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. 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% in 2030 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% in 2030 [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. 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 up to 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 Rechha 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.
Temperature (Mean °C) 22, 99, 026
Water course Beas River
Soil type Sandy loam
Percent Agricultural Development (%) 30
Normal Monsoon Rainfall (mm) 11,20,070
Existing gross ground water level 24,90,891
Major crops Wheat, rice
Population (as per 2011 census) 5056
Gurdaspur
227
Population growth from 2001 to 2011 (%) 15.48
Normal Annual Rainfall (mm) 24,90,891
Rate of decline of water level (m/yr) 1.70-16.76
Table 1: Details of the districts under study at a glance.

Irrigation as a major cause for high water level depletion. 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 ground 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 3.33 m 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

Gurdaspur

Tarn Taran

The climate of the district is tropical 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 Khut) 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 Churian. In the same way the post monsoon water levels are variable from 1.70 mbgl (Behram pur) to 16.76 mbgl (Shri Hargobindpur). Groundwater is CaMg- HCO₃ type and EC ranges from 235 to 1640 µS/cm at 25°C [8].

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 Sarghovindpur) of Gurdaspur district and 5 blocks (Bikhiwind, Gauriwind, Khadur Sahib, Naubasta 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 (bgln) 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 3.33 m 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.
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
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 Majitha 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, Nausher Panwana and Taran 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
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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References

1. CGWB, Central Ground Water Board (2011) Dynamic Ground Water Resources of India, Ministry of Water Resources, Govt of India.
2. Chopra RPS, Krishan (2014). Analysis of aquifer characteristics and groundwater quality in southwest Punjab, India. J Earth Sci Climg Engg 4: 1-8.
3. Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletion in India. Nature Geosc 2: 221-226.
4. Krishan G, Lapworth DJ, Rao MS, Kumar CP, Smilovic M, et al. (2014) Natural (Baseline) Groundwater Quality in the Bist-Doab Catchment, Punjab, India: A Pilot Study Comparing Shallow and Deep Aquifers. Int J Earth Sc Engg 7: 6-26.
5. Krishan G, Lohani AK, Rao MS, Kumar CP (2014) Prioritization of groundwater monitoring sites using cross-correlation analysis. NDC-WWC Journal 3: 28-31.
6. Krishan G, Rao MS, Purushothaman P, Yawat Y S,Kumar CP, et al. (2014) Groundwater Resources in Bist-Doab region, Punjab, India-An overview. NDC-WWC Journal 3: 5-13.
7. Lohani, A.K., Krishan, Gopal, Rao, M.S., Kumar, Sudhir. 2015. Groundwater Level Simulation Using Artificial Neural Network: A Case Study from Punjab, India. In: Proceedings of an International conference "India Water Week 2015-Water Management for Sustainable Development" (IWW-2015), 13-17 January, 2015 at New Delhi, India, 114.
8. Rao MS, Purushothaman P, Krishan G, Rawat YS, Kumar CP (2014) Hydrochemical and Isotopic Investigation of Groundwater Regime in Jalandhar and Kapurthala Districts, Punjab, India. Int J Earth Sc Engg 7: 06-15
9. Valipour M (2012) A Comparison between Horizontal and Vertical Drainage Systems (Include Pipe Drainage, Open Ditch Drainage, and Pumped Wells) in Anisotropic Soils. Journal of Mechanical and Civil Engineering, 4: 7-12.
10. Valipour M (2012) Effect of Drainage Parameters Change on Amount of Drain Discharge in Subsurface Drainage Systems. Journal of Agriculture and Veterinary Science 1: 10-18.
11. Krishan G, Lohani AK, Rao MS, Kumar CP, Semwal P (2013) Optimization of groundwater monitoring network in Bist-Doab, Punjab. In: International Conference "India Water Week 2013- Efficient Water Management: Challenges and Opportunities" (IWW-2013) 274, Delhi.
12. Krishan G, Rao MS, Kumar CP, Semwal P (2013). Identifying Salinization using Isotopes and Ionchemistry in Semi-Arid Region of Punjab, India. J Geol Geosci 2:4
13. Krishan G, Rao MS, Loyal RS, Lohani AK, Tuli NK, et al. (2014) Octa Journal of Environmental Research. 2: 221-226.
14. Krishan G, Lapworth DJ, Rao MS, Kumar CP, Smilovic M, et al. (2014) Natural (Baseline) Groundwater Quality in the Bist-Doab Catchment, Punjab, India: A Pilot Study Comparing Shallow and Deep Aquifers. Int J Earth Sc Engg 7: 6-26.
15. Krishan G, Lohani AK, Rao MS, Kumar CP (2014) Prioritization of groundwater monitoring sites using cross-correlation analysis. NDC-WWC Journal 3: 28-31.
16. Krishan G, Rao MS, Purushothaman P, Yawat Y S,Kumar CP, et al. (2014) Groundwater Resources in Bist-Doab region, Punjab, India-An overview. NDC-WWC Journal 3: 5-13.
17. Lohani, A.K., Krishan, Gopal, Rao, M.S., Kumar, Sudhir. 2015. Groundwater Level Simulation Using Artificial Neural Network: A Case Study from Punjab, India. In: Proceedings of an International conference "India Water Week 2015-Water Management for Sustainable Development" (IWW-2015), 13-17 January, 2015 at New Delhi, India, 114.
18. Rao MS, Purushothaman P, Krishan G, Rawat YS, Kumar CP (2014) Hydrochemical and Isotopic Investigation of Groundwater Regime in Jalandhar and Kapurthala Districts, Punjab, India. Int J Earth Sc Engg 7: 06-15
19. Valipour M (2012) A Comparison between Horizontal and Vertical Drainage Systems (Include Pipe Drainage, Open Ditch Drainage, and Pumped Wells) in Anisotropic Soils. Journal of Mechanical and Civil Engineering, 4: 7-12.
20. Valipour M (2012) Effect of Drainage Parameters Change on Amount of Drain Discharge in Subsurface Drainage Systems. Journal of Agriculture and Veterinary Science 1: 10-18.
21. Valipour M (2014) Drainage, Waterlogging and Salinity. Archives of Agronomy and Soil Science 60 ; 1625-1640.
22. Suresh K, Krishan G, Saha SK (2008) Measuring soil salinity with WET sensor and characterization of salt affected soils. Agroecology. 18: 124-128.
23. Krishan G, Srivastav SK, Suresh K, Saha SK, Dadhwal VK (2009) Quantifying the underestimation of soil organic carbon by Walkley and Black technique- an example from Himalayan landscape and Central Indian soils. Current Science 96: 1133-1136.
24. Krishan G, Kushwaha SPS, Velmurugan A (2009) Land degradation mapping in upper catchment of river Tons. Journal of Indian Society of Remote Sensing 37: 118-128.
25. Tripathi D, Raverkar KP, Krishan G (2005) Physico-chemical properties of some wasteland soils of Himachal Pradesh. Annals of Plant and Soil Research. 7:205-207.
26. Velmurugan A, Krishan G, Swamam TP, Dadhwal VK, Suresh K et al. (2009) Harmonizing soil organic carbon estimates in historical and current data. Current Science 97: 554-558.
27. Gallichand J (1994) Numerical simulations of steady-state subsurface drainage with vertically decreasing hydraulic conductivity. Irrigation and Drainage Systems 8: 1-12.
28. Hunt B (2005) Flow to Vertical and Nonvertical Wells in Leaky Aquifers. Journal of Hydrologic Engineering 10: 477-484.
29. Census of India (2011) Provisional Population Totals : Punjab Data Sheet.
30. Economic & Statistical Organisation (2013) Statistical Abstract of Punjab, Government of Punjab.