Investigation of Groundwater Level Fluctuation and Trends: A Case Study of Bhiwani District, Haryana

Sonu, Sanjay Kumar** and Narender Kumar****

ABSTRACT

Groundwater is a major source of freshwater in many parts of the world and India is the largest groundwater user in the world, with an estimated usage of around 230 cubic km per year, more than a quarter of the global total. Groundwater has made significant contributions to the growth of India's Economy and about 15 percent of India's food production and 85 percent of drinking water supplies is currently dependent on unsustainable groundwater use. Due to the rapid growth in population and the associated land-use have led to a groundwater resources are overexploited in different part of the India. The state of Haryana has witnessed a spectacular increase in agricultural production with perpetual deficit of groundwater because canal/river water is not sufficient to meet the demands of drinking and irrigation practices, farmers are mining groundwater through a large number of tube wells has increased from 0.02 million in 1966 to 0.93 million in 2021 showing alarming sign of exploitation. The main objective of this study has analyzed the variability in depth to water level below ground level, study is to identify the groundwater critical zones and abrupt change point detections spatially and temporally rests on secondary data sources pertaining to rainfall, area under irrigation, net irrigation demand of crops, technical stipulations of river, number of wells, and groundwater level data of 204 observation wells obtained from the Groundwater cell, Department of Agriculture, Government of Haryana with respect to seven community development block of district Bhiwani during 1974-2021. The trend and rate of change in groundwater levels was predicted by performing statistical tests such as Mann–Kendall test, Sens slope estimator and simple linear regression. The analysis of results indicated a mix of negative and positive trends in the groundwater levels. However, the negative trends were much more pronounced than positive ones. Significant decrease in groundwater level is found in 82.12% of wells as obtained through Mann-Kendall analysis at 95% confidence level. The average depth to groundwater level in the district Bhiwani has ranged from 21.04 to 28.48 meter below ground level (mbgl). The mean of groundwater level was found to be 24.26 mbgl. The groundwater depletion in major part of the district may be considered to indiscriminate abstraction for irrigation and drinking purpose and fluctuation in rainfall trend. In addition both anthropogenic and climatic factors have led to groundwater depletion in the study area. The research will be helpful for planners and policy makers toward judicious utilization of groundwater resources in the district.

Keywords: *Economy; Overexploited; Spatially and temporally; Trend; Anthropogenic and climatic factors; Mann–Kendall test; Sens slope estimator.*

1.0 Introduction

Water is the most fundamental substance to the existence of Life. Water scarcity in

**Corresponding author; Research Scholar, Department of Soil and Water Engineering, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India (E-mail: sonusingh2014ae30@gmail.com)*

***Professor and Head of Department, Department of Soil and Water Engineering, Chaudhary Charan Singh Haryana Agriculture University, Hisar, Haryana, India*

****Research Schloar, Department of Soil and Water Engineering, Chaudhary Charan Singh Haryana Agriculture University, Hisar, Haryana, India*

many part of world has become a common problem because 40% of earth surface is covered by arid and semiarid zones (Oki & Kanae 2006; Khayat *et al*., 2006). More than 2 billion human being live in water stressed river basins with less than 1,700 m3/year of available water per capita and in northern Chile, water availability per person is lie between 500 to 1000 m^3/year such a range is considered internationally to be constraining for the sustainable and economic development of countrys (Johnson *et al*., 2001; Ribeiro *et al*., 2014). It is widely recognised as one of the major challenges to social development. Approx. one third of the world's freshwater demand is fulfil through groundwater natural resources (Moreaux & Reynaud 2006; Hetzel *et al*., 2008; Mevlut & Tayfun 2010). Groundwater is the important components of the hydrological cycle and it may be defined as water occupying all the voids within a geologic stratum (Todd & Mays 2005; Goyal *et al*., 2008) or it may be defined as water which occurs in the zone of saturation and theoretical surface to which groundwater rises in an open hole under its natural potential is known as water table. Groundwater is that interstitial water which occurs in the zone of saturation. Theoretical surface to which ground water rises in an open hole under its natural potential is known as water table. The depth of the ground water table from the ground level is termed as water level. The ground water is considered as a resource for human societies. Groundwater is an important part of the global freshwater natural resource because of the physiological needs of living being. It not only supports life on earth, but also governs the economic, industrial and agricultural growth of a nation. Groundwater is the key source of water for agriculture and drinking in low rainfall arid and semiarid regions where there are no other water resources. In fact worldwide, greater than 2 billion people depend on groundwater for their daily uses (Kemper, 2004). According to Tharme, 2003 groundwater forms the largest contribution approx. 97% of the world is freshwater supply and also it perform the crucial role of maintaining the biodiversity and habitats of sensitive ecosystem. Groundwater abstraction has been spontaneously and continuously increasing worldwide and it is often overexploited to relieve water stress (Yang & Zehnder 2002; Van *et al*., 2010). The overexploitation of groundwater has caused serious declines in groundwater level (Phien-wej *et al*., 2006; Aggarwal *et al*., 2009; Chawla *et al*., 2010; Shamsudduha *et al*., 2009; Kaur *et al*., 2011; Panda *et al*., 2012;). In most parts of the developing world overexploitation of groundwater occurred between 1970 and 1990 (UN/WWAP, 2003; Villholth, 2006). Akther *et al*., 2009 said about the declining trend of groundwater level have adverse impacts on the environment such as groundwater depletion and land subsidence, firstly affects aquifer sustainability and the latter results due to the compaction of aquifer materials (Konikow & Kendy 2005). The other impact are groundwater pollution due to additional recharge from other wastewater sources (Hoque *et al*., 2007; Berg *et al*., 2007). Reduction in the availability of surface water due to the decrease groundwater discharge can adversely affect ecosystems (Zektser *et al*., 2005; Konikow & Kendy 2005). Global estimates show that more than 4,430 cubic kilometer of fresh water resources are withdrawal yearly of which more than 70% are used in agriculture and rest are used in other sector (Kinzelbach *et al*., 2003). Among all the country India is the greatest consumer of groundwater in the world, it consume more than total groundwater abstraction of the USA and

China with an estimated annual abstraction more than 230km^3 (Chinnasamy & Agoramoorthy, 2015; Bhanja *et al*., 2017). Besides, household and agriculture sector consume over 85 and 60% respectively of the groundwater (Hoekstra, 2013). According to the central groundwater board (CGWB) 2012 report based on the annual water abstraction – to- water available ratio, the mostly part of India's land areas lie in the category of highly water-stressed. Climate change is one of the major problems facing human being today. According to the Intergovernmental Panel on Climate Change (IPCC, 2011a), global sea levels have risen between 0.1m and 0.25m and global mean temperature have risen 0.3-0.6°C by 2100 relative to 1990 due to the emissions of greenhouse gases (McCarthy *et al.,* 2001). Climate change will bring about numerous environmental problems may include loss of vegetation, reduction of porosity, and the most severe will relate to groundwater resources and the effects of global warming on groundwater natural resource will depend on the its geographical location, groundwater system and change in hydrological variables (Alley, 2001; Biswas, 2003; Huntington, 2006; Sophocleous, 2004; Loaiciga *et al*., 1996; Milly *et al*., 2005 & IPCC, 2007). Temperature increase also affect the hydrological cycle by directly increasing evaporation and vegetation transpiration and indirectly impacts the flux and storage water in surface and subsurface reservoirs (Toews, 2003).Groundwater level changes and its trends were assessed spatially and temporally in Bhiwani district, Haryana, using geographical information system (GIS) for the period 1973–2019. As per the Statistical Abstract from the department of economics and statistical analysis, the number of tube wells for irrigation usage has increased from 0.02 million in 1966 to 0.93 million in 2019. Due to continue increased demand of available groundwater resources has caused depletion of groundwater. All these factors have eventually led to more power requirement for lifting of water for irrigation consumption and thus affect the economic conditions (Tiwana *et al*., 2007). In 2020-2021, net irrigated area in the district was 283000ha, out of which, 60000ha (21%) was irrigated by surface water and 220000ha (79%) with groundwater (Anon. 2021). Due to more dependence on groundwater to meet its huge irrigation needs, the sustainability of the resource is a major concern in the district. Hence, there is a need for a detailed study of groundwater levels and the factors (both anthropogenic and natural) affecting its dynamics and resulting in negative effects to the environment. Therefore, the objective of the present study has been to analyze long term variability in groundwater levels, its relation with other factors groundwater development, and possible consequences in the Bhiwani district.

1.1 Objectives of the study

In Bhiwani district, groundwater is used intensively and some blocks are over-developed or developed as per the norms of Central ground Water Board. In the light of these facts, the present study has been attempted to investigate the "Impact of Depleting Ground Water Resources on the Start-Up Ecosystem and Rural Entrepreneurship" with following objectives.

- To develop spatio-temporal maps for the groundwater level and its fluctuations in Bhiwani district

- To identify the causes of groundwater fluctuations and remedial measures

2.0 Review of Literature

Numerous studies have attempted to quantify the magnitude of global groundwater depletion ratesand accessibility (Almedeij & Al-Ruwaih 2006; Shamsudduha *et al.,* 2009; Schwartz & Ibaraki 2011; Bloomfeld *et al.,* 2018). Christakos (2000) studied the use of geo-statistical techniques (parametric and non-parametric test) on the height of water table of 70 wells in Kansas with successful results. Hoque *et al*., (2007), Akther *et al*., (2009) and Shamsudduha *et al.,* (2009) utilized the geo-statistical modeling to examined the spatio-temporal variability of groundwater level fluxes and trends in Dhaka and the Ganges–Brahmaputra–Meghna Delta and witnessed positive (declining) trends of groundwater levels in urban and semi-urban areas, whereas negative (rising) trends in estuarine and coastal region.

Tabari *et al*., (2012) have examined spatial and temporal patterns of groundwater levels in Darab plain of Northern Iran and showed the positive trends in groundwater levels.

Yao *et al.,* (2014) have applied geospatial interpolation techniques to reveal the groundwater level fluxes and trends in north-west China and observed falling trends.

Ribeiro *et al.,* (2015) conducted a study to evaluate the piezometeric trends in the alluvial aquifers of the Elqui river basin in central Chile and observed that the groundwater levels has decreased (falling trends) in majority of wells.

In the changing scenario of climate, the role of groundwater is significant, due to its relative stability in terms of quality, quantity and availability throughout the year. Moench (1992) analyzed the tendency of overexploitation of natural water resources is rooted in the rapid spread of modern pumping technology, subsidized power supply and governmental policies. The explosion in access to mechanical pumping technologies is a clear factor encouraging the overdevelopment of natural groundwater resources.

Shah *et al*., (2003) investigated the use of groundwater for agriculture purposes in south Asia and North China plains during 1970 to 1995 and found that India, China, Pakistan, Bangladesh account for bulk of world's use of groundwater in different sectors (agriculture, drinking and industrial. Overdevelopment of groundwater resources has created a serious problem of resource depletion and deterioration in the quality of water.

Bhalla (2007) assessed the impact of declining of groundwater level on the farmer's crop response function in Haryana (India). The natural groundwater resources problem in Haryana is distinct as the state experiences both waterlogging as well as declining trends of groundwater levels simultaneously. It is all more disturbing to find that cultivation of water-intensive crops like rice and number of tubewells are increasing in the regions where the depth to water levels is declining. However in Mahendergarh district cause of declining water levels is due to its rocky type topography.

Naik *et al*., (2008) have investigated the groundwater levels of Solapur (Maharashtra) and witnessed significant falling and rising trends in the main city (on account of increased recharge and decreased groundwater abstraction) and outside the city (due to use of groundwater for agricultural purposes), respectively.

3.0 Research Methodology

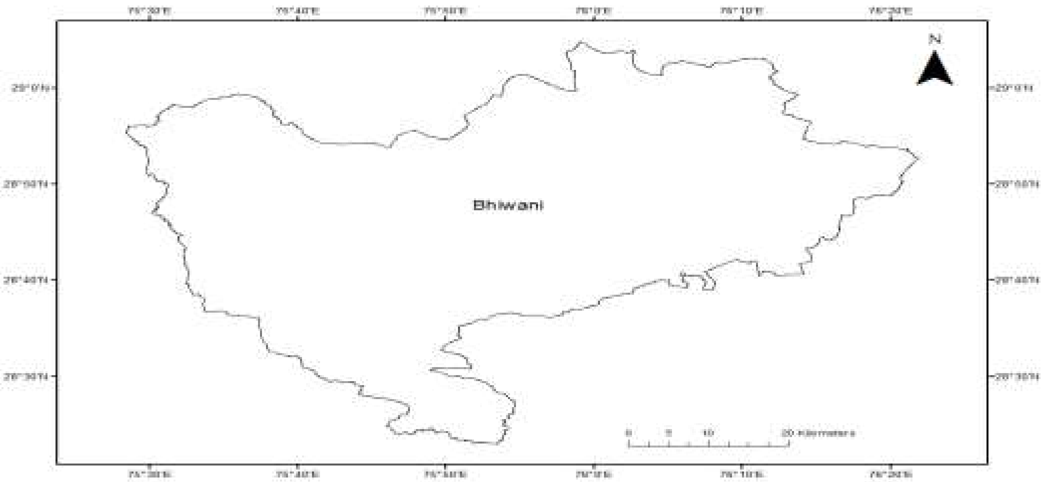
3.1 Study area

The state of Haryana, is located in northwest of India is one of the smallest states in India with its capital at Chandigarh, and it extends between 27°39' to 30°35' N latitude and between 74°28' and 77°36' E longitude. Haryana state covering an area of 44,212 sq. km accounting about 1.38 percent of the total geographical area of the country and it contributes more than 6% of country‘s total food production. Haryana was carved out of the former state of Punjab on 1966 and administratively, the state has been bisected into 22 district, 118 Community Development (CD) blocks and 9 physiographic units. Bhiwani district lies in South-Western part of Haryana state and it was carved out by reorganization of the state in 1972, the district was the largest district of the state by area, before the creation of Charkhi Dadri as a separate district. The total geographical area of the Bhiwani district is 3297sq. km accounting about 7.8 per cent of the total area of the state. The district comprised of 444 village, 8 town and seven blocks viz. Bawani Khera, Bhiwani, Kairu, Tosham, Siwani, Loharu and Behal. In general, geomorphologically the district consist of flat and level plain disturbed from place to place by clusters of sand dunes and the topography values lie in between 210 to 280 above mean sea level. According to census 2011, it had a population of 1634445 which had observed a growth of approx. 15% during 2001-2011. The literacy rate and density of population in the district are respectively 76% and 342 per sq.km. Approx. 21% of the population lives in urban area and remaining 79% population leaves in rural area. Dohan is the major river of the district and flows in direct response to precipitation. Only the tails of this stream falls in the south-central corner of the district and ultimately dies out in sands around villages. The climate of Bhiwani district can be labeled as tropical steppe, hot and semi-arid with excessive evapotranspiration and cold winter except in monsoon season when humid air of oceanic origin invade into the district (Raju *et al,.* 2013). The summer season start from mid March to last week of the June. May and June are the hottest month and December and January are the coldest month. Summer season is accompanied by south-west monsoon which lasts upto September. The September and October months forms the post-monsoon season. The winter season begins late in November and remain upto first week of March. The normal annual rainfall of the district is 420 mm which is unevenly distributed over the area 22 days. The south west monsoon, sets in from last week of June and withdraws in end of September, contributed about 85% of annual rainfall. July and August are the wettest months. Rest 15% rainfall is received during non-monsoon period in the wake of western disturbances and thunder storms. Generally rainfall in the district increases from southwest to northeast.

3.2 Data acquisition and methodology

This study is mainly based on secondary data, which have been procured for the period 1974–2021 from the Groundwater Cell, Department of Agriculture, Government of Haryana, Panchkula.

Figure 1: Geographic Location of the South-Western Haryana in Which My Study Area is Lies Top Most Left Sides



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 2: Geographic Location where We Got Secondary Data for Analysis South-Western Haryana in which My Study Area is Lies Topmost Left Sides

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

It records the depth to groundwater level biannually during pre-monsoon and post-monsoon seasons. Data of a 7 community development (CD) blocks for pre- and post-monsoon depths to groundwater level have been procured for analysis and interpretation to examine the pattern and dynamics of groundwater level. In addition, ancillary data pertaining to the factors affecting level of groundwater (tube-well irrigated area, number of tube wells, area under rice cultivation, canal-irrigated area, temperature (maximum and minimum), relative humidity and amount of rainfall) have been collected for the same period from the Department of Economic and Statistical Analysis, Haryana, and India Meteorological Department, Chandigarh. The details of the methodology adopted for examining the trend and homogeneity in the groundwater level series are as discussed below.

4.0 Results and Discussion

4.1 Spatial variability

- **Block wise average and spatial variations of groundwater depth during 1974**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 2-50m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 1974 (Fig. 3). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e.,0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 1974, in Bhiwani district, lowest (2.6 m) and highest (44.4 m) groundwater level was recorded in Bhiwani and Behal block, respectively (In Table 1).

- **Block wise average and spatial variations of groundwater depth during 1984**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 2-50m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 1984 (Fig. 4). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e., 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 1984, in Bhiwani district, lowest (2.8 m) and highest (47.6 m) groundwater level was recorded in Bhiwani and Behal block, respectively (In Table 2).

- **Block-wise average and spatial variations of groundwater depth during 1994**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 1.2-50m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 1994 (Fig. 5). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e., 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 1994, in Bhiwani district, lowest (1.4 m) and highest (49 m) groundwater level was recorded in Bhiwani and Behal block, respectively (In Table 3).

- **Block-wise average and spatial variations of groundwater depth during 2004**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 0.8-70 m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 2004 (Fig. 6). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e., 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 2004, in Bhiwani district, lowest (0.9 m) and highest (64 m) groundwater level was recorded in Bhiwani and Kairu block, respectively (In Table 4).

- **Block-wise average and spatial variations of groundwater depth during 2014**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 1.2-50m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 2014 (Fig. 7). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e., 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 2020, in Bhiwani district, lowest (0.3 m) and highest (94.1 m) groundwater level was recorded in Siwani and Behal block, respectively (In Table 5).

- **Block-wise average and spatial variations of groundwater depth during 2021**

Spatial variations of groundwater depth at intervals of ten years from 1974 to 2021 have been present (Fig. 3 to fig. 8). Comparison of 1974, 1984, 1995, 2004, 2014, 2021 maps found a spatially non-uniform groundwater depth incline or decline. Whereas a regular decline were seen in approx. 70% of the area (maximum in south region), the depth of groundwater were found fluctuating in a shallow range of 1.2-50m.

The average groundwater depth map for the study area was prepared by using Arc-GIS for the year 2021 (Fig. 8). By using different tools of ArcGIS, district-wise area under different groundwater depths, i.e., 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 m was calculated and is shown in Table 7.

During 2020, in Bhiwani district, lowest (0.3 m) and highest (94.1 m) groundwater level was recorded in Siwani and Behal block, respectively (In Table 6).

- **Block-wise average water depth (m), its range and standard deviation from the 1974 to 2021**

Table 1: Block-wise Average Water Depth (m), its Range and Standard Deviation for the Year 1974

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	20.8	9.9	22.3	3.8
	Behal	30.1	31.4	44.4	4.4
	Bhiwani	9.2	2.6	21.3	4.5
	Kairu	12.2	6.6	29.8	7.0
	Loharu	40.2	27.4	43.6	4.6
	Siwani	22.3	12.9	34.0	5.5
	Tosham	25.3	5.1	25.7	5.6

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 2: Block-wise Average Water Depth (m), its Range and Standard Deviation for the Year 1984

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	16.1	8.2	20.1	3.8
	Behal	34.0	32.6	47.6	5.3
	Bhiwani	7.7	2.8	18.3	4.4
	Kairu	16.6	8.5	30.4	6.9
	Loharu	38.5	32.0	45.2	4.5
	Siwani	26.1	12.2	34.7	6.2
	Tosham	18.9	5.0	25.7	5.0

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 3: Block-wise Average Water Depth, its Range and Standard Deviation for the Year 1994

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	12.2	1.9	17.2	3.8
	Behal	37.1	33.8	49.0	5.7
	Bhiwani	8.3	1.4	17.0	3.5
	Kairu	17.6	7.4	32.7	8.4
	Loharu	36.4	28.6	47.7	5.6
	Siwani	20.0	11.1	33.9	6.3
	Tosham	16.0	4.9	34.8	6.4

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 4: Block-wise Average Water Depth, its Range and Standard Deviation for the Year 2004

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	6.6	1.9	16.4	3.8
	Behal	37.1	5.7	54.8	16.9
	Bhiwani	6.1	0.9	32.2	7.3
	Kairu	19.2	11.8	64.0	18.4
	Loharu	44.1	6.1	53.5	16.3
	Siwani	20.4	9.7	39.2	6.4
	Tosham	10.6	2.8	60.0	18.8

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 5: Block-wise Average Water Depth, its Range and Standard Deviation for the Year 2014

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	4.5	1.6	10.1	2.4
	Behal	63.7	6.1	93.1	23.2
	Bhiwani	4.6	37.2	39.0	7.9
	Kairu	20.6	8.8	59.2	15.1
	Loharu	62.3	2.5	74.6	10.6
	Siwani	21.0	0.3	39.3	8.3
	Tosham	11.8	0.9	68.1	14.6

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 6: Block-wise Average Water Depth, its Range and Standard Deviation for the Year 2021

Name of district	Name of block	Average water table depth	Range of water table		Standard deviation of water table depth
			Minimum	Maximum	
Bhiwani	Bawani Khera	4.0	1.7	11.1	2.4
	Behal	65.7	7.1	94.1	23.2
	Bhiwani	4.8	38.2	40.0	7.9
	Kairu	21.6	8.8	60.2	15.1
	Loharu	63.3	2.3	75.6	10.6
	Siwani	22.0	0.3	40.3	8.3
	Tosham	12.8	0.9	69.1	14.6

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

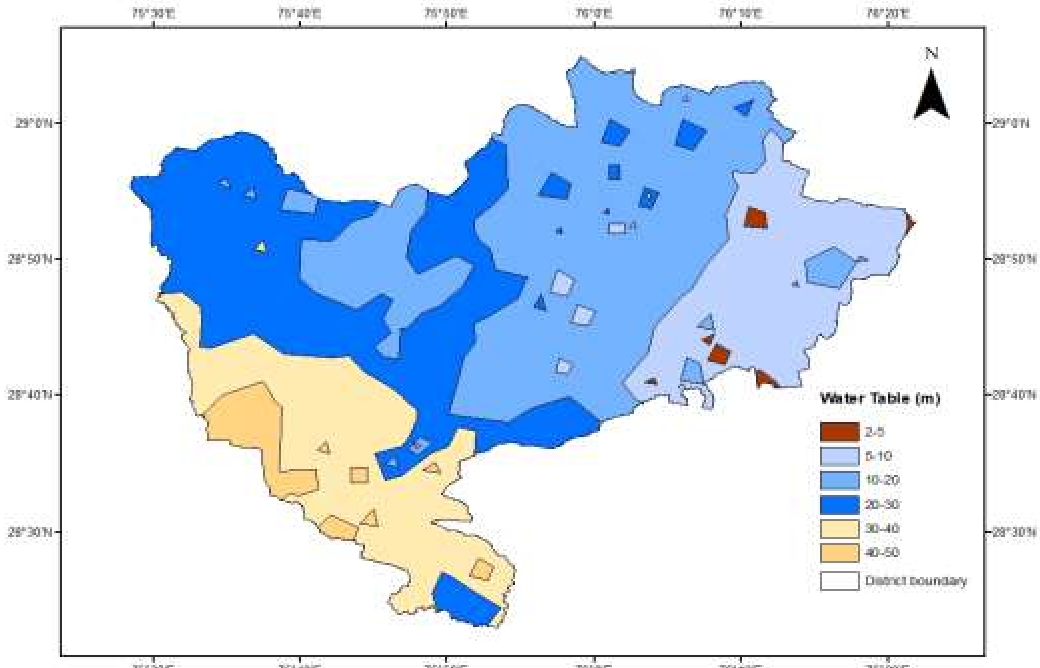
Table 7: Area (000 ha) under Different Ground Water Depths (m) from 1974 to 2021

Groundwater Depth	1974	1984	1994	2004	2014	2021
0 – 2 m	0.0	0.0	0.1	0.9	1.2	1.3
2 – 5 m	1.5	6.1	4.9	36.8	47	46.9
5– 10 m	50.0	50.7	78.5	84.2	65.7	66.7
10– 20 m	123.2	132.5	113.6	111.5	82.4	81.4
20– 30 m	90.5	72.4	61.7	25.3	46.5	45.5
30– 40 m	54.1	44.8	37.6	20.8	19.6	20.6
40– 50 m	10.4	23	33.4	22.4	11.1	12.1
50– 60 m	0.0	0.0	0.0	24.3	16.6	15.6
60– 70 m	0.0	0.0	0.0	3.6	19.3	21.3
70– 80 m				0.0	18.2	16.2
80 – 90 m					2.1	1.1
90-100 m					0.0	1.0
100-110 m					0.0	0.0
Total	329.7	329.7	329.7	329.7	329.7	329.7

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

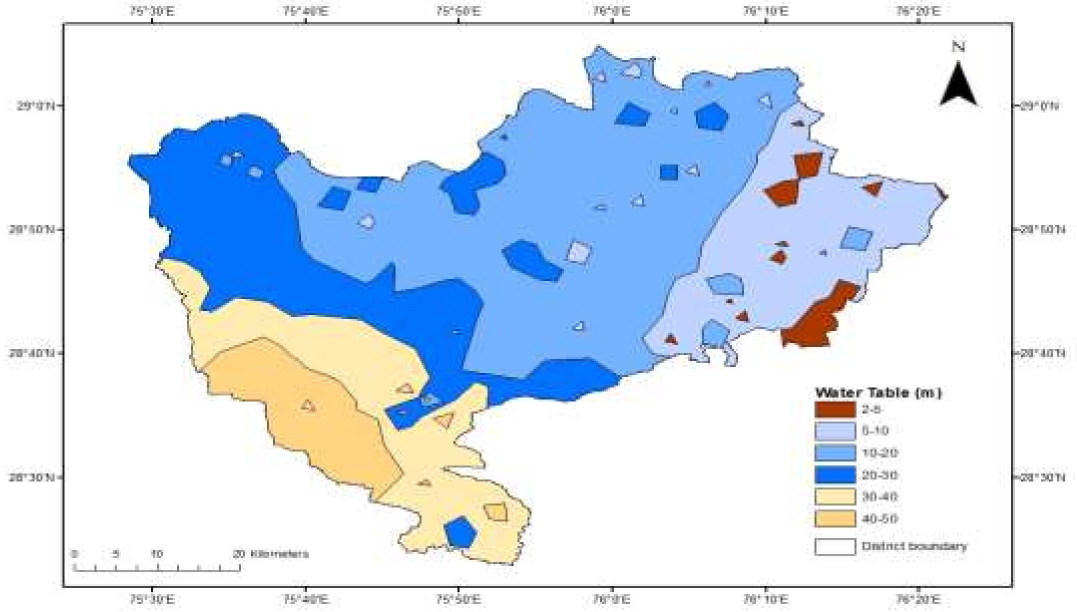
- **Spatial variation of groundwater depth from 1974 to 2021**

Figure 3: Spatial Variation of Groundwater Depth in 1974



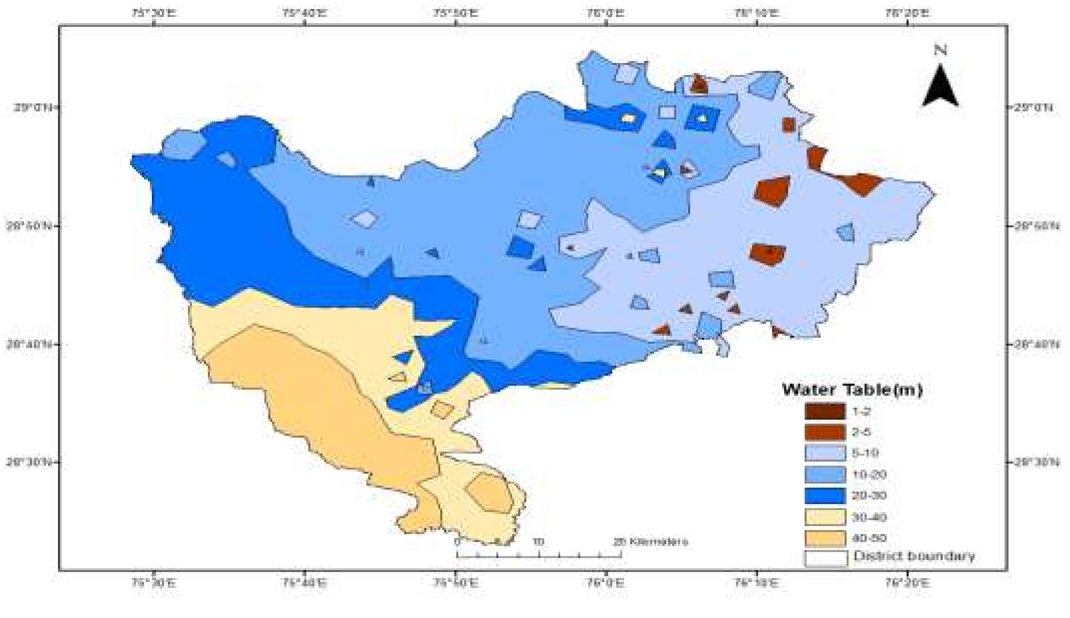
Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure: 4 Spatial Variation of Groundwater Depth in 1984



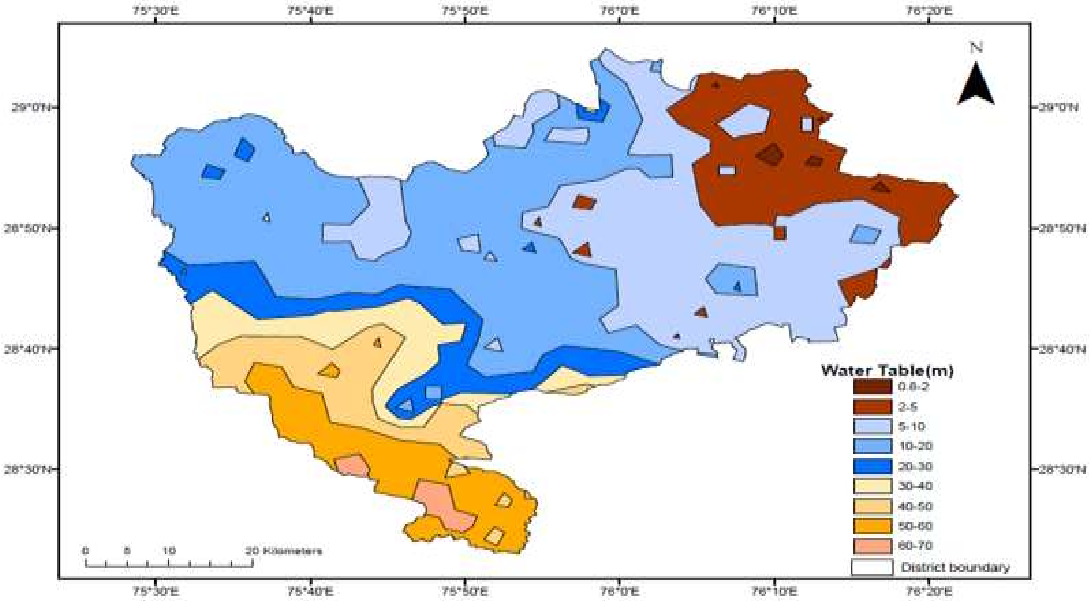
Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 5: Spatial Variation of Groundwater Depth in 1994



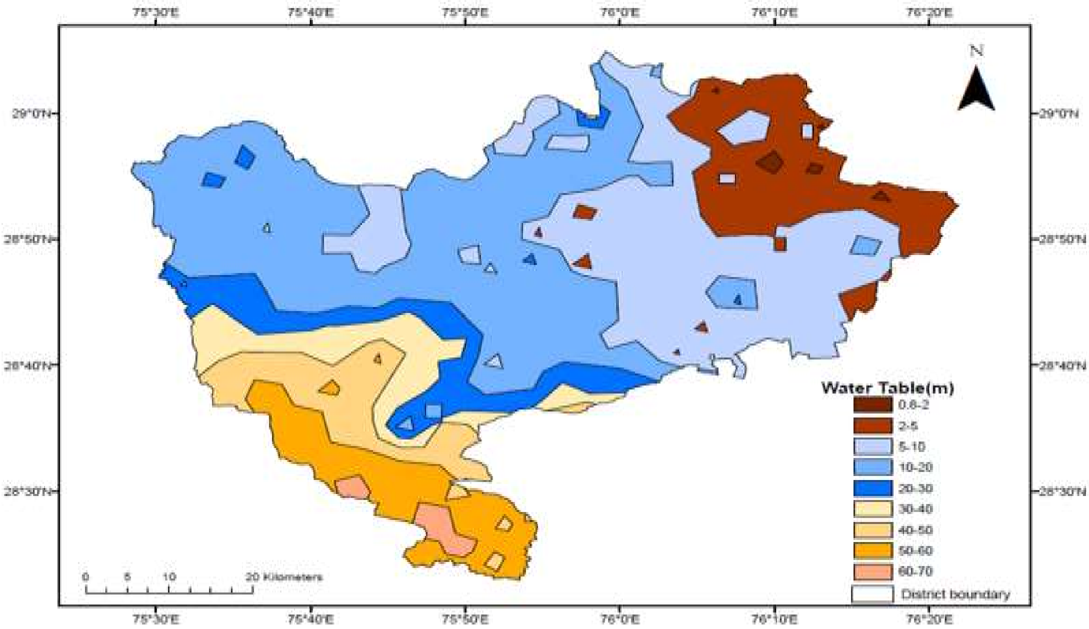
Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 6: Spatial Variation of Groundwater Depth in 2004



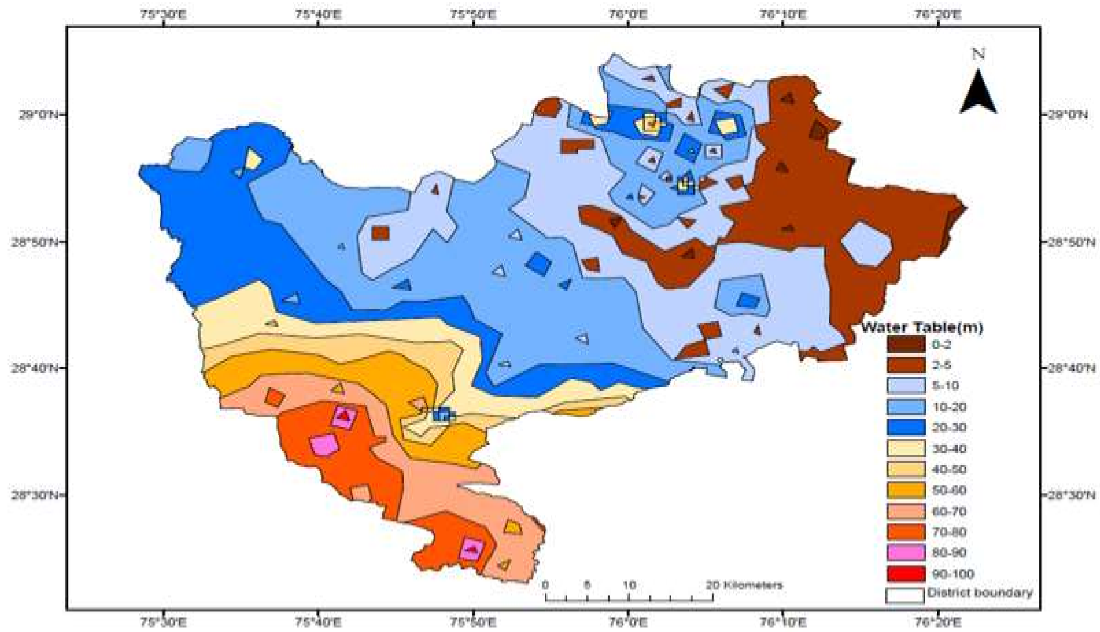
Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 7: Spatial Variation of Groundwater Depth in 2014



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 8: Spatial Variation of Groundwater Depth in 2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

The overall groundwater depth (m) of Bhiwani district declined from 23.44 m in 1974 to 28 m in 2021. This observation is similar with a recent study based on Gravity Recovery and Climate Experiment (GRACE), which has delineated an average decline of 0.3 m in groundwater depth in Northern India (Rodell *et al.,* 2009). The average groundwater fluctuations in each block at successive intervals of ten years is given in Table 8. During 1974-2004, the incline in groundwater depth in the district was observed to be small (district average 0.38 m). In the next ten years (2004-2014), a net decline was observed in groundwater depth, possibly due to increased discharge and rainfall in Bhiwani district.

Table 8: Block-wise Average Groundwater Depth and Groundwater Fluctuations

Sr. No.	Block	Average annual groundwater depth (m)					
		1974	1984	1995	2004	2014	2021
1	BAHAL	38.3	40.3	42.83	47	56.2	64
2	BAWANI KHERA	16.5	14.4	11.4	7.8	5.6	4
3	BHIWANI	9.9	8.6	7.2	5.9	4.6	5
4	KAIRU	18.2	17.9	17.4	18.3	19.5	22
5	LOHARU	37.8	40	41.6	51.6	58.6	63
6	TOSHAM	18.4	17.5	15.8	13.2	13.5	13
7	SIWANI	24.3	23.8	22.6	18.3	22.4	23
	District Average	**21.4**	**23.2**	**22.6**	**23.1**	**26**	**28**

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

The water withdrawals from the wells in the Bhiwani district are estimated to exceed a 438.24 mcm (Table 9), and shows the most volumi- nous use of natural water resources in the state Haryana). The Bhiwani district faces severe problem of drinking water and other usable waters in many areas, as it is witnessing drastic incline in water demand and change in societal water use pattern because of rapid urbanization (Scanlon *et al.,* 2010). Presently, about 80% of the area are irrigated by groundwater sources and 70.8% of gross area irrigated to total cropped area.

Table 9: Number of Villages under Different Groundwater Depths (m) from 1974 to 2021

Groundwater Depth	1974	1984	1994	2004	2014	2021
0 – 2 m	0	0	1	1	2	2
2 – 5 m	2	8	7	50	63	63
5– 10 m	67	68	106	113	88	90
10– 20 m	166	178	152	150	111	110
20– 30 m	122	98	83	34	63	61
30– 40 m	73	30	50	28	26	28
40– 50 m	14	31	45	30	15	16
50– 60 m	0	0	0	33	22	21
60– 70 m	0	0	0	5	26	29
70– 80 m	0	0	0	0	25	22
80 – 90 m	0	0	0	0	3	2
Total	**444**	**444**	**444**	**444**	**444**	**444**

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 10: Summary of Land Use Area, Total Population, Precipitation, Total Irrigated Area, % of Gross Area Irrigated to Total Cropped Area, Renewable Groundwater Resources, Groundwater Withdrawal and Total Water Uses in District Bhiwani

District	Total area estimates (as of 2011) Sq. Km.	State %	Population estimates (as of 2011) Thousands	State %	Annual precipitation (1973-2019 mean) (cm/year)	Net area under Irrigation (as of 2019)Hectare State %	% of Gross area irrigated to total cropped area (as of 2019)	Net Area irrigated by Groundwater resources (000 Ha)	Net Area irrigated by Surface water resources (000 Ha)	Groundwater abstraction (as of 2010) (mcm/year)	Stage of ground water development
Bhiwani	3432	7.7	1634.5	6.4	36.53	283	70.8	223	60	438.24 mcm.	79

Source: SAH (1979-1980); SAH (1989-1990); SAH (1999-2000); SAH (2010-2011).

The land uses were classified in three groups such as:
(i) Agriculture (ii) Built-up (iii) Barren lands.

After the analysis of 47 years data we concluded that the built up area has been increased by approx. 10% over the Bhiwani district from 2000–2001 to 2011–2012, indicating rapid urbanization over study area and conversely observed decline rate in ground water depth may also be attributed to over- exploitation of groundwater resources as reported by past studies (Khazaei *et al.,* 2004).

Table 11: Classification of Land Use

LULC class	1972-1973 (000 ha.)	1982-1983 (000 ha.)	1992-1993 (000 ha.)	2002-2003 (000 ha.)	2012-2013 (000 ha.)	% of variation from 1972-1973 and 2012-2013	% of variation from 1982-1983 and 2012-2013	% of variation from 1992-1993 and 2012-2013	% of variation from 2002-2003 and 2012-2013
Total area	505	460	403	466	466	-7.7	1.3	15.6	0
Forest	4	10	8	3	3	-25	-70	-62.5	0
Barren	11	13	19	20	20	81	53.8	5.2	0
Fallow	14	22	14	16	16	14.2	-27.2	12.5	0
Net area sown	441	390	345	403	400	-9.29	2.5	16	-0.7

Source: SAH (1979-1980); SAH (1989-1990); SAH (1999-2000); SAH (2009-2010); SAH (2018-2019).

4.2 Spatial and temporal variations of groundwater fluctuation of Bhiwani

District wise average groundwater fluctuation (cm) was calculated (Table 15) by taking 1974 as reference year, *i.e.,* 1974-1984, 1974-1994, 1974-2004, 1974-2014 and 1974-2021 for Bhiwani districts. Average fluctuation of the study area was calculated through cumulative arithmetic mean by considering the area of different districts as their weight. To visualize the spatial variability of the groundwater level fluctuation from1974 to 1984,1974-1994, 1974-2004, 1974-2014 and 1974-2021, maps were prepared by using Arc-GIS for the study area, as shown in Figs. from 15. By using different Arc GIS tools, area under different fluctuation range from year 1974-2021 was calculated and is presented in Table 12. Further per year fluctuation and percent area under different fluctuation range was calculated from the year 1974 to 2021.

Table 12: District-wise groundwater fluctuation (cm) of Bhiwani by 1974 as reference year

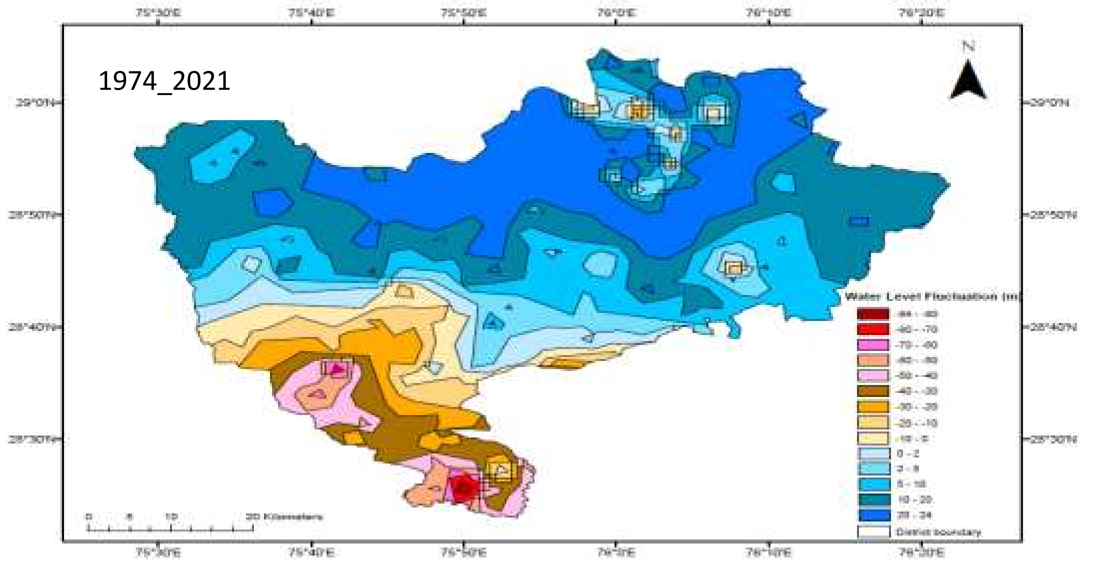
Year	Bhiwani District
1974-1984	90
1974-1994	240
1974-2004	330
1974-2014	-550
1974-2021	-680

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

The analysis found that maximum and minimum groundwater fluctuation depth in 1974_2021 years were 19.61 mbgl and -70 mbgl, respectively. The mean depth to groundwater fluctuation depth in the district in those years was -65.6 mbgl. The average annual groundwater fluctuations in each blocks at successive intervals of ten years were tabulated in Tables 12 and 13 and an average decline of 14.8 cm per year was observed during the study period of 1974 to 2021 in the Bhiwani district.

+ve represent rise in groundwater and –ve sign represent decline groundwater

Figure 9: Groundwater Level Fluctuation Map 1974-2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Table 13: Percent Area under Different Fluctuation Range from Year 1974-2021

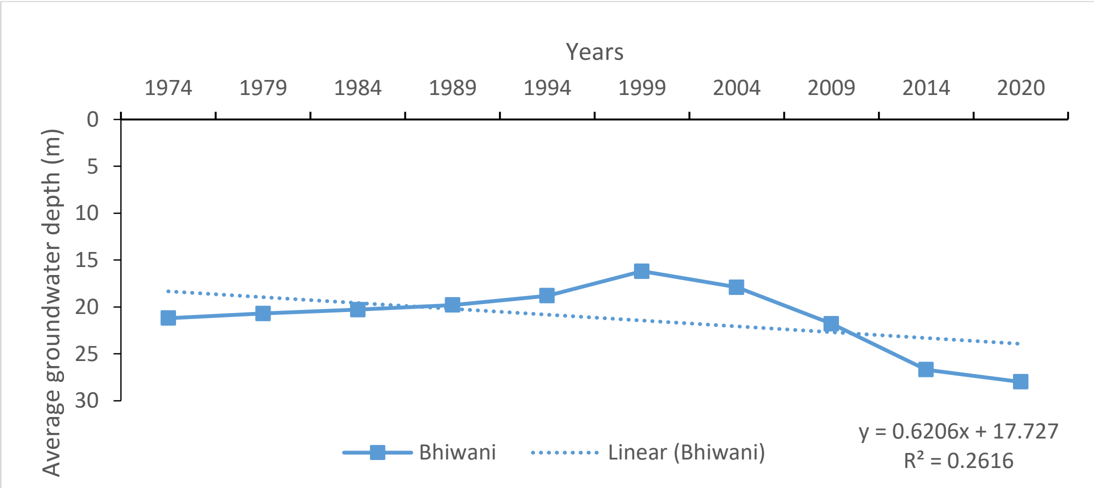
Range of fluctuation (m)	Average fluctuation (m)	Per year fluctuation (m/year)	Area (000 ha)	Percent area	S.D
-84 to -80	- 82	-1.74	0.25	0.08	2.51
-80 to -70	-75	-1.60	0.91	0.28	3.48
-70 to -60	-65	-1.38	1.40	0.42	2.11
-60 to -50	-55	-1.17	5.05	1.53	8.95
-50 to -40	-45	-0.96	8.69	2.64	18.18
-40 to -30	-35	-0.74	12.86	3.90	48.46
-30 to -20	-25	-0.53	13.24	4.02	31.25
-20 to -10	-15	-0.32	14.09	4.27	34.17
-10 to 0	-5	-0.11	15.13	4.59	31.31
0 to 2	1	0.02	17.68	5.36	18.72
2 to 5	3.5	0.07	27.10	8.22	25.92
5 to 10	7.5	0.16	50.15	15.21	52.58
10 to 20	15	0.32	90.82	27.55	148.93
20 to 24	22	0.47	72.34	21.94	175.13

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

4.3 Groundwater depth trend for Bhiwani from year 1974 to 2021

In Bhiwani district, groundwater depth was decreased up to year 1999 but afterword its depth was increased. On the basis of trend line, declining trend of groundwater level was observed but it not much significant as the value of R^2 is very less (0.2616).

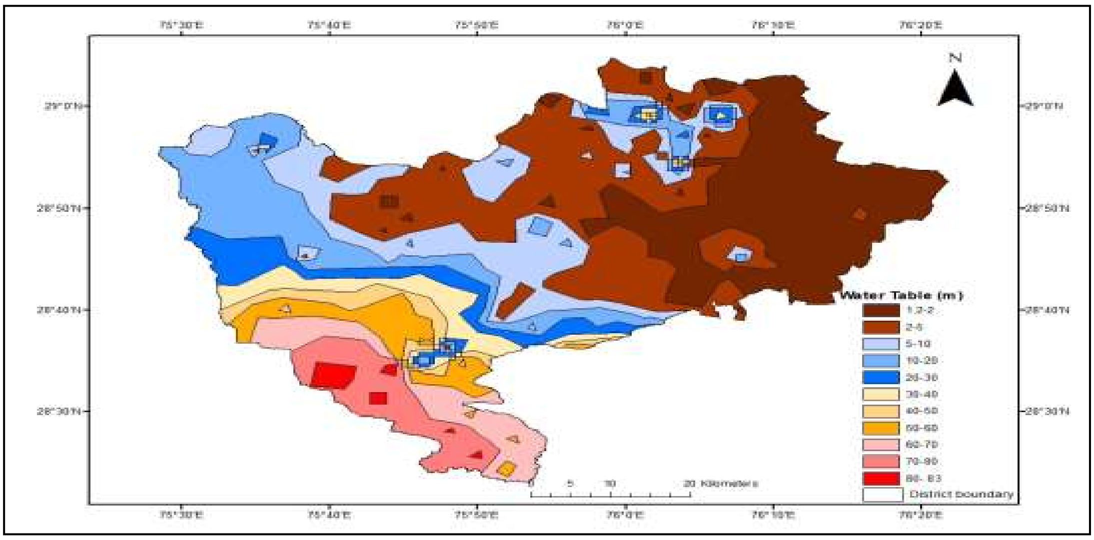
Figure 10: Average Five Year Interval Groundwater Depth (m) in Bhiwani District for the Study Period 1974-2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

4.4 Seasonal effect on groundwater depth

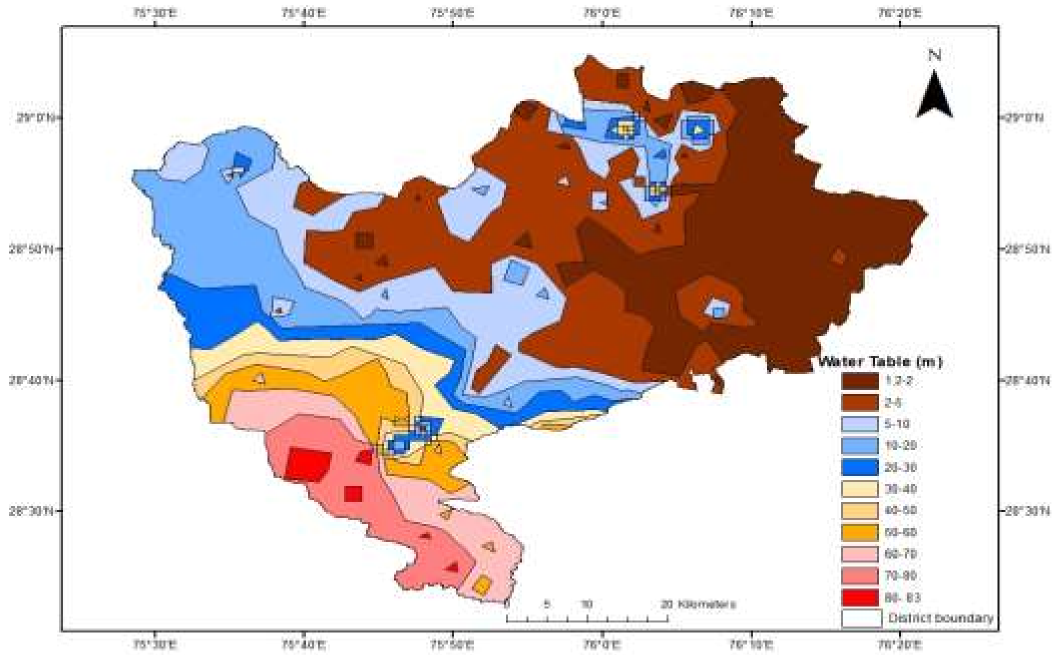
Figure 11: Average Groundwater Levels during Pre -Monsoon Season for the Period 1974-2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Available data on groundwater depth is being generally taken twice in a year, *i.e.*, before and after monsoon season because groundwater depth is mostly affected by recharge of rain water and in the study area 85% of annual rainfall occurs during the monsoon season. Therefore, it is important to study the seasonal effect. Accordingly, annual maps were prepared before and after the monsoon season by using the available data at each observation well from the year 2001 to 2021, are not presented here. By averaging the pre- and post-monsoon data of groundwater depth at each well individually for the study period, the groundwater depth map was prepared to study the season fluctuation in Bhiwani district, are represented in Fig. 11 & Fig. 12.

Figure 12: Average Groundwater Levels during Post-Monsoon Season for the Period 1974-2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

5.0 Discussion

5.1 Spatial and temporal variation of groundwater depth

The spatial and temporal variation maps of groundwater depth at an interval of ten years for the study period (1974-2021) was prepared as shown in Fig.3 to Fig. 8. On comparison of 1974, 1985, 1995, 2004, 2014 and 2021 maps, it was observed that groundwater level decline was not uniform. Although a decline was recorded in 71.4% part of study area, which mainly constituting Bhiwani districts, During the study period 1974-2021, among the 204 observation wells, the maximum value of groundwater depth varied from

47.73 m in year 1974 to 94 m in year 2021, whereas, its minimum value varied from 1.07 m in year 1974 to 0.74 m in year 2021 (Table 1 and 10). The average value of groundwater depth varied from 21.04 m in year 1974 to 28.03 m in year 2021 (Table 8).

5.2 Area change under different groundwater level

Aperusal of the results revealed that area under 2-10 m (prone to water logging) depth of groundwater has increased from 15% (1974) to 34.5% (2021), whereas, the area under groundwater level of 10-30 m (safe limit) has also reduced from 64% (1974) to 38% (2021) during the study period of 47 years. Also the area under more than 30m that was susceptible to over exploited has increased from 19% (1974) to 26% (2021) and the area under 0-2m groundwater level, exposed to water logged, increased from 0.01% to 0.3% during the study period.

5.3 Spatial variation of groundwater fluctuation under different layers

By add the value of area lying in different years (Tables 7) under different groundwater depths, *i.e.,* 0-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70,70-80, 80-90, 90-100 and 100-110 m. was prepared to find out the area under different depth during the study period. A graph was plotted to observe the variation in area under different depths of the study area. During 2021, 1300 ha area was estimated in the range of 0-2m, which is very less (0.3%) as compared to total area of Bhiwani but this area is a matter of serious concern because it reflects the problem of water logging. During 2020, in 2-10m groundwater depth, 113600 ha area was estimated but inclining trend in its value was observed on comparing to area under this category of previous years.

Table 14: Area (000 ha) under Different Groundwater Depths (m) for the Period 1974 to 2021

Range	1974	1984	1995	2004	2014	2021
0-2 m	0	0	0.1	0.9	0.5	1.3
2-10 m	51.5	56.8	83.4	121	106.4	113.6
10-30 m	213.7	204.9	175.3	136.8	137.5	126.9
Above 30 m	64.5	67.8	71	71.1	85.4	87.9

Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

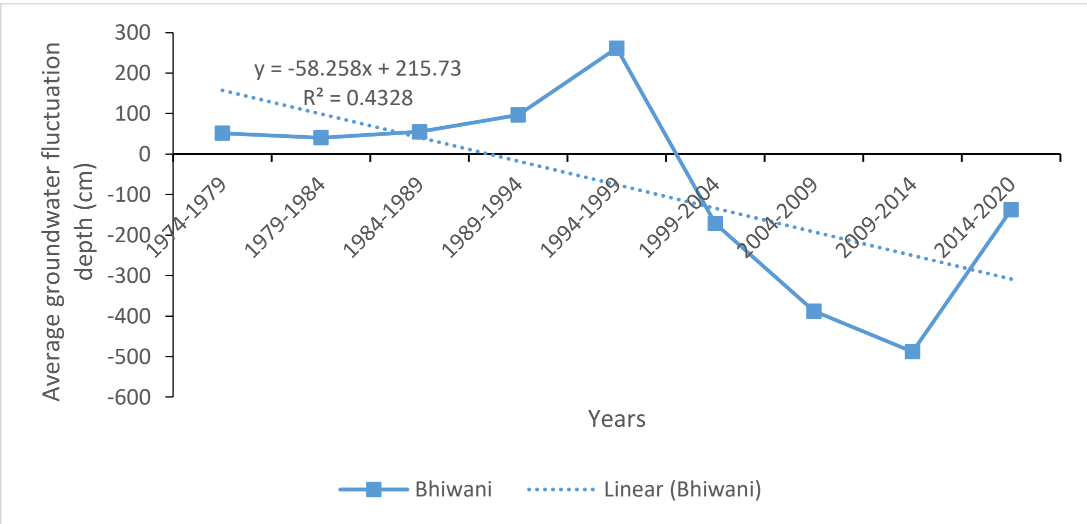
It is still very large area (34.4%) and it lies under the category of prone to water logging, needs attention of the planners. During 2021, in 10-30m groundwater depth, 126900 ha area was estimated and again declining trend in its value was observed on comparing to area under this category of previous years. This category lies in the safe limit and don’t require any serious concern. During 2021, in above 30m groundwater depth area has been increased from 64500 ha to 87900 ha in year 2020. This is approximate 1.5 times the area under 2020 in comparison to 1974. Which reflect serious attention to check the further decline in groundwater depth. Above 70m groundwater depth, in year 1974 (Table 7), no area was existing in this category but in year 2020, it showed an area of 18000 ha (Table 7), this reflects the shifting of groundwater level from lower to higher depth, which is a matter of overexploitation of groundwater resources. This type of area is easily assessable through maps (Fig. 9) and appropriate measures can be taken place by the planners.

Figures from 9 are representing the spatial variation of groundwater under different fluctuation range for different duration, *i.e.,* 1974-1984, 1974-1994, 1974-2004, 1974-2014 and 1974-2021. From year 1974-2021, the average fluctuation was ranging from – 82 m (-ve means decline) and 22 m, which was calculated on the basis of 209 observation wells lying in the study area. In rising trend of groundwater level, maximum area (27 %, Table 13) was recorded in the range of 10 to 20 m, whereas on declining side, maximum area (4 %) was recorded in the range of – 30 to -20 m. To study the seasonal effect (pre and post monsoon) on groundwater depth, maps were prepared before and after the monsoon season by using the available data at each observation well from the 1974-2021.

5.4 Overall declining and rising trend of groundwater level

The average fluctuations in groundwater levels in each district at 10, 20, 30, 40 and 47 years intervals with reference to base year 1974 was computed. Average decline of 14.8 cm per year was observed during the study period of 1974 to 2021 in the study area (Fig. 10). The relationship between maximum, minimum, average groundwater depth and annual rainfall (mm) was presented in Figs. 15 and 16.

Figure 13: Average Five Year Interval Rise/Fall (cm) in Groundwater Levels in Different Block of Bhiwani District for the Study Period 1974-2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

5.5 Major Factors Affected the Groundwater Level in Bhiwani district

5.5.1 Impact of natural and anthropogenic factors on groundwater Level

Understanding of spatial and temporal trends of groundwater depth is essential for sustainable development of natural water resources. Some anthropogenic and climatic variables (area under rice cultivation, number of tube wells and rainfall) were studied in relation to groundwater level.

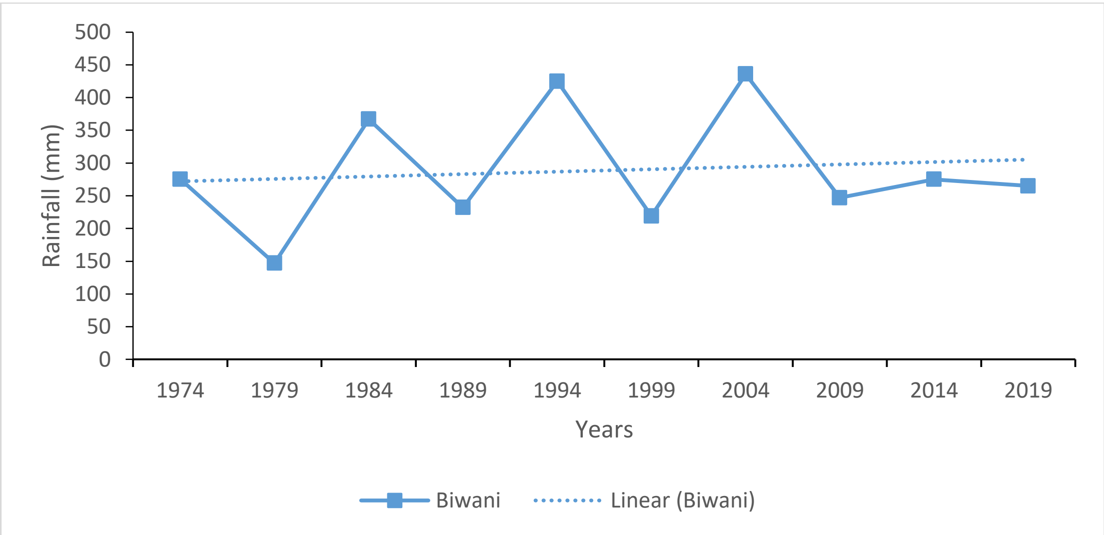
(a) Average Annual Rainfall (mm)

Annual rainfall (mm) and groundwater level (m) were plotted against the time (year) for the year 1974 to 2021, which indicates the positive response to incidence of rainfall (Fig. 14). Height of line are reflecting the rainfall depth and their decreasing height is reflecting the declining trend in rainfall during 2009-2014 and 2014-2020 and groundwater depth inversely increased during this period, thus, contributed adverse effect on the groundwater level besides other factors.

(b) Impact of number of tubewells on groundwater level

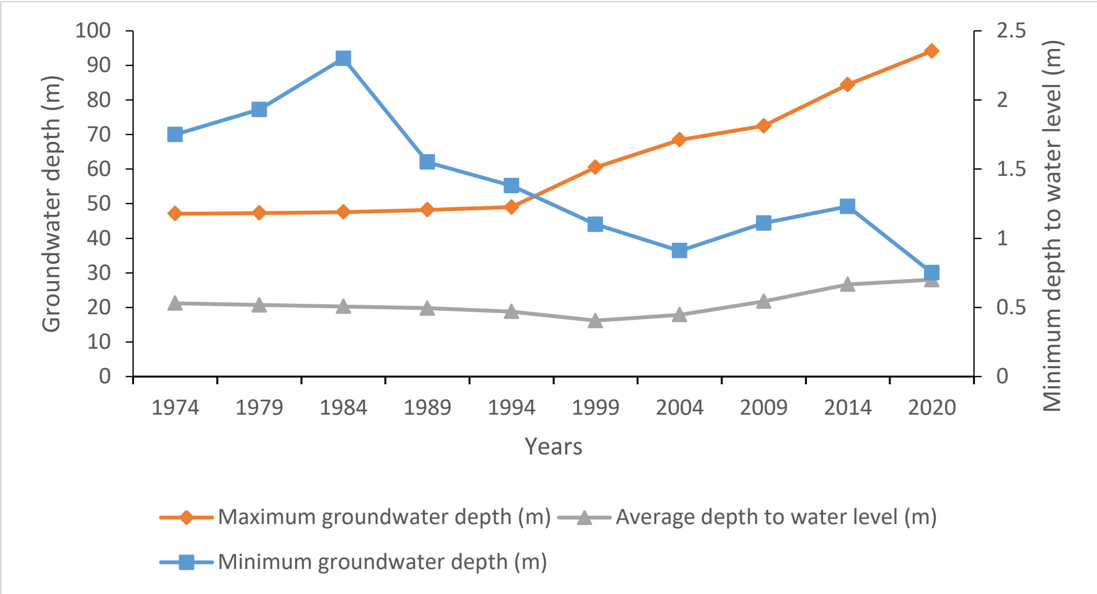
The most conspicuous falling groundwater level trends and patterns with greater negative fluctuations over the study period (1974–2021) are in Bhiwani district (Figs. 10 and 13). Groundwater levels have depends significantly in these regions by affecting most of the water-related activities (especially food production) leading to socioeconomic stress in the region and also number of tubewells has been increased during the same time period (Fig. 21), *i.e.*, from 0.007 million (1974) to 0.065 million (2021).

Figure 14: Annual Rainfall (mm) in Bhiwani Part of Haryana for the Study Period 1974-2021



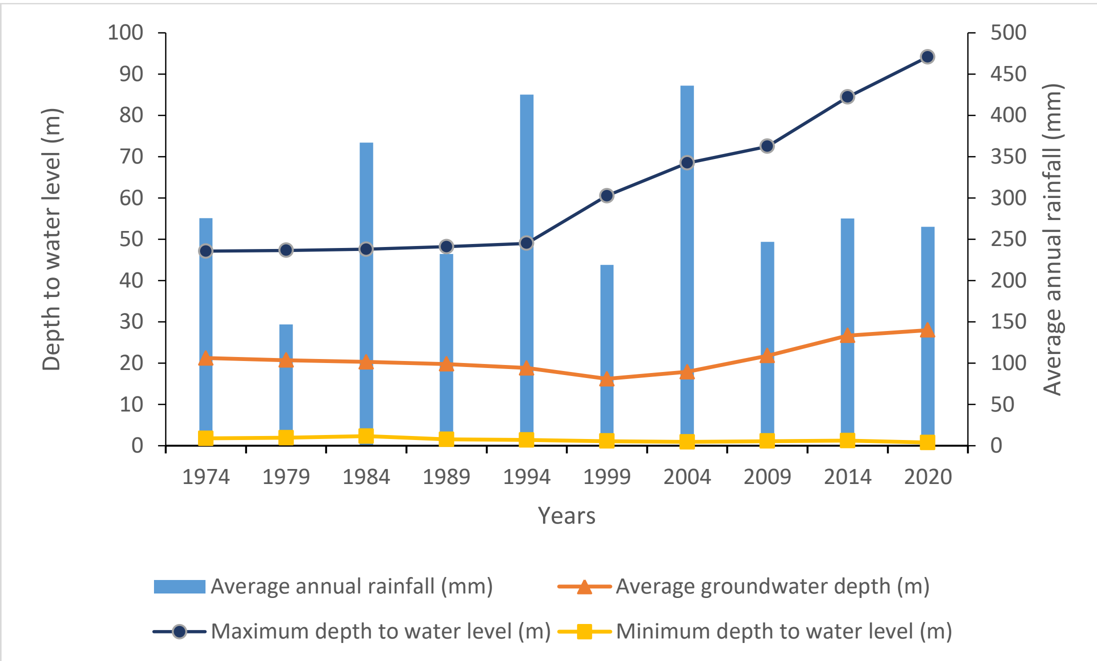
Source: Secondary data obtained from department of Metrological, Chandigarh, Chandigarh(India)

Figure 15: Relationship between Minimum, Maximum and Average Groundwater Level (m) of Bhiwani District from 1974 to 2021



Source: Secondary data obtained from groundwater cell, department of agriculture, Panchkula, Haryana (India)

Figure 16: Relationship between Minimum, Maximum, Average Groundwater Level (m) and Average Annual Rainfall (cm) Bhiwani District from 1974 to 2021

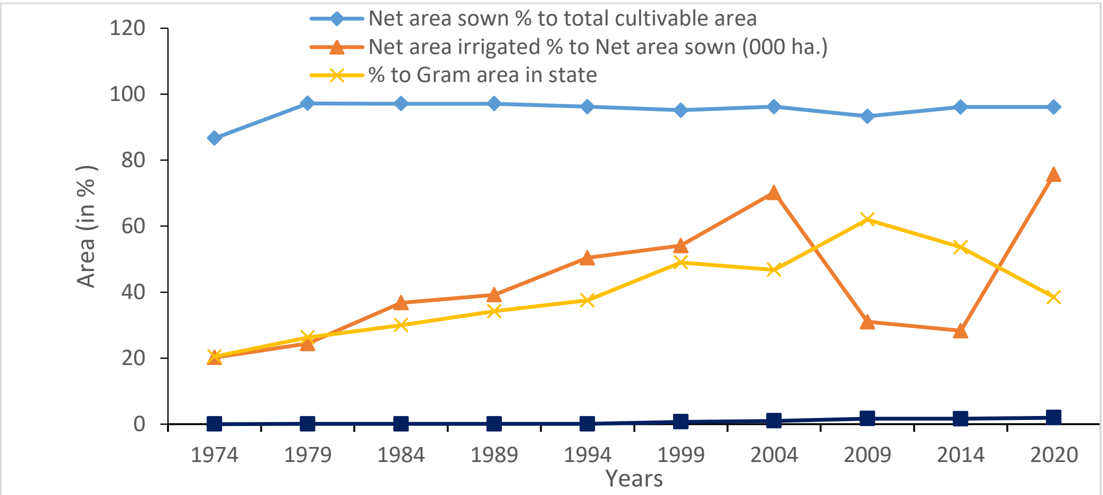


Source: Secondary data obtained from department of Metrological, Chandigarh, Chandigarh (India)

(c). Impact of cropping pattern on groundwater level

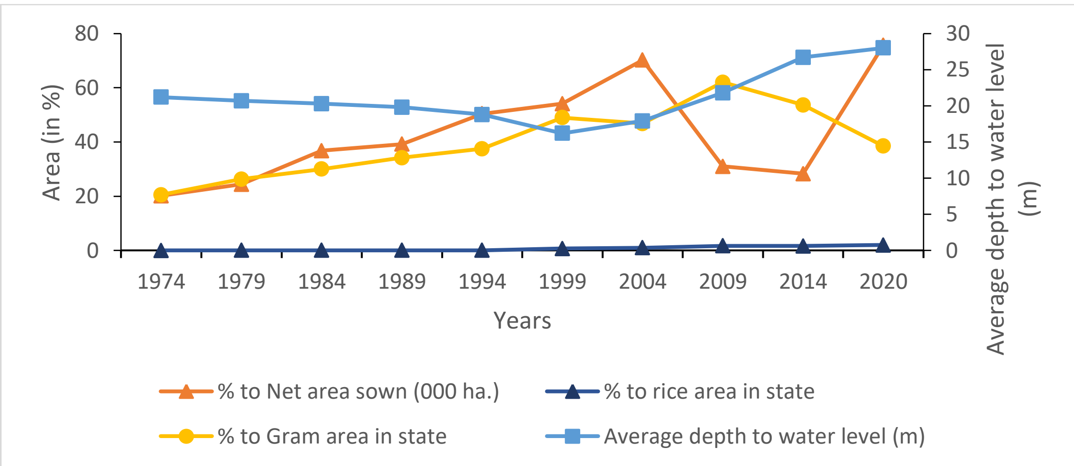
The general depletion of groundwater level in the study area may be due to increased cultivation of different crops (Figs. 17 to 19), especially more water consuming agricultural crop like paddy.

Figure 17: Relationship between Net area sown % to total cultivable area, Net area irrigated % to net area sown (000 ha) and average groundwater level (m) of Bhiwani district from 1974 to 2021



Source: Secondary data obtained from different organizations, department of agriculture, Panchkula, Haryana (India)

Figure 18: Relationship between % to Net area sown (000 ha), % to rice area in state, % to gram area in state and average groundwater level (m) of Bhiwani district from 1974 to 2021



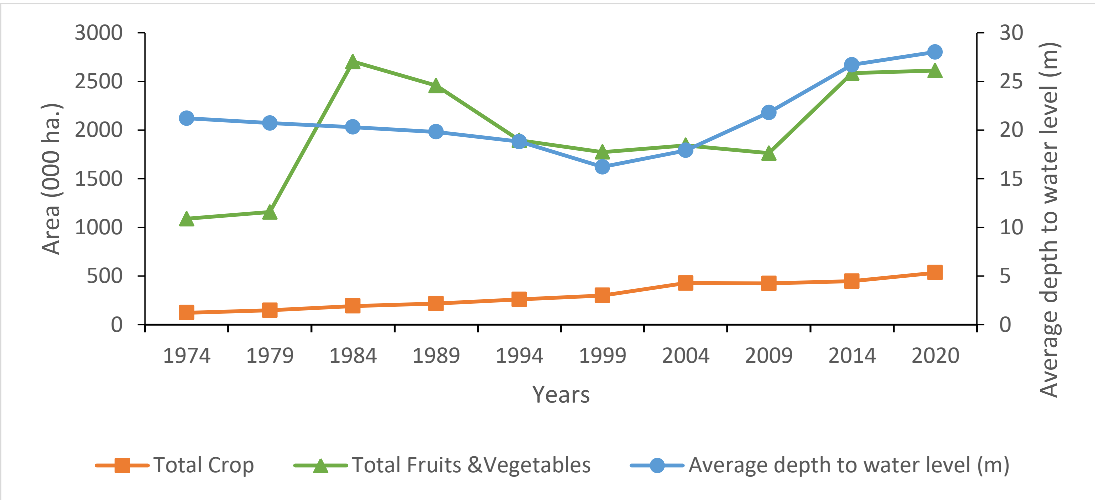
Source: Secondary data obtained from different organizations, department of agriculture, Panchkula, Haryana (India)

In Bhiwani district, area under rice cultivation has been increased from 0.004% (1974) to 0.07% (2021), *i.e.*, from 1 thousand hectare in 1974 to 30 thousand hectare in 2021. Besides this, cultivation of two paddy crops in the kharif season also being practiced during the last 10 year, which further aggravated the problem in certain areas. As the transplantation timing of saathi variety is from last week of April to 3rd week of May (before the onset of monsoon), more dependence on groundwater other than rainfall, resulted further decline in groundwater level.

(d). Impact of irrigated area, percent sown area and source of irrigation water on groundwater level

Irrigated area in Bhiwani district has been increased from 89000 ha in year 1974 to 302000 ha in year 2021, which reflects 239.3 % increase in the irrigated area (Fig. 18). As well as percent to net area sown is also increased from 20.2 to 71.3 percent in the study area (Fig. 19).

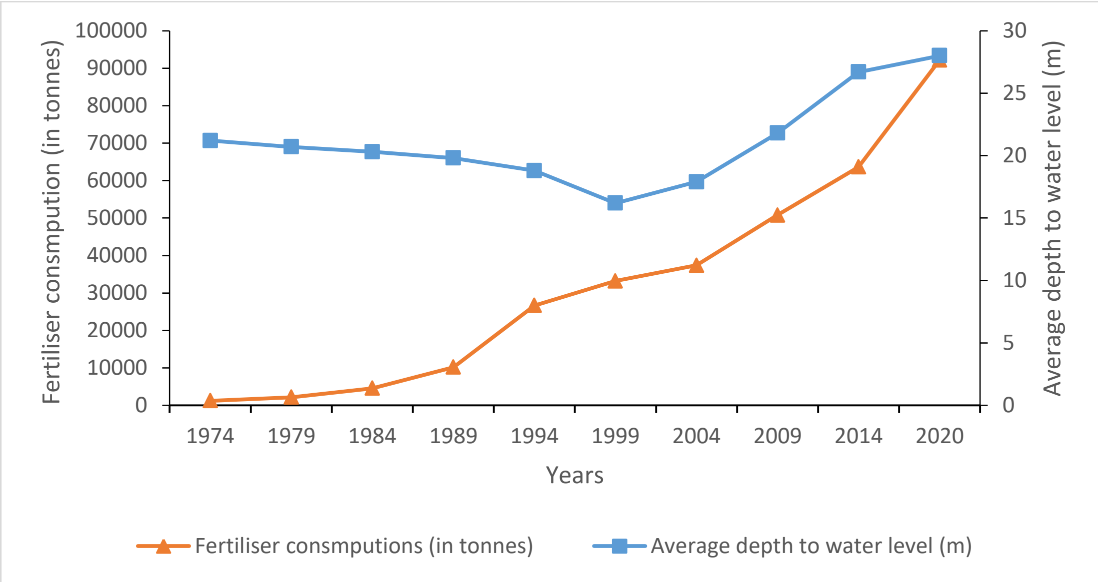
Figure 19: Relationship between Total crop area (000 ha), Total fruit and vegetables and average groundwater level (m) of Bhiwani district from 1974 to 2021



Source: Secondary data obtained from different organizations, department of agriculture, Panchkula, Haryana (India)

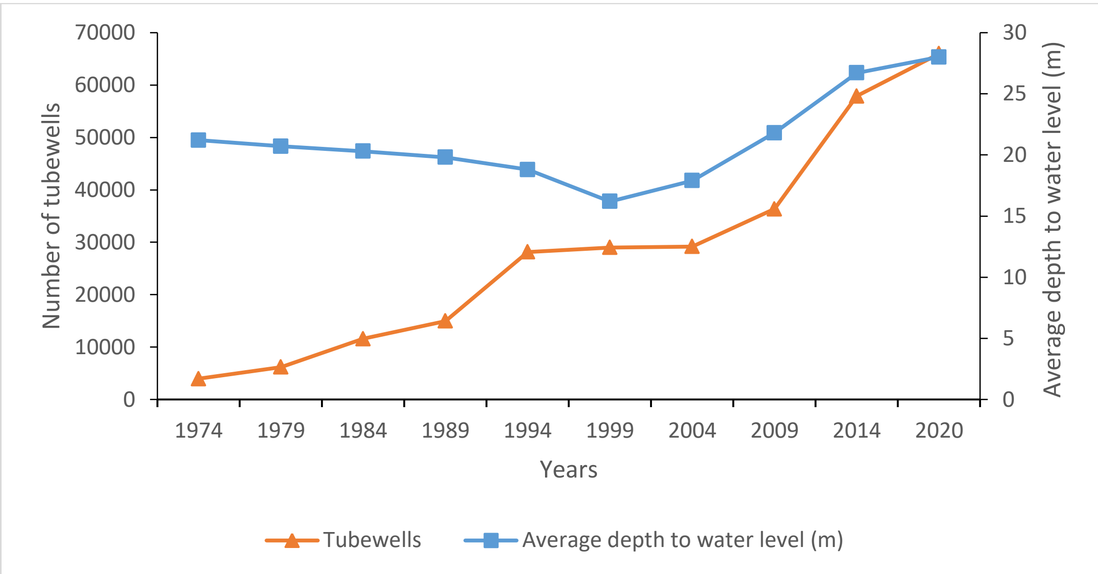
It is already cited that share of submersible pumps irrigated area to the total irrigated area has increased from 7.2 per cent in 1974 to 71.5 per cent in 2021. Tubewell irrigated area is also increased from 7000 ha in year 1974 to 216000 ha in year 2021. Canal irrigated area was 78000 ha in year 1974, which was increased to 169000 ha in year 2004 but it was further decreased 86000 ha in 2021, which is about same as in year 1974. This increase in irrigated area, percent sown area and tube well irrigated are directly affects the groundwater level, as shown in Fig. 17 to 20. The fertiliser consumption is also increased from 10000 tonne (1974) to 99000 tonne (2021) in Fig. 20.

Figure 20: Relationship between Total Fertiliser consumptions (in tones) and average groundwater level (m) of Bhiwani district from 1974 to 2021



Source: Secondary data obtained from different organizations, department of agriculture, Panchkula, Haryana (India)

Figure 21: Relationship between Number of tubewells and average groundwater level (m) of Bhiwani district from 1974 to 2021



Source: Secondary data obtained from different organizations, department of agriculture, Panchkula, Haryana (India)

E-ISBN: 978-81-950136-0-9
Building Resilient Organizations

6.0 Summary and Conclusion

India is primarily an agricultural commodity dominating country which primarily depends upon irrigation. The country has witnessed a tremendous increase in agricultural production and irrigated area since its inception in the year 1966. The surface water resources in the country are scarce and now a days approx. 50 per cent of the cultivated area is irrigated by natural groundwater resources. This phenomenal use of natural groundwater through large number of tubewells has caused severe decline in groundwater depth, resulting in depletion of natural groundwater resources. Therefore, an understanding about the groundwater trends, development and accessibility are essential for devising judicious management. In Bhiwani district, groundwater is used intensively and some blocks are over-developed or developed as per the norms of Central ground Water Board. In the light of these facts, the present study has been attempted to investigate the "Impact of Depleting Ground Water Resources on the Start-Up Ecosystem and Rural Entrepreneurship" with following objectives.

- To develop spatio-temporal maps for the groundwater level and its fluctuations in Bhiwani district
- To identify the causes of groundwater fluctuations and remedial measures

The investigation was conducted to study the trends of groundwater depth and different cause of groundwater fluctuations from 1974 to 2021. The study was carried out on the basis of secondary data (groundwater level and factors affecting it) procured from different departments of Haryana. Firstly, spatial fluctuations maps were drawn at the interval of ten i.e., 1974, 1984, 1994, 2004, 2014 and 2021. Furthermore, relationship between groundwater depth and factors affecting it was developed. The major observation and results obtained from the above study are summarized as follow.

- The average groundwater level in Bhiwani district ranged between 21.04 to 28.3 m from the during the study period 1974-2021.
- The average annual groundwater depth declining at the rate of approximately 14.8 cm/year during 1974-2021 in Bhiwani district.
- The minimum groundwater level depth during the study period varied from 1.75 to 0.74 m, whereas, its maximum value ranged between 47.1 to 94.1 m and its mean value varied from 21.04 to 28.03 m, respectively, during 1974-2021 in Bhiwani district.
- Area under 2-10 m (prone to water logging) depth of groundwater has reduced from 15.2% (1974) to 34.5% (2021), whereas, the area under groundwater level of 10 - 30 m (safe limit) has also reduced from 64.6% (1974) to 38.2% (2021) during the study period of 47 years
- Area under 0-2 m groundwater level, exposed to water logged, increased from 0.0% to 0.003%, whereas, area under more than 30 m of groundwater level has been increased by 7.6 %. During the study period Extremity of groundwater level on both sides (water logging and overexploitation) has been increased.
- Maximum, minimum and mean annual rainfall of 43.0 cm (2004), 14.7 cm (1979) and 28.7 cm, respectively was observed during the study period of 1974 to 2021.

- Number of tubewells has been increased from 0.007 million (1974) to 0.065 million (2021) in the study area.
- In Bhiwani district, percent area under rice cultivation has been increased from 0.004% (1974) to 0.07% (2021) and corresponding area has increased from 1 to 30 thousand ha.
- Irrigated area in Bhiwani district has been increased from 89000 ha in year 1974 to 302000 ha in year 2021, i.e., 239.3% increase in the irrigated area.
- Tubewell irrigated area is increased from 7000 ha in year 1974 to 216000 ha in year 2021. Canal irrigated area was 78000 ha in year 1974, which was increased to 169000 ha in year 1994 but it was further decreased 86000 ha in 2021, which is almost same as in year 1974.
- Present study found a significant increase and decrease in ground water depth in different villages over Bhiwani district of south-western part of Haryana.
- The decline of groundwater levels shows coherent variability with maximum temperature, urbinization and annual rainfall.
- The main causes of ground water level depletion over the Bhiwani district has been observed with decrease in rainfall, increase in paddy crop cultivation area and conversely decrease in ground water recharge.
- Present study highlight that Loharu block of study area is critically affected by severe depletion in ground water level and rate of ground water depletion has been accelerated during last decade due to a several reasons discussed in this paper.
- Water management is essential to mitigate the severe problems related to depleted ground water depth. This includes increasing groundwater use efficiency, apply modern irrigation policy, water regulation, recycling of wastewater, artificial recharge wells and rural awareness program..
- An integrated approach involving dairy/piggery farming, conjunctive use of other source of water and poor quality groundwater could also reduce pressure on fresh water use.

References

Aggarwal, R., Kaushal, M., Kaur, S. & Farmaha, B. (2009). Water resource management for sustainable agriculture in Punjab, India. *Water Science and Technology*, *60*, 2905–2911.

Akther, H., Ahmed, M. S., & Rasheed, K. B. S. (2009). Spatial and temporal analysis of groundwater level fluctuation in Dhaka City, Bangladesh. *Asian Journal Earth Science, 2*, 49–57.

Alley, W. M., (2001). Ground Water and Climate. *Ground Water reports*, *39*(2), 161-161.

Anonymous, (1974).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (2013).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (2016).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (2017).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (2019).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (2020).Statistical abstract of Haryana, Government of Haryana.

Anonymous, (1995).Central Ground Water Board (CGWB) (1995). Ministry of Water Resources, Faridabad. *Annual Report 1995-96.*

Anonymous, (2007).Central Ground Water Board (CGWB) (2007).Ministry of Water Resources, Faridabad. *Annual Report 2007-08*

Anonymous, (2010).Central Ground Water Board (CGWB) (2010). Ministry of Water Resources, Faridabad. *Annual Report 2010-11.*

Anonymous, (2011).Central Ground Water Board (CGWB) (2011). *Dynamic Groundwater Resources of India*. Ministry of Water Resources, Faridabad.

Anonymous, (2013).Central Ground Water Board (CGWB) (2013). Ministry of Water Resources, Faridabad. *Annual Report 2013-14.*

Anonymous, (2014). Central Water Commission, Water Resources Information System Directorate, Central Water Commission, New Delhi. *Water and Related Statistics*.

Berg, M., Stengel, C., Trang, P. T. K., Viet, P.H., Sampson, M. L., Leng, M., Samreth, S., & Fredericks, D. (2007). Magnitude of arsenic pollution in the Mekong and Red River deltas: Cambodia and Vietnam. *Science total Environment, 372*, 413–425.

Bhanja, S. N., Mukherjee, A., Rodell, M., Wada, Y., Chattopadhyay, S., & Velicogna, I. (2017). Groundwater rejuvenation in parts of India influenced by water-policy change implementation. *Groundwater scientific Report*, *7*, 7453.

Biswas, S. (2003). Groundwater flow direction and long term trend of water level of Nadia district, West Bengal: A statistical analysis. *Journal Geology Science India*, *61*, 22-36.

Chawla, J. K., Khepar, S. D., Sondhi, S. K. & Yadav, A. K. (2010). Assessment of long-term groundwater behaviour in Punjab, India. *Water International Journal*, 35, 63–77.

Chinnasamy, P., & Agoramoorthy, G. (2015). Groundwater storage and depletion trends in Tamilnadu state, India. *Water Resources Management, 29*, 2139–2152.

Hetzel, F., Vaessen, V., Himmelsbach, T., Struckmeier, W. & Villholth, K. G. (2008). Groundwater and climate change: Challenges and possibilities. GUES, Denmark.

Hoque, M. A., Hoque, M. M., & Ahmed, K. M. (2007). Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: Causes and quantification. *Hydrogeology Journal, 15*, 1523–1534.

Huntington, T. G. (2006). Evidence for intensification of the global water cycle: Review and synthesis. *Journal of Hydrology, 319*(1-4), 83-95. DOI: 10.1016/j.jhydrol.2005.07.003.

Kaur, S., Aggarwal, R. & Soni, A. (2011). Study of water table behaviour for Indian Punjab using GIS. *Water Science and Technology, 63*, 1574–1581.

Kemper, K. (2004). Groundwater from development to management. *Hydrology journal,* 12(1), 3-5. DOI: 10.1007/s10040-003-0305-1

Khayat, S. (2006). Hydrochemical investigation of water from the Pleistocene wells and springs, Jericho area, Palestine. *Hydrogeology Journal, 14*, 192–202. Doi:10.1007/s10040-004-0399-0.

Konikow, L.F., & Kendy, E. (2005). Groundwater depletion: A global problem. *Hydrogeol Journal, 13*, 317–320.

Kinzelbach, W., Bauer, P., Siegfried, T., & Brunner, P. (2003). Sustainable groundwater management—problems and scientific tools. *Institute for Hydromechanics and Water Resources Management,* 26 (4), 279–283. ETH, Zurich, Switzerland.

Johnson, N., Revenga, C., & Echeverria, J. (2001). Managing water for people and nature. *Journal of Hyrdology Science*, *292*, 1071–1072.

Mevlut, U. & Tayfun, C. (2010). Geostatistical for mapping groundwater nitrate concentration. 3rd international conference on cartography and GIS. Nessebar, Bulgaria

James. M. F., Osvaldo, C., Neil. L., David, J. D., & Kasey, S. W. (2001). Climate Change 2001: Impacts, adaptation, and vulnerability. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press. Retrieved from http://www.cambridge.org.

Moreaux, M., & Reynaud, A. (2006). Urban freshwater needs and spatial cost externalities for coastal aquifers: A theoretical approach. *Regional Science and Urban Economics, 36*, 163–186.

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. *Journal of Hyrdology Science, 313*, 1068–1072.

Panda, D. K., Mishra, A. & Kumar, A. (2012). Quantification of trends in groundwater levels of Gujarat in Western India. *Hydrology Science Journal, 57*, 1323–1336.

Phien-Wej, N., Giao, P. H., & Nutalaya, P. (2006). Land subsidence in Bangkok, Thailand. *Engineering Geology, 82*, 187–201.

Ren, J. F., Allison, I., Jorge. F. C. & Gergory, F. (2007). Climate change 2007. Synthesis report. Contribution of working group to the fourth assessment report of the intergovernmental panel on climate change. Gene. Retrieved from https://www.researchgate.net/publication/262260453.

Ribeiro, L., Kretschmer, N., Nascimento, J., Buxo, A., Rötting, T., Soto, G., Señoret, M., Oyarzún, J., Maturana, H. & Oyarzún, R., (2015) Evaluating piezometric trends using the Mann-Kendall test on the alluvial aquifers of the Elqui River basin, Chile. *Hydrological Sciences Journal*, *60*(10). Retrieved from http://dx.doi.org/10.1080/02626667.2014.945936.

Shamsudduha, M., Chandler, R. E. & Taylor, R. G. (2009). Recent trends in groundwater levels in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta. *Hydrology Earth System Science, 13*, 2373–2385.

Singh, O., Kasana, A., Singh, P. K., & Sarangi, A. (2019). Analysis of drivers of trends in groundwater levels under rice–wheat ecosystem in Haryana. India *Natural Resources Research*, *29*.

Singh, O., & Kasana, A. (2017). GIS-based spatial and temporal investigation of groundwater level fluctuations under rice-wheat ecosystem over Haryana. *Journal geological society of India*, *89*, 554-562.

Sophocleous, M. (2004). Climate Change: Why Should Water Professionals Care? *Ground Water*, 42(5), 637-637.

Toews, M. (2003). Modelling climate change impacts on groundwater recharge in a semiarid region, southern Okanagang, British Columbia. Unpublished Msc Thesis. University of Calgary.

Tharme, R. E. (2003). A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for river. *River research and applications*, *19*, 397-441.

UN/WWAP (United Nations/World Water Assessment Programme), 2003. UN world water development report: Water for people, Water for life, UNESCO (United Nations Educational, Scientific and Cultural Organization) and Berghahn Books, Paris, New York and Oxford.

Van, B. L. P., Wada, Y., Van, K. C., Reckman, J. W., Vasak, S. & Bierkens, M. F. (2010). A worldwide view of groundwater depletion. In: Proceedings of fall meeting 2010, H14F-07. *Amercian Geophysics Union*, Washington, DC.

Villholth, K. G., (2006) Groundwater assessment and management: Implications and opportunities of globalization. *Hydrogeology Journal, 14*, 330-339.

Yang, H., & Zehnder, A. J. B. (2002). Water scarcity and food import: a case study for southern Mediterranean countries. *World Development, 30*, 1413–1430. Doi:10.1016/S0305-750X(02)00047-5.

Zektser, S., Loaiciga, H. A., & Wolf, J. T. (2005). Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States. *Environment Geology, 47*, 396–404.