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ASSESSING THE DECADAL GROUNDWATER LEVEL FLUCTUATION-A CASE STUDY OF GUJARAT, INDIA

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ABSTRACT

Groundwater extractions have increased severely and have been consistently reported across the globe. The overexploitation of groundwater resources may cause a serious decline in water levels. Groundwater level fluctuations and their trends can be used to estimate changes in aquifer storage resulting from the effects of groundwater withdrawal and recharge. In Gujarat, very regions are dependent on groundwater for irrigation. Thus, it is necessary to assess the degree of exploitation and analyze the groundwater level trend in the Gujarat state. This study examined the pre- and postmonsoon groundwater level fluctuations using statistical methods over the 26 districts of Gujarat for a period of 11 years (2010-2020). Fourteen districts showed a rising trend, whereas 4 districts showed a falling trend for both the premonsoon and postmonsoon seasons, and 8 districts showed a rising trend during the premonsoon season and a falling trend during the postmonsoon season, including a reverse trend. The average annual rise in groundwater level was detected with a maximum rise (1.7064 m/yr) at Ahmedabad, whereas an average annual decline was detected with a maximum decline (1.4092 m/yr) at Gandhinagar during the premonsoon season. The rising trend is attributed to the construction of water conservation structures, and the falling trend is attributed to the overexploitation of groundwater.

Keywords: Decadal groundwater, F test, Groundwater level fluctuation, Zones of Gujarat, Overexploitation of groundwater, Statistical method

INTRODUCTION

Water is a valuable resource. Most of the water on Earth is saline water. Two-thirds of the water's 2.5% clearwater content, which has no definite quantities of dissolved minerals or salt, is icy in ice caps and glaciers. Only 0.01% of the water on the planet may be used for human consumption. An essential human requirement is access to uncontaminated drinking water. Unfortunately, in the poor world, more than one in six individuals still do not have uncontaminated drinking water access. (Baroniya et al., 2012).

One of the most important natural resources, groundwater, also plays a large part in the country's economy. It is the essential water supply for cultivation and the food sector. Around the world, more than 70% of all water withdrawal is used for irrigation (both surface and groundwater). Approximately 43% of the total irrigation water utilized is thought to come from groundwater. (Briar et al., 2001).

Several issues with groundwater, including groundwater depletion, groundwater quality deterioration, as groundwater levels decline (Seghir, 2014; Djabri et al., 2015; Habes et al., 2016; Zegait et al., 2021), land subsidence and hydrological droughts, result. Therefore, groundwater levels can be crucial for long-term water management, particularly because of growing climate unpredictability. However, studying the effects of groundwater use under climate change is urgently necessary.

The study was conducted to analyze the change in decadal groundwater levels in various districts of Gujarat. The systematic monitoring of groundwater may be a powerful tool for better management and planning of precious natural resources.

MATERIALS AND METHODS

Study Area and Data Source

Gujarat state is located in the western part of India. Gujarat, which has a land area of 196,024 square kilometers, is the fifth-largest state in India. Gujarat State is located between the longitudes of 68° 10' 00" and 74° 28' 00" east and the longitudes of 20° 06' 00" to 24° 42' 00" north (Fig. 1). Gujarat has the longest coastline in the nation, nearly 1600 km, compared to all other states. The state shares international borders in the northwest with Pakistan as well as common borders with the states of Rajasthan, Madhya

Pradesh, and Maharashtra. Daman is located in the south and west of Vapi, and Diu is an island that is close to the Saurashtra coast.

Physiographic, climatic, topographical, and geologic variations have resulted in a variety of groundwater situations across the state. Groundwater flow and occurrence are governed by rock formations with a range of ages, from the Archean to the recent, and a variety of compositions and structures. The landform varies as well, from the mountainous tract to the uplands of Kachchh and Saurashtra to the marshy to salty tracts of the Rann of Kachchh and Little Rann of Kachchh. The alluvial plains stretch from Banaskantha in the north to Valsad in the south. Runoff and groundwater recharge are mostly influenced by terrain and rainfall.

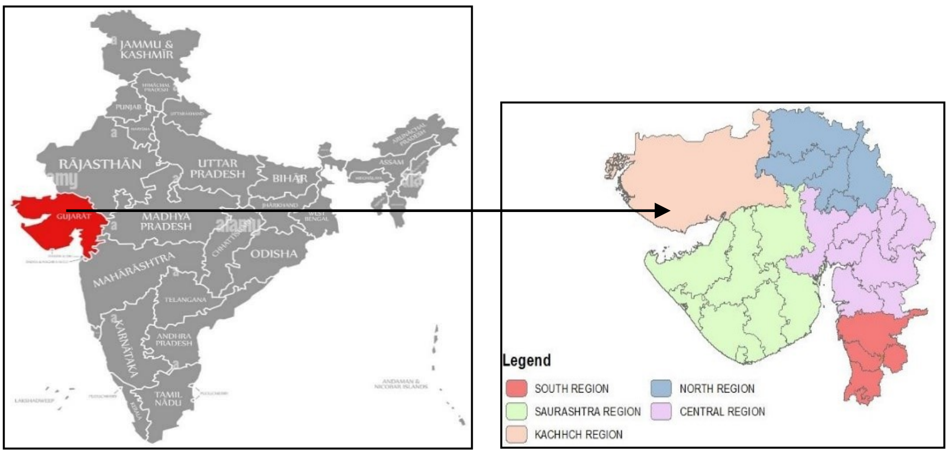

Figure 1: State of Gujarat Map

The primary supply of water for Gujarat is surface water, according to a study from the irrigation department of Gujarat. The state includes 185 river basins, and 55608 million cubic meters of water is readily available. The surface water allocation is not evenly allocated. The state has 17508 million cubic meters of subterranean water resources. The allotted amount of surface and subsurface water is utilized for industry, agriculture, hydroelectricity production, fishing, etc. A large portion of which nearly 80% is allocated for agricultural output, in which irrigation is crucial.

Gujarat has been at the forefront of debates regarding groundwater scarcity since preindependence times. Gujarat has been dependent upon groundwater to meet its agricultural and domestic needs. Gujarat state was declared the worst drought year in 2018, https://watersciencepolicy.com/. In May 2019, more than 20 districts of the state did not have sufficient reserves of water for drinking while facing a "massive water crisis". Farmers have been dependent on the productive groundwater resources of the state to cultivate crops and maintain livestock. https://watersciencepolicy.com. Therefore, there is an urgent need to study changes in groundwater levels and to identify groundwater deficit areas.

Gujarat's topography and river channels have ensured that the entire region is not equal in terms of water resources. While the Central and South Gujarat regions have a few rivers, regions such as Kachchh, North Gujarat and Saurashtra often face water scarcity in the absence of round-the-year supply. Due to weak and variable rainfall, droughts frequently occur in the areas of North Gujarat, Saurashtra, and Kachchh. From humid in the south to subhumid in the center to semiarid and desert in the north and west, the climate varies. Rainfall in the state is primarily experienced during the southwest monsoon season. The present study was conducted to analyze the decadal groundwater level changes in the period of 2010 to 2020.

The study used groundwater level data collected over an 11-year period (2010-2020) from 26 districts in Gujarat state during the premonsoon and postmonsoon seasons. Information on groundwater levels was gathered from the INDIA-WRIS website. Shape File data were collected from DIVAGIS (https://www.diva-gis.org).

Table 1: Zones of Gujarat state

Sr. No.	Zone	Districts	Zone Area
1	South Gujarat Region	(1) Valsad, (2) Dang, (3) Navsari, (4) Tapi, (5) Surat.	14,479 km^2
2	Central Gujarat Region	(6) Ahmedabad, (7) Vadodara,(8) Anand, (9) Dahod, (10) Kheda, (11) Bharuch, (12) Narmada, (13) Panchmahal	41,018 km^2
3	North Gujarat Region	(14) Gandhinagar, (15) Banaskantha, (16) Mehsana, (17)Patan, (18) Sabarkantha	30,470 km^2
4	Saurashtra Region	(19) Rajkot, (20) Amreli, (21) Bhavnagar, (22) Jamnagar, (23) Junagadh, (24) Porbandar, (25) Surendranagar	64,383 km^2
5	Kachchh region	(26) Kachchh.	45,674 km^2
		Total area of Gujarat state	**1,96,024** km^2

Methodology

The methodology adopted in the project is graphically presented in the chart below.

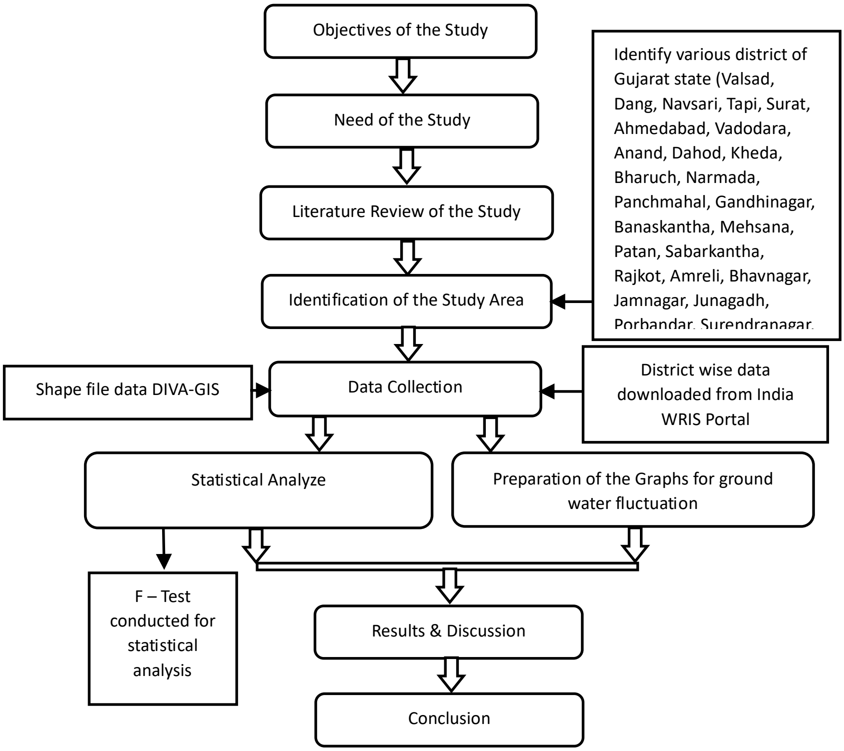

Figure 2: Flow chart of methodology

F Test

The F test is designed to test if two population variances are equal. It does this by comparing the ratio of two variances. Therefore, if the variances are equal, the ratio of the variances will be 1. All hypothesis testing is done under the assumption that the null hypothesis is true. In agricultural experiments, such as groundwater level and recharge fluctuations, the mean and variability are also important parameters to assess the performance of an operation. Hence, it attracts researchers' attention to compare and correlate the variability of two populations. Mean and variability are key parameters to evaluate the effectiveness of an experiment in agriculture, such as groundwater level and recharge changes. The data in an F test follow an f distribution. In this test, two variances are divided and compared using the f statistic. Depending on the problem's characteristics, an F test can be either one-tailed or two-tailed. When testing the equality of variances hypothesis, the larger and smaller variances are consistently placed in the numerator and denominator, respectively.

The F test was used to test the equality of two population variances, equality of two several regression coefficients, and ANNOVA. F has a range of 0 to ∞.

Let $x_1, x_2,...x_n$ and $y_1, y_2,...y_n$ be two independent random samples with sizes n_1 and n_2 drawn from two normal populations N (μ_1, σ_1^2) and N (μ_2, σ_2^2), respectively. S_1^2 and S_2^2 are the sample variances of the two samples. Null hypothesis H_0: $\sigma_1^2 = \sigma_2^2$

Alternative hypothesis H_1: $\sigma_1^2 > \sigma_2^2$

$$F_{(\mu_1, \mu_2)} = \frac{S_1 2}{S_2 2}\,;\ S_1^2 > S_2^2 \tag{1}$$

$$F_{(\mu_2, \mu_1)} = \frac{S_2 2}{S_1 2}\,;\qquad S_2^2 > S_1^2 \tag{2}$$

$$F_{(\mu_1, \mu_2)} = \frac{\text{Larger Sample Variance}}{\text{Smaller Sample Variance}}$$

If Calculated or statistical $F_{\alpha,\ \mu_2, \mu_1}$ > Tabulated or Critical $F_{\alpha,\ \mu_2, \mu_1}$

Then, H_0 is rejected. It can be said that there are significant changes between the two variances. If statistical F_{μ_2, μ_1} < Critical F_{μ_2, μ_1}

Then, H_0 is accepted. It can be said that there are no significant changes between the two variances.

$$S_1^2 = \frac{1}{n_1 - 1}\left[\sum x^2 - \frac{\Sigma(x)^2}{n_1}\right] \quad \text{and} \quad S_2^2 = \frac{1}{n_2 - 1}\left[\sum y^2 - \frac{\Sigma(y)^2}{n_2}\right]$$

For Sample-I, μ_1 = d.f. = n_1-1, and for Sample-II, μ_2= d.f. = n_2-1

The null hypothesis will be accepted if the computed value of F is smaller than the table value of F with (n_2-1, n_1-1) degrees of freedom at the determined level of significance; otherwise, the population variances will be diverse in character. The ratio of the variances in two samples is the F test. The F score will be extremely close to one if the variance is very close to being identical. The sample's hypothesis, which was drawn from populations with the same variance, should be accepted if the F value is near one. If the F score is not one, it should be assumed that the variance varies between populations. Formally, the test must be finished with two hypotheses. The first is the null hypothesis, or H_0, which states that there is no difference. The alternative hypothesis, H_1, is referred to as the second and states that there are differences.

RESULTS AND DISCUSSION

The F test was accomplished for the premonsoon and postmonsoon groundwater levels for all 26 districts of Gujarat. The average groundwater level data were used for scrutiny over the study period. The test statistics are given in Tables 2, 3, 4, 5, 6, 7 and 8. The Ftest was performed to compare the significant changes for both the premonsoon and postmonsoon seasons.

The change in the groundwater level is determined by comparing F_{stat} with the $F_{critical}$ value. At Valsad, Dang, Navsari, Tapi, Surat, Ahmedabad, Vadodara, Anand, Dahod, Kheda, Bharuch, Narmada, Panchmahal, Gandhinagar, Banaskantha, Mehsana, Patan, Sabarkantha, Rajkot, Amreli, Bhavnagar, Jamnagar, Junagadh, Porbandar, Surendranagar and Kachchh districts, F_{stat} value for pre and post monsoon was found 8.37, 12.83, 0.91, 1.65, 4.12, 0.98, 1.50, 21.12, 0.8, 1.15, 5.8, 0.1, 2.15, 9.56, 0.52, 2.63, 2.43, 2.75, 1.10, 1.15, 1.7, 0.8, 1.4, 0.2, 2.2 and 0.17 whereas F critical value were 2.98, 2.98, 0.34, 2.98, 2.98, 0.31, 2.98, 3.18, 0.3, 3, 3.2, 0.3, 2.98, 3.18, 0.31, 2.98, 2.98, 2.98, 2.98, 3.18,3.2, 0.3, 3, 3, 2.98 and 2.98. This analysis will help to identify the critical districts where the rate of groundwater levels has been declining over the years. Declining scenarios in the Vadodara, Banaskantha, Amreli and Kachchh districts were observed and are presented in Fig.4(g), Fig.6(o), Fig.7(t) and Fig.9(z).

Table 2: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Valsad		Dang		Navsari		Tapi	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	8.39	3.73	5.78	1.87	9.67	4.52	10.94	5.09
2	7.45	2.30	4.89	1.85	7.65	3.64	8.60	4.44
3	7.57	4.53	6.21	2.27	8.98	5.68	8.04	5.71
4	7.75	3.89	6.22	2.31	8.62	4.06	7.33	3.70
5	7.76	4.72	6.82	2.88	7.56	5.35	6.79	5.85
6	14.80	4.47	9.71	2.80	8.07	6.57	14.01	6.10
7	7.48	3.91	7.11	1.85	8.40	4.83	8.01	5.05
8	8.64	4.36	7.15	2.13	9.06	4.18	8.17	5.05
9	7.33	2.55	6.31	1.55	10.23	5.61	9.92	6.41
10	7.24	3.17	6.16	1.31	8.49	5.41	8.80	3.94
11	4.88	4.58	2.39	1.70	7.17	6.50	5.58	10.24
Mean	8.12	3.84	6.25	2.05	8.54	5.12	8.74	5.60
Variance	5.83	0.70	3.08	0.24	0.85	0.94	5.11	3.10
F_{Stat}	8.37		12.83		0.91		1.65	
P(F<=f)	0.00		0.00		0.44		0.22	
$F_{Critical}$	2.98		2.98		0.34		2.98	

Table 3: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Surat		Ahmedabad		Vadodara		Anand	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	7.34	4.30	30.29	20.23	10.99	8.15	11.97	8.93
2	6.28	3.88	31.76	24.79	10.18	9.83	12.46	10.67
3	7.01	5.79	28.63	19.17	11.49	9.55	12.51	11.78
4	8.32	5.28	30.45	23.55	13.98	8.69	26.56	10.55
5	7.35	5.79	25.25	23.81	11.90	11.08	11.43	8.97
6	12.17	5.88	21.84	18.19	13.58	11.57	8.56	10.34
7	7.63	4.77	22.82	22.77	13.71	11.33	12.08	11.23
8	7.46	4.57	19.85	7.44	13.95	10.56	13.76	9.66
9	7.26	3.62	23.11	20.43	11.77	9.12	14.72	11.63
10	6.75	3.70	14.63	8.22	13.15	9.40	13.08	10.91
11	5.18	4.20	9.43	8.21	11.02	9.27	13.04	12.50
Mean	7.52	4.71	22.78	17.66	12.34	9.87	13.82	10.82
Variance	3.02	0.73	48.22	49.17	1.88	1.26	22.69	1.07
Fstat	4.12		0.98		1.50		21.12	
P(F<=f)	0.02		0.49		0.27		0.00	
FCritical	2.98		0.31		2.98		3.18	

Table 4: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Dahod		Kheda		Bharuch		Narmada	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	11.0	5.9	9.2	7.3	8.5	4.7	12.1	9.3
2	10.5	3.4	9.3	8.1	6.6	5.5	10.2	9.3
3	8.2	13.1	9.7	10.6	6.6	4.9	11.8	10.1
4	8.4	4.6	12.9	9.3	7.0	4.6	11.5	8.5
5	7.1	4.8	11.4	8.9	6.4	4.2	12.5	7.4
6	15.5	9.8	12.8	8.9	11.2	5.5	11.3	8.0
7	9.4	5.1	11.7	8.7	7.9	5.0	10.2	7.3
8	8.3	5.7	11.5	10.7	6.4	4.3	9.3	8.8
9	8.9	4.5	9.8	7.7	6.8	3.8	14.7	31.5
10	8.6	3.6	10.1	6.3	6.4	3.3	11.8	9.3
11	4.9	4.9	7.1	6.8	4.4	4.3	9.5	9.8
Mean	9.0	5.9	10.5	8.5	7.0	4.5	11.4	10.8
Variance	7.4	9.5	3.0	2.0	2.9	0.5	2.4	47.6
Fstat	0.8		1.5		5.8		0.1	
P(F<=f)	0.4		0.3		0.0		0.0	
FCritical	0.3		3.0		3.2		0.3	

Table 5: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Panch Mahal		Gandhinagar		Banaskantha		Mahesana	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	9.72	4.93	69.09	69.95	34.30	40.28	42.32	33.69
2	8.31	4.10	13.14	80.02	46.57	36.29	9.42	25.59
3	9.49	5.22	85.55	84.62	43.15	39.41	42.31	46.95
4	9.01	3.64	80.97	79.20	41.56	38.81	38.36	38.26
5	7.94	4.27	88.88	80.28	48.04	30.51	55.72	30.84
6	11.68	8.20	84.88	84.39	39.13	34.13	38.48	31.54
7	12.04	6.49	84.57	79.47	39.53	40.82	35.44	35.55
8	10.96	6.05	81.29	72.27	40.37	34.62	40.83	33.73
9	8.15	4.61	70.18	67.17	42.24	39.78	21.32	21.09
10	8.90	4.21	70.55	67.01	45.25	43.38	24.18	22.71
11	4.97	4.17	67.22	66.47	43.18	43.01	23.02	21.01
Mean	9.20	5.08	72.72	76.09	42.90	38.08	33.76	31.00
Variance	3.91	1.82	494.08	51.66	8.86	17.02	167.92	63.88
Fstat	2.15		9.56		0.52		2.63	
P(F<=f)	0.12		0.00		0.17		0.07	
FCritical	2.98		3.18		0.31		2.98	

Table 6: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Patan		Sabarkantha		Rajkot		Amreli	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	32.43	35.17	15.38	10.17	10.55	4.20	15.87	9.52
2	32.31	33.25	15.73	8.78	8.48	4.73	13.08	8.40
3	51.34	46.08	15.16	10.29	10.06	9.44	14.41	13.42
4	28.08	26.30	14.66	7.99	10.59	5.06	13.87	8.96
5	28.67	31.20	12.55	8.37	8.54	6.36	16.61	9.19
6	53.05	34.47	14.32	10.38	10.91	7.40	14.50	10.51
7	34.60	45.22	16.27	10.53	10.74	7.28	15.65	9.72
8	50.67	39.71	16.10	9.38	10.79	5.75	14.73	12.19
9	28.49	33.59	13.33	10.76	10.26	6.67	16.65	12.74
10	33.52	30.33	14.84	7.04	10.78	4.12	17.51	10.29
11	30.35	29.08	8.91	7.99	5.07	4.26	11.49	9.99
Mean	36.68	34.94	14.30	9.24	9.70	5.93	14.85	10.54
Variance	97.54	40.17	4.46	1.62	3.11	2.83	3.31	2.87
Fstat	2.43		2.75		1.10		1.15	
P(F<=f)	0.09		0.06		0.44		0.42	
FCritical	2.98		2.98		2.98		3.18	

Table 7: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Bhavnagar		Jamnagar		Junagadh		Porbandar	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	13.7	8.2	12.4	3.2	14.8	5.3	8.7	3.1
2	10.8	8.5	9.7	4.3	12.1	6.7	6.9	3.8
3	15.4	13.1	10.2	10.3	13.2	13.4	7.9	10.9
4	15.1	7.3	12.9	4.5	16.4	8.7	14.8	3.5
5	19.0	9.5	10.5	6.3	15.4	6.6	10.5	5.5
6	13.2	9.8	8.9	9.7	9.5	10.7	9.7	11.1
7	13.8	6.4	13.0	8.1	17.2	8.8	14.0	8.9
8	13.4	7.9	13.1	5.0	15.5	8.6	15.2	6.7
9	12.7	8.1	10.8	7.8	15.0	7.1	9.3	5.5
10	12.3	5.5	11.9	4.0	14.4	6.0	10.7	3.2
11	6.0	3.9	5.2	2.9	8.4	6.9	4.5	3.2
Mean	13.2	8.0	10.8	6.0	13.8	8.1	10.2	5.9
Variance	11.2	6.4	5.6	6.7	7.9	5.4	11.3	9.5
Fstat	1.7		0.8		1.4		1.2	
P(F<=f)	0.2		0.4		0.3		0.4	
FCritical	3.2		0.3		3.0		3.0	

Table 8: Decadal depth of groundwater level fluctuation (2010 to 2020)

Sr. No.	Surendranagar		Kachchh	
	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	9.92	5.86	13.14	14.72
2	7.77	3.70	11.09	11.18
3	8.85	7.63	11.63	14.51
4	6.44	5.11	13.85	9.72
5	8.80	5.60	18.03	12.07
6	10.69	5.38	14.08	12.65
7	8.01	5.64	13.02	12.60
8	7.37	3.71	12.85	12.84
9	6.83	4.94	18.86	19.64
10	6.81	3.51	20.30	17.82
11	3.63	3.47	18.58	16.91
Mean	7.74	4.96	15.04	14.06
Variance	3.63	1.65	10.58	9.07
Fstat	2.20		1.17	
P(F<=f)	0.11		0.41	
FCritical	2.98		2.98	

Table 9 shows the average depth of groundwater level fluctuation per year during the premonsoon and postmonsoon seasons for the period of 2010 to 2020. During the premonsoon season the groundwater level has been reported maximum rise at Ahmedabad district (1.7406 m/year) and maximum fall at Gandhinagar district (-1.4092 m/year) whereas during the postmonsoon the groundwater level has been reported maximum rise at Mehsana district (1.2963 m/year) and maximum fall at Narmada district (-0.5535 m/year).

It was revealed that groundwater declined continuously in the Vadodara, Banaskantha, Amreli and Kachchh districts. The reason behind this is overdependency on the groundwater uses in these districts. Furthermore, the groundwater level has risen in Dang, Surat, Ahmedabad, Dahod, Kheda, Bharuch, Mahesana, Patan, Sabarkantha, Rajkot, Bhavnagar, Jamnagar, Junagadh and Surendranagar for the premonsoon and postmonsoon periods.

Table 9: Average rate of fluctuation of groundwater (2010 to 2020)

Sr. No.	Name of District	Pre-Monsoon (m/year)		Post-Monsoon (m/year)	
1	Valsad	0.1455	↑	-0.0161	↓
2	Dangs	0.0779	↑	0.0542	↑
3	Navsari	0.0301	↑	-0.1366	↓
4	Tapi	0.1446	↑	-0.2291	↓
5	Surat	0.0797	↑	0.0840	↑
6	Ahmadabad	1.7604	↑	1.2881	↑
7	Vadodara	-0.1208	↓	-0.0548	↓
8	Anand	0.0867	↑	-0.1557	↓
9	Dahod	0.2766	↑	0.2240	↑
10	Kheda	0.0784	↑	0.1334	↑
11	Bharuch	0.1695	↑	0.1131	↑
12	Narmada	0.0370	↑	-0.5535	↓
13	Panch mahals	0.1435	↑	-0.0159	↓
14	Gandhinagar	-1.4092	↓	1.1278	↑
15	Banaskantha	-0.2107	↓	-0.3723	↓
16	Mahesana	0.9568	↑	1.2963	↑
17	Patan	0.1898	↑	0.3198	↑
18	Sabarkantha	0.2872	↑	0.0952	↑
19	Rajkot	0.1240	↑	0.0672	↑
20	Amreli	-0.0273	↓	-0.1228	↓
21	Bhavnagar	0.4037	↑	0.4154	↑
22	Jamnagar	0.1845	↑	0.0647	↑
23	Junagadh	0.1463	↑	0.1003	↑
24	Porbandar	-0.0249	↓	0.0689	↑
25	Surendranagar	0.3328	↑	0.1943	↑
26	Kachchh	-0.6506	↓	-0.4931	↓

(Rise - ↑, Decline - ↓)

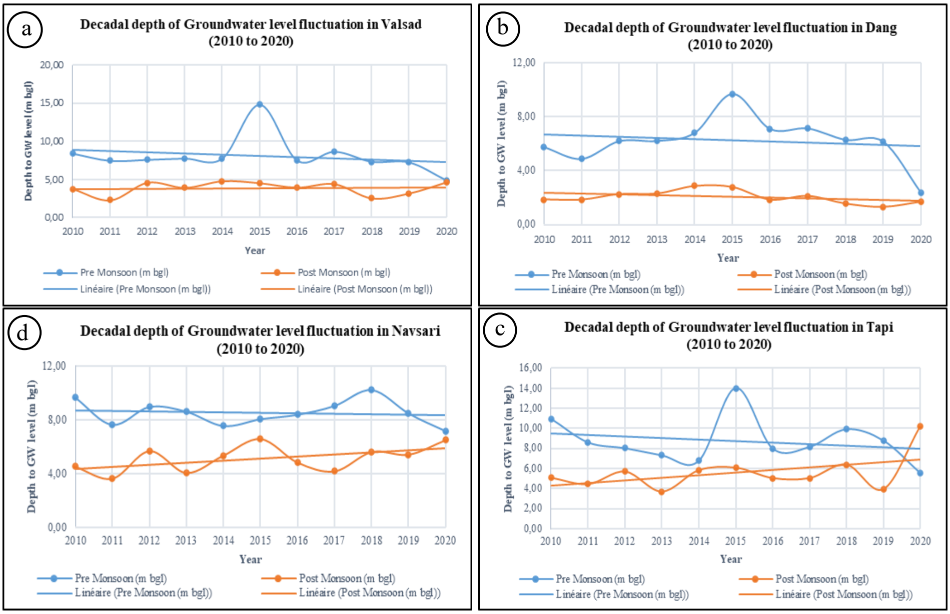

Figure 3 (a, b, c and d): Decadal depth of groundwater level fluctuation in Valsad, Dang, Navsari and Tapi Districts

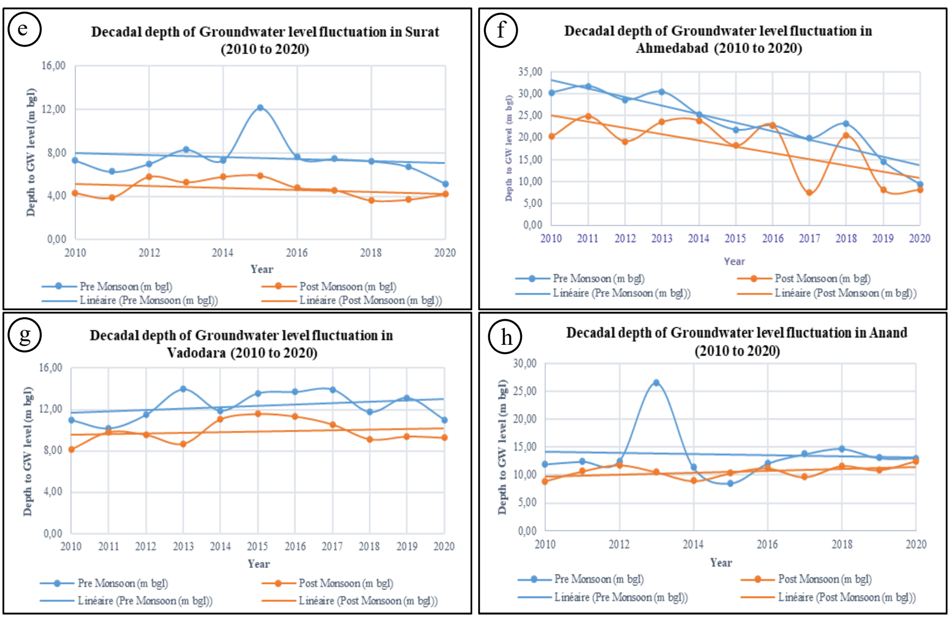

Figure 4 (e, f, g and h): Decadal depth of groundwater level fluctuation in Surat, Ahmedabad, Vadodara and Anand District

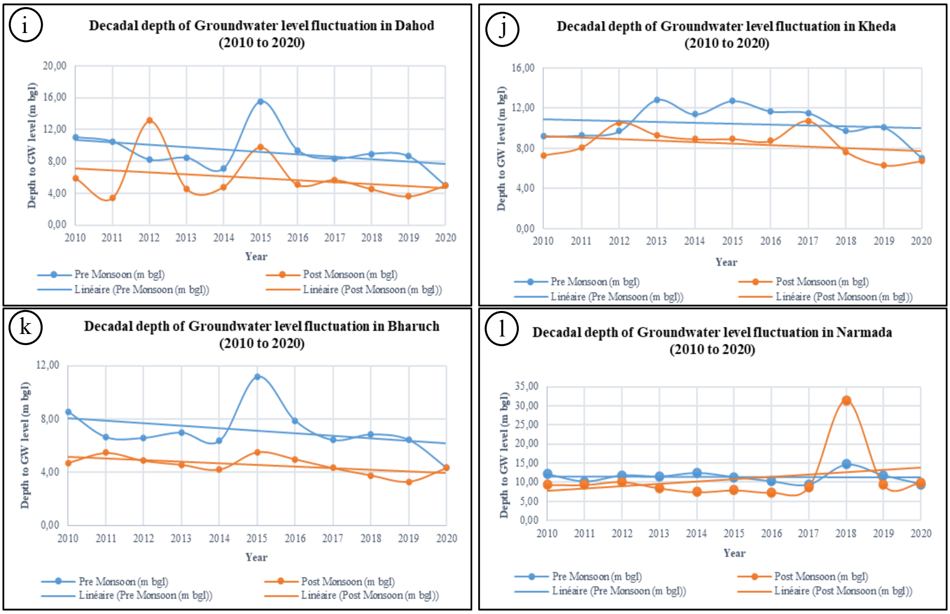

Figure 5 (i, j, k and l): Decadal depth of groundwater level fluctuation in Dahod, Kheda, Bharuch and Narmada Districts

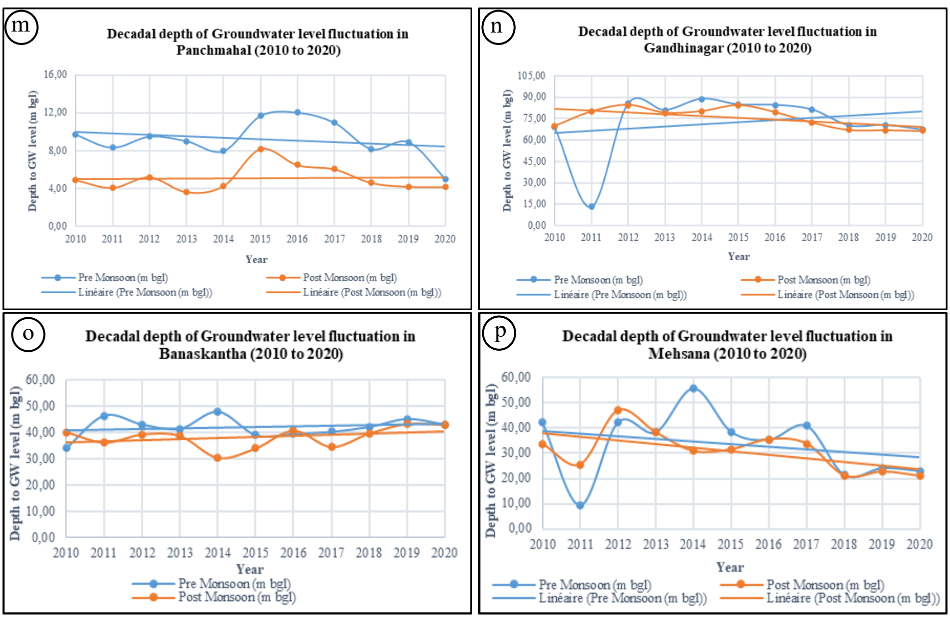

Figure 6 (m, n, o and p): Decadal depth of groundwater level fluctuation in Panchmahal, Gandhinagar, Banaskantha and Mehsana Districts

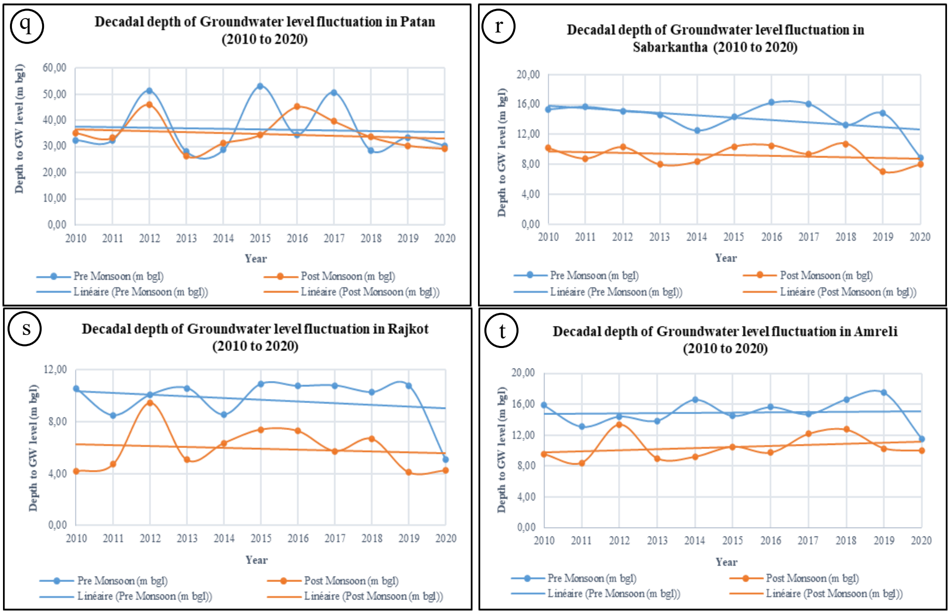

Figure 7 (q, r, s and t): Decadal depth of groundwater level fluctuation in Patan, Sabarkantha, Rajkot and Amreli Districts

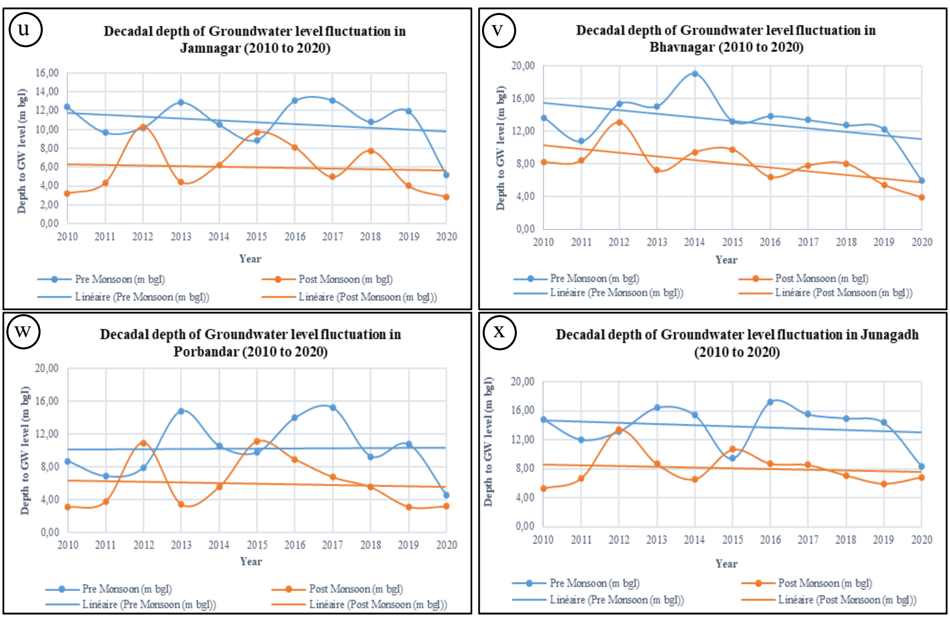

Figure 8 (u, v, w and x): Decadal depth of groundwater level fluctuation in Jamnagar, Bhavnagar, Junagadh and Porbandar Districts

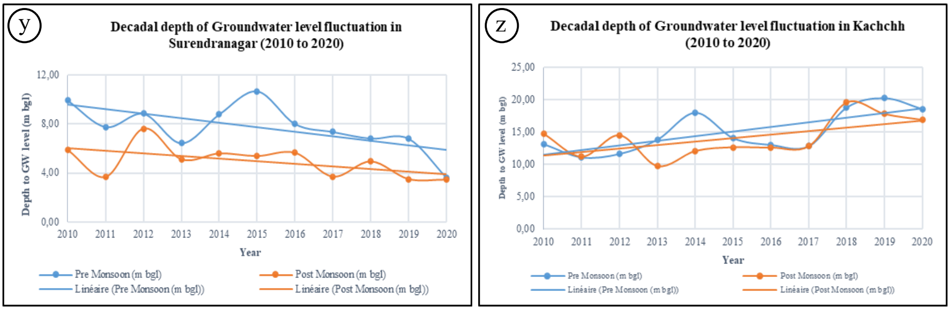

Figure 9 (y and z): Decadal depth of groundwater level fluctuation in Surendranagar and Kachchh Districts

CONCLUSION

This study was carried out to assess the decadal groundwater level fluctuation of Gujarat state. It aims to understand the behavior of the groundwater level over a decade. The depth of groundwater levels was analyzed for a period of 11 years (2010 – 2020) during the premonsoon and postmonsoon seasons over 26 districts of Gujarat state by graphical representation and F test statistical analysis.

The maximum rise was reported in the Ahmedabad district (1.7406 m/year), and the maximum fall was reported in the Gandhinagar district (-1.4092 m/year) during the premonsoon season. The maximum rise was reported in Mehsana district (1.2963 m/year), and the maximum fall was reported in Narmada district (-0.5535 m/year) during the postmonsoon season.

The Ahmedabad district reported a sharp rising trend of 1.7604 m/year for the premonsoon period and 1.2881 m/year for the postmonsoon period. The Kachchh district reported a sharp falling trend of -0.6506 m/year for the premonsoon season and -0.4931 m/year for the postmonsoon season.

Tapi, Kheda, Narmada, Panchmahal, Mehsana, Patan, Sabarkantha, Rajkot, Amreli, Bhavnagar, Junagadh, Porbandar, Surendranagar and Kachchh districts had no significant change in the groundwater level (Fstat < Fcritical).

The Valsad, Dang, Navsari, Surat, Ahmedabad, Vadodara, Anand, Dahod, Bharuch, Gandhinagar, Banaskantha and Jamnagar districts have significant changes in the groundwater level (Fstat > Fcritical).

The study shows that the inappropriate withdrawal of groundwater is a major cause of the declining trend in highly affected districts of Gujarat, such as Kachchh, Banaskantha, Vadodara and Amreli. The present study concludes that the groundwater level sharply rising leads to canal availability or conservation structures, and falling trends lead to overexploitation of groundwater, so attempts should be made toward aquifer recharge in this part of the study area. Overutilization should be restricted under the dynamic recharge zone, and new recharge structures should be constructed to enhance the recharge potential.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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