2)	2	2 (2)	2	7 (2)	2	12 (6)	6	1 (2)	2	0	0
Ernakulam	20 (8)	8	12 (8)	8	4 (2)	2	1 (2)	2	16 (6)	6	0	0
Idukki	0	0	0	0	0	0	24 (6)	6	0	0	30 (8)	8
Kottayam	13 (2)	2	4 (2)	2	0	0	1 (2)	2	5 (2)	2	0	0
Alappuzha	35 (8)	8	25 (8)	8	5 (2)	2	0	0	5 (2)	2	0	0
Pathanamthitta	2 (2)	2	0	0	0	0	10 (4)	4	0	0	0	0
Kollam	19 (4)	4	20 (6)	6	0	0	5 (2)	2	3 (2)	2	0	0
Thirvanathapuram	3 (2)	2	30 (4)	4	15 (6)	6	5 (2)	2	1 (2)	2	10 (4)	4
Total (in percent)	100	100	100	100	100	100	100	100	100	100	100	100

Fig. 5 Environmental vulnerability index map

Disaster Management Authority (KSDMA)). The state is highly prone to climate extremes like flood and drought. The high intensity of rainfall during the monsoons causes severe floods (Anonymous 2015). Increasing flood plain occupancy and reclamation of water bodies and wetlands results in increasing flood damages. In the state, 14.8% of the total area is prone to floods (<http://www.kerenvis.nic.in/WriteReadData/UserFiles/file/49412317-Kerala-Disaster-Management-Plan-Profile-India.pdf>). Kerala has been experiencing seasonal drought conditions every year during the summer months. The state is one of the most densely populated regions in the country, which adds to its vulnerability. The Western flank of the Western Ghats covering the eastern part of Kerala is identified as one of the major landslide prone areas of the country. Kerala has a very long

coastline of 570 km, out of which 322 km is prone to severe sea erosion is one of the most densely populated regions in the country, which adds to its vulnerability. Moreover, there is risk of sea level rise along the Kerala coast and the estimate for Kochi is 1.14 mm/year (Unnikrishnan et al. 2006). Vulnerability to severe and accelerating sea level rise can be compounded by high population density along the coast of Kerala. Hazards in the coastal zone include eroding, monsoon, storm surges, and sea level rise (Anonymous 2015).

Kerala is highly dependent on climate-sensitive sectors like agriculture, fisheries, and forests. The state suffers of freshwater scarcity. The steep gradient and high degree of dissection cause the entire rain falling in the catchment area drains into the sea and the residence time being extremely small (Anonymous 2015). Large-

scale encroachment, destruction of forests, reclamation of wetlands, ponds, and paddy fields, changes in cropping pattern, increase in impervious surface, and pollution have aggravated the problem of water scarcity. Agriculture and food security may also be impacted by unpredicted patterns and decline of rainfall. The agriculture sector in Kerala was badly affected due to continuous rainfall (worldwaterforum7.org/forum/view.asp?forum?seq=179&sh_code_cd1=010000). Temperature-sensitive crops like black peeper, cardamom, tea, coffee, and cocoa are badly affected as temperature range increases and rainfall declines.

Many fragile ecosystems like mangroves, Shola forest and tropical evergreen forest, river, and azhi exist in the state. The varied topographical features, high precipitation, and geological conditions have favored the formation of diverse vegetation groups: from high-altitude Shola forests on the high ranges to the coastal mangrove forests (shodhganga.inflibnet.ac.in/bitstream/10603/22578/14/14_chapter2.pdf). The boundary shifts for different forest types, with consequent implication for species diversity and forest-dependent communities (www.ids.ac.uk/files/dmfile/ORCHIDIndiaRR.pdf). Trends in the occurrence of various diseases, especially of vector borne diseases, are on the rise (Sheela et al. 2015). The increase in energy demands also leads to impact on climate-sensitive infrastructure. Land degradation has also been exacerbated in the state due to higher density of population in the state.

Development of composite vulnerability index

Environmental vulnerability index map

Table 2 presents the state districts classified into four vulnerability indices spanning very high, high, medium, and low vulnerability (Fig. 5 and Table 3). The values in Table 3 are derived by multiplying the percentage of land area with corresponding weightage of each environmental factors. Additive index has been used in the study.

The highest environmental vulnerability is found in the Alappuzha district, the only district with an environmental vulnerability index value larger than 500. This district has the largest extent of coastal wetlands and lagoons.

The values between 350 and 500 are considered to be representative of highly vulnerable regions. These comprise Kannur, Palakkad, Ernakulam, and Idukki districts. High vulnerability in Kannur is due to the highest concentration of mangrove forests and large extent of beach, in Palakkad and Ernakulam due to a large extent of coastal wetland and lagoons, and in Idukki due to a large extent of dense forests and Shola forests.

A medium vulnerability (200–350) is assigned to Wayanad, Kozhikode, Kollam, and Thiruvananthapuram districts. In Thiruvananthapuram, medium vulnerability is due to the presence of coastal lagoons and beaches. In Kozhikode, medium vulnerability is due to large extent of

Table 3 Environmental vulnerability index

Districts	CW	Lagoon	Beach	Dense forest	Mangrove	Shola	EVI
Kasargode	4	4	28	0	10	0	46
Kannur	2	6	160	2	180	0	350
Wayanad	0	0	0	40	0	240	280
Kozhikode	2	2	96	4	108	0	308
Malappuram	9	6	72	40	2	0	129
Palakkad	0	0	0	114	0	240	354
Thrissur	2	2	28	72	2	0	106
Ernakulam	160	96	8	2	96	0	362
Idukki	0	0	0	192	0	240	432
Kottayam	26	78	0	2	10	0	116
Alappuzha	280	200	20	0	10	0	510
Pathanamthitta	0	0		40	0	0	40
Kollam	76	120	0	10	6	0	212
Thiruvananthapuram	6	120	90	10	2	40	268

beaches and mangroves, and in Wayanad, it is due to a large extent of Shola forests and in Kollam due to coastal lagoons and wetlands.

The values below 200 are classified as representative of low environmentally vulnerable regions. These include Kasargode, Malappuram, Kottayam, Thrissur, and Pathanamthitta districts. Low vulnerability is due to a low extent of coastal wetlands, lagoon, beach, dense forest, mangrove, and Shola forests.

Environmental vulnerability is very high in the areas having a large extent of coastal wetlands and lagoons and that with high concentration of mangrove forests. It is high in the areas where there are large extent of dense forests, and Shola forests and where there is a large extent of beaches and lagoons. Hence, immediate attention is to be given for taking adaptive measures in areas where there is large extent of coastal wetlands, lagoons, and mangrove forests. This is in agreement with the finding of Poff et al. (2002) in US aquatic system that aquatic and wetland ecosystems are very vulnerable to climate change. Coastal wetlands are particularly vulnerable to sea level rise associated with increasing global temperature. The metabolic rates of organisms and the overall productivity of ecosystems are directly regulated by temperature. Increase in water temperature will cause a shift in the thermal stability of aquatic species for resident species. According to Gilman et al. 2008, mangrove systems do not keep pace

with changing sea level when the rate of change in elevation of the mangrove sediment surface is exceeded by the rate of change in relative sea level. The next priority is to be given in the areas having large extent of dense forests, Shola forests, beaches, and lagoons.

Socio-economic vulnerability map

The socio-economic vulnerability index was constructed by taking variables like population density, socially segregated groups (i.e., Scheduled Caste and Tribes), share of population dependent on climate-sensitive primary sectors (fishing and agriculture), and human development index of the 14 districts in the state (Table 4).

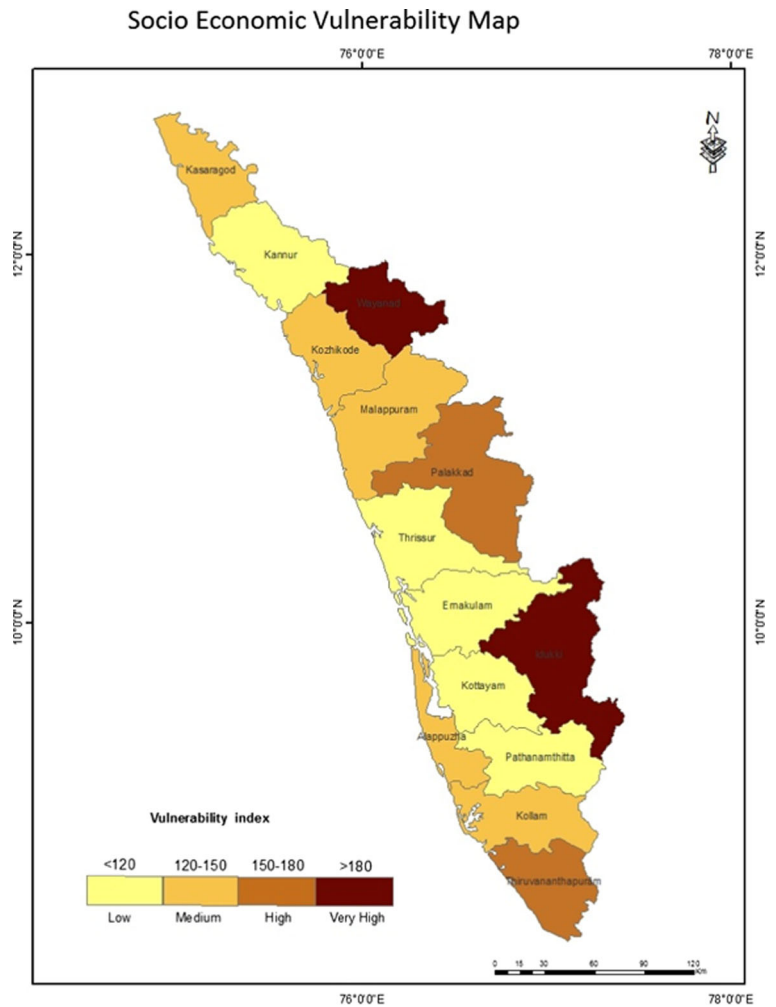
In Fig. 6, the state districts have been classified as very high, high, medium, and low according to the socio-economic vulnerability index. The value above 180 is classified as representative of very high socially vulnerable districts, i.e., Idukki and Wayanad. In these districts, more population depends on primary sector as well as the highest percentage of social deprived class and low overall human development performance.

The highly vulnerable districts are Thiruvananthapuram and Palaghat, where the values are in between 150 and 180. Thiruvananthapuram comes under this category because of high population density, low rank in the human development index, and sizeable population of deprived classes. Unlike Thiruvananthapuram, Palaghat

Table 4 Socioeconomic vulnerable index

Socioeconomic indicators	Population density in percentage	Deprived groups	Primary	HDI	SVI
District/weightage	4	3	2	1	
Thiruvananthapuram	59.4	48	34	9	150.4
Kollam	41.52	33	54	6	134.52
Alappuzha	59.84	21	48	4	132.84
Kottayam	28.88	27	56	2	113.88
Pathanamthitta	22.96	21	64	3	110.96
Idukki	10.08	57	110	12	189.08
Emakulam	40.2	33	36	1	110.2
Thrissur	39.24	36	34	5	114.24
Palakkad	23.36	72	52	10	157.36
Malappuram	40.88	36	50	14	140.88
Kozhikode	49.12	24	46	8	127.12
Wayand	14.4	114	102	13	243.4
Kannur	32.52	24	48	7	111.52
Kasargode	24.16	33	60	11	128.16

Fig. 6 Socio-economic vulnerability index map



has a lower population density but high dependence on the primary sector, high concentration of socially deprived groups, and low human development index.

The districts having values between 120 and 150 are classified medium vulnerable districts which include Kollam, Alappuzha, Malappuram, Kozhikhode, and Kasargode. These districts have comparatively less exposure and sensitivity in term of socio-economic variables.

The least vulnerable districts have the values below 120 and are classified as low socio-economic vulnerable regions. These include Kannur, Thrissur, Ernakulam, Kottayam, and Pathanamthitta districts. These districts are having relative top performance in the human development index in which Ernakulam and Thrissur are the top rankers, followed by Kottayam, Pathanamthitaa, and Kannur. Also, the share of population depending on the

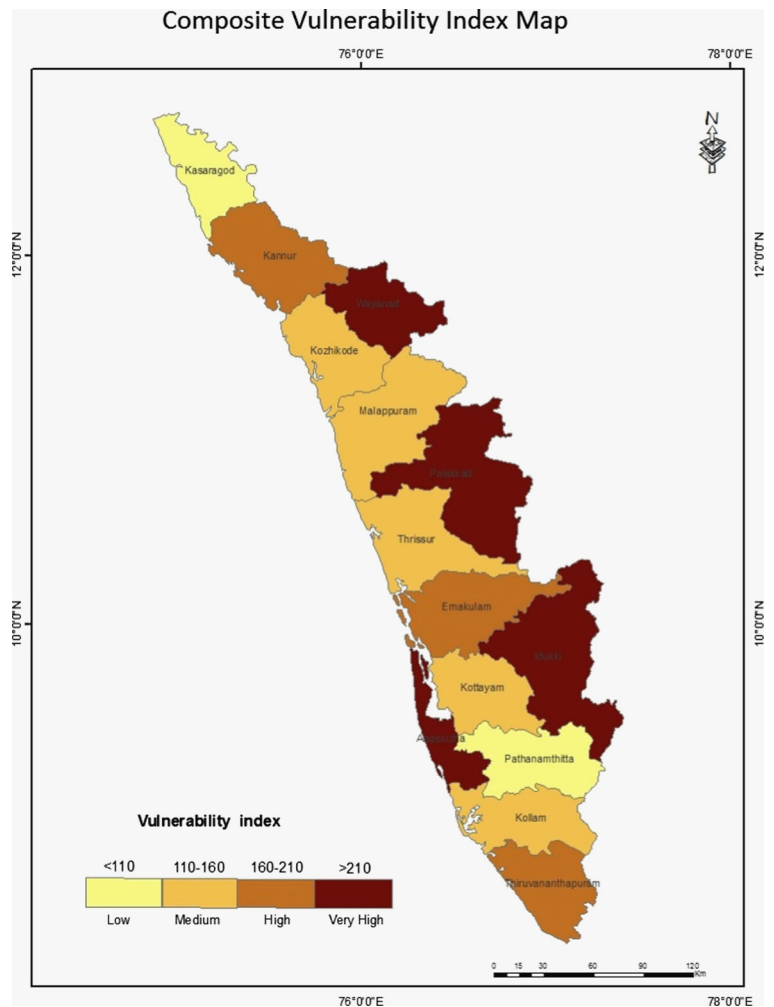
primary sector as well as socially deprived classes comparatively is lower in these districts.

Composite vulnerability map

The state’s districts have been classified as very high, high, medium, and low according to the composite vulnerability index (Fig. 7 and Tables 5 and 6).

Very high vulnerable districts (210 and above) Alappuzha, Idukki, Wayanad, and Palakkad districts have higher values of the composite vulnerability index. Although the districts are vulnerable for somewhat different reasons, they share a high degree of sensitivity and exposure to climate change. The hilly districts of Wayanad and Idukki have similar features in

Fig. 7 Composite vulnerability index map



terms of the examined socio-economic and environmental variables since they have a high concentration of socially deprived classes and people depending on primary sectors as well as environmental characteristics such as large extent of the dense forest and Shola forest. The coastal district of Alappuzha has a high composite vulnerability because it is a susceptible narrow coastal belt in a high population density region. In Alappuzha, the area of coastal wetlands, lagoons, mangrove forest, and sand beaches in the narrow stretch of coastal district makes it an environmentally sensitive area to climate change. Moreover, this district is the most highly populated one in the state, with a sizeable percentage of the population depending on sectors like paddy cultivation and fishery which are sensitive to climate change. Palakkad is also a very high vulnerable district, given its high social vulnerability. This is due to the higher

percentage of the population relying on agricultural related activities and the comparatively low performance on the human development index as well as high concentration of socially deprived groups; i.e., it has the highest number of Scheduled Caste population in the state. At the same time, the district has significantly lower performance in terms of the human development index which adds its sensitivity.

Highly vulnerable districts (160–210) Ernakulam and Kannur are highly vulnerable districts. The coastal district of Ernakulam is one of the most densely populated districts and has a high concentration of wetlands, lagoons, sand beaches, and mangroves. Kannur is also under this category as it has the largest extent of mangrove forest as well as high socio-economic vulnerability.

Table 5 Composite vulnerability index

District	EVI	SVI	CVI
Thiruvananthapuram	268	150.4	185.68
Kollam	212	134.52	154.76
Alappuzha	510	132.84	245.98
Kottayam	116	113.88	114.51
Pathanmathitta	40	110.96	89.67
Idukki	432	189.08	262.85
Ernakulam	362	110.2	198
Thrissur	106	114.24	111.76
Palaghat	354	157.36	216.35
Malappuram	129	140.88	137.31
Kozhikhode	212	127.12	152.58
Wayand	280	243.4	254.38
Kannur	350	111.52	183.06
Kasaraghode	44	128.16	102.91

Moderately vulnerable districts (110–160) Five districts (i.e., Kollam, Malappuram, Kozhikhode, Thrissur, and Kottayam) fall under the category of moderate climate change vulnerability due to lower exposure and sensitivity in terms of environmental and socio-economic variables.

Low vulnerable districts (below 110) Low climate change vulnerability district comprises the coastal district of Kasargode and the midland region comprising the Pathanamthitta district. These two districts have values of the composite vulnerability index which are far lower than any of the other districts. In other words, the comparatively better socio-economic and environmental variables render these districts less vulnerable. These districts having low values in the socio-economic vulnerability index because of the better performance in the HDI, lower number of socially segregated groups, and comparatively lower population active in climate-sensitive sectors.

Assessment of the confirmation of the composite vulnerability index using Cluster analysis

In order to confirm the results obtained from vulnerability index map, Cluster analysis was conducted. The dendrogram, obtained from the hierarchical Cluster analysis of environmental and socio-economic factors

responsible for climate change vulnerability, groups the districts into seven clusters (Figs. 8 and 9).

- Cluster I: Idukki, Palakkad, and Wayanad (very high vulnerability due to high population of primary sectors and socially deprived sector; large extent of Shola forests and dense forests)
- Cluster II: Alappuzha (very high vulnerability due to high population density, large extent of coastal wetlands, and lagoons)
- Cluster III: Kannur (high vulnerability due to large extent of mangrove forests and sand beach)
- Cluster IV: Thiruvananthapuram (high vulnerability due to high population density and comparatively large extent of sand beach)
- Cluster V: Kottayam, Ernakulam, and Kollam (medium vulnerability due to comparatively large extent of coastal wetlands and medium population of primary sectors and due to high human development index)
- Cluster VI: Thrissur and Kozhikhode (medium vulnerability due to population density, extent of beach and dense forests)
- Cluster VII: Pathanamthitta, Malappuram, and Kasargod (less vulnerability due to the absence of Shola forests and mangrove forest and also due to less extent of coastal wetlands and lagoons).

The study reveals that the results of composite vulnerability index are in agreement with the results of Cluster analysis, which supports the genuineness of the results obtained with the composite vulnerability index.

Comparison of models

A probability-weighted approach was adopted to determine the interclass/intermap dependency for the development of composite vulnerability index map. Weightage of each indicator is to be fixed based on vulnerability importance that is ascertained based on the different reports and based on discussion with concerned experts in the respective field. The composite climate change vulnerability index is to be tested by applying different normalization methods and using

Table 6 Composite vulnerability index

Cumulative index		
Very high vulnerable	210 and above	Alappuzha, Idukki, Wayanad, and Palakkad
High vulnerable	160–210	Thiruvananthapuram, Emakulam, and Kannur
Medium vulnerable	110–160	Kollam, Malappuram, Kozhikode, Thrissur, and Kottayam
Low vulnerable	Below 110	Kasargod and Pathanamthitta

different weighting factors for the selected indicators. In the case of Cluster analysis, it is simple as there is no need to assign weightage of the indicators.

Adaptive measures

Coastal wetlands, lagoons, mangroves, beaches, Shola forests, and dense forests are in highly vulnerable situation in the state. For the protection of forests, it is essential to limit anthropogenic disturbances, monitoring changes and especially allow for the regeneration of

keystone species, as well as maintenance and creation of connecting corridors over the landscape; supplementing natural regeneration with native species to improve forest stocking and canopy cover; fire management and control; and partnership with communities to limit disturbances and to rationalize forest use (Seidi et al. 2009). For the protection of mangroves, key adaptive measures include the identification through regional monitoring networks, and coastal planning that facilitates the inland migration of mangroves due to sea level rise and incorporates understanding of the consequence of shoreline

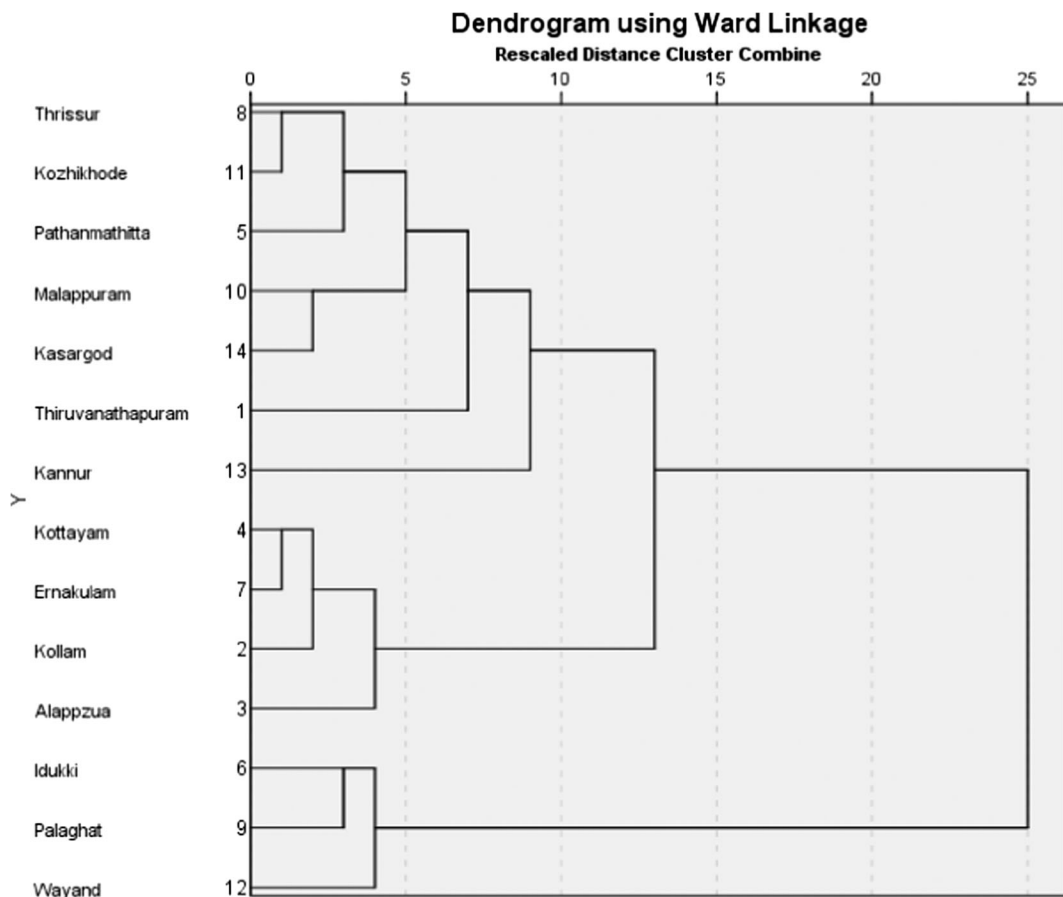
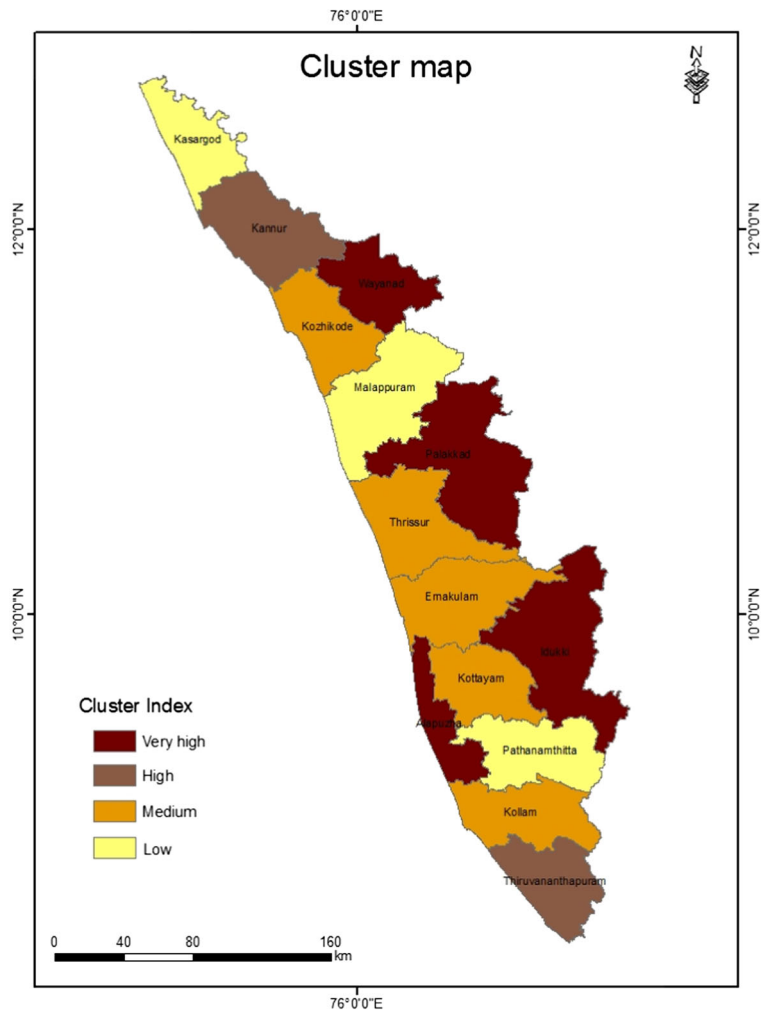
**Fig. 8** Classification of districts based on environmental and socio-economic factors related to climate change using Cluster analysis

Fig. 9 Cluster map showing vulnerability



changes; strategic planning of protected areas including mangroves and functionally linked ecosystems; rehabilitation of degraded mangroves; and outreach and education directed at communities residing adjacent to mangroves are to envisaged (Gilman et al. 2008). Beach nourishment, construction of sea walls and sea dikes, storm surge barriers, flood proofing measures, flood hazard mapping, flood warning, and forecasting systems can be adopted for the protection of beaches and lagoons (Linham and Nicholls 2010). Enforced prohibition or limitation of reclamation of wetlands, discharge of waste water into wetlands, treatment of wastes at the source, and soil erosion control measures in catchment area of tributaries to wetlands, measures to reduce siltation of wetlands would be beneficial for the protection of vulnerable coastal wetlands.

Conclusion

The study has been conducted to assess local dimensions of climate vulnerability using a composite vulnerability index in the tropical State of Kerala in India. Among the 14 districts that make up the state, the coastal district of Alappuzha is found to be the most highly vulnerable because of the high population density with very exposed coastal plain physiographic regions like wetlands, lagoons, and sandy beaches which are exposed to the anticipated climate change risk. Backwater banks and filtration ponds/paddy fields are other sections of the coastal zone which are highly susceptible to sea level rise (SAPCC), which are predominant geographical peculiarities in the district. The hilly districts of Idukki and Wayanad and Palakkad have similar

environmental and social characteristics such as high dependence of the primary sector, deprived classes, the low performance of human development index, and high concentration of forest density and Shola forest. This is agreement with the finding of Rao Prasada et al. (2008) that there is increase in the temperature across the highland region and of Krishnakumar et al. (2009) on the change in the distribution of rainfall in the Palaghat district. A composite vulnerability index based on environmental and socio-economic factors revealed that a higher percentage of the population relying on agricultural related activities and social deprivation groups and comparatively low performance in the human development index, existence of coastal wetlands, lagoons, mangrove forest, and beaches make the region highly vulnerable. Climate change vulnerability risk is highest in the coastal areas. The development of adaptive measure in a regional specific context for coastal areas, forested areas, and high densely populated areas and socially deprived hilly regions is essential. A large distribution of Shola forest and dense forest cover means leads to higher exposure to climate change risk. Beach nourishment, construction of sea walls and sea dikes, storm surge barriers, flood proofing measures, flood hazard mapping, flood warning, and forecasting systems can be adopted for the protection of beaches and lagoons. Prohibition of reclamation of wetlands, discharge of wastewater into wetlands, treatment of wastes at source itself and soil erosion control measures in catchment area of tributaries to wetlands, measures to reduce siltation of wetlands are to be adopted for the protection of coastal wetlands.

Acknowledgements We acknowledge United Nations Development Programme, Directorate of Environment and Climate Change, Kerala, Centre for Geo-information Science and Technology, University of Kerala, for the support.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Anonymous. (2015). *Kerala State disaster management plan profile*. Thiruvananthapuram: Kerala State Disaster Management Authority.

- Bohle, H.G., Downing, T.E., Watts M.J. (1994). Climate change and social vulnerability; towards sociology and geography of food security. *Global Environmental Change*.
- Brenkert, A. L., & Malone, E. L. (2005). Modeling vulnerability and resilience to climate change: a case study of India and Indian states. *Climate Change*, 72, 57–102.
- Deressa, T.T., Hassan, R.M., Ringer, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environ. Change* 19, 248–255
- Dev, V., & Dash, A. (2007). Rainfall and malaria transmission in North-Eastern India. *Annals of Tropical Medicine and Parasitology*, 101(5), 457–459.
- Devi, N. P., & Jauhari, R. (2006). Climatic variables and malaria incidence in Dehradun, Uttaranchal, India. *Journal of Vector Borne Diseases*, 43(1), 21–28.
- Downing, T.E., & Patwardhan, A. (2005). Vulnerability assessment for climate adaptation. In B. Lim.
- Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social environmental systems. *Annual Review of Environment and Resources*, 31, 365–394.
- Gbetibouo, G. A., Ringer, C., & Hassan, R. (2010). Vulnerability of the south African farming sector to climate change and variability: An indicator approach. *Natural Resources Forum*, 34, 175–187.
- Gilman, E.L., Ellison, J.B., Duke, N.C., Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. *Aquatic Botany*, 89, 237–250.
- Hahn, M.B., Riederer, A.M., Foster, S.O. (2009). The livelihood vulnerability index: A pragmatic approach to assessing risk from climate variability and change- a case study in Mozambique. *Global Environmental Change, IGEC*, 678.
- Iglesias, A., Quiroga, S., & Diz, A. (2011). Looking into the future of agriculture in a changing climate. *European Review of Agricultural Economics*, 38, 427–447.
- IPCC. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley (Eds.), *A special report of working groups I and II of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press 582 pp.
- Krishnakumar, K. N., Rao Prasad, G. G. L. H. V., & Gopal, C. S. (2009). Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*, 43(11), 1940–1944.
- Laner, K., Bhadra, A., Ionides, E. L., Bouma, M., Dhiman, R. C., Yadav, R. S., & Pascual, M. (2010). Forcing versus feedback: Epidemic malaria and monsoon rains in Northwest India. *PLoS Computational Biology*, 6(9), e1000898. <https://doi.org/10.1371/journal.pcbi.1000898>.
- Linham, M.M., & Nicholls, R.J. (2010). Technologies for climate change adaptation-coastal Erosion and flooding. UNEP.
- McMichael, A. J., Wilkinson, P., Kovats, R. S., Pattenden, S., Hajat, S., Armstrong, B., Vajanapoom, N., Niciu, E. M., Mahomed, H., & Kingkeow, C. (2008). International study of temperature, heat and urban mortality: The 'ISOTHURM' project. *International Journal of Epidemiology*, 37(5), 1121–1131.
- Metzger, M., & Schröter, D. (2006). Towards a spatially explicit and quantitative vulnerability assessment of environmental

- change in Europe. *Regional Environmental Change*, 6, 201–206.
- MoEF (2004). India’s initial national communication to the United Nations Framework Convention On Climate Change, Government of India.
- Monirul, M., & Mirza, Q. (2011). Climate change, flooding in South Asia and implications. *Regional Environmental Change*, 11(1), S95–S107.
- OECD. (2008). *Handbook on constructing composite indicators: Methodology and user guide*. Paris: OECD Publishing.
- Olmos, S. (2001). Vulnerability and adaptation to climate change: Concepts, issues, assessment methods. For the climate change knowledge network.
- Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O’Neill, B., Takahashi, K. (2014). Emergent risk and vulnerabilities. Chapter 19 in: climate change 2014: Impacts, adaptation, and vulnerability. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.), Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1039–1099). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Osman-Elasha, B. (2006). *Human resilience to climate change: Lessons for eastern and northern Africa. A final report of AIACC project no. AF14*. Washington: International START Secretariat.
- Pal, I., & Al-Tabbaa, A. (2009). Trends in seasonal precipitation extremes: An indicator of “climate change” in Kerala, India. *Journal of Hydrology*, 367, 62–69.
- Poff, N.L., Brinson, M.M., Day, J.W. (2002). Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and fresh water and coastal wetland ecosystems in the United States. O Center on Climate Change.
- Rao, G. G. S. N., Rao, A. V. M. S., Vanaja, M., Rao, V. U. M. & Ramakrishna, Y. S. (2008). Impact of Regional Climate change over India. Chapter 2. In: GSLHV Prasada Ra, GGSN Rao, VUM Rao and Y.S. Ramakrishna (Eds), *Climate change and Agriculture over India*. KAU-ICAR Publication. p. 258
- Rao Prasada, G.S.L.H.V., Alexander, D., Krishnakumar, K. N., Gopakumar, C. S. (2008). *Gopakumar impact of climate change on plantations over the humid tropics of Kerala*. Climate Change and Agriculture over India.
- Ravindranath, N. H., Joshi, N. V., & Sukumar, R. (2006). Impact of climate change of forests in India. *Current Science*, 90(3), 354–361.
- Schroter, D., Cramer, W., Leemans, R., Prentice, I. C., Araujo, M. B., Amell, N. W., ... Zierl, B. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science*, 310(5752), 1333–1337.
- Schroterm D., Zebisch, M., Grothmann, T. (2005). Climate change in Germany-Vulnerability and adaptation of climate-sensitive sectors. www.pik-potsdam.de/news/public-events/archiv/alter-net/former-ss/2008/working-groups/literature/schroeter-et-al-ksb06.pdf.
- Seidi, R., Schelhaas, M. J., & Lindner, M. (2009). Modelling bark beetle disturbances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. *Regional Environmental Change*, 9, 101–111.
- Sheela, A. M., Letha, J., Sabu, J., Thomas, J., & Sanal Kumar, S. P. (2012). Water quality assessment of a tropical coastal lake system using multivariate-cluster, principal component and factor analysis. *Lakes and Reservoir Management*, 17, 143–159(2012).
- Sheela, A. M., Sarun, S., Justus, J., Vineetha, P., & Sheeja, R. V. (2015). Assessment of Changes of Vector borne diseases with wetland characteristics using multivariate analysis. *Environmental Geochemistry and Health, Springer*, 37, 391–410.
- Soman (1997). *Geology of Kerala*. Geological Society of India, Bangalore.
- Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S. (2006). *Stern review: The economics of climate change*. OUP.
- The World Bank (2009). *Adapting to climate change in ECA countries*.
- Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14), 8074–8079.
- Unnikrishnan, A. S., Kumar, K. R., Fernandes, S. E., Michael, G. S., & Patwardhan, S. K. (2006). Sea level changes along the Indian coast: Observations and projections. *Current Science*, 90(3), 362–368.
- Vogel, C. H., & O’Brien, K. (2006). Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate risk management strategies. *Climate Research*, 33, 111–122.
- Wassmann, R., Jagadish, S. V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R. K., & Heuer, S. (2009). Chapter 3: Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Advances in Agronomy*, 102, 91–133.
- Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity: Moving toward a working definition of adaptive capacity. *Global Environmental Change*, 12, 25–40.
- Yusuf, A. A., & Francisco, H. A. (2009). *Climate change vulnerability mapping for Southeast Asia*. Singapore: Economy and Environment Programme for Southeast Asia.