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VARIATION IN GROUNDWATER QUALITY OF DIFFERENT MORPHOLOGICAL REGIONS IN INDIA

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Abstract*: Groundwater is a necessity now for humans as human population is growing rapidly and need of water is increasing extremely. Human life hinges on groundwater as it is easily available everywhere for drinking, irrigation and industrial purposes. This natural resource has been used continuously for many centuries and it has been deteriorating due to gigantic and anthropogenic activities. The objective of this paper to analyze the groundwater quality data of 16 years (2001-2016) in four types of morphological region (mountainous, plateau, desert and plain) from India. Five districts of India, particularly Solan and Mandi from Himachal-Pradesh, Bhatinda from Punjab, Jaisalmer from Rajasthan and Kurnool from Andhra-Pradesh has been selected as the study region. All of these districts have different morphology. For the study, secondary data has been collected through CGWB (Central ground water board) Ministry of Jal Shakti, Department of Water Resources. To compute the ground water quality Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) has been used. Mann-Kendall test (Non-parametric) was used to find a trend in WQI data for 2001-2016. Results show that mountain region has better ground water quality conditions maybe because of less population and industrial pressure or continuous fresh water supply. In all other regions Plain, Desert and Plateau ground water quality is not well. Desert region is suffering very badly with harsh ground water conditions. And with Mann-Kendall test results one can say that ground water conditions are going worse with time.

Keywords: Ground water quality, Morphological region, Central ground water board, Water Quality Index (CCME WQI), Mann-Kendall test,

INTRODUCTION

Groundwater is a necessity now for humans as the human population is growing rapidly, and the need for water is increasing extremely. Human life hinges on groundwater as it is easily available everywhere for drinking, irrigation, and industrial purposes. During rainfall, water percolates below the ground surface, passes through the voids of the rocks, and joins the water table. These voids are generally interconnected, permitting the movement of the groundwater. In some rocks, the voids may be isolated, preventing the movement of water between the interstices. Evidently, the mode of occurrence of groundwater depends largely upon the type of formation and hence upon the geology of the area. This natural resource has been used continuously for many centuries, and it has been deteriorating due to gigantic and anthropogenic activities. The quality of groundwater has declined to the extent that the use of such water could be harmful. Intensification in overall salinity of the groundwater and occurrence of high concentrations of fluoride, nitrate, iron, arsenic, total hardness, and a few toxic metal ions have been observed in large areas in quite a lot of states of India. Groundwater comprises a wide variety of dissolved inorganic chemical constituents in various concentrations as an outcome of chemical and biochemical interactions between water and the geological materials through which it flows and to a lesser extent because of involvement from the atmosphere and surface water bodies.

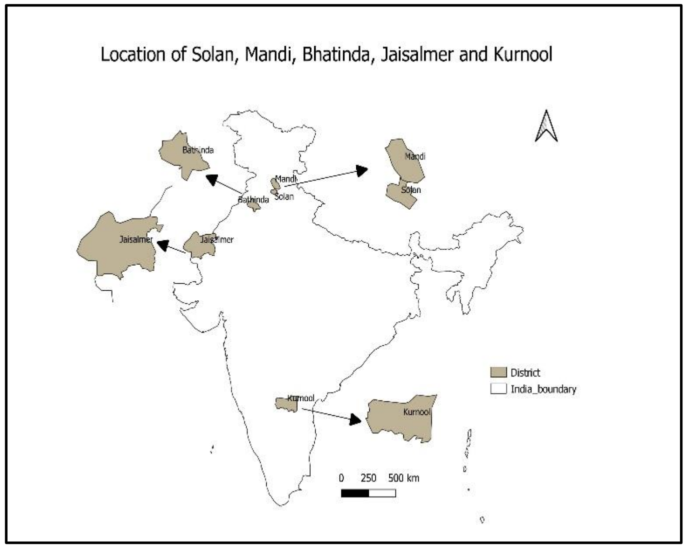
Groundwater quality varies in different regions of India; India has diversified relief features very much from mountain to plains, plateaus, deserts, and other morphological landforms. India has been classified into four major physical regions- the Himalaya, the Gangetic plain, the southern plateau, and the coastal region. This vast country has subdivisions furthermore. For this particular research, four morphological regions have been selected, which are situated in mountain, desert, plain, and plateau regions. The groundwater conditions and their use in a particular area are very much different from one another. Consumption of groundwater relies on population density in the area, industrial concentration, and agriculture pattern. Compared to rigid regions like deserts and mountains, plains and plateaus are always intensively populated as they have favorable human conditions. The impact of these different phenomena should affect the groundwater quality in a different manner in different morphology. This hypothesis made way for this research; the objective of this paper is to find differences in water quality in four morphological regions of India. Groundwater quality has been tested through Water Quality Index (WQI). Water Quality has been studied over a period of 16 years (2001-2016) in the selected representative districts located in mountain plains, plateaus, and deserts regions.

REVIEW OF LITERATURE

The Water Quality Index model was first proposed by Horton (1965)[1]. Brown et al. (1970) established a Water Quality Index by assigning a proper weight for the parameters based on their investigation. It thus becomes a significant parameter for the valuation and administration of groundwater (Chauhan et al. 2010). Ott (1978) and Steinhart (1981) studied more than 20 water quality indices being used before 1980. Steinhart et al. (1982) applied an original environmental quality index to recap technical information on the status of drifts in the Great Lakes Ecosystem. In Canada, the water quality index was presented in the mid-'90s (Rocchini and Swain, 1995; Dunn, 1995; Hebert, 1996) by the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment. This Task Group formed the Water Quality Index Technical sub-committee that in turn adapted the original British Columbia Water Quality Index into the CCME Water Quality Index (WQI), which was recognized by the CCME (CCME, 2001). This newly established CCME WQI has been employed by numerous provinces and Ecosystems all across Canada to evaluate water quality. The water quality index (CCME) for lakes of Mysore has been considered by Hosmani et al. (2011) and Mahesh et al. (2013) and the waters of Mandya by Deviprasad et al. (2012).

[1] Horton RK (1965) An index number system for rating water quality. J Water Pollut Control Fed 37:300–306

THE STUDY AREA



Five districts of India, particularly Solan and Mandi from Himachal-Pradesh, Bhatinda from Punjab, Jaisalmer from Rajasthan, and Kurnool from Andhra-Pradesh, have been selected as the study area. All of these districts have different morphology. Solan and Mandi districts are from the Indian state of Himachal Pradesh. Both the districts have a very less area compared to other districts, and the number of wells in the area is also very less; that's why two districts from one state Himachal Pradesh were taken for the study. The terrain of both the districts is **mostly mountainous,** with an elevation ranging from 300 to 3,000 meters above mean sea level. According to the 2011 census, the population of the solan district is 5.80 lakh. The district covers an area of 1936 km^2. Mandi district is nearly at the geographical center of Himachal, on the left bank of the river Beas in the hills of Shiwalik ranges. Mandi district has a population of 9. 99 lakhs (2011) and an area of 3951 km^2. Bathinda District is sited in the southern part of Punjab State in the core of the Malwa region, which is almost a **plain** region. The district extends across an area of 3,385 square kilometers._It is the second-largest in Punjab in terms of area, after the Ludhiana district. Bathinda district has a population of 13.88 lakh. With an area of 32,401 sq km, Jaisalmer is the largest district in the Indian state of Rajasthan and the third-largest district in India. Jaisalmer is almost entirely a sandy area, making a part of the great Indian **desert**. The overall aspect of the area is that of an incessant sea of Sandhills of all forms and sizes, some rising to a height of almost 150 ft (46 m). According to the 2011 census, Jaisalmer district has a population of 6.69 lakhs. Rayalaseema **plateau** is a geographic region in the Indian state of Andhra Pradesh. It contains four southern districts of the state explicitly, Anantapur, Chittoor, Kadapa, and Kurnool. Kurnool is the fifth district selected as the study area. It has a population of 40.53 lakhs and an area of 17,658 square kilometers.

OBJECTIVE

1. To analyze the groundwater quality data of 16 years (2001-2016) in four types of morphological regions (mountainous, plateau, desert, and plain) from India.

RESEARCH METHODOLOGY

For this study, secondary data has been collected through CGWB (Central groundwater board) Ministry of Jal Shakti, Department of Water Resources. To compute the groundwater quality Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) has been used. The index is founded on a formula established by the British Columbia Ministry of Environment, Lands, and Parks and improved by Alberta Environment and gives a value between 0 (poor water quality) to 100 (excellent water quality). The parameters used to compute the WQI are water quality measurements (e.g., Ph value, TDS), which are then compared to thresholds. In order to rank the inclusive water quality, the Canadian Council of Ministers of Environment CCME recognized the use of an index that mathematically combines all water quality trials and

Table 1.1 Standards used in the study

PARAMETERS	STANDARDS (SN)
CALCIUM(Ca)	75
CHLORIDE(Cl)	250
Electrical Conductivity	300
FLUORIDE(F)	1
POTASSIUM(K)	10
MAGNESIUM(Mg)	30
NITRATE(NO3)	45
SODIUM(Na)	20
SULPHATE(SO4)	200
TOTAL HARDNESS	300
TOTAL_ALKALINITY	120
PH	8.5

provides an overall and readily understood description of the quality of water. Over the years, many countries have accepted the CCME scheme representing the water quality index for water quality monitoring and assessment of surface and underground water in terms of their chemical, biological and nutrient constituents and overall esthetic condition. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) is preferred as a tool for the work due to its simplicity and ability to combine complex water quality data without compromising its technical integrity. The CCME Water Quality Index is considered the most effective method of measuring water quality to determine its suitability for the intended use.

The CCME index was calculated in Microsoft Excel for computing the WQI. The choice of variables depends on the availability of data, so 12 variables- Ca, Cl, Electrical Conductivity, F, K, Mg, NO3, Na, SO4, Total Hardness, Total alkalinity, and pH value were chosen for the study. Standards given in table 1.1 were used to calculate the index; these are based on Indian Standard: 10500-2012 Drinking Water Specification (Second Revision) and WHO guidelines.

The detailed structure of the WQI, as presented in the Canadian Water Quality Index 1.0, is as follows:

f1 (Scope) signifies the percentage of variables that do not meet their standard values at least once during the period under consideration ("failed variables"), relation to the total number of variables measured:

f1 = Sum of failed variables / Total variables × 100

f2 (Frequency) indicates the percentage of specific tests that do not meet guideline standards ("failed tests"):

f2 = Sum of failed tests / Total number of tests × 100

f3 (Amplitude) denotes the total by which failed test values do not encounter their guideline values. F3 is calculated in three stages. The number of times by which a exact concentration is superior to (when the objective is the lowest) the objective is termed an "excursion" and is articulated as follows. In case of test value must not, above the objective:

Excursion = Failed test value / Standard value -1

For other cases in which the test value must not come below the objective:

Excursion = Standard value / Failed test value -1

The united amount by which specific tests are out of compliance is calculated by summing the excursions of specific tests from their standard values and separating them by the total number of tests. This variable, stated as the normalized sum of excursions, or nse, is computed as:

nse = $\sum_{i=1}^{n} \text{Excursion}$ / number of tests

F3 is then computed by an asymptotic function that scales the regulated sum of the excursions from standard value (nse) to yield an array between 0 and 100.

f3= nse/0.01nse+0.01

Once all aspects have been found, the index itself can be intended by summing the three aspects as if they were courses. The summation of the squares of each aspect is therefore equal to the square of the index. This process gives the index as a 3D space defined by each aspect along one axis. With this model, the index changes in direct share to hang in all three aspects. The CCME Water Quality Index (CCME WQI):

CCME WQI = 100 – (√ f1+f2+f3/1.732)

The divisor 1.732 regularizes the resulting values to a range between 0 and 100, where 0 denotes the "worst" water quality and 100 denotes the "best" water quality. According to the CCME WQI water quality was ranked in the following 5 groups:

Table 1.2 Water quality index values and their description		
Designation	Index value	Description
Excellent	95-100	Very close to natural or original levels.
Good	80-94	Conditions hardly depart from natural or desirable levels
Fair	65-79	Conditions occasionally depart from natural or desirable levels.
Marginal	45-64	Conditions occasionally depart from natural or required levels.
Poor	0-44	Conditions generally depart from natural or desirable levels.

Mann-Kendall test (Non-parametric) was used to find a trend in WQI data for 2001-2016. There are a number of statistical tools for detecting trends and seasonal variation in the environmental time-series data. There are two mathematical tools to calculate the trend analysis: the parametric tools, which are more powerful but require the data to be independent and normally distributed, and the nonparametric tools, in which observations are dependent. The Mann Kendall test is one of the widely used nonparametric tests to detect the significant trends in time series data. Using Mann Kendall's test, it is possible to determine the existence of an increasing or decreasing trend. Mann Kendall's test, it is possible to determine the existence of an increasing or decreasing trend. Nonparametric tests to detect trends in water quality data has been used by many researchers among them are Hirsch and Slack, Gilbert, Walker, Yu-shen, and Zou, who used the tools because of the relative simplicity and minimal data assumption of the tests that make them a more popular choice for analyses of water quality time series.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_{J-}X_K)$$

Where

$$sgn(x) = \begin{cases} 1\ if\ x > 0 \\ 0\ if\ x = 0 \\ -1\ if\ x < 0 \end{cases}$$

The mean of *S* is E*(S)*= 0 and the variance σ^2 is

$$\sigma^2 = \{n(n-1)(2n+5) - \sum_{j=1}^{n} t_j(t_j - 1)(2t_j + 5\ ))/18$$

where p is the number of the tied groups in the data set and *tj* is the number of data points in the j^{th} tied group. The statistic *S* is nearly normal distributed provided that the following Z-transformation is employed:

$$Z = \begin{cases} \frac{s-1}{\sigma} if\ s > 0 \\ 0\ if\ s = 0 \\ \frac{s+1}{\sigma} if\ s < 0 \end{cases}$$

If $|Z_s|$ is greater than $Z_\alpha/2$, where α signifies the chosen significance level (E.g.: 5% with Z 0.025=1.96) then the Null hypothesis is invalid, implying that the trend is significant (Motiee and MeBean,2009).

RESULTS AND DISCUSSION

Data from 2001 to 2016 have been analyzed for each of the stations. Twelve parameters - Ca, Cl, Electrical Conductivity, F, K, Mg, NO3, Na, SO4, Total Hardness, Total alkalinity, and pH value have been included in the process.

TABLE 1.2 Computed CCME WQI values for each station in different regions (2001-2016)

STATION NAME	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	AVG	WQI
Bathinda (Plain region)																		
Ablu		81.6	56.82	**85.96**	**42**	52.03	75.72	59.72	70.54	53.64	75.37	48.55	63.59	60.34	47.13	62.86	62.39	Marginal
Balluana1		9.26	2.8	13.07	28.56	36.55	100	38.92	43.49	33.86	35.36	40.64	51.24	49.82	21.72	38.57	36.26	Poor
Bhagibandar	30.34	29.04	41.5	62.08	38.44	15.06	22.46	39.83	20.12	11.33	42.68		9.08	14.11	48.34	26.65	30.07	Poor
Deratapp		66.85	17.17	57.01	70.98	68.62	69.7	77.39	77.18	85.69	79.21	85.79	78.47	72.01	70.19	70.09	69.76	Fair
Dhapali		100	14.42	92.16	55.03		100		100	100	100	86.05		63.49	86.3	44.18	78.47	Fair
Dialpur mirza	23.53	29.09	4.16	27.61	40.64		35.32	34.05	29.96	43.68	47.03	46.23	42.08		36.57	30.85	33.63	Poor
Ghudda		43.68	7.56	34.13	26.17	37.41	42.25	34.07	34.6	18.71	31.05	18.7	32.92	22	28.52		29.41	Poor
Jajjal		40.69	57.57	35.72	20.87	33.13	48.9	39.58	28.48	42.54	48.02	40.91	40	100	19.26	46.42	42.81	Poor
Jassi bhagwali		63.76	10.2	58.77	48.17	39.12	47.41	53.39	36.95	45.11	28.78	38.55	44.97	33.76	29.32	41.05	41.29	Poor
Jhanduke	28.58	33.14	6.44	36.75	44.68	31.35	35.55	50.35		50.16	46.11	56.09	44.53	49.96	24.06	23.48	37.42	Poor
Kalla bandar		46.02	38.47	22.17	16.39	14.34	22.76	16.79	21.17	26.55	33.03	28.7		19.3	20.37	41.36	26.24	Poor
Kot shamir		19.54	6.51	15.61	29.7	23.9	23.32	22.77	19.02	24.99	26.24		32.84	16.71	23.76	25.6	22.18	Poor
Nahinwala		32.93	45.83	43.8	42.42	37.7	19.24	25.45	30.83	32.31	45.75	32.01		24.99	40.32		34.89	Poor
Raike kalan		18.08	46.19	35.43	48.16	29.46	51.28		39.45	34.28	48.75		37.35	16.99		31.54	36.41	Poor
Rampura		10.14	3.77	25.52	42.28	43.27	42.5	40	50.93	54.23	49.88	23.91	54.66	31.04	31.67	65.06	37.92	Poor
Bathinda (AVG.)																	**41.28**	**Poor**
Jaisalmer (Desert Region)																		
Ajasar	29.48	34.83		28.95		23.6		26.03	29.48	11.9		24.71					26.12	Poor
Bhainsara		50.57		38.61	32.44		48.2	36.58			51.06	9.5	55.78		50.72		41.50	Poor
Gotaru	47.12	50.63		46.41	44.25	42.83	45.39	42	47.12	26.03	45.97	35.21	32.18	32.2	31.34		40.62	Poor
Jaisalmer	19.49	49.48		20.28	28.77		24.61	28.48	19.49	16.52		11.69	17.09	17.09			23.00	Poor
Kalewa	33.09	33.58				34.11		21.76	33.09	16.6	26.89	14.79	27.07	26.89	17.02		25.90	Poor
Khuri	14.09	15.06		20.61	20.48		21.15	21.15	41.48	41.42	24.96	46.19	14.35		13.76		24.56	Poor
Khuyiala	27.98	47.94		36.03	44.1	49.82		65.6	27.98	55.47	49.98	35.77	50.58	50.58	49.73		45.51	Marginal
Kuria		40.45		45.54	39.94		34.72	40.98				35.44			39.68		39.54	Poor
Lawan	33.4	38.38		39.68	32.52			44	33.4	17.1		35.96	41.21	17.1	26.82		32.69	Poor
Loharki		34.49		29.28	28.83		28.93			18.78		22.51	17	22.51			25.29	Poor
Madasar	31.83	44.67		40.68	50.07			41.96	31.83	51.23	37.02	9.14	36.56	37.06	36.34		37.36	Poor
Moolsagar	42.89	57.36		23.72	35.6		35.18	23.67	42.89	36.9			47.56	45.49	46.87		39.83	Poor
Phalsund	39.52	37.43			17.19	30.17		23.66	39.52	12.81	23.7		28.84				28.09	Poor
Sadewala	25.02	34.34		19.65	24.83		24.59	19.34	25.02		24.39	19.63	19.64				23.65	Poor
Sam1	45.27	55.5		63.97	53.46	48.67	65.77	50.33	45.27			50.29	59.16	62.13	52.27		54.34	Marginal
Jaisalmer(AVG.)																	**33.87**	**Poor**
Kurnool (Plateau region)																		
Ahobilam		79.47	77.36	85.6	57.64	47.49	70.58	77.6	70.84	63.22	61.53	59.13	63.59	69.63	71.23		68.21	Fair
Battulur		24.77	47.36	21.97	41.49	19.19	19.25	23.99	25.07	13.08	23.68	42.03	24.25	18.42	18.9	13.96	25.16	Poor
Gonegondla		34.49	39.64	43.23	63.25	30.31		27.88	27.78	44.62		81.97	27.93	31.08	25.16	34.19	39.35	Poor
Holagondi		60.2	42.09		34.49	67.2	28.36	46.64	27.91	35.45	37.5	75.27		32.13		29.26	43.04	Poor
Karivemula		62.47	54.11	57.69	28.35	64.21	62.16	62.68		57.25	60.62	62.56	60.16	59.78	47.55	61.2	57.20	Marginal
Moravakonda		51.6		40.38		39.49	23.99	34.25	39.95	32.29	33.4	35.66		40.28	23.66	28.88	35.32	Poor
Naganathanahalli		20.87	7.05	22.8	11.55		32.21	27.17		10.63	16.22	21.16	16.47	16.01	14.86	16.51	17.96	Poor
Nandikotkur				40.18		30.74	27.89		38.98	42.02	34.16	41.32	39.28	27.16			35.75	Poor
Nossam		83.22		62.63		38.86		49.32	54.95	40.04	55.66		30.78	35.15	33.21	34.76	47.14	Marginal
Orvakallu		36.52		32.21	31.91	20.26	20.95	15.68	30.28	27	34.07	56.72	35.1				30.97	Poor
Santajutur		30.68	41.64		67.92		9.23	15.33	40.87	37.58	37.32	26.24	15.64	36.46	29.53	46.29	33.44	Poor
Veldurti		37.19	27.02	25.82	18.22	50.62	25.79		44.98		43.83	20.68	25.93		24.81	25.68	30.88	Poor
Velugodu		75.47	70.11	81.21	76.2	58.31	55.63	70.8	68.65	52.74	43.67	75.67	71.88	40.24			64.66	Fair
Venkatapuram2		58.22	13.17	54.37	62.3	56.51		49.89	54.46	57.55	54.79	60.28	31.59	30.24	23.46	56.52	47.38	Marginal
Yenugumarri		40.18	70.73	47.15		51.53	24.59	24.25	44	47.65	49.37	51.74	47.24	41.46	32.97		44.07	Marginal
Kurnool (AVG.)																	**41.37**	**Poor**
MANDI and SOLAN (Mountain Region)																		
Bahangrotu		65.29	63.22	61.73	84.08	71.15	37.58	43.19	37.67	83.55	48.11	40.07		51.3	43.93		56.22	Marginal
Gagal		91.82	91.83	100	100	100	100	100	100	100	100	100		100	100		98.74	Excellent
Gutkar		76.76	74.95	83.58	84.94	60.24	85.02	86.35	86.18	65.45	77.68	86.29		77.43	68.85		77.98	Fair
Jarl		82.8	100	82.87	84.76	81.49	77.59	85.77	84.94	100	83.52	79.25		79.43	79.42		84.76	Good
Jhiri		68.51	100	91.83	85.06	100		86.06	85.96	84.66	85.7	100		100	100		90.65	Good
Lohara		82.64	82.9	64.77	84.34	82.82	83.7	75.97	77.35	92.58	77.57	77.3		69.39	69.46		78.52	Fair
Baddi	76.41	55.87	43.84	44.68	61.9	64.67		57.47	49.35	68.39	54.67	100					61.57	Marginal
Barun	73.15	74.5	64.56	64.83	59.88	76.61	61.72	75.16		77.55	79.33	84.95		64.25	64.8		70.87	Fair
Bhagheri	75.93	84.77	54.42	42.95	59.47	60.64	63.55	61.06	49.63	61.6	58.79	58.1		85.13	76.31		63.74	Marginal

Bhatoli	53.41	67.92	83.23	74.65		77.31	79.58	63.68	78.06	77.31	85.06	86.22			78.7		75.43	Fair
Dhabota	74.99	75.39	72.96	64.77	69.35	75.12	71.57	60.18	69.17	67.9	78.16	70.5			76.17		71.25	Fair
Jagatpur	72.19	75.6	74.74	73.15	72.73	76.19	79.27	70.09	78.24	76.07	77.31	78.63		77.56	77.56		75.67	Fair
Khera-chak	66.44	74.61	62.03	71.7	64	71.9	80.88	57.92	72.31	72.91	69.76	73.5		76.71	70.41		70.36	Fair
Mahadev	63.8	67.79	63.04	67.11	68.1	72.04	73.23	70.7	72.85	73.87	68.04	71.54		61.39	62.43		68.28	Fair
Phalahi		76.88	70.34	82.09	77.06	76.48	78.05	71.41	69.77	69.49	71.83	77.83			64.88		73.84	Fair
MANDI and SOLAN (AVG.)																	**74.52**	**Fair**

CCME index WQI:

Table 1.2 shows the results of CCME WQI values of each region from 2001 to 2016. Every region has 15 monitoring stations; a total of 60 stations' WQI values were calculated. The plain region has an average value of 41.28, which shows a Poor status of Groundwater quality. Desert and plateau regions also have a Poor status as both have got WQI values less than 44. These are very critical groundwater quality conditions- almost always threatened or impaired. The only mountain region that has fair groundwater quality, condition as its WQI value is 74.52, where water is usually protected. The plain region has only three stations where groundwater quality is above marginal; all other 12 stations got the poor status of WQI. While in the desert region, 13 stations have poor groundwater quality, the other two have marginal status, and in the plateau region, nine stations are suffering from poor groundwater quality, four stations have marginal status, and only two stations have the fair status of groundwater quality. Whereas the mountain region doesn't have Poor quality status anywhere, only three stations have a marginal status; all others have fair, good, and excellent groundwater quality.

Mann-Kendall test:

Table 1.3 Mann-Kendall test results

Station Name	Observations	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	p-value	Sen's slope
Bathinda (Plain region)								
Ablu	16	42.00	85.96	63.59	13.54	-0.26	0.176	-1.320
Balluana1	16	2.80	100.00	34.57	22.95	0.44	**0.019**	2.338
Bhagibandar	16	9.08	62.08	29.81	14.77	-0.18	0.344	-1.155
Deratapp	16	17.17	85.79	69.58	15.80	0.43	**0.024**	1.045
Dhapali	16	14.42	100.00	80.87	25.20	-0.21	0.299	-0.463
Dialpur mirza	16	4.16	47.03	34.26	10.54	0.35	0.065	0.998
Ghudda	16	7.56	43.68	30.25	9.95	-0.35	0.064	-0.958
Jajjal	16	19.26	100.00	42.67	18.22	0.06	0.787	0.145
Jassi bhagwali	16	10.20	63.76	42.69	13.90	-0.44	**0.019**	-1.644
Jhanduke	16	6.44	56.09	38.22	13.26	0.17	0.392	1.316
Kalla bandar	16	14.34	46.02	27.34	10.53	-0.09	0.652	-0.305
Kot shamir	16	6.51	32.84	22.47	6.37	0.33	0.087	0.650
Nahinwala	16	19.24	45.83	34.71	7.97	-0.17	0.391	-0.236
Raike kalan	16	16.99	51.28	35.48	11.55	-0.08	0.718	-0.258
Rampura	16	3.77	65.06	36.19	17.83	0.46	**0.015**	2.389
Jaisalmer (Desert Region)								
Ajasar	16	11.90	34.83	25.57	5.27	-0.50	**0.010**	-0.399
Bhainsara	16	9.50	55.78	44.01	11.26	0.24	0.223	0.473
Gotaru	16	26.03	50.63	40.53	7.78	-0.66	**0.001**	-1.325
Jaisalmer	16	11.69	49.48	22.68	9.46	-0.56	**0.003**	-1.226
Kalewa	16	14.79	34.11	26.98	7.29	-0.47	**0.013**	-0.955
Khuri	16	13.76	46.19	22.57	10.76	0.05	0.822	0.119
Khuyiala	16	27.98	65.60	46.31	10.28	0.22	0.259	0.537
Kuria	16	34.72	45.54	39.04	2.80	-0.27	0.162	-0.212
Lawan	16	17.10	44.00	33.21	8.26	-0.24	0.223	-0.628
Loharki	16	17.00	34.49	25.52	5.46	-0.61	**0.001**	-1.000
Madasar	16	9.14	51.23	38.59	9.74	-0.30	0.114	-0.561

Moolsagar	16	23.67	57.36	40.50	8.68	0.32	0.095	0.616
Phalsund	16	12.81	39.52	27.63	7.22	-0.03	0.928	0.000
Sadewala	16	19.34	34.34	23.24	4.05	-0.56	**0.004**	-0.460
Sam1	16	45.27	65.77	53.80	6.55	0.03	0.892	0.145
Kurnool (Plateau region)								
Ahobilam	16	47.49	85.60	69.10	9.87	-0.20	0.299	-0.730
Battulur	16	13.08	47.36	25.14	9.95	-0.34	0.071	-0.590
Gonegondla	16	25.16	81.97	39.90	16.18	-0.13	0.528	-0.365
Holagondi	16	27.91	75.27	43.71	15.10	-0.31	0.105	-1.009
Karivemula	16	28.35	64.21	57.70	8.83	-0.11	0.589	-0.087
Moravakonda	16	23.66	51.60	37.46	8.20	-0.53	**0.005**	-1.228
Naganathanahalli	16	7.05	32.21	18.45	6.25	-0.16	0.417	-0.340
Nandikotkur	16	27.16	42.02	35.34	5.69	-0.37	0.055	-0.636
Nossam	16	30.78	83.22	50.80	17.03	-0.66	**0.000**	-3.075
Orvakallu	16	15.68	56.72	32.31	9.14	0.08	0.716	0.059
Santajutur	16	9.23	67.92	34.92	14.78	-0.13	0.528	-0.271
Veldurti	16	18.22	50.62	32.06	9.89	-0.26	0.176	-0.432
Velugodu	16	40.24	81.21	62.28	14.83	-0.53	**0.006**	-2.485
Venkatapuram2	16	13.17	62.30	48.42	14.96	-0.21	0.279	-0.448
Yenugumarri	16	24.25	70.73	43.46	11.44	-0.10	0.620	-0.456
MANDI and SOLAN (Mountain Region)								
Bahangrotu	16	37.58	84.08	55.36	15.50	-0.30	0.114	-1.507
Gagal	16	91.82	100.00	98.47	3.30	0.58	**0.007**	0.000
Gutkar	16	60.24	86.35	77.57	8.16	-0.02	0.964	-0.007
Jarl	16	77.59	100.00	83.96	6.71	-0.24	0.206	-0.284
Jhiri	16	68.51	100.00	90.58	10.75	0.41	**0.042**	1.008
Lohara	16	64.77	92.58	77.89	7.29	-0.37	0.052	-0.942
Baddi	16	43.84	100.00	71.14	21.66	0.47	**0.015**	3.175
Barun	16	59.88	84.95	71.07	7.42	0.13	0.528	0.271
Bhagheri	16	42.95	85.13	65.02	12.15	0.24	0.207	1.333
Bhatoli	16	53.41	86.22	76.43	8.42	0.43	**0.024**	0.753
Dhabota	16	60.18	78.16	71.91	4.76	0.18	0.367	0.206
Jagatpur	16	70.09	79.27	75.94	2.66	0.40	**0.038**	0.286
Khera-chak	16	57.92	80.88	70.66	5.74	0.23	0.241	0.289
Mahadev	16	61.39	73.87	67.80	4.26	-0.09	0.652	-0.087
Phalahi	16	64.88	82.09	72.96	5.05	-0.50	**0.008**	-0.816

Mann-Kendall test was done for trend analysis. The results show that in the plain region, only four stations have seen a trend; all other stations in the region have no trend. Balluana1 and Rampura stations with a ***p*-value of 0.019 and 0.0015** show positive trends, while Deratapp and Jassi bhagwali stations **(*p*-value 0.024 and 0.019)** have a negative trend as per Sen's Slope values. Desert region has six stations with a trend. All six stations (Ajasar (***p*-value 0.010),** Gotaru (***p*-value 0.001),** Jaisalmer (***p*-value 0.003),** Kalewa (***p*-value 0.013),** Loharki (***p*-value 0.001),** Sadewala (***p*-value 0.004)**) have a negative trend with negative Sen's slope value. Only three stations with a trend found in the Plateau region. Moravakonda (***p*-value 0.005)**, Nossam(***p*-value 0.000)** and Velugodu(***p*-value 0.006)** all three stations have negative trend. In the mountain region, six stations have been found with a trend. Five of them are having a positive trend (Gagal (***p*-value 0.007),** Jhiri (***p*-value 0.042),** Baddi (***p*-value 0.015),** Bhatoli (***p*-value 0.024)**, Jagatpur (***p*-value 0.038)**), the only Phalahi station has a negative trend with ***p*-value of 0.008**.

Conclusion

In this small-scale study, results show that the mountain region has better groundwater quality conditions, maybe because of less population and industrial pressure or continuous freshwater supply. In all other regions, Plain, Desert, and Plateau, groundwater quality is not well. The Desert region is suffering very badly from harsh groundwater conditions. And with Mann-Kendall test results, one can say that groundwater conditions are going worse with time. A few stations show some positive change in groundwater quality, but it's not enough for sustainable development in all morphological regions.

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