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Drought vulnerability assessment in Karnataka : Through composite climatic index

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सार – कर्नाटक राज्य के लिए ताल्लुका स्तर पर दक्षिण पश्चिमी मॉनसून (SWM-CV) के दौरान वर्षा की मात्रा के सहसंबंध, उत्तर पूर्व मॉनसून (NEW-CV), अनावृष्टि सूचकांक विसंगति (AIA), मॉनसून पूर्व अवधि में औसत वर्षा के दिन (PMARD), दक्षिण पश्चिम मॉनसून (SWARD) उत्तर पूर्व मॉनसून (NEARD) और वार्षिक (ANNARD) जैसे सात उप-घटकों के आधार पर मिला जुला जलवायु अनावृष्टि संवेदी सूचकांक विकसित किया गया। जलवायु अनावृष्टि संवेदी सूचकांक के साथ ऊपर बताए गए सात उप-घटकों में से पहले तीन उप-घटकों के संबंघ सकारात्मक फंक्शनल हैं जबकि अन्य चार उप-घटकों के साथ संबंध नकारात्मक फंक्शनल हैं। 176 ताल्लुकों के संघटित सूचकांक मान, माध्य और मानक विचलन के साथ सामान्य वितरण के है। ताल्लुका स्तर पर के अधिकतम न्यूतम मान के आधार पर निश्चित श्रेणी अंतराल पर पाँच श्रेणियाँ (1 से 5) नियत की गई जो बढ़ती हुई अनावृष्टि संवेदी को दिखाता है और यह श्रेणी प्रत्येक ताल्लुका के लिए निर्धारित किया गया है। इस जलवायु अनावृष्टि संवेदी सूचकांक श्रेणी के अनुसार 82 ताल्लुके (47%) अति संवेदनशील (श्रेणी 4), 50 ताल्लुके (28%) अत्यधिक संवेदनशील (श्रेणी 5), 27 ताल्लुके (15%) सामान्य रूप से संवेदनशील (श्रेणी-3), 11 ताल्लुके (6%) थोड़े अधिक संवेदनशील (श्रेणी-2) और 6 ताल्लुके (4%) अत्यधिक कम संवेदनशील (श्रेणी-1) पाए गए हैं। इस राज्य के चार क्षेत्रों में अधिकांश ताल्लुके दक्षिण कर्नाटक के अंदरूनी भाग (87%) हैं और उत्तरी कर्नाटक के अंदरूनी भागों (97%) में अनावृष्टि के संवदेनशील होने की अधिक और बहुत अधिक संभावना है उसके बाद मालनाड़ (36%) और तटीय क्षेत्र (5%) आते हैं। राज्य के प्रभावित ताल्लुकों में लोगों और पशुधन की सुरक्षा बनाए रखने के लिए पारिस्थितक पर्यावरण को बनाए रखने तथा अनावृष्टि को कम करने के उपाय किए गए।

ABSTRACT. A composite climatic drought vulnerability index based on seven sub-components such as the coefficient of variation of rainfall during south west monsoon (SWM-CV), north east monsoon (NEM-CV), aridity index anomaly (AIA), Average rainy days during pre-monsoon (PMARD), south west monsoon (SWARD), north east monsoon (NEARD) and annual (ANNARD) was developed at taluk level for the state of Karnataka. Out of the above seven sub-components the first three were found to have positive functional relationship while the other four sub-components have negative functional relationship with climatic drought vulnerability index. These composite index values of 176 taluks were subjected to normal distribution with mean and standard deviation. Based on maximum, minimum values of the indices at taluk level, five classes (1 to 5) at fixed class interval that depict progressive drought vulnerability are formed and these classes were assigned to each of the taluks. As per this climatic drought vulnerability index class, it is observed that 82 taluks (47%) are highly vulnerable (class-4), 50 taluks (28%) are very highly vulnerable (class-5), 27 taluks (15%) are moderately vulnerable (class-3), 11 taluks (6%) are slightly vulnerable (class-2) and 6 taluks (4%) are very slightly vulnerable (class-1). Among the four regions in the state, majority of the taluks in South Interior Karnataka (87%) and North Interior Karnataka (97%) are highly and very highly drought vulnerable followed by Malnad (36%) and Coastal region (5%). The drought mitigation measures to restore the eco-environment and to ensure sustainability of the people and livestock could be planned for implementation in the affected taluks of the state.

Key words – Drought vulnerability, Composite climatic index, Drought vulnerability class.

1. Introduction

The climate of the region is determined mainly by the geographical location with respect to the sea, monsoon winds and physiography. Karnataka State has humid to sub-Humid monsoonal climate on the West Coast and Western Ghats and semi-arid to arid (very warm) climate in central and northern districts of plateau region. The year is divided into four seasons *viz.*, Winter (January-February), Summer (March to May); South-West monsoon (June to September) and North East monsoon (October to December). The occurrence of rainfall and its spatial distribution is highly variable. Taluk wise Normal rainfall of the state vary from 508 mm to 5051 mm with an average annual rainfall of 1150 mm in the state. Rainfall contribution is very high, from southwest

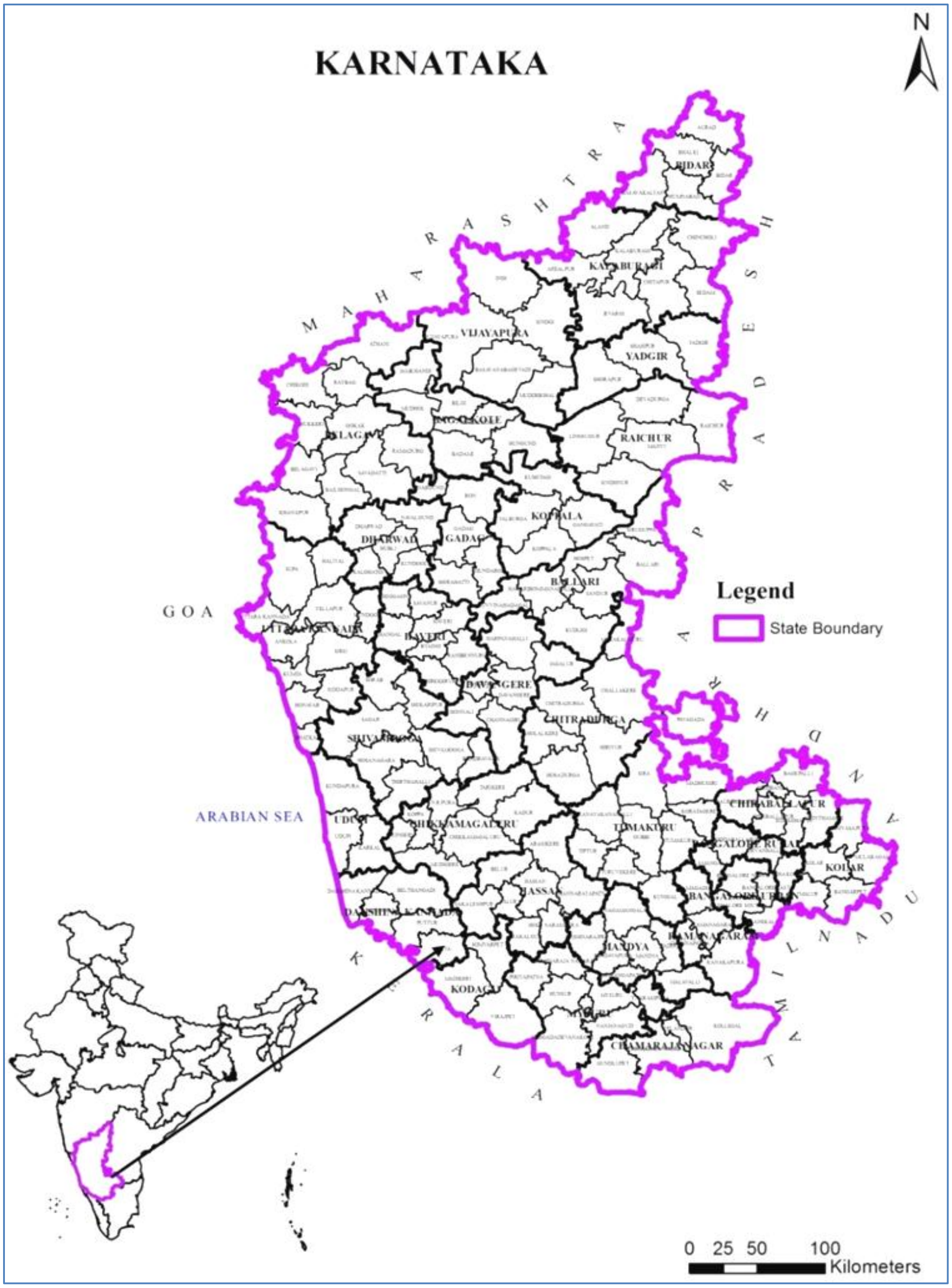

Fig. 1. Location map of the study area in India

monsoon season (around 80% of the state rainfall). It is observed that the annual rainfall is highest over the Western Ghats and lowest in the eastern parts of Chitradurga district. The percentage departure of annual rainfall in Karnataka (1970-2016) indicate that out of 46 years 21 years had deficit rainfall that ranged from -28% to -1% (Fig. 2). More than 2/3rd of the state receives less than 750 mm of rainfall. Taluk wise Annual coefficient of variation (CV) of the rainfall ranges from 16 to 40%. The atmospheric temperature in the state ranges

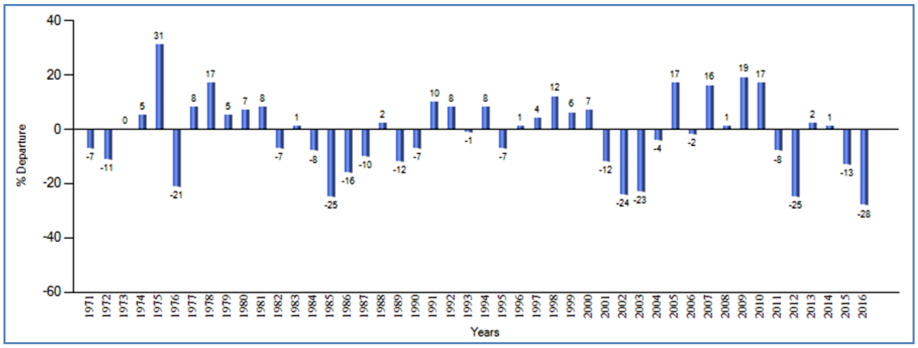

Fig. 2. Percentage departure of annual rainfall from normal for Karnatka (1970-2016)

from 23 °C to 43 °C in summer and 9 °C to 27 °C in winter. Hailstorms are common in plateau region of the state during pre-monsoon period.

Occurrence of droughts in Karnataka state is common phenomenon, due to spatial and temporal variation in rainfall within and between the regions and seasons (Chadrashekhar & Venugopal, 1995). Hence different regions are prone to disasters like floods and droughts simultaneously in the state. The State is regularly affected by drought though, less by other disasters. The entire rain fed agricultural area is drought prone and it covers almost 80% of the taluks in the State. Rainfall is an important element of economic growth of an area or region, especially in a country like India, where a large number of people are occupied in agricultural activities. The amount of rainfall does not show an equal distribution, either in space or in time. It varies from heavy rain to scanty in different parts. It also has great regional and temporal variations in distribution. The study of rainfall distribution pattern and its temporal variations is very important, as it depicts the drought vulnerability of an area due to climate. Looking to the climatic variability and droughty conditions in the state an attempt was made to identify the drought vulnerable areas through composite climatic index with the use of seven sub components.

2. Study area

Karnataka state is located between 11.50 to 18.50° N latitudes and 74.25 to 78.50° E longitudes and covers an area of 19.1 M ha which accounts for 5.8 percent of the total area of the country. It is home to 6.11 crore people (2011 Census) accounting for 5.05% of India's population. The state is composed of 30 districts divided into 176 Taluks (Fig. 1). These Taluks are further divided into 747 hoblis. The state is bounded by Goa in the northwest, Maharashtra in the north, Andhra Pradesh in the east, Tamil Nadu in the south and Kerala in the south west. It has four major regions namely (*i*) North Interior Karnataka (NIK), (*ii*) South Interior Karnataka (SIK), (*iii*) Malnad region and (*iv*) Coastal region. It has four administrative divisions namely (*i*) Mysore division, (*ii*) Gulbarga division, (*iii*) Belgaum division and (*iv*) Bengaluru division.

Out of the total 19.1 M hectares in Karnataka the net cultivated area (2010-11) was 10.5 M hectares, net irrigated area 3.49 M hectares and net rain fed cultivated area 7.01 M hectares. Karnataka has the second largest area under rain-fed agriculture after Rajasthan in the country. Nearly 55% of total food grain production and 74% of oilseeds production come from rain-fed agriculture in Karnataka. Therefore rain-fed agriculture plays an important role in total food grain production in the state. Further the rain-fed agriculture has substantial untapped potential, this can be brought to use by increasing the crop yields in the dry land areas through the adoption of proper dry-land production technologies and drought mitigation measures.

3. Materials and method

3.1. *Earlier approaches for delineation of drought prone areas*

Drought prone and drought vulnerability areas identification have distinct boundary. The drought prone areas are identified based on indices developed from one or two indicators while the drought vulnerability is an index based on many indicators considered over a period of time.

Till date the criteria used (Drought Manual, 2009) for delineation of drought prone areas of Karnataka state by KSNDMC (Karnataka State Disaster Monitoring Centre) are: (*i*) Rainfall deficiency of more than 20% of the normal; (*ii*) ≥4 consecutive weeks of dry spell; (*iii*) moisture Adequacy Index (MAI); (*iv*) Normalized Difference Vegetation Index (NDVI) and (*v*) extent of sowing status in a season.

Majority of the criteria used for delineation of the drought prone areas were rainfall based both in the state and national level. A threshold value of <750 mm of annual rainfall (Irrigation Commission, 1972) is considered to demarcate the drought prone areas. At times, this criteria may not hold good since some of the areas with annual rainfall >750 mm also experience the droughty conditions. Indian Meteorological Department (IMD) considers a drought year with annual rainfall of 75% or less of normal in a year. Further, the rainfall deficit of 25% of normal value in an area, is considered for meteorological drought.

Additionally many indices used for demarcating drought prone areas are usually developed from one or two components/parameters/indictors, like, rainfall, Potential Evapo-Transpiration (PET) and Actual Evapo-Transpiration (AET). Among these indices , Standardized Precipitation Index (SPI) based on precipitation, Aridity Index Anomaly (AIA) based on rainfall, PET & AET, Palmer Drought Severity Index (PDSI) based on moisture conditions between the locations temporally, Crop Moisture Index (CMI) compares degree to which crop moisture requirements are met, Normalized Difference Vegetation Index (NDVI) based on vegetation vigour and cover; Moisture Adequacy Index (MAI) based on weekly water balance, Soil Moisture Deficit Index (SDMI) based on soil moisture deficit, Evapo-transpiration Deficit Index (ETDI) based on evapo-transpiration deficit and Drought Severity Index (DSI) are usually used for identifying drought prone areas.

Attempts were also made to delineate drought prone areas based on climate-soil approach (Challa & Wadodker, 1998; Naidu *et al.*, 2005) as per the length of growing period (LGP). Additionally, the droughts may occur in early, mid or late during the crop season. The moisture stress during the phonological crop growth stages which causes yield variation, may also be used as drought indicator. All these earlier methods are aimed at one or two causal factors and their impact on the exposed area for the assessment of the severity of the hazard.

Assessment of Drought Vulnerability is multi-dimensional than only the delineation of drought prone areas since it considers many indicators (KSNDMC, 2017). Three indices such as exposure, sensitivity and adaptivity and their composite index were used to delineate vulnerable areas (Murthy *et al.*, 2015; Madhuri *et al.*, 2014; LIU xiaoquian *et al.*, 2013). The indicators used for expressing these three dimensions are: (a) Exposure: precipitation, rainy days, (b) Sensitivity: crop cover through NDVI and (c) Adaptive capacity: soil, irrigation, land holdings. There are few more models (Wisner *et al.*, 2004) like PAR model (the Pressure And Release model) which deals with two forces: those forces that generate or cause vulnerability and the hazardous event. Cardona (1999) developed a conceptual holistic approach which views as physical damage from exposure & physical susceptibility and impact factor from socio-economic fragilities and lack of resilience. The framework provides information on the basis of selection of major components and sub components for developing a combined/composite index (OECD, 2008).

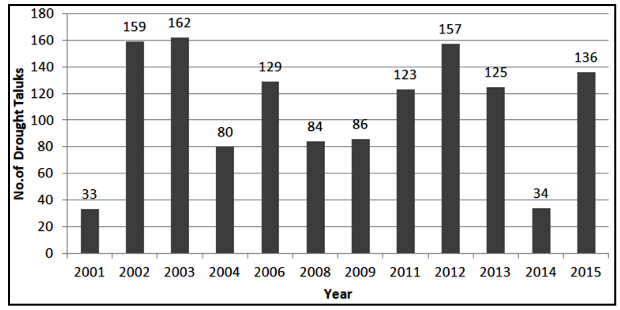

Fig. 3. Number of Drought affected Taluks (2001-2015) in Karnataka

3.2. *Details of data and methods used in the present study*

Looking to the earlier approaches, a holistic multi component approach was used to develop a composite index to assess drought vulnerability. For this approach, the spatio-temporal variability in the climatic and other related conditions leading to droughts in the state, at Taluk level were used for developing a composite index.

3.3. *Selection of sub components/indicators*

In the present approach, seven sub-components/ indicators of climate which are relevant and prime contributors to drought vulnerability and express the sensitivity of the area to droughts have been used for developing composite climatic indices for 176 taluks in the state. This approach considers multi-component data sets over a time period. The time series data sets and their major component-wise analysis separately provides an excellent opportunity to show their functional relationship precisely and helps to develop effective composite index at taluk level. The composite index thus developed clearly depicts the vulnerability of any Taluk with respect to drought.

The time series data of the sub-components at taluk level for different periods as per the availability are collected and compiled for further analysis under each major component. Each sub-component is treated as an independent variable during the analysis and is presumed to contribute either positively or negatively towards the major component with respect to drought vulnerability in an area.

TABLE 1

Relative weightages of sub-components

Climate based	
Sub-component	Weightage
P1(SWM-CV)	0.14
P2(NEM-CV)	0.17
P3(PMARD)	0.15
P4(SWARD)	0.11
P5(NEARD)	0.15
P6(ANNARD)	0.12
P7(AIA)	0.16

For the development of the composite index based on climate, the sub-components selected are mainly related to rainfall.

Rainfall is an important subcomponent or Indicator of an area or region. The study of rainfall distribution pattern and its temporal variation is very important in assessing the vulnerability, since the rainfall and its aberrations, directly affect the crop performance in the area.

Taluk wise historical rainfall data of Karnataka State for 55 years (1960 to 2014) was considered for the study. Average rainfall over the 55 years period is considered as Normal rainfall. For the calculation of climatic (CI) vulnerability Index, the seven sub components used at taluka level are as under:P1- (SWM) South West monsoon rainfall coefficient of variation (CV); P2- (NEM) North East monsoon rainfall coefficient of variation (CV); P3-(PMARD) Pre monsoon average rainy days; P4-(SWARD) South West monsoon average rainy days; P5-(NEARD) North East monsoon average rainy days; P6-(ANNARD) Annual average rainy days; P7-(AIA) Aridity Index Anomaly. The sub-components, their formulae and importance, for the climatic drought vulnerability index are described as under:

(*i*) Coefficient of Variation (CV): The coefficient of Variation (CV) is defined as the ratio of the standard deviation (SD) to the normal, multiplied by 100.

$$\mathrm{CV} = \frac{\text{SD of the rainfall}}{\text{Mean rainfall}} \times 100$$

CV shows consistency of the rainfall. If CV is very high, the variability in rainfall is high indicating the possibility of drought. CV of south west monsoon and North east Monsoon is used as indicators in drought vulnerability study to find out drought condition.

(*ii*) Rainy day: if a day receives ≥2.5 mm of rainfall then that is called as a rainy day.

$$\text{Average rainy days} = \frac{\text{Sum of rainy days in a given period}}{\text{Length of the Period in days}}$$

Average Rainy days over the Seasons are very important to know the condition of drought. If the number of rainy days are very less in the Monsoon, then there is possibility of Drought. So Average Rainy days for three seasons (Pre-monsoon, South west monsoon, North east monsoon) and Annual have been considered for the study.

(*iii*) Additionally Aridity index and Aridity index Anomaly were estimated for each Taluk over the years by using the following equation:

(a) $\text{Aridity Index (AI)} = \frac{\text{PET}-\text{AET}}{\text{PET}} \times 100$

where, the PET denotes the water need/ demand of the crops. AET is actual evapo-transpiration obtained from water balance approach with the use of AWC (available water capacity) of the soil in that location. (PET-AET) denotes the water deficit.

(b) Aridity index Anomaly (AIA): Weekly actual aridity index and normal aridity index are computed by the above formula from the weekly actual rainfall and normal rainfall at a location. The difference between the actual aridity and normal aridity for the week is the AIA for that location. This AIA indicate the water shortage over a long time normal/climatic value. For Aridity index Anomaly there are two conditions, those are:

- If AIA value is negative or zero, this would imply that the area/location would experience less arid/droughty conditions than normal.

- If AIA value is positive, this would indicate that the location experiences more arid/droughty conditions than the normal.

Hence, all areas with negative or zero values of AIA are treated as humid areas. As per the positive values of the AIA three different drought classes that indicate the intensity of drought (Mild: 1-25%; Moderate: 26-50%; Severe: >50%) are also in vogue.

The aridity index anomaly values obtained for each Taluk over the years were averaged for each Taluk and these values are used under the study.

TABLE 2

Drought affected taluks in different regions of Karnataka (2001-2016)

Region (Total Taluks)	2001-2010		2011- 2015		2016	
	No. of taluks	%	No. of taluks	%	No. of taluks	%
SIK(63)	38	61	48	76	63(k),63(r)	100(k)&(r)
NIK(69)	54	78	54	78	52(k),65(r)	75(k), 94)(r)
MALNAD(25)	11	42	11	43	17(k),18(r)	68(k),72(r)
COASTAL(19)	2	12	3	14	7(k),14(r)	36(k),74(r)
Total	105	59	115	65	139(k),160(r)	75(k), 91(r)

Source: Karnataka State Natural Disaster Monitoring Centre, Note: (k) - Kharif, (r) - Rabi

As per the above indicators the data was analyzed for each of the Taluks over a period of 55 years and kept for further use in the calculation of climate based Index (CI).

3.4. *Data base-analysis*

Out of the normalization methods, the Mini-Max method was considered appropriate and was followed for this study. In this method, the normalized indicators will have an identical range [0, 1] obtained by subtracting the minimum value and dividing by the range of the indicator values. Usually, extreme values/or outliers could distort the transformed indicator during normalization. On the other hand, normalization by Mini-Max Method could widen the range of indicators lying within a small interval, increasing the effect on the composite indicator more than the z-score transformation.

In this method, based on the relationship of an indicator to the major component index, the following formulae are used:

(1) If an indicator/sub-component '*x*' in '*i*' number of Taluks has positive functional relation to respective major component, for normalization the following formula is used

$$X_i\text{- normalized value } = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

(2) and if the indicator/ sub-component has negative functional relationship with the respective major component , the normalization formula is

$$X_i\text{- normalized value } = \frac{X_{max} - X_i}{X_{max} - X_{min}}$$

By this normalization all the values of indicators will be ranging from 0 to 1 and their direction of change is same.

The normalized values of all the seven sub-components were calculated by Mini-Max method for all 176 Taluks of the state and these values were used for further composite index calculations.

3.5. *Weightage for the (indicators) sub-components*

After normalization of input data of the indicators, assigning the weight age to these normalized values of indicators gains a key role in assessing the vulnerability. Different researchers used various methods (Li *et al.*, 2006; Chen *et al.*, 2013; Brooks *et al.*, 2005) the weight ages were given based on relative importance of the indicator towards vulnerability. Some used Principal Component Analysis (PCA) to have weight ages for the indicators (Chen *et al.*, 2013). A few used equal weight ages to each indicator, this may lead to the under estimation of the risk assessment (Julich, 2015). In this study the method used for assigning the weight ages is based on the assumption that the weight ages vary inversely with variance over Taluks. So the weight age 'w_j' is determined by

$$W_j = \frac{c}{\sqrt{var(x_{ij})}}$$

where,

W_j = weightage factor of the j^{th} indicator.

x_{ij}= Normalized value of j^{th} indicator and of the i^{th} Taluk

c = normalizing constant,

$$c = \left[\sum_{j=1}^{k} \frac{1}{\sqrt{var_{i(x_{ij})}}}\right]^{-1}$$

By the assignment of weight ages to these components (Brooks, 2005) through this method, the large variations, if any, in these subcomponents will not dominate over the contribution of other sub components within the major component.

3.6. *Development of indices*

$$\overline{y_i} = \sum_{j=1}^{k} w_j \; x_{ij}$$

Composite index of i^{th} Taluk $\overline{y_i}$ is assumed to be a linear sum of x_{ij}.

Relative weight ages of sub-components under the major component obtained by the above method are presented in Table 1.

In general the weight ages range from 0 to 1, *i.e.*, Weight age "w" is 0<w<1 and $\sum_{j=1}^{k} w_j = 1$. These weight ages ranged from 0.11 to 0.17 in climate based sub components.

Using respective weight ages and the normalized score values of each sub-component, the effective value of each sub-component at taluk ($\overline{y_i}$-value) was arrived (Hiremath & Shiyani, 2012). These values depict the contribution of each sub-component towards the climatic drought vulnerability index.

4. Results and discussion

4.1. *Drought scenario in Karnataka state*

In Karnataka there are arid-semiarid and humid to sub-humid climatic conditions in different regions. All the four types of droughts namely (*i*) meteorological (*ii*) Hydrological, (*iii*) Agricultural and (*iv*) socio-economic droughts are observed in the state. Based on the criteria (Drought manual, 2009) the drought affected Taluks in Karnataka state were identified `

This indicates that in these fifteen years (2001 to 2015), three years (2005, 2007 & 2010) have no drought or droughty situation (a period of below-average precipitation (deficit of 25% to normal) in a given region, resulting in prolonged shortage in the water supply). In rest of the 12 years 2003 was a severe drought year (long period of abnormally low rainfall (deficit of >50% to normal), especially one that adversely affects growing and living conditions) since 162 Taluks out of 176 Taluks (92%) were reeling under drought. In 2002 & 2012 out of 176 Taluks 159 Taluks (90%) and 157 Taluks (89%) were affected by drought. Among these 12 years in 2001 & 2014

TABLE 3

Drought vulnerable classes/zones

Classes	Index Values	
	Start	end
1VSV (Very Slightly Vulnerable)	0.05	0.21
2SV (Slightly Vulnerable)	0.21	0.36
3MV (Moderately Vulnerable)	0.36	0.52
4 HV (Highly Vulnerable)	0.52	0.68
5 VHV (Very highly Vulnerable)	0.68	0.84

the drought was less intense (18-19%) and only 33 to 34 Taluks were affected while in all the 10 years the drought was wide spread (>50%) and severe to very severe in the state. The total number of Taluks and the percent to total Taluks affected by drought in each region during 2001 to 2010 and 2011 to 2015 (Table 2) are compiled. In 2001-2010 about 105 Taluks on an average (59%) are affected by drought in all the regions while in 2011-2015 on an average 115 Taluks (65%) are affected by drought. It shows that on an average there is an increase in drought affected Taluks within a short period of five years in the state indicating rain fall variability. Among the regions NIK showed the highest average number of Taluks (54) prone to drought both during 2001-2010 and 2011-2015 while the number of Taluks prone to drought is least in Coastal region. Percent of drought prone Taluks during 2001-2010 in these regions follow this order: NIK (78%) > SIK (61%) > MALNAD (42%) > COASTAL (12%). The similar trend of proneness to drought is observed among the regions during 2011-2015 also with a little variation in the number of Taluks and percentage.

In 2016 due to variation in rain fall almost all taluks in SIK and 75% in NIK in Kharif and all taluks in SIK, 94% in NIK, 72% in Malnad, 74% in Coastal region, in Rabi are drought prone in the state (Table 2).

In general, the identification of drought prone areas is dealt with few indices developed based on one or two indicators related to drought, while the drought vulnerability assessment has wider perspective and is based on many indicators pertinent to the hazardous event (drought).

In this study seven indicators that primarily contribute towards drought are considered while assessing drought vulnerability. Among these indicators some have positive functional relation while others have inverse relation towards drought.

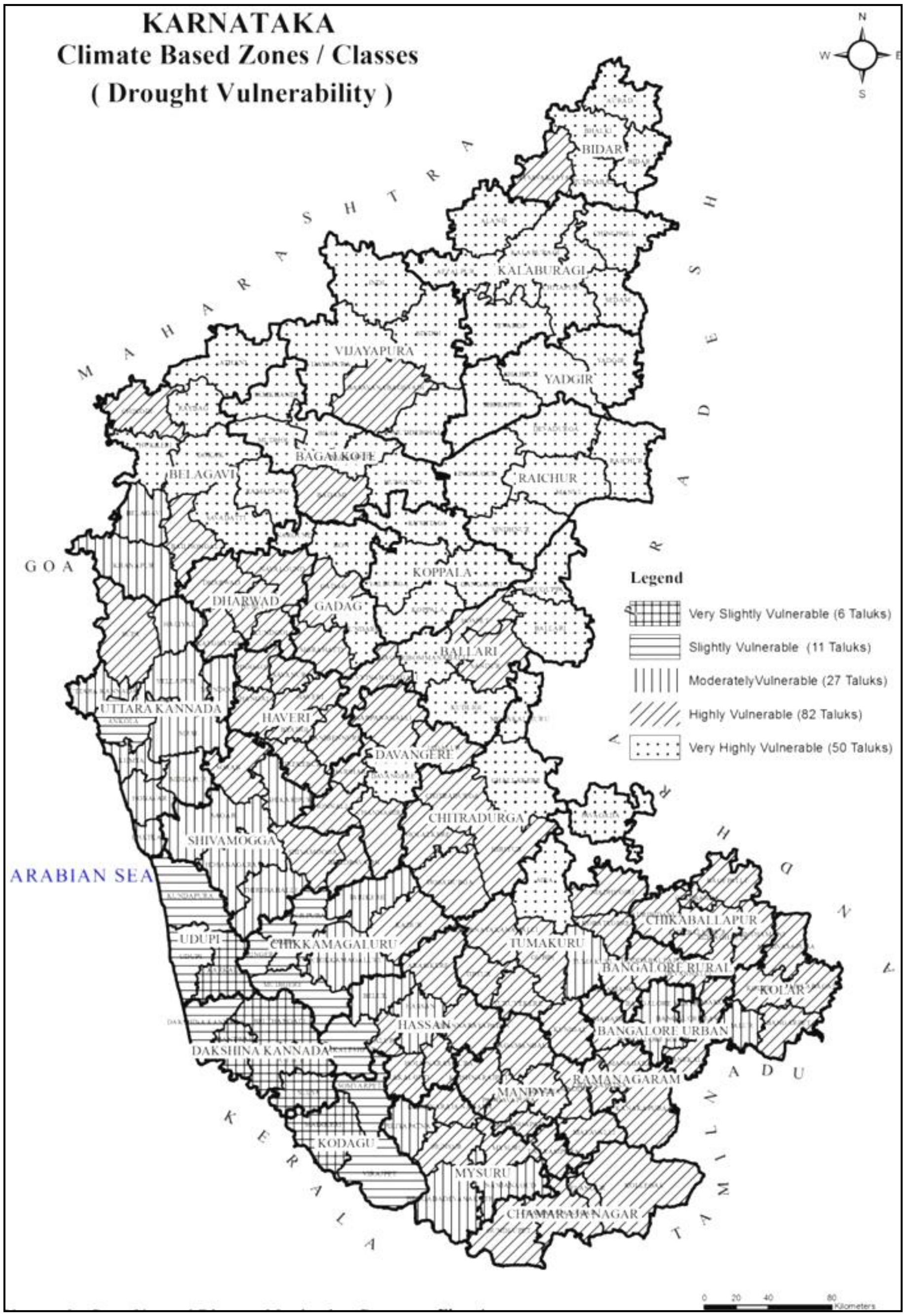

Fig. 4. Karnataka climate based zones/ classes (drought vulnerability)

4.2. *Contribution of sub-components towards climatic index*

Seven sub-components (Indicators) P1 to P7 are considered from 1980 to 2014, for assessing the climate based drought index. Among these seven sub-components the South West Monsoon coefficient of variation (SWM-CV), North East Monsoon coefficient of variation (NEM-CV) and AIA have positive functional relationship and their effect is directly proportional to the values of CI index while the other four sub components such as PMARD, SWARD, NEARD, ANNARD have negative functional relationship with drought inversely related with the CI index.

Among the seven sub-components, the contribution from Aridity Index Anomaly (AIA-P7) was 81% in Sulya taluk of Dakshina Kannada district, from Pre-monsoon

TABLE 4

Drought vulnerable Taluks in Karnataka based on composite climatic index

District (No. of taluks)	Drought Vulnerable Taluks				
	VSV class	SV class	MV class	HV class	VHV class
(1)	(2)	(3)	(4)	(5)	(6)
Bengaluru Urban (4)	-	-	Bengaluru North, Bengaluru South, Bengaluru East	Anekal	-
Bengaluru Rural (4)	-	-	-	Devanahalli, Dodballapur, Hosakote, Nelamangala	-
Ramanagaram (4)	-	-	-	Channapatna, Kanakapura, Magadi, Ramanagara	-
Kolar (5)	-	-	Malur	Kolar, Mulabagal, Bangarapet, Srinivasapura	-
Chikballapur (6)	-	-	-	Bagepalli, Chikballapur, Chintamani, Sidlaghatta, Gauribidanur, Gudibanda	-
Tumakuru (10)	-	-	Tumakuru	C.N. Halli, Koratagere, Madhugiri, Tiptur, Gubbi, Kunigal, Turuvekere	Sira, Pavagada
Chitradurga (6)	-	-	-	Chitradurga, Hiriyur, Holalkere, Hosadurga	Challakere, Molakalmuru
Davangere (6)	-	-	-	Channagiri, Honnali Harapanahalli, Harihar, Jagalur	Davangere
Chamarajanagar (4)	-	-	-	Chamarajanagar, Gundlupet, Kollegal, Yelandur	-
Mysuru (7)	-	-	Heggadadevanakote, Periyapatna, Nanjanagud	Hunsur, Krishnarajanagar, Mysuru, T. Narasipur	-
Mandya (7)	-	-	-	Maddur, Malavalli, Nagamangala, Pandavapura, Srirangapatna, Krishnarajapet, Mandya	-
Ballari (7)	-	-	-	Hadagali, Sadur, Hospet,	Ballari, Hagaribommanahalli, Kudligi, Siruguppa,
Koppala (4)	-	-	-	-	Gangavathi, Kushtagi, Koppala, Yelburga
Raichur (5)	-	-	-	-	Deodurga, Lingsugur, Manvi, Raichur, Sindhanur
Yadgir (3)	-	-	-	-	Shahapur, Shorapur, Yadgir
Bidar (5)	-	-	-	Basavakalyan	Aurad, Bhalki, Bidar, Humnabad
Belagavi (10)	-	-	Belagavi, Khanapur	Bailhongal, Chikkodi	Hukkeri, Raibagh, Soundatti, Gokak, Ramdurga, Athani
Bagalkote (6)	-	-	-	Badami	Bagalkote, Jamkhandi, Mudhol, Bilgi, Hungund
Vijayapura (5)	-	-	-	Muddebihal	Basavanabagewadi, Vijayapura, Indi, Sindgi

Table 4 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)
Gadag (5)	-	-	-	Gadag, Shirahatti	Mundargi, Naragund, Ron
Haveri (7)	-	-	-	Byadgi, Hanagal, Haveri, Hirekerur, Ranibennur, Savanur, Shiggaon	-
Dharwad (5)	-	-	-	Hubli, Kundgol, Navalgund, Dharwad, Kalghatgi	-
Shivamogga (7)	-	-	Hosanagar, Tirthahalli, Sagara, Shikaripur,	Shivamogga, Bhadravathi, Sorab	-
Hassan (8)	-	Sakaleshpur	Belur, Hassan	Arasikere, Channarayapatna, Holenarasipur, Alur, Arkalgud,	-
Chikkamagaluru (7)	-	Mudigere, Narasimharajapur, Koppa, Sringeri	Chikkamagaluru, Tarikere	Kadur	-
Kodagu (3)	Madikeri	Somwarpet, Virajpet	-	-	-
Dakshina Kannada (5)	Beltangadi, Bantwal, Puttur, Sulya	Mangalore	-	-	-
Udupi (3)	Karkala	Kundapur, Udupi	-	-	-
Uttara Kannada (11)	-	Ankola	Honnavar, Bhatkal, Haliyal, Karwar, Kumta, Mundgod, Siddapur, Sirsi, Yellapur	Supa	-

average rainy days (PMARD-P3) in Udupi taluk of Udupi district was 32%, from south west monsoon coefficient of variation (SWM-CV-P1) in Gundlupet taluk of Chamaraja nagar district was 27%, from North East Monsoon average rainy days (NEARD-P5) in Belgavi taluk of Belgavi district was 26%, from North East Monsoon coefficient of variation (NEM-CV-P2) in Sedam taluk of Kalaburgi district was 24%, from south west monsoon average rainy days (SWARD-P4) in Gunlupet taluk of Chamaraj nagar district and from annual average rainy days (ANNARD-P6) in Chintamani taluk of Chikballapur district was 20% each, while the contribution from SWM-CV(P1) in Honnavar taluk of Uttara Kannada district, from PMARD(P3) in Mudigere taluk of Chikmagalur district, from SWARD(P4) in Karkala taluk of Udupi district, from NRARD(P5), ANNARD(P6) in Sulya taluk of Dakshina Kannada district, from AIA(P7) in Alur taluk of Hassan district was nil and NEM-CV(P2) was 3% in Malur taluk of Kolar district, individually towards the drought vulnerability. It is evident that the seven sub components considered for climatic index contribute differently in different taluks of the state thus indicating their importance in the composite drought vulnerability index in these taluks.

The average contribution of different sub-components (P1 to P7) in 176 Taluks towards the index ranged from 12 to 17%. The sub-components SWM-CV (P1) and NEM-CV (P2) contributed least (12%) while PMARD (P3) & NEARD (P5) contributed highest (17%) towards the climate based drought vulnerability (CI) index in the state. This indicates that on an average in these taluks (176) pre-monsoon rainy days (P3) and North East monsoon average rainy days (P5) are the major contributors towards the drought vulnerability, since these two sub-components influence the in time sowing for kharif season and forms a base for the performance of rabi crops respectively in the state.

The average contribution of the seven sub-components in these 176 taluks to the CI index was in the following order: NEARD (P5) > PMARD (P3) > AIA (P7) > ANNARD (P6) > SWARD (P4) > NEM-CV (P2) > SWM-CV (P1).

4.3. *Composite climatic index*

The summation of the index values of these seven sub-components (P1-P7) depicts the composite climatic drought vulnerability index value at each taluk level.

TABLE 5

Drought vulnerability taluks in different regions of Karnataka

Region	Total taluks	Drought vulnerability taluks				
		Class-1 (V SV)	Class-2 (SV)	Class-3 (MV)	Class-4 (HV)	Class-5 (V HV)
South interior Karnataka	63	-	-	8	50	5
North interior Karnataka	69	-	-	2	22	45
Malnad	25	1	7	8	9	-
Coastal	19	5	4	9	1	-
Total	176	6	11	27	82	50

These climate based index values of different taluks range from 0.05 to 0.84. It is observed that the humid & per humid taluks of Uttara Kannada, Dakshina Kannada and Udupi districts of Coastal region and all three taluks of Kodagu district of Malnad region showed lower index values (<0.36) indicating low vulnerability. Rest of the taluks mostly of SIK & NIK regions have high index values (>0.36) which relate to the moderate, severe and very severe vulnerability due to variation in rainfall related sub-components in all the seasons. In these SIK & NIK regions, some taluks like Shorapur (0.84) of Yadgir district and Chincholi (0.82) of Kalaburgi district showed high index values indicating very high vulnerability.

4.4. *Drought vulnerability classes*

As per the minimum (0.05) and maximum (0.84) composite climatic index values in 176 taluks, five drought vulnerable classes/zones with fixed class interval (0.15) were arrived (Table 3). These classes are: (*i*) Very slightly vulnerable (VSV), (*ii*) Slightly vulnerable (SV), (*iii*) Moderately vulnerable (MV), (*iv*) Highly vulnerable (HV), (*v*) Very highly vulnerable (VHV). All 176 taluks were categorized as per those vulnerability classes.

As per the climatic drought vulnerability class/zone, the number of Taluks (Table 4 & Fig. 4) under each class/zone are arrived. The distribution of taluks in each class are in the following order: highly vulnerable (82 taluks, 47%), very highly vulnerable (50 taluks, 28%), Moderately vulnerable (27 taluks, 15%), slightly vulnerable (11 taluks, 6%) and very slightly vulnerable (6 taluks, 4%).

Besides, the region wise distribution of the taluks under different drought vulnerability classes (Table 5) indicate that majority of the taluks in SIK (87%) and NIK (97%) are highly and very highly vulnerable to drought, while in Malnad and Coastal regions the vulnerable taluks are to the extent of 36% and 5% respectively. As per the study, about 75% of the Taluks are prone to high and very high drought vulnerability, while 25% are very slight to slightly and moderately vulnerable in Karnataka state. This clearly depicts that majority of the Taluks in the state are vulnerable to meteorological drought or drought like situations over the years due to aberrant weather conditions. Hence drought proofing measures are to be taken up on priority in these taluks in order to have food security for the people and fodder availability to live stock in the area.

5. Conclusions

The composite climatic index indicates that the percentage distribution of taluks under different classes of vulnerability is in the following order: 47% (under class HV), 28% (under class VHV), 15% (under class MV), 6% (class SV) and 4% (under class VSV). In Karnataka state, almost 75% of the taluks are highly and very highly drought vulnerable. Region wise, the highly and very highly vulnerable taluks are spread in SIK & NIK regions. Even among these two regions majority of taluks in NIK (97%) are highly and very highly vulnerable to drought. This implies that these two drought vulnerable regions have utmost need of the systematic and holistic implementation of drought proofing measures with respect to saving and sharing of water, food grains and fodder supply.

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References

Brooks, N., Adger, W. N. and Kelly, P. M., 2005, "The determinants of vulnerability and Adaptive capacity at the national level and the implications for adaptation", *Global Environmental Change*, **15**, 2, 151-163.

Cardona, O. D., 1999, "Environmental management and disaster prevention: Holistic risk assessment and management", *J. Ingleton (ed.)*, Natural Disaster Management, Tudor Rose, London.

Challa, O. and Wadodker, M. R., 1998, "Delineation of drought prone areas in Maharashtra : A Soil-Climate based approach", *Agropedology*, **6**, 2, 21-27.

Chandrashekhar, H. and Venugopal, T. N., 1995, "Drought assessment and response system Chitradurga district, Karnataka-A Summary", p94.

Chen, W., Cutter, S. L., Emrich, C. T. and Shi, P., 2013, "Measuring social vulnerability to natural hazards in the Tangtze river delta region, China", *International Journal of Disaster Risk Science.*, **4**, 4, 169-181.

Drought Manual, 2009, "Department of Agriculture & co-operation", Min. of Agric. Gov. India, New Delhi, p192.

Hiremath, B. D. and Shiyani, R. L., 2012, "Evaluating regional vulnerability to climate change: A case of sourashtra", *Indian Journal of Agricultural Economics*, **67**, 334-344.

Irrigation Commission, 1972, "Ministry of irrigation and power", Govt. of India, New Delhi, **Vol. 1**, p160.

Julich, S., 2015, "Development of a composite index with quantitative indicators for drought Disaster risk analysis at the micro level", *Hum. Ecol. Risk. Assess. International Journal*, **21**, 1, 37-66.

KSNDMC, 2017, "Drought Vulnerability Assessment in Karnataka", *Tech. Bulletin*, KSNDMC Pub., p103.

Li, A., Wang, A., Liang, S. and Zhou, W., 2006, "Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS-A case study in the upper reaches of Minjiang River, China", *Ecological Modelling*, **192**, 175-187.

Liu Xiaoqian, Wang Yanglin, Peng Jian, Ademola K Braimoh and Yin He, 2013, "Assessing Vulnerability to Drought Based on Exposure, Sensitivity and Adaptive capacity: A Case Study in Middle Inner Mangolia of China", *China. Geographical Science*, **23,** 13-25.

Madhuri, Tewari, H. R. and Bhowmick, P. K., 2014, "Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar", *Journal of disaster Risk Studies*, **6**, 1, *Article. 127, 1-13.*

Murthy, C. S., Laxman, B. and Seshasai, M. V. R., 2015, "Geospatial analysis of agricultural drought vulnerability using a composite index based on exposure, sensitivity and adaptive capacity", *International Journal of Disaster Risk Reduction*, 1-9.

Naidu, L. G. K. and Srinivas, S., 2005, "Length of growing period as criteria for identifying different drought types in Karnataka", *Indian J. Agric. Sciences*, **75**, 9, 614-615.

OECD, 2008, "Handbook on Constructing Composite Indicators methodology and user guide", p151, www.oecd.org.

Wisner, B., Blaikie, P., Cannon, T. and Davis, I., 2004, "At risk: Natural hazards, people's vulnerability and disasters", 2nd edn., Routledge, London.