Journal of
Environmental & Analytical Toxicology

Krishan et al., J Environ Anal Toxicol 2015, 5:5
DOI: 10.4172/2161-0525.1000298

Research Article Open Access

Water Level Fluctuation as the Sum of Environmental and Anthropogenic Activities in Southeast, Punjab (India)

Gopal Krishan[1,2*], Singh RP[1] and Tashi KS[3]

[1]National Institute of Hydrology, Ministry of Water Resources, Roorkee, Uttarakhand, India
[2]IGB Groundwater Resilience Project, British Geological Survey, United Kingdom
[3]Irrigation and Power Research Institute, Amritsar, Punjab, India

Abstract

In the present paper, the water levels data versus time plots for pre-monsoon and post-monsoon seasons over a period of 8 years 2006 to 2013 show a progressive decline at all the 13 observation points. During the 8 years (2006-13), out of the total 13 blocks, groundwater level in 8 blocks declined during post-monsoon season and groundwater level increased in 4 blocks and no fluctuation was observed in 1 block. The maximum decline of -1.52 m was observed in Bhunerheri block of Patiala and the minimum decline of -0.09 m observed in Firozepur block. The groundwater level showed a maximum increase of 0.91 m in Mamdot block. In Patiala district, the depth of water level is very high in comparison to the other districts. A strong positive correlation existed between groundwater levels in all the blocks of Patiala to groundwater levels in Kotkapura and moderate to good positive correlation with the groundwater levels in Firozepur, Guruharsarai and Pakhowal because of the extensive and laterally continuous aquifer in these blocks. However, the declines are not very sharp at Faridkot and Machivara stations because there is a gain of subsurface recharge through canal seepages in the areas where these observation wells are located.

Keywords: Groundwater; Fluctuation; Environmental; Anthropogenic Activities; Southeast Punjab

Introduction

Punjab state forms part of the Indus basin which is one of the most fertile areas of the world and for the same reason Punjab is considered to be the food basket of India and this also put an immense strain upon its environment. There is an enormous dependency on ground water resources to meet out the irrigation requirements. However, improved management practices, during the last 5 decades, has helped in boosting agricultural production and resulted in all round development in Punjab which caused decline in water levels and deteriorations in water quality [1-22]. These problems are observed all over Punjab including the Southeast part of the Punjab. Now, all the resources are fully explored and these are not able to fulfill the total water requirement. These are expected to decrease further in future to meet the growing demands and thus become a matter of concern for the agricultural sustainability in the state.

The groundwater resource potential changes due to the environment flows and anthropogenic activities. The anthropogenic activities include the groundwater draft for irrigation, industrial and domestic purposes. Irrigation is the principal use of groundwater in the study area. The groundwater resources are replenished annually through the southwest monsoons, which are active between June to September. The water levels are stabilized, after all the outflows, in the beginning of the November. Therefore, the difference between the month of May and November are taken as annual water level fluctuations. The annual water level fluctuation is the sum total of all environmental flows and withdrawals for different uses.

Drainage plays an important role in controlling groundwater table and the design of horizontal and vertical drainage which is required for water resource management and its selection should be proper [23-25]. For this the pore water is a crucial factor. The pore water pressure dissipation which depends on soil characteristics parameters [26-30] should be accurately predicted in groundwater studies.

Many districts of Punjab show 100% or even higher stage of groundwater development and the same is manifested in the form of water level decline both in pre-monsoon and post monsoon periods except for extremely wet years. In early studies, the groundwater level fluctuations and associated work was discussed in detail in Northern and North-eastern parts of Punjab [6-7,13,15], Southwest Punjab [3-5,11,12,18] and in Bist-Doab, Punjab [8-10,16,17,19-21]. No specific study was carried out in Southeast Punjab; therefore, to assess the groundwater level fluctuations, monitoring has been carried out in 13 groundwater observation wells located in Faridkot, Firozepur Ludhiana and Patiala districts of Southeast Punjab.

Study area

The Southeast Punjab (Figure1) lies between 29°30' to 31°10' N and 73°50' to 76°50' E. It has River Sutlej in the North, Haryana in the East and South, Rajasthan in the Southwest corner and Pakistan in the West. Southeast Punjab comprises 50 percent of the administrative districts of the Punjab, viz., Firozpur, Faridkot, Moga, Muktsar, Bathinda, Sangrur, Mansa, Ludhiana, Patiala, Fatehgarh Sahib and Ropar.

Southeast Punjab has 65.1 per cent of the total area and 58.5 per cent of the total population. The density of population district-wise varies vastly between Ludhiana and Firozpur. The Southeast Punjab, except for a narrow strip along the Sutlej, was a semi-arid desert covered with slow-growing trees such as *Quercus incana*, *Prosopis spicigera* and thorny bushes like the *Capparis aphylla.*

***Corresponding author:** Gopal Krishan, National Institute of Hydrology, Ministry of Water Resources, Roorkee, Uttarakhand, India, IGB Groundwater Resilience Project, British Geological Survey, United Kingdom Tel: 91-1332-272108; E-mail: drgopal.krishan@gmail.com

Received April 27, 2015; **Accepted** May 25, 2015; **Published** May 31, 2015

Citation: Krishan G, Singh RP, Tashi KS (2015) Water Level Fluctuation as the Sum of Environmental and Anthropogenic Activities in Southeast, Punjab (India). J Environ Anal Toxicol 5: 298. doi:10.4172/2161-0525.1000298

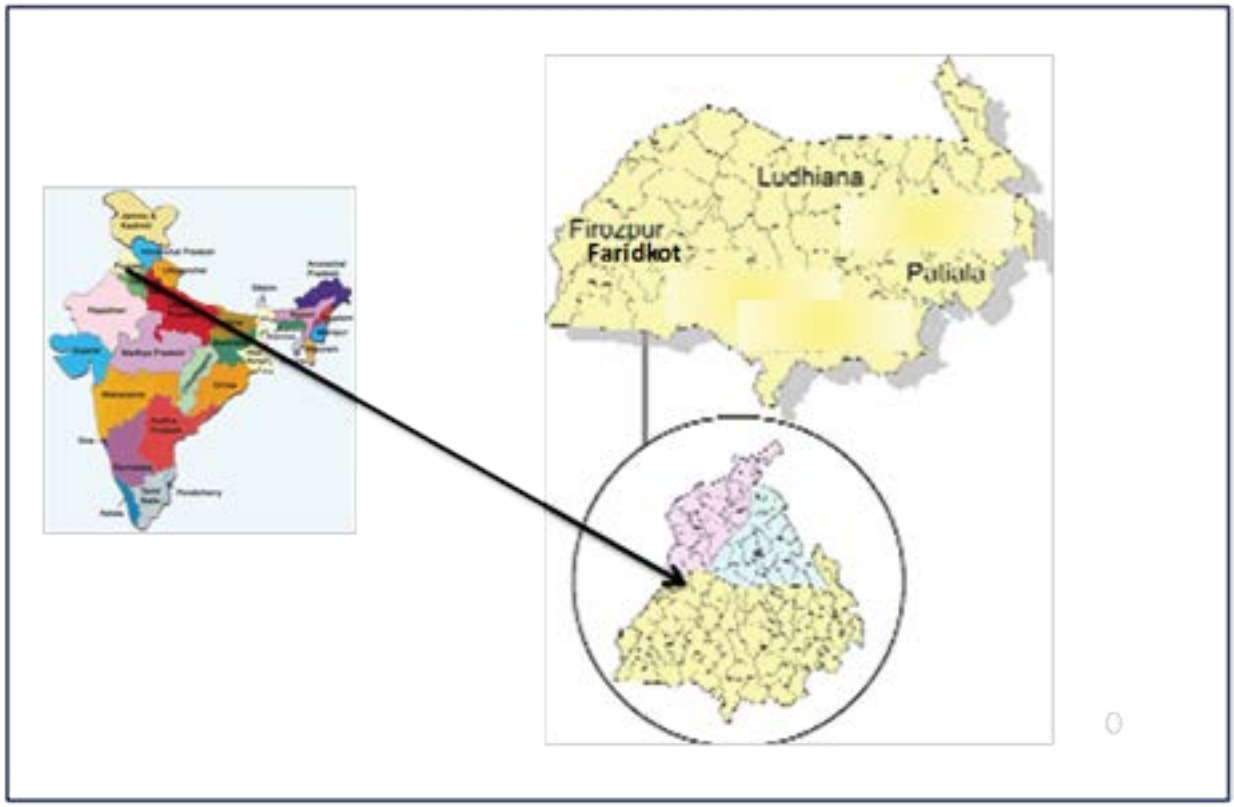

Figure 1: Study of figure area.

Earlier cultivation was rain dependent since rains were erratic and usually scanty which led to introduction of canal irrigation and after this the developments were seen especially in the harnessing of water resources, the availability of cheap hydro-electricity and this all helped to make Punjab the granary of India.

The present study is limited to 4 districts of the Southeast Punjab: Faridkot, Firozepur, Patiala and Ludhiana. Firozepur has maximum (5850 sq.km) total geographical area and population growth (16.17%) from 2001 to 2011 and Faridkot has the minimum area (1468.75 sq.km.) with least population growth of 12.18%. The maximum rainfall 681 mm is recorded in Ludhiana and out of the total rainfall more than 75% is received during monsoon in all the districts. The water in shallow groundwater is Na-HCO_3 type in Faridkot, Firozepur and Patiala, while it is Ca-HCO_3 in Ludhiana. The main crops grown in these areas are wheat and rice [31-35].

Materials and Methods

Monthly water levels were monitored at widely distributed 13 groundwater observation wells located at Faridkot, Kotkpara, Firozepur, Machivara, Mangat, Pakhoval, Bhunerheri, Nabha, Patiala, Rajpura and Samana. The groundwater level is measured as 'meter below ground level (m bgl). A data base of 8 years water levels has been prepared and analysed for the changes and trends during the period of observations. The pre-monsoon and post-monsoon water levels were plotted against the time to study the water level trends (Table 1, Figures 2-5). Each year fluctuations between pre-monsoon and post-monsoon water levels were calculated. The average water level fluctuations were contoured to study the areal distribution of the water level fluctuations (Figure 6).

Results and Discussion

Water is one of the three elements of environment, viz: (1) Water (2) Air and (3) Soil. These components are linked with each other and they move with different velocities under the influence of natural processes following the principle of uniformitarian. Water travels through both surface and subsurface paths. The subsurface path is more complicated than the surface path followed by water since it travels through atmosphere, biosphere and lithosphere unlike the surface water which travels through atmosphere and biosphere only. Depth to water is the function of the environmental processes active in these spheres like condensation, evaporation, transpiration, infiltration, sublimation and anthropogenic activities. Anthropogenic activities include all the activities the human performs on the face of the earth prominent of which are agricultural and industrial activities. Reflecting deep through these processes, in the context of groundwater, it is envisaged that the sum total of their impacts is the depth to water or piezometric surface with a time reference. The change in the rate of environmental processes and human activities are manifested in the form water level fluctuations.

The groundwater resources are replenished annually through the Southwest (SW) monsoons. The SW monsoon onset is observed in June in the Indo-gangetic basin and its retreat in the recorded in month of October [36-40]. Therefore, the fluctuations in the groundwater level were seen calculating the difference for pre-monsoon in May and post-monsoon in November. The average water level depth was found maximum in Patiala district and the maximum water level fluctuations

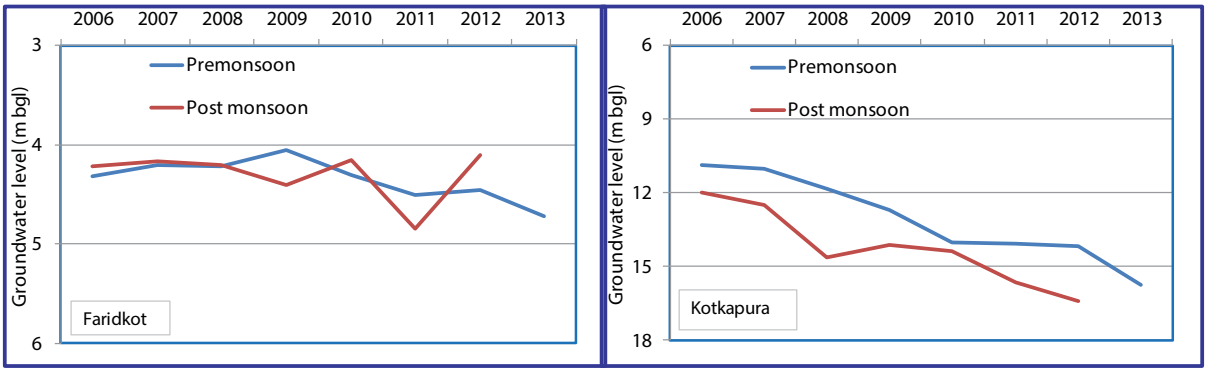

Figure 2: Groundwater level fluctuation between pre-monsoon and post monsoon periods in 2 blocks of Faridkot district during 2006-13.

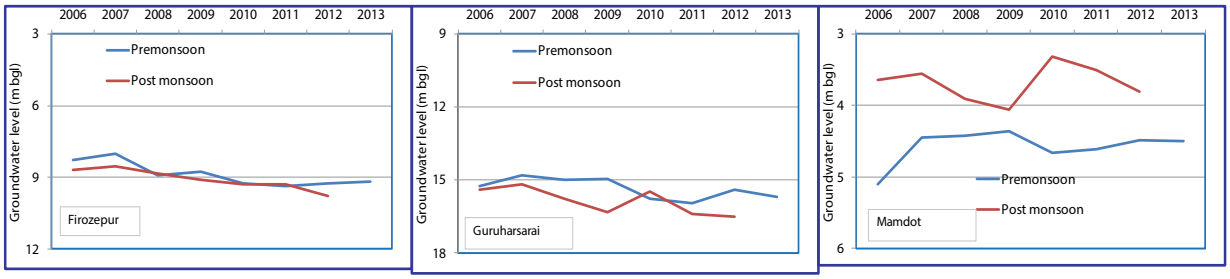

Figure 3: Groundwater level fluctuation between pre-monsoon and post monsoon periods in 3 blocks of Firozepur district during 2006-13.

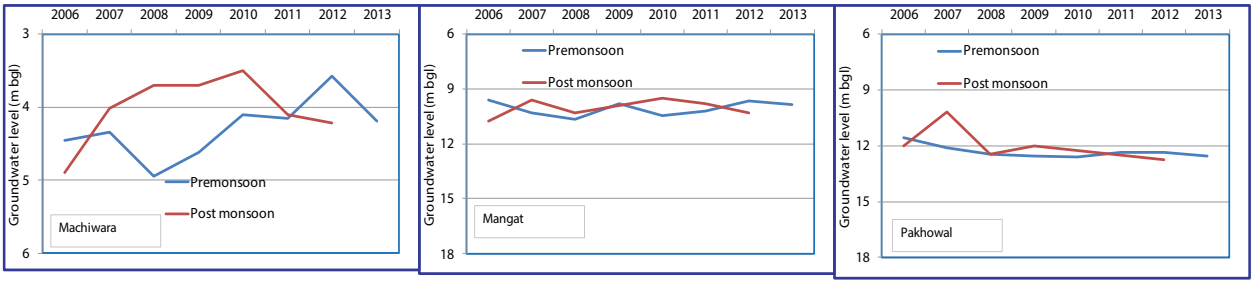

Figure 4: Groundwater level fluctuation between pre-monsoon and post monsoon periods in 3 blocks of Ludhiana district during 2006-13.

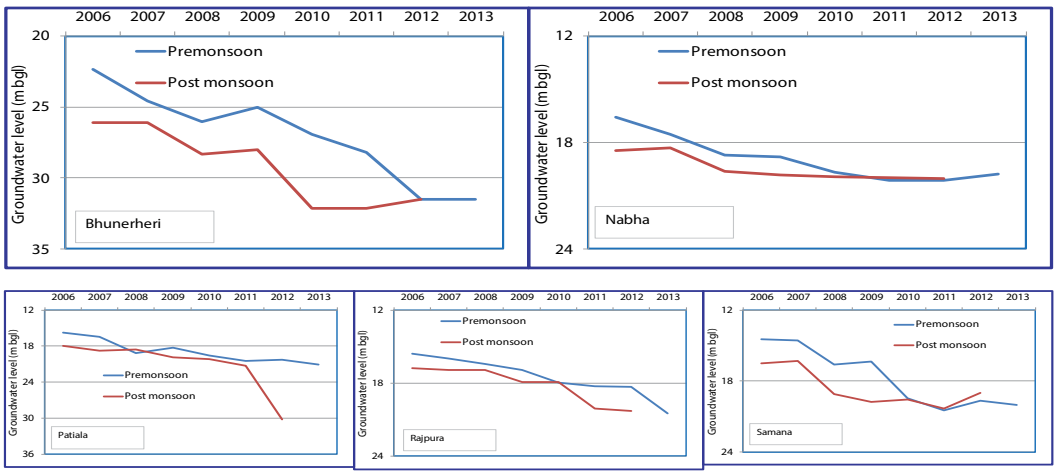

Figure 5: Groundwater level fluctuations between pre-monsoon and post monsoon periods in 5 blocks of Patiala district during 2006-13.

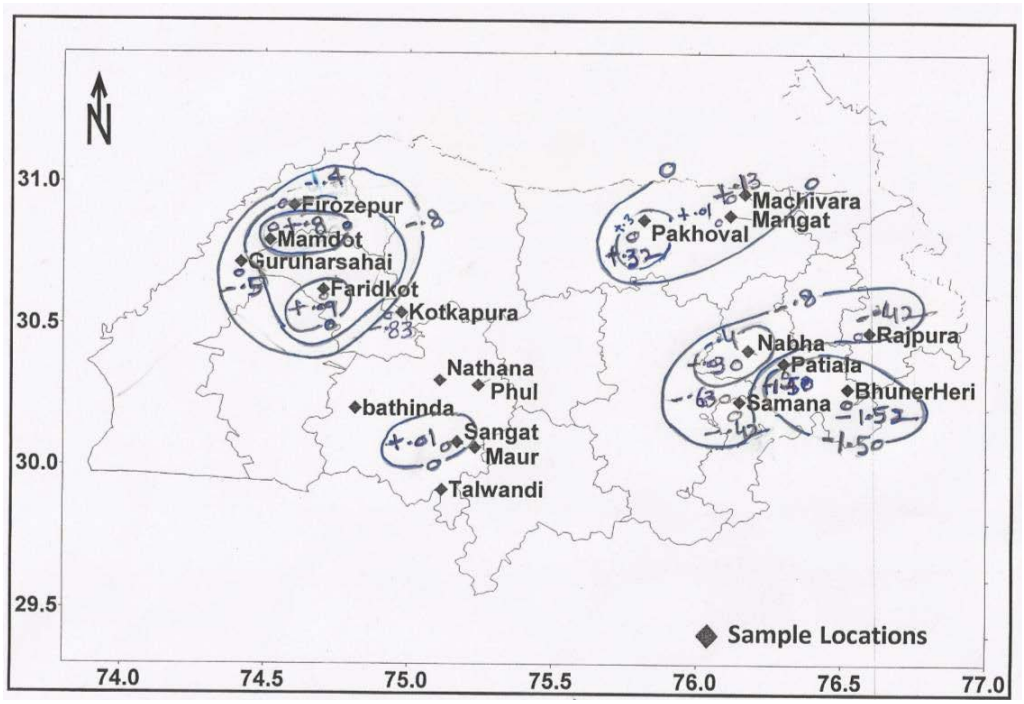

Figure 6: Water table fluctuations between pre-monsoon and post monsoon periods.

were observed in increasing order as Ludhiana<Faridkot<Firozepur< Patiala districts (Table 1).

The water levels data versus time plots for pre-monsoon and post-monsoon seasons over a period of 8 years 2006 to 2013 show a progressive decline at all the 13 observation points. However, the declines are not very sharp at Faridkot and Machivara stations because there is a gain of subsurface recharge through canal seepages in the areas where these piezometers are located.

As evident from Table 2 and Figures 2-5, during 8 years (2006-13), out of the total 13 blocks, groundwater level in 8 blocks declined during post-monsoon season and groundwater level increased in 4 blocks and no fluctuation was observed in 1 block. The maximum decline of -1.52 m was observed in Bhunerheri block of Patiala and the minimum decline of -0.09 observed in Firozepur block. The groundwater level showed a maximum increase of 0.91 m in Mamdot block. In Patiala district, the depth of water level is very high in comparison to the other districts. The increased depth of water level was found in 62% of the blocks studied during monsoon season is due to extreme usage in irrigation for kharif crops. The difference in decline in phreatic water levels may be due to local aquifers or variation in the aquifer structures and availability of groundwater [3,8-10,16,17,19].

The correlation in groundwater level during 2006-13 among all the blocks studied in southeast, Punjab is shown in Table 3. It has been found that a strong positive correlation existed between groundwater levels in all the blocks of Patiala to groundwater levels in Kotkapura and moderate to good positive correlation with the groundwater levels in Firozepur, Guruharsarai and Pakhowal. Good to strong positive correlation in groundwater levels existed among all the blocks of Patiala district. This suggests that the aquifer is very extensive and laterally continuous in these blocks. The negative moderate correlation in groundwater levels at Machivara of Ludhiana district is because of the surface water irrigation in these areas. In Machiwara area the irrigation is both from surface and sub-surface water sources which have reflected as negative-moderate correlation.

Similar results were also found by Krishan et al. in Bist-Doab area of Punjab [8-10,16-17,19] and in Punjab state [14]. In a study conducted in Bist-Doab, Punjab by Krishan et al. [9,19] the Automatic Groundwater Level Recorder (Solinist-make) were installed in the shallow (20-60 m) Piezometers developed by Punjab Water Resources and Environment Directorate (PWRED), Chandigarh at Saroya (Nawanshahr), Tanda (Hoshiarpur), Bhogpur and Nakodar (Jalandhar) and Kapurthala and Sultanpur Lodhi (Kapurthala) and the readings for the water level recorders were taken at a fixed interval of 1 hour for a period of August, 2011 to June, 2012. A strong positive correlation existed between Bhogpur and Tanda blocks. The depletion in the groundwater level to the tune of 2 m, 1 m and 3.4 m in May, 2012 was observed in Saroya, Bhogpur and Tanda, respectively as compared to the August, 2011. However, the water level decreased at all the stations during the period from December, 2011 to March, 2012 and a maximum decrease of 31% was observed at Bhogpur which was followed by 24% at Saroya and the least 19% at Sultanpur lodhi. The water level again started increasing after the month of March, 2012. It was also concluded in the study [8,19] that in managing and monitoring groundwater network, these information derived can be used for establishing the stations at suitable sites where there is very good correlation among the sites. In stations, where correlation is not good can be kept for further observations and the reason for poor correlation might be due to the different aquifers or other hydro-geological conditions. The other researchers who have observed similar results of depleting water quality and fall in water tables in Punjab Dhawan [2], Sondhi et al. [41], Ambast et al. [42] and Rodell et al. [43].

District	Block	Groundwater level (mbgl)						
		Min	Max	Difference (Max-Min)	Mean	Median	Mode	Standard deviation
Faridkot	Faridkot	3.65	5.01	1.36	4.30	4.29	4.30	0.27
	Kotkapura	10.65	17.50	6.85	13.63	13.95	14.50	1.89
Firozepur	Firozepur	7.50	10.47	2.97	9.06	9.06	9.20	0.62
	Guruharsahai	14.58	16.73	2.15	15.68	15.79	16.00	0.61
	Mamdot	2.59	5.50	2.91	4.14	4.11	4.06	0.53
Ludhiana	Machivara	3.50	4.98	1.48	4.20	4.15	4.00	0.40
	Mangat	8.88	10.80	1.92	10.07	10.13	10.32	0.40
	Pakhoval	10.20	12.73	2.53	12.23	12.30	12.08	0.38
Patiala	BhunerHeri	21.45	32.30	10.85	27.71	26.91	31.50	3.07
	Nabha	16.17	20.37	4.20	18.95	19.56	20.00	1.18
	Patiala	15.41	31.10	15.69	19.54	19.57	19.60	3.06
	Rajpura	15.04	21.00	5.96	17.58	17.55	18.00	1.47
	Samana	13.95	20.80	6.85	17.81	18.85	19.50	2.16

Table 1: Statistical parameters of groundwater level in southeast Punjab (2006-13).

District	Location/ Block	Depth to groundwater level (m bgl)						
		Pre-monsoon			Post monsoon			Fluctuation
		Min	Max	Mean	Min	Max	Mean	
Faridkot	Faridkot	4.05	4.72	4.35	3.99	4.85	4.26	0.09
	Kotkapura	10.85	15.75	13.05	11.35	16.40	13.88	-0.83
Firozepur	Firozepur	8.00	9.38	8.88	8.20	9.79	8.97	-0.09
	Guruharsahai	14.83	15.98	15.37	15.20	16.50	15.87	-0.50
	Mamdot	4.36	5.10	4.57	3.31	4.06	3.67	0.91
Ludhiana	Machivara	3.58	4.95	4.30	3.50	4.90	4.07	0.23
	Mangat	9.60	10.64	10.07	9.49	10.75	10.07	0.00
	Pakhoval	11.56	12.58	12.32	10.20	12.73	12.00	0.32
Patiala	BhunerHeri	22.32	31.50	27.00	23.84	32.16	28.52	-1.52
	Nabha	16.57	20.15	18.92	17.12	20.05	19.16	-0.24
	Patiala	15.80	21.10	18.90	16.20	30.25	20.38	-1.48
	Rajpura	15.58	20.50	17.50	16.34	20.30	17.89	-0.39
	Samana	14.47	20.45	17.69	14.28	20.33	18.10	-0.41

Table 2: Water level fluctuations (pre-monsoon and post monsoon) in southeast Punjab (2006-13).

Blocks	Faridkot	Kotkapura	Firozepur	Guruharsahai	Mamdot	Machivara	Mangat	Pakhoval	BhunerHeri	Nabha	Patiala	Rajpura	Samana
Faridkot	1												
Kotkapura	0.3 (0.09)	1											
Firozepur	0.33(0.11)	0.85(0.72)	1										
Guruharsahai	0.27(0.07)	0.67(0.44)	0.75(0.56)	1									
Mamdot	0.32(0.10)	-0.1	-0.02	-0.20(0.04)	1								
Machivara	-0.02	-0.51(0.26)	-0.31(0.09)	-0.25(0.06)	0.27(0.07)	1							
Mangat	-0.12	0	-0.05	0.05(0.00)	0.08(0.01)	0.49(0.24)	1						
Pakhoval	0.10(0.01)	0.61(0.37)	0.50(0.25)	0.39(0.15)	-0.03	-0.11(0.01)	0.37(0.14)	1					
BhunerHeri	0.28(0.08)	0.81(0.66)	0.71(0.50)	0.54(0.29)	-0.07(0.07)	-0.49(0.24)	-0.16(0.02)	0.53(0.28)	1				
Nabha	0.24(0.06)	0.83(0.68)	0.68(0.46)	0.50(0.25)	-0.23(0.05)	-0.54(0.29)	0.07(0.004)	0.66(0.44)	0.83(0.68)	1			
Patiala	-0.08	0.76(0.58)	0.59(0.34)	0.44(0.19)	-0.09(0.01)	-0.28(0.08)	0.09(0.01)	0.52(0.27)	0.66(0.43)	0.63(0.40)	1		
Rajpura	0.28(0.08)	0.82(0.67)	0.56(0.31)	0.43(0.19)	-0.21(0.04)	-0.42(0.17)	-0.07(0.005)	0.56(0.31)	0.83(0.70)	0.79(0.62)	0.74(0.55)	1	
Samana	0.29(0.09)	0.81(0.71)	0.69(0.47)	0.53(0.28)	_0.18(0.03)	_0.59(0.34)	_0.04(0.002)	0.61(0.37)	0.83(0.69)	0.95(0.95)	0.61(0.37)	0.82(0.67)	1

Values in parenthesis are R^2 (coefficient of determination)

Table 3: Correlation (R) in groundwater level among all the blocks studies in southeast, Punjab (2006-13).

Conclusion

There is a continuous increase in the area under irrigation by groundwater through tube wells with the corresponding decrease in the area under irrigation by canals. There has also been a stunning increase in the number of tube wells as the state water resources are limited and are fully utilized which is resulting in the water table decline which has led to low discharge of tube wells, deepening of tube wells and increased energy cost, thereby affecting the socio-economic condition of small farmers of the state. Further, regular monitoring of groundwater provide clues to understanding of trend of water level in study area so that the proper management practices as: reducing the groundwater withdrawal and increasing groundwater recharge through rain water harvesting, rivers, tube wells, dug wells and paddy fields can be adopted for sustainable use of groundwater in this agriculture-dominated region.

Acknowledgments

Authors thank Director, National Institute of Hydrology for all his support and encouragement for this study. Dr. Gopal Krishan (GK) thanks Dr. Alan MacDonald, Dr. Dan Lapworth and Dr. Helen Bonsor (BGS, UK) for all the help and support provided. Dr. GK also thanks Director, PWRED, Chandigarh.

References

1. Ambast SK, Tyagi NK, Raul SK (2006) Management of declining groundwater in the Trans Indo-Gangetic Plain (India): Some options. Agricultural Water Management 82: 279-296.
2. Dhawan BD (1995) Groundwater depletion, land degradation and irrigated agriculture in India. New Delhi: Commonwealth Publishers.
3. Chopra RPS, Krishan G (2014) Analysis of aquifer characteristics and groundwater quality in southwest Punjab, India. Earth Science and Engineering. 4: 597-604.
4. Chopra RPS, Krishan Gopal (2014) Assessment of groundwater quality in Punjab. Journal of Earth Science and Climate Change. 5: 243.
5. Krishan Gopal, Chopra RPS (2015) Assessment of water logging in south western (SW) parts of Punjab, India-a case study from Muktsar district. NDC-WWC Journal 4: 7-10.
6. Krishan Gopal, Takshi KS, Rao MS, Kumar Sudhir, Lohani AK (2015) Spatial analysis of groundwater level in 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 125.
7. Krishan, Gopal AK, Lohani Rao MS, Kumar Sudhir B (2015) Spatio-temporal variability analysis of groundwater level for water resources development and management in Northern Punjab, India, India. Journal of Environment and Analytical Toxicology (in press).
8. Krishan Gopal, Lapworth DJ, Rao MS, Kumar CP, Smilovic M, Semwal P (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: 16-26.
9. Krishan Gopal, Lohani AK, Rao MS, Kumar CP (2014) Prioritization of groundwater monitoring sites using cross-correlation analysis. NDC-WWC Journal. 3: 28-31.
10. Krishan Gopal, Rao MS, Purushotaman P, Yawat YS, Kumar CP, et al. (2014) Groundwater resources in Bist-Doab region, Punjab, India-An overview. NDC-WWC Journal.
11. Krishan Gopal, Rao MS, Kumar CP, Garg Pankaj, Semwal, Prabhat (2014) Assessment of salinity and groundwater quality with special emphasis to fluoride in a semi-arid region of India. Journal of Earth Science and Climate Change 5: 149.
12. Krishan Gopal, Rao MS, Lohani AK, Kumar CP, Takshi KS, et al. (2014) Assessment of groundwater level in southwest Punjab, India. Hydraulics, Water resources, Coastal & Environmental Engineering-Hydro 2014 Tiwari HL, Suresh S, Jaiswal RK (Eds) Excellent Publishing House, New Delhi 23: 248-254.
13. Krishan Gopal, Lohani AK, Rao MS, Kumar CP, Takshi KS (2014) Groundwater fluctuation and trend in Amritsar, Punjab, India. In: Janardhana Raju N (ed). Geo-statistical and Geospatial approaches for the characterization of natural resources in the environment: challenges, processes and strategies. Capital Publishing House, New Delhi. 108-111.
14. Krishan Gopal, Rao MS, Loyal, RS, Lohani AK, Tuli NK, Takshi KS, Kumar CP, Semwal P, Kumar Sandeep (2014). Groundwater level analyses of Punjab, India: A quantitative approach. Oct. Jour. Env. Res. 2(3): 221-226.
15. Krishan G, Garg P, Takshi KS, Lohani AK, Rao MS et al. (2014) Monitoring of Groundwater fluctuations and trend in parts of Northern Punjab (vern. Majha), India. In: Proceedings of an International conference on "Annual Water Resources Association 2014 AWRA" during 3-6 November, 2014 at Virginia, USA.
16. Lapworth Dan, Krishan Gopal, Rao MS, MacDonald Alan, (2014) Intensive Groundwater Exploitation in the Punjab - an Evaluation of Resource and Quality Trends. Technical Report. NERC Open Research Archive, BGS-UK.

17. Lapworth DJ, Krishan G Macdonald AM, Rao MS, Gooddy DC, et al. (2014) Using Environmental Tracers to Understand the Response of Groundwater Resources in Nw India to Sustained Abstraction. In Proc. of 41st International Conf. of International Association of Hydro-geologist (IAH-2014) on Groundwater: Challenges and Strategies during Sep. 18-19 at Marrakech Morocco.

18. Krishan Gopal, Rao MS, Kumar CP, Semwal P (2013) Identifying salinization using isotopes and ion chemistry in Semi-arid region of Punjab, India. J. Geol. Geosci. 2: 4.

19. Krishan Gopal, 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. 274.

20. Rao MS, Purushothaman P, Krishan Gopal, 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.

21. Sharma Manishi, Rao MS, Rathore DS, Krishan Gopal (2014) An integrated approach to augment the depleting ground water resource in bist- doab, region of Punjab, India. Int J Earth Sc Engg 7: 27-38.

22. Sondhi SK, Kaushal MP, Aggrawal R (2001) Management of groundwater resources in Punjab. In ICAR-IWMI Groundwater Policy Initiative.

23. 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.

24. 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.

25. Valipour M (2014) Drainage, Waterlogging and Salinity Archives of Agronomy and Soil Science 60: 1625-1640.

26. Kumar Suresh, Krishan Gopal, Saha SK (2008) Measuring soil salinity with WET sensor and characterization of salt affected soils. Agropedology 18: 124-128.

27. Krishan Gopal, Srivastav SK. Kumar Suresh, 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.

28. Krishan Gopal, Kushwaha, SPS, Velmurugan A (2009) Land degradation mapping in upper catchment of river Tons. Journal of Indian Society of Remote Sensing 37: 119-128.

29. Velmurugan A, Gopal K, Swarnam TP, Dadhwal VK, Suresh K, et al. (2009) Harmonizing soil organic carbon estimates in historical and current data. Current Science 97: 554-558.

30. Tripathi D, Raverkar KP, Gopal K (2005) Physico-chemical properties of some wasteland soils of Himachal Pradesh. Annals of Plant and Soil Research 7: 205-207.

31. CGWB (2007) Groundwater information booklet of Faridkot district, Punjab, Central Groundwater Board, North West Region, Chandigarh. 1-22.

32. CGWB (2007) Groundwater information booklet of Firozepur district, Punjab, Central Groundwater Board, North West Region, Chandigarh. 1-18.

33. CGWB (2007) Groundwater information booklet of Ludhiana district, Punjab, Central Groundwater Board, North West Region, Chandigarh. 1-17.

34. CGWB (2007) Groundwater information booklet of Patiala district, Punjab, Central Groundwater Board, North West Region, Chandigarh. 1-16.

35. Census (2011) Punjab Data Sheet-Census.

36. Krishan G, Rao MS, Kumar B, Kumar CP, Kumar S, et al. (2014) Monitoring of Southwest Monsoon using isotope analysis of ground level vapour (Glv) in Indian Sub-Continent. Journal of Earth Science and Climate Change 5: 8.

37. Gopal K, Lohani AK, Rao MS, Kumar CP, Kumar Bhishm, et al. (2013) Studying Dynamics of the South West Monsoon in Indian Sub-Continent through Geospatial Correlation of Isotopes in Air Moisture. Journal of Geology and Geosciences 3: 1.

38. Krishan Gopal, Rao MS, Jaiswal RK, Kumar Bhishm, Kumar CP (2013) Southwest (SW) monsoon dynamics study in Indo-Gangetic plains using isotopic techniques. Journal of Geology and Geosciences 2: 2

39. Krishan Gopal, Rao M.S, Kumar Bhishm, Kumar CP (2015) Possibility of using isotopic composition of ground level vapour (Glv) for monitoring arrival and withdrawal of southwest monsoon. Current Science. 108: 784-786.

40. Krishan Gopal, Rao MS, Kumar CP, Kumar Bhishm, Thayyen Renoj J (2013) Using Stable Isotope (δ) of atmospheric water vapour in southwest monsoon studies. NDC-WWC Journal. 2: 18-20.

41. Sondhi SK, Kaushal MP, Aggrawal R (2001) Management of groundwater resources in Punjab. In ICAR- IWMI Groundwater Policy Initiative-2001.

42. Ambast SK, Tyagi NK, Raul SK (2006) Management of declining groundwater in the Trans Indo-Gangetic Plain (India): Some options. Agricultural Water Management, 82: 279-296.

43. Rodell M, Velicogna I, Famiglietti, JS (2009) Satellite-based estimates of groundwater depletion in India. Nature 460: 999-1003