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Research Article

RECONNAISSANCE DROUGHT INDEX AS POTENTIAL DROUGHT MONITORING TOOL IN A DECCAN PLATEAU, HOT SEMI-ARID CLIMATIC ZONE

KWARTENG FRANCIS, SHWETHA G.*AND PATIL RAHUL
Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur, Karnataka, India
*Corresponding Author: Email-shwethag.937@gmail.com

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Abstract- The risk associated with climate and its variability over Raichur district is the major determining factor for agricultural productivity and has a major impact on food security in that region. The district most of the time reels under drought and have devastating effects on agricultural production and livelihood. Such has justified concerns of assisting with climate information converted into indices forming part of early warning tools to assist with multifactorial decisions of the sort agricultural producers need to make in relation to drought. Due to the hot semi-arid climate of Raichur district, the Reconnaissance Drought Index, which is sensitive to global warming, was employed to assess drought over 100-year time series. The tool was effective in drought assessment and predicts probability of drought occurrence, which is in a better position to inform stakeholders and decision makers on early warning measures with respect to mitigating drought in the district.

Keywords- Reconnaissance Drought Index, Global warming, Drought, Food security, Hot semi-arid climate, Raichur

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Introduction

Drought is a recurrent feature of climate that is characterized by temporary water shortages relative to normal supply, over an extended period of time – a season, a year, or several years. The term is relative, since droughts differ in extent, duration, and intensity and widely considered to be the most complex and perhaps least understood of all natural hazards. Owing to the large range of perspectives on drought across society, drought may be considered as a socially-constructed concept. However, identification and definition of drought range from simple rainfall deficiency-based approaches to the more recent sophisticated integrations of climatological, biological, hydrological, economic and social factors [1,2]. Other held definitive statements on drought centre around a period of deficient precipitation with impacts on agriculture, water resources, and the natural ecosystems or succinctly, a natural phenomenon that occurs when water availability is significantly below normal levels over a long period and the supply cannot meet the existing demand [3,4]. It is indeed a natural hazard that differs from aridity and has both direct and indirect impacts. Their devastating effect span many sectors - production, lives, health, livelihoods, assets and infrastructure that contribute to food insecurity and poverty [5]. However, the indirect effects of drought could be through its impact on crop and livestock prices, which could be larger than its direct effects [6, 7]. By extension, for instance, where irrigation is practised decreased water allocations reduces the production of irrigated crops which in turn increases prices, creates tension between different water users, and results in major and costly infrastructure.[8]

According to [9,10], in recent years the damage from droughts to agriculture in some countries has been far-reaching, and the amount of losses caused by drought ranks first in the list of all natural hazards. However, past reactive responses have done little to reduce the risk associated with drought. Traditional methods of a mix of strategies to mitigate drought have equally proven insufficient or falter entirely to protect livelihoods in drought-prone regions [5]. The message is that drought in all its manifestations requires a much more planned and developmental, rather than crisis management approach [11]. However, owing to the complexities of drought, it becomes difficult to accurately or objectively identify the onset and end of a drought, and in quantifying drought severity in terms of its duration, magnitude and spatial extent due to its creeping nature [12,2]. To assist producers' decision making, climate information is often converted into factors of more direct interest such as yields, economic benefit or livelihood options through a climate-oriented decision support system (DSS) that systematically combines climate data with other information to assist with multi factorial decisions of the sort agricultural producers need to make in relation to drought" [13]. For this reason much effort has been keen to developing drought indicators for risk analysis and drought monitoring since they enable identification and quantification of droughts. Even though the challenge lies in the establishment of a unique drought indicator as there are innumerable indices proposed [14-18]

Perhaps, the most widely used drought indices are the Palmer Drought Severity Index (PDSI) and the Standard Precipitation Index (SPI). The inputs required for estimation of PDSI is based on the supply and demand concept of the water balance equation, and thus incorporates prior precipitation, moisture supply, runoff and evaporation demand at the surface level [19]. This does not however comes without a limitation as the fixed temporal scale of PDSI makes it difficult in analysing the impacts of droughts owing to the differences in characteristic drought resilience times of various natural and economic systems. This may account for the urge of SPI over the PDSI as it can be calculated at different time scales to monitor drought affecting a particular system with different resilient time. However, the SPI has the important shortcoming that it is based only on precipitation data, and does not consider other critical variables such as evapotranspiration, which can have a marked influence on drought conditions [20, 21]. Recently gaining prominence is the Reconnaissance Drought Index (RDI), which is more sensitive than the SPI to climatic conditions as it, considers evapotranspiration in the drought assessments. A comparative study carried out by [22]between SPI and RDI methods of indices for their sensitivity towards climatic conditions found that even though both indices behave in a similar manner under similar climatic condition, the RDI due to the inclusiveness of potential evapotranspiration was more sensitive. According to [23], temperature rise between 2.7-4.3 °C is expected over the India subcontinent in the next 60 years. Assessing and monitoring drought in relation between drought and climate change, [11] asserts that drought indicators sensitive to global warming is best to be employed. According to [24] about 107mha of the area of India spread over administrative districts in several states are affected by drought out of which the Raichur district in Karnataka state is of great mention. The Raichur district falls within the plateau and the most arid band of the country and are constantly hit by drought. This region suffers drought mostly due to the cumulative effects of changing precipitation pattern. The people in this region depend on agriculture and thus, whenever there is drought suffer severely from agro-meteorological drought effects and could need more than US$ 250,000 in relief. There are yet to be any previous studies utilising a precipitation-temperature based drought index to simulate the occurrence and magnitude of drought in this region. Hence, the overarching goal of present study is to calculate time series of RDI to analyse drought to support real-time decision making specifically to improve the management of water supply in the district since productive agriculture critically depends on the ability to satisfy the water demands of a water intensive irrigation system.

MaterialsandMethods

Study area

Raichur is a city municipality in the district of Raichur in the South Indian state of Karnataka, India. Raichur District falls in a plateau region and located between 15°33' and 16°34' N latitudes and 76°14' and 77°36' E longitudes and at an elevation of 390 m above mean sea level. It is a drought prone region and falls within the most arid band of the country. Raichur weather remains almost dry throughout the year, a very hot summer with mean monthly maximum temperature of 46.15°C in May and a minimum of 16.6°C in December. The climate of the district characterized by dryness for the major part of the year and a very hot summer receives very low and erratic precipitation with an average annual rainfall of 621 mm. It is this low and highly variable rainfall that renders the district liable to drought. The year may be divided broadly into four seasons. The hot season begins by about the middle of February and extends to the end of May; the South-west monsoon is from June to end of September. October and November are the post monsoon or retreating monsoon months and the period from December to the middle of February is the cold season. Raichur district is notable for the production of paddy, cotton, sunflower, redgram, beans among other horticultural crops and vegetables. As one of the administrative districts of the state chronically affected by drought conditions, impacts affect very notably the agricultural activities in this region and this is the main reason for it being considered under this study. [Fig-1] represents the location map of the area.

Data

Weather stations with more than 100 years (starting from 1914 to 2014) of climatological data (rainfall and temperature)were chosen from various stations in the Raichur district. Climatological data was obtained from the Main Agricultural Research Station located at the University of Agricultural Sciences, Raichur and India Water Portal. The monthly data were used as input for the calculation of RDI to observe the spatio-temporal extent and intensity of meteorological drought event.

Calculation of Reconnaissance Drought Index

The Reconnaissance Drought Index (RDI) [25,26] can be characterised as a general meteorological index for drought assessment. The RDI can be expressed with three forms: the initial value α_k, the normalised RDI (RDIn) and the standardised RDI (RDIst). In this paper we will focus on $\alpha_k$and RDIst. The initial value (α_k) is presented in an aggregated form using a monthly time step and may be calculated on a monthly, seasonal or annual basis. The $\alpha_k$for the year i and a time basis k (months) is calculated as:

$$a_k^{(i)} = \frac{\sum_{i=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}};\, i = 1\ to\ N\ and\ j = 1\ to 12 \qquad [1]$$

where Pij and PETij are the precipitation and potential evapotranspiration of the jth month of the it hhydrological year. N is the total number of years of the available data (which is 100 years in this study).

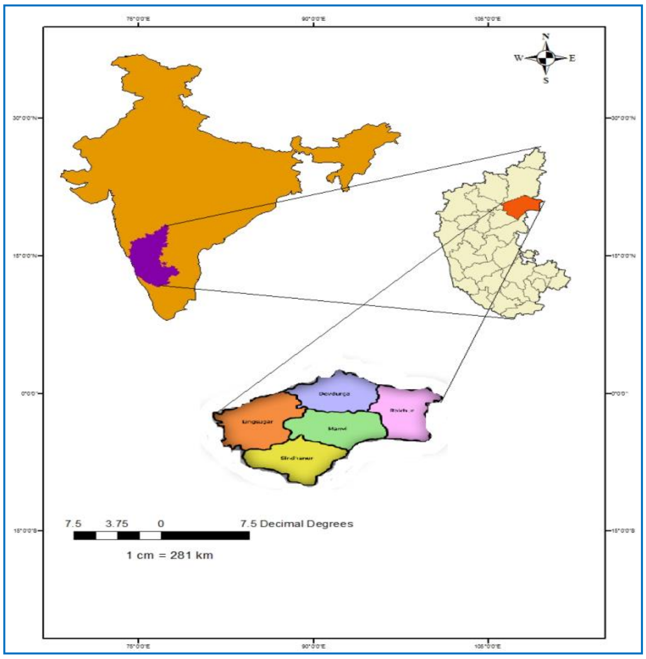

Fig-1 Location map of the Study area

The initial formulation of the RDIst according to [25] used the assumption that the $\alpha_k$values follow the lognormal distribution and RDIstis calculated as:

$$RDI_{st(k)}^{(i)} = \frac{y_k^i - \bar{y}_k}{\hat{\sigma}_{yk}} \qquad [2]$$

where y_k is the ln(α_k(i)),$\bar{y}$ is its arithmetic mean and $\hat{\sigma}_{yk}$ is its standard deviation. From an extended research on various data from several locations and different time scales (3, 6,9 and 12 months) it was concluded that the α_k values follow satisfactorily both the lognormal and the gamma distributions in almost all locations and time scales, but in most of the cases the gamma distribution was more successful. Therefore, the calculation of the RDIst could be performed better by fitting the gamma probability density function (pdf) to the given frequency distribution of the α_k, following the procedure described below. This approach also solves the problem of calculating the RDIst for small time steps, such as monthly, which may include zero-precipitation values (α_k= 0), for which Eq. (2) cannot be applied. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}$$

where$\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$is the gamma function, which is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y}\, dy$$

Fitting the distribution to the data requires α and β to be estimated. [20] suggested estimating these parameters using the approximation of [27] for maximum likelihood as follows:

$$\alpha = \frac{1}{4A}[1 + \sqrt{1 + \frac{4A}{3}}$$

$$\beta = \frac{x}{\alpha}, \text{with } A = \ln x - \frac{\sum \ln x}{n}$$

where n is the number of observations. Integrating the probability density function with respect to x yields the following expression G (x) for the cumulative probability:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta}$$

Substituting $t = x/\beta$, (4) is reduced to:

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt$$

The resulting parameters are then used to find the cumulative probability of α_k for a given year forthe location in question. Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q) G(x)$$

where q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in an $\alpha_k$time series, then q can be estimated by m/n. The cumulative probability $H(x)$, is then transformed to the standard normal random variable z with mean zero and variance of one [26], which is the value of the RDIst.

Drought evaluation indicators

The relative frequency (RF) of drought is the evaluation of a station's frequency of drought in some years and estimated as:

$$RF = \frac{n}{N} \times 100\%$$

Where: n-the total number of drought (negative RDI); N-the number of precipitation data of the site.

According to [27], the magnitude of a considered drought event corresponds to the cumulative water deficit over the drought period, thus the sum of RDI and the average of this cumulative water deficit over the drought period is mean intensity. He asserted that the negated sum of the drought index represents its magnitude. Therefore, since RDI are negative values, the drought magnitude could be said to be the absolute sum of the RDI. Hence, the magnitude and intensity of drought in a particular category in this study is estimated as follows:

$$DM_{ij} = \sum_{i=1}^{n} |RDI_i|$$

Drought Intensity (Sij) is used to represent the severity of the drought. The drought intensity of a site within a certain period is usually reflected by the RDI value. Bigger the RDI absolute value is, more serious the drought is. Its formula is as follows:

$$S_{ij} = \frac{1}{n} \sum_{i=1}^{n} |RDI_i|$$

Results and Discussion

Drought monitoring through RDI

The devastating impacts of drought span many sectors of the economy and reaches well beyond the area experiencing physical drought. This intricacy of drought may exist because water is essential to society's ability to produce goods and provide services. Impacts are commonly referred to as direct and indirect. Direct impacts include reduced crop, rangeland, and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat. The consequences of these direct impacts illustrate indirect impacts. For example, a reduction in crop, rangeland, and forest productivity may result in reduced income for farmers and agribusiness, increased prices for food and timber, unemployment, reduced tax revenues because of reduced expenditures, foreclosures on bank loans to farmers and businesses, migration, and disaster relief programs.

The Raichur district falls in the arid tract of the Karnataka state and is prone to drought. The normal annual rainfall of the district is 621 mm. The annual number of the rainy days is about 49 days. Nearly 67 % of the rain is received during the southwest monsoon period (June-Sept) and the northeast monsoon contributes about 24 %. The Raichur district has about 303,410 hectares of cultivable area and is one of an agrarian based economy. Majority of the people here are farmers and rely on year round produce to sustain their families. The impact of drought in this region is mostly seen in massive crop failure which also sometimes results in farmer's suicide due to fear and anxiety in failure in loan reimbursement. Others are also mostly forced to sell their cattle and farm equipment and migrate to other cities in search of jobs.

Owing to the difficulties in objectively identifying the onset and end of a drought, and in quantifying drought severity in terms of its duration, magnitude and spatial extent, drought indicators may prove to be the most essential element for drought analysis and monitoring since they enable identification and quantification of drought [11]. The RDI for drought monitoring in the Raichur district and to support real-time decision making is represented graphically in [Fig-2].

Fig-2 Standardized RDI values from 1914-2014 (1-100)for assessing drought in the Raichur district and support real-time decision making

The drought of the Raichur district monitored via the RDI reveals the dryness of the district and indicating about 47% of the time as drought; an indication that the district suffers from drought in fairly most of the years. The RDI could record most of the reported drought events in the district. Notable amongst them are the reported drought events in 1918-21, 1939-43, 1970-73, 1983-87 [28]; drought events between the periods 2001 and 2004 and between 2012 and 2014. The RDI could also record the flood event of 2009. Succinctly, this is an indication that the RDI is an effective tool in monitoring and assessment of natural disasters in Raichur district and can efficiently provide information to support decision making. The longest duration of a drought event as per the RDI in this study occurred between 1922 and 1930; spanning an annual drought of 7 years. This being the longest in the 100 year time period. Drought recorded between 2011 and 2013 happens to be the extreme events in the 100 year time period, evidently positing of climate change with time and thus extreme degree of hotness experienced between these periods. Temperature being an input data in the estimation of RDI cements the choice of RDI as an effective meteorological drought tool in a global warming-induced climate change setting.

Predicting occurrence of drought in the Raichur district

Since drought is very much linked with the performance of the monsoon, it can be predicted by monitoring rainfall over the target region and taking into account previous rainfall history of the monsoon seasons [28]. As said earlier, the monsoon season of the district falls within June-September and supports crops grown in the Rabbi and Kharif seasons. Water shortage in this sense would result in crop failure and subsequently low crop productivity. Based on the analysis the RDI indicates mild drought 24% of the time, moderate drought 8% of the time, severe drought 3% of the time, and extreme drought 3% of the time. Because the estimated RDI is standardized, these percentages are expected from a normal distribution of the RDI. For instance the 3% of RDI values within the extreme drought category is a percentage that is typically expected for an extreme event.

The magnitude, intensity and probability of occurrence of drought in the Raichur district are shown in [Table-1].

Table-1 *Categorisation, magnitude, intensity and probability of drought occurrence in Raichur District*

RDI	Category	Number of times in 100 years	Probability of occurrence	Magnitude	Intensity
-0.5 to -1.0	Mild dryness	24	1 in 4 years	12.8	0.5
-1.0 to -1.5	Moderate dryness	8	1 in 12 years	9.5	1.2
-1.5 to -2.0	Severe dryness	3	1 in 33 years	4.9	1.6
< -2.0	Extreme dryness	4	1 in 33 years	9.2	3.1

The analysed data over 100-year time series reveal the possibility of mild drought occurring once 4 years, moderate drought once in 12 years, severe drought and extreme drought each once in 33 years. The magnitude and severity of probability of occurrence are presented in [Table-1] above. It shows extreme drought would have the most devastating effect, followed by severe drought, moderate and mild in that order. It should be noted that, the results do not depict the number of drought occurrences in a particular year; but analysis of annual precipitation deviating from normal distribution over the time. This means that in a particular year recorded as drought year, there could be more than one drought events occurring. This, however, should not imply that any slight deviation of precipitation from the normal should result in the entire year being declared a drought year. In either ways, the results straddle policy-makers and stakeholders on decision to put in drought mitigating measures.

Conclusion

The Reconnaissance Drought Index has proven to be an effective tool to analyse the risk and vulnerability of a system to a drought. Considering the climate of Raichur district, it is also an effective early warning tool to develop monitoring and early warning systems based on real-time information to support decision making.

Conflict of Interest: None declared

References

[1] Stafford-Smith D. M. and McKeon G.M. (1998) *Agric. Syst*., 57(3), 271-299.
[2] Botterill L.C. and Hayes M.J. (2012) *Nat. Hazards,* 64(1), 139-151.
[3] Havens A. V. (1954) *Weather wise*, 7, 51-55.
[4] Redmond K.T. (2002) *Bulletin of the American Meteorological Society*, 83, 1143-1147.
[5] Shiferaw B., Tesfaye K., Kassie M., Abate T., Prasanna B. M. and Menkir A. (2014) *Weather and Climate Extremes* 3, 67-79.
[6] Zimmerman F.J. and Carter M.R. (2003) *J. Dev. Econ.,* 71, 233-260.
[7] Holden S. T. and Shiferaw B. (2004) *Agric. Econ.,* 30, 31-49.
[8] Howden M., Schroeter S., Crimp S. and Hanigan I. (2014) *Weather and Climate Extremes,* 3, 80-89.
[9] Song L.C, Deng Z. Y. and Dong A. X. (2003) Drought. China Meteorological Press, Beijing. p. 22.
[10] Han P., Wang P.X., Zhang S. Y. and Zhu D. H. (2010) *Mathematical and Computer Modelling,* 51, 1398-1403.
[11] Vicente-Serrano S. M., Beguería S., Gimeno L., Eklundh L., Giuliani G., Weston D., El Kenawy A., López-Moreno J. I., Nieto R. and Ayenew T., Konte D., Ardö J. and Pegram G.G.S. (2012) *Applied Geography,* 34, 471-486.
[12] Quiring S. M. and Papa kryiakou T. N. (2003) *Agricultural and Forest Meteorology*, 118, 49-62.
[13] Nelson R.A., Hammer G.L., Holzworth D. P. and Hayman P. (2002) *Agric.Syst*., 74,393-414.
[14] Heim R. R. (2002) *Bulletin of the American Meteorological Society,* 83, 1149-1165.
[15] Keyantash J. and Dracup J. (2002) *Bulletin of the American Meteorological Society*, 83, 1167-1180.
[16] Mishra A. K. and Singh V. P. (2010) *Journal of Hydrology*, 391, 202-216.
[17] Sivakumar M.V.K., Motha R.P., Wilhite D.A. and Wood D.A. (2010) Agricultural drought indices. In Proceedings of an expert meeting, 2-4 June 2010, Murcia,Spain (pp. 219). Geneva: World Meteorological Organization.
[18] Vasiliades L., Loukas A. and Liberis N. (2011) *Water Resour. Manage*., 25, 1087-1101.
[19] McKee T.B., Doesken N.J. and Kleist J. (1993) *Amer. Meteor. Soc*., 179-184.
[20] Palmer W.C. (1965) Meteorological drought. U.S. Department of Commerce Weather Bureau Research Paper 45, 58 pp.
[21] Carnicer J., Coll M., Ninyerola M., Pons X., Sánchez G. and Peñuelas J. (2011) Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. Proceedings of the National Academy of Sciences of the United States of America, 108, 1474-1478.
[22] Jamshidi H., Khalili D., Zadeh M.R. and Hosseinipour E.Z. (2011) Assessment and comparison of SPI and RDI meteorological drought indices in selected synoptic stations of Iran. In Reston, VA: ASCE copyright Proceedings of the 2011 World Environmental and Water Resources Congress; May 22. 26, 2011, Palm Springs, California. American Society of Civil Engineers.
[23] IPCC (2007) Climate Change 2007: Synthesis Report.Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Core Writing Team, Pachauri R K, Reisinger A, eds.). IPCC, Geneva, Switzerland. p. 104.
[24] Nagarajan R. (2003) Drought: Assessment, Monitoring, Management and Resource Conservation, Capital Publishing Company, New Delhi, p. 312.
[25] Tsakiris G. and Vangelis H. (2005) *European Water*, 9(10), 3-11.
[26] Abramowitz M. and Stegun A. (1965) Handbook of mathematical formulas, graphs, and mathematical tables, Dover Publications IncNew York.
[27] Tsakiris G., Pangalou D. and Vangelis H. (2007) *Water Resources Management,* 21, 821-833.
[28] Thom H.C.S. (1958) *Monthly Weather Review,* 86(4), 117 -122.
[29] Gupta A. K., Tyagi P. and Sehgal V. K. (2011) *Current Science*, 100(12), 795-806.