Vulnerability Assessment Using Composite Drought Index (CDI) for Chamarajanagara District

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***Abstract*-Drought is a natural disaster which is having a negative impact on water resources and crop growth. The objective of the study is to identify the drought prone areas using Composite Drought Index, developed using the major components of drought i.e., Meteorological, Agricultural and Hydrological components which includes the sub components such as Departure Index (DI), Dry Spell, Moisture Adequacy Index (MAI), Normalized Difference Vegetation Index (NDVI) and Ground Water Drought Index (GWDI), in Chamarajanagara District of Karnataka from the year 2009 to 2017. Rainfall pattern (South-West monsoon and North- East Monsoon) has been incorporated in the study. Using variance method, composite indices were developed by computing weights for each Meteorological, Agricultural and Hydrological components. Composite Drought Index (CDI) was developed for each Hobli by integrating all the major components and finally drought vulnerability classifications were generated and drought prone areas were identified. Geographical Information System (GIS) is an effective tool to represent and draw the results. The resultant drought maps will help in development of mitigation measures. The drought risk maps were generated which shows that parts of Santemarahalli hobli, Harve hobli and Begur hobli are slightly vulnerable to drought and all the others parts of the district are moderately vulnerable to drought. This study will help in future to adopt measures for mitigating the effect of drought.**

***Keyword:* - Drought, Chamarajanagara District, Indian Meteorological Department (IMD), Departure Index (DI), Dry Spell, Moisture Adequacy Index (MAI), Normalized Difference Vegetation Index (NDVI) and Ground Water Drought Index (GWDI), Composite Drought Index (CDI), GIS, Drought Vulnerability.**

I. INTRODUCTION

Drought is one of the natural disasters that weaken the sustainable development of people and the related resources. Increasing temperature and erratic precipitation patterns, leads to the extreme weather events like drought. It is hard to give an exact and widely accepted definition for drought as it is having fluctuating characteristics and effects. It is usually explained in terms of spatial distribution, severity and its duration. Drought occurs primarily on account of rainfall deviation from the normal rainfall, that inflicts an adverse impact on crops over an agricultural season or successive seasons. Mainly there are three types of drought namely, Meteorological, Hydrological and Agricultural drought. Meteorological drought is the condition when a region receives seasonal rainfall less than 25 percentage of its normal value. Hydrological drought is the condition where in regions runoff is less than 75 percentage of the normal runoff. Agricultural drought is due to soil moisture deficiency during crop growth period, plant water stress leading to wilting and reduces yield and this type of drought has a direct impact of meteorological and hydrological droughts on the crop yield [1]. The study provides information on the basis of selection of the major components and also sub component for developing a combined/ composite drought index (CDI). The CDI developed clearly depicts the vulnerability of any area with respect to drought. For the development of the CDI, the major components and sub components selection are relevant [2] [3]. Three major components namely, Meteorological, Hydrological and Agricultural components that are relevant to drought vulnerability are selected. Each sub-component is treated to be 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 Chamarajanagara district. Under Meteorological, Hydrological and Agricultural components the sub-component are Departure Index (DI) and Dry Spell which requires rainfall data, Groundwater Drought Index (GWDI) which requires groundwater table data and Normalized Difference Vegetation Index (NDVI) and Moisture Adequacy Index (MAI) respectively.

II. MATERIALS AND METHOD

Study Area

The study area, Chamarajanagara district is located in the Southern tip of Karnataka. The district is located 185 kms away from Bangalore state capital and lies between the North latitude 11º 40` 58`` and 12º 06` 32`` and East longitude 76º 24` 14`` and 77º 46` 55`` with an altitude of 1816m above mean sea level. The district has a territory of 5,648 square kilometers and undulating and mountainous with north south trending hill ranges of both Eastern and Western Ghats. The district has been segregated into 4 Taluks for regulatory convenience namely Chamarajanagara Taluk, Gundlupet Taluk, Kollegal and Yalandur Taluks. The district is having in total 16 Hoblies [4]. The location map of the study area is as shown in Figure 1.

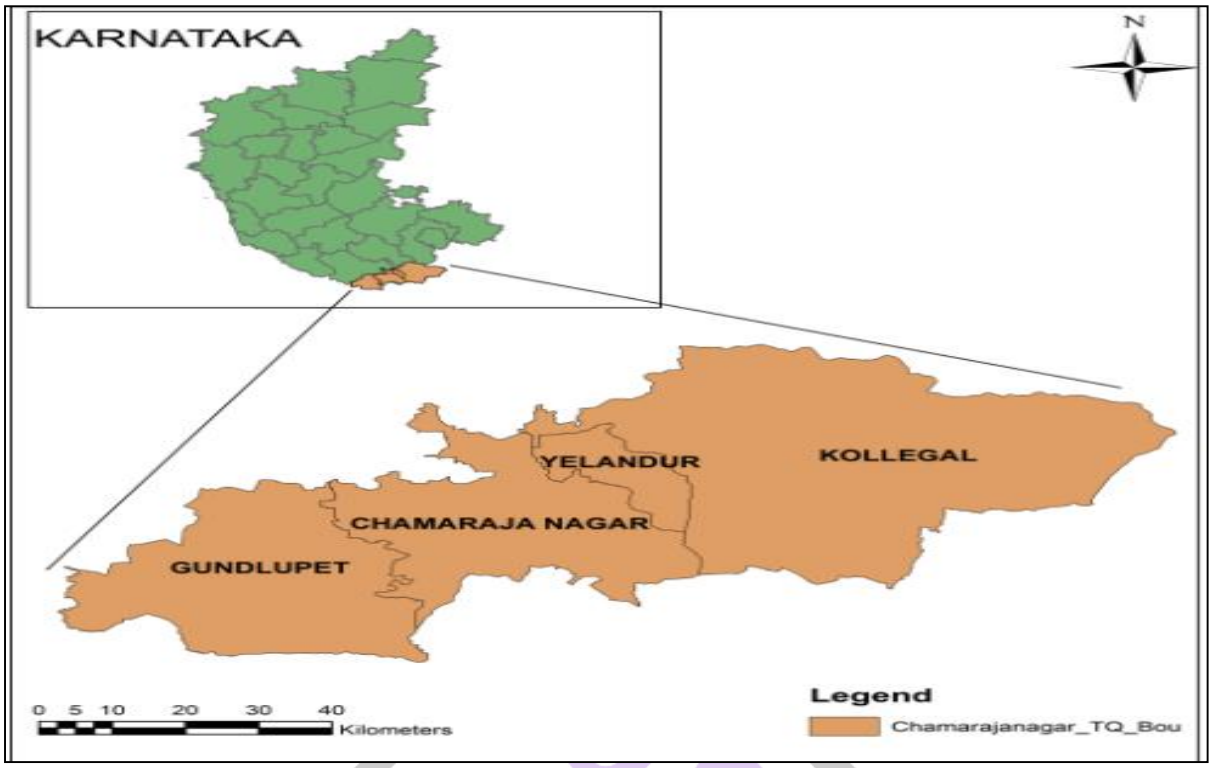

Fig-1: Location map of Chamarajanagara District

The behavioral pattern of rainfall with reference to the amount of rainfall and number of rainy days in a week were calculated using historic daily rainfall records (1986-2016). The annual average rainfall of Chamarajanagara district is 764mm with 47 rainy days. The region receives moderate rainfall in Pre Monsoon (26%) and receives good amount of rainfall during South-West Monsoon (40%) and North -East Monsoon (34%).

The sub-components Departure Index (DI) and Dry Spell, Groundwater Drought Index (GWDI) and Normalized Difference Vegetation Index (NDVI) and Moisture Adequacy Index (MAI) were calculated using standard procedure of Government of India Department of Agriculture and Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, (2016). "Manual for Drought Management". The assessment is carried out for the years 2009 to 2017 and for South-West and North-East Monsoons.

Data Used

In the present study, data on precipitation were collected from Karnataka State Natural Disaster Monitoring Center (KSNDMC). Ground water table data was collected from Central Ground Water Board (CGWB). MODIS-TERRA (H25V07) data of NDVI with a spatial resolution of 250m. Normal Potential Evapotranspiration data from KSNDMC.

Meteorological Drought Index (MDI)

Under Meterorological Drought Index, departure index and dry spell are the two main criteria's that has to be considered for drought analysis.

Departure Index (DI)

Any deviation in rainfall from its normal value from the Long Period Average (LPA) has to be considered as a base for declaring drought.

$$\text{Departure Index (\%)} = \left(\frac{\text{ARs} - \text{NRs}}{\text{NRs}}\right) * 100 \qquad (1)$$

Where, AR-Actual Seasonal Rainfall (mm) and NR-Normal Seasonal Rainfall (mm). According to Indian Meteorological Department (IMD) if DI as classified as Normal (+19 to -19), Deficient (-20 to -59), Large Deficient (-60 to -99) and No rain (-100).

Dry Spell

The consecutive 3-4 weeks after the onset of the monsoon with rainfall less than 50 percentage of the normal in each week is defined as Dry spell [5].

Hydrological Drought Index (HDI)

Hydrological Drought Index, is found using groundwater table depletion recordings of the study area.

Groundwater Drought Index (GWDI)

The monthly groundwater (GW) table records are required for minimum period of 10 years for the calculation of mean value of monthly ground water depletion rate. When the rate of depletion of groundwater level in a given month/period is more than the corresponding mean value then it is an indication of water deficit.

$$GWDI_{ij} = \frac{\mathrm{MGWD_j} - \mathrm{GWD_{ij}}}{\mathrm{GWD_{imax}}} \qquad (2)$$

Where, $GWDI_{ij}$ = Groundwater Drought Index for ith month and jth year, $MGWD_j$ = Mean depth to Groundwater table below surface, GWD_{ij} = Depth to groundwater table in ith month and jth year, GWD_{imax} = Maximum depth to groundwater table in ith month in available data set for n number of years. n = total number of years for which monthly groundwater records are used. According to IMD, GWDI is classified as Normal (>-0.15), Mild (-0.16 to -0.30), Moderate (-0.31 to -0.45), Severe (-0.46 to -0.60) and Extreme (<-0.60).

Agricultural Drought Index (ADI)

The two main aspects to be considered in Agricultural Drought Index are Normalized Difference vegetation Index and moisture Adequacy Index.

Normalized Difference Vegetation Index (NDVI)

The NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to assess whether the target being observed contains live green vegetation or not. Generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light. Unhealthy vegetation reflects more visible light and less near-infrared light. Bare soils, reflects moderately in both the red and infrared portion of the electromagnetic spectrum. Satellite based crop condition which point towards agricultural drought can be generated by computing NDVI deviations from the Normal years. Normal NDVI is generated by averaging NDVI of at least 3 recent normal years.

$$\mathrm{NDVI_{dev}} = \left\{\frac{\mathrm{NDVI_i} - \mathrm{NDVI_n}}{\mathrm{NDVI_n}}\right\} * 100 \qquad (3)$$

Where the subscript 'n' refers to normal value and 'i' to current period. According to IMD, NDVI deviation of -20 to -30% represents moderate drought conditions and <-30% represent severe drought condition.

Moisture Adequcey Index (MAI)

Moisture Adequacy Index is a quantitative relationship between actual evapotranspiration and potential evapotranspiration. It is an index to measure moisture condition in soil in relationship to water requirement. In general it is calculated by weekly water balance, but in this project MAI is calculated using monthly data and finally summarized to obtain the values for S-W and N-E Monsoon of each Hobli of the district.

$$\mathrm{MAIs} = \left(\frac{\mathrm{AEs}}{\mathrm{PEs}}\right) * 100 \qquad (4)$$

Where, MAIs – Seasonal Moisture Adequacy Index (%), AEs – Seasonal Actual Evapotranspiration, PEs - Seasonal Normal Potential Evapotranspiration. According to IMD, the classification of moisture stress with respect to MAI is as follows: >75% (No Stress), 74-50% (Mild Stress), 49-25% (Moderate Stress) and <24% (Severe Stress).

Composite Drought Index (CDI)

CDI provides a clear approach for evaluating the drought intensity. In this current study CDI was developed by selection of drought indicators, generation of database, assigning weights, integration of indices to assess drought vulnerability. The first step is selection of indicators which triggers drought situation, indicators selected for modelling of CDI are DI, Dry spell, MAI, NDVI and GWDI. To standardize the units of drought input indicators data sets are normalized, after normalization, all the indicators will have the values ranging from 0 to 1. Normalization is done using, Xis-normalized value = (Xis-Xms)/σ. Next step is to assign weights to the indicator, in this study weights are selected by technique given by Iyengar and Sudarshan, pursued by Hiremath and Shiyani, for assessment of drought vulnerablility. The weights are determined by,

$$y_i = \sum_{j=1}^{K} w_j x_{ij} \quad (5)$$

Where, yi = composite Index of ith hobli, Xij = Normalized data set, Wj = weights assigned to each indicators and is calculated as follows

$$w_j = \frac{C}{\sqrt{var\,(x_{ij})}} \quad (6)$$

Where C – Normalizing constant and is calculated as,

$$C = \left[\sum_{j=1}^{K} \frac{1}{\sqrt{var_i\,(x_{ij})}} \right]^{-1} \quad (7)$$

After obtaining the normalized weights of Meteorological, Hydrological and Agricultural Drought Index for each hobli is calculated, we will obtain the CDI of each Hobli using the respective weights and it is scaled from zero to one for easy interpretation. All these indicators act as positive towards drought hence positive sign, further with respect to CDI values drought is classified as: very slightly vulnerable (<0.2), slightly vulnerable (0.2 – 0.4), moderately vulnerable (0.4 – 0.6), and highly vulnerable (0.6 – 0.8) and very high vulnerable (>0.8) to drought.

III. RESULT AND DISCUSSION

The sub-components under each major component are calculated and CDI is obtained for each hobli for the 9 years (2009-2017).

Table-1: Major Component –wise Composite Indicators of CDI for Chamarajanagara district

CHAMARAJANAGARA HOBLI					
YEAR	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.8	0.3	0.8	0.6	HV
2010	0.7	0.1	0.6	0.5	MV
2011	0.8	0.3	0.4	0.5	MV
2012	0.5	0.8	0.9	0.7	HV
2013	0.5	0.3	0.6	0.5	MV
2014	0.4	0.2	0.4	0.3	SV
2015	0.7	0.1	0.3	0.4	SV
2016	0.5	0.8	0.1	0.5	MV
2017	0.5	0.3	0.0	0.3	SV
CHANDAKAVADI HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.6	0.6	0.7	HV
2010	0.8	0.2	0.7	0.6	MV
2011	0.7	0.5	0.7	0.6	HV
2012	0.8	0.5	0.9	0.8	HV
2013	0.7	0.5	1.0	0.7	HV
2014	0.7	0.2	0.3	0.4	MV
2015	0.8	0.2	0.3	0.4	MV
2016	0.5	0.8	0.1	0.5	MV
2017	0.3	0.7	0.3	0.4	MV
HARADANHALLI HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.4	0.6	0.5	MV
2010	0.5	0.1	0.5	0.3	SV
2011	0.7	0.3	0.0	0.3	SV
2012	0.7	0.7	0.5	0.6	HV
2013	0.6	0.3	0.5	0.5	MV
2014	0.4	0.2	0.7	0.4	MV
2015	0.6	0.1	0.3	0.4	SV
2016	0.5	0.8	0.3	0.5	MV
2017	0.3	0.4	0.6	0.5	MV

HARVE HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.3	0.2	0.5	0.3	SV
2010	0.7	0.1	0.4	0.4	SV
2011	0.3	0.2	0.3	0.3	SV
2012	0.4	0.8	0.4	0.5	MV
2013	0.1	0.2	0.0	0.1	VSV
2014	0.0	0.1	0.6	0.3	SV
2015	0.6	0.1	0.7	0.5	MV
2016	0.3	0.7	0.5	0.5	MV
2016	0.3	0.3	0.5	0.4	SV
SANTEMARAHALLI HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.3	0.3	0.3	0.3	SV
2010	0.5	0.2	0.2	0.3	SV
2011	0.3	0.3	0.2	0.2	SV
2012	0.3	0.8	0.1	0.4	MV
2013	0.6	0.5	0.3	0.4	MV
2014	0.3	0.1	0.3	0.2	SV
2015	0.5	0.3	0.0	0.3	SV
2016	0.6	0.6	0.1	0.5	MV
2017	0.6	0.5	1.0	0.7	HV
GUNDLUPET HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.4	0.3	0.6	0.4	MV
2010	0.5	0.2	0.3	0.3	SV
2011	0.4	0.2	1.0	0.5	MV
2012	0.3	0.8	0.7	0.6	MV
2013	0.4	0.3	0.7	0.4	MV
2014	0.4	0.1	0.3	0.3	SV
2015	0.7	0.2	0.1	0.3	SV
2016	0.5	0.8	0.1	0.5	MV
2017	0.6	0.5	0.7	0.6	HV
BEGUR HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.4	0.3	0.1	0.3	SV
2010	0.4	0.2	0.1	0.2	SV
2011	0.4	0.3	0.1	0.3	SV
2012	0.6	0.8	0.6	0.6	HV
2013	0.3	0.2	0.1	0.2	SV
2014	0.4	0.1	0.3	0.3	SV
2015	0.5	0.2	0.6	0.4	MV
2016	0.5	0.8	1.0	0.8	HV
2017	0.6	0.4	0.2	0.4	MV
TERAKANAMBI HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.3	0.3	0.9	0.5	MV
2010	0.3	0.1	1.0	0.4	MV
2011	0.3	0.2	0.8	0.4	MV
2012	0.2	0.7	1.0	0.7	HV
2013	0.5	0.3	0.0	0.3	SV
2014	0.3	0.2	1.0	0.5	MV
2015	0.4	0.3	0.0	0.2	SV
2016	0.4	0.8	0.1	0.4	MV
2017	0.3	0.4	0.6	0.4	MV
HANGALA HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.4	0.3	0.4	0.4	SV
2010	0.8	0.2	0.5	0.5	MV
2011	0.4	0.3	0.0	0.2	SV
2012	0.5	0.7	0.8	0.7	HV

2013	0.6	0.4	0.9	0.6	HV
2014	0.7	0.2	0.8	0.6	MV
2015	0.6	0.3	0.4	0.4	MV
2016	0.5	0.7	0.3	0.5	MV
2017	0.7	0.7	0.7	0.7	HV
KOLLEGAL HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.6	0.3	0.4	0.4	MV
2010	0.8	0.3	0.0	0.4	SV
2011	0.6	0.3	0.1	0.3	SV
2012	0.5	0.8	0.8	0.7	HV
2013	0.6	0.2	0.6	0.5	MV
2014	0.5	0.2	1.0	0.6	MV
2015	0.5	0.2	0.6	0.4	MV
2016	0.5	0.7	0.8	0.6	HV
2017	0.3	0.7	0.8	0.6	MV
HANUR HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.3	0.4	0.4	MV
2010	0.6	0.1	0.1	0.3	SV
2011	0.7	0.2	0.0	0.3	SV
2012	0.5	1.0	1.0	0.8	VHV
2013	0.7	0.3	0.6	0.5	MV
2014	0.6	0.3	0.7	0.5	MV
2015	0.5	0.1	0.2	0.3	SV
2016	0.9	0.8	0.1	0.6	MV
2017	0.2	0.5	0.2	0.3	SV
LOKKANAHALLI HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.3	0.4	0.5	MV
2010	0.7	0.2	0.1	0.3	SV
2011	0.7	0.3	0.0	0.3	SV
2012	0.6	0.8	1.0	0.8	VHV
2013	0.7	0.2	0.6	0.5	MV
2014	0.5	0.2	0.7	0.5	MV
2015	0.7	0.2	0.2	0.3	SV
2016	0.5	0.8	0.1	0.5	MV
2017	0.3	0.6	0.2	0.3	SV
PALYA HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.6	0.3	0.2	0.4	SV
2010	0.6	0.2	0.1	0.3	SV
2011	0.6	0.2	0.2	0.3	SV
2012	0.6	0.8	0.5	0.6	HV
2013	0.6	0.4	0.5	0.5	MV
2014	0.7	0.2	0.5	0.5	MV
2015	0.6	0.2	0.8	0.5	MV
2016	0.4	0.8	1.0	0.7	HV
2017	0.5	0.7	0.1	0.4	MV
RAMAPURA HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.4	0.4	0.5	MV
2010	0.7	0.0	0.1	0.3	SV
2011	0.7	0.3	0.0	0.3	SV
2012	0.8	0.8	1.0	0.9	VHV
2013	0.7	0.2	0.6	0.5	MV
2014	0.5	0.3	0.7	0.5	MV
2015	0.6	0.2	0.2	0.3	SV
2016	0.4	0.8	0.1	0.4	MV
2017	0.2	0.7	0.2	0.4	SV

YELANDUR HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.7	0.4	0.3	0.5	MV
2010	0.5	0.1	0.2	0.3	SV
2011	0.7	0.2	0.2	0.4	SV
2012	0.3	0.7	0.1	0.4	SV
2013	0.5	0.3	0.3	0.4	SV
2014	0.5	0.1	0.3	0.3	SV
2015	0.5	0.2	0.0	0.3	SV
2016	0.5	0.7	0.1	0.4	MV
2017	0.3	0.6	1.0	0.6	HV
AGARA HOBLI					
Year	**MDI**	**ADI**	**HDI**	**CDI**	**CLASS**
2009	0.4	0.3	0.4	0.4	SV
2010	0.5	0.2	0.0	0.2	SV
2011	0.4	0.2	0.1	0.3	SV
2012	0.4	0.8	0.8	0.7	HV
2013	0.8	0.2	0.6	0.5	MV
2014	0.4	0.4	1.0	0.6	MV
2015	0.8	0.2	0.6	0.5	MV
2016	0.7	0.6	0.8	0.7	HV
2017	0.6	0.7	0.8	0.7	HV

In this study drought severity maps are developed to show the areas of Chamarajanagara district which are affected by drought. These maps were mapped using Inverse Distance Weight (IDW) method. IDW interpolation assumes that the points that are close to each other are alike than those which are apart. To extrapolate value of unmeasured point or location, the technique makes use of neighbouring measured values which are surrounding the unmeasured point Geostatistical analysis tool of Arc Map 10.2 was used to carry out interpolation. Figure 2 shows the drought prone areas in the study area.

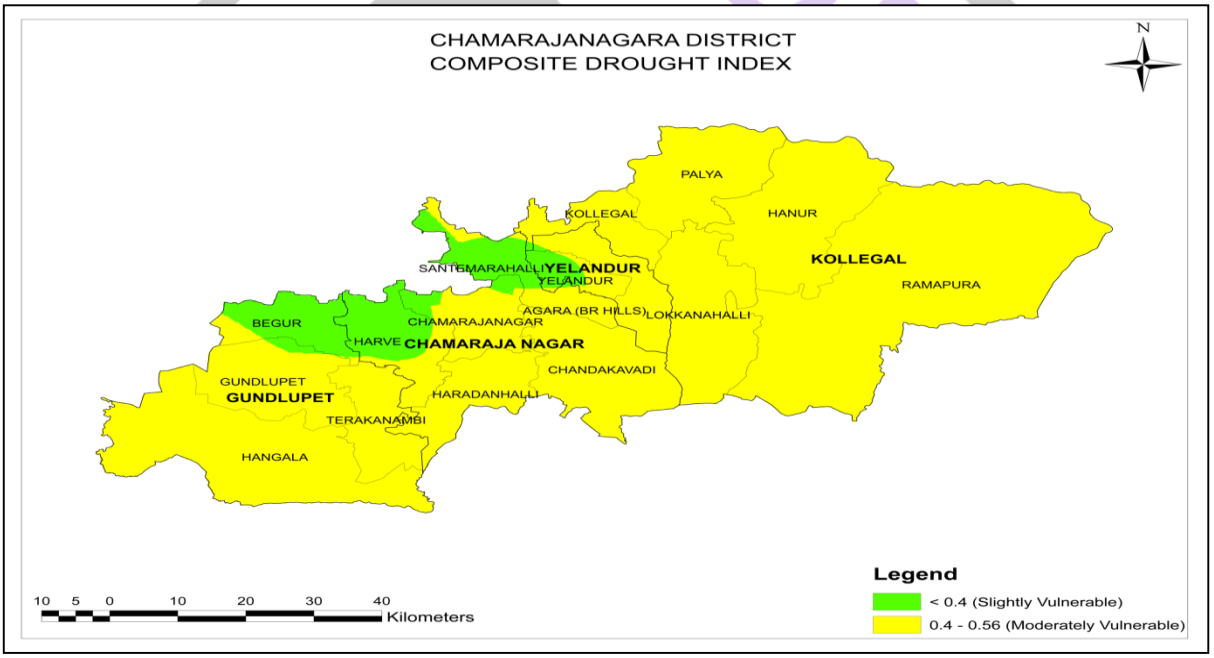

Fig-2: Drought Severity Map of Chamarajanagara district using Composite Drought Index

IV. CONCLUSIONS

Based on the study, parts of Santemarahalli hobli, Harve hobli and Begur hobli are slightly vulnerable to drought and all the others parts of the Chamarajanagara district are moderately vulnerable to drought. There is need to adopt rain water harvesting by sinking pits, water storage by farm ponds and renovation of tanks etc. to mitigate the effect of drought in the district.

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