Self-Generating Training Model (SGTM) Algorithm to Estimate Groundwater Level in Consensus with Climate Change Impact Study in Cauvery Delta Zone, Tamil Nadu, India

A. Stanley Raj, J. P. Angelena, R. Damodharan, and D. Senthil Kumar

Abstract Cauvery Delta Zone is present in the eastern part of Tamil Nadu, popularly known as 'rice bowl' of Tamil Nadu. It constitutes of about 11.1% of total area of the state. It lies between 10.00 and 11.30° N latitude and 78.15°–79.45° E longitude. Cauvery Delta Zone includes the districts of Thanjavur, Thiruvarur, Nagapattinam, Mayiladuthurai, Perambalur and some parts of Pudhukottai and Cuddalore Districts. This zone plays a vital role not only in rice production but also in other varieties of crops and raw materials for industries. It receives more than 50% of rainfall in North East monsoon. Variation in rainfall in this zone causes serious environmental effects. Sources of groundwater recharge zones are mostly influenced by rainfall variability. In this research work, the connection between the climate change impact and rainfall variability has been studied and the successive study has been made. The temporal trends of rainfall variability are studied extensively to predict the future scenario using the Self-Generating Training Model (SGTM) algorithm. This work is potentially helpful for farmers to identify the threatening zones and can understand the fluctuations in groundwater level due to implications of climate change.

Keywords Rainfall variability · Climate change impact · Machine learning algorithm · SGTM

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1   Introduction

Tamil Nadu is a state that lies in the Southernmost part of the India. Kerala bounds it on the West and Karnataka and Andhra Pradesh along the North-West and North respectively. Bay of Bengal is present at Eastern part and also the state encircles the Union Territory Puducherry on its East. Kanyakumari, the Southernmost tip of Indian subcontinent, is where Arabian Sea, Bay of Bengal and Indian Ocean meet. The state spreads over 130,058 km^2. It covers for about 4% of the total area of the India [3]. The Western and North-Western part of the state are of hilly in nature. This State comprises of 38 Districts with diversified Geography and Geology. The Coastline of Tamil Nadu is the Third longest in India. There are 13 districts along the East coast of the state which extends up to 1076 km. It possesses 16 non major, 3 major ports and many coastal industries like nuclear and thermal power plants, refineries etc., 8 districts are present over the Eastern slope of Western Ghats.

The impact of various natural hazards with differing intensities on Tamil Nadu is more than that of the other states in India [21]. The phenomenal occurrence of the historical cyclonic storms in Tamil Nadu shows its necessity to study the impact of climate change over the state. The studies show that an average of two cyclonic storm has occurred in a decade. In November 2000, a severe cyclone crossed at the coast of cuddalore district with wind speed of 110 kmph [12, 14] Further Cyclone Nisha has hit in 2008, Cyclone Laila in 2010 and Cyclone Thane hits in 2011, there were worst hit cyclones in the state includes Jal in 2010, Cyclone Nilam and Cyclone Phailin in 2012 and 2013 respectively. The tsunami of the Indian Ocean in 2004 has had a tremendous, long-lasting impact on the state [31]. SGTM algorithm is used to analyse the rainfall variability.

On addition to this, there are several environmental problems occurred due to the impact of various factors in climate change of Tamil Nadu. Rainfall is one of the important climate factors that plays a vital role in socioeconomic and environmental conditions of Tamil Nadu. The profound trends in the environment affecting the natural resources and setup of the Earth is due to the unpredictability nature of rainfall [16]. This state experiences wet subtropical climate and mostly hot temperature throughout the year except in the period of the monsoons. Tamil Nadu possess three different monsoon periods of rainfall. The *south west monsoon* occurs between the month of June and September. The *north east monsoon* occurs from the period of October to December *dry season* extends from January to the end of May. This state has an annual rainfall of 945 mm of which 32% of rainfall is obtained through the South West monsoon and 48% of rainfall through the North East monsoon. Tamil Nadu is the only state in India's Meteorological sub division that receives less rainfall in South West Monsoon than that of North East Monsoon. Tamil Nadu being an agricultural state, is mostly depends on monsoonal rains, which shows internal variability and also variations due to external factors such as the El Nino-Southern Oscillation, so monsoon failures result as water scarcity and drought. Moreover, climate factors like rainfall variability have also had an impact on the climate change over past year.

El Nino and La Nina are associated together with the oscillation of atmospheric pressure throughout the southern Pacific Ocean, which is termed as Southern Oscillation [1]. This shows the contrast between the warm phase and Southern Oscillation (SO), which is known as El Nino—Southern Oscillation (ENSO) cycle. Both the El Nino and La Nina which are the extreme events of El Nino-Southern Oscillation (ENSO). ENSO have been in association with the rainfall and temperature anamolies globally [10] It is an important climate process associated with climate variability regionally throughout the world [9, 28]. The El Nino and Southern Oscillation are allied with each other whenever an El Nino process headed in the Pacific Ocean. An ENSO event is a cyclical event, which occurs every 2–7 years and can last for up to eighteen months. The frequency and intensity of ENSO has been variable, this ENSO variability leads us to have concern about the possibility of impact of climate change over Pacific Ocean which creates impact to the global climate change [11].

McBride et al. [20] and Rotstayn et al. [29] have studied and reported the influence of El Niño-Southern Oscillation (ENSO) effects in both the Eastern and Western part of the Pacific Ocean. Pramanik and Jagannathan, Parthasarathy, Parthasarathy et al. [22–24] studied the long term trends of Indian monsoon rainfall for Indian subcontinent. Rao and Jagannathan [27], Thapliyal and Kulshrestha [34] and Srivatsava et al. [33]. Southwest monsoon and annual rainfall throughout the country has no particular significant trend which was studied by and Thapliyal and Kulshrestha [34], Jagannathan and Bhalme [13] and Srivatsava et al. [33]. Jagannathan and Bhalme [13], and Singh and Sontakke [32] reported the long term rainfall trend over smaller scale in space. The fore mentioned a study evidences the variability of Monsoonal rainfall throughout the country.

The anomalies of both temperature and rainfall are connected to ENSO [6, 15] over several parts of the world and also in India. In the Indian Ocean and the Equatorial Pacific Ocean, the sea surface temperature anomalies has been inter linked to the variability of Indian Summer Monsoon Rainfall which was reported by [5]. The relationship between the Indian Summer Monsoon Rainfall and the El Nino shows the inverse relationship as the result of analysis of long term data. The relation between ENSO and global rainfall [4] which has been investigated in previous studies most part of India has less rainfall during El Nino and more rainfall during La Nina. Even though there is no direct relationship between years of El Nino and Droughts in Indian union, there were many severe remarkable droughts occurred with the association of El Nino in the country [26]. The remarked influence of the ENSO events over the rainfall with inverse relationship for North East Monsoon particularly in Tamil Nadu which was highly variable from rest of the India had studied by [16].

2 Cauvery Delta Regions

The Cauvery river with its tributaries are situated in the Sothern peninsular of India. This river is a major water source for the domestic, irrigational and industrial needs of two states i.e. Karnataka and Tamil Nadu. The drainage of the river is almost

$90,000 \text{ km}^2$. It starts from Coorg (Karnataka) which is situated in the Western Ghats, which flows through North-Western and Central parts of Tamil Nadu and empties in the Bay of Bengal. Vennaru, Kudamuruti, Paminiar, Arasalar and Kollidam are the major rivers in its watershed. The important contributories in Tamil Nadu include Noyyal, Bhavani and Amaravathi rivers. Grand Anicut, Bhavanisagar and Mettur Dams are the major dams functioning in this river. The Cauvery basin in Tamil Nadu has an average annual rainfall of 956 mm and over 4.4 million people are working in the agricultural fields over this area. The upper catchment area receives more rainfall in South West Monsoon and the delta regions of Cauvey River receive more rainfall during North East Monsoon. The river before emptying into the Bay of Bengal, divides as 36 distributaries which results as the wide deltaic formation (Fig. 1).

Cauvery Delta Zone is present in the eastern part of Tamil Nadu, which is popularly known as 'rice bowl' of Tamil Nadu. It constitutes of about 11.1% of total area of the state. It lies between 10.00–11.30° N latitude and 78.15°–79.45° E longitude. Cauvery Delta Zone includes the districts of Thanjavur, Thiruvarur, Nagapattinam,
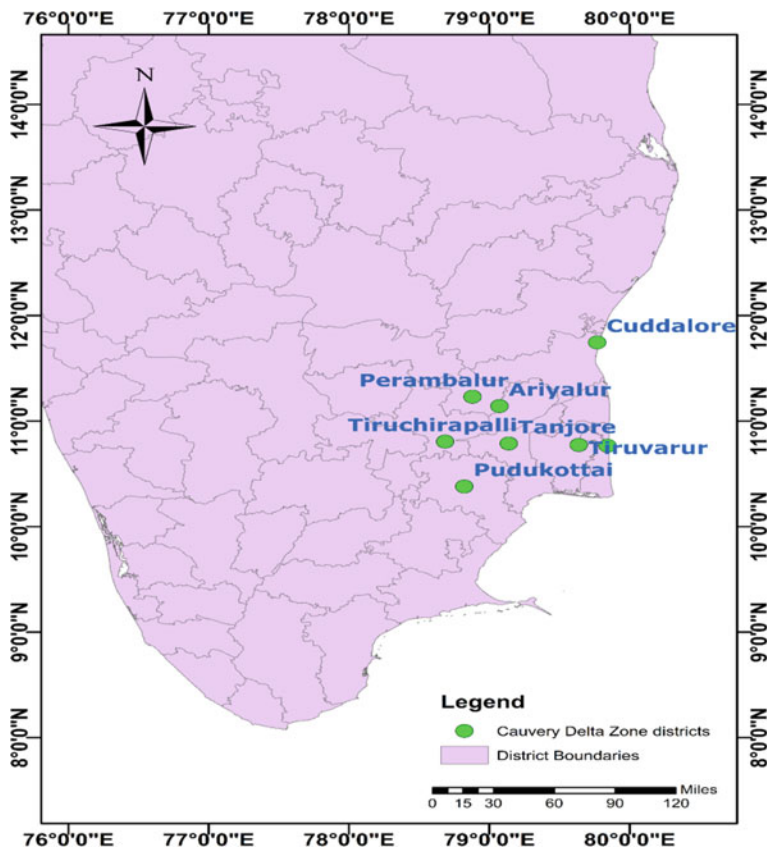

Fig. 1 Shows the Cauvery delta regions in Tamil Nadu

Mayiladuthurai, Perambalur and some parts of Pudhukottai and Cuddalore Districts (Fig. 1). This zone plays a vital role not only in rice production and other varieties of crops and raw materials for industries. It receives more than 50% of rainfall in North East Monsoon. Variation in rainfall in this zone causes environmental severe effects.

3 Impact of ENSO on Tamil Nadu

In Tamil Nadu, the role of rainfall during October to December is vital in nature. This is because their increased activity in North East Monsoon over the state. So, It is crucial to study the link between North East Monsoon Rainfall (NEMR) of the state and global telecommunication indicators.

Influence of ENSO over South West Monsoon rainfall is lower than that of in North East Monsoon Rainfall of the state (Goutham 2019). Larger variation with respect to the location and the year has been exhibited by North East Monsoon. Bhatnagar [2] indicated that several climate factors such as El Nino-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are the reason for the difference in amount and distribution of North East Monsoon Rainfall. But their limited number of studies carried out on the influence of IOD and ENSO over NEMR [17, 19].

Most of the country receives less rainfall during El Nino years and more rainfall during La Nina years. This is in contrast with the Southernmost state Tamil Nadu which follows an opposite trend to that. A positive correlation of both El Nino and La Nina years with the South West Monsoon Rainfall had been observed by Goutham (2019). The inter relationship of Nino-3 sea-surface temperature and SOI with the Tamil Nadu's North East Monsoon Rainfall have shown the result that SOI has been negatively correlated with the NEMR of the state [8]. The Nino-3 SST has positive correlation [7], which shows that the precipitation in autumn–winter season has effected by global climate signals.

Kumar et al. [19] reported that the relationship of North East Monsoon Rainfall with ENSO is gaining its strength. Even though the less summer monsoon rainfall has been observed in ENSO years, in last decade, it has been recorded that the summer monsoon rainfall was above normal, when the two ENSO events occurred [18]. So the detailed investigation has to be done, to explore the long term relationship of ENSO with the local and regional variability of Rainfall over Tamil Nadu. The variable nature of rainfall in Cauvery Delta Zone have been reported by [30]. The varying trends of rainfall pattern, temperature and other climate parameter in this region has been reported by [25].

3.1 Nagapatinam

Nagapattinam district covered 5 taluks, 434 villages, 8 town panchayats, 4 munici-palities, 31 firkas and 523 revenue villages. The district is channelled by Kollidam

Table 1 Shows the statistical variations of rainfall in Nagapattinam during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	136.8633	167.4686	2.068794	1.635995	0.2	531.4
2011	169.9558	81.26093	1.582689	0.894336	67.66	358.98
2012	126.8825	89.44489	−1.58198	0.01646	14.6	262.17
2013	83.55417	85.16287	0.287902	1.148475	0.39	263.41
2014	110.2825	138.3214	1.051412	1.448417	0	410.02
2015	142.5508	236.7422	3.835941	2.151878	0	750.46
2016	54.51833	57.27833	0.476448	1.04025	0	176.79
2017	92.64917	129.1121	8.016623	2.666687	0	473.35
2018	80.07667	128.1614	4.877189	2.296603	1.31	425.29
2019	115.8975	148.0234	−1.11032	0.863992	0.2	347.28

and Cauvery River. Crystallic metamorphic and sedimentary formations underline it. Wide variety of topographical formulations constitutes the primary factor of rainfall and groundwater recharge. The groundwaters in fractured zones are extended to the maximum of 30 m and average of 10–15. Hard rock formations like Granitic Gneiss, Charnockite makes the water table conditions more stable in the district (Table 1).

3.2 Tiruvarur

Tiruvarur district receives from northwest and south west monsoon season. Average rainfall in the district ranges from 1100 to 1260 mm. The district is covered with semi consolidated formation with lower Miocene and Pliocene quaternary shallow aquifer system. Tiruvarur has 10 blocks with 2097.97 km^2 geographical area. It receives the average annual rainfall of 1184 mm. Based on the geological formation the water table depth ranging from 4.36 to 23 m. Canals contributed more in the irrigation of the district (Table 2).

3.3 Tanjavur

Tanjuvur has 14 blocks, 589 villages covered with three river basins: Vennar sub basin, Cauvery sub-basin and new delta area. The major rock types are sedimentary and hard rock with geological formations of sandstone, Laterite, Clay, Alluvium, Gneiss and Quartzite. The district receives the average of 1013 mm rainfall. The depth of aquifer is 1–8 m. The groundwater level in the district during the premonsoon and postmonsoon are 13.6 and 19.9 m in average respectively. There are 5 firkas in critical groundwater condition and more than 24 firkas are over exploited (Table 3).

Table 2 Shows the statistical variations of rainfall in Tiruvarur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	152.1675	176.5941	1.87677	1.544164	0.15	562.74
2011	173.4	81.58333	1.58726	0.911664	72.17	363.29
2012	129.1008	90.94857	−1.57858	0.024433	15.03	264.46
2013	78.95417	65.43641	−1.411	0.561834	2.19	177.23
2014	105.535	126.5206	0.460028	1.2393	0	361.07
2015	139.1475	187.5237	2.149698	1.767224	0	574.5
2016	54.375	58.40456	1.146308	1.211848	0	187.24
2017	85.62	197.9184	7.047761	2.451454	0	396.69
2018	85.5472	146.3247	7.52335	2.072672	0.54	512.12
2019	105.6483	127.148	−1.4851	0.667417	0	306

Table 3 Shows the statistical variations of rainfall in Tanjavur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	135.1917	147.8096	1.894151	1.433675	0.02	490.29
2011	178.48	87.2477	1.614567	0.995428	70.04	312.07
2012	132.9183	96.26128	−1.59522	0.049755	13.93	264.94
2013	69.95833	56.62338	−1.52257	0.42082	2.71	151.64
2014	90.77167	101.4174	−0.32397	0.940799	0	219.6
2015	110.205	124.0989	2.070899	1.623882	0	402.85
2016	53.4175	46.84705	−0.33928	0.38994	0	145.03
2017	50.38917	58.66345	3.249278	1.795775	0	200.15
2018	63.0075	99.04784	6.117469	2.491226	0.06	341.06
2019	92.5225	107.4919	−1.69396	0.573016	0.06	257.29

3.4 Trichirapalli

Tiruchirapalli district has 14 blocks, 404 villages lie in the central part of the state. Major geological formations are Charnockite, Gneiss, Quartzite, Pegmatite, Sandstone, Shale, Limestone and Alluvium. The district receives 818 mm of average rainfall. The depth of water level is 3 m to 15 m with a premonsoon average of 12.8 and an average postmonsoon of 16 m. There are 13 firkas which are over exploited and 7 and 5 firkas are critical and semicritical respectively. Table 4.

3.4.1 Cuddalore

Cuddalore district is covered with Villupuram in north and northwest, Perambalur in southwest, Ariyalur and Nagapatinam in south, and Bay of Bengal in east. It consists

Table 4 Shows the statistical variations of rainfall in Nagapatinam during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2011	165.085	105.9779	0.473363	0.946385	38.68	395.54
2012	126.1467	103.9506	−1.47034	0.239112	7.21	297.02
2013	51.205	52.0238	−1.45266	0.696473	1.35	129.34
2014	57.78917	62.57243	0.32973	1.012532	0.05	193.13
2015	78.47917	74.60123	1.486493	1.15741	0.97	253.06
2016	45.44667	48.15813	−0.37168	0.875956	0	140.46
2017	30.5825	28.37592	−0.13631	0.837402	0.05	88.92
2018	34.89917	43.17087	0.873997	1.362805	0.34	131.94
2019	61.95333	71.94282	−0.45681	0.962276	0.02	196.65

Table 5 Shows the statistical variations of rainfall in Cuddalore during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	105.0477778	179.3798	6.970174	2.574342	0	563.56
2011	92.0075	110.6719	3.81935	1.94005	21.45	235.75
2012	104.85	72.20781	1.03996	0.10431	4.38	217.66
2013	84.8125	91.61312	0.382528	1.187928	0	262.45
2014	110.568333	118.1069	0.593376	1.049303	0	372.32
2015	155.2516667	230.7571	4.655382	2.245427	0	771.66
2016	46.78833333	41.45805	−1.3031	0.261377	0	110.91
2017	90.3125	110.0262	2.272451	1.514823	1.66	248.09
2018	66.68166667	95.68196	2.202898	1.745997	0	295.44

of 13 blocks and 683 villages. Major geological formations are sandstone, Conglomerate, Gneiss, Charnockite, marine deposits and Alluvium. The district receives 1206.7 mm of rainfall. Average groundwater level of the district in premonsoon and post monsoon ranges from 23 m and 20.3 m respectively. There are 6 firkas with over exploited, 2 in critical and 7 firkas in semi critical condition (Table 5).

3.5 Ariyalur

Ariyalur has 6 blocks and 201 villages. The district is covered with parts of Vellalar and Cauvery river basin. The district receives an average of 107.8 mm of rainfall. The average groundwater level in the pre monsoon and post monsoon for the past five years were 23.2 and 28 m respectively. There are two sectors in semi critical condition (Table 6).

Table 6 Shows the statistical variations of rainfall in Ariyalur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	123.7758	155.1392	3.150657	1.828646	0	525.38
2011	169.8067	94.077	0.877471	0.953011	53.51	379.99
2012	128.1167	96.80474	−1.58455	0.083045	10.26	281.78
2013	73.61167	79.17487	−0.12333	1.022054	0.5	233.9
2014	94.20833	101.4326	−0.13266	0.857404	0	306.85
2015	117.1875	155.3911	5.693227	2.327941	0	548.65
2016	51.6	53.96355	1.868417	1.293091	0	179.49
2017	58.57833	71.28856	5.182427	2.034845	0	254.12
2018	63.8075	91.92927	2.288062	1.811847	0.01	279.22
2019	100.6367	120.5404	−1.43508	0.667186	0	293.44

3.6 Pudukottai

Pudukottai is located in central region of Tamil Nadu and its boundry extend upto 4,663 km^2 and the population is 145269. The district surrounded with Tanjavur and Tiruchirapalli. There are two municipalities in this district are Pudukottai municipality and Tiruchirapalli in northeast. The district is located in 10.3833° N, 78.8001° E. There are eleven taluks in Pudukottai district (Pudukkottai, Gandarvakottai, Alangudi, Thirumayam, Kulathur, Illupur, Arantangi, Ponamaravathy, Karambakudi, Avudayarkoil and Manalmelkudi). The taluks are further classified to thirteen blocks, eight town panchayats, 757 revenue villages and 498 village panchayats. The district receives highest rainfall of 397 mm during northwest monsoon and it receives 303 mm rainfall in average during southwest monsoon. The summer and winter receive 81 and 40 mm of rainfall respectively. During summer the temperature is very high and low during the winter and average in other months (Table 7).

4 Results and Discussion

4.1 Model Development and Application

SGTM algorithm is framed specifically to predict the rainfall variability if the available data source is very minimal. With less number of data, SGTM can perform well using the multiple level of self generating module. These multiple sets of training levels will enhance the algorithm's performance (Fig. 2).

Table 7 Shows the statistical variations of rainfall in Pudhukottai during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	98.855	100.6635	1.244477	1.204878	0	332.68
2011	182.9508333	88.19446	1.557815	1.027391	73.14	387.92
2012	135.7825	98.6251	−1.58912	0.059832	14.16	283.01
2013	52.70333	39.08259	−0.41933	0.546415	1.94	131.12
2014	66.8175	69.727976	−1.73119	0.442642	010	181.85
2015	85.60667	81.86026	2.080076	1.320527	0.6	285.53
2016	41.46083	34.47911	−1.51901	−0.0833	0	93.81
2017	27.13083	32.89075	4.962191	2.114235	0.13	1116.7
2018	43.20083	52.21239	2.630649	1.781476	0.04	170.1
2019	71.392	86.02486	−0.78714	0.862776	0	133.43

Step 1:

The user can import the data for training the model. The imported data must be of any form, including text files, excel spreadsheets, CSV, etc.

Step 2:

For ANFIS training is more important. Thus based on the number of iterations and random permutations of data, SGTM generates synthetic data. This self-generation of synthetic data will be helpful to evaluate noisy and missed data. Thus this step is a very important step in this algorithm.

Step 3:

This the key step where the neuro fuzzy algorithm generates synthetic dataset for each data with connection to the adjacent data that controls the noises and errors present in data.

Step 4:

In this step the algorithm calculates the error percentage of the data based on the coefficient of variation.

   Step 5:

Every iteration the system generates one synthetic data and a model is generated based on the number of iterations decided by the user. More the number of synthetic data better the performance of the algorithm.

Step 6:

Finally, the developed model is based on variable rate of synthetic data predicted by the neuro fuzzy algorithm.
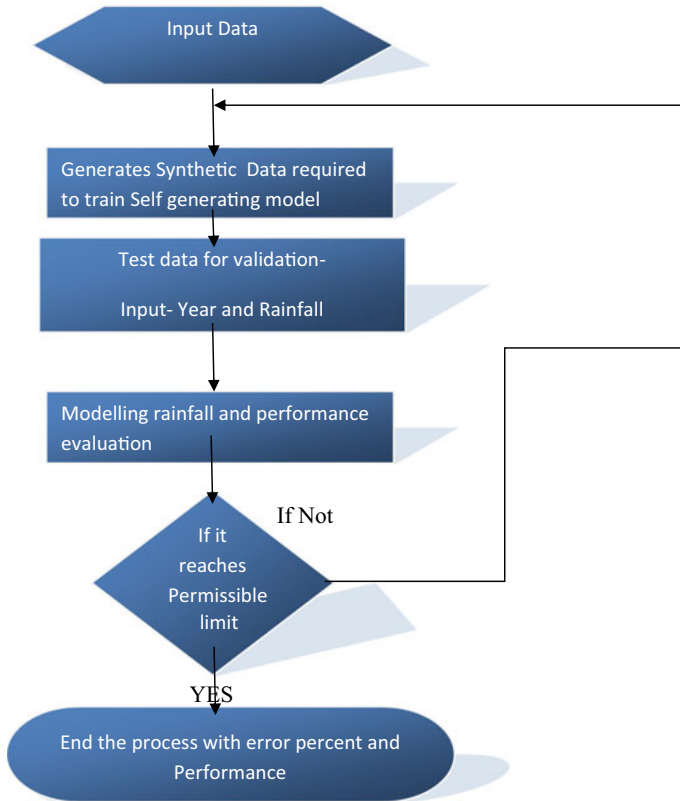
Fig. 2 Flow chart for self generating training model (SGTM) to predict rainfall variability with minimum number of training dataset

5 Algorithm Description and Application

This algorithm works on the basis of self-generating training dataset. In self-generating model, the system considers the mean, standard deviation, upper (Maximum value) and lower (minimum value) bounds. Rainfall data of 2001–2019 are taken into account for analysing the rainfall variability. After considering all the statistical values from the given input data, the algorithm generates the synthetic data using random permutations. Figures 3 and 4 represents the training dataset used for SGTM algorithm for rainfall variations and groundwater level variations in Nagapatinam district respectively. For every iteration, it generates one synthetic data. For getting more number of synthetic data, user has to fix the number of iterations. Figures 5 and 6 represents the tested results of rainfall and groundwater level variations. The consistency may be lost once the user fixes more number of iterations than the memory allocated by the system to train the data. The system became

unstable after a particular number of epochs. Figures 7, 8 and 9 represents the Gaussian membership function, comparative results of rainfall and groundwater results of conventional fuzzy and SGTM algorithm.
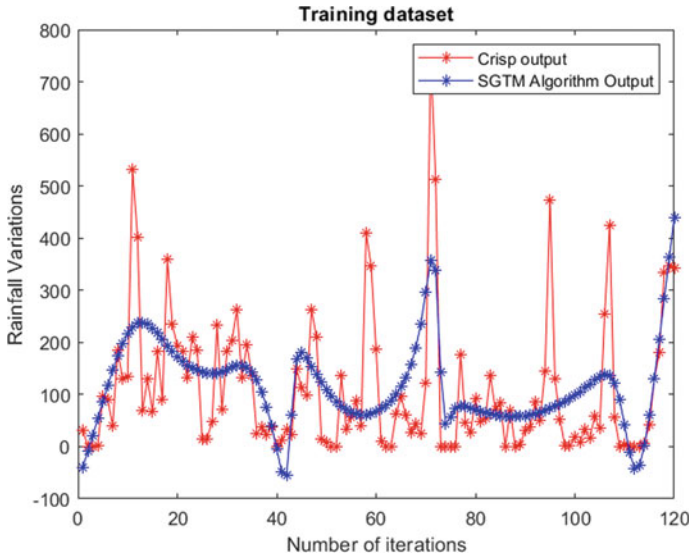
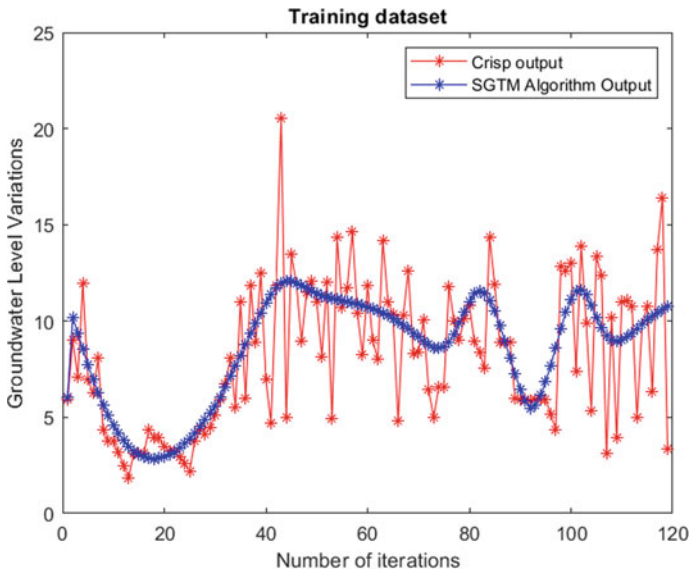**Fig. 3** Training dataset for SGTM for Nagapatinam district rainfall variations

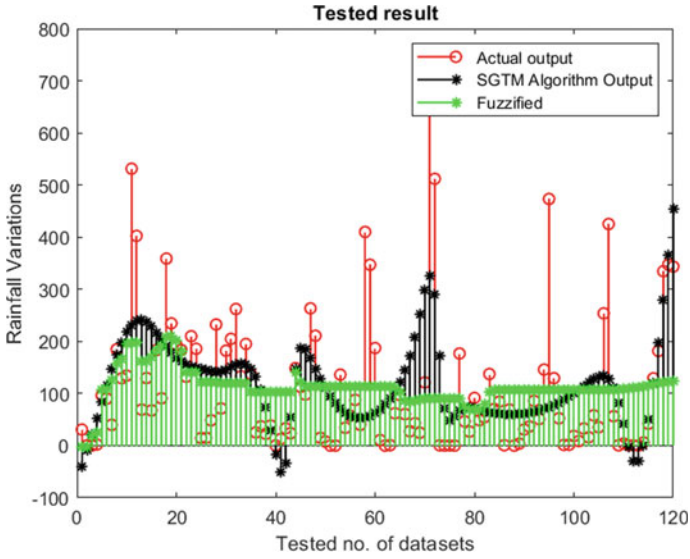**Fig. 4** Groundwater level data used for training SGTM algorithm

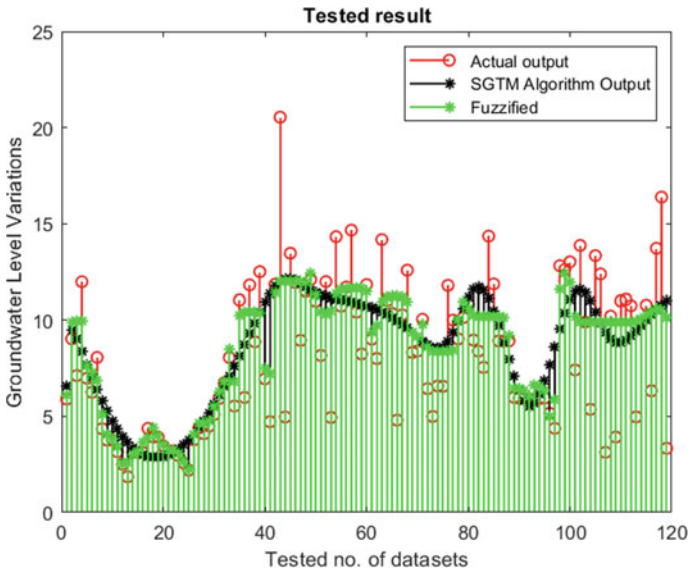**Fig. 5** Testing dataset for SGTM for Nagapatinam district rainfall variations

Fig. 6 Tested result for SGTM for Nagapatinam district groundwater variations
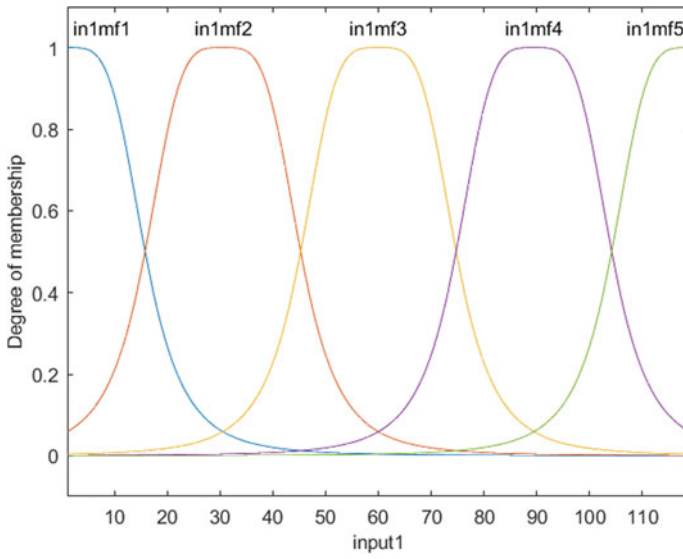
Fig. 7 Gaussian membership function used for SGTM
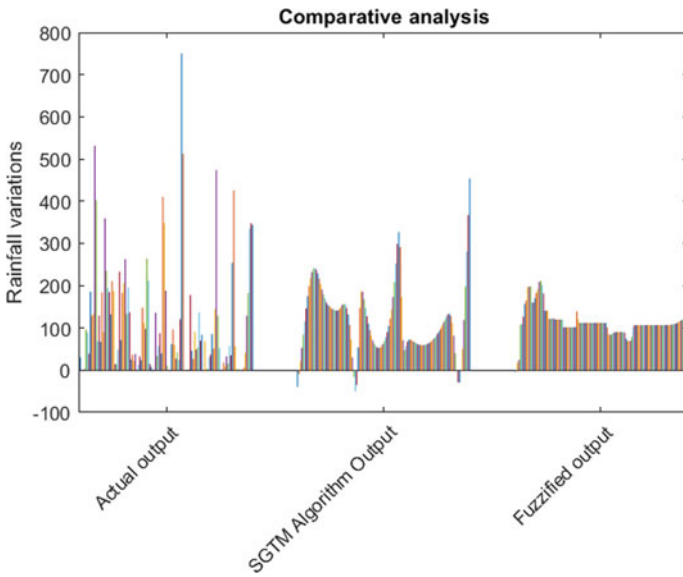
Fig. 8 Comparative results for SGTM and conventional fuzzy interpretation results for rainfall variation
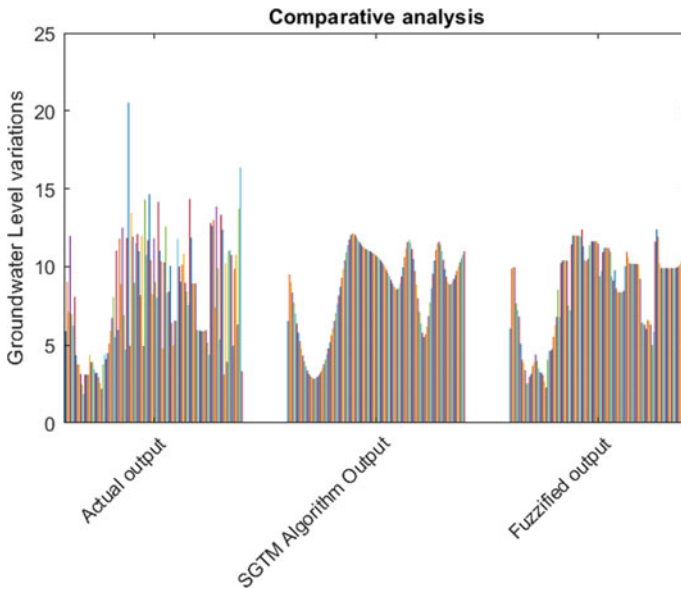
Fig. 9 Comparative analysis of SGTM and fuzzy interpretation results for groundwater level fluctuation

6 Conclusion

Self-generation of data has certain advantages Errors or noises in the data can be eliminated. It can be interpolated if there is any missing data between two data points, based on the standard deviation and the trend. The trend will be maintained. Synthetic training datasets are elastic because the datasets can run between maximum and minimum of the original data and predict the exact results though the data is nonlinear. Developing synthetic data using this algorithm helps the ANFIS system to decide the output very easily. Fixing the membership functions for a bunch of data, though it consumes time, it will predict the exact result after defuzzification. Many hybrid systems can be built on the combining platform of neural networks, fuzzy logic and neuro fuzzy networks. For example, fuzzy logic can be used to combine results from several neural networks; although some hybrid systems have been built, this present work has attained promising results when combining the fuzzy logic and neural networks. The field validation proves that this algorithm can have the bright future for estimating many non-linear problems. If the available data is very minimum, this type of algorithm will generate its own training dataset to predict the output more lucidly.

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