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Assessment of Drought Using Standardized Precipitation Index and Reconnaissance Drought Index and Forecasting by Artificial Neural Network

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Abstract: ***Drought is normal recurring feature of climate occurring due to less than average rainfall at a place during a given period of time, which consequently leads to short term water deficit and economic loss. In this study, the known index for drought assessment based on only precipitation data is Standardized Precipitation Index (SPI) and new index based on precipitation as well as potential evapotranspiration data Reconnaissance Drought Index (RDI) were applied for meteorological drought analysis at Banaskantha District. Long term monthly precipitation and potential evapotranspiration data from 1962 to 2001 were used. Analysis were performed on 3, 4, 5, 6, 9, and 12 month long data sets for both indices SPI and RDI. For finding out the indices "DrinC" software is used. From the result, the worst drought years were 1973-74, 1986-87. The SPI and RDI drought classifications were forecasted by Artificial Neural Network (ANN). The models were tested and checked using the Root Mean Square Error (RMSE), Coefficient correlation (r) and coefficient of determination (R^2). According to SPI and RDI model analysis, it can be concluded that, for Banaskantha District, it is better to use SPI9 and RDI9 for forecasting compare to SPI6,SPI12, RDI6 and RDI 12models. The value of SPI9 and RDI9 for forecasting of drought as it gives least error and maximum value. R^2 is 0.99 for training and 0.95 for checking of SPI9. And R^2 is 0.98 for training and 0.99 for checking of RDI9. It is recommended to use LM algorithm with Feed Forward Back Propagation Network.***

Keywords: Drought assessment, SPI index, RDI index, Drought Forecasting, Artificial Neural Network (ANN)

1. Introduction

Drought is a natural dynamic phenomenon that can inflict damages of disastrous proportions, which includes among other effects, the reduction of crop production and distressing the general population over the lack of water. Droughts occur in almost all climatic regions of the world with varying frequency, severity and duration but their impacts are aggravated in countries with limited water supply. Drought is an unexpected reduction in precipitation over period of time in an area which is not necessarily arid. Characterizing periods of deficit and drought has been an important aspect of planning and management of water resources systems for many decades. Drought is one of the most harmful natural disasters that affected the human population.

Drought

Drought is a protracted period of deficient precipitation resulting in extensive damage to crops, further resulting in loss of yield.

Operational Definition

An operational definition of drought help define the onset, severity and end of droughts. To determine the beginning of drought, operational definitions specify the degree of departure from the average of precipitation or some other climatic variables over some time period. This is done by comparing the current situation to the historical average, often based on a 30-years period of record. Following categories of drought are usually considered:

Hydrological Drought

Hydrological drought is associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale.

Meteorological Drought

Meteorological drought is usually defined on the basis of the degree of dryness and duration of dry period. Definitions of meteorological drought must be considered as specific to a region since the atmospheric condition that result in deficiencies of precipitation are highly variable from region to region.

Agricultural Drought

Agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortage, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.

Socio economic Drought

This condition is when some supply of some goods and services such as energy, food and drinking water are reduced or threatened by changes in meteorological and hydrological conditions.

An objective of assessment of drought conditions in a particular region is to plan the water resources in order to prevent and mitigate the occurrence of the drought in further years. In this paper, SPI and RDI are used for assessment of drought.

2. Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) developed by McKee et al (1993) was used in this study to quantify the precipitation deficit for multiple time scales reflecting the impact of precipitation deficiency on the availability of various water supplies. Technically, SPI is the number of standard deviations that the observed value would deviate from the long-term mean for a normally distributed random variable. Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution (Rouault and Richard 2003). SPI is calculated based on long-term precipitation record at the desired station and fitted to gamma distribution which is then transformed into a normal distribution so that the mean SPI is zero. The time series of the SPI can be used for drought monitoring by setting application-specific thresholds of the SPI for defining drought beginning and ending times. Accumulated values of the SPI can be used to analyze drought severity. The SPI is usually calculated for monthly periods. The meteorological station(s) to be analyzed should be chosen to be representative of the area being assessed for drought risk. The quality of the monthly data should be checked for reliability and suitability prior to its use for an SPI analysis. Long records are desirable because SPI is a statistical approach and long records provide more reliable statistics.

3. Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris and Vangelis 2005; Tsakiris et al. 2007c). It is based both on cumulative precipitation (P) and potential evapotranspiration (PET), which are one measured (P) and one calculated (PET) determinant. The initial value (α_k) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$a_k^{(i)} = \sum_{j=1}^{k} Pij / \sum_{j=1}^{k} PETij, i = 1(1)N \qquad (1)$$

in which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j-th month of the i-th year and N is the total number of years of the available data.

The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas 2008; Tsakiris et al. 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of RDIst:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma} y} \qquad (2)$$

in which $y^{(i)}$ is the $\ln(a_k{}^{(i)})$, $\bar{y}$ is its arithmetic mean and $\hat{\sigma} y$ is its standard deviation.

In case the gamma distribution is applied, the RDIst can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tsakiris et al. 2008; Tigkas 2008). For short reference periods (e.g. monthly or 3-months) which may include zero values for the cumulative precipitation of the period, the RDIst can be calculated based on a composite cumulative distribution function including the probability of zero precipitation and the gamma cumulative probability. Positive values of RDIst indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area.

Table 1: Drought classification based on SPI and RDI values

SPI and RDI Values	Class
>2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
<-2	Extremely dry

4. Artificial Neural Network (ANN)

Artificial Neural Network is computational model based on the structure and function of biological neural networks. Information that flows through the network affects the structure of ANN because a neural network changes-or learns, in a sense-based on that input and output.

The ANN models used in this study have a feed
Forward back propagation architecture which was trained with the Levenberg-Marquardt (LM) back propagation algorithm. have often been used in hydrologic forecasting due to their simplicity. FFBs consist of an input layer, one or more hidden layers, and an output layer.

5. Study Area and Data Collection

Banaskantha is one among the thirty-three districts of the Gujarat state of India. The district is located in the Northeast of Gujarat and is presumably named after the West Banas River which runs through the valley between Mount Abu and Aravalli Range, flowing to the plains of Gujarat in this region and towards the Rann of Kutch

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5.1 Geography: Banaskantha District

Banaskantha District is located at 23.33° to 24.25°North latitude, 71.03° to 73.02°East longitude. Banaskantha shares its borders with Rajasthan state in the North, Sabarkantha district in East, Kutch district in West and Patan district and Mehsana district in the South.

5.2 Climate

The climate of Banaskantha District is semi-arid with fairly dry and hot summer. Winter is fairly cold and sets in, in the month of November and continues till the middle of February. Summer is hot and dry which commences from mid of February and ends by the month of June. May is the hottest month with mean maximum temperature around 45°C. The average rainfall is 668.27 mm.

6. Methodology

This section describes how the SPI and RDI have been calculated for the Banaskantha District. Different SPI and RDI timescales to be computed 1-month, 3-month, 6-month, 9-month and 12-month. Positive and negative SPI and RDI values indicate wet and dry conditions respectively. A drought event starts when SPI and RDI value reaches -1.0 and ends when SPI and RDI becomes positive again. By the analysis we will get the drought prone years in particular regions. Also from the trend analysis we will get to know the starting and ending period of drought in particular region.

DrinC (Drought Indices Calculator) aims at providing a user-friendly tool for the calculation of several drought indices, the Reconnaissance Drought Index (RDI) and the Stream flow Drought Index (SDI). Also, the widely used Standardized Precipitation Index (SPI) and the Rainfall Deciles can be calculated. DrinC provides a module for the calculation of potential evapo-transpiration (PET). The common characteristic of the selected indices is that they require relatively small number of data for their calculation and the results can be easily interpreted and used in strategic planning and operational applications. For the calculation of the indices in annual basis, data may be either annual or monthly, while for calculations in seasonal basis (monthly, 3-months, 6-months or other time step), monthly data are required. Regarding the monthly data files, the software is able to recognize automatically the position of the data and to ignore other information included in the file.

7. Result and Analysis

7.1 Drought years according to SPI value

According to SPI value the drought severity years of the Banaskantha district has been categories by three classes. i.e., Moderate, severe and extreme drought. In this paper the SPI value is found out at 3, 4, 5, 6, 9 and 12 month.

Table 2 shows analysis of drought, there is extreme drought situation in 1973-74 and 1986-87 which is reflected in analysis of SPI4, SPI5, SPI6, SPI9 and SPI12 but not reflected in SPI3.

For moderate and severe drought condition similar results are obtained. For moderate SPI5, SPI6, SPI9, SPI12. in 1967-68, 1971-72. For severe SPI4, SPI5, SPI6, SPI9 SPI12 in 1968-69.

Here Figure 1, Figure 2 and Figure 3 of SPI6, SPI9 and SPI12 month is shown below. According to graph, there was an extreme drought during 1973-74 and 1986-87in Banaskantha District.

Table 2 : Banaskantha District Drought Year

SPI	*Classification*	*Year*
SPI3	Moderate	1965-66, 1968-69,
	Severe	1986-87
	Extreme	1973-74
SPI4	Moderate	1967-68
	Severe	1968-69
	Extreme	1973-74, 1986-87
SPI5	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
SPI6	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
SPI9	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
SPI12	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87

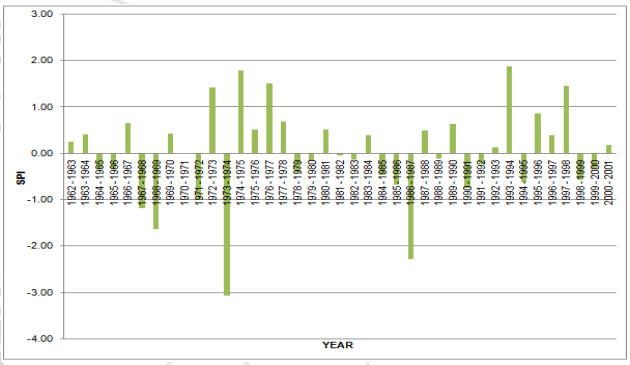

Figure 1: SPI6 for Banaskantha District

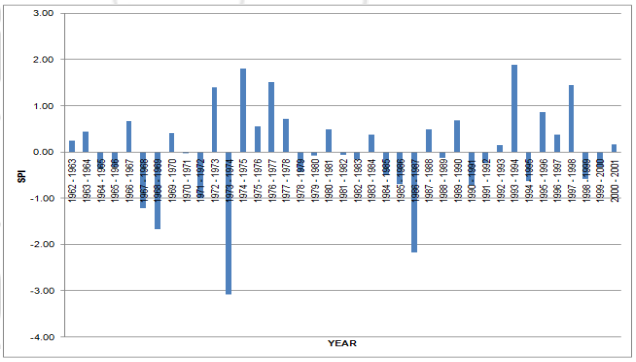

Figure 2: SPI9 for Banaskantha District

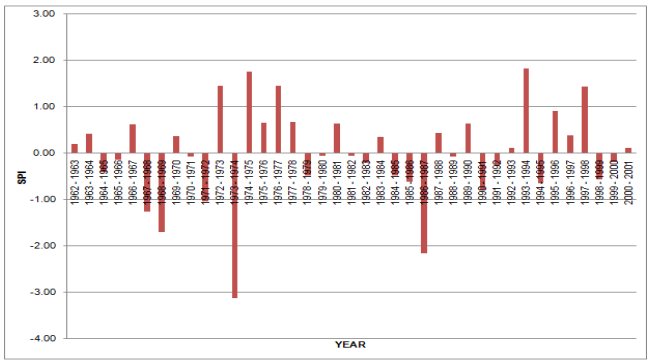

Figure 3: SPI12 for Banaskantha District

Trend analysis

As shown in Figure 4, Figure 5, and Figure 6 there were trend analysis carried for Banaskantha District. The trend line shows increasing rate. From year 1962-63 to 1977-78, the trend line is showing drought period. But after year 1977-78 the trend line shows wet period or no drought condition, may be due to increasing rainfall or other water resources.

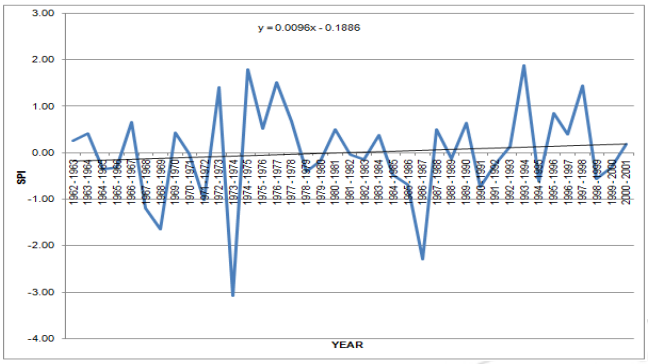

Figure 4: SPI6 for Banaskantha District

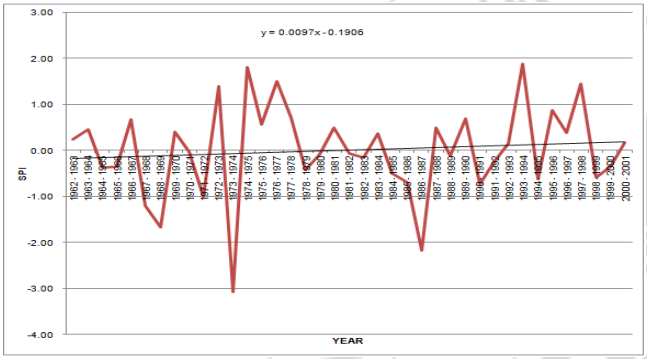

Figure 5: SPI9 for Banaskantha District

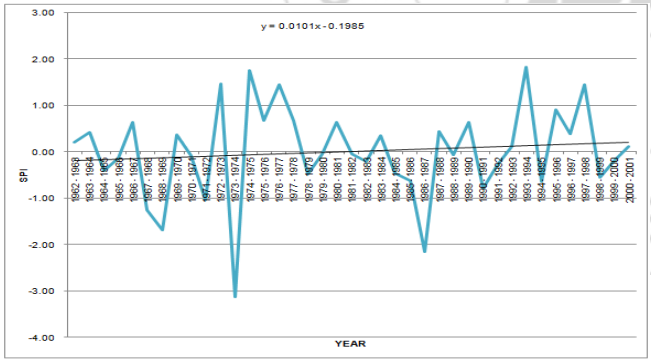

Figure 6: SPI12 for Banaskantha District

7.2 Drought years according to RDI value

Table 3: Banaskantha District Drought Year

RDI	*Classification*	*Year*
RDI3	Moderate	1965-66, 1968-69,
	Severe	1986-87
	Extreme	1973-74
RDI4	Moderate	
	Severe	1968-69
	Extreme	1973-74, 1986-87
RDI5	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
RDI6	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
RDI9	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87
RDI12	Moderate	1967-68, 1971-72
	Severe	1968-69
	Extreme	1973-74, 1986-87

According to RDI value the drought severity years of the Banaskantha district has been categories by three classes. i.e., Moderate, severe and extreme drought. In this paper the SPI value is found out at 3, 4, 5, 6, 9 and 12 month.

As per the analysis of drought shown in Table 3, there is extreme drought situation in 1973-74 and 1986-87 which is reflected in analysis of RDI4, RDI5, RDI6, RDI9, and RDI12 but not reflected in RDI3.

For moderate and severe drought condition similar results are obtained. For moderate RDI5, RDI6, RDI9, RDI12 in 1967-68, 1971- 72. For severe RDI4 RDI5, RDI6, RDI9 RDI12. In 1968-69.

Here Figure 7, Figure 8 and Figure 9 of RDI6, RDI9 and RDI12 month is shown below. According to graph, there was an extreme drought during 1973-74 and 1986-87in Banaskantha District

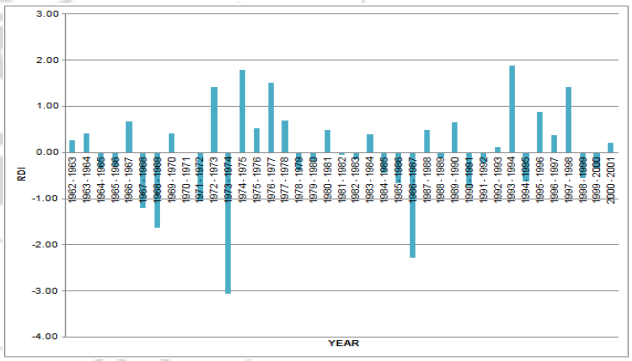

Figure 7: RDI6 for Banaskantha District

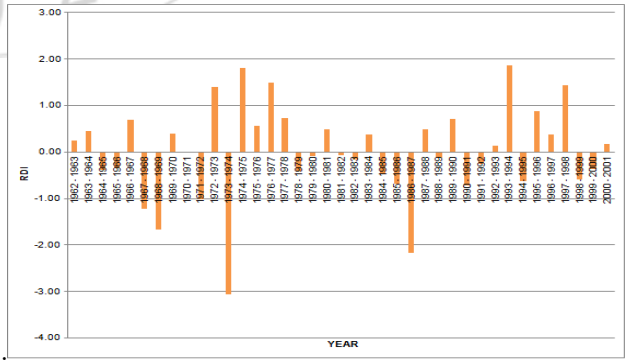

Figure 8: RDI9 for Banaskantha District

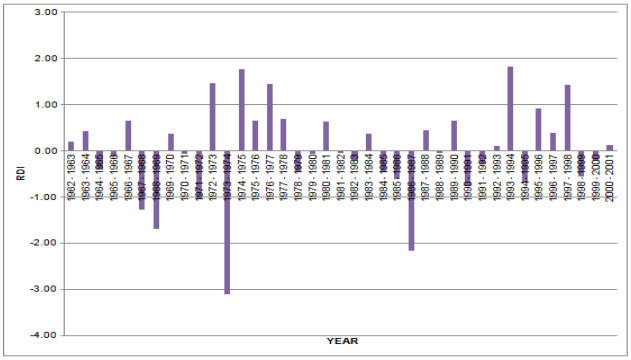

Figure 9: RDI12 for Banaskantha District

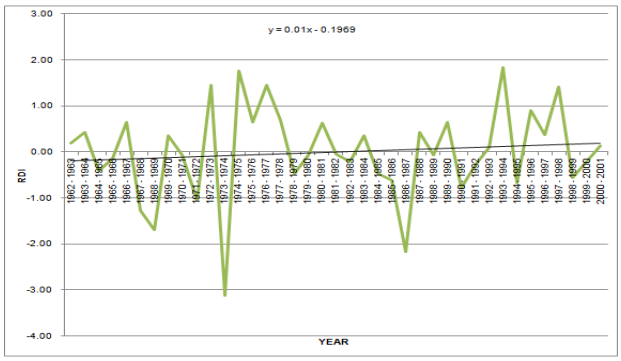

Figure 11: RDI12 for Banaskantha District

Trend analysis

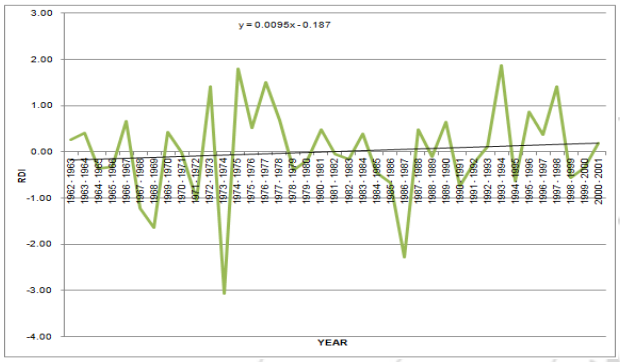

Figure 10: RDI6 for Banaskantha District

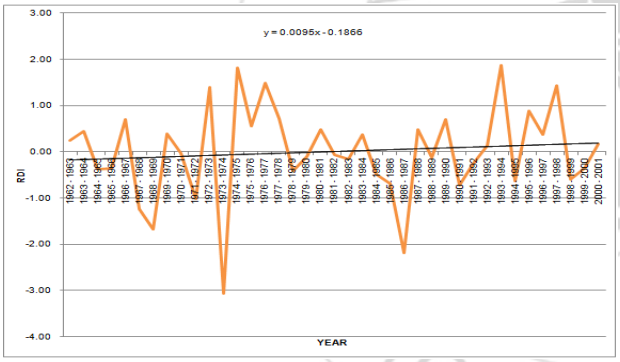

Figure 11: RDI9 for Banaskantha District

As shown in Figure 10, Figure 11, and Figure 12 there were trend analysis carried for Banaskantha District. The trend line shows increasing rate. From year 1962-63 to 1977-78, the trend line is showing drought period. But after year 1977-78 the trend line shows wet period or no drought condition, may be due to increasing rainfall or other water resources.

6.3 Drought forecasting using ANN

For Banaskantha District, Drought forecasting is done by creating different types of models on SPI and RDI. Models are developed using different type of combinations with rainfall, SPI values and rainfall with RDI values. These different type of models SPI6, SPI9, SPI12, RDI6, RDI9 and RDI12 are forecasted by ANN model.

Table 5: Different type of models (using SPI) with RMSE, r, and R^2

MODEL	INPUT	OUTPUT	RMSE		R		R^2	
			Training	Checking	Training	Checking	Training	Checking
M1	SPI3 SPI4 SPI5	SPI6	0.2	0.26	0.99	0.96	0.97	0.93
M2	SPI3 SPI6	SPI9	0.07	0.27	0.99	0.97	0.99	0.95
M3	SPI3 SPI6 P(6)	SPI9	0.09	0.13	0.99	0.99	0.99	0.98
M4	SPI3 SPI6 SPI9	SPI12	0.18	0.09	0.99	0.98	0.97	0.99

8. Conclusion

- This study has tried to assess the drought severity of the Banaskantha District for the year of 1962 to 2001.
- The parameters of SPI and RDI at various time scale is identifying dry/wet periods.
- From the result, there was more extreme drought situation in Banaskantha District in 1973-74 and 1986-87. Therefore, there is need to allocate more water resources.
- It is better to use SPI4, SPI5, SPI6, SPI9 and SPI12 to assess extreme drought condition.
- For moderate drought condition SPI5, SPI6, SPI9 and SPI12 gives similar results. And for severe drought condition SPI4, SPI5, SPI6, SPI9 and SPI12 gives similar results.
- As per trend analysis, drought period was observed from 1962-63 to 1978-79. Severity of drought is decreasing from 1979-80 to 2000-01.
- According to RDI, in Banaskantha District there was extreme drought condition in 1973-74.

Table 6: Different type of models (using RDI) with RMSE, r, and R^2

MODEL	INPUT	OUTPUT	RMSE		R		R^2	
			Training	Checking	Training	Checking	Training	Checking
M1	RDI3 RDI4 RDI5	RDI6	0.20	0.12	0.98	0.99	0.97	0.98
M2	RDI3 RDI6	RDI9	0.13	0.05	0.99	0.99	0.98	0.99
M3	RDI3 RDI6 P(6)	RDI9	0.08	0.47	0.99	0.93	0.99	0.87
M4	RDI3 RDI6 RDI9	RDI12	0.31	0.12	0.98	0.99	0.97	0.98

- There was extreme drought situation in 1973-74 and 1986-87 is reflected from RDI4, RDI5, RDI6, RDI9 and RDI12. So it is better to use these indices.
- For moderate drought condition RDI5, RDI6, RDI9 and RDI12 gives similar results. And for severe drought condition RDI4, RDI5, RDI6, RDI9 and RDI12 gives the similar results.
- As per trend analysis, drought period was observed from 1962-63 to 1978-79. Severity of drought decreasing from 1979-80 to 2000-01.
- According to SPI model analysis, it can be concluded that , for Banaskantha District, it is better to use SPI9 for forecasting compare to SPI6 and SPI12 models. It is recommended to use LM algorithm with Feed Forward Back Propagation Network.
- From analysis, it is recommended to use SPI9 for forecasting of drought as it gives least error and maximum value of R^2 0.99 for training and 0.95 for checking. Observed SPI value is almost same to the forecasted value of SPI9. Therefore it is better to use SPI9 for forecasting of drought for Banaskantha District.
- Same way for RDI, RDI9 forecasting model gives the least error with maximum R^2 values.
- From analysis, it is recommended to use RDI9 for forcasting of drought as it gives least error and maximum value of R^2 0.98 for training and 0.99 for checking. Observed RDI value is almost same to the forecasted value of RDI9. Therefore it is better to use RDI9 for forecasting of drought for Banaskantha District.
- The study reveals that ANN can be successfully used to forecast the drought situation for this study area.

References

[1] Gandhi, F. R. and Parekh F. P. (2015)," Assessment of Drought Using SPI- A case study of Patan District", "VIER jounal of Enginnering Reaserch", April 2015.
[2] Karavitis, C. A. et al.(2011), " Application of the Standardized Precipitation Index (SPI) in Greece", water 2011,3,787-805.
[3] Keskin, M. E. et al. (2011)," Meteorological drought analysis using ANN", "Scientific research" , vol.6(21), 4469-4477.
[4] Kumar, M. N. et al. (2009) ," On the use of Standardized Precipitation Index (SPI) for drought intensity assessment", Meteorological application, 16:381-389.
[5] Solanki, J. K. and Parekh, F.P. (2014), " Drought Assessment and Forecasting : A case study of Dharoi sub basin", in " International Journal of Science Enginnering and Technology" , Special issue(2014), Bhopal.
[6] T.B.Mckee , N.J. Doesken , J. Kleist . The relationship of drought frequency and duration to time scales. 8th Conference on Applied Climatology. 17-22 January 1993.

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