Nature Environment and Pollution Technology
An International Quarterly Scientific Journal | ISSN: 0972-6268 | Vol. 14 | No. 3 | pp. 501-508 | 2015

Original Research Paper

Clustering of the Districts of West Bengal Based on Spatial and Temporal Distribution of Groundwater Table Depth Towards Effective Monitoring and Management of the Valuable Water Resources

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 23-3-2015
Accepted: 1-5-2015

Key Words:
Groundwater table depth
Water resources
Probability distribution
Clustering of districts

ABSTRACT

Fluctuations of groundwater table (GWT) has great role in agriculture through assured supply of irrigation in industry and other fronts. As such, probability of possible GWT also plays an important role in terms of efficient usages of this valuable resource. An attempt has been made to find probability distributions taking seasonal (January, May, August and November for 2005 to 2013) information on GWT for the districts under five agro-climatic zones of West Bengal. The study reveals that 17 districts of West Bengal, India, can be categorised into 6 probability model groups: Weibul, Normal, Weibul (3P), Log Logistic (3P), Log Normal (3P) and Gamma (3P). These models can be used to ascertain the probability of occurrences of GWT in specific district. Cluster analysis, using GWT figures for various seasons over the period of study reveals that the districts could be grouped into four clusters, which in-turn may facilitate clusterwise strategy for restricting the depletion of GWT depth or maintenance of the same. These techniques can be used for intra-district GWT analysis for efficient monitoring of GWT.

INTRODUCTION

Groundwater is a significant source of water in many parts of India particularly for drinking purpose. About 50% of the total irrigated area is dependent on groundwater and about 60% of the food production depends on irrigation from groundwater wells (CWC 2006). Rural and urban households and public water supplies depend on wells and groundwater. Industries, commercial business and other activities of human beings like generation of electric power, food, beverages, paper and material production etc. also depend on groundwater. West Bengal is endowed with 7.5 per cent of the water resources of the country to maintain 7.54 % of lives in the country (Anonymous 2013). The main source of water in West Bengal is rainfall, the annual average rainfall is around 1762mm (Anonymous 2010). Out of this 76% is received during the monsoon months and the rest in the non monsoon period. 21% of the rainfall infiltrates through the soils and recharges the groundwater table and 49% goes back to the atmosphere as evapo-transpiration. The net annual water resource generated from rainfall in West Bengal amounts to 51.02 billion cubic meters (bcm) (WBPCB 2009). About 60% of the surface water and 28% of the groundwater in West Bengal is available in North Bengal that supports only 18% population of the state. Whereas 82% of the population residing in south Bengal depends only on 40% of the surface water and extracts 78% of the total groundwater for its needs (Acharyya 2012). The replenishable groundwater resources including natural discharge is 34.20 bcm of which 31% is in north Bengal and 69% in south Bengal (Anonymous 2012). Due to increase in the population density, the consumption of water from the ground is increased, pressure on it also increases and exploitation of deep groundwater cannot be ruled out. Deep groundwater is less vulnerable to pollution than shallow aquifers (Baalousha 2010). Distribution patterns of groundwater table depth can vary with the change in seasons and other environmental factors along with its usage. So the probability of assessing the groundwater table depth and clustering of the districts on the basis of groundwater table depth behaviour of 17 districts of the states is needed for efficient planning of groundwater use. The knowledge of appropriate distribution will help us to obtain the depth of groundwater and corresponding probabilities at a particular place and season, which in turn can help in efficient use of groundwater. Towards efficient planning for groundwater management, grouping of the districts will help in taking up clusterwise management strategy. As such, in this paper, attempt has been made to search for the probability distribution of the groundwater table depth of the districts in West Bengal individually and cluster the districts into a small number of groups to facilitate clusterwise efficient groundwater management strategy.

MATERIALS AND METHODS

West Bengal is situated in the eastern part of India between 21°20' and 27°32' N latitude and 85°50' and 89°52' E longitude. Poor or scarcity of seasonwise long term consistent data on groundwater is the main problem in this type of study. The present study has been undertaken with the help of 17 districtwise groundwater level data on seasonal basis (i.e., January, May, August, November) for the period 2005 to 2013 (http://gis2.nic.in/cgwb/Gemsdata.aspx 2014).

Descriptive statistics is useful tool to describe the patterns and general behaviour of a data set; it includes numerical and graphical statistical measure. As such in this paper attempt has been made to describe the nature of groundwater table depth spatially as well as temporally using the above measures.

An attempt has been made to find out the probability distribution of groundwater table depth for each and every district under the six agro-climatic zones of West Bengal. For each fitted distribution, three goodness of fit statistics are used namely Chi-squared, Kolmogorov-Smirnov and Anderson-Darling test. Based on the above criteria, best probability model in each case is ascertained. Distributions found best in different situations are given in Table 1.

The chi-squared statistic is the best known as goodness-of-fit statistic. To test the hypothesis:

H_0: The data follow a specified distribution, against the alternative hypothesis.

H_1: The data do not follow the specified distribution;

the chi-squared statistic is defined as:

$$\chi^2_{Cal}=\sum_{i=1}^{K}\frac{\left(Y_i-\hat{Y}_i\right)^2}{\hat{Y}_i},$$

Where, K = the number of bins, Y_i = the observed number of samples in the i^{th} bin, $\hat{Y}_i$ = the expected number of samples in the i^{th} bin

The hypothesis that the data are from a population with the specified distribution is rejected if;

$$\chi^2_{Cal} > \chi^2_{tab(1-\alpha,k-c)}$$

Kolmogorov-Smirnov test statistic for the hypothesis mentioned above is defined as:

$$D_n = \sup\left[\left|F_n(x)-F(x)\right|\right]$$

Where, $F(X)$ = the fitted cumulative distribution function; $F_n(X)=\frac{N_x}{n}$; N_x = the number of $X_i's$ less than x.

The hypothesis regarding the distributional form is rejected if the test statistic, D, is greater than the critical value. Anderson Darling test statistics is defined as:

$$A^2 = -N - S$$

Where,

$S=\sum_{i=1}^{N}\frac{(2i-1)}{N}\left[\ln F(Y_i)+\ln\left(1-F(Y_{N+1-i})\right)\right]$, F is the cumulative distribution function of the specified distribution, Y_i is the ordered data and N is the sample size.

Table 1: Distributions found best in different situations.

Distribution	Probability density function	Parameters.
Normal	$f(x)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)$	where x is random variable, μ and σ^2 are mean and variance respectively $-\infty<x<\infty$, $-\infty<\mu<\infty$, $\sigma>0$
Weibull	$f(x)=\frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)$	where x is random variable, $\alpha>0$ is shape parameter, $\beta>0$ is scale parameter
Lognormal (3P)	$f(x)=\frac{\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$	where x is random variable; σ is shape parameter (σ >0); μ is scale parameter and γ is a location parameter; $\gamma<x<+\infty$
Weibull (3P)	$f(x)=\frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$	where x is random variable; $\alpha>0$ is shape parameter; $\beta>0$ is scale parameter and γ is called location parameter.
Gamma (3P)	$f(x)=\frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-\frac{(x-\gamma)}{\beta}\right)$	where x is random variable; α is shape parameter (α >0); β is scale parameter (β >0) and γ is location parameter; $\gamma\leq x<+\infty$
Log-Logistic (3P)	$f(x)=\frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-2}$	where x is random variable; $\alpha>0$ is shape parameter; $\beta>0$ is scale parameter and γ is called location parameter

The critical values for the Anderson-Darling test are dependent on the specific distribution that is being tested. The test is a one-sided test and the hypothesis that the distribution is of a specific form is rejected if the test statistic, A, is greater than the critical value.

Cluster analysis is a multivariate statistical technique used for a wide variety of research approaches and here it is used to group the 17 districts into clusters such that each cluster is as homogeneous as possible with respect to groundwater table values. Here, no assumptions are made regarding the number of clusters/groups and the group membership, and it is done on the basis of similarities or dissimilarities (distances). A hierarchical clustering creates a hierarchical decomposition of data elements in the form of a tree like diagram called *Dendrogram*, which looks like a tree of set of nested clusters. There are two approaches to build a cluster hierarchy:

i) Agglomerative method: A bottom-up approach i.e., from single whole cluster to clusters of single elements and

ii) Divisive method: Top-down approach i.e., from single element cluster to group of elements as cluster.

Tree clustering method uses the dissimilarities or distances between objects while forming the clusters. In the present study complete linkage is used for computing the distance between clusters and it works on the principle of distant neighbour or dissimilarities-farthest neighbour. The maximum distance between elements of each clusters is given by:

$$\max\{d(x,y): x \in A, y \in B\}$$

Euclidean distance measure has been used to measure the distance between two data points, which involves computing the square root of the sum of the squares of the differences between corresponding values. If X and Y are two elements measured for i=(1,2, ...,n) characters, then Euclidean distance between X and Y is given as;

$$d = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$$

In the present study squared Euclidean distance is used between sites, which gives progressively greater weightage to objects which are far apart from each other. Squared Euclidean distance is frequently used in optimization problems where distances are only compared.

One way ANOVA is carried out to verify the hypothesis that, groundwater level in various clusters formed in different seasons are same.

i.e., H_0: $\mu_1 = \mu_2 = ... = \mu_k$ (k=1,2,. . . .) against, H_1= All clusters are not equal,

Where,

μ_k (k=1, 2, ...) is the ground water depth of kth cluster

RESULTS AND DISCUSSION

Descriptive analysis showed that the mean value during August month for all the selected districts is comparatively lower than other seasons (Table 2) of the present study,

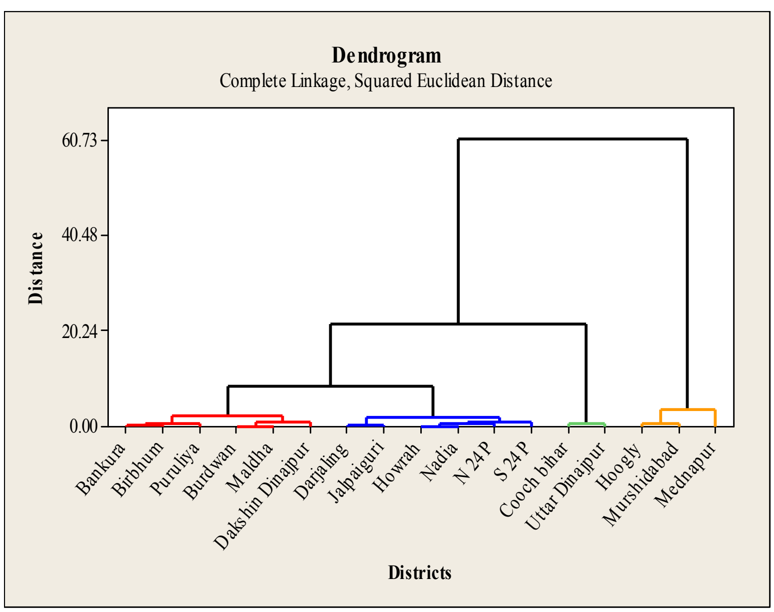

Fig. 1: Dendrogram showing districtwise clusters of West Bengal.

Table 2: *Per se* performance of groundwater level in 17 districts of West Bengal.

	January	May	August	November	Average	January	May	August	November	Average
			Bankura					**Birbhum**		
Mean	4.715	6.198	2.391	3.404	4.177	4.808	6.381	2.636	3.681	4.377
Standard Error	0.195	0.146	0.279	0.282	0.17	0.134	0.208	0.255	0.229	0.128
Skewness	1.869	1.067	1.933	1.409	2.109	-0.373	0.005	0.509	0.615	0.181
Minimum	4.212	5.774	1.663	2.209	3.816	4.14	5.5	1.628	2.839	3.833
Maximum	6.09	6.945	4.367	5.328	5.398	5.318	7.276	3.894	4.883	4.923
SGR %	0.49	0.326	-1.968	-3.758	-0.86	1.597	3.091	0.798	-1.08	1.398
			Burdwan					**Cooch Bihar**		
Mean	4.951	6.581	3.591	4.013	4.784	3.185	3.44	1.495	2.304	2.606
Standard Error	0.535	0.608	0.524	0.449	0.156	0.051	0.053	0.069	0.134	0.034
Skewness	1.795	1.338	2.119	2.274	1.41	0.44	0.57	-1.626	-0.286	0.237
Minimum	0.747	1.629	0.514	1.053	3.805	2.996	3.272	1.024	1.628	2.482
Maximum	17.903	19.553	16.233	16.968	5.442	3.421	3.719	1.69	2.845	2.749
SGR %	1.982	-1.517	-2.375	-3.351	-1.205	-1.317	-0.086	1.405	-1.301	-0.553
			Dakshin Dinajpur					**Darjeeling**		
Mean	4.407	7.302	3.19	3.735	4.658	4.267	4.971	2.116	3.325	3.67
Standard Error	0.126	0.165	0.199	0.146	0.104	0.075	0.1	0.103	0.124	0.04
Skewness	-1.133	-0.725	-0.463	-0.185	-1.346	1.173	1.423	-0.106	0.078	-0.017
Minimum	3.733	6.405	2.133	3.009	3.978	3.939	4.578	1.682	2.759	3.485
Maximum	4.813	7.957	3.83	4.416	5.006	4.757	5.647	2.511	3.987	3.845
SGR %	0.693	2.692	3.536	3.462	2.403	0.11	0.011	-2.848	-2.124	-0.93
			Hooghly					**Howrah**		
Mean	5.882	7.536	3.966	4.789	5.543	3.767	4.936	2.6	3.421	3.681
Standard Error	0.943	1.214	0.571	0.721	0.833	0.392	0.465	0.335	0.334	0.304
Skewness	-0.006	-0.228	-0.129	0.201	-0.196	0.995	0.8	-1.32	0.329	0.36
Minimum	2.716	2.934	1.589	2.156	2.411	2.474	3.325	0.46	2.135	2.661
Maximum	10.035	11.604	6.621	8.01	8.247	5.996	7.295	3.601	4.939	4.911
SGR %	-0.178	-0.615	0.356	-3.92	-1.231	-4.535	-2.732	-4.059	-5.967	-4.254
			Jalpaiguri					**Maldah**		
Mean	4.274	4.640	2.193	3.091	3.549	4.855	6.826	3.562	4.128	4.843
Standard Error	0.100	0.108	0.138	0.099	0.081	0.139	0.159	0.242	0.160	0.110
Skewness	0.164	-0.005	-0.639	-1.042	-0.696	0.545	-0.768	-0.187	0.600	0.515
Minimum	3.880	4.156	1.407	2.581	3.102	4.391	5.990	2.623	3.512	4.425
Maximum	4.770	5.075	2.770	3.405	3.850	5.480	7.442	4.406	5.000	5.475
SGR %	-1.063	-1.089	-4.655	-2.268	-1.912	2.376	0.849	4.898	4.709	2.636
			Midnapur					**Mursidabad**		
Mean	7.073	8.961	4.311	4.987	6.333	5.855	7.557	4.353	5.529	5.824
Standard Error	0.143	0.427	0.384	0.316	0.132	0.24	0.554	0.297	0.588	0.39
Skewness	0.363	0.393	0.022	0.098	1.975	0.192	0.696	0.426	1.31	1.242
Minimum	6.518	7.218	2.566	3.64	5.943	4.747	5.316	3.151	3.665	4.664
Maximum	7.791	10.895	6.261	6.34	7.282	7.149	10.44	5.687	8.651	7.979
SGR %	0.689	2.99	-3.326	-2.203	0.287	1.71	5.185	2.547	7.084	4.165
			North 24 Parganas					**Nadia**		
Mean	4.309	5.397	2.988	3.624	4.079	3.804	4.878	2.932	3.294	3.727
Standard Error	0.213	0.263	0.12	0.131	0.119	0.215	0.204	0.25	0.205	0.146
Skewness	0.753	-0.788	-0.558	1.297	0.737	0.648	0.41	-0.003	0.192	0.502
Minimum	3.523	3.855	2.263	3.25	3.624	2.45	3.278	1.13	1.854	3.666
Maximum	5.476	6.352	3.539	4.44	4.771	5.979	6.831	4.923	5.003	4.986
SGR %	4.3	3.811	0.438	-0.227	2.325	1.43	1.52	0.89	0.29	1.104
			Purulia					**South 24 parganas**		
Mean	4.76	6.976	2.309	3.667	4.428	4.157	4.539	3.277	3.841	3.953
Standard Error	0.218	0.195	0.371	0.364	0.227	0.072	0.216	0.177	0.187	0.083
Skewness	1.174	0.694	1.795	1.168	1.288	1.503	-2.051	-0.622	0.44	0.192
Minimum	4.059	6.346	1.178	2.444	3.751	3.939	2.976	2.167	2.989	3.542
Maximum	6.155	7.953	4.89	5.985	5.913	4.635	5.099	4.189	4.846	4.389
SGR %	-2.1	0.014	-4.127	-4.394	-2.212	0.271	0.142	0.079	1.297	0.426
			Uttar Dinajpur							
Mean	2.944	4.074	1.774	2.287	2.77					
Standard Error	0.125	0.093	0.165	0.109	0.068					

Table cont....

...Cont. Table					
Skewness	0.285	1.544	1.01	-1.023	0.531
Minimum	2.283	3.783	1.191	1.69	2.52
Maximum	3.683	4.698	2.772	2.66	3.119
SGR %	4.299	-1.022	7.144	0.92	1.63

Note: SGR% is the simple growth rate and calculated as $SGR\% = \frac{Y_t - Y_0}{nY_0} x100$, where, Y_t is the value of Y for last period, Y_0 is the initial value, n is the number of data points.

Table 3: Best fitted distribution for groundwater level in 17 districts of West Bengal.

District	Best fitted Distribution	K S Statistic	A D Statistic	Chi-Squared Statistic	Estimated parameter		
Bankura	Weibull	0.114	0.460	1.235	α = 2.688	β =4.630	
Birbhum	Normal	0.066	0.210	0.494	σ = 1.533	μ =4.376	
Burdwan	Lognormal (3P)	0.094	0.355	2.121	σ = 0.192	μ= 2.044	γ= -3.464
Cooch Bihar	Weibul (3P)	0.156	1.315	5.069	α=2.80E+7	β= 1.78E+7	γ= 1.78E+7
Dakshin Dinajpur	Log-Logistic (3P)	0.120	0.650	1.458	α= 3.148	β = 2.624	γ= 1.607
Darjeeling	Weibul	0.133	0.621	1.638	α= 3.300	β = 4.042	
Hooghly	Weibul (3P)	0.108	0.374	1.406	α = 1.360	β= 4.4352	γ= 1.465
Howrah	Log-Logistic (3P)	0.090	0.266	0.581	α = 9.666	β = 7.108	γ= -3.573
Jalpaiguri	Weibul	0.127	0.647	3.718	α = 3.473	β = 3.906	
Maldah	Log-Logistic (3P)	0.087	0.467	1.310	α = 5.090	β = 3.804	γ= 0.829
Midnapur	Normal	0.084	0.243	0.711	σ = 2.088	μ =6.333	
Murshidabad	Lognormal (3P)	0.056	0.121	1.588	σ = 0.376	μ=1.430	γ=1.337
Nadia	Gamma (3P)	0.047	0.111	0.167	σ = 0.345	μ=1.045	γ=1.06
North 24 Parganas	Lognormal (3P)	0.082	0.323	0.694	α =71.404	β = 0.119	γ = -4.328
Purulia	Weibull	0.094	0.352	0.238	α = 2.272	β = 4.928	
South 24 Parganas	Weibull (3P)	0.101	0.308	0.858	α = 6.175	β = 3.802	γ= 0.423
Uttar Dinajpur	Lognormal (3P)	0.116	0.391	0.603	σ = 0.192	μ =1.566	γ = -2.107

Note: K S: Kolmogorov Smirnov; A D: Anderson Darling

which is mainly due to high rainfall in the month, also in previous months. Whereas groundwater level seems to be depleting in May month which may be due to removal of water for irrigation purpose, more water absorption by plants particularly deep rooted plants, increase in evapo-transpiration because of high temperature, poor or no rainfall in and around the month of May, and other water evolved activities.

Since 2005, among the districts of West Bengal, on average Hooghly is found to be more fluctuating district with a standard error of 0.83m (Table 2), whereas Cooch Bihar shows less variation in groundwater level with standard error 0.034m. Among the seasons, May month in case of Burdwan, Hooghly, Howrah, Midnapur, North 24 Parganas and South 24 Parganas; August month in case of Birbhum, Dakshin Dinajpur, Jalpaiguri, Maldah, Nadia, Purulia and Uttar Dinajpur; November in case of Bankura, Cooch Bihar, Darjeeling and Mursidabad are found to be more fluctuating months respectively. Positive skewness for most of the districts except Dakshin Dinajpur, Darjeeling, Hooghly and Jalpaiguri, indicates that most of the above mentioned districts are maintaining a lower depth of groundwater table whereas the four districts mentioned above are showing higher groundwater table depth during the period under study and should be noted seriously. Negative growth rate in case of Bankura (-0.86%), Burdwan (-1.20%), Cooch Bihar (-0.55%), Darjeeling (-0.93%), Hooghly (-1.23%), Howrah (-4.25%), Jalpaiguri (-1.91%) and Purulia (-2.21%) indicates that the water table has improved since 2005, which may be due to the implementation of groundwater recycling/recharging programs like construction of water channels, rain water harvesting techniques, improved methods of irrigation in recent years or may be due to comparative favourable rainfall during the course. But remaining districts viz., Birbhum (1.39%), Dakshin Dinajpur (2.40%), Maldah (2.63%), Mednapur (0.28%), Mursidabad (4.16%), North

Table 4: Estimated probability of groundwater level using best fitted distribution for various districts.

District	x	P(x1 ≤ X ≥ x)	P(X ≤ x)	District	x	P(x1 ≤ X ≥ x)	P(X ≤ x)
	1.660	0.000	0.000		1.620	0.052	0.036
	2.580	0.176	0.188		2.840	0.157	0.159
Bankura	4.180	0.229	0.531	Birbhum	4.380	0.260	0.499
	5.770	0.138	0.836		5.910	0.158	0.841
	6.940	0.059	0.948		7.270	0.043	0.970
	0.514	0.001	0.000		1.024	0.068	0.044
	4.320	0.269	0.491		2.503	0.460	0.372
Burdwan	4.780	0.237	0.632	Cooch Bihar	2.606	0.499	0.422
	5.250	0.195	0.734		2.709	0.533	0.475
	19.550	0.000	0.999		3.719	0.211	0.958
	2.133	0.037	0.006		1.682	0.103	0.054
	4.348	0.286	0.534		3.549	0.316	0.478
Dakshin Dinajpur	4.658	0.244	0.616	Darjeeling	3.670	0.316	0.517
	4.969	0.202	0.686		3.791	0.314	0.555
	7.957	0.027	0.942		5.647	0.087	0.951
	1.589	0.084	0.008		0.460	0.010	0.004
	3.043	0.165	0.217		2.768	0.285	0.249
Hooghly	5.543	0.122	0.590	Howrah	3.681	0.330	0.549
	8.044	0.064	0.819		4.594	0.194	0.793
	11.604	0.019	0.954		7.295	0.014	0.984
	1.407	0.069	0.028		2.623	0.059	0.021
	3.308	0.336	0.429		4.513	0.343	0.459
Jalpaiguri	3.549	0.343	0.511	Maldah	4.843	0.311	0.568
	3.791	0.335	0.594		5.173	0.262	0.663
	5.075	0.142	0.916		7.442	0.041	0.943
	2.566	0.038	0.036		3.151	0.050	0.013
	5.936	0.188	0.425		4.653	0.264	0.269
Midnapur	6.333	0.191	0.500	Mursidabad	5.824	0.232	0.574
	6.730	0.188	0.575		6.994	0.136	0.789
	10.895	0.018	0.986		10.440	0.014	0.981
	2.263	0.043	0.006		1.130	0.001	0.000
	3.724	0.425	0.424		3.290	0.292	0.192
North 24 Parganas	4.079	0.377	0.568	Nadia	3.730	0.378	0.441
	4.435	0.303	0.689		4.170	0.222	0.814
	6.352	0.044	0.964		6.830	0.016	0.992
	1.170	0.071	0.037		2.160	0.027	0.007
	2.500	0.157	0.192		3.270	0.308	0.155
Purulia	4.430	0.184	0.543	South 24 Parganas	3.950	0.588	0.468
	6.360	0.107	0.832		4.630	0.421	0.847
	7.950	0.043	0.948		5.090	0.135	0.977
Uttar Dinajpur	1.190	0.095	0.026				

X: Groundwater table depth in m

Table 5: Clusters of 17 districts of West Bengal.

Cluster-1	Cluster-2	Cluster-3	Cluster-4
No. of District: 6	No. of District: 6	No. of District: 2	No. of District: 3
Bankura	Darjeeling	Cooch Bihar	Hooghly
Birbhum	Howrah	Uttar Dinajpur	Midnapur
Purulia	Jalpaiguri		Murshidabad
Burdwan	North 24 Parganas		
Dakshin Dinajpur	Nadia		
Maldah	South 24 Parganas		

Table 6: Cluster distances and groundwater table depths (m) in different clusters.

	Cluster distance				Groundwater table depth (m)			
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	January	May	August	November
Cluster1	0.000	3.932	1.978	2.718	4.749	6.711	2.947	3.771
Cluster2	3.932	0.000	2.180	6.553	3.065	3.757	1.635	2.296
Cluster3	1.978	2.180	0.000	4.427	4.096	4.894	2.684	3.433
Cluster4	2.718	6.553	4.427	0.000	6.270	8.018	4.210	5.102
F Value					43.325	50.33	13.036	45.266
Significance Level					0.000	0.000	0.000	0.000

24 Parganas (2.32%), Nadia (1.10%), South 24 Parganas (0.42%) and Uttar Dinajpur (1.60%) recorded positive growth rate for almost all the months, clearly indicating that either withdrawal of groundwater in these districts is increasing year by year or recharging of groundwater table is getting worse year by year or both. In this content it may be noted that in spite of the ongoing implementation of *"Jal Dharo, Jal Bharo"* meaning "harvest water (rain) and store it" programme, this differential performance may be taken into consideration for further tuning of the programme.

Best fitted probability distribution for all the selected districts is presented in Table 3. Weibul in case of Bankura, Darjeeling, Jalpaiguri and Purulia; Weibul (3P) in case of Cooch Bihar, Hooghly and South 24 Parganas; Normal in case of Birbhum and Midnapur; Log-normal (3P) in case of Burdwan, Mursidabad, North 24 Parganas and Uttar Dinajur; Gamma (3P) in case of Nadia; Log-Logistic (3P) in case of Dakshin Dinajpur, Howrah and Maldah are found to be best probability distribution for groundwater table respectively. Using the best fitted distribution, chance of getting water below the ground level (Minimum, Mean-SD, Mean, Mean + SD, Maximum) are estimated and presented in Table 4. Using the procedure, one can find the probability of getting any depth of groundwater for any particular district.

As mentioned, clustering of districts based on groundwater table depth may help in efficient use of groundwater as well as in formulating its maintenance strategy. Complete linkage clustering is carried out to identify and to group the districts of West Bengal taking seasonal groundwater table depth for the period under study. Four clusters were obtained and districts in different clusters are depicted in Table 5 and their dendrogram is presented in Fig. 1. Comparatively more similarity was observed between the cluster-1 and cluster-3 with a least distance of 1.978 (Table 6).

For the four different clusters formed, one way ANOVA was carried out to verify the hypothesis of differences among the clusters with respect to the groundwater level and the result is presented in Table 6. This indicates that clusters formed are significantly different in all the seasons under study, which once again proves the correctness of the classification. Multiple comparison among the clusters with respect to GWT depth clearly indicates that excepting for the months of August and November between the cluster-1 and cluster-2 in all the months, GWT depths are significantly different among the clusters. Thus, cluster analysis indicates for different management strategies for different clusters of districts in West Bengal.

From the whole study, one clearly finds that there has been a difference in the changes of groundwater table depth among the districts and among the seasons under the study. Importantly, two districts, viz. Bankura and Purulia under dry belt of West Bengal along with Burdwan, Cooch Bihar, Darjeeling, Hooghly, Howrah and Jalpaiguri exhibited mostly negative growth rates in groundwater table depth, which is very much encouraging; on the other hand positive growth rates in other districts and in almost all seasons are major concern for the groundwater planning. This study also reveals that various probability distributions are suitable for various districts in modelling groundwater table depth. From the distributions, probability of occurrence of different groundwater table depth for different districts could be worked out and used for effective planning. Cluster analysis also reflects that in spite of all these variations among the districts, they could be grouped under four groups, which may warrant/facilitate clusterwise different corrective measures to meet the challenges of groundwater depletion.

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