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Spatiotemporal Variability Analysis of Groundwater Level for Water Resources Development and Management in Northern Punjab, India

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Abstract

The present study was conducted for investigating spatiotemporal variations in the groundwater levels recorded on monthly basis during 2006-2013 in northern parts of Punjab, India, comprising of 3 districts viz., Amritsar, Gurdaspur and Tarn Taran. The entire data of 8 years was divided into three seasons: pre-monsoon (February-May), monsoon (June-September) and post monsoon (October-January). It was observed in Gurdaspur district that the groundwater level depths increased in monsoon seasons with an overall variation range of 0.22% to 9.67%. In Amritsar district, in monsoon season, the highest increase of 6.22% in groundwater level depth was found in the Ajanala block and least increase of 0.36% in Tarshika, while in Tarn Taran district, the highest increase of 3.87% in groundwater level depth was found in the Noushera Pannua block and least increase of 0.95% was found in Tarn Taran block. The groundwater level decreased in the range of 0.15 m to 1.80 m with an annual decrease in groundwater level in the range of 0.02 m to 0.23 m. The increase in groundwater level depth in monsoon seasons was found due to extreme usage in irrigation for rice crop and the recharging of aquifers is not speedy. However, it has also been observed that the groundwater level rises again in the post monsoon season due to the groundwater resilience of the aquifers. Besides this, the extensive recharge in the area is observed by Ravi and Beas rivers because of perennial nature. A regular monitoring of groundwater in different seasons of the year and its spatiotemporal analysis is required for adopting the appropriate management practices including conjunctive use of surface and groundwater for maintaining its sustainability.

Keywords: Groundwater level; Spatial and temporal variations; trend; Fluctuations; Northern Punjab

Introduction

The present trend of ever-increasing human and livestock populations, change in cropping pattern and polluting surface water bodies leading to heavy usage and consequential depletion of fresh water resources in all over the World and the groundwater regime may not be sustainable for more than a few decades. Estimates of ground water resources of India as on 2011 shows that about 245 billion cubic meter (BCM) fresh water resource is abstracted annually of which 91% is used in agriculture and remaining 9% is used in domestic and industrial purpose [1]. The use of groundwater to agriculture is more as compared to other uses leading to groundwater depletion. Such patterns of steady groundwater decline are witnessed in many parts of the country, particularly Punjab [2,3] which occupies more than twice of the national average (40%) of the available cultivated land. The annual rate of groundwater level decline found to increase by about 80% during 1980-2005 [4] and which is projected to fall by about 21 meter in 2/3rd area of central Punjab during next 2 decades [5].

In Punjab, most of the studies were carried out focusing on the groundwater level and quality in Bist-Doab, Punjab [6-19] but no such study was carried out in the northern area (Majha, Vern). This area comprises of the modern districts of Amritsar, Gurdaspur and Tarn Taran. The cultivable area in all these 3 districts is more than 80%. The main problem of the Amritsar and Tarn Taran districts is the over-exploitation of groundwater and in Gurdaspur district the groundwater is depleting at an alarming level and the stage of groundwater development is more than 100% (Table 1).

The present study was carried out to analyze the monthly groundwater level monitored during 2006-13 for assessing the spatiotemporal variations. This study will provide useful input to the engineers and water resource planners for development and management of surface and groundwater resources.

Study Area

The northern Punjab also called “Majha” (means “central” or “that lies in the middle” of the historical Punjab) is the region of Punjab bounded by rivers Beas and Sutlej on the right banks extending upto river Jhelum at its north most part. Majha includes a considerable portion of the Bari Doab (the region between the rivers Beas and Ravi) and the Rechna Doab (the region between the rivers Ravi and Chenab), and a smaller portion of the Jech Doab region (the region between the rivers Jhelum and Chenab). The northern Punjab includes 3 districts Amritsar, Gurdaspur and Tarn Taran and the details of the districts are given in (Table 1) [6-8, 29, 30].

Amritsar

Amritsar comes under tropical steppe, semi-arid and hot climate with normal annual rainfall 680 mm and over 31 rainy days. The south west monsoon contributes 75 % of the total rainfall [6]. Soils in the western part of the district are coarse loamy, calcareous soils, where as in the central part of the district soils are fine loamy, calcareous and are well drained. As per report of [6] depth to water level in the district ranges from 6.41 to 22.98 mbgl (meter below ground level) during pre monsoon period and between 4.91 to 22.98 mbgl during post monsoon

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Serial No.	Parameters	Amritsar	Gurdaspur	Tarn Taran
1	Latitude (N)	31°28' - 32°15'	31°36' - 32° 34'	30°05' - 31°30'
2	Longitude (E)	74°29' - 75°24'	74°56' - 75° 24'	74°30' - 75°15'
3	Elevation from mean sea level (MSL) (m)	230	305-381	227
4	Area (Sq. km)	5056	3513	2449
5	Population(as per 2011census)	24,90,891	22,99,026	11,20,070
6	Population growth from 2001 to 2011(%)	15.48	9.30	19.28
7	Normal Annual Rainfall (mm)	680	1013	545
8	Normal Monsoon Rainfall (mm)	510	890	382
9	Normal Rainy days	31	48	30
10	Temperature (Mean Minimum) (°C)	5.1 (January)	5.0 (January)	4.5 (January)
11	Temperature (Mean Maximum)(°C)	41.1 (May & June)	44.0 (May & June)	40.5 (May & June)
12	Soil type	Loamy sand, sandy loam	Reddish chestnut & tropical arid	Arid
13	Depth water level (pre monsoon) (mbgl-meter below ground level)	6.41-22.98	2.39-18.93	7.97-21
14	Depth water level (post monsoon) (mbgl-meter below ground level)	4.91-22.98	1.70-16.76	8.23- 21.5
15	Rate of decline of groundwater (m/yr)	0.50	0.35	0.29
16	Net area sown (Sq. km)	2220	2850	2100
17	Percent Agricultural Area	84	81	86
18	Net Annual Groundwater availability (ham)	129956	185256	116164
19	Existing gross ground water draft (ham)	190691	197697	182284
20	Stage of Ground Water Development (%)	147	107	160.
21	Water Type (Shallow Groundwater)	CaMg-HCO_3	CaMg-HCO_3	CaMg- HCO_3
22	EC (µS/cm)	375-875	235-1640	355-1200
23	Water course	Upper Bari Doab canal, Beas River	Rivers Beas & Ravi	Upper Bari Doab canal
24	Major crops	Rice, Wheat	Wheat, rice	Wheat, rice,

Table 1: Details of the districts under study at a glance.

period. Groundwater is CaMg- HCO_3 type and EC is found less than 1000 µS/cm at 25˚C). All the blocks come under the category "over-exploited" [6].

Gurdaspur

The climate of the district is tropical type with normal annual rainfall of the area is 1113 mm out of which 80% is contributed by south western monsoon [8]. The district can be divided into three geo-morphological types-hilly area, piedmont zone and alluvial plain. Water levels of the area in pre-monsoon period varies from 2.39 (Khani Khui) to 18.93 mbgl with the shallowest water level in the eastern and north-eastern portion of Gurdaspur town and the deepest water levels are around Shri Hargobindpur and Fatehgarh Churrian. In the same way the post monsoon water levels are variable from 1.70 mbgl (Behram pur) to 16.76 mbgl (Sri Hargobindpur). Groundwater is CaMg- HCO_3 type and EC ranges from 235 to 1640 µS/cm at 25˚C [8].

Tarn taran

Tarn Taran comes under tropical steppe, semi-arid and hot with normal annual rainfall of the district is 545 mm with 30 rainy days. Out of the total, south west monsoon contributes 74%. Saline and alkaline soils occur in the district. Water levels in pre-monsoon and post-monsoons are found 7.97-21 m (bgl) and 8.23-21.50 mbgl, respectively [7]. Groundwater is CaMg- HCO_3 type and EC ranges from 355 to 1200 µS/cm at 25˚C [7].

Materials and Methods

The monthly water level data was measured in shallow piezometers/ bore holes (60 m) developed by Punjab Water Resources and Environment Directorate, Chandigarh in 4 blocks (Ajnala, Majitha, Rayya and Tarsika) of Amritsar district; 8 blocks (Batala, Dera Baba Nanak, Dina Nagar, Gurdaspur, Fatehgarh Churian, Kahnuwan, Kalanaur and Sri Hargovindpur) of Gurdaspur district and 5 blocks (Bhikhiwind, Gandiwind, Khadur Sahib, Naushera Pannua and Tarn Taran) of Tarn Taran district using the water level recorders. The locations map is given in (Figure 1). Across these districts, detailed water level data sets has been generated sequentially on monthly basis over the last 8 years between January 2006 to December 2013 for assessing the patterns of groundwater level trends. The entire data was divided into 3 seasons as pre-monsoon (February-May), monsoon (June-September) and post monsoon (October-January). The data processing was done to remove the erroneous data before statistical analysis. The erroneous values were rectified.

Results and Discussion

The average water level and its spatial distribution are shown in (Figures 2 and 3), respectively. The average water level (bgl) during 2006-2013 in Amritsar, Gurdaspur and Tarn Taran was 10.04 m, 6.64 m and 14.83 m below ground, respectively. In Gurdaspur district, the water level is very high followed by Amritsar with an extreme low in Tarn Taran district. The observed dataset point towards the declining and fluctuating groundwater levels in the Majha Region of Punjab during 2006-2013. The maximum decline to 3.33m level was found in Tarn Taran district, which is followed by a decline of 1.37 m in Amritsar district and least decline to the tune of 1.08 m was found in Gurdaspur district. Analysis of water table depth has shown that the groundwater depth shows variation from 8.20 to 11.25 mbgl in Amritsar, 5.75 to 7.26 mbgl in Gurdaspur and 13.49 to 15.50 mbgl in Tarn Taran. The increased depth of water level was found in June and July months in all the blocks, due to extreme usage in irrigation for rice crop. Besides this, the least depth of water level was found in the months of February-March due to the recharge in post monsoon season.

The continuous rotation of wheat and paddy cropping pattern, degraded and depleted soil and water and the extensive water usage in Punjab resulted in falling groundwater levels. Rodell *et al.* [3] have also reported irrigation as a major cause for high water level depletion. Similar results are also obtained in the detailed study carried out in Bist Doab region by Krishan *et al.* [13,14]. In the study, the automatic water level recorders were installed in the 6 piezometers and a high resolution data was obtained. It was observed that the water level depth increased due to the more use of groundwater during Kharif season and the water level depth decreased during the pre-monsoon period.

As evident from (Table 2 and Figure 4) that the groundwater level depths were increased in monsoon seasons with an overall variation range of 0.22% to 9.67%, which were observed in Gurdaspur district. In Amritsar district, in monsoon season, the highest increase of

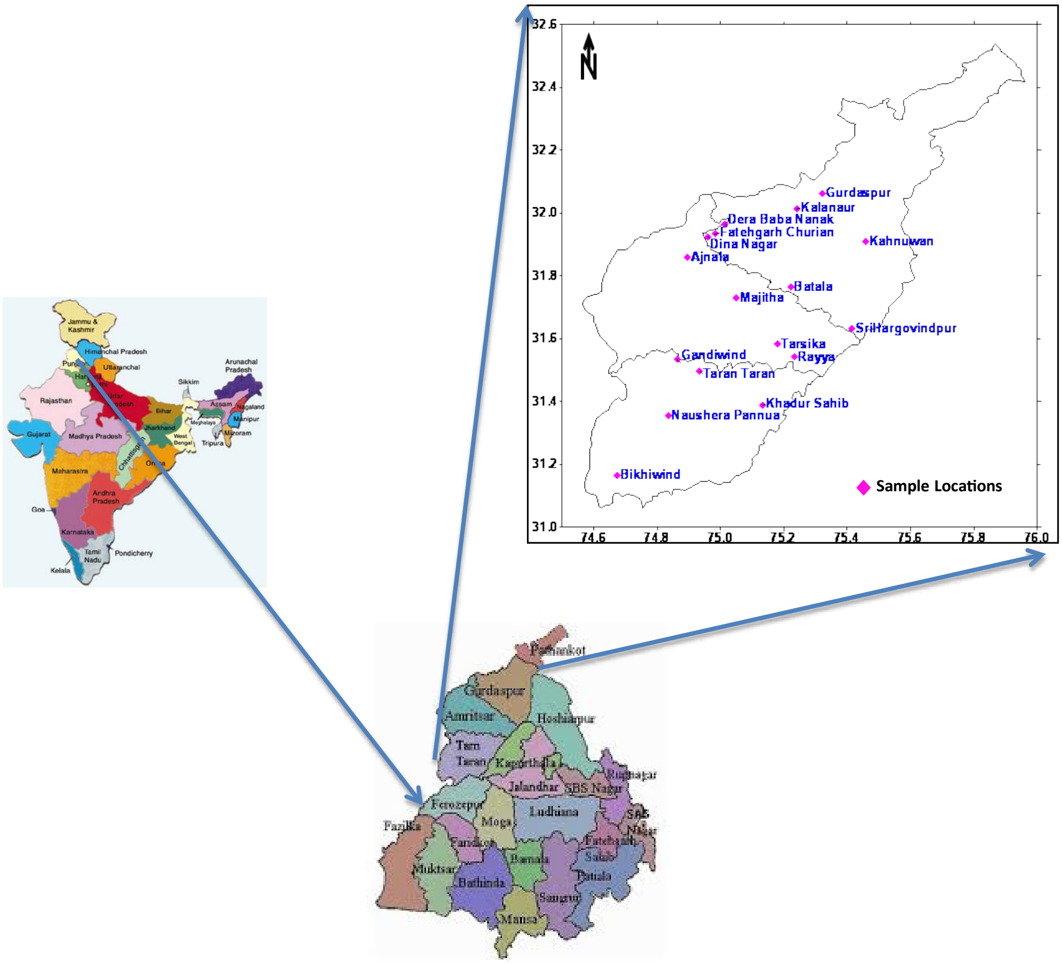

Figure 1: Groundwater monitoring points of northern Punjab.

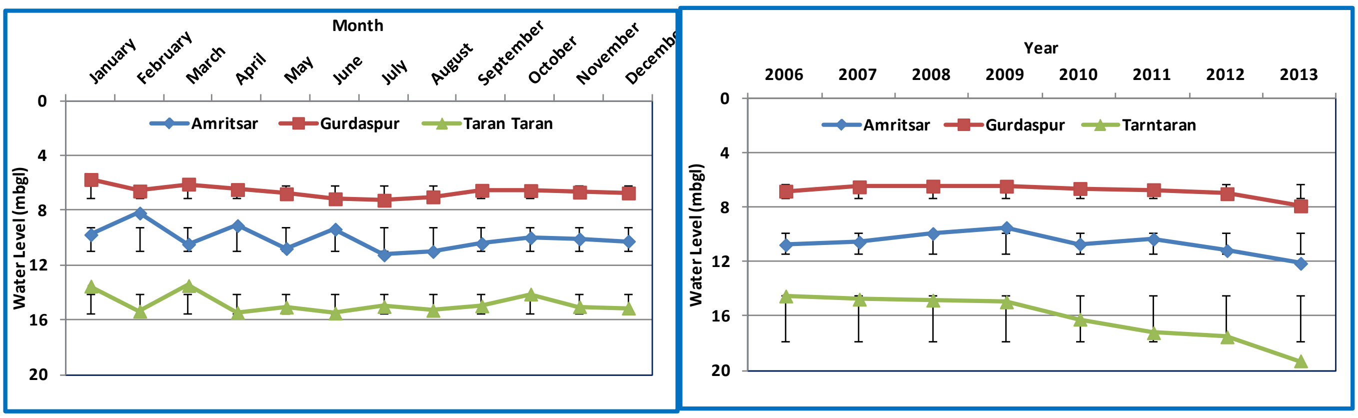

Figure 2: Monthly and Yearly Groundwater level (m bgl) of northern Punjab.

6.22% in groundwater level depth was found in the Ajanala block and least increase of 0.36% in Tarshika, while in Tarn Taran district, the highest increase of 3.87% in groundwater level depth was found in the Noushera Pannua block and least increase of 0.95% in Tarn Taran block. However, it has also been observed that the groundwater level rises again in the post monsoon season which shows the resilience nature of the aquifers and same has been reported in an extensive study carried out in Bist-Doab, Punjab, India by Lapworth *et al.* [10]. Besides this, the extensive recharge in the area is observed by Ravi and Beas rivers because of perennial nature in the study area.

The annual fluctuation pattern of the groundwater of the study area

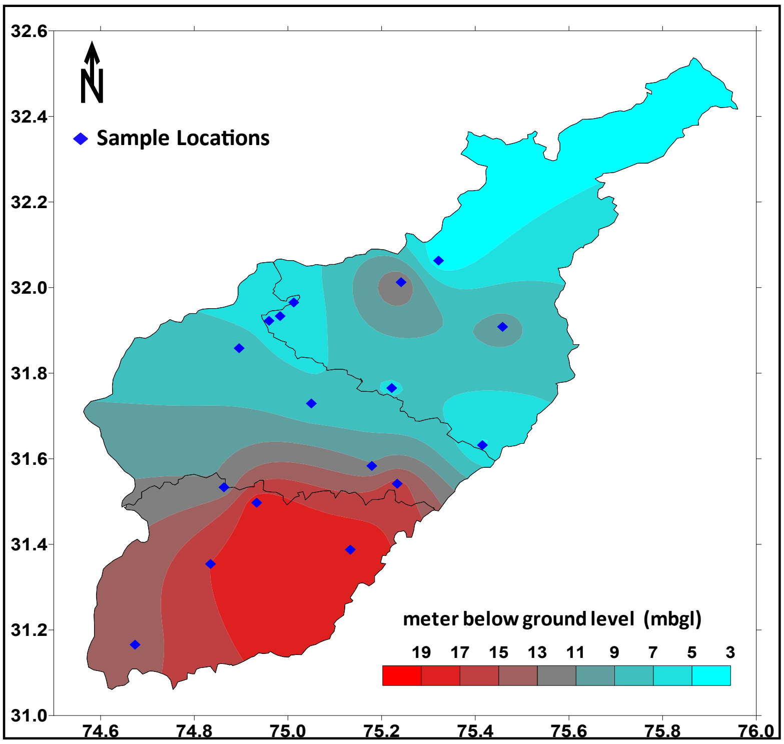

Figure 3: Average Groundwater level (m bgl) across all months of northern Punjab.

Distt.	Locations/ Blocks	Groundwater level (m bgl)											
		Pre-monsoon (Feb –May)				Monsoon (Jun –Sep)				Post-monsoon (Oct –Jan)			
		Min	Max	Av	SD	Min	Max	Av	SD	Min	Max	Av	SD
Amrit sar	Ajnala	6.86	9.70	7.67	0.57	6.60	10.75	8.14	0.78	6.18	8.70	7.60	0.61
	Majitha	5.20	10.20	7.28	1.25	6.00	11.25	7.77	1.36	5.60	9.66	7.37	1.34
	Rayya	13.67	18.10	15.76	0.90	14.68	19.15	16.28	0.93	14.21	17.04	15.72	0.79
	Tarsika	8.76	13.00	11.19	1.14	9.00	14.15	11.23	1.32	9.10	12.84	11.17	1.25
Gurdas pur	Batala	5.50	9.20	6.60	0.88	5.00	9.10	7.24	0.96	4.70	8.40	6.35	1.02
	Dera Baba Nanak	4.47	7.60	5.07	1.02	3.20	7.40	5.32	0.97	4.10	7.30	4.93	1.01
	Dina Nagar	5.53	8.15	6.18	0.65	5.40	7.65	6.60	0.62	5.20	8.00	6.10	0.69
	Gurdaspur	2.73	4.75	3.32	0.46	2.35	4.30	3.41	0.57	2.65	4.60	3.28	0.52
	Fatehgarh Churian	4.30	6.85	4.92	0.60	4.00	6.50	5.29	0.66	3.90	6.70	4.83	0.80
	Kahnuwan	8.97	10.75	9.89	0.46	9.27	10.77	10.04	0.40	9.07	10.90	9.76	0.46
	Kalanaur	12.45	15.70	13.08	0.68	12.48	15.40	13.42	0.76	12.35	14.75	13.02	0.69
	SriHar govindpur	4.06	6.20	4.82	0.49	3.96	5.66	4.83	0.38	3.96	5.16	4.57	0.35
Tarn taran	Bikhiwind	11.56	17.40	13.87	2.01	12.25	17.63	14.25	1.84	11.80	16.76	13.90	1.81
	Gandiwind	7.95	13.05	11.08	1.80	8.07	13.52	11.38	1.80	8.40	13.96	12.04	1.56
	Khadur Sahib	16.00	20.20	18.14	0.99	16.70	21.20	18.76	1.16	16.30	19.41	18.07	0.94
	Naushera Pannua	14.20	20.40	16.78	2.37	14.00	21.40	17.43	2.42	14.10	19.94	16.87	2.23
	Taran Taran	17.10	21.15	18.55	1.12	16.68	21.58	18.72	1.33	16.51	21.02	18.42	1.16

Table 2: Season wise variations in Groundwater level (m bgl) in northern Punjab (2006-13).

is shown in (Figure 5). In Amritsar, the groundwater level depth was increasing in 3 blocks –Ajnala, Tarshika and Rayya from 2006 to 2013 but in Majiha block the groundwater depth decreased in year 2013. The groundwater level found decreased by 1m to 1.80 m during these 8 years with an annual decrease of 0.13 m to 0.23 m.

In Gudaspur, the groundwater level depth was increasing in 5 blocks –Batala, Gurdaspur, Fatehgarh, Kahnuwan and Kalanaur from 2006 to 2013 in the range of 0.15 m to 0.65 m with an annual decrease in the groundwater level in the range of 0.02 m to 0.08 m. But in 3 blocks-Dera Baba Nanak, Dina Nagar and Sri Hargobindpur the groundwater level rise was found in the range of 0.05 m to 0.49 m with an annual increase of 0.01 m to 0.06 m.

In Tarn Taran, the groundwater level depth was increasing in 4 blocks –Bhikhiwind, Khadur Sahib, Noushera Pannua and Tarn Taran from 2006 to 2013 in the range of 0.73 m to 1.52 m with an annual decrease in the groundwater level in the range of 0.06 m to 0.17 m. But

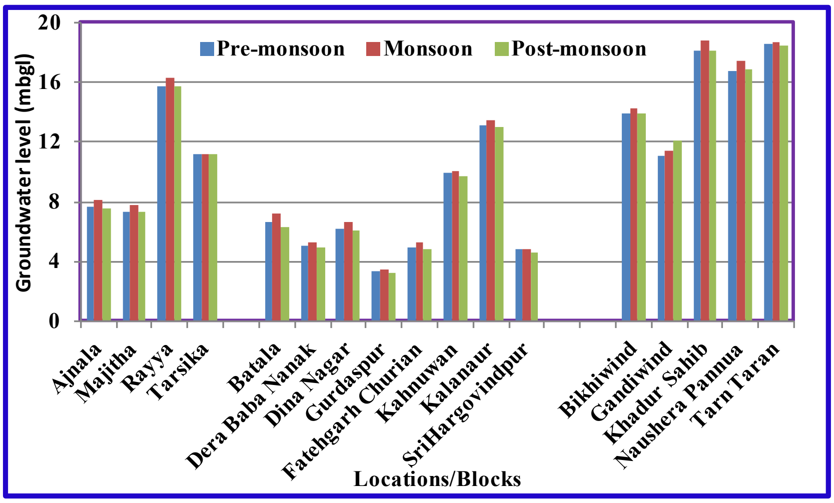

Figure 4: Season wise average groundwater level (m bgl) in northern Punjab (2006-13).

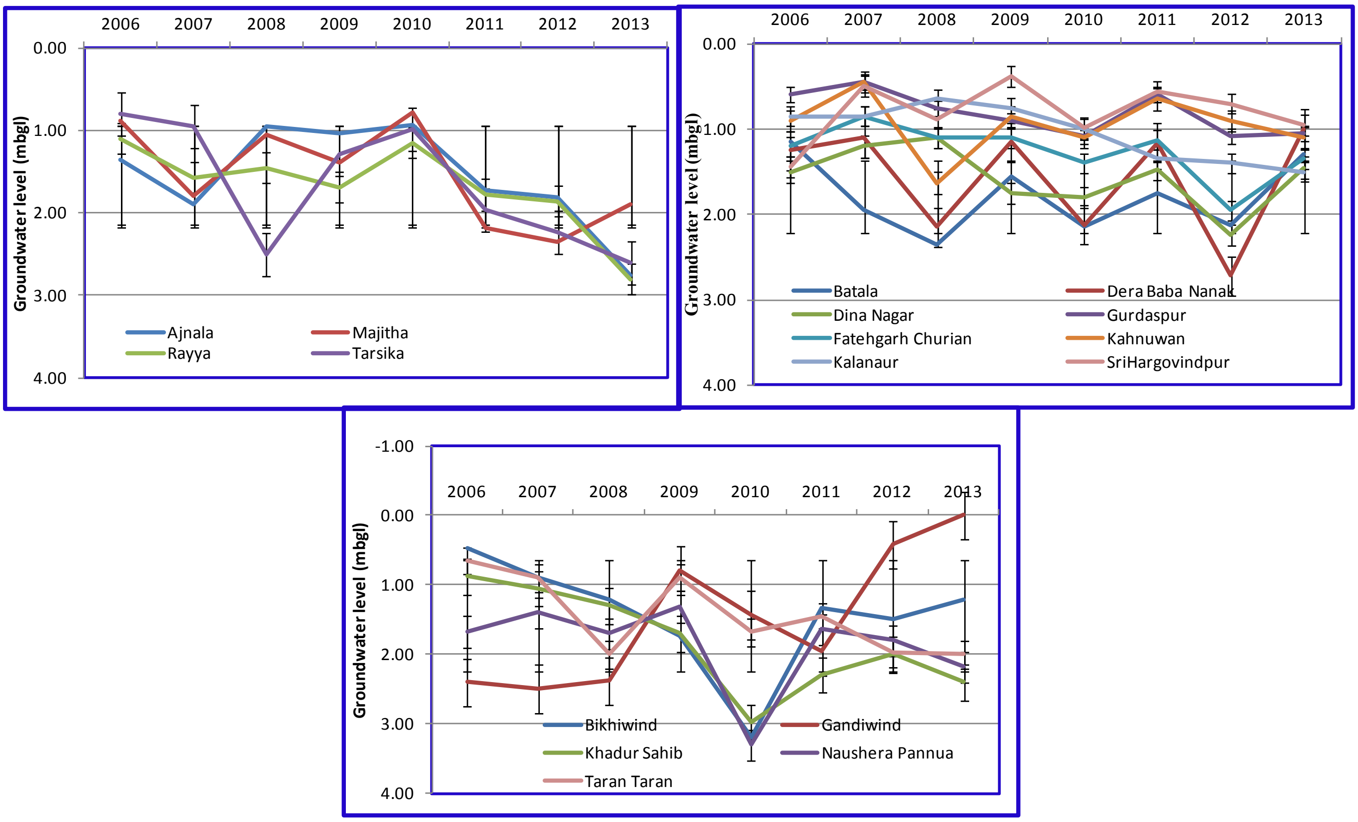

Figure 5: Annual fluctuation pattern of groundwater level (m bgl) in northern Punjab (2006-13).

in Gandhiwind block the groundwater level rise was found to the tune of 2.40 m with an annual increase of 0.30 m.

The difference in decline in phreatic water levels may be due to local aquifers or variation in the aquifer structures and availability of groundwater [2,9].

For water resource management, drainage also has an important role to control ground water table and the design of horizontal and vertical drainage. The layout, depth and spacing of the drains are often done using subsurface drainage equations with parameters like drain depth, depth of the water table, soil depth, hydraulic conductivity of the soil and drain discharge. Selecting a proper drainage system always has been discussed in agricultural or other fields [19-21]. The analytical solutions improved the accuracy of predicting the dissipation of pore water pressure and the associated settlement which depends on soil characteristics parameters [22-26]. Gallichand presented numerical simulations of steady-state subsurface drainage with vertically decreasing hydraulic conductivity [27]. The results presented could be used to estimate the error on water table depth resulting from ignoring the vertical variations of hydraulic conductivity. Hunt discussed about flow to vertical and non-vertical wells in leaky aquifers [28].

Conclusions

The study conducted for investigating spatiotemporal variations in the groundwater levels recorded during 2006-2013 in northern parts of Punjab, India showed that the groundwater level decreased from 0.15 m to 1.80 m with an annual decrease in groundwater level in the range of 0.02 m to 0.23 m. The increase in groundwater level depth in monsoon seasons was found due to extreme usage in irrigation for rice crop and the recharging of aquifers is not speedy. However, it has also been observed that the groundwater level rises again in the post monsoon season due to the groundwater resilience of the aquifers. Besides this, the extensive recharge in the area is observed by Ravi and Beas rivers because of perennial nature.

The declining water level trends suggest that groundwater management must be taken seriously before declining water levels impact agricultural activity. It is essential to strengthen soil, water and groundwater institutions along with capacity building, training and education in specific areas like artificial recharge, groundwater modelling, watershed management, quality monitoring, and aquifer remediation on a continuous basis. Only with this increased capacity groundwater can be managed successfully and sustainably.

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