Water Quality Assessment of Southwest Punjab Emphasizing Carcinogenic Contaminants and their Possible Remedial Measures
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Lead organization

National Institute of Hydrology, Roorkee

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Dr. Rajesh Singh
Scientist D, Environmental Hydrology Division

National Institute of Hydrology
Jalvigyan Bhawan
Roorkee – 247667
Uttarakhand

PREFACE

The water of sound quality is the key for socio-economic functions on Earth. However, water resources are degrading, due to rise in pollutants caused by increased population and economy. The water resources for direct and indirect human use can be contaminated by pollutants of geogenic as well as anthropogenic origin. Human activities that lead to contamination of water resources include untreated wastewater discharge from industries and municipalities, leachates from solid waste dumping sites, agricultural activities, burning of fossil fuels, vehicular traffic, fireworks, etc. In fact, any and all of the chemicals generated by human activity can and will find their way into water supplies and are related to population mortality. Punjab has been the subject of much skepticism in the last decade. It has previously been called the “grain bowl of the country”, but has recently adopted a new nickname, “the cancer bowl of the country”. The pride of holding the title “a state with maximum per capita income” came with the price of cancer due to unrestricted use of chemicals (pesticides, fertilizers, metals, polycyclic aromatic hydrocarbons, pharmaceutically active hydrocarbons, etc.) in the agricultural fields and industries. The per capita cancer cases in the south western districts of Punjab, namely Bathinda, Faridkot, Ferozepur, Mansa, Muktsar, and Fazilka is reported to be higher than the average per capita cancer cases in Punjab. Although there are many issues that can lead to cancer, studies suggest that the high usage of pesticides in the state of Punjab is the main contributor to the high number of cancer cases in the area. It has also been advocated that the low quality of drinking water in Punjab has attributed to the high number of cancer cases. Therefore, in this report, attempts have been made to analyze the comprehensive drinking water quality and statistically compute the human health hazard.

The report has been prepared by Dr. Rajesh Singh, Sc. ‘D’, Dr. Pradeep Kumar, Sc. ‘D’, Dr. M. K. Sharma, Sc. ‘E’, and Dr. Sumant Kumar, Sc. ‘D’ under the guidance of Dr. R. P. Pandey, Sc. ‘G’ & Head, Environmental Hydrology Division. The technical assistance has been provided by Dr. Sandeep Singh, RA; Dr. Sandeep Malyan, RA; Ms. Meenakshi Rawat, JRF; Er. Kaptan Singh, Res. Scholar; and Mr. Prashant Kaushik.

Place: Roorkee
Date: 15.01.2022 (Rajesh Singh)

PROJECT TEAM

Lead organization	National Institute of Hydrology Jal Vigyan Bhawan Roorkee – 247 667 Uttarakhand	Dr. Rajesh Singh, Sc. D (PI)* Dr. Pradeep Kumar, Sc. D (Co-PI) Dr. M. K. Sharma, Sc. E Dr. Sumant Kumar, Sc. D Sh. Rakesh Goyal, Tech. Gr. I Dr. Sandeep Malyan, RA (up to 2018) Dr. Sandeep Singh, RA Ms. Meenakshi Rawat (up to 2020)
Name and address of IA	Water Resources Administration, Punjab Irrigation, Mohali	
Partner organization/s (enter each partner organization in a separate row)	Water Resources Administration, Punjab Irrigation, Mohali Punjab	Er. K. S. Takshi, Chief Engr. (WRA) Er. N. K. Jain, Director (WR&ED) Dr. K. K. Kaushal, Sr. Hydrogeologist, WR&ED) Mr. Sanjeev Bansal (Sr. Tech. Asst., WR&ED)
Collaborators	University of Nebraska-Lincoln, USA	Dr. Karrie A. Weber, Professor, School of Biological Sciences
	Banaras Hindu University, Varanasi	Dr. S. P. Rai, Assoc. Professor, Centre of Advance Study in Geology
	Indian Institute of Technology, Roorkee	Dr. Brijesh K. Yadav, Professor, Dept. of Hydrology Dr. Naseem Ahmed, Professor, Dept. of Chemistry

*If PI/ Co-PI are changed/ retired, enter those names as follows in above table
Name and designation (PI up to ___)
Name and designation (Co-PI up to ____)

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Abstract:

The consumption of contaminated water is the main source of human health issues in this century. The south-western districts of Punjab are witnessing high per capita cancer cases, almost twice of national average. Accordingly, this study was undertaken to identify and quantify the carcinogenic contaminants present in the groundwater of the study area, which is the primary source of drinking water. The residents of the study area are quite aware about the issues related to drinking water and are trying to opt for other options for drinking water if available. The study indicated around 23% samples exceeded the maximum permissible limit for TDS. NH_4 was observed in more than 75% of samples indicating contamination of water resources and anoxic environment in the aquifer. F concentration exceeded the maximum permissible limit in 19.6% and 31% samples during pre-monsoon and post monsoon respectively. Concentration of B, Fe, Co, Ni, Pb, Be, As, Se, Hg, U, Al, Cr, Cu, Mn, and Zn also exceeded the maximum permissible limit in significant number of samples, however, pesticides were observed below the recommended limits for drinking water. The water samples were observed to be more deteriorated in pre-monsoon period. The cancer-associated risk based on Ni, Pb, As, Hg, U, Cr, Be, Co, Se, Cd, and NO_3 was computed and around 83.7% of samples were in the high-risk category during pre-monsoon which got reduced to 61.1% in the post-monsoon period. Removal of U, As, Cr, and Pb from the groundwater samples will result in 93.9% and 98.4% groundwater samples under low-risk category for pre-monsoon and post-monsoon period respectively. The concentration of radon in water samples ranged from 11.1 pCi/l to 319 pCi/L and can result in around 58.2 to 1670 deaths/million population/year. The study indicated need for further research on the factors responsible for the dissolution of U and other trace metals in the groundwater for in-situ remediation and estimation of indoor radon concentration for holistic estimated of overall cancer risk.

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1. INTRODUCTION

1.1.The Punjab state profile

Punjab is situated in northwest India. The Indian state borders the Pakistani province of Punjab to the west, Jammu and Kashmir to the north, Himachal Pradesh to the northeast, Chandigarh to the east, Haryana to the south and southeast, and Rajasthan to the southwest. The total area of the state is 50,362 square kilometres. The population of the state is 2,77,04,236 (Census 2011). Punjab's capital is Chandigarh, which is administered separately as a Union Territory since it is also the capital of the neighbouring Haryana State. As per the 2011 Census, Punjab has a total population of 2,77, 04,236 out of which 1,46,34,819 are males and 1,30,69,417 are females. It constitutes 2.29% of the total population of India. The population density of Punjab is 550 persons per sq.km. The population of Punjab according to the 2011 Census stands at about 27 million people, making it the 15th most populated state in India. The state is spread over an area of about 50,362 sq. km. making it the 19th largest state in the country in terms of area. The state has a growth rate of about 13%, which is below the national average of 17%. The population of the state is rising considerably due to rapid efforts towards development and progress. The literacy rate in the state is about 76.7% that has improved tremendously in the last few years due to consistent efforts of the government. The sex ratio in Punjab leaves a lot to be desired as it lags the national average**.** The Punjab state profile is presented in Table 1.1 (Government of Punjab Website).

Table 1.1. Punjab State Population, literacy and Area in Sq. Km.

Sr. No.	Characteristics	Unit	Value
1.	Area • Rural -Area • Urban Area	Sq. Km	50,362 48,265 2,097
2.	Tehsils	Number	81
3.	Total population (census 2011) • Urban population • Rural population	Lakh	277.04 103.5 (37.5 %) 173.2 (62.5%)
4.	Density	Per Sq. Km.	550
5.	Female per 1000 Male	Number	893
6.	Literacy Rate	%	76.7

Punjab is the **land of five rivers** in northwest India and northeast Pakistan. ***Punj*** means "five" and ***aab*** means "waters", so *"punjab"* means *"land of five rivers"*. These five rivers that run through Punjab, having their originating source as various small lakes in Himalayas. If one were to go across the Punjab starting from Delhi and to Afghanistan, the rivers Beas, Satluj, Ravi, Chenab, Jhelum are in the order respectively.

The Beas merges into the Satluj at Harike near Ferozepur in Punjab just before crossing the border into west Punjab (Pakistan) where it eventually merges into the river Indus.

The area of Punjab that is between the Beas and Satluj is called the **Doaba**. The major cities in this part of Punjab are Jalandhar, Hoshiarpur and Nawanshahr. **Majha** is between the Beas and Chenab and on both sides of the Ravi, this part is called the heart of Punjab and its cities include, Lahore, Amritsar, Gurdaspur, Sialkot, Kasur, Lyallpur (Faisalabad), Faridkot and Ferozepur.

In the Majha part of Punjab many new cities were developed by converting the forests into cultivating land and is called **Bar**, cities include Lyallpur (Faisalabad), Montgomery, etc. The area beyond the Chenab river in North and around river Jhelum is called Pothohar, cities include Rawalpindi, Hasan Abdal, etc. The area between the Ravi and Chenab rivers is called the **Rachna doab**, its cities are Gujrat, Sargodha, etc. The area of **Malwa** is in southern Punjab facing Rajasthan and East of river Beas, cities include Ludhiana, Patiala, Ambala, Karnal, Sangrur, Malerkotla, Shahabad, and Abohar.

1.2.Cropping Pattern in Punjab

Except in the north, where there are forested mountains yielding salt and coal, the Punjab is a level alluvial plain. Rainfall is scant and irregular, but extensive irrigation systems using the waters of the great rivers have made possible enormous agricultural productivity. Wheat is, by far, the leading crop. But millet, barley, cotton (one area was called the land of white gold), and sugarcane are grown as well and there are extensive fruit orchards.

Punjab with a 1.53% share in the geographical area of India produced 36.95% of the total wheat and rice produced in the country in 2015–16. Punjab's contribution towards India's food self-sufficiency has been widely acknowledged. In this section, the changing cropping pattern in Punjab between 1966–67 and 2017–18 is discussed. The major crops considered here include rice, wheat, tur, gram, bajra, barley, jowar, ragi, maize, small millets, groundnut, sesamum, sunflower, linseed, rapeseed and mustard, sugar cane, and cotton.

The above-mentioned 17 crops occupy 7,068 thousand hectares (≈90%) of the total cropped area in Punjab in 2017–18. The total area under the major crops in 1966–67 was 4,179 thousand hectares, which in 2017–18 has risen to 7,068 thousand hectares with an increase of 2,889 thousand hectares during this period. Out of the total cropped area in 1966– 67, rice and wheat together occupied 1,900 thousand hectares (45.46%) when compared to the 2,279 thousand hectares (54.54%) under all the other crops put together (Table 1.2). With the advent of green revolution, the area under rice and wheat expanded, and as per the latest data available for 2017–18, rice and wheat together occupied 6,168 thousand hectares (88.51%), whereas the area occupied by all the other crops has reduced drastically to 900 thousand hectares (9.43%). The area under wheat which in 1966–67 was 1,615 thousand hectares (38.64%) has grown to 3,338 thousand hectares (47.23%) in 2017–18. Thus, from 1966– 67 to 2017–18, the area under wheat increased by 1,723 thousand hectares.

The area under rice which in 1966–67 was a meagre 285 thousand hectares (6.82%) has increased phenomenally to 2,918 thousand hectares (41.28%) in 2017–18. Thus, from the period of 1966–67 to 2017–18, there was an increase of 2,633 thousand hectares of area under rice. The interesting point to note is that the area under wheat touched 49% of the total cropped area in the early phase of green revolution (in 1970–71) and has stabilised since then, hovering around the value of 49%. In contrast with that, rice touched its peak in year 2017–18 with 41.28% of the total cropped area under it. Unlike wheat where the area stabilised in the early 1970s, there was a slow and gradual increase in the expansion of area under rice.

The area under the other crops which was 54.54% of the total cropped area during 1966–67, has come down drastically to 9.43% in 2017–18. The area under the other crops has been mainly cannibalised by the expansion of area under rice.

1.3. Fertiliser and Pesticide Consumption

The comparison of the fertiliser usage during 2010 to 2017 in lakh tonnes, kg/ hectare and NPK ratio (nitrogen, phosphorus and potassium) of Punjab and at all-India level is shown in Table 1.3. It can be seen that in 2014–15 the usage of nitrogen, phosphorus and potassium was 176.03, 43.46 and 4.97 kg/hectare respectively.

The consumption of fertilizers is an important factor and there should be appropriate balance in the consumption of different fertilizer nutrients. The appropriate NPK ratio under Indian soil conditions is stated to be 4:2:1 and any deviation in fertiliser use from this norm would constrain growth in crop productivity (Chand and Pavithra, 2015). The NPK ratio of Punjab 36:9:1 (in 2014–15) is towards the higher side when compared to the generally accepted NPK ratio of 4:2:1. The intensive cultivation has led to the decline in the soil fertility status in Punjab (Singh 2008). The Punjab government is in a process of reducing the fertilizer consumption as is evident from the recent data of 2015-16 and the NPK ratio has improved to 19:5.8:1.

Punjab has approximately 4% of the total cropped area of the country but consumes 11% of the total pesticides consumed in India (TSMG and FICCI 2016). The pesticide and insecticide consumption reached its peak in 1995-96, which got stabilized to ≈5700 MT in 2008-09 (Figure 1.1). Moreover, the central government banned around 30 pesticides (Aldicarb, Aldrin, BHC, Calcium Cyanide, Captafol, Chlorobenzilate, Chlordane, Copper acetoarsenite, Dibromochloropropane (DBCP), DDT, Dieldrin, Endrin, Ethylene dibromide, Ethyl mercury chloride, Ethyl parathion, Heptachlor, Maleic Hydrazide, Menazon, Nicotine sulphate, Nitrofen, Paraquat-di-methyl sulphate, Pentachloro Nitrobenzene (PCNB), Pentachlorphenol (PCP), 24 Phenyl mercury acetate(PMA), Sodium methane arsonate, TCA (Trichloro acetic acid), Tetradifon, Toxaphene, Metoxuron, Chlorofenvinphos) for use in agriculture, which was also implemented in Punjab.

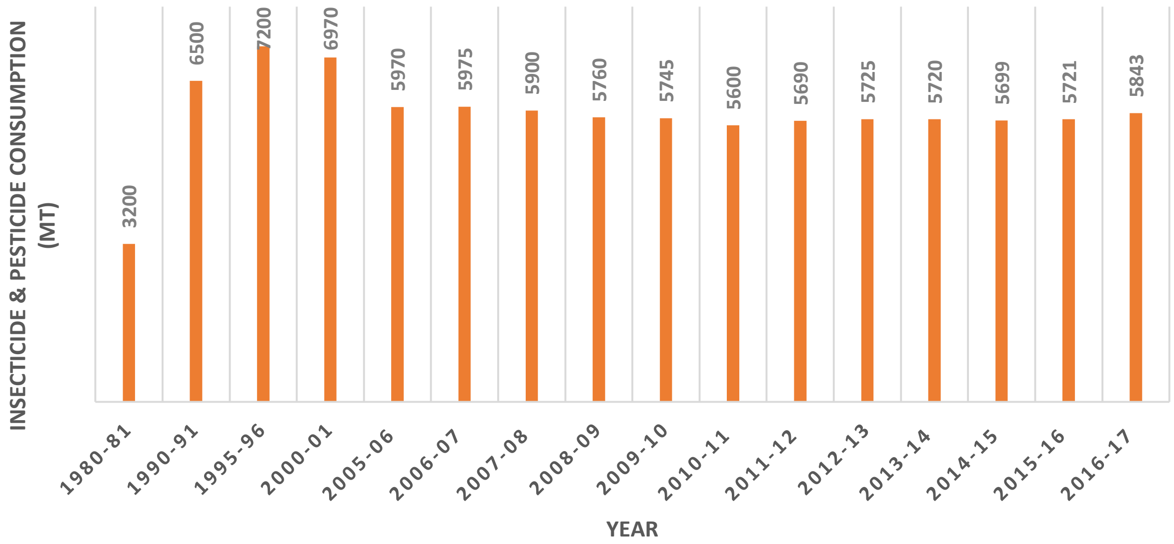


Fig. 1.1. Insecticide and pesticide consumption in Punjab (Source: Dept. of Agriculture, Govt. of Punjab, 2018)

1.4. Groundwater status

Owing to the widespread cultivation of rice, the groundwater levels have gone down drastically in Punjab. As of 2011, out of the total 138 blocks in Punjab, 110 are overexploited, four are critical, two are semi-critical and only 22 are safe (CGWB 2015). Thus, 84% of the blocks in Punjab are either overexploited, critical or in a semi-critical category, and only 16% blocks are safe. As per CGWB (2015), Punjab has the highest stage of groundwater development of 172 amongst all the states in the country. This is not a good indicator for the groundwater status of Punjab. The groundwater development of 100% indicates that its consumption is equal to its recharge, groundwater development stage of above 100% indicates that the "annual groundwater consumption is more than the annual groundwater recharge" (CGWB 2015). A very high stage of groundwater development of 172 indicates that its annual consumption in Punjab is very high compared to its annual recharge. The groundwater availability for future irrigation use for Punjab is least in the country (Table 1.4). The high stage of groundwater development gives an alarming warning signal about the future water problem in Punjab.

CGWB (2017) reported the decadal mean fluctuations during January (2007:2016) and January 2017, shows that decline in 90% of observation wells monitored covering about 91% area of the state (Figure 1.2). The decline was observed in all districts in the state. The decline of 0-2 m was observed in about 60% of wells and 58% of area. Water level decline of 2-4 m was observed in 23% of the wells and 26% of the area. Water level decline of >4m was observed in about 7% of the wells and 7% of area. Rise in water level has also been observed in 10% of wells and 9% of area in Pathankot, Gurdaspur, Amritsar, Tarntaran, Kapurthala, Hoshiarpur, Nawanshahr, Ropar and SAS Nagar districts in north and north eastern parts. Rise in water level was also observed in in few pockets of Ferozepur, Fazilka, Muktsar, Bathinda and Faridkot districts. Water level rise in the range of 0-2 m is observed in 9% of wells and 8% of the area. Water level rise of 2-4m is observed in 1%of wells and 1% of the area.

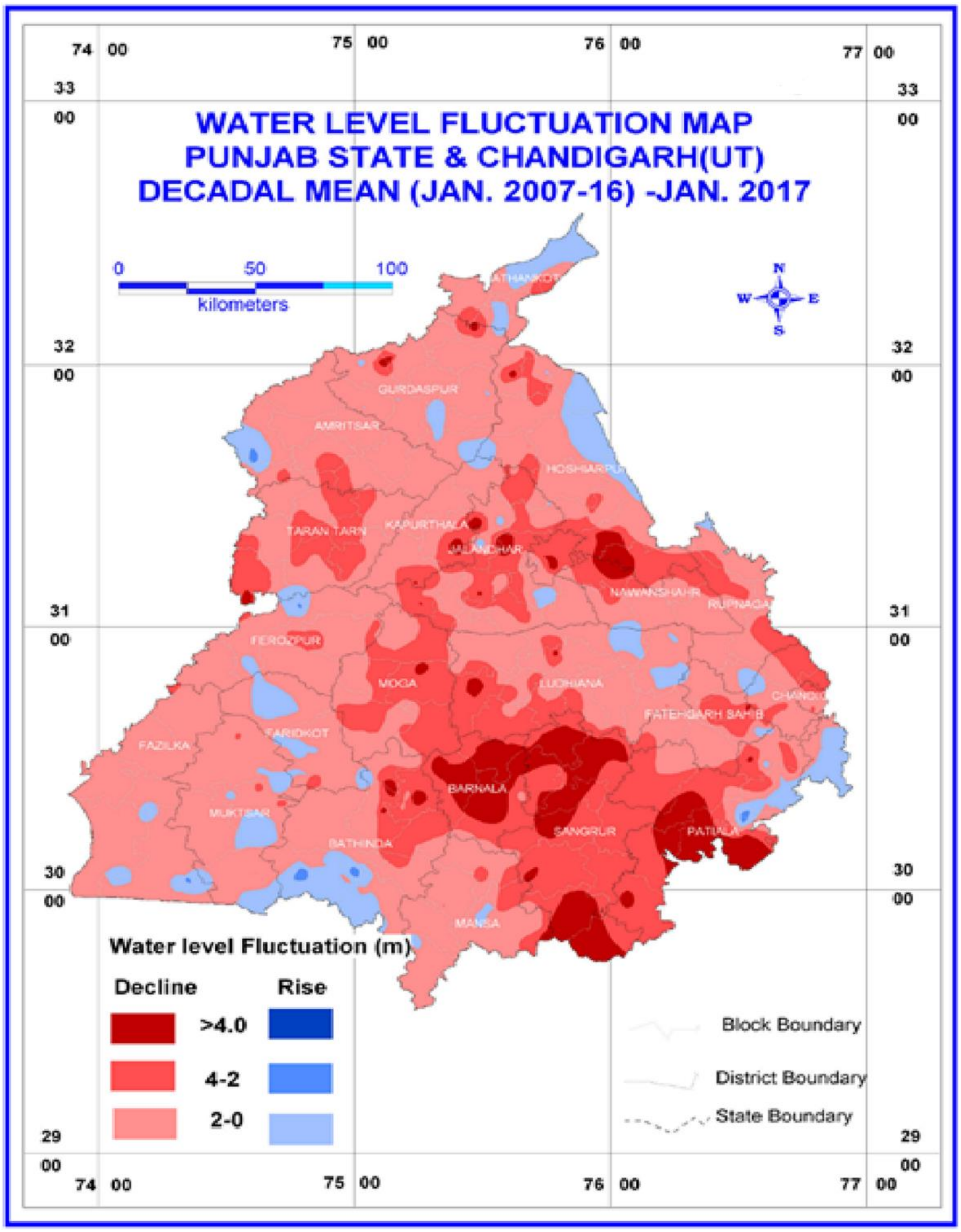


Fig. 1.2. Water Level Fluctuation Map for during January (2007:2016) & January 2017 (Source: CGWB Annual Report 2017)

Table 1.2. Area under Major Crops in Punjab (area in ha)

Year	Wheat (W)	Rice (R)	W+R	Tur	Gram	Bajra	Barley	Jowar	Ragi	Maize	Small Millets	Ground-nut	Sesamum	Sun-flower	Linseed	Rapeseed and Mustard	Sugar cane	Cotton	Others Total	Total
1966–67	1615	285	1900	1.7	633.6	184	103.8	5.8	0.5	0.4	0.4	181.6	17.9	-	2	116	156	432	2273.3	4179.3
1970–71	2299	390	2689.1	3	357.9	207.1	56.6	5.1	-	0.7	0.7	173.8	14.6	-	2.7	103	127.7	397.4	2004.2	4693.3
1975–76	2436	567	3005.6	5.6	381.2	181.7	120.2	5.2	-	-	-	168.4	23	-	2.1	122	114.2	580.4	2281.3	5286.9
1980–81	2812	1178	3990	17.9	258	71	65	1.2	-	-	-	83	17.3	-	1.7	146	71	648	1758.1	5748.1
1985–86	3112	1714	4826	40	108	31	49.8	-	-	-	-	45	13.7	-	1.3	146	78	559.6	1332.1	6158.4
1990–91	3272	2024	5296	13.6	60.7	11	37	0.3	-	-	-	10	18.1	14	0.6	73	101	701	1228.3	6524.3
1995–96	3223	2161	5384	9.8	19.5	8	38	2.6	-	-	-	9	22.7	103	0.5	117	132	750	1383.1	6767.1
2000–01	3408	2611	6019	8.7	7.7	5	32	0.1	-	0	-	4	19.2	9.7	0.6	53	121	474	900	6919
2005–06	3468	2642	6110	7.8	4	5	19	-	-	3	3	3.4	11.3	17.8	0.2	49	84	557	909.5	7019.5
2010–11	3510	2831	6341	4.2	2.1	3	12	-	-	0	-	2.2	5.7	14.6	-	31	70	530	807.8	7148.8
2014–15	3505	2894	6399	2.6	1.8	0	11	-	-	-	-	1.4	4.7	8.5	-	31	94	420	701	7100
2015-16	3508	2975	6483	2.6	1.7	0	9	-	-	115	-	1	4.7	6.4	-	31	90	339	700	7351.8
2016-17	3491	3047	6538	5.9	1.7	3.7	8.8	-	-	118	-	1.2	2.5	5.9	-	31.7	89	285	700	7408
2017-18	3507	3065	6572	2.6	1.7	1	7.5	-	-	114	-	1.2	2.7	5.7	-	30.7	96	291	700	7425.1
2018-19 (Target)	3480	2900	6380	5	5	2	15	-	-	150	-	2	5	7	-	45	100	400	700	7311

Source: data available at the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India (GoI).

Table 1.3. Fertiliser Consumption and NPK Ratio for Punjab and India

State/Country	Year	Fertiliser consumption (Lakh tonnes)				Fertiliser Consumption (Kg/hectare)				NPK Ratio		
		N	P	K	Total	N	P	K	Total	N	P	K
Punjab	2010-11	1402.91	435.17	73.43	1911.51	177.97	55.2	9.31	242.73	19	6	1
	2011-12	1416.56	448.65	52.85	1918.06	179.7	56.91	6.7	243.56	27	8	1
	2012-13	1485.7	462.48	24.06	1972.24	188.78	58.76	3.06	250.6	62	19	1
	2013-14	1364.02	325.23	24.02	1713.27	174.68	41.65	3.08	219.41	57	14	1
	2014-15	1352.05	328.17	37.53	1717.75	176.03	43.46	4.97	227.46	36	9	1
All India	2010-11	16558.23	8049.71	3514.27	28122.21	86.15	41.88	18.28	146.32	5	2	1
	2011-12	17300.25	7914.3	2575.45	27.79	88.61	40.54	13.19	142.33	7	3	1
	2012-13	16820.93	6653.42	2061.8	255361.2	86.15	34.08	10.56	130.79	8	3	1
	2013-14	16750.08	5633.46	2098.87	24482.41	81.11	27.28	10.16	118.55	8	3	1
	2014-15	16945.43	2532.32	2532.32	25576.12	84.858	30.54	12.68	128.08	7	2	1

Source: Agricultural Statistics at a Glance (ASAG) 2013, 2014 and 2015.

Table 1.4. Groundwater Resources Availability, Utilisation and Stage of Development in Punjab

State	Annual Replenishable Groundwater Resources					Natural Discharge during Non-Monsoon Season	Net Annual Ground-water Availability	Annual Groundwater Draft			Projected Demand for Domestic and Industrial Uses up to 2025	Ground-water Availability for Future Irrigation Use	Stage of Ground-water Development (%)
	Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial Uses	Total			
	Recharge from Rainfall	Recharge from Other sources	Recharge from Rainfall	Recharge from Other Sources									
Punjab	5.82	10.64	1.33	4.74	22.53	2.21	20.32	34.17	0.71	34.88	0.98	-14.83	172

Source: Adapted from CGWB (2015).

1.5.South Western Punjab & Cancer

Cancer is extensive mainly in the cotton belt of Punjab known as the home of India's green revolution (Figure 1.3). A survey conducted by the Health department (2005) reveals that the per capita cancer cases are highest in four districts of Punjab namely Mansa, Muktsar, Faridkot and Bathinda, out of these Bathinda district is the uppermost (Table 1.5).

Table 1.5. Number of Cancer Patients (Source: Health Department, Punjab, 2005)

Sr. No.	District	Population	Cancer Patients	Cancer Patients per Lakh Population
1.	Mukstar	8,27,906	453	54.7
2.	Bathinda	12,00,736	711	59.2
3.	Faridkot	5,85,500	164	28
4.	Mansa	7,31,535	420	57

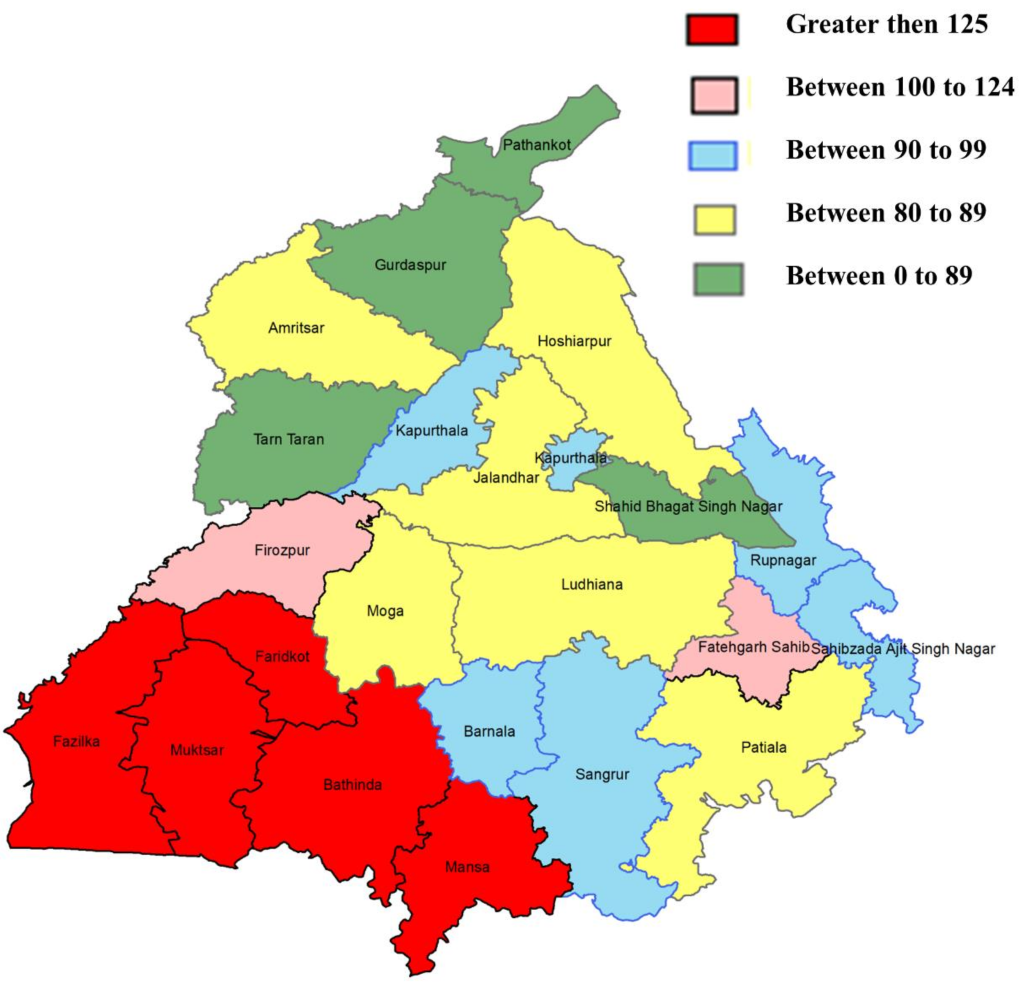


Fig. 1.3. Cancer Prevalence (per 1,00,000 PE) in Punjab

Bathinda district health authorities have led a door-to-door survey of the cancer patients, dead or alive both, in the district in December 2009 for the period 2001 to 2009. The survey identified 2,733 (1,090 males and 1,643 females) cancer cases in the district. Out of these, there were over 2,200 patients alive at that time (Kumar & Kaur, 2014). These patients had been suffering from various types of cancer including blood, breast, cervix, uterus, liver, mouth, stomach, brain etc. The numbers of cancer deaths higher in Talwandi Sabo (Bathinda) than other parts of Punjab that are probably due to overuse of pesticides, tobacco and alcohol. Moreover, the presence of heavy metals such as arsenic and uranium were found at low level in the water of Talwandi Sabo are responsible for more deaths due to cancer in Talwandi Sabo (Thakur et al., 2008). Thakur et al. (2015) analysed trace metals, pesticides, and other relevant parameters in some major drains, water samples (surface as well as groundwater), fodder, vegetable, and blood samples, and concluded that these samples contained harmful contaminants in excess of desired levels. Intake of these contaminants through the water as well as food is leading to deleterious health effects such as gastrointestinal disorders, reproductive toxicity, neurotoxicity, renal toxicity, and carcinogenic manifestations (WHO, 2011). Another study conducted by Thakur et al. (2008) observed a higher prevalence of cancer cases and cancer-related deaths in the area. A year-long study entitled "An epidemiological study of cancer cases reported from villages of Talwandi Sabo block, district Bathinda, Punjab", conducted by School of Public Health (SPH) at the Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, compared cancer incidents in the villages producing cotton with those producing rice and wheat, and found high cancer rates in the villages where pesticide usage was high. A recent hospital-based study for Punjab shows that out of the 1328 cancer cases in the state, 1230 cases were from the seven districts of Southern Punjab comprising Muktsar, Firozpur, Bathinda, Faridkot, Fazilka, Moga & Mansa districts (Aggarwal et al., 2015). According to latest report, the number of cancer patients from southwestern districts of Punjab who received support from the Chief Minister Cancer Relief Fund for the year 2016, 2017 and 2018 is provided in table 1.6.

Table 1.6. Number of Cancer Patients received support from Chief Minister Cancer Relief Fund (Source: Health Department, Punjab)

Sr. No.	District	Population	Cancer Patients (2016)	Cancer Patients (2017)	Cancer Patients (Upto March 2018)
1.	Bathinda	1388859	695	552	211
2.	Faridkot	617508	302	248	123
3.	Fazilka	1180483	282	262	87
4.	Mansa	769751	322	330	130
5.	Sri Muktsar Sahib	901896	400	352	128
6.	Firozpur	2029074	335	337	251

1.6.Cancer

Cancer is one of the foremost causes of death in the world and the name is given to a collection of related diseases. In all types of cancer, some of the body cells begin to divide without stopping and become invasive, resulting in tumours. Most tumours arise from multiple genetic and epigenetic changes in the DNA sequence. The genetic and epigenetic modifications generally involve modification (e.g., by methylation or acetylation) of DNA or histones in chromatin or the binding of microRNAs (noncoding RNAs ~20 bases) to homologous sequences in mRNA, resulting in a double-stranded structure that can modulate production of the corresponding protein (Garzon et al. 2009; Mathews et al. 2009). Recent advances in cancer biology support the hypothesis that carcinogenic agents can act through multiple signalling pathways and mechanisms, including both genetic and epigenetic changes. Alterations in gene expression and levels of key proteins are considered an essential component of the mechanisms by which most tumours arise (Croce 2009; Jones and Baylin 2007).

1.6.1. Cancer Growth & Metastasis

In a healthy body, the trillions of cells are made to grow and divide, as the body needs them to function daily. Healthy cells have a specific life cycle, reproducing and dying off is determined by the type of cell. New cells take the place of old or damaged cells as they die. Cancer disrupts this process and leads to abnormal growth in cells. Many of the characteristics of cancer are manifestations of abnormal changes in the physiology of cancer cells. A recent review presented a unified concept of these changes as steps, acquired by a lineage of cells, resulting in malignant growth (Hanahan and Weinberg, 2000). These changes include self-sufficiency in growth signals, insensitivity to growth-inhibitory signals, evasion of programmed cell death, limitless replicative potential, sustained angiogenesis, and tissue invasion/metastasis. These physiological changes result from the stepwise accumulation of heritable genetic alterations, and for any change, a different gene, or group of genes might be involved. Even in cancers of the same cell type and tissue of origin, a different combination of genetic alterations might account for similar physiological changes that contribute to the development of cancer.
Mutations can cause cells that should be replaced, to survive instead of die, and new cells to form when they are not needed. These extra cells can divide uncontrollably, causing growths called tumours to form. Tumours can cause a variety of health problems, depending on where they grow in the body. However, not all tumours are cancerous. Benign tumours are noncancerous and do not spread to nearby tissues. Sometimes, they can grow large and cause problems when they press against neighbouring organs and tissue. Malignant tumours are cancerous and can invade other parts of the body.

Some cancer cells can also migrate from their primary site of origin to different areas of body, through the bloodstream or lymphatic system to distant areas of the body is termed as metastatic cancer, or metastatic tumour. This process is called metastasis. Tumors formed from cells that have spread are called secondary tumors. The cancer may have spread to areas near the primary site, called regional metastasis, or to parts of the body that are farther away, called distant metastasis, and is classified as advanced cancer. Even when cancer spreads to a new location, it is still named after the area of the body where it started. For example, a person with breast cancer that has spread to the bones is said to have breast cancer with bone metastases. If a cancer has spread widely throughout the body before it is discovered and it is unknown exactly where it started, it is called cancer of unknown primary origin. Metastatic cancers tend to be harder to treat and more fatal.

1.6.2. Type of Cancer

Cancers are named for the area in which they begin and the type of cell they are made of, even if they spread to other parts of the body. For example, cancer that begins in the lungs and spreads to the liver is still called lung cancer. The cancer cases have been divided into 23 types namely Brain and other nervous system, Breast, Cervix, Colorectum, Esophagus, Hodgkin Lymphoma, Kidney & renal pelvis, Larynx, Leukemia, Liver and intrahepatic bile duct, Lung & bronchus, Melanoma of the skin, Myeloma, Non-hodgkin lymphoma, Oral cavity & pharynx, Ovary, Pancreas, Prostate, Stomach, Testis, Thyroid, Urinary bladder, and Uterine corpus (Cancer Statistics Centre Website). There are also several clinical terms used for certain general types of cancer-

- Carcinoma is cancer that starts in the skin or the tissues that line other organs.
- Sarcoma is a cancer of connective tissues such as bones, muscles, cartilage, and blood vessels.
- Leukaemia is a cancer of bone marrow, which creates blood cells.
- Lymphoma and myeloma are cancers of the immune system.

1.6.3. Major Cancer types in 2018 (IARC, 2018)

Cancers of the lung, female breast, and colorectum are the top three cancer types in terms of incidence, and are ranked within the top five in terms of mortality (first, fifth, and second, respectively). Together, these three cancer types are responsible for one third of the cancer incidence and mortality burden worldwide.

Cancers of the lung and female breast are the leading types worldwide in terms of the number of new cases; for each of these types, approximately 2.1 million diagnoses are estimated in 2018, contributing about 11.6% of the total cancer incidence burden. Colorectal cancer (1.8 million cases, 10.2% of the total) is the third most commonly diagnosed cancer, prostate cancer is the fourth (1.3 million cases, 7.1%), and stomach cancer is the fifth (1.0 million cases, 5.7%).

Lung cancer is also responsible for the largest number of deaths (1.8 million deaths, 18.4% of the total), because of the poor prognosis for this cancer worldwide, followed by colorectal cancer (881 000 deaths, 9.2%), stomach cancer (783 000 deaths, 8.2%), and liver cancer (782 000 deaths, 8.2%). Female breast cancer ranks as the fifth leading cause of death (627 000 deaths, 6.6%) because the prognosis is relatively favourable, at least in more developed countries.

GLOBOCAN, a project of the International Agency for Research on Cancer (IARC) provides estimates by cancer site and sex using the best available data in each country and several methods of estimation. The latest released estimated age standardised cancer incidence rates by the Globocan is provided in Figure 1.4. In case of India, the cancer incidences followed the order: Breast > Lung > Colorectum > Cervix uteri > Stomach > Prostate > Liver > Oesophagus > Ovary > Thyroid > Corpus uteri > Lip/Oral Cavity > Leukaemia.

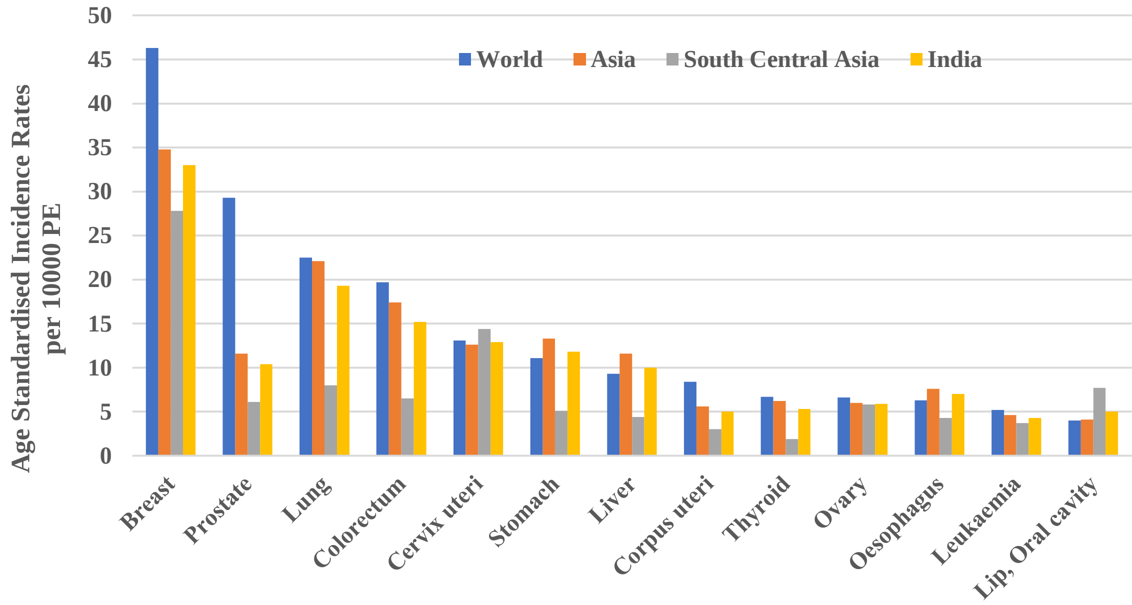


Fig. 1.4. Estimated Age Standardised Cancer Incidence Rates per 100000 PE (Source: Globocan 2018)

1.6.4. Water & Cancer

The water of sound quality is the key for socio-economic functions on Earth. However, water resources are degrading, due to rise in pollutants caused by increased population and economy. The water resources for direct and indirect human use can be contaminated by pollutants of geogenic as well as anthropogenic origin. Human activities that lead to contamination of water resources include untreated wastewater discharge from industries and municipalities, leachates from solid waste dumping sites, agricultural activities, burning of fossil fuels, vehicular traffic, fireworks, etc. In fact, any and all of the chemicals generated by human activity can and will find their way into water supplies and are related to population mortality (Hendryx et al., 2012).

Surface and groundwater are interrelated, and pollution of either can impair the other (Winter et al., 1998). Due to this, both surface and groundwater must be monitored to ensure sound water quality in a hydrologic system. There are many water pollutants which are of major concern due to their potential adverse human health effects including mutagenicity and carcinogenicity. In 2012, of the estimated 56 million global deaths, 38 million (68%) were attributed to non-communicable diseases (NCDs), and 8 million (21% of the NCDs) were cancer-related deaths (Stewart & Wild, 2014; WHO, 2014). Although the annual number of deaths due to infectious disease is projected to decline, the total annual number of NCD deaths is projected to increase to 52 million (74% of Global deaths). Especially, the cancer-related deaths are projected to 13 million (25% of the NCDs) by 2030 (WHO, 2004; Mathers and Loncar, 2008; Ferlay et al., 2014; WHO Mortality Projection on Website). It has been predicted that India's cancer burden will nearly double from slightly over a million new cases in 2012 to more than 1.7 million by 2035, and an absolute number of cancer deaths will also rise from about 0.7 million to 1.2 million in the same period (Mallath et al., 2014). However, the predicted rise in the cancer cases and mortality will actually depend on the various factors like improvement in health care facilities, cancer-related research, wider public understanding of cancer causes, contentment and reduction of carcinogens in the environment, etc. Several reports indicate that contaminants present in water are an important factor for the development of several types of malignancies in human, for example, colorectal, stomach, liver, kidney, bladder, skin cancer (IARC, 2004; Guyton et al., 2015; Loomis et al., 2015).

The International Agency for Research on Cancer (IARC) has identified 492 chemicals/compounds which are carcinogenic to humans, out of which 119 chemicals are in Group 1, meaning they are definitely carcinogenic. Most of these chemicals are soluble in water, and even if generated elsewhere finds their way into the water resources. This means that they are not content at the place of generation and it is easy for them to degrade in water into more toxic products after they are disposed of. Furthermore, the products of this degradation can sometimes be more toxic/carcinogenic to humans than their aggregates. This further illustrates the importance of clean water when considering cancer avoidance.

Ironically, one of the major water pollutants that lead to cancer originates from the disinfection of water to avoid other diseases. Disinfecting the water for public water supplies and the treated wastewater with chlorine reduces the illness and death associated with waterborne microbes but results in organic halides, also known as disinfection byproducts. Strong evidence from epidemiologic studies suggests that long-term exposure to disinfection byproducts in drinking water increases the risk of bladder cancer and possibly colon, rectal and esophageal cancers (Cantor et al., 2006).

Apart from organic halides, the presence of nitrosamines in drinking water is also considered detrimental to human health due to their potential carcinogenicity and has been linked to the risk of stomach, esophageal, and nasopharyngeal cancers (Eichholzer and Gutzwiller, 1998). Nitrosamines are soluble in water and negligibly adsorbable to soil, resulting in high leaching potential from surface water to groundwater (Drewes et al., 2006). Nitrosamines can be formed unintentionally from a range of industrial processes such as rubber manufacturing and processing, leather tanning, metal casting, food processing, and pharmaceutical manufacturing (Ducos et al., 1988; Sacher et al., 1997). They can also be emitted into the atmosphere directly, for example, from tobacco smoke, cooking, or vehicle emissions; alternatively, they are formed in the atmosphere through oxidation or nitrosation reactions of their precursor amines and can be deposited in the water bodies through precipitation. Nitrosamines and secondary amines can also be discharged into the aquatic environment via domestic sources. Relatively high concentrations of nitrosamines were detected in urine samples and sewer trunk lines (Sacher et al., 1997; Krauss et al., 2009; Mostafa et al., 1994; Van Maanen et al., 1996; Van Maanen et al., 1996; Sedlak et al., 2005). Secondary amines can also be formed via biodegradation of proteins and nitrogen-containing compounds found in domestic wastewater (Sacher et al., 1997; Wang et al., 2014).

The presence of pesticides and nitrate in water from agricultural activities also leads to cancer. Pesticides encompass a large and diverse number of chemicals designed to kill pests, including weeds, insects, rodents, molds, etc. Although all the pesticides present a potential hazard to human health, only two group of pesticides (Inorganic arsenic compounds & Lindane) and one pesticide contaminant (Dioxin TCDD), are classified by the IARC as Group 1, carcinogen to humans. The pesticide DDT and its metabolite DDE & DDE, fungicide Captafol, and the fumigant ethylene dibromide are classified as Group 2A, probably carcinogenic. There are also several pesticides that are listed as Group 3, means the evidence of carcinogenicity is inadequate for humans. This is significant because several studies have linked exposure to pesticides with increases risk of prostate, leukemia, liver, and colon cancer (Loomis et al., 2015). Chen and Young (2008) worked on the agricultural runoff and found that diuron, an herbicide, produces NDMA upon chloramination.

Another class of contaminants that are expected in the water resources of the region are pharmaceuticals and personal care products. Pharmaceuticals used for various hormonal treatment (Diethylstilbestrol, Oestrogen, Progestagen, Tamoxifen) are listed in Group 1, and increases the risk of breast, cervical, testis, endometrium and liver cancer (Hankinson et al., 1992; Grosse et al., 2009; Hunter et al, 2010). Presence of analgesics (Phenacetin), antineoplastic (Busulfan, Chlorambucil, Methyl CCNU, Cyclophosphamide, Etoposide, Melphalan, MOPP, Tamoxifen, Thiotepa, Treosulfan, Azathioprine, Chlornaphazine, Methoxsalenin combination with UVA radiation), calcineurin inhibitor (Ciclosporin), antiinflammatory (Aristolochic acid) drugs, which are also listed in Group 1, in water may also increase the risk of leukemia, bladder, skin, and ureter cancer (IARC, 2012). Apart from these established carcinogenic pharmaceutical compounds, a plethora of pharmaceutical and personal care products end up in N-Nitrosodimethylamine precursors, a potential carcinogen (Shen and Andres, 2011; Hanigan et al., 2015). The research indicates that 30-65% of the total quantity of drugs administered in the human body is excreted unchanged (Hosey et al., 2014) and forms the constituents of wastewater and drinking water of downstream population. These pharmaceuticals end up into N-Nitrosodimethylamine which is carcinogenic (Kolpin et al., 2002; Hanigan et al., 2015).

Polyaromatic Hydrocarbons (PAHs) are another class of carcinogens that may be present in sub-(surface) water. These are derived from hydrocarbon oils, coal, and tar and are mostly released by incomplete combustion of organic matter, for instance, in combustion engines, by grilling meat over an open flame, or wood burning. They are also generated from motor vehicles, from fuel combustion, as well as burning and wear and tear of tire rubber (Dickhut et al., 2000; Aatmeeyata, 2010; Sadiktsis et al., 2012). Depending on their structure, PAHs can effect human health adversely causing cancer of the lungs, skin, and prostate and acting as endocrine-disrupting compounds

(EDCs). As one of the most toxic PAHs, benzopyrene is generally chosen and analyzed as a marker substance.

Apart from organic carcinogens, drinking water may also get contaminated with inorganic/radioactive carcinogens (Such as arsenic, chromium, radon, etc.) which are generally of geogenic origin but may be contributed from anthropogenic sources as well. The IARC has incorporated arsenic, beryllium, cadmium, chromium, nickel, and radon as Group 1 carcinogens (Straif et al., 2009). A combined analysis of case–control studies estimates that residential exposure to radon gas is the leading cause of lung cancer after tobacco smoke (Darby et al., 2005). In the Indian subcontinent, the elevated concentration of arsenic (As) was first reported from Chandigarh area by Datta and Kaul (1976) and now it has been detected in the groundwater of Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Assam (MoWR, RD&GR, 2014; Singh & Vedwan, 2014; Kumar et al., 2016). Arsenic in drinking water has been recognized as a major public health issue and its exposure has been identified in Bangladesh, India, Taiwan, China, Mexico, Argentina, Chile, and USA. Epidemiological studies have shown that exposure to arsenic through drinking water causes cancer of lung, skin, and urinary bladder (IARC, 2004).

Cancer can also occur due to the presence of microbial agents in water. The IARC has considered Hepatitis B & C virus, Epstein-Barr virus, Kaposi's sarcoma herpes virus, Human immunodeficiency type 1 virus, Human papillomavirus type 16, Human T-cell lymphotropic virus, Helicobacter pylori, Clonorchis sinensis, Opisthorchis viverrini, and Schistosoma haematobium as Group 1 agent (Bouvard et al., 2009).

The cancer risks from contaminant pollution of water bodies are challenging to study considering the fact that people are exposed to hundreds, if not thousands, of chemicals and other agents through their environment. The composition of drinking water, therefore, is complex and varies between sites and with the seasons. Modern technologies are capable of minimizing the concentration of many of these substances.

1.7.Problem, Aim, & Objective

Punjab has been the subject of much skepticism in the last decade. It has previously been called the "grain bowl of the country", but has recently adopted a new nickname, "the cancer bowl of the country". The pride of holding the title "a state with maximum per capita income" came with the price of cancer due to unrestricted use of chemicals (pesticides, fertilizers, metals, polycyclic aromatic hydrocarbons, pharmaceutically active hydrocarbons, etc.) in the agricultural fields and industries. A train which connects the affected region with the nearby Bikaner city, which contains a cancer hospital, has been nicknamed Cancer Express. A study conducted by Aggarwal et al. (2015), indicated higher per capita cancer cases in the seven districts of Southern Punjab comprising Muktsar, Firozpur, Bathinda, Faridkot, Fazilka, Moga & Mansa districts (Aggarwal et al., 2015). The residents of these districts are suffering from mental and other health issues including cancer and physical deformities. Epidemiological surveying at the micro-level in Talwandi block of

Bhatinda district by Post Graduate Institute of Medical Education and Research, Chandigarh revealed that the prevalence of confirmed cancer cases was 103 per lakh population in the year 2007 and the ratio is exhibiting an increasing trend. Although there are many issues that can lead to cancer, studies suggest that the high usage of pesticides in the state of Punjab is the main contributor to the high number of cancer cases in the area. It has also been advocated that the low quality of drinking water in Punjab has attributed to the high number of cancer cases. The study conducted by various researchers indicate that groundwater in the area is high in conductivity and TDS along with the presence of fluoride, uranium, and arsenic. Pesticides and trace metals in the groundwater are also of concern.

In addition, globally, several studies dealing with the carcinogenic properties of contaminants present in drinking water and the mechanisms controlling them have been carried out, but most of these studies deal with contaminants on an individual level. The limits prescribed by the IARC and other government agencies are also based on studies of contaminants as individuals not as a culmination. In order to provide a completely confident estimation on the carcinogenic impact of a drinking water source all pollutants present must be considered together, not individually. It may be possible that individual contaminants present in water may be below the MCL (maximum contaminant level) but their cumulative effect may be detrimental. There are only a handful of studies available on the cumulative effect of contaminants/carcinogens present in water (Ni et al., 2009; Wason et al., 2012; Sexton, 2012; Russel, 2016) and completely lacking in the Indian context, highlighting the need for further studies.

Considering the high cancer numbers in the southwestern districts of Punjab and the poor water quality described above, it was decided to embark on this investigation involving comprehensive water quality assessment of the area with an emphasis on carcinogenic chemicals and assessing their cummulative effect, identifying their sources, and suggesting appropriate remedial measures.

The objectives of the study are-

1. Spatial and temporal variation of water quality parameters and carcinogenic contaminants.
2. Quantification of mutagenic potential (carcinogenicity) of water samples.
3. Source identification of major contaminants in the study area and impact assessment on human health.
4. Suggestions for possible remedial measures to reduce the impact of contaminants.
5. Dissemination of knowledge and findings to field engineers/scientists and common people

2. STUDY AREA AND DATA USED

2.1. Study Area

The study area is located between North latitude 29°32' to 31°10' and East longitude 73°52' to 76°14′ is a part of Malwa region of Punjab and covers a large tract of Indo-Gangetic Alluvial Plains covering six districts, Mansa (2174 km^2), Bathinda (3385 km^2), Muktsar (2615 km^2), Faridkot (1476 km^2), Fazilka (3113 km^2), Ferozepur (2407 km^2), with total geographical area 14.945 km^2 (Fig. 2.1)

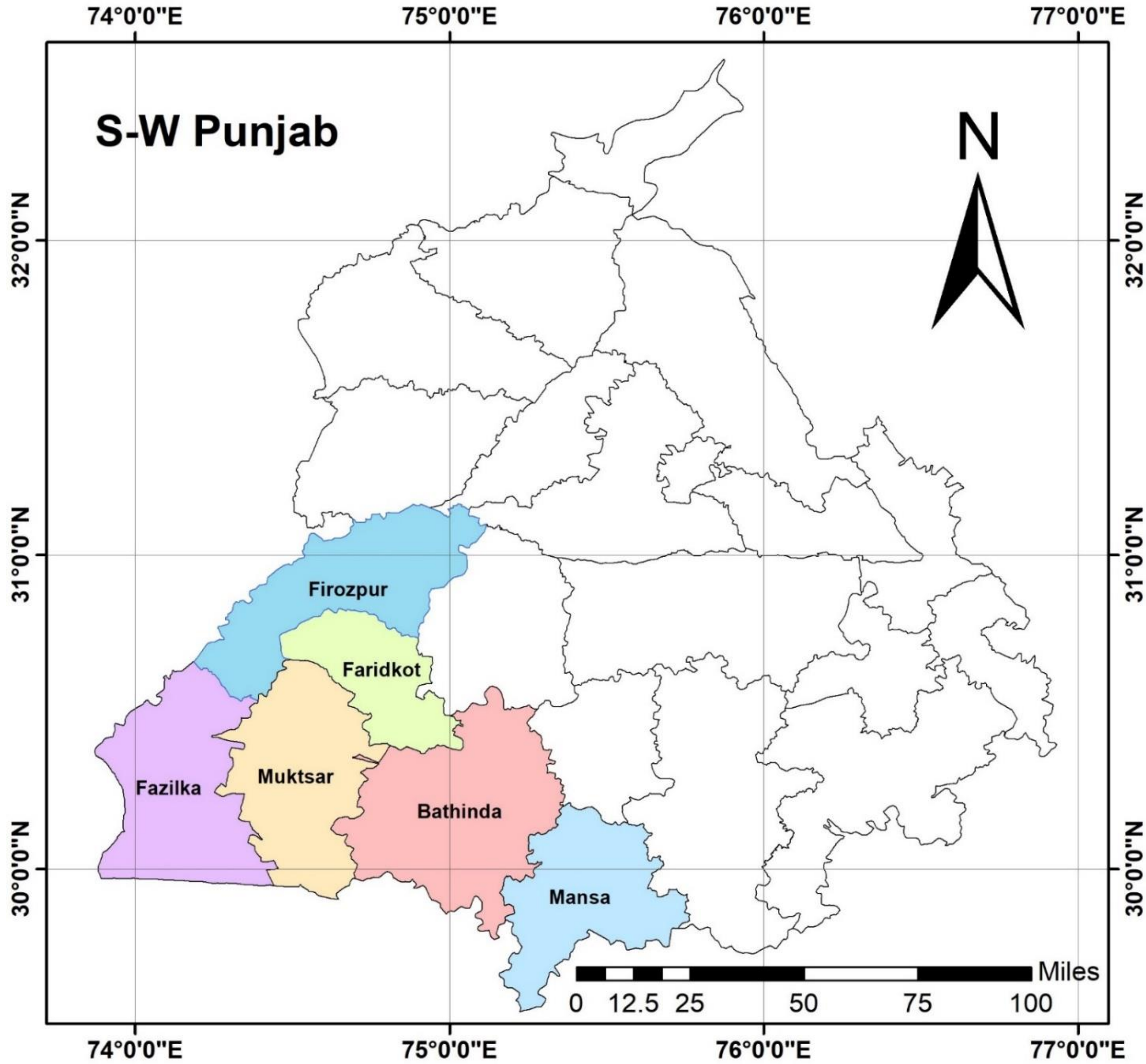


Fig. 2.1. Study area

2.1.1. Mansa

Mansa District is located in the southern part of Punjab State and lies between North latitude 29°30' to 30°15' and East longitude 75°10' to 75°46' (Fig. 2.1). It is bounded by Sangrur district in the east, Bathinda District in the west, Barnala District in the North and Haryana State in the South. The district has total Population of 7,68,808 as per census 2011, with a population density of 350 persons/km^2. 70.40 % population of Mansa districts lives in rural areas of villages.

The climate in the area is typical semi-arid type with distinct wet and dry seasons. The climate of district is classified as sub- tropical steppe, semi-arid and hot which is mainly dry except in rainy months characterized by intensely hot summer and cold winter. The normal average annual rainfall of the district is 378.2 mm (around 83% during July to September and rest 17% during October to June). The rainfall occurs due to southwest monsoon which sets in the last week of June and withdraws towards end of September. The cold weather season prevails from December to February followed by hot weather season which ends up to the last week of June.

The area forms a part of the Indo-Gangetic Alluvial plains consisting of quaternary sediments. These sediments can be broadly classified into three subdivisions viz. older alluvium formed by the depositional processes of older stream, newer alluvium formed by the present day streams, and Aeolian deposits in the form of sand dunes and sheets representing the depositional feature of the wind action. The older alluvium and the aeolian deposits are extensive whereas the newer alluvium has limited distribution. Although a number of remnants of sand dunes are present throughout the area, these are more conspicuous towards the western and southern parts of the district.

The older alluvium comprises interbanded clay, sandy clay, silt and sand with horizons of kankar. On the surface, it is chiefly represented by massive, pale reddish brown, clayey silt to fine sand with disseminated kankar. A horizon of sticky clay usually a meter or so thick, locally called pandoo, occurs 1.5 to 3.0 meter below the surface. Kankar bearing levels are usually found over this pandoo zone. The pandoo zone not only traps water under artesian conditions but also causes water logging and consequent formation of kankar and sodium and magnesium salts, thereby rendering the soil infertile. At places the grains are cemented together by infiltrating silica and lime to form impervious layers.

The pre monsoon depth to water level ranges from 5.56 to 15.01 m bgl, and post monsoon value ranges from 2.18 to 10.33 m bgl. In most of the area, depth to water level occurs within 10 m b.g.l. The area experiences a rise in water level from pre-monsoon to post monsoon periods due to recharge from rainfall occurred in the area. The long-term water level fluctuation over the past shows the rising trend in the northeastern part up to 5m.

The rise in water table is due to less withdrawal of ground water owing to its bad quality and the intensive irrigation by network of canals. The decline in water level at few places may be attributed to withdrawal of ground water due to its fresh and marginal quality and/or non- availability of canal water to meet the requirement for agricultural purposes. The water table elevation ranges from 186 m to 209 m above mean sea level. The general ground water flow is from northeast to southwest direction.

2.1.2. Bathinda

The Bathinda district is Located in the southern part of Punjab state of India and lies between 29°33′ N to 30°36′ N and 74°38′ E to 75°46′ E (Fig. 2.1). By area, Bathinda district is the second largest district in Punjab. It shares boundaries with Faridkot district and Moga district on the north, Muktsar district on the west, Barnala and Mansa districts on the east, and the state of Haryana on the south. As per the 2011 census, the district has a population of 1,388,525 out of which 0.74 million are male and 0.65 million are female, with an average literacy rate of 68%. The district recorded an increase of 17.34% in population from 2001 to 2011. The district has a good network of canals for irrigation, however, a significant amount of groundwater is used for irrigation and is the major source of drinking water. The climate of the Bathinda district is tropical, semi-arid, and hot, which is mainly dry throughout the year except in the monsoon season and is characterized by intensely hot summer and cold winter. The mean maximum temperature is 42 ºC in May and June, and the mean minimum temperature is 3.9 ºC in January. The normal annual rainfall is 408 mm which is unevenly distributed over the district, and the normal monsoon rainfall is 335 mm. The district receives around 82% of annual rainfall from July to September. Rainfall in the district increases from southwest to northeast.

The district is occupied by Indo-Gangetic alluvium. The calcareous arid brown soil is found in the east of the Bathinda and siezoram soil white in color is found in the southwest part of the district. Salinity and alkalinity are the principal problems of this arid brown soils with imperfect to moderate drain. In siezoram soils, the accumulation of calcium carbonate is in amorphous or concretionary form (kankar), and the presence of high amount of calcium carbonate and poor fertility is the main problem. The overall soil of the Bathinda district is sandy, saline in nature.

The district is having a low-lying flat topography with isolated sand dunes of various dimensions in the southern part. The maximum elevation of the area is 220.6 m amsl and the minimum elevation is 197.5 m amsl. The master slope of the area is towards Southwest. The southern part contains isolated sand dunes of various dimensions. The depth to the water level in the area ranges from 2.24 to 20.76 m bgl (Singh et al. 2018).

2.1.3. Faridkot

Faridkot is located in the south-western part of Punjab State. The area lies between 30°22' to 30°50' North latitude and 74°28' to 75°03' (Fig. 2.1) and is the smallest district of Punjab state. It shares common boundaries with Moga district in east, Ferozepur district in North & West and Muktsar and Bathinda districts in South. The highest elevation 213.3 m amsl is near Jiwanwala in the eastern part whereas the minimum of 190 m amsl at Pind Balochan in the western part with a gentle gradient of 0.45m/km to the SSW. Total Population of the district, as per the 2011 Census, is 6,18,008 out of which 3,27,121 are males and 2,90,887 are females. The total rural population in the district is 2,17,514 and the urban population is 4,00,494.

The climate of the district is classified as sub-topical steppe, semi-arid and hot which is mainly dry except in rainy months and characterized by intensely hot summer and cold winter. The Normal Annual Rainfall is 449 mm and Normal Monsoon Rainfall is 349 mm (during July to September) unevenly distributed over the district. Rainfall in the district increases from southwest to northeast.

The study area forms a part of the Sutlej Basin and exhibits gradational landforms, mainly fluvial, formed by sediments. On the whole it exhibits a low-lying flat topography generally sloping towards southwest, except few linear depressions occupied by paleo-bluff and paleo channel near Pakka and southeast of Kamiyana Villages and by sand dunes, which are concentrated in north-western and southern part of the study area. Because of the exceptionally flat topography there is not much developed drainage system.

The study area is developed by Indo Gangetic Alluvium; main landforms are Alluvial Plain, Sand sheets, Sand dunes and Palaeo Channels. Alluvial plain forms the major part of the area followed by Sand Sheets and Sand dunes as patches. Palaeo channel is occurred in central part of the study area. The soils classes are mainly loams, loamy sand, sandy to fine sandy loams and silty loams. Loamy sand is covered in major part of the study area. Faridkot is mainly an agricultural district with 126678 ha (≈89%) agricultural land and 16719 ha (≈11%) non-agricultural land.

The soil of the district is mainly alkaline containing saltpetre called Kalmi Shora in local language, which has application in chemical, oxide, glass, soap industry and leather tanning at several locations. It is being extracted at Sirsari and Kot Sukhia villages. Saltpetre is an important source of Niter (KNO_3), which is used in cracker industry, matchbox manufacture and as a fertilizer.

2.1.4. Sri Muktsar Sahib

Muktsar district lies in the south western part of the state and lies between North Latitude 29º54' & 30º40' and East Longitude 74º15' & 74º19' with a population of 9,02,702 as per 2011 census. The district shares its boundary with Faridkot district in north and north east, with Ferozepur district in North West and eastern, with Bathinda district on the east, and with Hanumangarh (Rajasthan) and Sirsa (Haryana) on the south.

The district forms a part of Satluj sub basin and main Indus basin. The area is flat and plain and slopes from NE to SW. The climate of the district is dry sub humid with grass land type of vegetation. The district receives an annual rainfall of 430.7 mm with 79% of the annual rainfall during monsoon period and 21% during non-monsoon period. The area has both unconfined and confined aquifers. In general, unconfined condition exists only upto 30m depth. The proportion of permeable beds at deeper depth is generally low.

2.1.5. Ferozepur

Ferozepur district lies in the western part of the state between North latitude 30°44' to 31°10' and East longitude 74°17′ to 75°08’ with a population of 10,01,918 as per 2011 census. The district shares its boundary with Taran Taran in north, Kapurthala and Jalandhar in north-east, Moga in the east, Faridkot and Fazilka in the south, and Pakistan in West.

The Ferozepur district forms a part of Sutlej sub basin of main Indus basin and is interrupted by clusters of sand dunes. The district area is almost a flat terrain with a gentle slope towards south west direction. Physiographically, the district is characterized by four distinct features i.e. the upland plain, sand dune tracts, younger flood plain and active flood plain. The river Sutlej that is of perineal nature mainly drains the area. The area is traversed by a dense network of canals. In irrigation practices, contribution of tubewells are larger as compared to canal system.

The climate of the district is classified as sub-tropical steppe, semi-arid and hot which is mainly dry except in rainy months and characterized by intensely hot summer and cold winter. The normal annual rainfall is 449 mm and Normal Monsoonal rainfall is 349 mm (July to September). Rainfall in the district increases from southwest to northeast.

2.1.6. Fazilka

Fazilka district lies in the south-western part of the state between North latitude 29°57' to 30°48' and East longitude 73°53′ to 74°28’ with a population of 11,80,483 as per 2011 census. The average elevation of the district is around 177m amsl. The district shares an international border with Pakistan to its west, district Firozpur to its north, Sri Muktsar Sahib to its east, and Rajasthan (Sri Ganganagar and Hanumangarh) to the south. It is fed by Sutlej sub-basin of the Indus basin.

The district is characterized by four distinct topographies - the younger flood plain, active flood plain, upland plain and sand dune tracts. Groundwater serves as the major potable and irrigation source for most rural and semi-urban areas of the study area. Fazilka follows two main crop seasons in a year i.e. Kharif and rabi. Paddy, Maize, Bajra, Cotton, Moong, Mash, Moth, Arhar and Sugarcane are the major Kharif crops are grown in this region, while major Rabi crops include wheat, barley, gram, sarson, taramera and toria. Fazilka records an annual rainfall in the range of 325–350mm and experiences a hot summer from March to June, monsoon in July to mid-September and a bracing winter from November to March.

The study area comprises of a flat alluvial plain that belongs to the Indo-Gangetic alluvium formed during the quaternary period of geological time scale. Sandy clay with saltpeter encrustations and clay with sporadic sandy nodules are recognized as the major geological formations. Saltpetre contains a significant amount of potassium and sodium nitrate, unlike chloride, sulfate, and carbonate present in minor fractions. The northern part of the study area possesses sierozem soil, while the southern part consists of sandy soils.

Groundwater occurs in both unconfined and confined conditions. According to CGWB (2017) the depth of unconfined and confined aquifers range 300m below surface. Eolian and Older alluvium form the major aquifer and is composed of sand, silt and clay. The flow of groundwater is in the south-west direction. According to the report of Water Resources & Environment Directorate (2018) the groundwater of Fazilka and Jalalabad blocks of Fazilka districts are over-exploited with the total annual groundwater recharge and total annual additional potential groundwater recharge being 102689 and 442 ham, respectively.

3. METHODOLOGY

3.1. Delineation of Villages

The village-wise number of cases for year 2016, 2017, & 2018 were collected from the district hospitals and Dept. of Health & Family Welfare, Govt. of Punjab, and was used for selecting the sampling sites. The village wise population data was downloaded from the MHA website (http://censusindia.gov.in/2011census/Listofvillagesandtowns.aspx). Each district was divided into grid of 10x10 km, and the cancer prone grids were identified and selected based on number of cancer cases, per capita cancer cases, and number of villages. Further, the village for sampling in a cancer prone grid was selected based on highest per capita cancer cases. Twenty sampling locations were finalized for each district, 17 from cancer prone grids and 03 from minimal affected grids as given below-

3.1.1. Sampling Locations in Bathinda District

Table 3.1. Sampling sites in Bathinda district

Sr. No.	Village	Code	Latitude	Longitude
1	Akalia Jalal	A1	30.512	75.1467
2	Gurusar	A2	30.4905	75.1397
3	Goniana Khurd	A3	30.2531	74.9114
4	Khemuana	A4	30.3764	75.0007
5	Dyalpura Bhaika	A5	30.4843	75.2009
6	Ganga	A6	30.3161	75.0782
7	Rampura Phul	A7	30.3079	75.2387
8	Gill Kalan	A8	30.2809	75.2692
9	Bathinda City	A9	30.2268	74.9554
10	Bhucho Kalan	A10	30.2401	75.0852
11	Kotra Korianwala	A11	30.2431	75.2122
12	Badlala	A12	30.2357	75.3152
13	Ghudda	A13a	30.1224	74.7909
14	Ghudda (Cw)	A13b	30.1273	74.8078
15	Jai Singhwala	A14a	30.1344	74.8578
16	Jai Singhwala (Cw)	A14b	30.1468	74.8593
17	Jhanduke	A15	30.1625	75.1467
18	Ghuman Khurd	A 16	30.0941	75.2635
19	Talwandi Sabo	A 17	29.9891	75.0921
20	Barkhandi	MA 18	30.3803	74.8376
21	Mari	MA 19	30.054	75.1865
22	Lool Bai	MA 20	30.1514	74.664

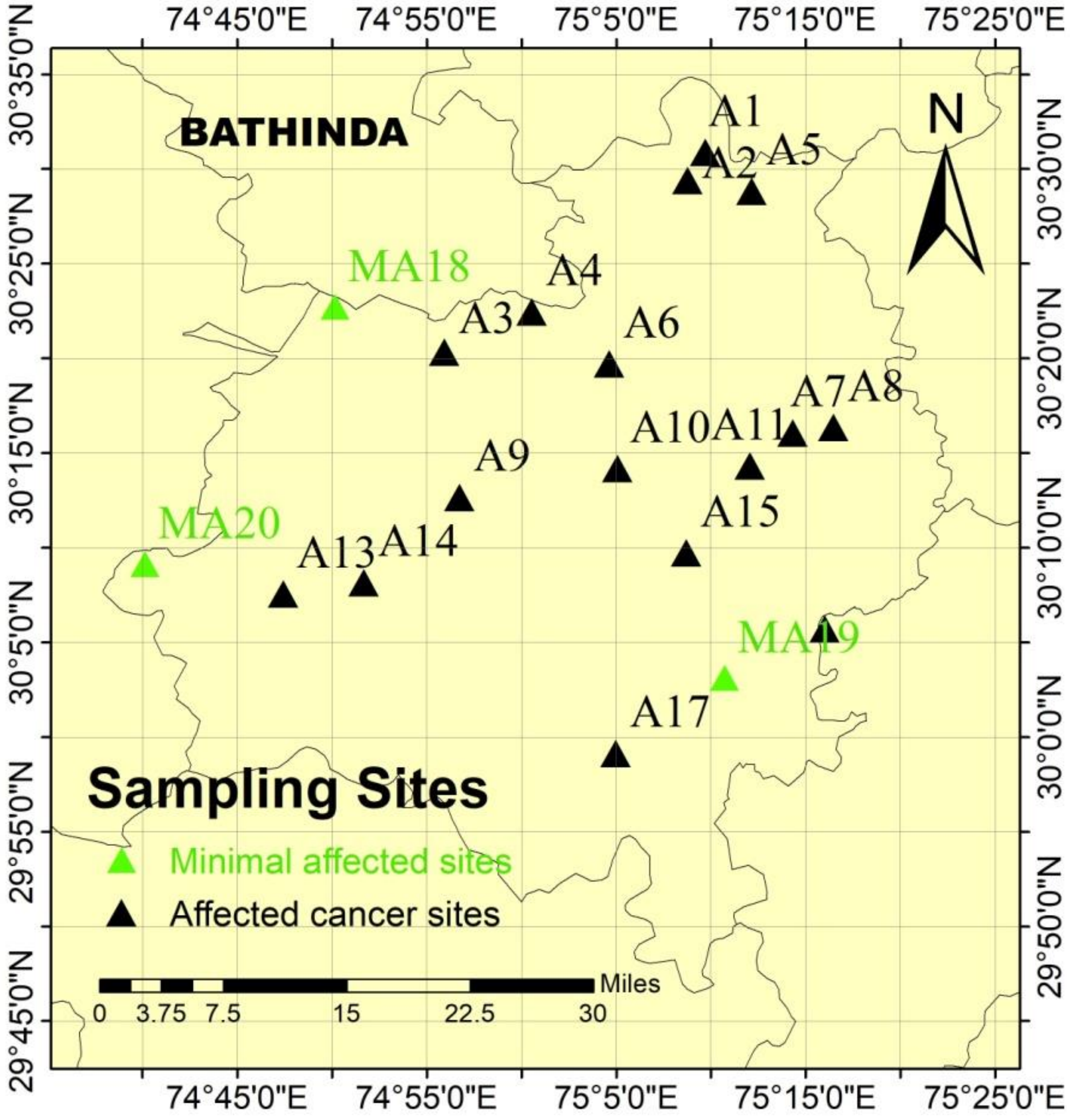


Fig. 3.1. Sample Sites of Bathinda District.

3.1.2. Sampling Locations in Mansa District

Table 3.2. Sampling sites of Mansa district

Sr. No.	Village	Code	Latitude	Longitude
1	Joga	A1	30.1602	75.4203
2	Khiwa Kalan	A2	30.1018	75.5667
3	Thuthianwali	A3	30.0365	75.3862
4	Dalel Singhwala	A4	30.0243	75.4609
5	Bhikhi	A5	30.0694	75.5348
6	Mansa	A6	30.0214	75.3969
7	Budhlada	A7	29.9275	75.5484
8	Kalipur	A8	29.8969	75.5521
9	Tandian	A9	29.8753	75.2286
10	Chhachhohar	A10	29.8399	75.3943
11	Barah	A11	29.8976	75.4790
12	Sangreri	A12	29.8981	75.6650
13	Bareta	A13	29.8576	75.6844
14	Boha	A14	29.8441	75.5299
15	Sardulgarh	A15	29.6969	75.2393
16	Kalehri	A16	29.9488	75.4908
17	Malkan	A17	29.8092	75.4453
18	Perron	MA 18	29.9100	75.2027
19	Kulrian	MA 19	30.1133	75.5525
20	Patta Mulake	MA 20	30.1523	74.6688

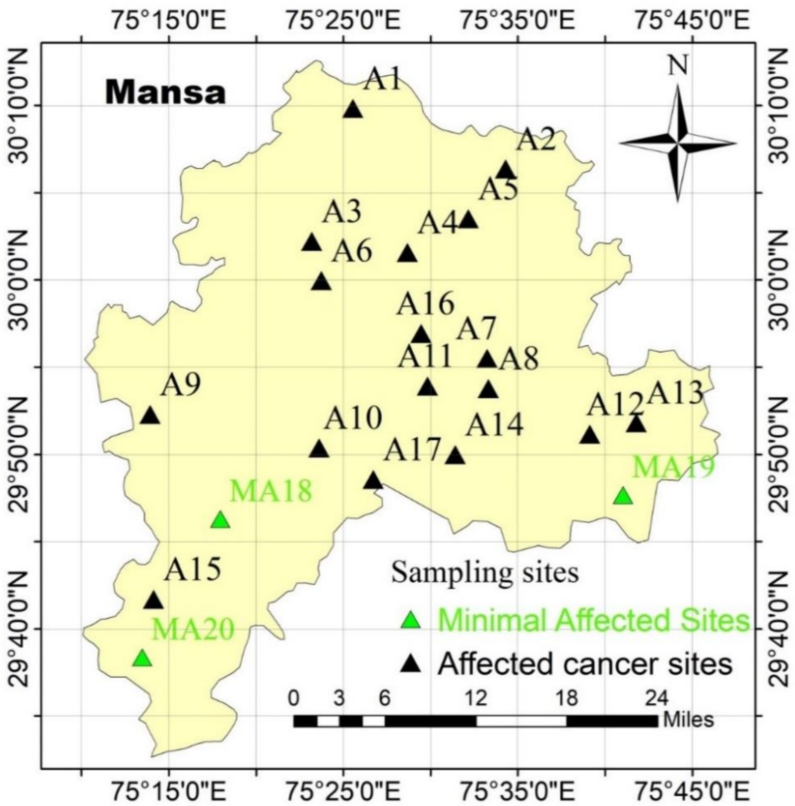


Fig. 3.2. Sampling Sites of Mansa District.

3.1.3. Sampling Locations in Faridkot District

Table 3.3. Sampling sites in Faridkot District

Sr. No.	Village	Code	Latitude	Longitude
1	Faridkot	A1	30.3959	74.4536
2	Pakhi kalan	A2	30.4508	74.4536
3	Pipli	A3	30.4352	74.4400
4	Jaito	A4	30.2702	74.5258
5	Dhimanwali	A5	30.3552	74.4417
6	Kot kapura	A6	30.3528	74.4841
7	Khachran	A7	30.2555	74.4618
8	Dhudi	A8	30.4144	74.5107
9	Kingra	A9	30.4035	74.3415
10	Golewala	A10	30.4713	74.4200
11	Panjgarain kalan	A11	30.3637	74.5448
12	Mumaru	A12	30.4733	74.3522
13	Mehmuana	A13	30.4145	74.3829
14	Gobindgarh	A14	30.2441	74.5740
15	Bargari	A15	30.3115	74.5710
16	Wara daraka	A16	30.3259	74.4530
17	Ghaniewala	A17	30.3759	74.5623
18	Sarawan	MA18	30.5221	74.8806
19	Ramana	MA19	30.7458	74.6416
20	Ahail	MA20	30.3912	74.4206

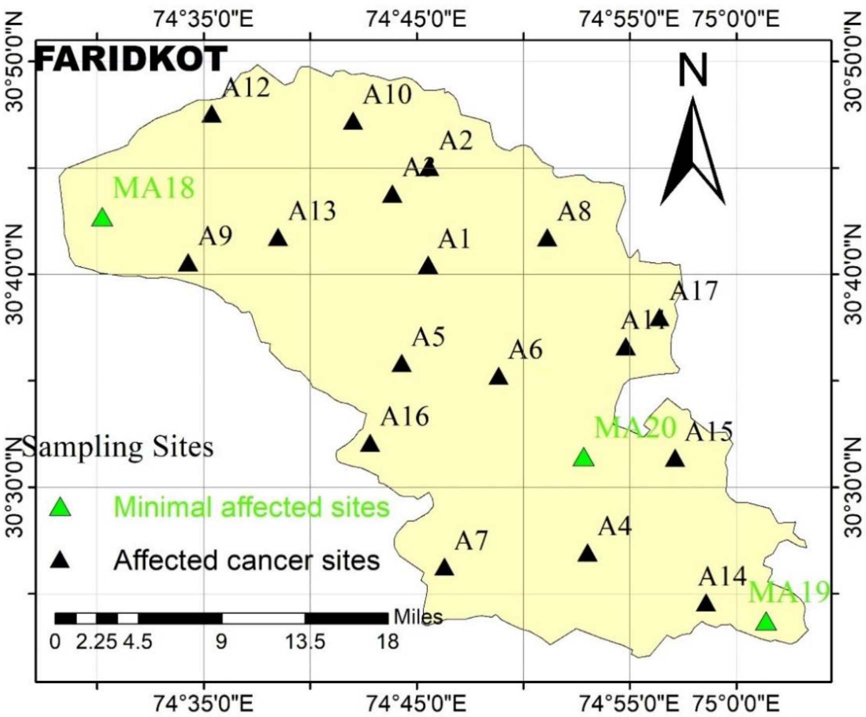


Fig. 3.3. Sampling Sites of Faridkot District.

3.1.4. Sampling Locations in Sri Muktsar Sahib District

Table 3.4. Sampling sites in Sri Muktsar Sahib District

Sr. No.	Village	Code	Latitude	Longitude
1	Mahuana	A1	30.0323	74.3344
2	Khokhar	A2	30.2857	74.4041
3	Saddarwala	A3	30.3123	74.2857
4	Gurusar	A4	30.1631	74.3524
5	Dohak	A5	30.3743	74.3609
6	Doda	A6	30.2301	74.3818
7	Sri Muktsar Sahib	A7	30.2813	74.3105
8	Malout	A8	30.1121	74.3019
9	Gidderbaha	A9	30.1226	74.3927
10	Ratta khera	A10	30.1724	74.2459
11	Motlewala	A11	30.3329	74.3842
12	Gulabewala	A12	30.3339	74.2838
13	Akalgarh	A13	30.3053	74.2335
14	Kot bhai	A14	30.1555	74.4144
15	Jagat singhwala	A15	30.3905	74.2923
16	Bhangchari	A16	30.2306	74.2754
17	Lal bai	A17	30.0835	74.3649
18	Gander	MA18	30.2450	74.2240
19	Tarmala	MA19	30.3306	74.3242
20	Waring Khera	MA20	30.3354	74.3110

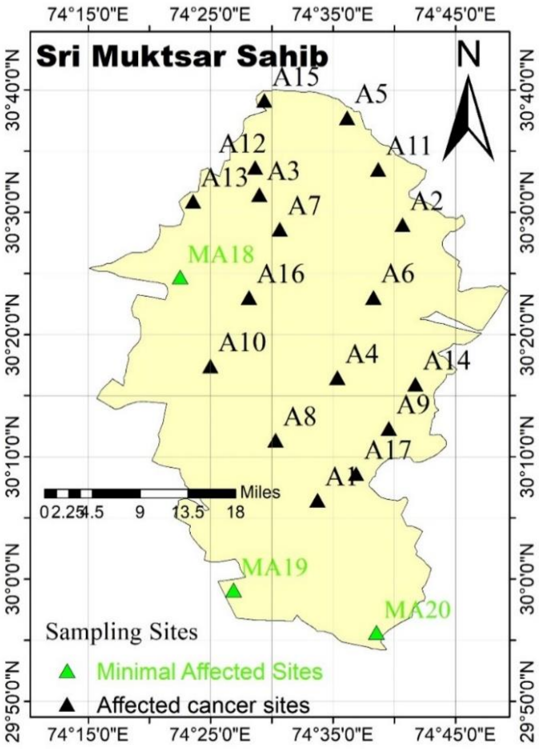


Fig. 3.4. Sampling Sites of Sri Muktsar Sahib District.

3.1.5. Sampling Locations in Ferozepur District

Table 3.5. Sampling sites in Ferozepur District

Sr. No.	Village	Code	Latitude	Longitude
1	Lehra Bet	A1	31.0819	75.0267
2	Talwandi Jalle Khan	A2	30.9479	75.0604
3	Khai	A3	30.905	74.5517
4	Bandala	A4	31.1093	74.774
5	Naraingarh	A5	30.8969	74.8441
6	Mallanwala	A6	31.0489	74.8122
7	Madhre	A7	30.9664	74.5794
8	Jamaitpur Dheru	A8	30.9388	74.7563
9	Firozpur	A9	30.9574	74.6113
10	Mannu Machhi	A10	31.1364	75.0015
11	Chak Ghobai Alias Tangan	A11	30.88	74.4557
12	Guru Har Sahai	A12	30.7136	74.4053
13	zira	A13	30.9758	74.9857
14	Aku Mastu Ke	A14	31.0012	74.7084
15	Killi Gudha	A15	31.1023	74.8911
16	Mudki	A16	30.7862	74.8784
17	Ruknewala	A17	31.0845	74.7882
18	Kasubegu	MA18	30.8578	74.6632
19	Lakho ke behram	MA19	30.8234	74.4487
20	Jhoke hari har	MA20	30.8703	74.6115

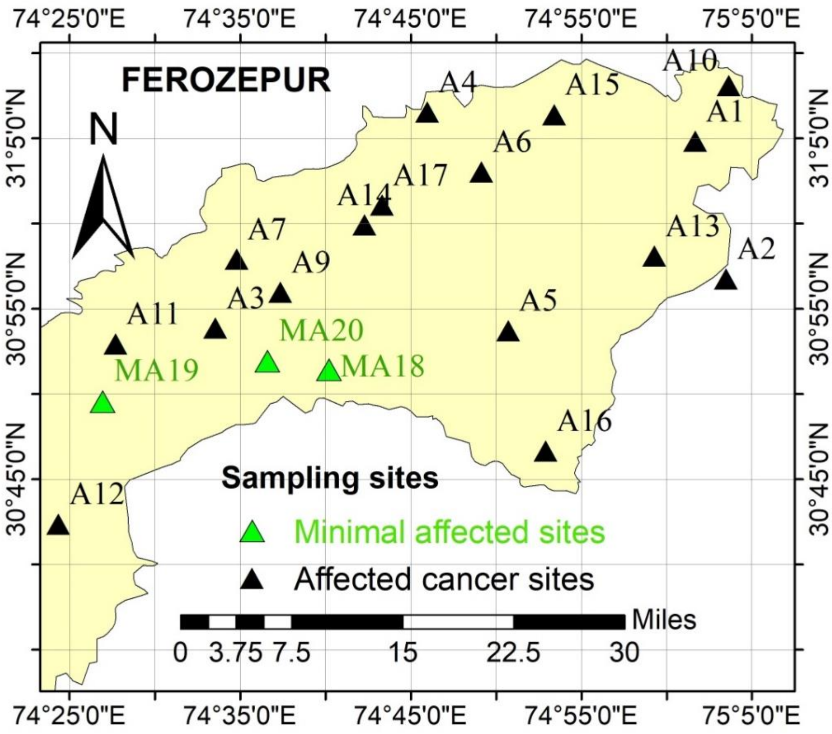


Fig. 3.5. Sampling Sites of Ferozepur District.

3.1.6. Sampling Locations in Fazilka District

Table 3.6. Sampling sites in Fazilka District

Sr. No.	Village	Code	Latitude	Longitude
1	Pakan	A1	30.2403	74.1916
2	Chak Bazida	A2	30.3522	74.0622
3	Baghe Ke Hithar	A4	30.3626	74.1010
4	Muhammad Pira	A5	30.2417	73.5910
5	Islamwala	A6	30.2131	74.1041
6	Chak Kherewala	A7	30.3084	74.1407
7	Jalalabaad	A8	30.3617	74.1583
8	Chak Lakhowali	A9	30.2951	74.1143
9	Chak Kheowali	A10	30.2453	74.1023
10	Abohar	A11	30.0843	74.1157
11	Dhaban Kokarian	A12	30.0642	74.1932
12	Dalmir Khera	A13	30.0513	74.0447
13	Patti Amra Urf Patti Sadiq	A14	29.9844	74.1181
14	Kawanwali	A15	30.2745	74.0058
15	Khanwala	A16	30.1920	73.5670
16	Halimwala	A17	30.2651	74.1500
17	Khui Khera	MA18	30.3005	74.0613
18	Panjkosi	MA19	30.1828	73.5947
19	Khuban	MA20	30.1701	74.0823
20	Fazilka	A3	30.4008	74.0259

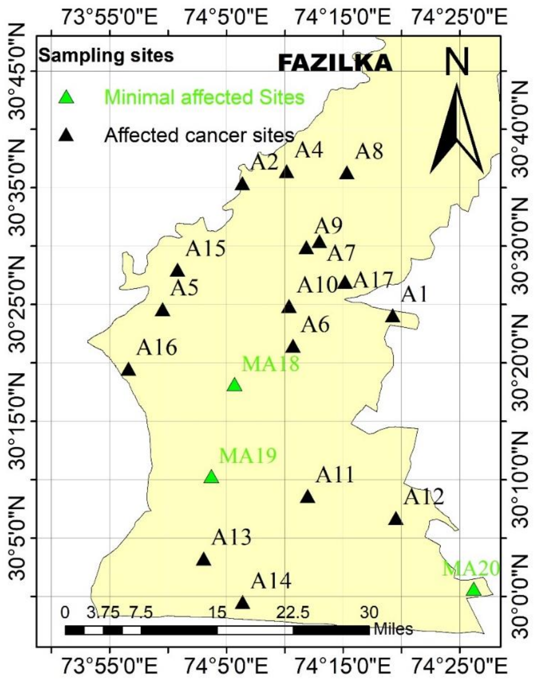


Fig. 3.6. Sampling Sites of Fazilka District

3.2.Sampling & Analysis of Samples

Drinking water samples from the identified villages were collected after discussion with the villagers based on the usage. The hand-pumps were continuously pumped for at least 15 minutes prior to the sampling, to ensure the groundwater to be sampled was representative of groundwater aquifer. All the groundwater samples were collected from the sources, which are being used extensively. The samples from Bathinda and Mansa for pre-monsoon period were collected in April 2019 and sampling from other districts are in progress. From each district, 20 samples are being collected, 17 from cancer prone villages and 3 from villages with negligible cancer incidences. The samples will be also carried out for the post monsoon period.

The water samples are collected in appropriate sampling bottles as given in table 3.7 using grab sampling method and preserved as per standard methods (APHA, 2017). For organoleptic, major ions and trace metal analysis, samples were collected in polyethylene bottles along with their GPS coordinates. For pesticide and PAHs analysis, the samples were collected in amber color glass bottles and brought to lab in ice bath at around 6 °C and were kept in freezer maintained at 4 °C till extraction was completed. The extraction was completed within 7-days of collection and analyzed within 30 days of extraction.

Table 3.7. Sample Collection & Handling

Sr. No.	Parameter	Container	Sample Size (ml)	Preservation	Analysis Time
1	pH	--	--	--	Onsite
2	Temperature	--	--	--	Onsite
3	Conductivity	--	--	--	Onsite
4	Radon	--	--	--	Onsite
5	Major Ions	Plastic bottle	500	--	<10 days
6	Trace Metals	Plastic bottle	100	0.5 ml HNO_3	<30 days
7	Organic Compounds	Amber color glass bottle	1000	Cool, ≈4 °C	<30 days

The organoleptic parameters, major ions, trace metals, pesticides, and polyaromatic hydrocarbons were analyzed following APHA's Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

3.2.1. Chemicals & Reagents

All chemicals used for analysis were of analytical reagent grade (Merck/BDH/ThermoFisher). Standard solutions of metals ions were procured from Merck, Germany. Pesticide standards were procured from Reagecon Diagnostics Ltd., Ireland. De-ionized water was used throughout the analysis work. All glassware and other containers used for trace metal analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 hours and finally rinsed with de-ionized water several times prior to use. All glassware for pesticide analysis were rinsed with chromatography grade solvents prior to use.

3.2.2. Analytical Methodology

The samples were analyzed as per Standard Methods for the Examination of Water and Wastewater (APHA, 2017). The details of analytical methods and equipment used in the study are given in Table 3.8.

The major cations and anions in the samples were analyzed with the help of Metrohm Ion Chromatograph. Ion chromatography is a form of liquid chromatography, in which ion exchange resins are employed to separate atomic and molecular ions for analysis. IC involves the retention of ions from the sample being retained based on ionic interactions. Quantification of cations and anions in the sample is based upon calibration curve of standard solutions of respective cations/anions. Ionic balance was calculated and the error in the ionic balance for majority of the samples was within 5%.

Perkin-Elmer Inductively Coupled Plasma Mass Spectrometer (ICP-MS) and Agilent ICP-OES was used for analysis of trace metals. The operational conditions were adjusted in accordance with the manufacture's guidelines to yield optimal determination. The calibration curve of mixed trace metal solution of 10, 50, and 100 ppb were prepared and with the help of same the concentration of metals in the samples were quantified. These calibration curves were determined several times during the period of analysis. The samples were digested in nitric acid and hydrogen peroxide for oxidation/removal of organics in Anton Paar Multiwave PRO Microwave Reaction System and filtered through 0.45 micron filter paper before injecting in ICP-MS.

The water samples for the analysis of pesticides were extracted with n-hexane three times, followed by three times extraction with dichloromethane and chloroform, and the combined extract was concentrated (1000 times) using Kuderna-Danish Assembly under reduced vacuum. The moisture from the extracts was removed using anhydrous sodium sulfate. This concentrated solution was filtered through nylon syringe filter (0.2 µm) and collected in 15 ml vial. Then, 1 µl of solution was injected with the help of auto-sampler with syringe (PAL RSI 85) in GC oven of GC-MS-MS system of Agilent Technologies Gas Chromatograph (8890 GC) coupled with triple quad mass spectrometer (7010 B MSQQQ) in the EI (Electron Impact) mode with the electron energy set at 100 eV and the mass range at m/z 5–1070. A capillary column HP 5 (30 m (length) x 0.25 mm (ID)) of 0.25 µm film thickness of coated material (5% diphenyl and 95% dimethylpolysiloxane) was used. The injector was set at 280 °C. The detectors used were MS detector. The temperature programmed as follow: 1 min hold at 60 °C with 40 °C/min rise up to 170 °C followed by 10 °C/min rise up to 310 °C. The flow rate of carrier gas (helium) was maintained at 1.0 ml/min. A post-run of 2 min at 310 °C was sufficient for the next injection. Identification of compounds was done by comparing the retention times with those of standard pesticides. The qualitative determination of the pesticides was carried out by comparing the retention time and peak area of the pesticides.

Table 3.8. Analytical Methods and Equipments used in the Study

Sr. No.	Parameter	Method	Equipment Used
A.	**Physicochemical**		
1	pH	Electrometric	pH meter - WTW
2	Electrical Conductivity	Electrometric	Conductivity meter - WTW
3	Total Dissolved Solids	Gravimetric Method	
4	Bicarbonate	Titration by H_2SO_4	Digital Burette
5	Calcium	Conductivity Method	Ion Chromatograph, Dionex (ICS 5000)
6	Magnesium		
7	Sodium		
8	Potassium		
9	Chloride		
10	Fluoride		
11	Nitrate		
12	Sulfate		
13	Phosphate		
B.	**Trace Metals**		
14	Arsenic	Digestion followed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	ICP-MS
15	Aluminium		
16	Beryllium		
17	Chromium		
18	Cadmium		
19	Cobalt		
20	Copper		
21	Iron		
22	Lead		
23	Manganese		
24	Mercury		
25	Nickel		
26	Selenium		
27	Uranium		
28	Zinc		
C.	**Pesticides & Polyaromatic Hydrocarbons**		
29	α-Hexachlorocyclohexane	Extraction followed by Gas Chromatography Mass Spectrometry (GC-MS)	GC-MS-MS
30	β-Hexachlorocyclohexane		
31	δ-Hexachlorocyclohexane		
32	γ-Hexachlorocyclohexane		
33	Methyl parathion		
34	Malathion		
35	Chlorpyriphos		
36	Dieldrin		
37	Atrazine		
38	Alachlor		
39	Butachlor		
40	p-p-DDE		
41	o-p-DDE		
42	o-p-DDD		

43	p-p-DDD		
44	o-p-DDT		
45	p-p-DDT		
46	α-Endosulfan		
47	β-Endosulfan		
48	Endosulfan sulfate		
49	Ethion		
50	Acenaphthene		
51	Anthracene		
52	Benzo(a)anthracene		
53	Chrysene		
54	Fluoroanthene		
55	Fluorene		
56	Naphthalene		
57	Phenanthrene		
D.	**Gas**		
58	Radon	Solid State Alpha Detector	Continuous Online Radon Monitor RAD7

3.3.Statistical Analysis of the Contaminant data and Cancer Incidences

The collected and generated data will be processed using different multivariate statistical techniques, such as Cluster Analysis (CA), Discriminant Analysis (DA), Principal Component Analysis(PCA), and Factor Analysis (FA) using SPSS and XLSTAT software's. Further, these techniques help in providing information on the most meaningful parameters, which describes a whole data set affording data reduction with minimum loss of original information for formulating most appropriate adaptive measures for safe drinking water supplies and other inter sectorial demands.

The descriptive analysis for minimum, maximum, range mean, standard deviation, and Pearson's correlation coefficient (r) for different chemical and physical parameters and the principal component analysis (PCA) in the study were conducted by SPSS version-22 software.

Pearson's correlation analysis was used for revealing and highlighting the relationship among the parameter (Egbueri 2018, 2019). Correlation coefficients < 0.5 are supposed to exhibit poor correlation. The correlation coefficient of 0.5 is termed as good correlation and > 0.5 is termed to have excellent correlation (Kaiser 1958). Further, p values <0.01 and <0.05 indicate a strong and significant correlation among the parameters respectively (Goyal et al., 2021).

PCA was used to identify major variable factors responsible for the source (natural and anthropogenic) of solutes in the observed data set (Varol and Davraz 2015); (Zhang et al. 2016). Factor loading helps to arrive near the significant factor and the Kaiser Normalization scheme is used for the interpretation of the factor score on varimax rotation. The maximum variance factor selected which had Eigen value >1 (Demirel and Guler 2006; Singaraja et al. 2014).

The hydrochemical facies represents the dominancy of the major cations and anions in the groundwater (Subba Rao 2008; (Adimalla 2020) was prepared by the trilinear diagram (piper chart) using Grapher software version-14. Water Quality Indices (WQI) for drinking and irrigation usage, and health risk assessment were computed using MS-excel -2016.

3.4. Water Quality Indices (WQI)

WQI is used to classify the water quality based on different designated usage (Ahada and Suthar 2018; Egbueri, Mgbenu, and Chukwu 2019; Adimalla 2020; Jaswal et al. 2021; Shalumon et al. 2021)

The water quality indices for both pre- and post-monsoon samples were calculated by weighted arithmetic WQI by using simple formulas (Pant et al. 2021; ahada, 2018). The Unit Weight (AWi), Relative Weight(Wi), Quality Rating (Qi), Sub-Index (SIi), and WQI was calculated for each parameter by use of equation (3.1), (3.2), (3.3), (3.4), and (3.5) respectively.

$$\mathrm{AWi} = 1/\sum_{k=0}^{n} 1/\mathrm{Si} \tag{3.1}$$

$$\mathrm{Wi} = \frac{\mathrm{AWi}}{\mathrm{Si}} \tag{3.2}$$

$$\mathrm{Qi} = \left(\frac{\mathrm{Ci}}{\mathrm{Si}}\right) \mathrm{X}\ 100 \tag{3.3}$$

$$\mathrm{SIi} = \mathrm{Wi\ X\ Qi} \tag{3.4}$$

$$\mathrm{WQI} = \sum_{i=0}^{n} \mathrm{SIi} \tag{3.5}$$

Where Ci: Measured concentration; Si: Standard Permissible Limit

WQI values in the range 0-25, 26-50, 51-75, 76-100, and >100 were classified as excellent, good, medium, poor, and unsuitable for use (Mgbenu and Egbueri 2019; Pant et al. 2021). The permissible limits for computing the WQI were considered from BIS (2012), BIS (1986), WHO (2017), and Singh et al. (2021).

3.5.Health Risk Assessment

Health risk assessment in human is conducted to evaluate the toxic effects of contaminants present in drinking water on human health. Contaminants in drinking water, especially trace elements, are major stressor and health hazard to the consumers. Assessment of health hazards from trace element exposure can be definitely accomplished by health effect studies. However, the epidemiological study for the contaminants on human health at several locations and large population is usually impractical; therefore, health risk assessment methods have been developed to estimate the health hazards associated with the contaminant exposure. One of the basic strategies used to perform these types of assessment is to compare the concentration of the contaminants with the regulatory standards and guidelines, resulting from the toxicological criteria, and is known as the quotient approach to hazard assessment (Nimick et al., 2004). The Chronic Daily intake (CDI) and hazardous Quotient (HQ) was calculated by following USEPA (1989) guideline (Toxicity and Hazards 2001; Kumar et al. 2017; Ravindra and Mor 2019; Ghosh et al. 2020).

The CDI and HQ were calculated by using equations (3.6) and (3.8) respectively.

$$CDI = (C \times CR \times EF \times ED) / (BW \times AT \times YL) \quad (3.6)$$

Where, *C* = average observed concentration of contaminant in mg/l, CR = consumption rate (in l/day) assumed 3 l/Day , EF = exposure frequency (in days/year) assumed as 365 day, *ED* = exposure duration (in year) assumed as 70 year, *BW* = body weight (in kg) assumed as 70 kg for adult (Adimalla 2020), *AT* = period over which exposure is averaged (in days/year) assumed 365 day, and YL (year/life)=70 year/life.

$$HQ = CDI / RfD \quad (3.7)$$

$$\text{Hazard Index (HI)} = \sum HQi \quad (3.8)$$

where CDI is in mg/kg-D and RfD (Reference Dose) in mg/kg-D. RFD values were considered from (EPA 2015; WHO 2010).

The HQ less than 0.1 indicates no adverse effects on health, 0.1 to 1.0 value indicates low hazard and potential for adverse effects, 1.0 to 10.0 value indicates moderate hazard, and values above 10.0 indicates high health hazard (Nimick et al., 2004).

The health risk assessment was computed using MS-excel -2016 and spatial distribution of human health risk was plotted using Arc GIS 10.7.1.

3.6. Mutagenicity of Water Resources

The samples were processed for mutagenicity through the Ames test, which is the most widely used test. The test measures the capacity of a chemical to cause mutations in the bacterium Salmonella typhimurium. The Ames test involves mixing the chemical under test with a bacterial culture and then manipulating the culture so that only mutated bacteria will grow. The number of mutated bacteria is a measure of the potency of the tested material as a mutagen.

3.6.1. Principle

Ames test uses several strains of bacteria (*Salmonella*, *E.coli*) that carry a particular mutation. Point mutations are made in the histidine (Salmonella typhimurium) or the tryptophan (Escherichia coli) operon, rendering the bacteria incapable of producing the corresponding amino acid. These mutations result in his- or trp- organisms that cannot grow unless histidine or tryptophan is supplied.

But culturing His- *Salmonella* in a media containing certain chemicals which can cause mutation in histidine encoding gene, such that they regain the ability to synthesize histidine **(His+**). This is to say that when a mutagenic event occurs, base substitutions or frameshifts within the gene can cause a reversion to amino acid prototrophy. This is the reverse mutation. These reverted bacteria will then grow in histidine- or tryptophan-deficient media, respectively.

A sample's mutagenic potential is assessed by exposing amino acid-requiring organisms to varying concentrations of chemical and selecting for the reversion event. Media lacking the specific amino acid are used for this selection which allow only those cells that have undergone the reversion to histidine / tryptophan prototrophy to survive and grow. If the test sample causes this reversion, it is a mutagen.

3.6.2. Method

- Isolate an auxotrophic strain of Salmonella Typhimurium for histidine. (ie. His-ve)
- Prepare a test suspension of His-ve Salmonella Typhimurium in a plain buffer with test chemical (eg. 2-aminofluorene). Also add a small amount of histidine. Note: small amount of histidine is required so bacteria starts growing. Once histidine is depleted only those bacteria mutated to gain the ability to synthesize histidine form colonies.
- Also prepare a control suspension of His-ve Salmonella Typhimurium but without test chemicals.
- Incubate the suspensions at 37°C for 20 minutes
- Prepare the two agar plate and spread the suspension on agar plate.
- Incubate the plates at 37°C for 48 hours.
- After48 hours count the number of colonies in each plate.

3.6.3. Result Interpretation

- The mutagenicity of chemicals is proportional to number of colonies observed.
- If there is a large number of colonies on the test plate in comparison to control, then such chemicals are said to be mutagens.
- Very few numbers of colonies can be seen on control plate also. This may be due to spontaneous point mutation on histidine encoding gene.

4. RESULTS & DISCUSSION

4.1. Drinking Water Quality of the Districts of SW Punjab

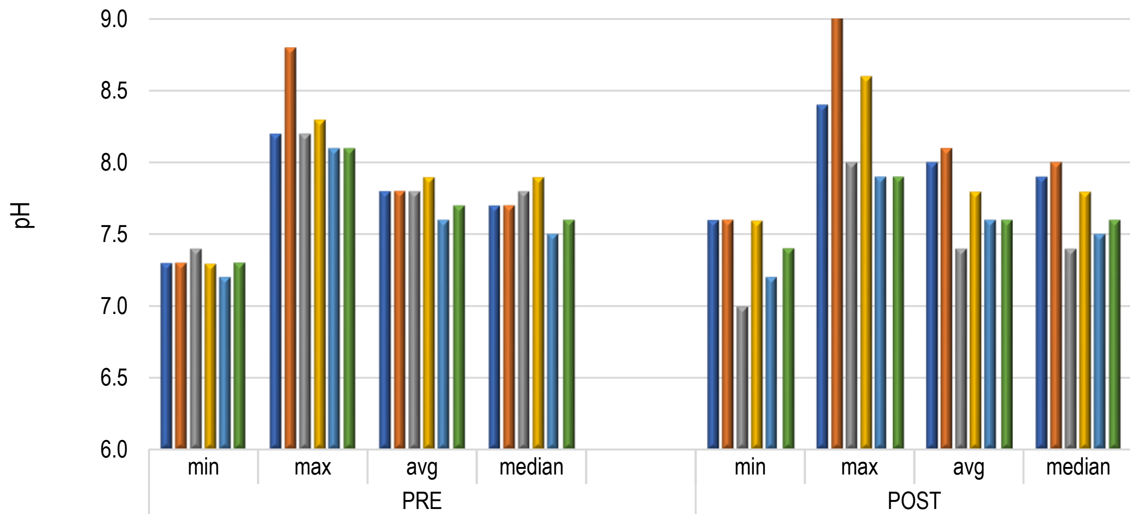
4.1.1. Pre and Post Monsoon Sampling

20 drinking water samples, 17 from cancer prone areas and 3 from minimal affected areas were collected from each district for organoleptic, major ions, trace metals, pesticides, and PAHs. Onsite radon measurement was also done for each location. The groundwater samples were collected after pumping the water for about 5 minutes for the frequently used ones.

4.1.2. Physical Parameter

4.1.2.1. pH & Electrical Conductivity

pH is one of the most important parameter in water chemistry and is defined as log[H+], and is measured as intensity of acidity or alkalinity on a scale ranging from 0-14. In natural water, pH is governed by the equilibrium between carbon dioxide, bicarbonate and carbonates ions and in general, ranges between pH 4.5 to 8.5. Although pH has no direct impact on the health of consumers, it is one of the most important operational water quality parameter. BIS (2012) have prescribed pH value in the range of 6.5 to 8.5 for water used for drinking purpose.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	7.3	8.2	7.8	7.7	7.6	8.4	8.0	7.9
Mansa	7.3	8.8	7.8	7.7	7.6	9.7	8.1	8.0
Sri Muktsar Sahib	7.4	8.2	7.8	7.8	7.0	8.0	7.4	7.4
Fazilka	7.3	8.3	7.9	7.9	7.6	8.6	7.8	7.8
Firozepur	7.2	8.1	7.6	7.5	7.2	7.9	7.6	7.5
Faridkot	7.3	8.1	7.7	7.6	7.4	7.9	7.6	7.6

Fig. 4.1. pH of Pre & Post Monsoon samples of SW Punjab

In the pre-monsoon sampling, the average pH value of drinking water in the Fazilka district was highest (7.9±0.06) and the lowest value (7.6±0.059) the was for Ferozepur district. During post-monsoon sampling, the maximum average pH value was observed for Mansa (8.1±0.091) and minimum value was for Sri Muktsar Sahib (7.4±0.059) (Figure 4.1). During pre-monsoon, the pH of drinking water samples from 2 locations, Bhikhi (8.80) and Sangreri (8.83), exceeded the maximum permissible limit, and during post monsoon sampling, 1 location in Mansa, Sangreri (9.66), and 1 location in Fazilka, Jalalabad (8.55), exceeded the maximum permissible limit (Figure 4.2).

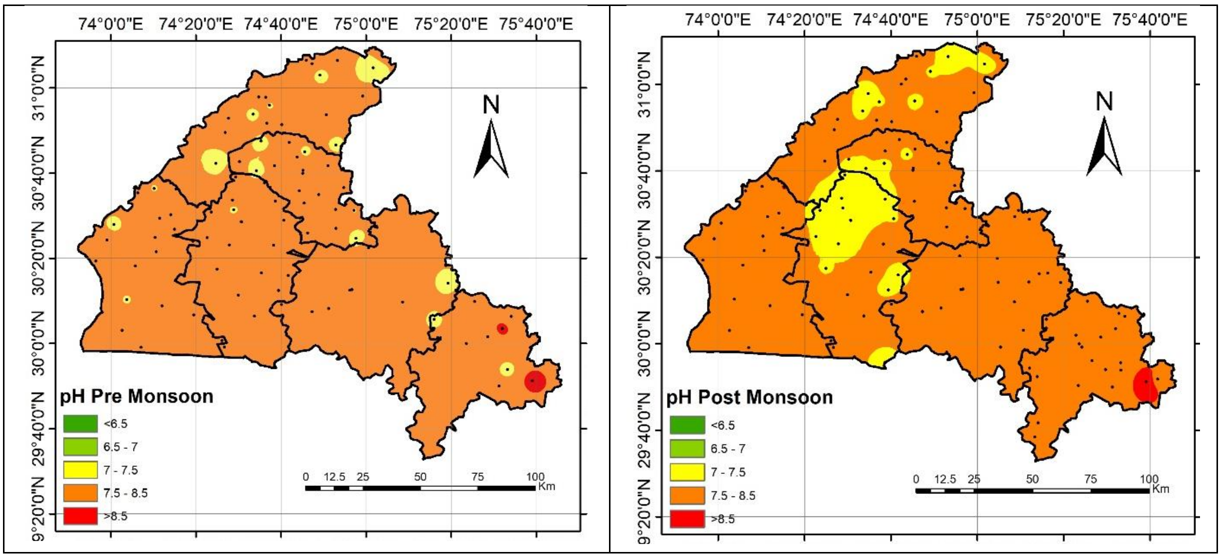
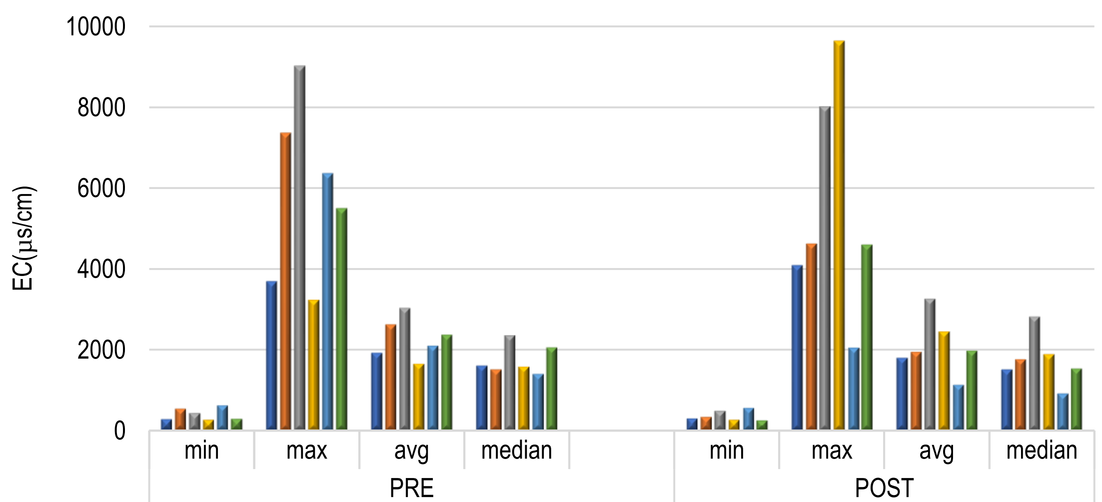


Fig. 4.2. Spatial variation of groundwater pH during pre & post monsoon



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	275	3680	1919	1599	290	4080	1790	1502
Mansa	539	7370	2627	1514	329	4630	1949	1767
Sri Muktsar Sahib	424	9020	3028	2350	479	8010	3255	2810
Fazilka	257	3230	1645	1572	258	9640	2444	1887
Firozepur	613	6360	2087	1390	550	2040	1125	910
Faridkot	286	5500	2370	2050	248	4600	1974	1526

Fig. 4.3. EC of pre & Post monsoon samples of SW Punjab.

The electrical conductivity for the pre monsoon and post monsoon sampling for the study area was in the range 257 µS/cm to 9020 µS/cm and 248 µS/cm to 9640 µS/cm respectively. The average conductivity was highest for Sri Muktsar Sahib in both pre- and post-monsoon samples, and lowest for Fazilka in Pre monsoon sampling and Ferozepur in post monsoon samples (Figure 4.3 & 4.4).

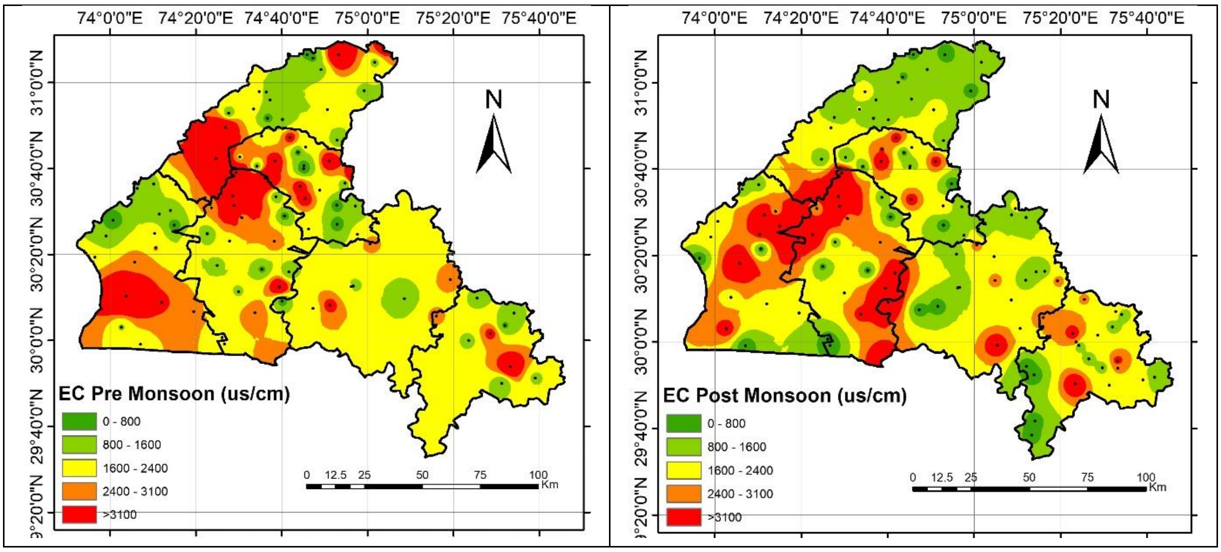


Fig. 4.4. Spatial variation of groundwater EC during pre & post-monsoon

4.1.2.2. Total Dissolved Solids

Total Dissolved Solids (TDS) in water includes all dissolved material in solution, whether ionized or not. TDS is numerical sum of all mineral constituents dissolved in water and is expressed in mg/l. TDS in drinking-water originates from weathering of minerals (natural sources), sewage, urban runoff and industrial wastewater. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals.

Total dissolved solids (TDS) in water includes all dissolved material in solution, whether ionized or not. TDS is numerical sum of all mineral constituents dissolved in water and is expressed in mg/l. TDS in drinking water is contributed from natural sources, sewage, urban runoff and industrial wastewater. Due to the difference in the solubility of minerals in different geological regions, the dissolved solids in water vary from one place to another. Based on TDS contents, water can be classified in to four categories as fresh, brackish, saline and brine water (Table 4.1).

Table 4.1 Classification of Water Based on Total Dissolved Solids

Sr. No.	TDS (mg/l)	Water Quality
1	0 – 1,000	Fresh Water
2	1,000 – 10,000	Brackish Water
3	10,000 – 100,000	Saline Water
4	>100,000	Brine

No health-based guideline value for TDS has been proposed due to unavailability of reliable data on possible health effects due to consumption of TDS in drinking water (WHO, 2011). However, drinking water is palatable up to 600 mg/l, and significantly unpalatable at TDS levels greater than 1000 mg/l. TDS associated with high concentrations of carbonates of Ca and Mg results in scale formation and bitter test, however, TDS associated with high concentration of chlorides and sulfates of cations, particularly Na & K, leads to salty/brackish taste and increased corrosivity. BIS (2012) have prescribed 500 mg/l as the acceptable limit and 2000 mg/l as permissible limit in absence of alternate source for drinking and other domestic usage.

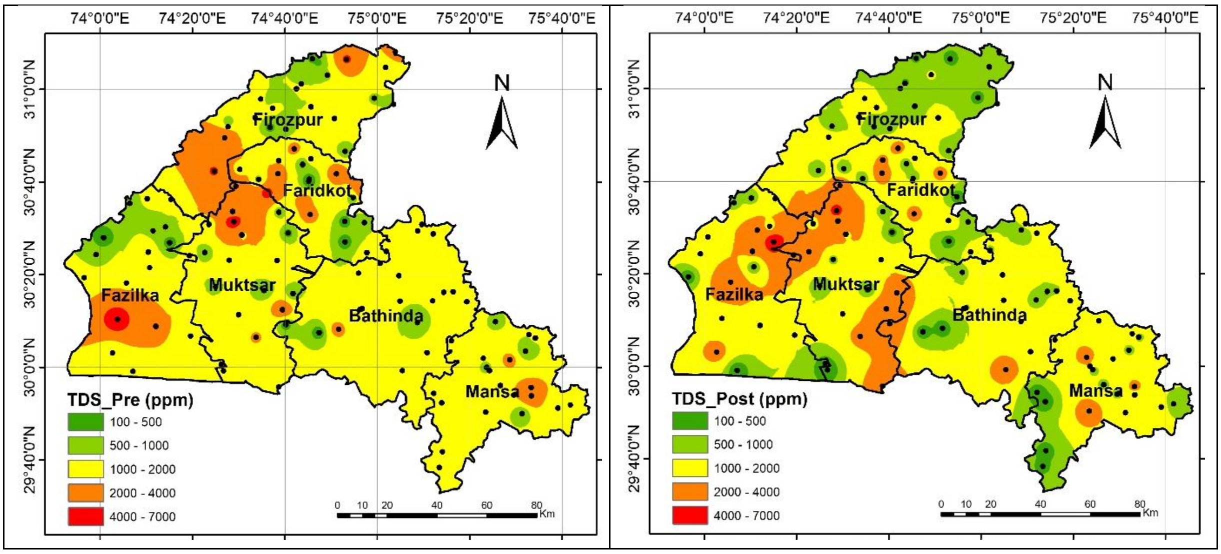


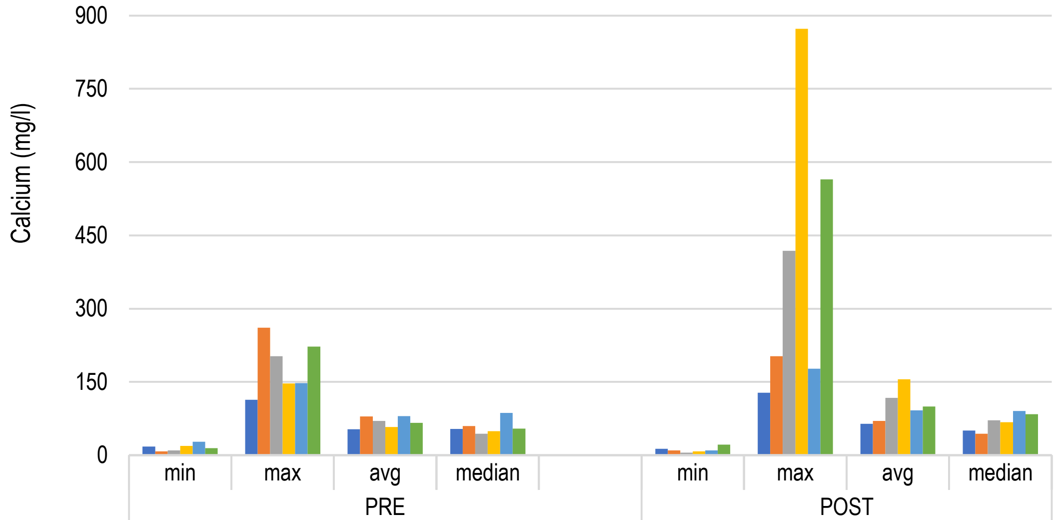
Fig. 4.5. Spatial variation in groundwater TDS during pre & post monsoon

In the pre monsoon samples, the average TDS value of drinking water in Sri Muktsar Sahib was highest and lowest for Bathinda. The TDS values of Sri Muktsar Sahib was observed to be higher during post monsoon period (Figure 4.5). The TDS concentration in the samples of the study area ranges from 174.2 mg/l (Sarwan, Faridkot) to 5863 mg/l (Saddarwala, Mukatsar, Mansa) and 148.2 mg/l (Tarmala, Mukatsar) to 6266 mg/l (Halimwala, Fazilka) in pre-monsoon and post-monsoon respectively. The average concentration of TDS in pre and post monsoon samples was observed to be 1466±119 mg/l and 1336±97 mg/l respectively. Around 81.63% samples exceeded the acceptable limit and 23.47% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 76.72% samples exceeded the acceptable limit and 23.28% samples exceeded the permissible limit.

4.1.3. Major Ions (Cations and Anions)

4.1.3.1. Calcium (Ca)

Drinking-water can be an important contributor of calcium and magnesium to those who are marginal for calcium and magnesium. Typical recommended dietary intake for Ca & Mg is 1000 mg/day and 200-400 mg/day respectively (WHO 2011), and a glass of milk (200 ml) can met ≈30% Ca and ≈15% Mg requirement (Brink et al. 1992, Gaucheron 2005). The recommended upper intake level for Ca is 2500 mg/day, and the individuals exposed to high concentration are protected by a tightly regulated intestinal absorption and elimination mechanism through the action of 1,25-dihydroxyvitamin D. The excess absorbed calcium is excreted by the kidney in healthy people who do not have renal impairment. Drinking water with both magnesium and sulfate, above 250 mg/l each, can have a laxative effect, although the effect recedes as exposure continues. The taste threshold for the calcium ion is in the range of 100 mg/l – 300 mg/l, however, some consumers can tolerate water hardness in excess of 500 mg/l. WHO has not established any guideline value considering the fact that the levels found in drinking water does not pose a health hazard to humans (WHO, 2011). BIS (2012) have prescribed 75 mg/l as the acceptable limit and 200 mg/l as permissible limit in absence of alternate source for drinking and other domestic usage.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	18.03	113.65	53.03	54.075	12.97	128.08	64.40	50.55
Mansa	7.59	261.10	79.51	59.392	9.73	202.69	70.50	43.96
Sri Muktsar Sahib	9.73	202.69	70.50	43.96	5.08	418.36	117.68	71.19
Fazilka	19.35	147.12	57.41	49.02	7.83	872.57	155.45	67.73
Firozepur	27.79	147.40	80.32	86.49	9.71	177.28	91.67	90.54
Faridkot	14.68	222.17	66.53	54.16	21.48	564.65	99.39	83.67

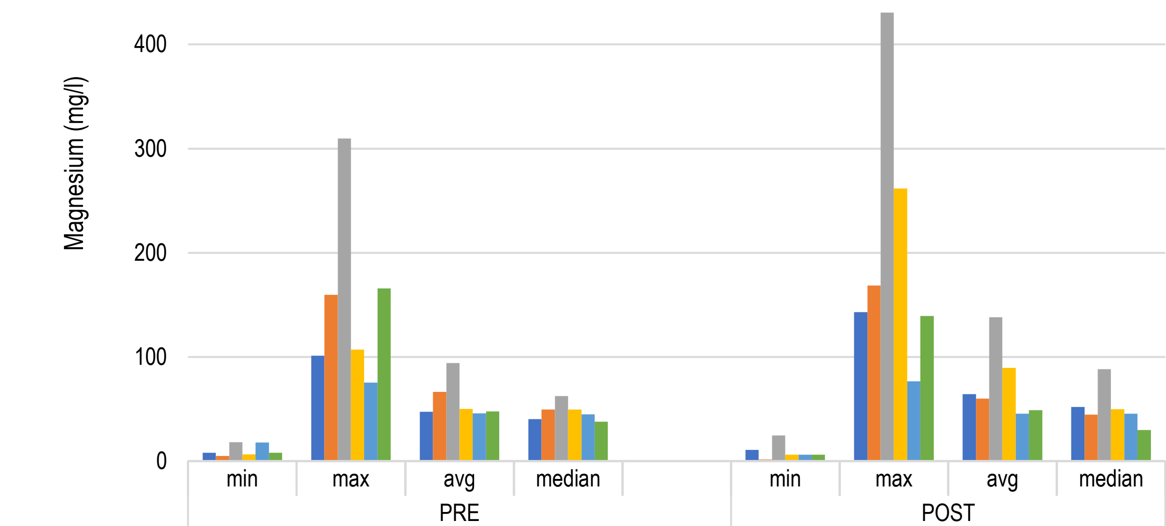
Fig. 4.6. Calcium in pre & post monsoon samples of SW Punjab.

Calcium ions and calcium salt are among the most commonly encountered substances in water. Calcium in water arises mostly from the dissolution of Ca bearing minerals of the aquifer formation and often it is the most abundant cation in water. Weathering and dissolution of calcium carbonate (limestone and dolomite) and calc-silicate minerals (amphiboles, pyroxenes, olivine, biotite etc.) are the most common source of calcium in aquatic system.

The Ca concentration in the samples of the study area ranges from 5 mg/l (Kotbhai, Muktsar) to 443.4 mg/l (Khui khera, Fazilka) and 7.8 mg/l (Jalalabad, Fazilka) to 872.6 mg/l (Dalmir khera, Fazilka) in pre-monsoon and post-monsoon respectively (Fig. 4.6). The average calcium concentration of Ca in pre and post monsoon samples was observed to be 79.3±7.87 mg/l and 106.7±12.06 mg/l respectively. Around 39.8% samples exceeded the acceptable limit and 6.1% samples exceeded the permissible limit in pre-monsoon, however, during pre-monsoon period around 42.8% samples exceeded the acceptable limit and 10.3% samples exceeded the permissible limit.

4.1.3.2. Magnesium (Mg)

Magnesium is abundant in earth crust and is a common constituent of natural water. Olivine, clay minerals, dolomite, pyroxenes are the common source minerals for magnesium in the waters. Natural sources contribute more magnesium to the environment than all anthropogenic sources. The principle source of magnesium in natural water is ferromagnesian mineral in igneous rock and magnesium carbonate in sedimentary rock. The sulphate and chloride of magnesium are very soluble.



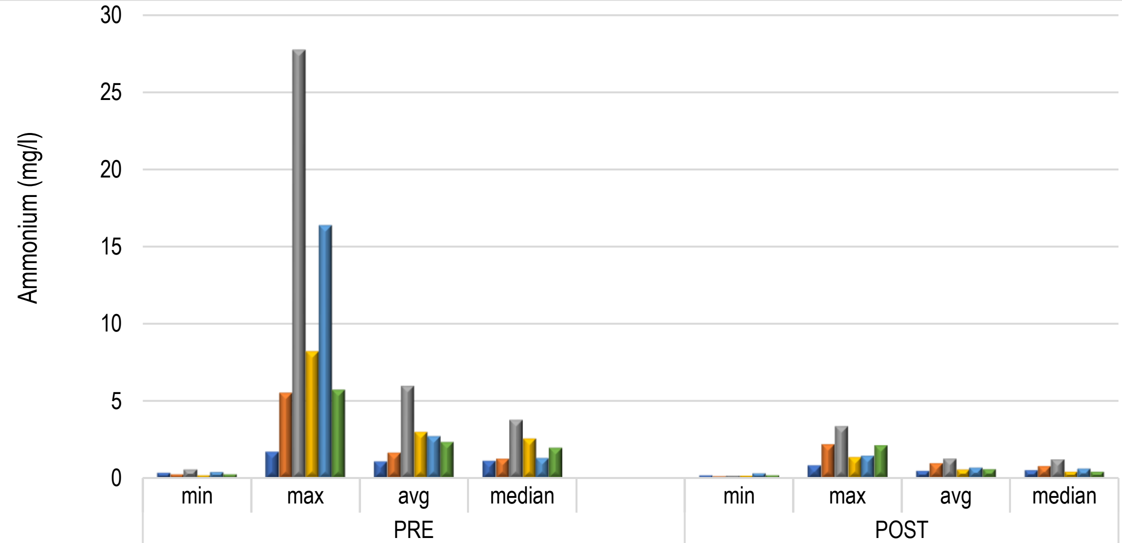
	PRE					POST			
	min	max	avg	median		min	max	avg	median
Bathinda	7.98	101.23	47.49	40.488		10.94	143.19	64.36	52.08
Mansa	5.02	159.54	66.58	49.473		1.55	168.50	60.13	44.51
Sri Muktsar Sahib	18.17	309.73	94.17	62.41		24.67	430.67	138.20	88.41
Fazilka	6.48	107.19	50.18	49.58		6.13	261.64	89.55	49.84
Firozepur	17.91	75.45	45.88	44.86		6.32	76.47	45.60	45.60
Faridkot	7.90	165.94	47.61	37.80		6.27	139.44	48.81	29.97

Fig. 4.7. Magnesium in pre & Post monsoon samples of SW Punjab

The Mg concentration in the samples of the study area ranges from 5 mg/l (Bhikhi, Mansa) to 309 mg/l (Dohak, Muktsar) and 1.6 mg/l (Sangreri, Mansa) to 466.7 mg/l (Waring khera, Muktsar) in pre-monsoon and post-monsoon respectively (Figure 4.7). The average concentration of Mg in pre and post monsoon samples was observed to be 59.73±5.56 mg/l and 73.97±7.27 mg/l respectively. Around 72.4% samples exceeded the acceptable limit and 11.22% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 62.70% samples exceeded the acceptable limit and 20.63% samples exceeded the permissible limit.

4.1.3.3. Ammonium (NH_4^+)

Ammonium (NH_4^+) is present in groundwater naturally as a result of anaerobic degradation of organic matter and artificially as a result of organic waste disposal. Anthropogenic NH_4^+ is one of the major dissolved components in aquifers contaminated by landfill leachate, septic systems and agricultural practices, and can cause degradation of groundwater quality and usability. It can have substantial effects on water-rock interactions, and it can be a substantial source of N in surface waters receiving groundwater discharge (Bohlke et al., 2006). Natural NH_4^+ levels in groundwater and surface water are usually below 0.2 mg/l. Higher concentration of ammonia is an indicator of possible bacterial, sewage, and animal waste pollution (WHO, 2012) and anoxic aquifer conditions resulting in cessation of NH_4^+ consuming reaction (nitrification and anammox). The guideline value (0.5 mg/l as NH_4-N) prescribed by BIS for ammonia is aesthetic based and not health-based, as the toxicological effects are about 200 mg/kg body weight. WHO has not prescribed any guideline value for ammonia. The threshold odor and taste concentration is approximately 1.5 mg/l and 35 mg/l respectively (WHO, 2017).



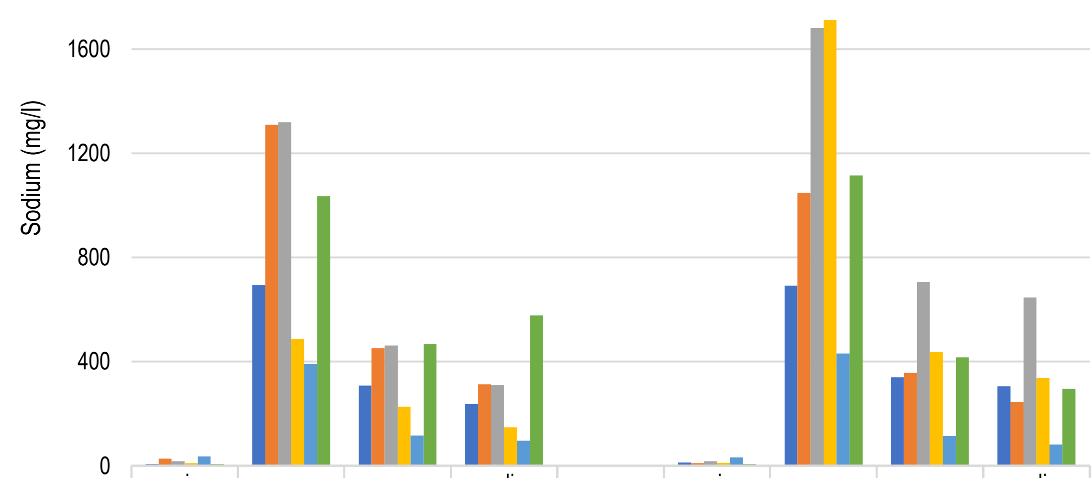
	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	0.35	1.71	1.09	1.127	0.20	0.84	0.49	0.53
Mansa	0.24	5.53	1.65	1.244	0.10	2.18	0.97	0.78
Sri Muktsar Sahib	0.55	27.73	5.97	3.78	0.16	3.37	1.25	1.20
Fazilka	0.18	8.21	2.99	2.57	0.14	1.35	0.54	0.39
Firozepur	0.37	16.35	2.70	1.28	0.31	1.44	0.67	0.61
Faridkot	0.23	5.71	2.33	1.96	0.18	2.11	0.57	0.39

Fig. 4.8. Ammonium in pre & post monsoon samples of SW Punjab

The NH_4^+ concentration in the samples of study area ranges from ND to 27.7 mg/l (Dohak, Muktsar) and 0.10 mg/l (Tandia, Mansa) to 5.6 mg/l (Waring khera, Muktsar) in pre-monsoon and post-monsoon respectively (Figure 4.8). The average concentration of NH_4^+ in pre and post monsoon samples was observed to be 3.11±0.48 mg/l and 0.81±0.09 mg/l respectively. Around 78.5% and 35.7% samples exceeded the permissible limit (0.5 mg/l) in pre-monsoon and post-monsoon period respectively. The ammonium concentrations were observed to reduce in the post-monsoon samples.

4.1.3.4. Sodium (Na) & Potassium (K)

The sodium in the aquatic system is derived from the atmospheric deposition, evaporate dissolution and silicate weathering. The evaporate encrustation's of sodium/potassium salts may also be developed due to cyclic wetting and drying periods causes the formation of alkaline/saline soils, which may also serve as a source of sodium and potassium. The weathering of Na and K silicate minerals like albite, anorthite, orthoclase and microcline are the major source of the Na and K in the aquatic system. Although potassium (K+) is nearly as abundant as sodium in igneous rocks and metamorphic rocks, its concentration in groundwater is one-tenth or even one-hundredth that of sodium. Parity in concentration of sodium and potassium is found only in waters with low mineral contents. Two factors are responsible for the scarcity of potassium in groundwater, one being the resistance of potassium minerals to decomposition by weathering and the other the fixation of potassium in clay minerals formed due to weathering.



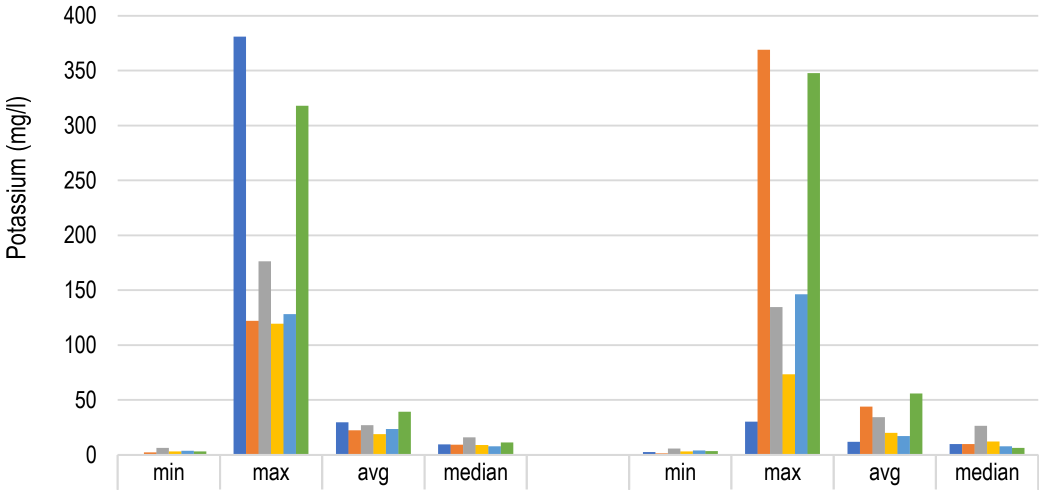
	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	6.44	694.50	308.27	237.323	12.54	692.21	340.14	306.12
Mansa	27.55	1309.69	452.50	313.216	10.38	1048.50	357.47	244.97
Sri Muktsar Sahib	18.11	1318.72	462.06	310.87	17.79	1681.32	706.04	646.46
Fazilka	10.29	487.04	226.50	147.86	11.66	1711.95	437.08	337.21
Firozepur	35.68	391.59	116.58	96.09	32.84	430.50	115.45	82.29
Faridkot	6.61	1034.46	468.06	577.27	6.68	1114.89	416.25	296.17

Fig. 4.9. Sodium in pre & post monsoon samples of SW Punjab

The Na concentration in the samples of study area ranges from 6.6 mg/l (Jaiti, Faridkot) to 1318.72 mg/l (Saddarwal, Muktsar) and 6.68 mg/l (Panjgrain kalan, Faridkot) to 1711.95 mg/l (Halimwala, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.9). The average concentration of Na in pre and post monsoon samples was observed to be 318.96±31.14 mg/l and 400.17±38.11 mg/l respectively.

The K concentration in the samples of study area ranges from ND to 380.79 mg/l (Ghudda, Bathinda) and 1.51 mg/l (Kalipur, Mansa) to 368.89 mg/l (Budhlada, Mansa) in pre-monsoon and post-monsoon respectively (Figure 4.10). The average concentration of K in pre and post monsoon samples was observed to be 31.8±6.34 mg/l and 28.04±5.29 mg/l respectively.

Na+K concentration in the samples of study area ranges from 10.3 mg/l to 1495 mg/l and 11.7 mg/l to 1815.9 mg/l in pre-monsoon and post-monsoon respectively.



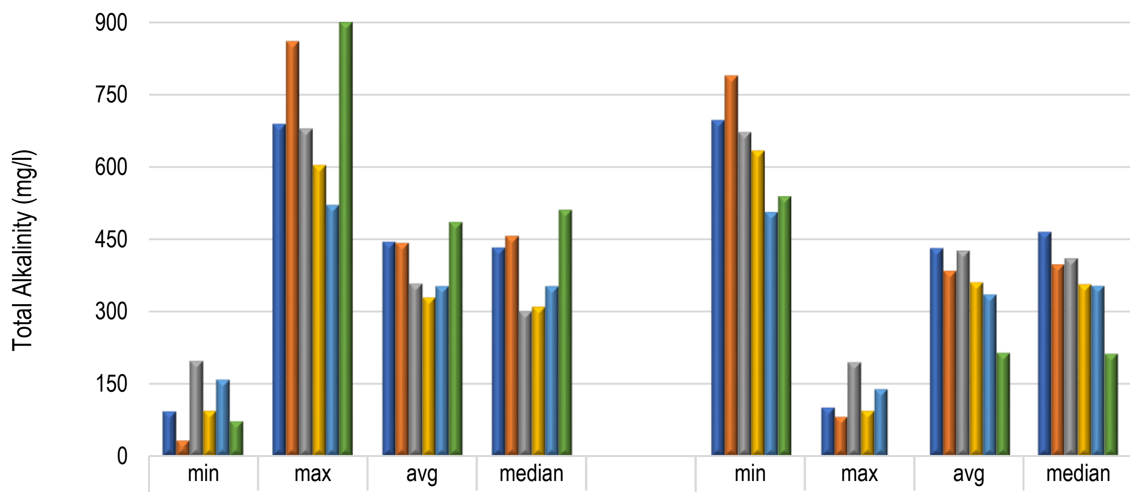
	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	0.62	380.79	29.60	9.605	2.63	30.43	12.07	9.86
Mansa	2.34	121.97	22.41	9.317	1.51	368.89	43.96	10.03
Sri Muktsar Sahib	6.38	176.19	27.20	16.14	5.69	134.54	34.29	26.55
Fazilka	3.33	119.38	18.87	9.03	3.23	73.31	20.15	12.37
Firozepur	3.89	128.29	23.57	7.91	3.98	146.32	17.23	7.89
Faridkot	3.09	318.07	39.38	11.23	3.61	347.76	56.00	6.34

Fig. 4.10. Potassium in pre & Post monsoon samples of SW Punjab

4.1.3.5. Alkalinity

Alkalinity is the buffering capacity of the water to neutralize acids and bases, and is dependent on the presence of certain chemicals in the water like bicarbonate, carbonate, and hydroxides. The alkalinity in the water comes mostly from the rocks and land of the catchment area of the water body. Water with alkalinity levels less than 150 mg/l is more likely to be corrosive, and alkalinity levels greater than 150 may contribute to scaling. The alkalinity of water affects the amount of chemicals required to accomplish effective coagulation and softening during treatment. Alkalinity in drinking water, due to naturally occurring materials such as carbonate and bicarbonate up to approximately 400 mg/l as calcium carbonate, is not a health hazard (USEPA 1976), therefore, WHO has not prescribed any guideline value for alkalinity. BIS (2012) has prescribed 200 mg/l as acceptable limit and 600 mg/l as permissible limit in absence of alternate source for drinking and other domestic usage.

The Alkalinity concentration in the samples of the study area ranges from 72 mg/l (Bargari, Faridkot) to 900 mg/l (Dhudi, Faridkot) and 80.6 mg/l (Kalipur, Mansa) to 778 mg/l (Mansa) in pre-monsoon and post-monsoon respectively (Figure 4.11). The average concentration of Alkalinity in pre and post monsoon samples was observed to be 390±17 mg/l and 372±15 mg/l respectively. Around 86.73% samples exceeded the acceptable limit and 12.24% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 83.93% samples exceeded the acceptable limit and 7.14% samples exceeded the permissible limit.



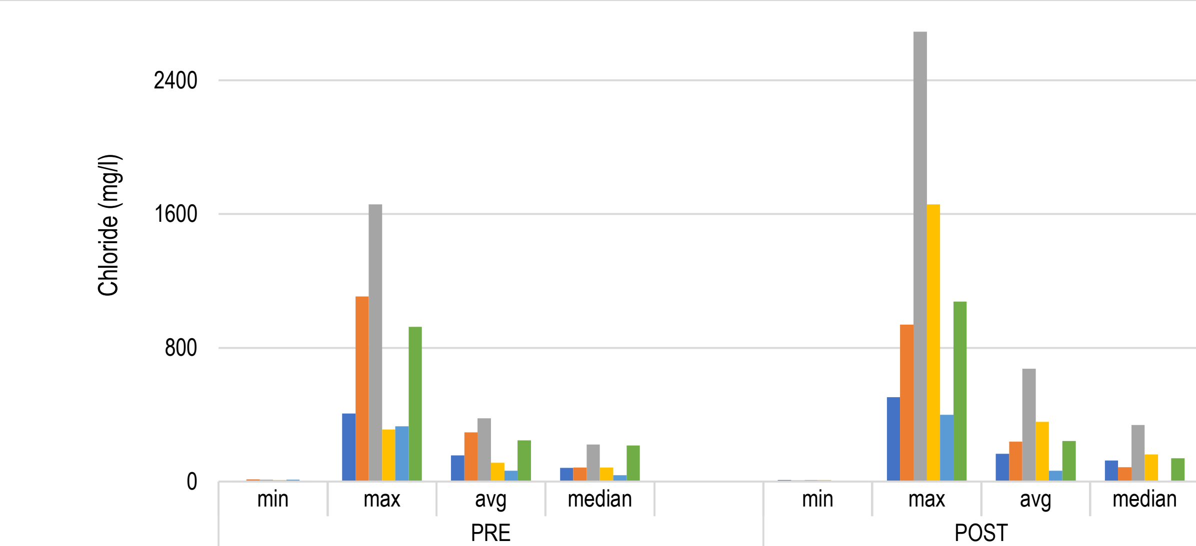
	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	92.00	688.00	444.00	432	696.00	100.00	431.00	464.60
Mansa	32.00	860.00	441.07	456	788.80	80.60	383.58	396.60
Sri Muktsar Sahib	197.00	678.00	357.56	300.20	670.80	194.40	425.81	409.80
Fazilka	93.80	603.00	329.34	310.20	632.80	93.40	360.26	356.10
Firozepur	158.00	520.00	351.98	352.00	506.00	138.00	334.18	352.60
Faridkot	72.00	900.00	487.29	512.60	540.00	0.00	215.52	213.80

Fig. 4.11. Alkalinity of pre & post monsoon samples of SW Punjab

4.1.3.6. Chloride

Chloride ions come into water either from geogenic or anthropogenic sources. The geogenic sources includes chloride bearing minerals like halite, potassium chloride, calcium chloride, limestone, sandstone, shale, etc. Anthropogenic sources of chloride are human sewage, livestock waste, synthetic fertilizer, etc. Chloride is a conservative anion in most aqueous environments and its movement is not retarded by the interaction of water with soils, sediments, and rocks. Further, it is not affected by the microbial action or redox chemistry in environment. Hence, it can be used as an indicator of other type of contamination. High concentration of chloride in water gives a salty taste. Concentration of chloride associated with calcium, sodium and potassium in excess of 250 mg/l is detected by taste, however, no side effects on human health has been observed at the levels found in drinking water, due to which WHO has not proposed any guideline value. Excessive chloride concentration in water makes it corrosive and is important from operational point of view. BIS (2012) has prescribed 250 mg/l as acceptable limit and 1000 mg/l as permissible limit in absence of alternate source for Cl in drinking and other domestic usage.

The Chloride concentration in the samples of the study area ranges from 4.8 mg/l (Jaito, Faridkot) to 1686 mg/l (Khui khera, Fazilka) and 4.5 mg/l (Madhre, Ferozepur) to 2616 mg/l (Waring khera, Mukatsar) in pre-monsoon and post-monsoon respectively (Figure 4.12). The average concentration of Chloride in pre and post monsoon samples was observed to be 204±31 mg/l and 289±41mg/l respectively. Around 24.43% samples exceeded the acceptable limit and 3.06% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 31.90% samples exceeded the acceptable limit and 7.76% samples exceeded the permissible limit.



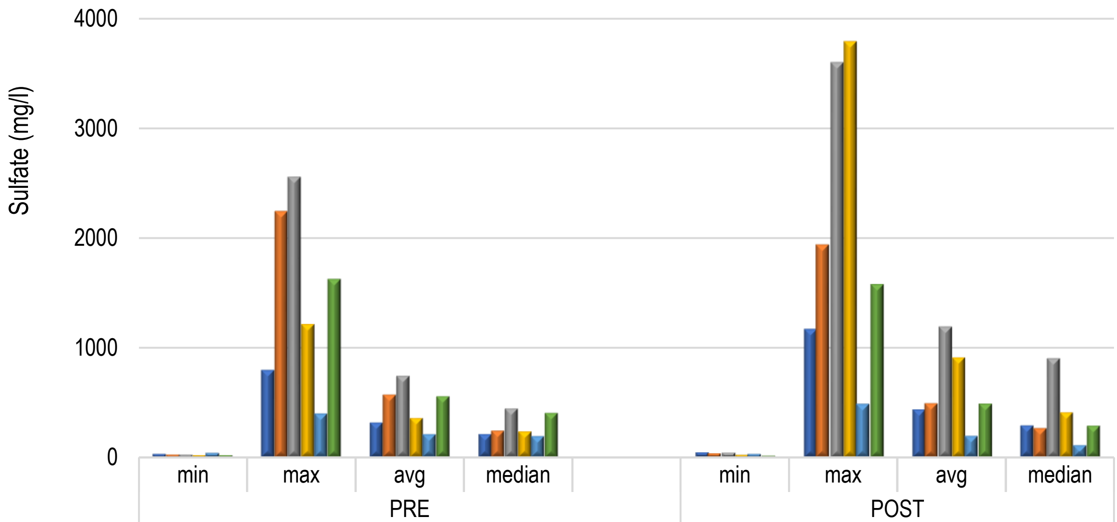
	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	4.50	407.12	155.44	81.108	8.61	504.56	166.66	125.03
Mansa	12.68	1106.58	293.79	83.798	6.10	938.82	238.05	85.92
Sri Muktsar Sahib	11.23	1658.30	377.74	221.32	9.69	2691.54	675.47	337.21
Fazilka	9.26	310.79	112.06	84.38	9.53	1658.13	356.32	161.52
Firozepur	10.40	330.86	64.30	36.77	4.50	399.36	64.36	
Faridkot	4.89	924.98	245.19	215.05	5.07	1077.14	242.80	138.53

Fig. 4.12. Chloride in pre & post monsoon samples of SW Punjab

4.1.3.7. Sulfate

Sulfates (SO_4^{-2}) occur naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). Other sources of sulfur in water includes decomposition of organic, plant and animal, matter. Sulfate in drinking-water can cause taste impairment depending on associated cation, ranging from 250 mg/l for sodium sulfate to 1000 mg/l for calcium sulfate. Very high levels of sulfate may cause a laxative effect in unaccustomed consumers, and therefore, the health authorities should be notified of sources of drinking water that contain sulfate concentrations in excess of 500 mg/l (WHO, 2011). Adults generally adapt to high sulfate concentrations within 1 or 2 weeks, however, infants may be more sensitive (USEPA 2003). The concentration of sulfate found in natural waters is generally not at levels to cause adverse health effects and the existing data do not identify a level of sulfate that is likely to impact the human health, due to which WHO has not proposed any health based guideline (WHO 2017). BIS (2012) has prescribed 200 mg/l as acceptable limit and 400 mg/l as permissible limit in absence of alternate source for SO_4 in drinking and other domestic usage.

The Sulfate concentration in the samples of the study area ranges from 18.7 mg/l (Pipli, Faridkot) to 2557 mg/l (Saddarwala, Mukatsar) and 14.0 mg/l (Faridkot) to 3796 mg/l (Halimwala, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.13). The average concentration of Sulfate in pre and post monsoon samples was observed to be 463±50 mg/l and 623±73 mg/l respectively. Around 60.20% samples exceeded the acceptable limit and 34.69% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 60.07% samples exceeded the acceptable limit and 41.38% samples exceeded the permissible limit.

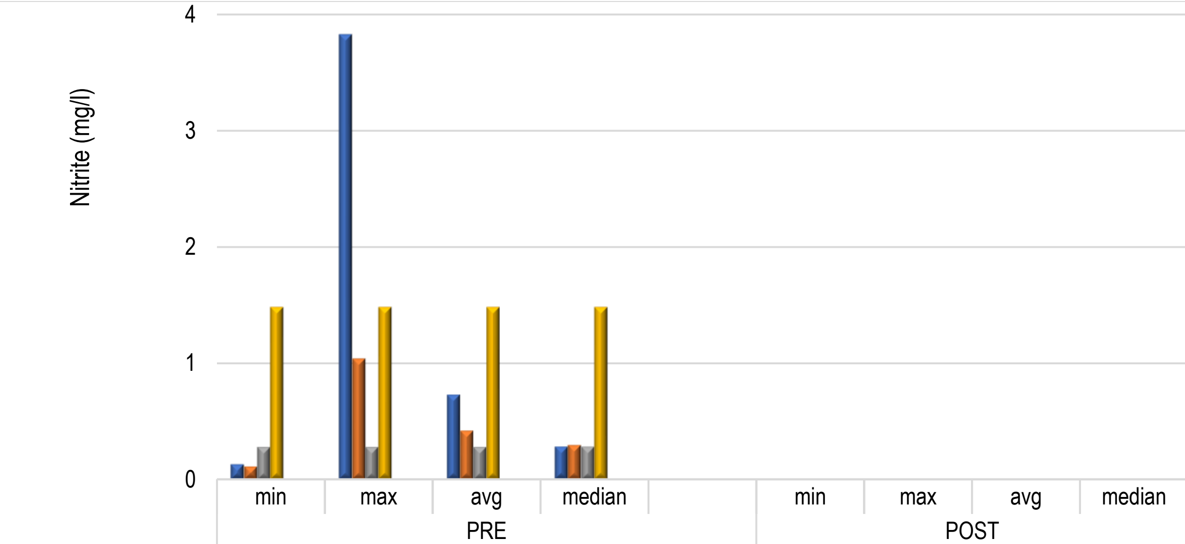


	PRE min	PRE max	PRE avg	PRE median		POST min	POST max	POST avg	POST median
Bathinda	31.54	796.27	316.55	212.073		46.07	1169.31	435.66	292.23
Mansa	26.17	2241.48	573.28	245.289		38.69	1938.26	494.76	268.32
Sri Muktsar Sahib	26.73	2557.47	743.63	444.52		42.15	3599.39	1192.14	904.50
Fazilka	20.56	1222.81	360.04	238.08		22.79	3796.06	917.48	412.04
Firozepur	39.86	396.53	208.87	191.02		32.19	481.96	194.70	109.19
Faridkot	18.72	1623.10	556.34	404.60		13.97	1578.26	488.04	288.47

Fig. 4.13. Sulfate in pre & post monsoon samples of SW Punjab

4.1.3.8. Nitrite

Nitrite contains nitrogen in the unstable state, which either gets oxidized to nitrate or reduced to nitrogen by chemical or microbial actions. The Nitrite concentration in the samples of the study area ranges from ND to 3.83 mg/l (Ghudda, Bathinda) and ND in pre-monsoon and post-monsoon respectively (Figure 4.14). The average concentration of Nitrite in pre and post monsoon samples was observed to be 0.16±.07 mg/l and ND respectively. Nitrite was observed in the groundwater samples from Bathinda, Mansa, Shri Muktsar Sahib, and Fazilka indicating anoxic conditions and was absent in the samples from Ferozepur and Faridkot.



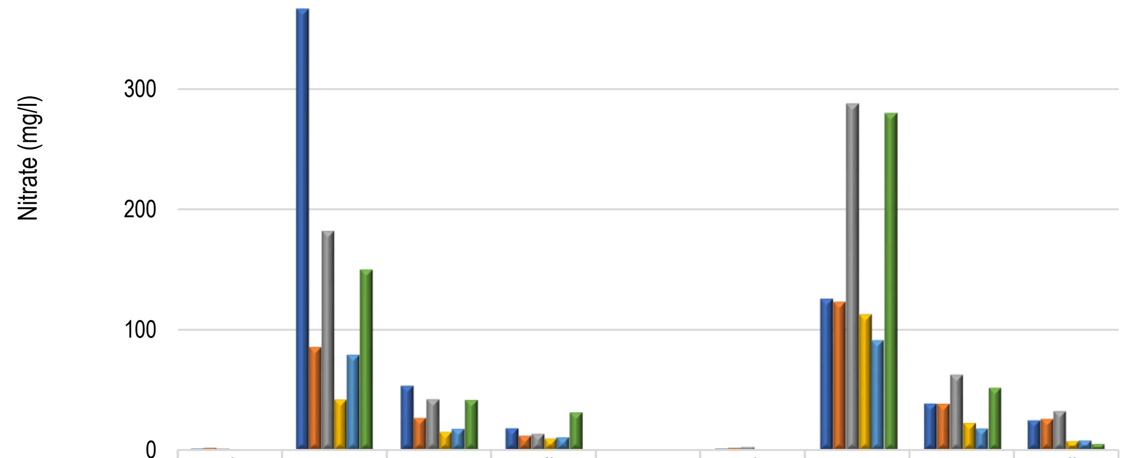
	PRE min	PRE max	PRE avg	PRE median		POST min	POST max	POST avg	POST median
Bathinda	0.13	3.83	0.73	0.283		0.00	0.00	0.00	0.00
Mansa	0.11	1.04	0.42	0.296		0.00	0.00	0.00	0.00
Sri Muktsar Sahib	0.28	0.28	0.28	0.28		0.00	0.00	0.00	0.00
Fazilka	1.48	1.48	1.48	1.48		0.00	0.00	0.00	0.00
Firozepur	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
Faridkot	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00

Fig. 4.14. Nitrite in pre & post monsoon samples of SW Punjab

4.1.3.9. Nitrate

Nitrate (NO_3^-) concentration in both surface water and groundwater is due to agricultural activities, natural vegetation, wastewater, and human and animal excreta waste. Nitrate concentration in drinking water is a potential health hazard, when present in large quantities. Nitrites are formed by reduction of nitrate in the human body, which combines with hemoglobin in the blood to form methemoglobin that leads to methaemoglobinaemia (blue baby syndrome) in infants. The combination of nitrates with amines, amides, or other nitrogenous compounds through the action of bacteria in the digestive tract results in the formation of nitrosamines, which are potentially carcinogenic. The guideline values prescribed by WHO (2017) for nitrate in drinking water is 50 mg/l as NO_3 considering the fact that no adverse health effects have been observed below this concentration in epidemiological studies. BIS (2012) has prescribed 45 mg/l (as NO_3) as the maximum permissible limit.

Nitrate is the stable form of nitrogen and its concentration in the samples of study area ranges from 0.17 mg/l (Ruknewala, Ferozepur) to 366.66 mg/l (Jai singh wala, Bathinda) and 0.09 mg/l (Faridkot) to 279.65 mg/l (Mehmuana, Faridkot) in pre-monsoon and post-monsoon respectively (Figure 4.15). The average concentration of Nitrate in pre and post monsoon samples was observed to be 37±6 mg/l and 37±5 mg/l respectively. Around 23% and 28% samples exceeded the permissible limit (45 mg/l) in pre-monsoon and post-monsoon period respectively.



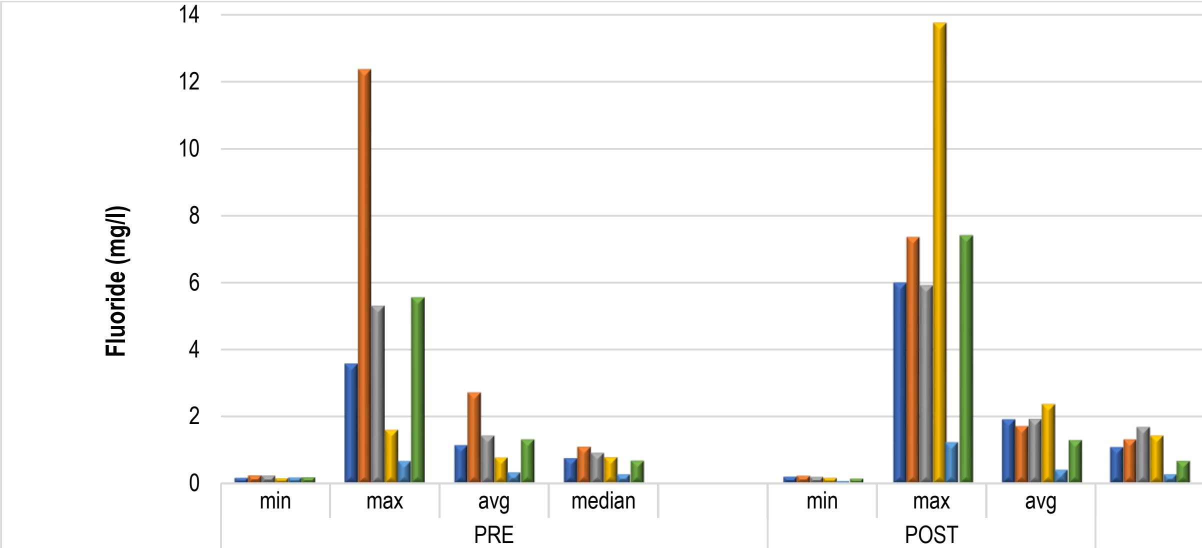
	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	1.01	366.66	53.74	18.062	1.09	126.59	38.89	24.84
Mansa	1.72	85.68	26.60	11.845	1.56	122.92	38.32	25.81
Sri Muktsar Sahib	1.00	181.99	41.99	13.28	2.37	287.66	62.34	32.08
Fazilka	0.33	41.64	14.93	9.37	0.39	112.41	22.32	7.12
Firozepur	0.17	79.30	17.62	10.32	0.17	91.16	17.93	7.75
Faridkot	0.21	149.79	41.53	31.01	0.09	279.66	51.51	4.80

Fig. 4.15. Nitrate in pre & post monsoon samples of SW Punjab

4.1.3.10. Fluoride

The average abundance of fluoride in earth's crust is 300 mg/kg, and is found at significant levels in a wide variety of minerals, including fluorspar, rock phosphate, cryolite, apatite, mica, hornblende and others. It is found in all-natural waters at some concentration; in seawater, it is about 1 mg/l; in rivers and lakes, it is less than 0.5 mg/l; and in groundwater, its concentration varies depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. Fluoride concentration in water is limited by fluorite solubility, means, the presence of 40 mg/l calcium will limit fluoride concentration to 3.1 mg/l (Hem 1989). Therefore, high fluoride concentrations are expected in groundwater from calcium poor aquifers and in areas where fluoride-bearing minerals are common (Nanyaro et al. 1984, Gaciri and Davis 1993; Kundu et al., 2001). The highest natural level reported is 2800 mg/l (WHO 2004).

Fluoride in drinking water has a narrow range between intakes that cause beneficial (0.5-1.0 mg/l) and detrimental health effects (>1.0 mg/l), primarily dental and skeletal fluorosis. WHO (2011) and BIS (2012) have prescribed the maximum allowable limit for fluoride uptake to human's in drinking water as 1.5 mg/l. However, the national standard should be based on the average water intake and intake from other sources.



	PRE				POST			
	min	max	avg	median	min	max	avg	
Bathinda	0.16	3.59	1.15	0.751	0.20	5.99	1.92	1.09
Mansa	0.24	12.37	2.73	1.096	0.23	7.37	1.72	1.32
Sri Muktsar Sahib	0.23	5.30	1.42	0.91	0.19	5.91	1.92	1.68
Fazilka	0.15	1.61	0.77	0.78	0.17	13.77	2.38	1.44
Firozepur	0.17	0.66	0.32	0.26	0.06	1.21	0.40	0.26
Faridkot	0.18	5.56	1.31	0.67	0.14	7.41	1.29	0.67

Fig. 4.16. Fluoride in pre & post monsoon samples of SW Punjab

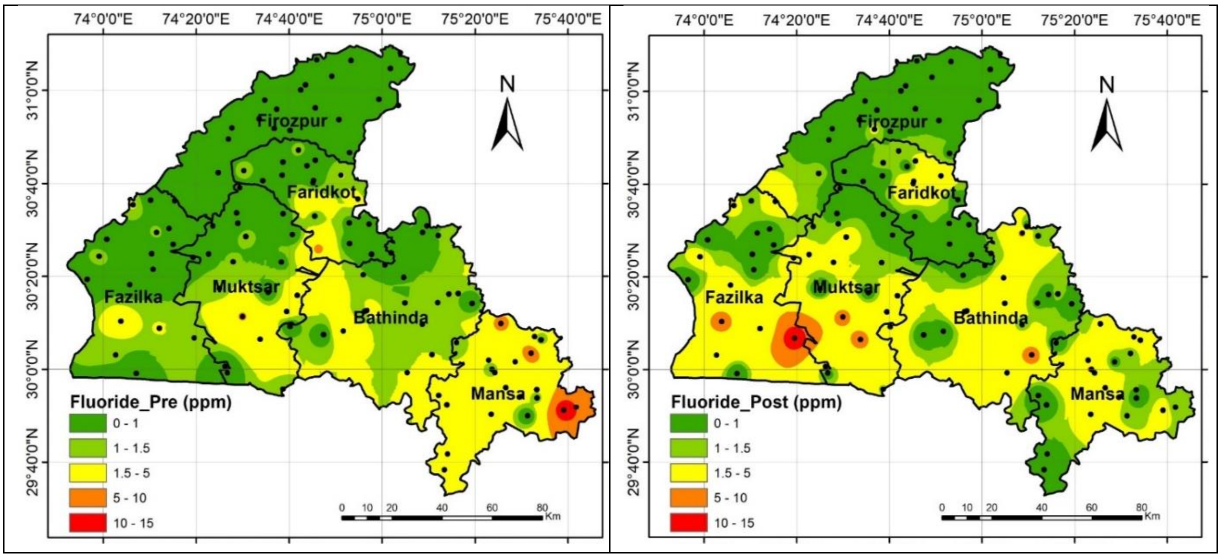


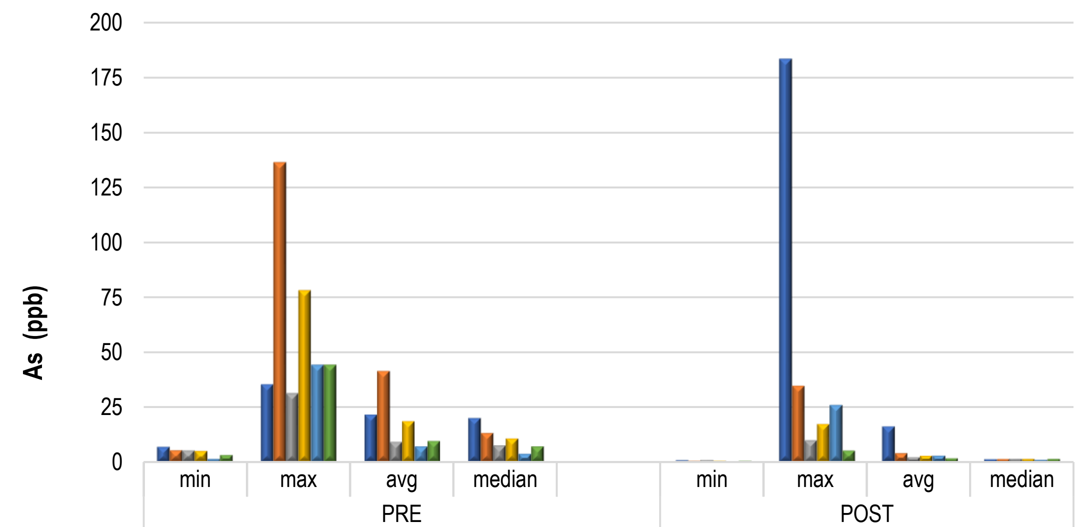
Fig. 4.17. Spatial variation of fluoride in groundwater during pre & post monsoon

The Fluoride concentration in the samples of the study area ranges from ND to 12.36 mg/l (Sangreri, Mansa) and ND to 13.76 mg/l (Dhaban kokrian, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.16). The average concentration of Fluoride in pre and post monsoon samples was observed to be 1.17±0.1 mg/l and 1.5±0.1 mg/l respectively. Around 35.05% samples exceeded the acceptable limit and 19.59% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 44.74% samples exceeded the acceptable limit and 34.21% samples exceeded the permissible limit (Figure 4.17).

4.1.4. Trace Metals/Metalloids

4.1.4.1. Arsenic

Arsenic (As), a group XV metalloid, is usually present in natural wa-ters at concentrations of less than 1–2 µg/l. However, in groundwa-ters, the concentrations can be significantly elevated depending on the aquifer geology. Arsenic can exist in four valences –3, 0, +3, and +5, out of which arsenite (As^{+3}) is dominant in reducing conditions and arsenate (As^{+5}) is dominant in oxic environment. The acute toxicity of arsenic compounds in humans is predominantly a function of their rate of removal from the body. Arsine is considered to be the most toxic form, followed by the arsenites, the arsenates and organic arsenic compounds. Signs of chronic arsenicism, including dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular disease, have been observed in populations ingesting arsenic-contaminated drinking-water. WHO (2017) has recommended 0.010 mg/l as the provisional guideline value for drinking water. The Bureau of Indian Standards has recommended 0.010 mg/l as the as desirable limit and 0.050 mg/l as the permissible limit for drinking water (BIS, 2012).



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	6.89	35.45	21.50	19.94	0.67	183.58	16.21	1.18
Mansa	5.24	136.45	41.42	13.06	0.37	34.65	3.97	1.29
Sri Mukatsar Sahib	5.15	31.09	9.01	7.43	0.71	9.77	2.06	1.37
Fazilka	4.94	78.04	18.51	10.59	0.45	17.20	2.81	1.33
Firozepur	1.34	43.93	6.91	3.65	0.18	25.71	2.72	0.84
Faridkot	3.08	43.93	9.48	6.91	0.40	5.13	1.52	1.27

Fig. 4.18. Arsenic in pre & post monsoon samples of SW Punjab

The As concentration in the samples of the study area ranges from 0.001 mg/l (Aku maste ke, Ferozepur) to 0.13 mg/l (Sangreri, Mansa) and 0.0001 mg/l (Naraingarh, Ferozepur) to 0.18 mg/l (Goniana Khurad, Bathinda) in pre-monsoon and post-monsoon respectively (Figure 4.18). The average concentration of As in pre and post monsoon samples was observed to be 0.01±0.002 mg/l and 0.004±0.001 mg/l respectively. Around 36.73% samples exceeded the acceptable limit and 6.35% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 4.08% samples exceeded the acceptable limit and 1.59% samples exceeded the permissible limit (Figure 4.19).

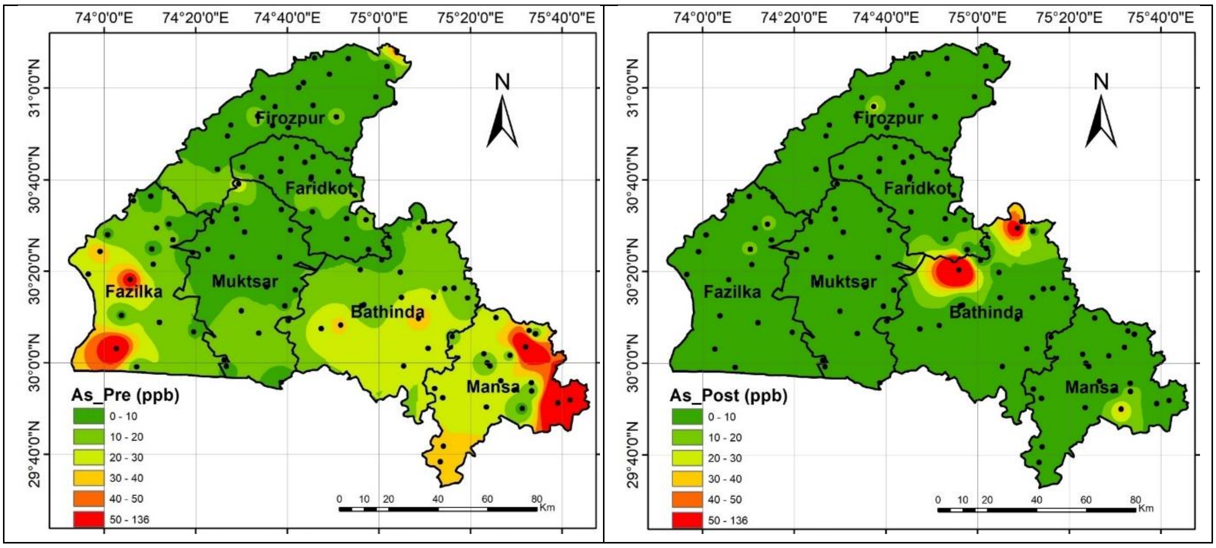
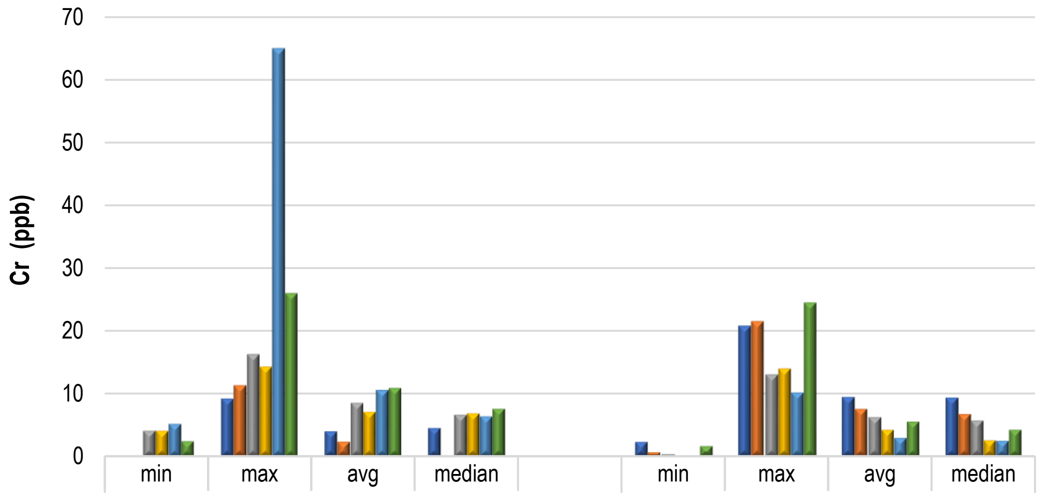


Fig. 4.19. Spatial variation of Arsenic in groundwater during pre & post monsoon

4.1.4.2. Chromium (Cr)

Cr is widely distributed in Earth's crust. It can exist in valences of +2 to +6. Cr (III) is an essential human dietary element and is found in many vegetables, fruits, meats, grains, and yeast. Cr enters the environment by industrial processes discharge. Further, Cr enters the environment by leakage, poor storage, or inadequate industrial waste disposal practices. IARC has classified chromium (VI) in Group 1 (human carcinogen) and chromium (III) in Group 3 (not classifiable as to its carcinogenicity to humans). Chromium (VI) compounds are active in a wide range of in vitro and in vivo genotoxicity tests, whereas chromium (III) compounds are not. The Bureau of Indian Standards has recommended 0.05 mg/l as the permissible limit for drinking water (BIS, 2012).

The Cr concentration in the samples of study area ranges from ND to 0.06 mg/l (Naraingarh, Ferozepur) and ND to 0.02 mg/l (Dhudi, Faridkot) in pre-monsoon and post-monsoon respectively (Figure 4.20). The average concentration of Cr in pre and post monsoon samples was observed to be 0.008±0.0007 mg/l and 0.005±0.0004 mg/l respectively. Around 1.02% and 0% samples exceeded the permissible limit (0.05 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.21).



	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	0.00	9.18	4.00	4.51	2.30	20.75	9.43	9.35
Mansa	0.00	11.33	2.33	0.00	0.67	21.53	7.58	6.74
Sri Mukatsar Sahib	4.11	16.27	8.52	6.66	0.36	13.06	6.22	5.70
Fazilka	4.10	14.28	7.08	6.84	0.01	14.00	4.26	2.56
Firozepur	5.22	64.99	10.65	6.45	0.00	10.28	2.98	2.52
Faridkot	2.38	25.94	10.87	7.58	1.66	24.43	5.50	4.24

Fig. 4.20. Chromium in pre & post monsoon samples of SW Punjab

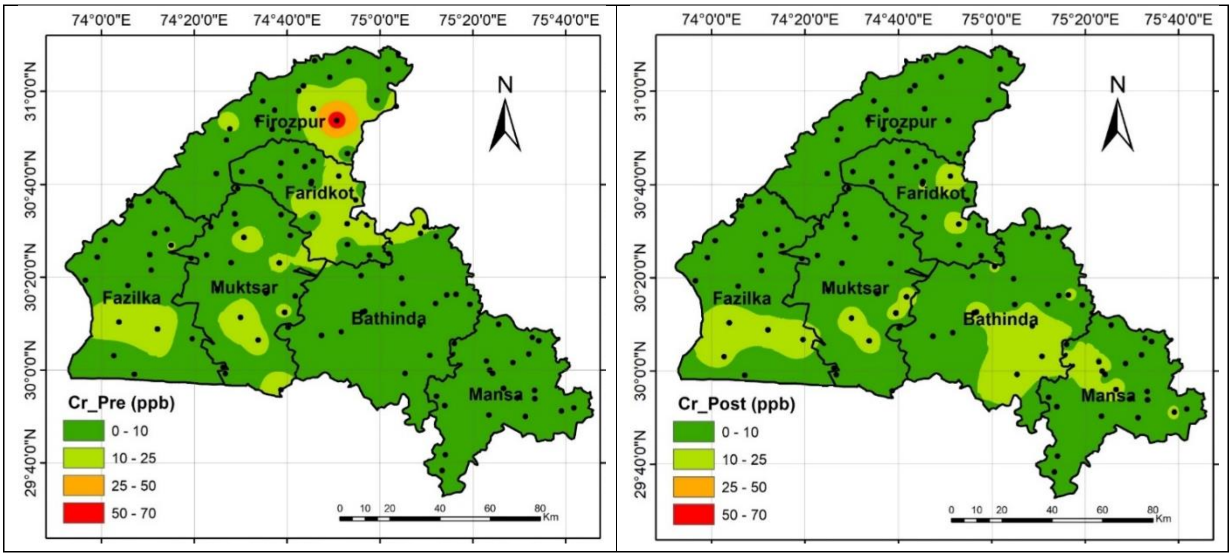
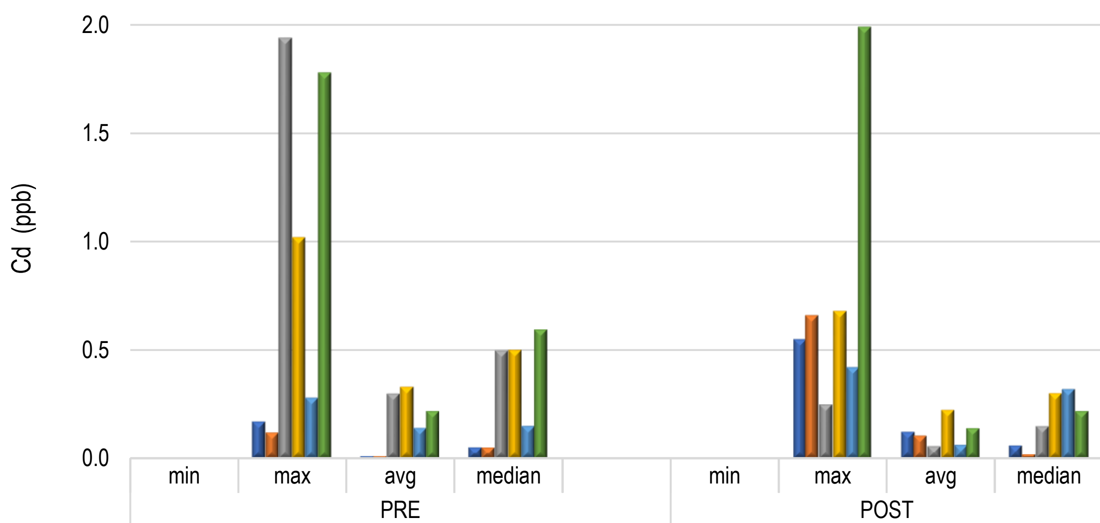


Fig. 4.21. Spatial variation of chromium in groundwater during pre & post monsoon

4.1.4.3. Cadmium (Cd)

Cadmium (Cd), a group XII element, and its compounds are widely used in batteries, pigments, electronic components, and nuclear reactors. It is released to the environment through wastewater, leaching of solid waste, and diffuse pollution from fertilizers and local air pollution. Cadmium concentration in natural waters is usually below 1 µg/l and can go up to

100 µg/l. Cadmium accumulates primarily in the kidneys, has a long biological half-life in humans of 10–35 years, and adversely affects the kidney. The absorption of cadmium compounds is dependent on the solubility of the compounds. The epidemiological studies had established the Cd induced carcinogenicity by the inhalation route, and IARC has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans), however, evidence of carcinogenicity by the oral route is lacking (WHO 2011d, Health Canada 2019, Idrees et al. 2018). WHO (2017) and BIS (2012) has prescribed a guideline value of 0.003 mg/l for Cd in drinking water.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	0.00	0.17	0.01	0.05	0.00	0.55	0.12	0.06
Mansa	0.00	0.12	0.01	0.05	0.00	0.66	0.11	0.02
Sri Mukatsar Sahib	0.00	1.94	0.30	0.50	0.00	0.25	0.06	0.15
Fazilka	0.00	1.02	0.33	0.50	0.00	0.68	0.22	0.30
Firozepur	0.00	0.28	0.14	0.15	0.00	0.42	0.06	0.32
Faridkot	0.00	1.78	0.22	0.60	0.00	1.99	0.14	0.22

Fig. 4.22. Cadmium in pre & post monsoon samples of SW Punjab

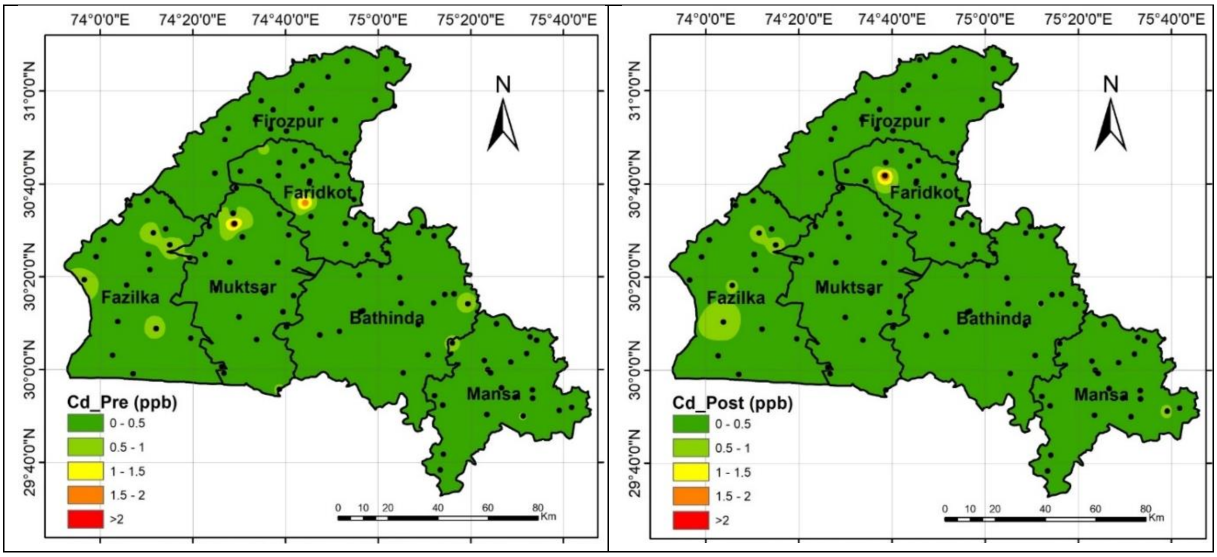
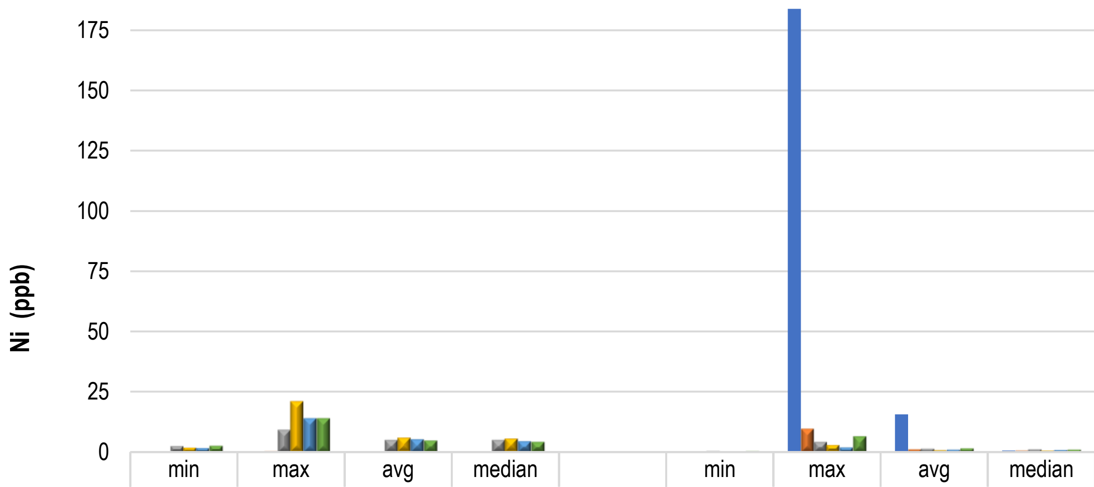


Fig. 4.23. Spatial variation of Cd in groundwater during pre & post monsoon

The Cd concentration in the samples of the study area ranges from ND to 1.94 ug/l (Saddarwala, Mukatsar) and ND to 1.99 ug/l (Mehmuana, Faridkot) in pre-monsoon and post-monsoon respectively (Figure 4.22). The average concentration of Cd in pre and post monsoon samples was observed to be 0.25±0.03 ug/l and 0.11±0.02 ug/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.23).

4.1.4.4. Nickel (Ni)

Nickel (Ni), a group X element, is an essential metal for several animal species, micro-organisms and plants, and toxicity symptoms can occur when too little or too much nickel is taken up. The average abundance of nickel in the earth's crust is 1.2 mg/l, in soils it is 2.5 mg/l, in streams it is 1 µg/l and in groundwater it is <0.1 mg/l. Nickel is obtained chiefly from pyrrhotite and garnierite. Nickel is released to the environment from the burning of fossil fuels and waste discharge from electroplating industries. In general concentration of nickel in water resources is generally below 0.02 mg/l. IARC has included inhaled nickel compounds in Group 1 (carcinogenic to humans) and metallic nickel in Group B (possibly carcinogenic), however, there is a lack of evidence of a carcinogenic risk from oral exposure to nickel. The guideline value for nickel prescribed by WHO (2017) and BIS (2012) is 0.07 mg/l and 0.02 mg/l respectively.



	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	0.00	0.03	0.00	0.00	0.23	183.85	15.62	0.56
Mansa	0.00	0.29	0.04	0.00	0.08	9.46	1.16	0.56
Sri Mukatsar Sahib	2.46	9.14	5.05	5.05	0.44	4.16	1.42	1.17
Fazilka	1.67	20.80	5.82	5.44	0.12	2.75	0.64	0.44
Firozepur	1.64	13.77	5.22	4.50	0.07	1.95	0.96	0.92
Faridkot	2.65	13.77	4.72	4.20	0.45	6.49	1.57	1.08

Fig. 4.24. Nickel in pre & post monsoon samples of SW Punjab

The Ni concentration in the samples of study area ranges from ND to 0.02 mg/l (Fazilka) and ND to 0.18 mg/l (Goniana Khurad, Bathinda,) in pre-monsoon and post-monsoon respectively (Figure 4.24). The average concentration of Ni in pre and post monsoon samples was observed to be 0.004±0.003 mg/l and 0.003±0.01 mg/l respectively. Around 1.02% and 2.38% samples exceeded the permissible limit (0.02 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.25).

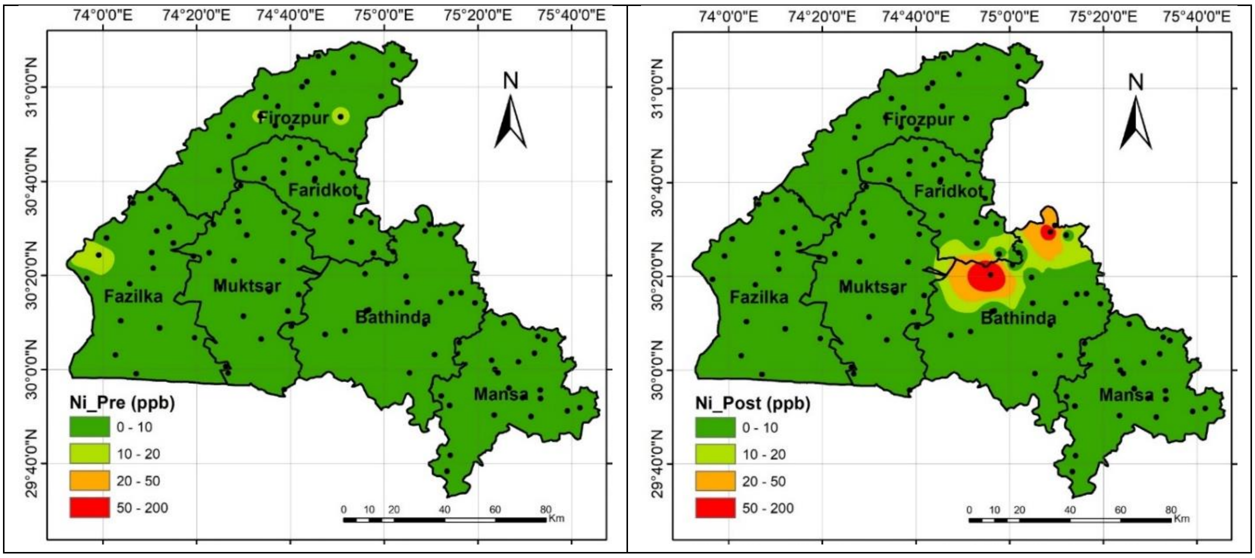


Fig. 4.25. Spatial variation of Ni in groundwater during pre & post monsoon

4.1.4.5. Copper (Cu)

Copper (Cu) is an essential nutrient as well as a drinking water contaminant. It is used to make pipes, valves and fittings, and is present in alloys and coatings. Copper concentration above 1 mg/l results in staining of laundry and sanitary ware, and beyond 5 mg/l, copper imparts astringent taste and cause discoloration. The epidemiological studies have not been able to establish the relationship between ingestion of copper in drinking water on the gastrointestinal tract, carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis (NRC 2000). US EPA (1991) classifies copper as Group D, not classifiable as to human carcinogenicity. The guideline value of 2 mg/l prescribed by WHO (2017) is to protect against gastric irritation. BIS (2012) has recommended 0.05 mg/l as the as desirable limit and 1.5 mg/l as the permissible limit for Cu in drinking water.

The Cu concentration in the samples of the study area ranges from ND to 0.05 mg/l (Khachran, Faridkot) and ND to 1.07 mg/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of Cu in pre and post monsoon samples was observed to be 0.004±0.0006 mg/l and 0.01±0.008 mg/l respectively (Figure 4.26). Around 1.02% samples exceeded the acceptable limit and 0% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 2.38% samples exceeded the acceptable limit and 0% samples exceeded the permissible limit (Figure 4.27).

	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	0.00	10.31	3.81	2.92	0.00	12.17	1.02	0.00
Mansa	0.00	6.36	1.55	0.66	0.00	1079.95	66.05	0.00
Sri Mukatsar Sahib	0.23	17.68	4.55	3.56	0.00	8.71	1.09	0.00
Fazilka	0.00	22.54	5.49	3.96	0.00	0.00	0.00	0.00
Firozepur	0.00	8.59	1.73	0.86	0.00	50.73	2.74	0.00
Faridkot	0.26	57.13	6.93	1.95	0.00	56.64	3.86	0.63

Fig. 4.26. Copper concentration in pre & post monsoon samples of SW Punjab

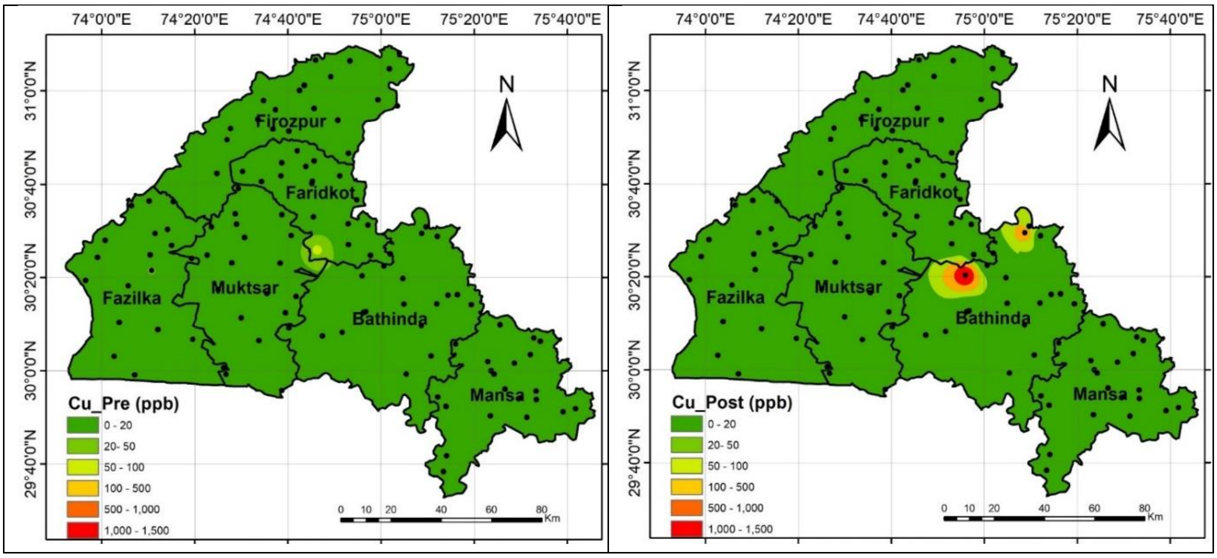
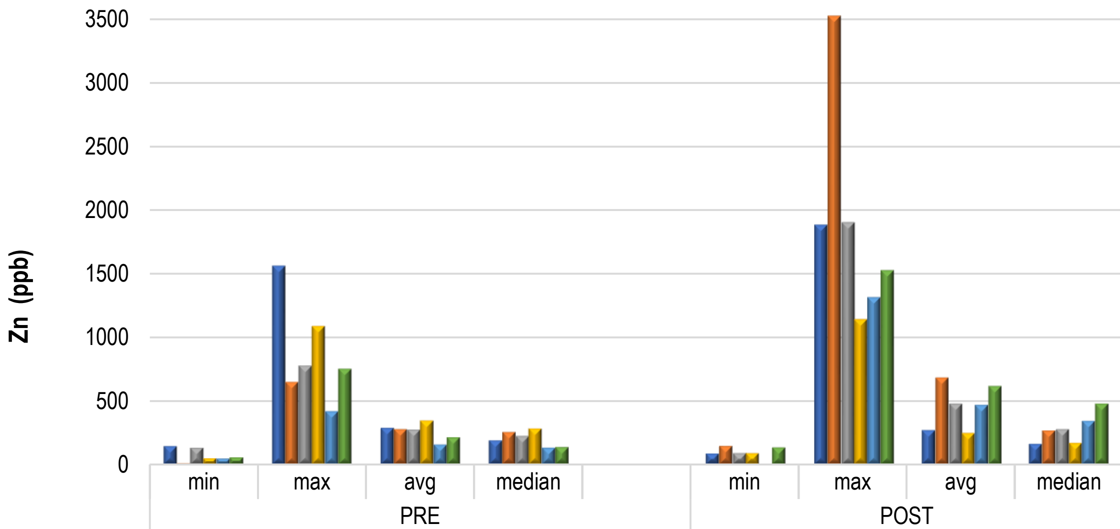


Fig. 4.27. Spatial variation of Cu in groundwater during pre & post monsoon

4.1.4.6. Zinc (Zn)

Zinc (Zn), a member of group XII, is an essential trace element found in virtually all food and potable water. The concentration of Zn in surface water and groundwater normally does not exceed 0.01 and 0.05 mg/l respectively. Zn concentrations in excess of 3-5 mg/l impart an undesirable astringent taste to water and develop a greasy film on boiling, although, drinking water rarely contains Zn concentration above 0.1 mg/l. The daily requirement of Zn for adult humans is 15-22 mg. Drinking water usually makes a negligible contribution to zinc intake and is not of health concern at levels found in drinking water, therefore, WHO (2017) has not established any guideline value. BIS (2012) has recommended 5 mg/l as the as desirable limit and 15 mg/l as the permissible limit for Cu in drinking water.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	142.89	1563.47	286.88	189.62	87.04	1885.03	268.73	161.53
Mansa	7.60	654.14	279.69	257.77	146.60	3528.50	690.49	269.07
Sri Mukatsar Sahib	132.07	776.94	273.77	224.35	87.98	1905.27	477.97	277.52
Fazilka	47.88	1086.38	345.15	283.38	89.56	1141.48	248.24	169.75
Firozepur	46.12	417.33	157.83	131.66	0.00	1313.13	469.51	342.71
Faridkot	55.40	753.68	213.48	137.05	133.60	1529.12	617.04	479.69

Fig. 4.28. Zinc concentration in pre & post monsoon samples of SW Punjab

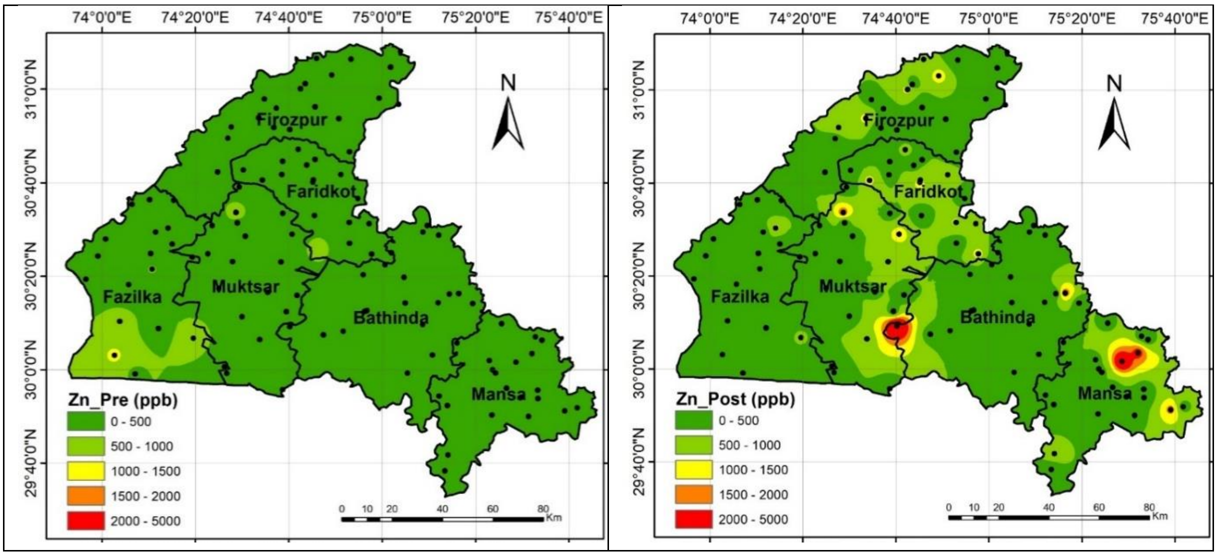


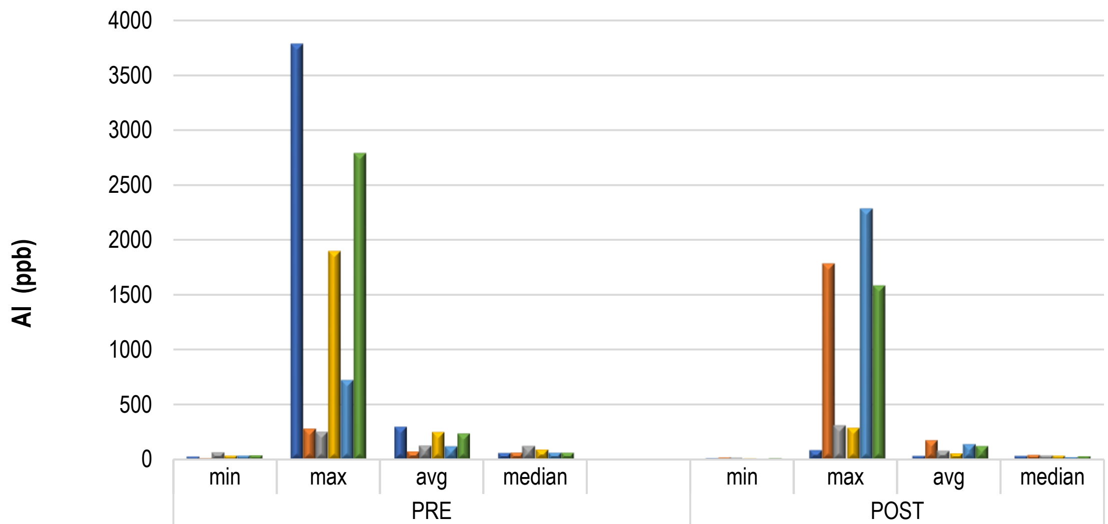
Fig. 4.29. Spatial variation of Zn in groundwater during pre & post monsoon

The Zn concentration in the samples of the study area ranges from.007 mg/l (Joga, Mansa) to 1.08 mg/l (Dalmir khera, Fazilka) and ND to 3.82 mg/l (Lool bai, Bathinda) in pre-monsoon and post-monsoon respectively (Figure 4.28). The average concentration of Zn in pre and post monsoon samples was observed to be 0.23±0.01mg/l and 0.46±0.05 mg/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.29).

4.1.4.7. Aluminium (Al)

Aluminum (Al) is the most abundant metallic element and constitutes about 8% of Earth's crust. High Al concentration in drinking water results in undesirable color and turbidity. The orally ingested aluminum is not acutely toxic to humans, however, it has been hypothesized that aluminum exposure is a risk factor for the development or acceleration of onset of Alzheimer disease in humans. WHO (2017) recommends the guideline value of 0.9 mg/l for aluminum in drinking water. BIS (2012) recommends 0.03 mg/l as the acceptable limit and 0.2 mg/l as permissible limit in absence of alternate source for Al in drinking water.

The Al concentration in the samples of the study area ranges from .011mg/l (Joga, Mansa) to 2.78 mg/l (Dhimawali, Faridkot) and ND to 2.4 mg/l (Panjkosi, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.30). The average concentration of Al in pre and post monsoon samples was observed to be 0.15±0.03mg/l and 0.09±0.02 mg/l respectively. Around 96% samples exceeded the acceptable limit and 11% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 52.38% samples exceeded the acceptable limit and 9.52% samples exceeded the permissible limit (Figure 4.31).



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	24.58	3787.22	297.40	58.14	9.04	83.65	30.47	30.12
Mansa	11.72	277.24	72.52	59.64	17.10	1777.99	173.52	39.58
Sri Mukatsar Sahib	63.11	250.12	123.67	120.60	13.16	306.75	76.19	33.31
Fazilka	34.67	1892.01	249.82	88.06	6.04	286.03	54.99	34.47
Firozepur	32.39	723.99	117.93	61.10	0.00	2284.47	138.92	20.26
Faridkot	35.62	2785.09	234.27	58.71	9.92	1582.84	121.37	28.39

Fig. 4.30. Aluminium concentration in pre & post monsoon samples of SW Punjab

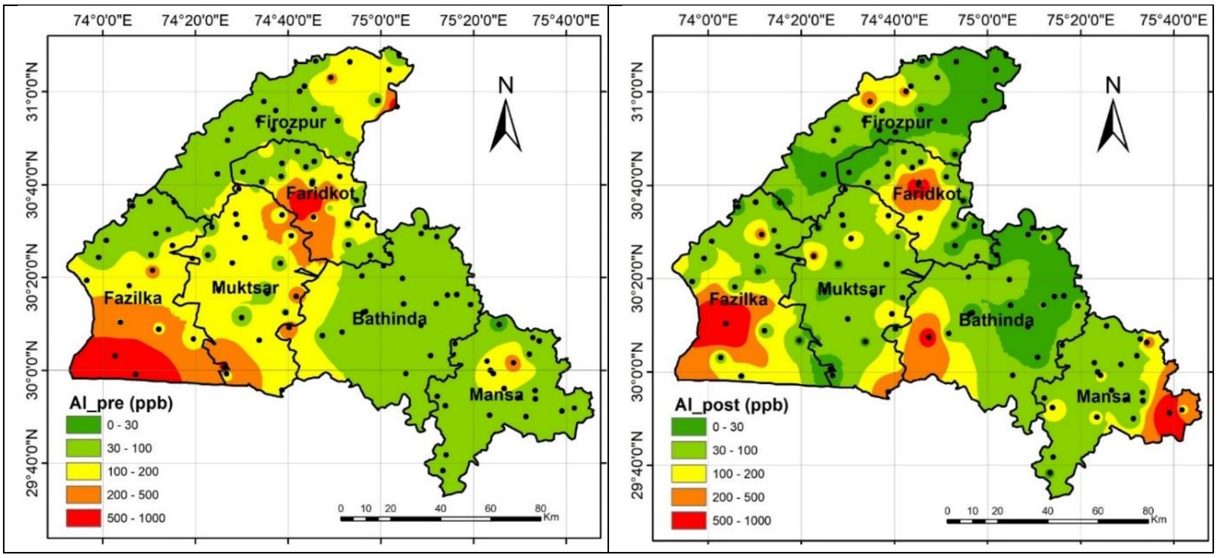
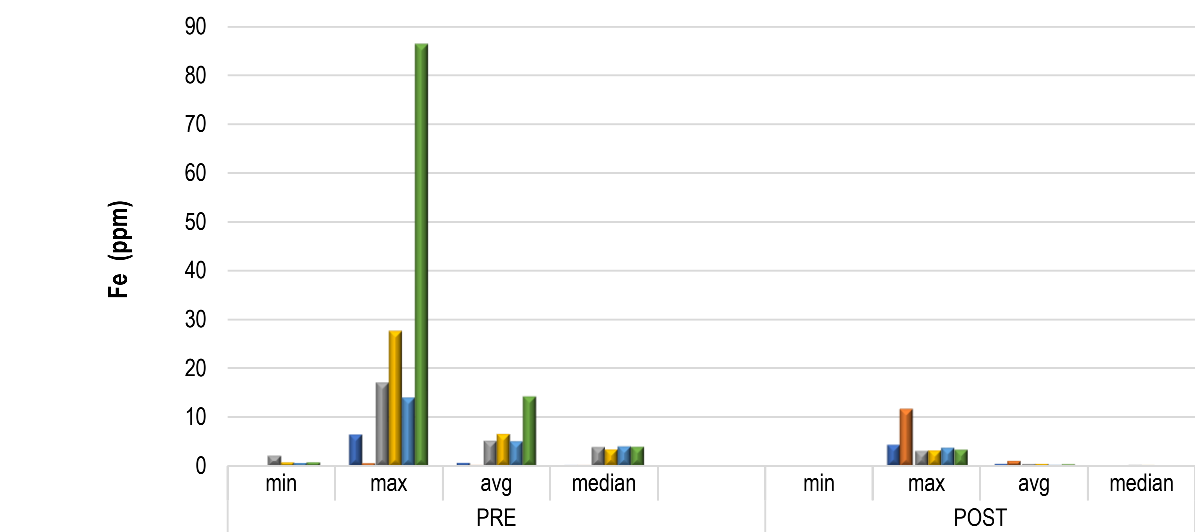


Fig. 4.31. Spatial variation Al in groundwater during pre & post monsoon

4.1.4.8. Iron (Fe)

Iron (Fe) is one of the most abundant metals in Earth's crust, and in fresh waters, it ranges from <0.001 mg/l to 90 mg/l (Health Canada 1978). Fe in trace amount is essential for nutrition, however, higher concentrations impart inky flavor, bitter, and astringent taste to water. Taste and odor problems may be caused by filamentous organisms that prey on iron compounds (frenothrix, gallionella and leptothrix). In addition, these bacterial may clog the well screens or may develop in the distribution system. Fe in water also stains the laundry and plumbing fixtures. So, the presence of Fe is unacceptable in drinking water, not due to health reasons but due to aesthetic/operational reasons. No guideline value for iron in drinking-water is proposed by WHO (2017) citing the reason that concentrations found in drinking water do not pose any health effect. BIS (2012) recommends 0.3 mg/l as the acceptable limit for Fe in drinking water.

The Fe concentration in the samples of the study area ranges from .00003 mg/l (Khiwa kalan, Mansa) to 3.69 mg/l (Mumaru, Faridkot) and N.D. mg/l to 11.62 mg/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively (Figure 4.32). The average concentration of Fe in pre and post monsoon samples was observed to be 0.28±0.05mg/l and 0.46±0.11 mg/l respectively. Around 23% and 27.78% samples exceeded the permissible limit (0.3 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.33).



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	0.01	6.45	0.66	0.11	0.01	4.32	0.49	0.05
Mansa	0.00	0.63	0.18	0.15	0.02	11.62	1.09	0.06
Sri Mukatsar Sahib	2.09	17.09	5.19	3.89	0.01	3.07	0.45	0.27
Fazilka	0.83	27.64	6.58	3.43	0.01	3.20	0.50	0.13
Firozepur	0.65	14.01	5.07	4.04	0.00	3.73	0.30	0.03
Faridkot	0.80	86.30	14.24	3.97	0.01	3.33	0.39	0.05

Fig. 4.32. Iron concentration in pre & post monsoon samples of SW Punjab

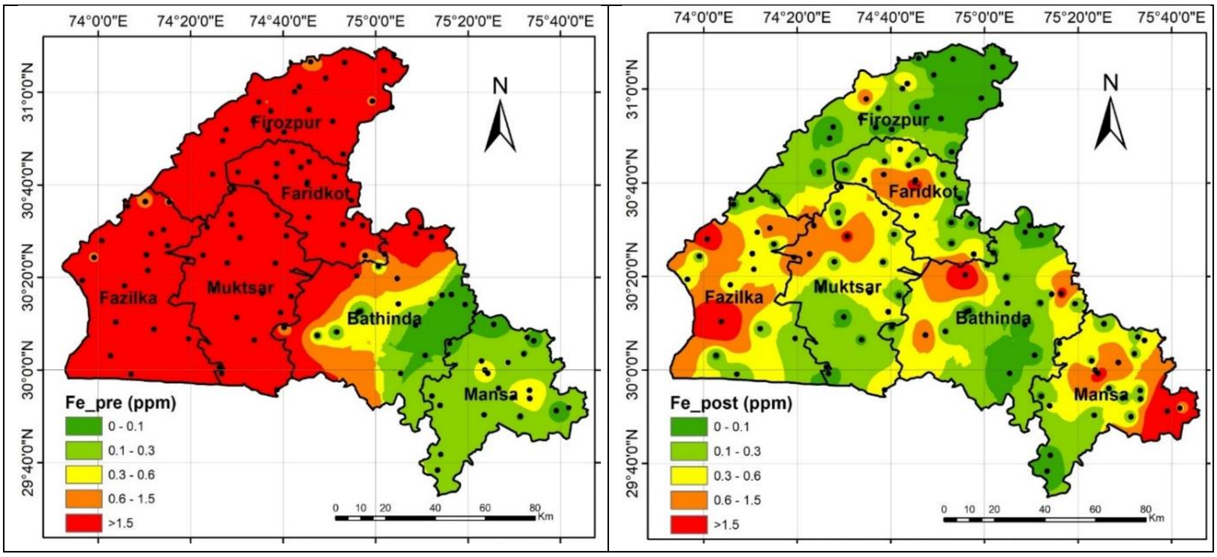
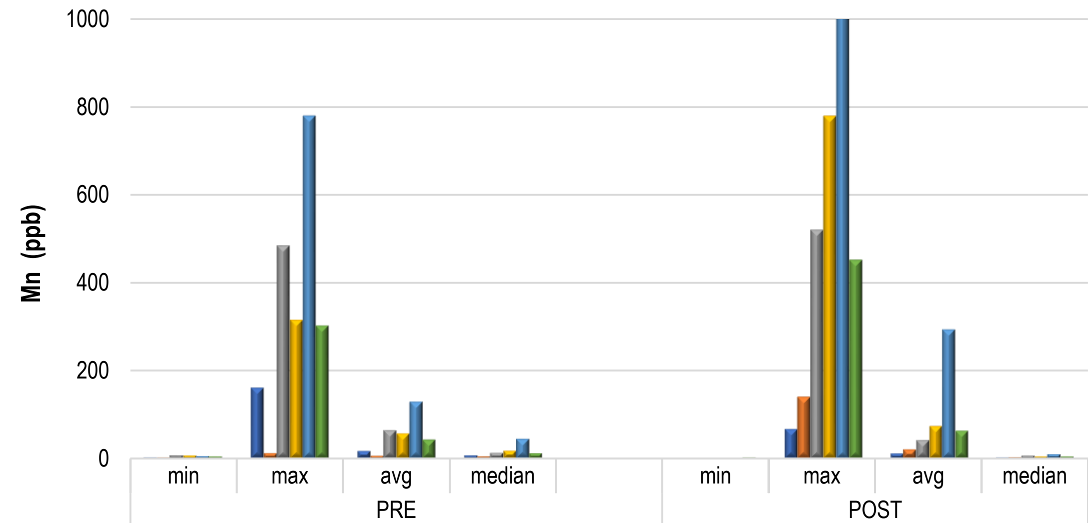


Fig. 4.33. Spatial variation of Fe in groundwater during pre & post monsoon

4.1.4.9. Manganese (Mn)

Manganese is one of the most abundant metals in Earth's crust and generally co-exist with iron. It is used in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate), and as an octane enhancer (as methyl-cyclo-pentadienyl manganese tri-carbonyl) in petrol. Manganese occurs in surface water sources which are anaerobic or anoxic. At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry, and at levels exceeding 0.2 mg/l, manganese will often form a coating on pipes which may slough off as a black precipitate.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	1.51	159.75	16.93	6.09	0.00	66.29	10.55	1.39
Mansa	1.27	11.45	5.69	4.21	0.00	139.14	20.06	1.80
Sri Mukatsar Sahib	6.99	484.32	64.25	11.93	0.93	520.15	41.13	6.50
Fazilka	6.48	315.52	56.44	17.54	0.15	779.24	73.65	4.55
Firozepur	5.30	780.42	129.04	44.24	0.06	5378.85	292.49	9.32
Faridkot	3.92	302.66	42.98	11.77	1.52	452.18	63.14	4.47

Fig. 4.34. Manganese concentration in pre & post monsoon samples of SW Punjab

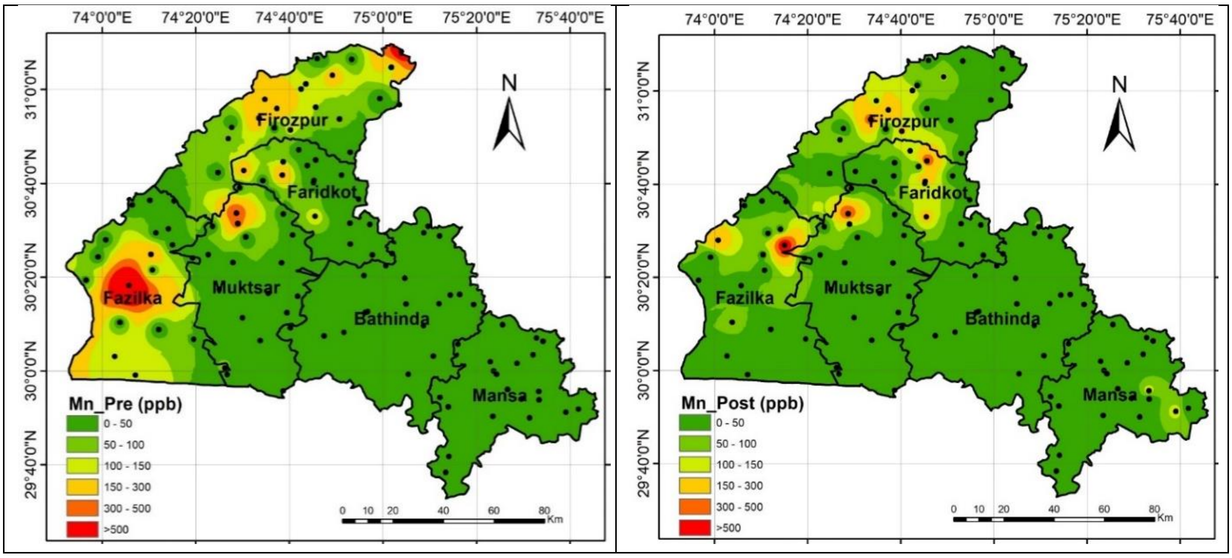


Fig. 4.35. Spatial variation of Mn in groundwater during pre & post monsoon

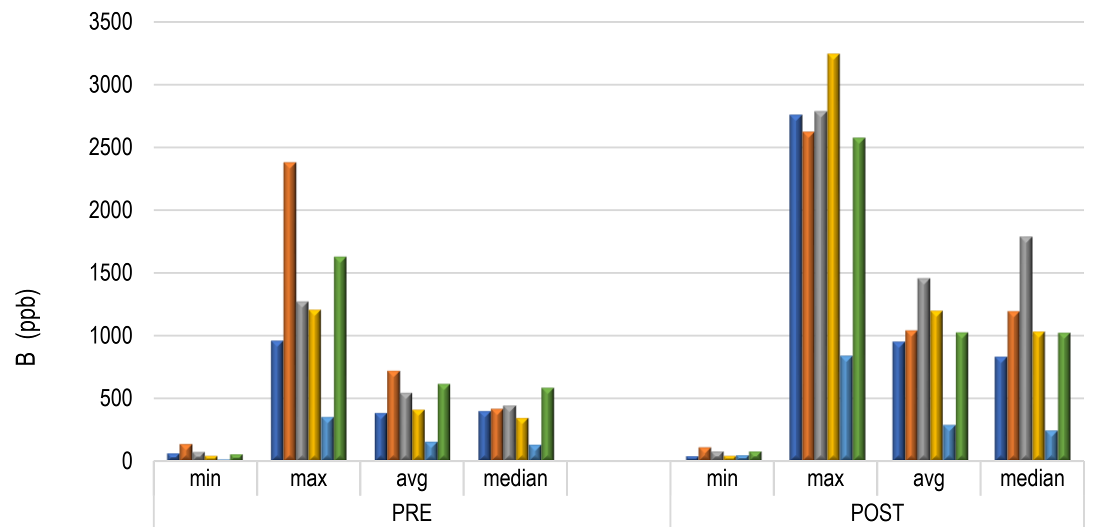
Manganese is an essential element for humans, however, consuming drinking water with concentration more than 0.4 mg/l is expected to be associated with adverse effect on learning in children. WHO (2017) has not established a guideline value for manganese, as the health based value (0.4 mg/l) is well above concentrations of manganese, 0.1 mg/l, normally causing acceptability problems in drinking water. BIS (2012) recommends 0.1 mg/l as the acceptable limit and 0.3 mg/l as permissible limit in absence of alternate source for Mn in drinking water.

The Mn concentration in the samples of the study area ranges from .001 mg/l (Joga, Mansa) to 1.63 mg/l (Khui Khera, Fazilka) and ND to 0.77 mg/l (Halimwala, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.34). The average concentration of Mn in pre and post monsoon samples was observed to be 0.07±0.01 mg/l and 0.04±0.009 mg/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.35).

4.1.4.10. Boron (B)

Boron (B) is a naturally occurring element and is used in many consumer products like fiberglass, borosilicate glass, soaps and detergents, flame retardants, neutron absorbers for nuclear installations, mild antiseptics, cosmetics, pharmaceuticals (as pH buffers), boron neutron capture therapy (for cancer treatment), pesticides, and fertilizers. The concentration of boron in the earth's crust has been estimated to be <10 mg/kg, but in boron-rich areas, boron concentrations may be as high as 100 mg/kg. Boron enters in the environment mainly through the weathering of rocks, boric acid volatilization from seawater, and volcanic activity. Boron concentration in groundwater and surface water is generally small, however, the concentration can be significantly increased depending on the anthropogenic activities and surrounding geology. Boron toxicity results in gastrointestinal tract distress, vomiting, abdominal pain, diarrhea, and nausea (Simonnot et al. 2000, Yazbeck et al. 2005, Health Canada 2020). The guideline value of 2.4 mg/l has been prescribed by WHO (2017) for boron in drinking water. However, BIS (2012) has prescribed an acceptable limit of 0.5 mg/l and permissible limit of 1.0 mg/l for B in drinking water.

The B concentration in the samples of the study area ranges from 0.016 mg/l (Jhoke hari har, Ferozepur) to 2.377 mg/l (Dalel singh wala, Mansa) and .041 mg/l (Akalia jalal, Bathinda) to 3.24 mg/l (Panjkosi, Fazilka) in pre-monsoon and post-monsoon respectively (Figure 4.36). The average concentration of B in pre and post monsoon samples was observed to be 0.45±0.04 mg/l and 0.95±0.07 mg/l respectively. Around 33.67% samples exceeded the acceptable limit and 11.22% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 61.90% samples exceeded the acceptable limit and 42.06% samples exceeded the permissible limit (Figure 4.37).



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	63.67	960.60	385.40	401.31	41.68	2755.86	953.16	834.41
Mansa	137.62	2377.16	721.04	417.64	111.59	2620.01	1043.75	1196.36
Sri Mukatsar Sahib	74.78	1274.05	545.94	443.47	79.02	2785.04	1456.86	1788.22
Fazilka	43.17	1205.13	411.22	345.07	43.42	3242.85	1195.61	1031.07
Firozepur	16.31	352.34	156.34	131.98	49.50	837.88	289.61	244.03
Faridkot	56.84	1630.28	616.48	587.92	78.59	2574.72	1028.66	1026.29

Fig. 4.36. Boron concentration in pre & post monsoon samples of SW Punjab

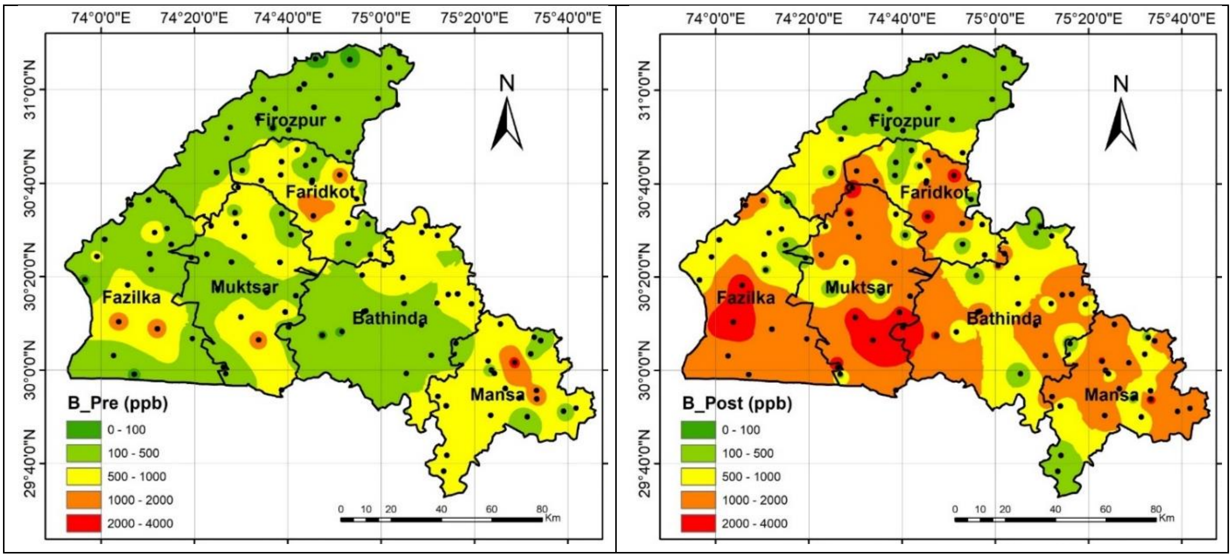
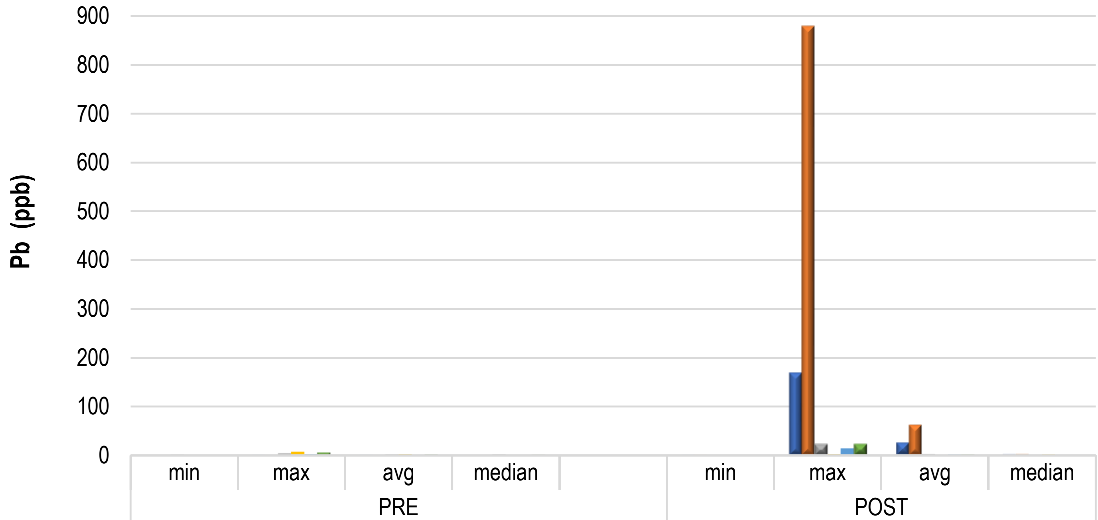


Fig. 4.37. Spatial variation of B in groundwater during pre & post monsoon

4.1.4.11. Lead (Pb)

Lead (Pb), a group X element, accounts for 13 mg/kg of Earth's crust, and is used principally in the production of lead-acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors, ammunition, glazes, and plastic stabilizers. The organic lead compounds tetraethyl and tetra methyl lead has also been used extensively as antiknock and lubricating agents in petrol, although their use in many countries including India has largely been phased out. Exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. The evidence for the carcinogenicity of lead in humans is inconclusive because of the limited number of studies, and therefore, Pb has been placed in Group 2B (possible human carcinogen) of the IARC classification, however, inorganic lead compounds have been placed in Group 2A (namely probable human carcinogen). The provisional guideline value for lead in drinking water prescribed by WHO (2017) is 0.01 mg/l. BIS (2012) has also prescribed 0.01 mg/l as limit for Pb in drinking water.



	PRE					POST			
	min	max	avg	median		min	max	avg	median
Bathinda	0.00	0.05	0.00	0.00		0.09	168.28	25.08	0.89
Mansa	0.00	0.00	0.00	0.00		0.13	878.95	61.79	1.83
Sri Mukatsar Sahib	0.87	4.06	1.94	1.57		0.07	21.89	2.35	0.75
Fazilka	0.81	7.63	2.19	1.38		0.29	2.82	1.37	1.48
Firozepur	0.67	2.44	1.29	1.08		0.01	14.34	1.76	0.42
Faridkot	0.51	5.79	1.74	1.09		0.08	22.71	1.90	0.57

Fig. 4.38. Lead concentration in pre & post monsoon samples of SW Punjab

The Pb concentration in the samples of study area ranges from ND to .007 mg/l (Dalmir Khera, Fazilka) ND to 0.87 mg/l (Boha, Mansa) in pre-monsoon and post-monsoon respectively (Figure 4.38). The average concentration of Pb in pre and post monsoon samples was observed to be 0.001±0.0001 mg/l and 0.010±0.007 mg/l respectively. Around 0% and 7.14% samples exceeded the permissible limit (0.01 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.39).

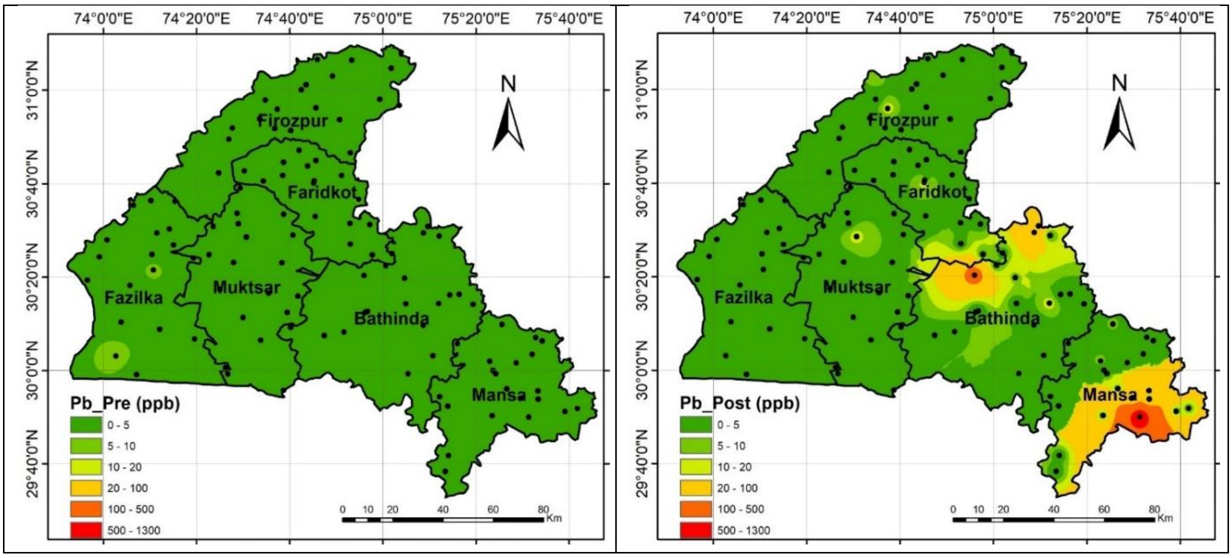


Fig. 4.39. Spatial variation of Pb in groundwater during pre & post monsoon

4.1.4.12. Beryllium (Be)

Beryllium is naturally present in soils, sediments, and fossil fuels. The most notable minerals containing beryllium are beryl (beryllium aluminum silicate), and bertrandite (beryllium silicate), which are found in rocks formed from solidified lava or magma. The average beryllium concentration in coal is between 1.8 and 2.2 µg/g. The major emission source to the environment from human activity is the combustion of coal and fuel oil, which releases particulates and fly ash containing beryllium into the atmosphere. Other sources of beryllium into the atmosphere include the incineration of municipal solid waste, ore processing, metal fabrication; the production, use, and recycling of beryllium alloys and chemicals and, to a minor extent, the burning of solid rocket fuel. Atmospheric beryllium particulates eventually settle to the Earth's surface. Beryllium naturally enters waterways through the weathering of rocks and soils. Other sources of beryllium in surface waters include treated wastewater effluents from beryllium or related industries, and the runoff from beryllium-containing waste sites. Beryllium and its compounds are toxic and are classified as carcinogens by the International Agency for Research on Cancer. A health-based value for beryllium in drinking water is 12 µg/l based on an allocation of 20% of the tolerable daily intake (TDI) of 2 µg/kg body weight, assuming a 60 kg adult drinking 2 l of water per day (WHO, 2009). EPA has set a maximum allowable amount of 0.004 mg/L beryllium in drinking water (ASTDR, 2002).

The Be concentration in the samples of study area ranges from ND to 0.003 mg/l (Dohak, Muktsar) and ND to 0.18 mg/l (Waring khera, Muktsar) in pre-monsoon and post-monsoon respectively (Figure 4.40). The average concentration of Be in pre and post monsoon samples was observed to be 8.2551E-05± 3.46047E-05 mg/l and 0.002±0.001 mg/l respectively. Around 0% and 2.38% samples exceeded the permissible limit (0.012 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.41).

	min	max	avg	median		min	max	avg	median
			PRE					POST	
Bathinda	0.00	0.02	0.00	0.00		0.00	187.71	15.36	0.00
Mansa	0.00	0.02	0.01	0.00		0.00	0.06	0.01	0.00
Sri Mukatsar Sahib	0.00	0.06	0.02	0.02		0.00	0.12	0.03	0.00
Fazilka	0.00	3.03	0.34	0.04		0.00	0.18	0.01	0.00
Firozepur	0.00	0.10	0.04	0.04		0.00	0.06	0.00	0.00
Faridkot	0.00	0.10	0.02	0.02		0.00	0.12	0.02	0.00

Fig. 4.40. Beryllium concentration in pre & post monsoon samples of SW Punjab

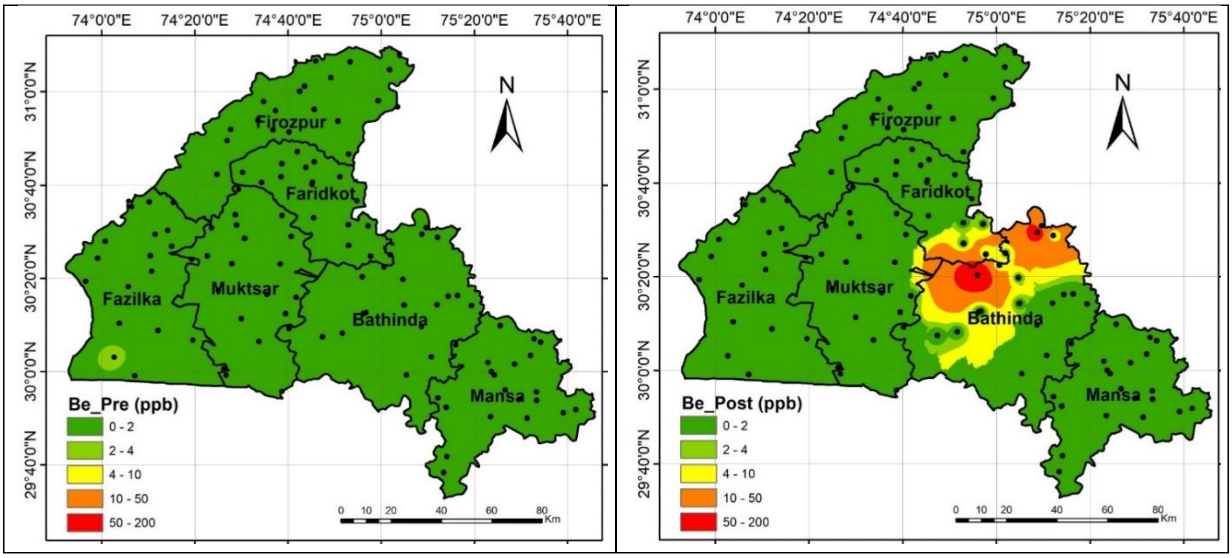
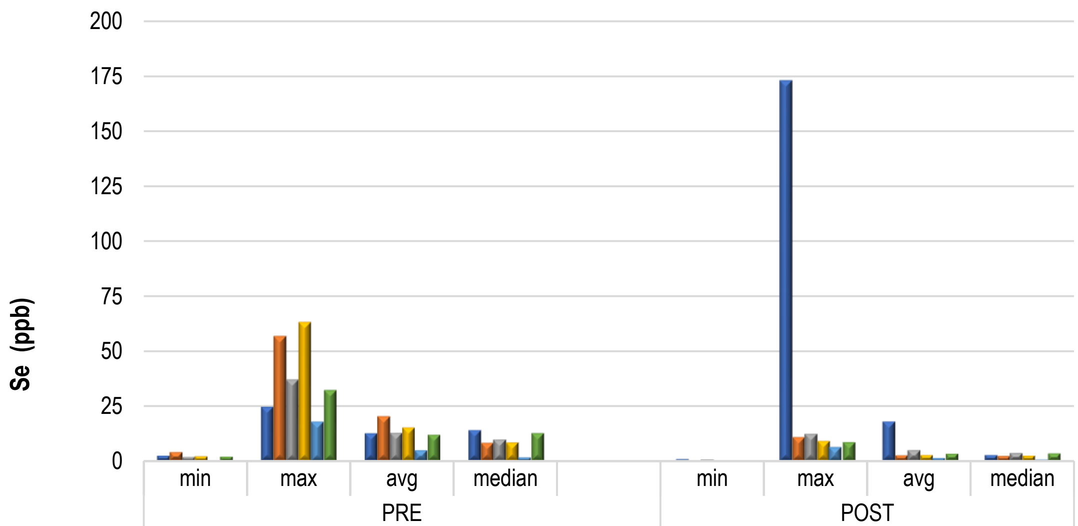


Fig. 4.41. Spatial variation of Be in groundwater during pre & post monsoon

4.1.4.13. Selenium (Se)

Selenium (Se), a metalloid, is a member of group VIA and generally present in elemental form or ionic (selenide (Se^{-2}), selenate (SeO_4^{-2}), or selenite (SeO_3^{-2})). It is widely distributed in the Earth's crust, in association with sulfur containing minerals, at a concentration of 50-90 µg/kg.

Its concentration in groundwater and surface water ranges from 0.06 µg/l to 400 µg/l. It is an essential element and FAO/WHO recommends daily intake of 6-21 µg/l, 26 µg/l, and 30 µg/l Se for infants/children, females, and males respectively. Most water soluble inorganic and organic selenium are efficiently absorbed across the gastrointestinal tract, which is cleared by the liver, transported to peripheral tissues, and distributed to all organs, with highest concentration in kidney, liver, spleen, testes, and skeletal muscle. High intake of Se results in gastrointestinal disturbances, discoloration of the skin, decayed teeth, hair or nail loss, nail abnormalities, changes in peripheral nerves, and several type of cancer (WHO 2011c, Health Canada 2014). A provisional guideline value of 0.04 mg/l has been recommended by WHO (2017). BIS (2012) recommends limit of 0.01 mg/l for Se in drinking water.



	PRE min	PRE max	PRE avg	PRE median	POST min	POST max	POST avg	POST median
Bathinda	2.30	24.57	12.46	13.98	0.71	173.06	17.84	2.54
Mansa	3.93	56.65	20.23	8.08	0.12	10.75	2.47	2.13
Sri Mukatsar Sahib	1.76	36.86	12.68	9.56	0.59	12.17	4.72	3.48
Fazilka	2.06	63.07	15.07	8.29	0.12	8.98	2.54	2.30
Firozepur	0.12	17.73	4.88	1.76	0.12	6.38	1.48	0.71
Faridkot	1.88	32.08	11.74	12.53	0.12	8.39	3.21	3.31

Fig. 4.42. Selenium concentration in pre & post monsoon samples of SW Punjab

The Se concentration in the samples of study area ranges from 0.001 (Bandala, Ferozepur) to 0.13 mg/l (Dalmir khera, Fazilka) and ND to 0.17 mg/l (Goniana Khurad, Bathinda) in pre-monsoon and post-monsoon respectively (Figure 4.42). The average concentration of Se in pre and post monsoon samples was observed to be 0.01±0.002 mg/l and 0.004±0.001 mg/l respectively. Around 41.84% and 4.76% samples exceeded the permissible limit (0.01 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.43).

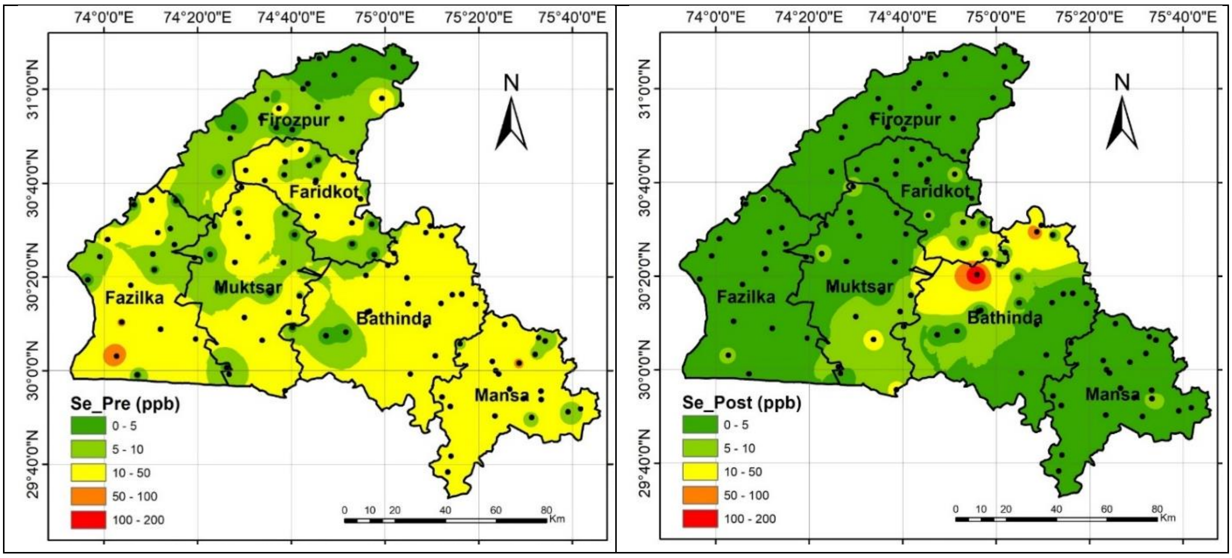
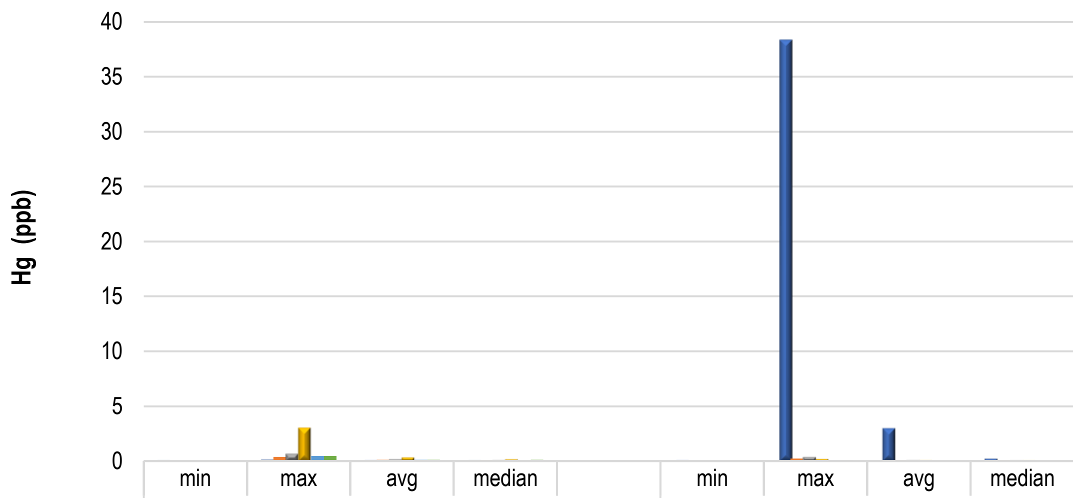


Fig. 4.43. Spatial variation of Se in groundwater during pre & post monsoon

4.1.4.15. Mercury (Hg)

Mercury (Hg), a group XII element, is a toxic element. It is present in Earth's crust at an average concentration of 0.08 mg/kg and cinnabar (HgS) is the most common ore. Mercury and its compounds are used in dental preparations, thermometers, fluorescent and ultraviolet lamps, and pharmaceuticals, fungicides, and chlor-alkali industry. In oxic waters, Hg exists as $Hg(OH)_2$ and $HgCl_2$, and in anoxic sediments, it is immobilized as the sulfide. Mercury content in the surface and groundwater is generally less than 0.5 µg/l, however, concentration up to 5.5 µg/l has been reported in the wells in Izu Oshima Island (Japan). Mercury poisoning results in neurological and renal disturbances. Neurological disturbances are due to organic mercury ingestion and renal disturbance is due inorganic mercury. The guideline value for mercury prescribed by WHO (2017) is 0.006 mg/l. BIS (2012) recommends maximum limit of 0.001 mg/l for Hg in drinking water.

The Hg concentration in the samples of study area ranges from 0.00002 (Pipli, Faridkot) to 0.003 mg/l (Fazilka) and 0.000006 mg/l (Lehra bet, Ferozepur) to 0.038 mg/l (Goniana Khurad, Bathinda) in pre-monsoon and post-monsoon respectively (Figure 4.44). The average concentration of Hg in pre and post monsoon samples was observed to be 0.0001±3.24251E-05 mg/l and 0.0005±0.0003 mg/l respectively. Around 1.03% and 3.17% samples exceeded the permissible limit (0.001 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.45).



	min (PRE)	max (PRE)	avg (PRE)	median (PRE)	min (POST)	max (POST)	avg (POST)	median (POST)
Bathinda	0.06	0.16	0.09	0.07	0.08	38.33	3.00	0.23
Mansa	0.04	0.38	0.12	0.10	0.04	0.25	0.10	0.09
Sri Mukatsar Sahib	0.03	0.68	0.17	0.10	0.02	0.38	0.10	0.06
Fazilka	0.04	3.05	0.36	0.19	0.03	0.21	0.09	0.07
Firozepur	0.03	0.48	0.11	0.06	0.01	0.10	0.05	0.05
Faridkot	0.02	0.48	0.13	0.12	0.02	0.09	0.05	0.04

Fig. 4.44. Mercury concentration in pre & post monsoon samples of SW Punjab

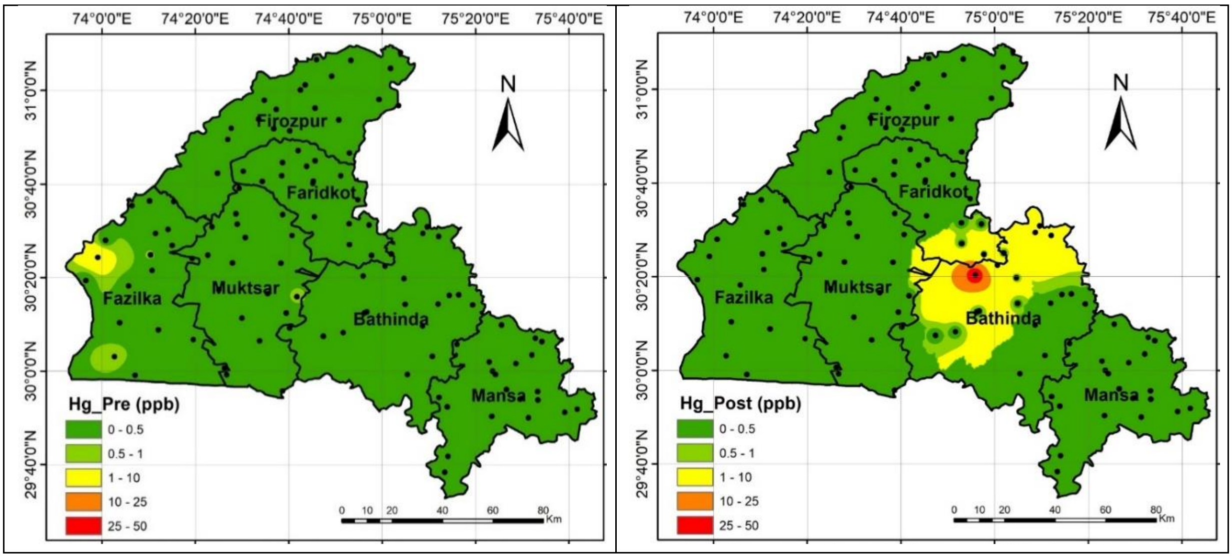
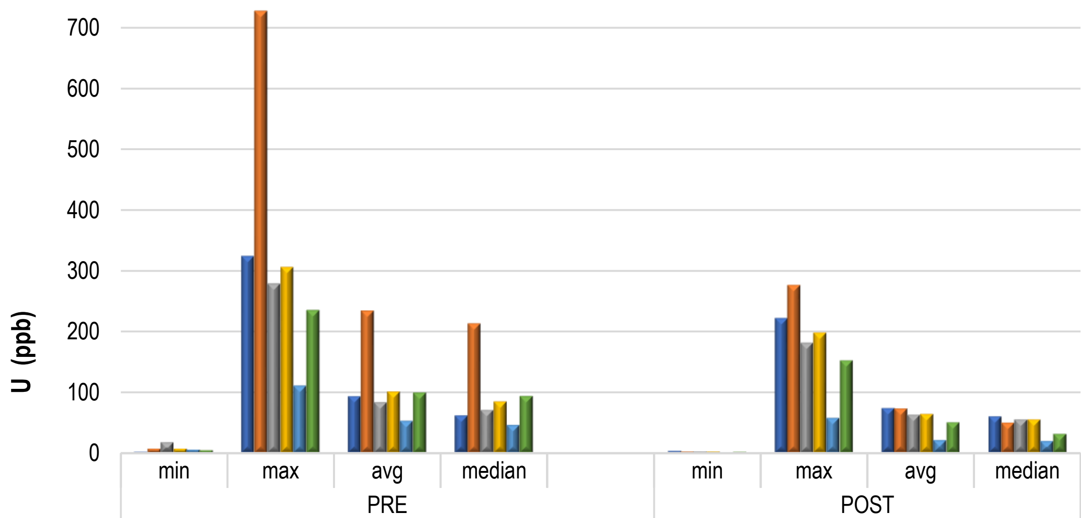


Fig. 4.45. Spatial variation of Hg in groundwater during pre & post monsoon

4.1.4.14. Uranium (U)

Uranium is a primordial and heaviest naturally occurring radioactive element that occurs in dispersed state in the earth's crust with an average concentration of 2–4 mg/kg. It is commonly present in lignite, monazite and phosphate rocks (typically in the order of 0.005 to 0.02%). It is a normal part of rocks, soil, air and water. Uranium occurs in nature in the form of minerals, but never as a metal. In nature, hexavalent Uranium is commonly associated with oxygen as the uranyl ion, UO_2^{2+}. Uranium enters water by leaching from soil and rocks, or in releases from processing plants. In concentrations below 10^{-6}M, $UO_2(OH)^+$ is the dominant species, while above this concentration polymeric forms occur. Carbonate and mixed hydroxo carbonate complexes are formed in geological environment. Dissolved uranium can also form stable complexes with naturally occurring inorganic and organic ligands such as phosphate complexes. (CGWB, 2020) Uranium has demonstrated toxic effects on human kidneys leading to their inflammation and changes in urine composition. Uranium can decay into other radioactive substances, such as radium, which can cause cancer with extensive exposure over a long period of time (U.S. EPA, 2013). BIS (2012) and WHO (2017) has prescribed a guideline value of 0.03 mg/l U in drinking water. The 0.030 mg/l is based on increased risk of kidney toxicity and is equivalent to about 27 picocuries per liter (pCi/L) of radioactivity, which also presents an increased risk of cancer from uranium (WQA, 2013).

The U concentration in the samples of study area ranges from 0.002 (Jai sing wala, Bathinda) to 0.73 mg/l (Dalel sing wala, Mansa) and 0.0005 mg/l (Ferozepur city) to 0.276 mg/l (Khiwa kalan, Mansa) in pre-monsoon and post-monsoon respectively (Figure 4.46). The average concentration of U in pre and post monsoon samples was observed to be 0.09±0.01 mg/l and 0.05±0.004 mg/l respectively. Around 76.5% and 61.9% samples exceeded the permissible limit (0.03 mg/l) in pre-monsoon and post-monsoon period respectively (Figure 4.47).



	PRE				POST			
	min	max	avg	median	min	max	avg	median
Bathinda	1.52	323.78	93.27	61.35	3.03	221.58	73.81	59.75
Mansa	6.89	727.39	233.69	212.37	1.95	275.55	72.69	49.61
Sri Mukatsar Sahib	17.13	278.64	83.16	70.71	1.89	181.09	62.64	54.86
Fazilka	6.60	305.68	100.45	84.19	1.74	197.68	63.64	54.54
Firozepur	4.89	110.57	52.42	45.52	0.45	57.56	20.88	19.57
Faridkot	4.05	234.31	98.75	93.17	1.47	151.70	50.04	30.81

Fig. 4.46. Uranium concentration in pre & post monsoon samples of SW Punjab

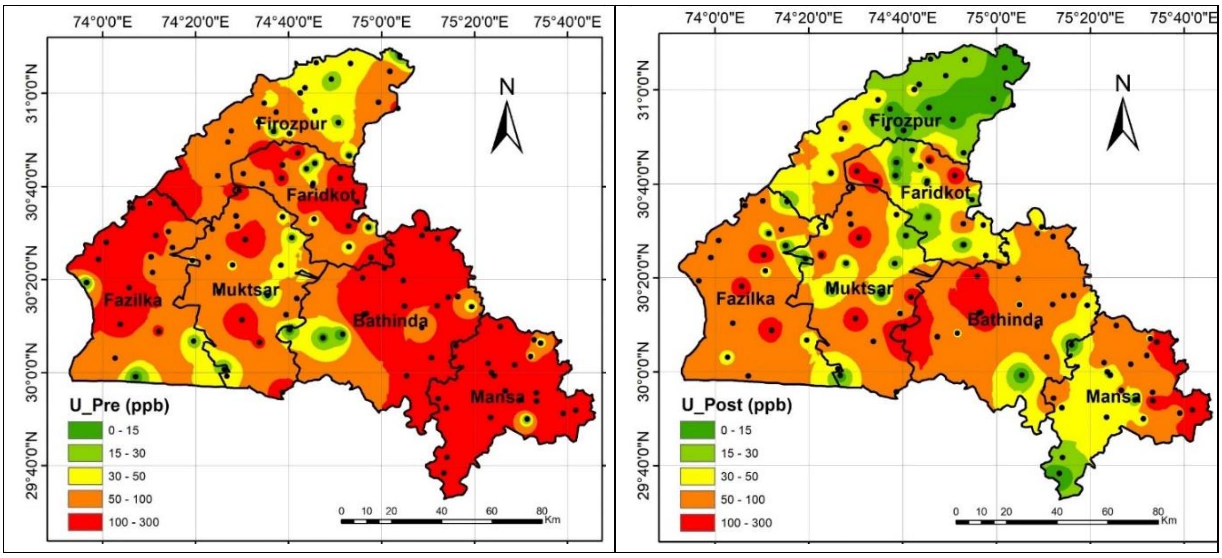


Fig. 4.47. Spatial variation of U in groundwater during pre & post monsoon

4.1.5. Pesticides

Pesticide is a composite term that encompasses all chemicals that are used to kill or control insects, weeds, fungi and other pests, to protect the crops. They are divided into herbicides (protection against weeds), insecticides (against insects), and fungicides (against fungi) based on their usage. Although the use of pesticides has improved the agricultural yield and ensured food security, the quality of yield has significantly affected. Most of the pesticides are inherently toxic, not only to the pests, against which they are used, but also to other organisms. Damage to non-target organisms, perturbation of structure and function of environment, and toxic contamination of environment are few consequences of pesticide use. Long term and rampant use of pesticides resulted in persistence, bio-accumulation and long range transport of these hazardous chemicals. The toxicants affect entire ecological balance and result in severe health hazards to human beings. These changes occur at a very slow pace and the adverse impacts become visible at a stage where it is almost impossible to reverse the trend. The health effects of pesticides depend on the type of pesticide, concentration in water, duration of exposure, and individual health status. Humans and animals can be exposed to pesticides through contact with the skin, ingestion, or inhalation. Within a human or animal body, pesticides may be metabolized, excreted, stored, or bio-accumulated in body fat. The negative health effects associated with chemical pesticides are dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive, and endocrine effects (Nicolopoulou-Stamati et al. 2016, Sabarwal et al. 2018).

4.1.5.1. Alachlor

Alachlor is a chloroacetanilide herbicide. It is used to control the annual grasses and broad leaved weeds in corn, peanuts, soybeans, and other crops. The research data indicates that the groundwater contamination due to alachlor usage takes place after a gap of considerable time. Alachlor and its metabolite 2,6-diethylanilchlor has shown to be mutagenic. IARC has not evaluated alachlor and has recommended for identification of carcinogenic hazards in medium priority (IARC 2019a). The guideline value prescribed by BIS & WHO for Alachlor in drinking water is 0.02 mg/l.

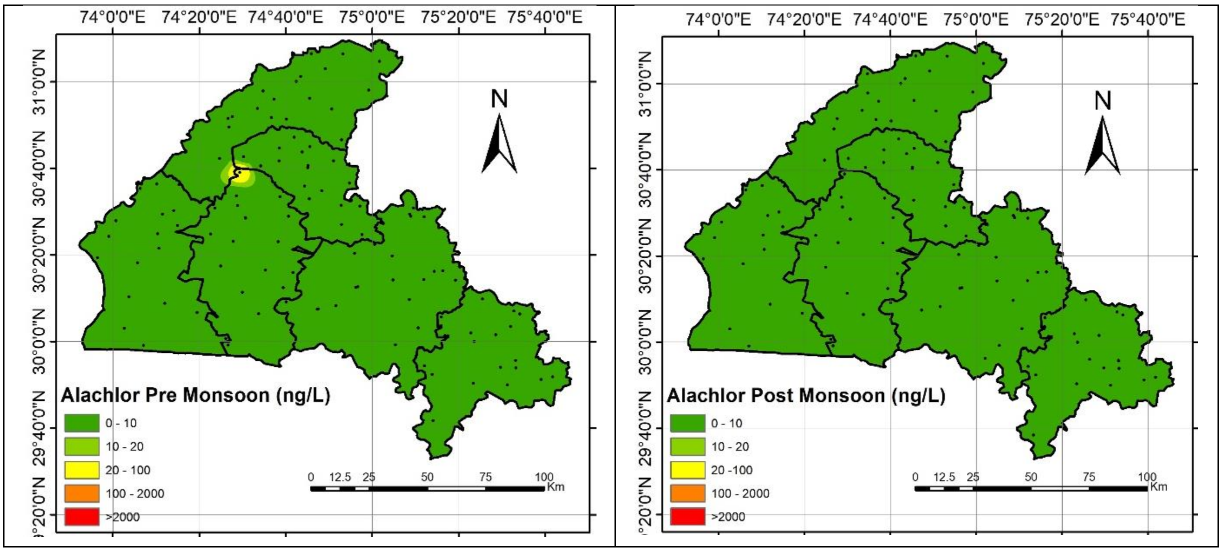


Fig. 4.48. Spatial variation of Alachor in groundwater during pre & post monsoon

The Alachor concentration in the samples of study area ranges from ND to 52.96 ng/l (Jagat singh wala, Mukatsar) and ND to 7.39 ng/l (Jagat singh wala, Mukatsar) in pre-monsoon and post-monsoon respectively. The average concentration of Alachlor in pre and post monsoon samples was observed to be 0.56±0.45 ng/l and 0.33±0.11 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.48).

4.1.5.2. Atrazine

Atrazine is a chlorotriazine herbicide. It is used to selectively control the annual broadleaf and grassy weeds in fruit orchards, coffee plantation, grasslands, cereal crops, sugar cane, roses and vines. Along with atrazine, the metabolite hydroxyatrazine is found in water contaminated with atrazine. IARC has concluded that atrazine is not classifiable as to its carcinogenicity in humans (Group 3) and the 2019 Priorities Advisory Group assigned atrazine a medium priority (IARC, 2019a). WHO (2017) has prescribed the guideline value of 0.1 mg/l and 0.2 mg/l for atrazine and hydroxyatrazine respectively.

The Atrazine concentration in the samples of study area ranges from ND to 1571 ng/l (Khuban, Fazilka) and ND to 42.33 ng/l Dyalpura, Bathinda) in pre-monsoon and post-monsoon respectively. The average concentration of Atrazine in pre and post monsoon samples was observed to be 18.47±13.26 ng/l and 44.66±7.61 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.49).

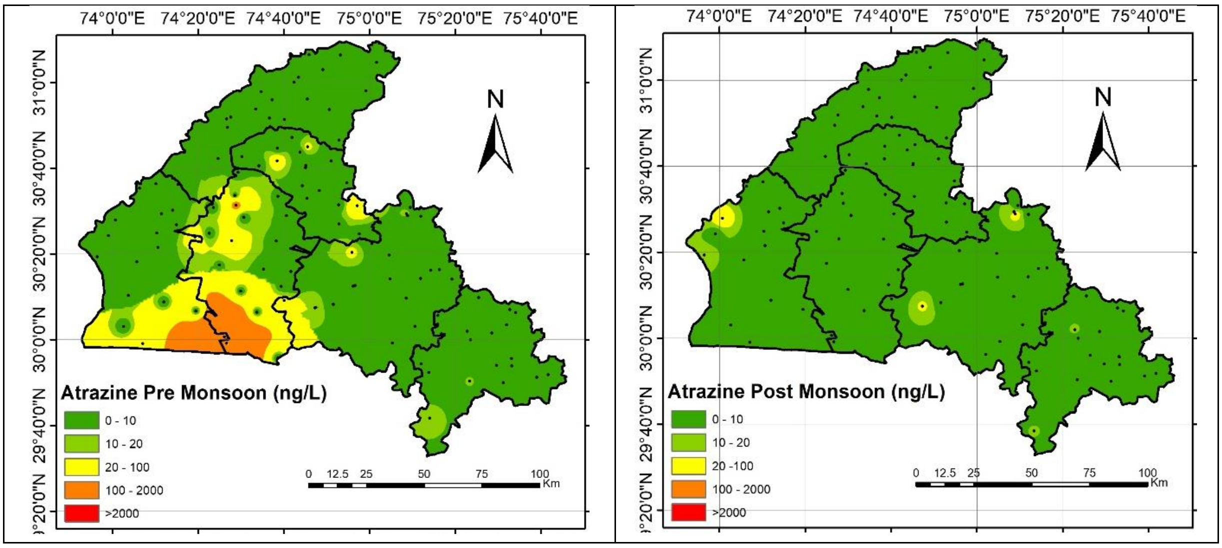


Fig. 4.49. Spatial variation of Atrazine in groundwater during pre & post monsoon

4.1.5.3. Butachlor

Butachlor is a chloroacetanilide herbicide for the pre-emergent control of grass and broadleaf weeds in rice and barley. Butachlor is non-irritating to the skin and moderately irritating to the eyes, and almost non-toxic. Further, it has been shown that butachlor is not genotoxic and is not oncogenic (Heydens et al. 2010, Furukawa et al. 2014). WHO has not prescribed any guideline value for butachlor.

The Butachlor concentration in the samples of study area ranges from ND to 339 ng/l (Gobindgarh, Faridkot) and ND to 12.67 ng/l (Chhachhohar, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of Butachlor in pre and post monsoon samples was observed to be 3.12±2.85 ng/l and 1.21±0.19 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.50).

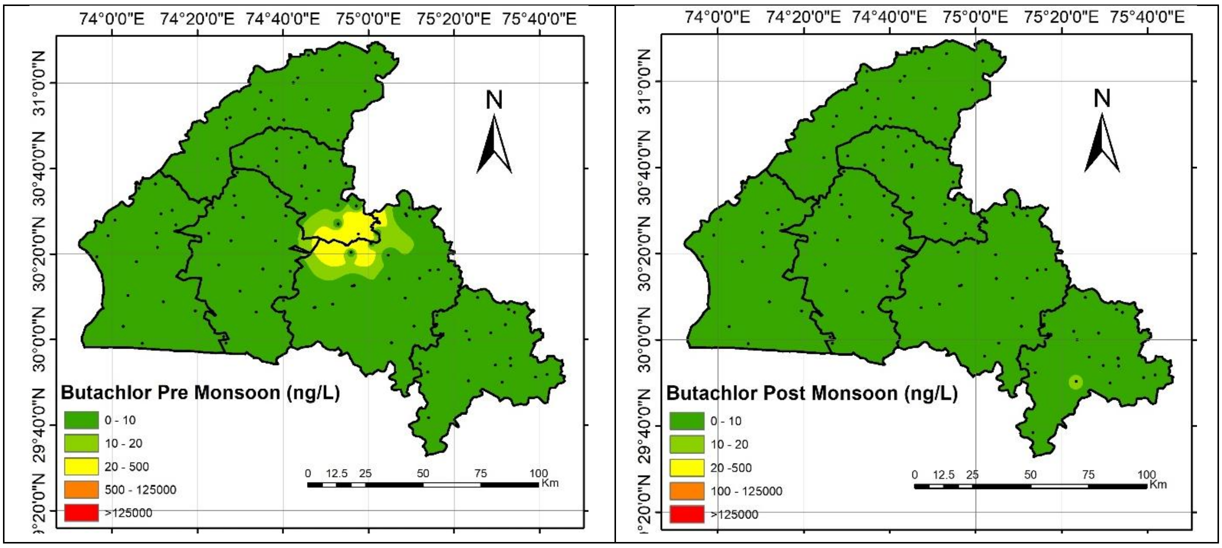


Fig. 4.50. Spatial variation of Butachlor in groundwater during pre & post monsoon

4.1.5.4. Chlorpyriphos

Chlorpyriphos is a broad-spectrum organophosphorus insecticide, used for soil treatment (pre-plat and at planting), seed treatment, and foliar spray. They are used to control mosquitoes, flies, various crop pests in soil and on foliage. It is used as an insecticide on grain, cotton, corn, almonds, vegetable crops, ornamental plants and fruit trees (Femia et al. 2013). WHO Pesticide Evaluation Scheme (WHOPES) does not recommend the addition of chlorpyriphos to water for public health purposes, however, its use as an aquatic larvicide for the control of mosquito larvae in some countries can't be ruled out. Chlorpyriphos has low solubility in water. Further, the chlorpyriphos attached to the soil is not leached out because of the strong ionic interaction between the two, however, it gets degraded by microbial action at a slow rate. Chlorpyriphos exposure can result in neurological disorder, persistent developmental disorders and autoimmune disorders. Exposure during pregnancy retards the mental development of children. Chlorpyriphos is not genotoxic and do not pose carcinogenic risk to humans. WHO (2017) has prescribed the guideline value of 0.03 mg/l for drinking and other domestic usage, considering the fact that it is used as a mosquito larvicide in water bodies.

The Chlorpyriphos concentration in the samples of study area ranges from ND to 63.43 ng/l (Bathinda) and 3.9 ng/l (Patti Amra, Fazilka) to 203.6 ng/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of Chlorpyriphos in pre and post monsoon samples was observed to be 15.31±1.32 ng/l and 23.89±2.82 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.51).

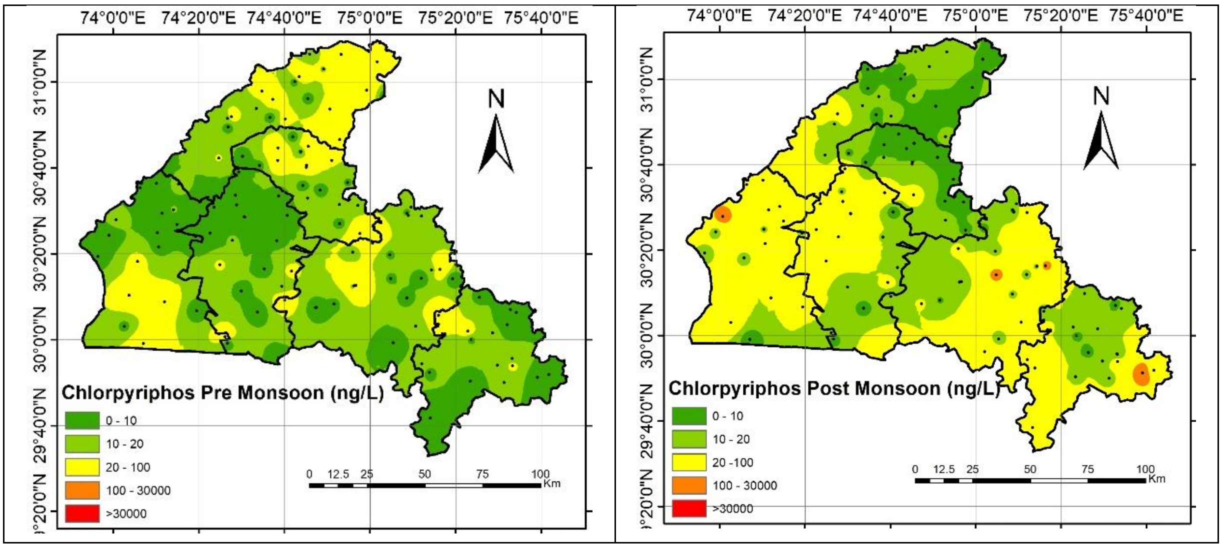


Fig. 4.51. Spatial variation of Chlorpyriphos in groundwater during pre & post monsoon

4.1.5.5. Dichlorodiphenyltrichloroethane (DDT) & Metabolites

DDT (1,1,1-trichloro-II,2-bis(p-chlorophenyl)ethane) is an organochlorine insecticide. It was widely used across the globe to control insects on agricultural crops and vectors. Nowadays, it is used only in a few countries for controlling vectors transmitting diseases like malaria, typhus, yellow fever, and sleeping sickness. Technical-grade DDT is a mixture of three forms, p,p′-

DDT (85%), o,p′-DDT (15%), and o,o′-DDT (trace amounts), and may also contain DDE (1,1-dichloro-II,2-bis(p-chlorophenyl)ethylene) and DDD (1,1-dichloro-II,2-bis(p-chlorophenyl)ethane) as contaminants. DDD was also used to kill pests, and one form, o,p′-DDD, has been used to treat cancer of the adrenal gland. DDT and its metabolites, DDE and DDD, are persistent in the environment for a very long time, potentially for hundreds of years. Most of the DDT in the soil breaks down to DDD and DDE through microbial degradation and therefore, the metabolites should be analyzed instead of DDT. Further, these metabolites may evaporate into the air and deposited in other places. DDT and its metabolites get strongly adsorbed to the soil, and therefore generally remain in the surface layers of soil. Part of DDT and its metabolites may reach the surface water resources along with the soil particles, and only a very small fraction may seep into the groundwater.

IARC (1991) has concluded that there is insufficient evidence in humans and sufficient evidence in experimental animals for the carcinogenicity of DDT (Group 2B). BIS (2012) and WHO (2017) prescribes a guideline value of 0.001 mg/l for DDT and its metabolites in drinking water to protect the human health, however, it further states that the benefits of DDT use in malaria and other vector control programmes outweigh any health risk from the presence of DDT in drinking-water.

The DDE,p-p' concentration in the samples of study area ranges from ND to 1.83 ng/l (Ratta Khera, Mukatsar) and ND to 4 ng/l (Waring Khera, Mukatsar) in pre-monsoon and post-monsoon respectively (Figure . The average concentration of DDE,p-p' in pre and post monsoon samples was observed to be 0.07±0.02 ng/l and 2.08±0.15 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.52).

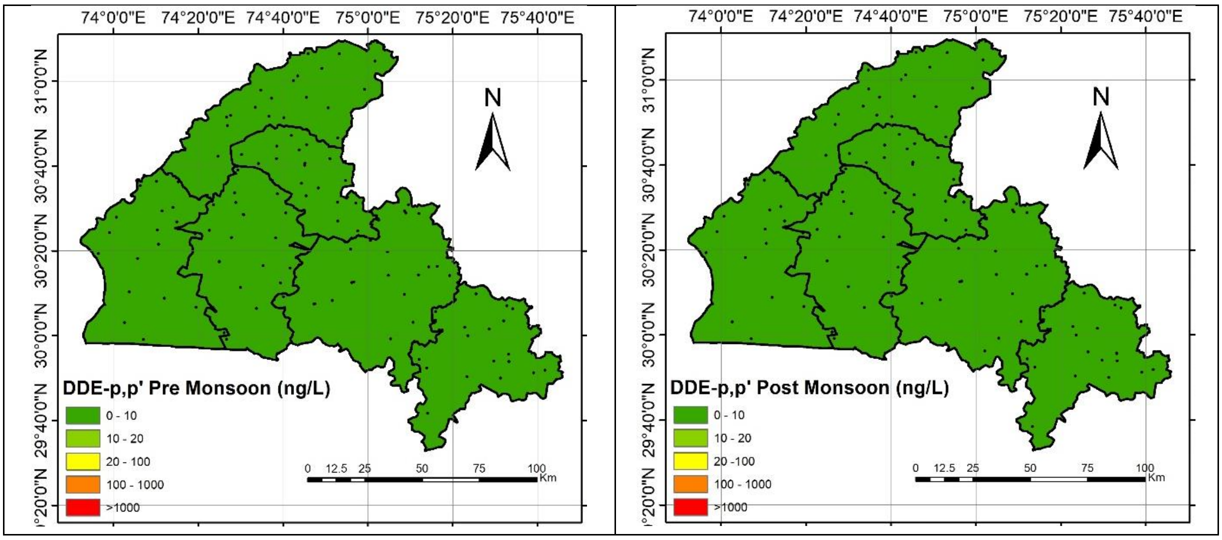


Fig. 4.52. Spatial variation of DDE in groundwater during pre & post monsoon

The DDT-p,p' concentration in the samples of study area ranges from ND to 8.87 ng/l (Lool bai, Bathinda) and ND to 12.67 ng/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of DDT-p,p' in pre and post monsoon samples was observed to be 0.23±0.08 ng/l and 4.02±0.19 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.53).

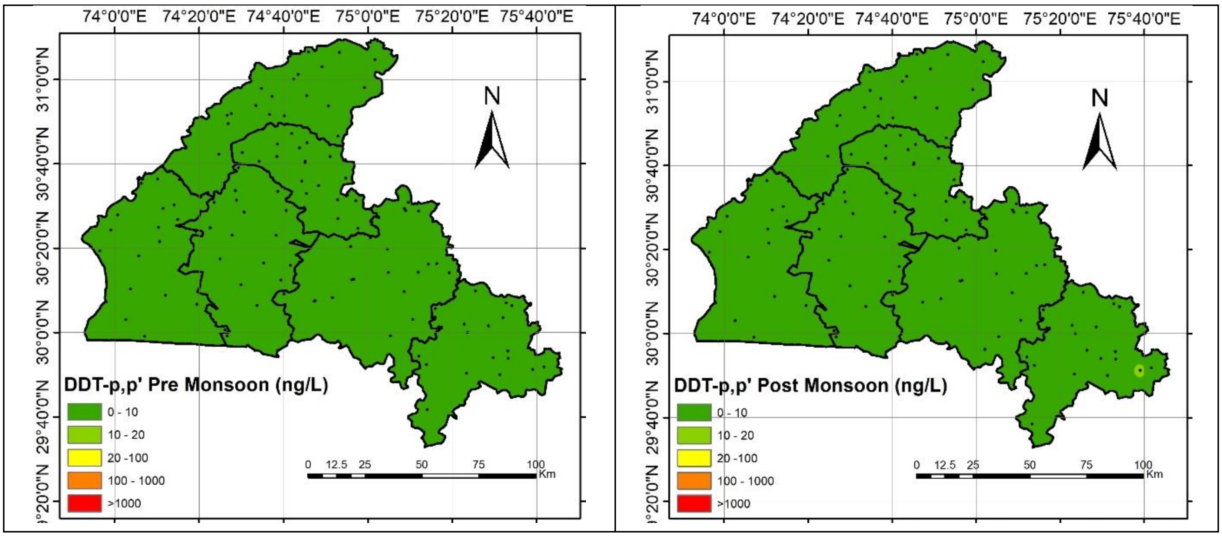


Fig. 4.53. Spatial variation of DDT in groundwater during pre & post monsoon

4.1.5.6. Ethion

Ethion is an organophosphate pesticide. It used to kill aphids, mites, scales, thrips, leafhoppers, maggots and foliar feeding larvae, on a wide variety of food, fiber and ornamental crops, orchids, lawns and turf. It is also used as a cattle dip for ticks and for buffalo flies. Ethion is absorbed by the skin, as well as by the respiratory and gastrointestinal tracts. Short term exposure symptoms include nausea, vomiting, abdominal cramps, diarrhea, excessive salivation, headache, giddiness, weakness, muscle twitching, difficult breathing, blurring or dimness of vision, and loss of muscle coordination. Ethion is very toxic for humans at a probable oral dose of 50–500mg/kg, and may lead to death from failure of the respiratory center, paralysis of the respiratory muscles, intense bronchoconstriction, or all three. Long term exposure may damage the nervous system (Pohanish 2015). WHO (2017) has not recommend any guideline value for ethion, however, BIS (2012) has recommended a limit of 0.003 mg/l for ethion in drinking water.

The Ethion concentration in the samples of study area ranges from ND to 425 ng/l (Lool bai, Bathinda) and ND to 168.12 ng/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of Ethion in pre and post monsoon samples was observed to be 17.76±5.58 ng/l and 2.38±1.46 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.54).

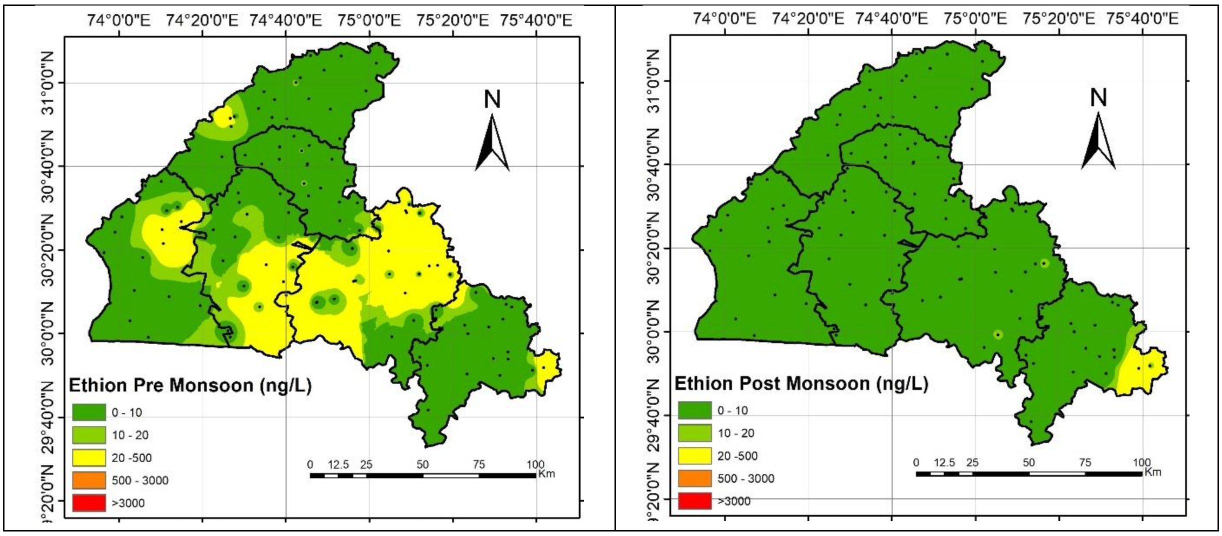


Fig. 4.54. Spatial variation of Ethion in groundwater during pre & post monsoon

4.1.5.7. Isoproturon

Isoproturon (3-(4-isopropylphenyl)-1,1-dimethylurea) is a selective, systemic phenylurease class herbicide used to control annual grasses and broad-leaved weeds in cereals. It is mobile in soil, however, it gets photodegraded, hydrolyzed and biodegraded. It does not possess significant genotoxic activity, but it causes marked enzyme induction and liver enlargement (EC 2002, WHO 2003). Its use has been banned in EU after 2007 considering potential groundwater contamination and risk to aquatic life. BIS (2012) and WHO (2017) recommends guideline value 0.009 mg/l for Isoproturon.

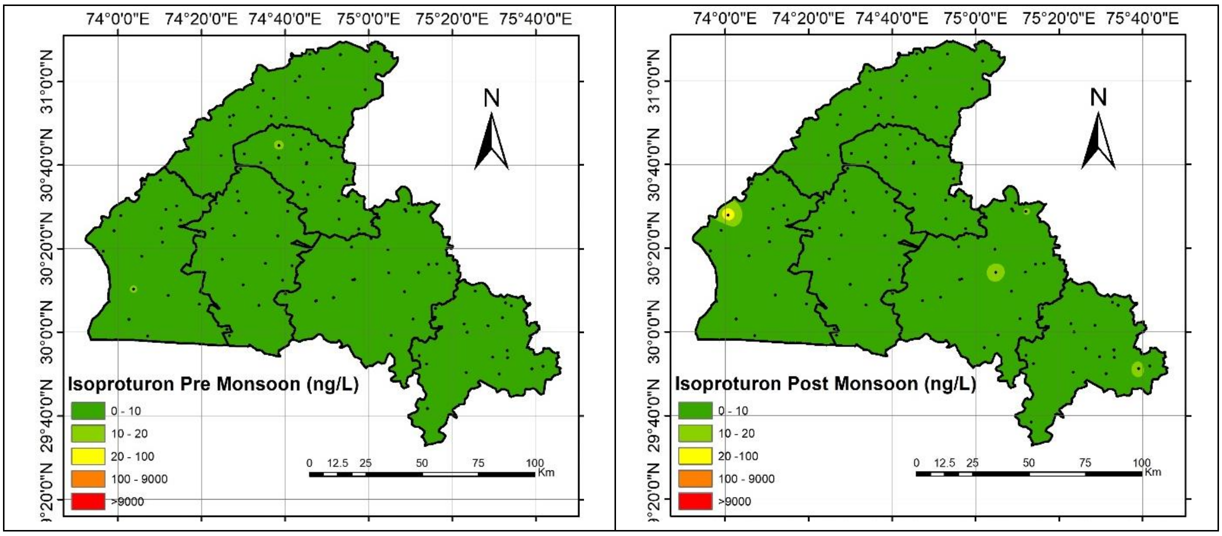


Fig. 4.55. Spatial variation of Isoproturon in groundwater during pre & post monsoon

The Isoproturon concentration in the samples of study area ranges from ND to 14.89 ng/l (Ramana, Faridkot)) and ND to 25.6 ng/l (Kawan wali, Fazilka) in pre-monsoon and post-monsoon respectively. The average concentration of Isoproturon in pre and post monsoon samples was observed to be 1.32±0.22 ng/l and 1.41±0.35 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.55).

4.1.5.8. Hexachlorocyclohexane (HCH)

HCH consists of eight isomers, but only α-HCH, β-HCH, γ-HCH, and δ-HCH are of commercial significance. All of the isomers are toxic to animals to varying degrees and are persistent in the environment, with only γ-HCH (Lindane) has an appreciable insecticidal activity. Lindane is used as an insecticide on fruit and vegetable crops, for seed treatment, and in forestry. Technical BHC is a mixture of a number of stereoisomers, principally alpha-BHC, beta-BHC, gamma-BHC and delta-BHC, and the proportion of these isomers can vary in different technical mixtures. The Stockholm Convention held in 2009 accepted inclusion of γ-, α-, and β-HCH in Persistent Organic Pollutants (POPs) list requiring the address to these chemicals at global level (Vijgen et al. 2010). However, the convention exempted the use of lindane as human health pharmaceutical. Several countries have already restricted the use of lindane. Lindane is not likely to pose a carcinogenic risk to humans, which was further confirmed by the epidemiological study designed to assess the potential association between breast cancer and exposure to chlorinated pesticides (WHO, 2011). WHO (2017) has prescribed the guideline value 0.002 mg/l for γ-BHC.

The Lindane concentration in the samples of study area ranges from ND to 4.75 ng/l (Jalalabad, Fazilka) and ND to 4.77 ng/l (Waring khera, Mukatsar) in pre-monsoon and post-monsoon respectively. The average concentration of Lindane in pre and post monsoon samples was observed to be 0.09±0.04 ng/l and 4.38±0.06 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.56).

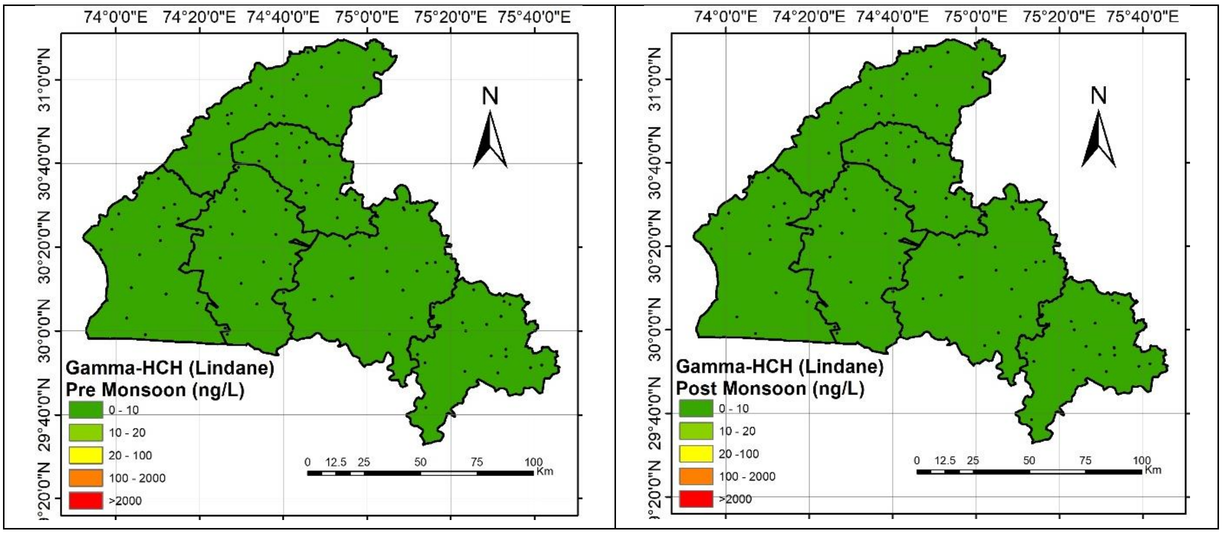


Fig. 4.56. Spatial variation of Lindane in groundwater during pre & post monsoon

4.1.5.9. Malathion

Malathion is an organophosphorus insecticide to control mosquitoes and a variety of insects that attack fruits, vegetables, landscaping plants and shrubs, by acetylcholinesterase inhibition. It is also used to control ticks and insects on pets and lice on human body. Under least favorable conditions (i.e. low pH and little organic content), Malathion in low pH water, with little organics, may persist for years, however, in normal conditions, the half-life is roughly 7–14 days. Malathion travels to the liver and kidneys and affects the nervous system. Generally, the body can break down Malathion and removes it quickly. The health based value for malathion is 0.9 mg/l, and the values encountered in drinking water resources are much lower than this values and hence WHO (2017) considered unnecessary to derive a formal guideline value for malathion in drinking water, however, BIS (2012) has recommended a limit of 0.19 mg/l for malathion in drinking water.

The Malathion concentration in the samples of study area ranges from ND to 13.93 ng/l (Ferozepur) and ND to 6.57 ng/l (Sangreri, Mansa) in pre-monsoon and post-monsoon respectively. The average concentration of Malathion in pre and post monsoon samples was observed to be 1.37±0.25 ng/l and 1.73±0.18 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.57).

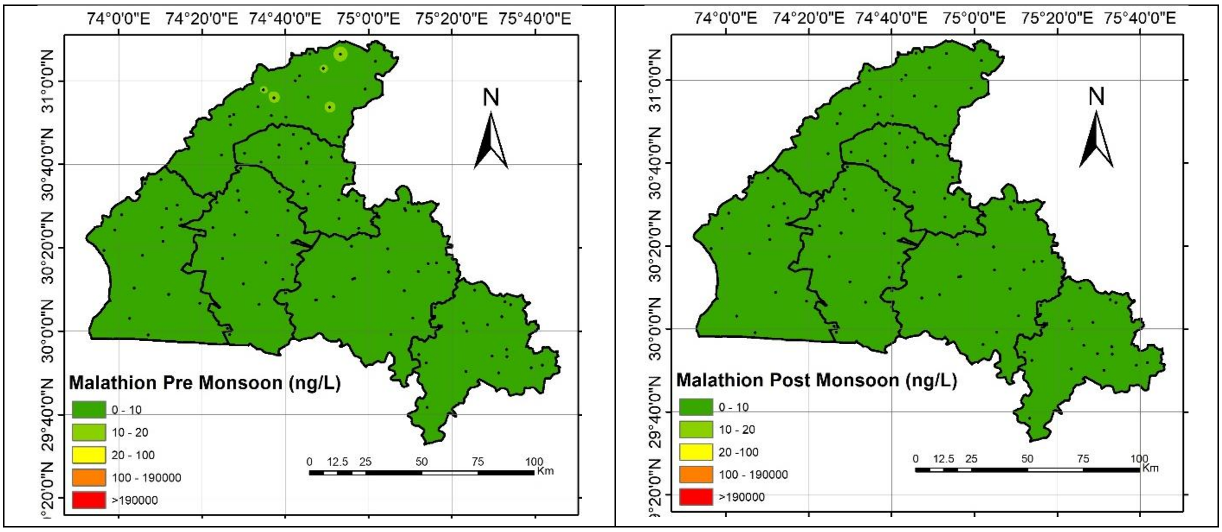


Fig. 4.57. Spatial variation of Malathion in groundwater during pre & post monsoon

4.1.5.10. Phorate

Phorate is an organophosphate insecticide/nematocide used for the control of sucking, biting, and chewing insects, mites and certain nematodes. Phorate is a restricted use pesticide with no residential application and is among the most poisonous chemicals commonly used for pest control. Phorate can cause cholinesterase inhibition in humans causing nausea, dizziness, confusion, and at very high exposures, respiratory paralysis and death. Phorate applied to soil is rapidly degraded by microorganisms and interaction with water. It's half-life in field study was observed to be 7.5 days and in aqueous solution, it is two hours at pH 8 and 70 °C (Health

Canada 1986), due to which phorate is unlikely to occur in drinking water (WHO 2017). BIS (2012) has recommended a limit of 0.002 mg/l for phorate in drinking water.

The Phorate concentration in the samples of study area ranges from ND to 296 ng/l (Zira, Ferozepur) and ND to 567 ng/l (Waring khera, Mukatsar) in pre-monsoon and post-monsoon respectively. The average concentration of Phorate in pre and post monsoon samples was observed to be 6.21±2.96 ng/l and 44.62±7.61 ng/l respectively. No sample exceeded the permissible limit in pre-monsoon and post-monsoon period (Figure 4.58).

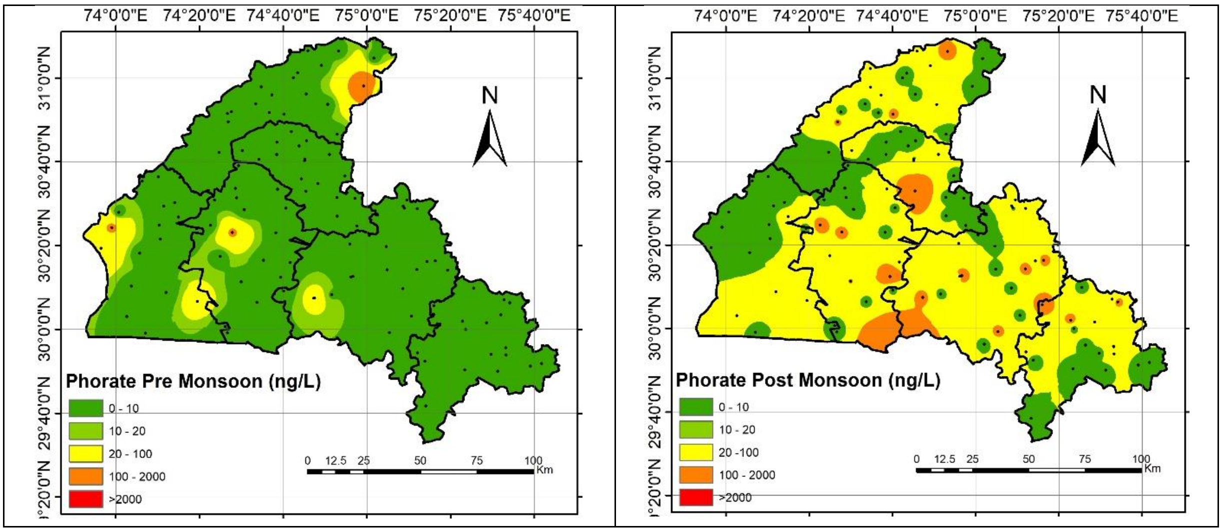
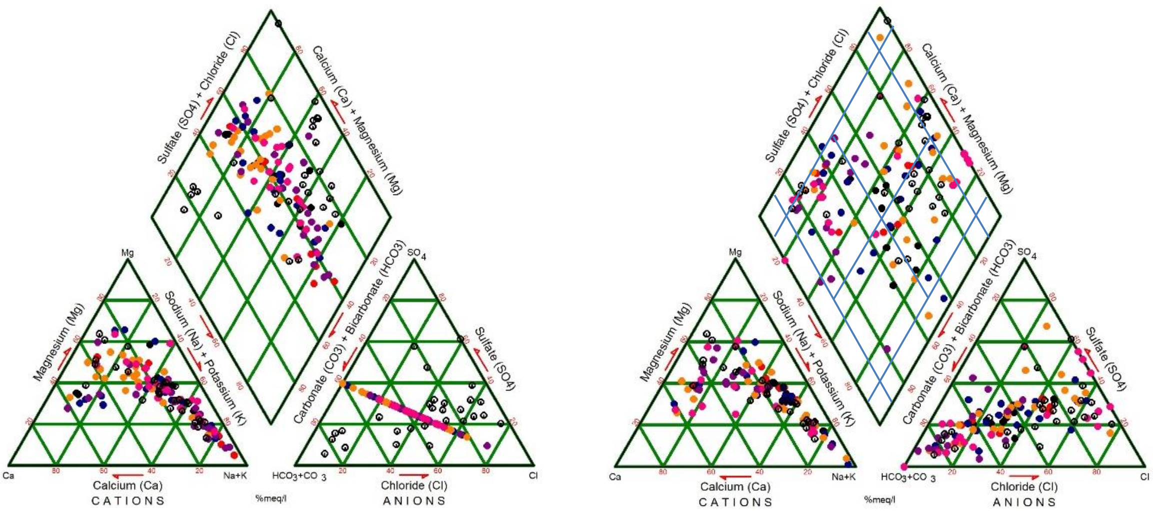


Fig. 4.58. Spatial variation of Phorate in groundwater during pre & post monsoon

4.2.Hydrogeochemical Facie

To understand the hydro-geochemical facies of groundwater of the study area, the ions were plotted on Piper trilinear plot (Piper, 1994) consisting of one triangle plot for cations, one for anions, and a diamond plot for the combined indication to the water type. The plots clearly indicate change in the groundwater composition during pre-monsoon period and post monsoon period (Figure 4.59). The pre-monsoon samples were mostly of no-dominant type for cations and anions with some samples sodium or potassium and Magnesium type, and chloride type. Similar trend was observed for the post monsoon samples with more samples in no-dominant type. The groundwater was observed to be Ca(Mg)Cl(SO4) type and Na(K)Cl(SO4) type during pre-monsoon and mix type with dominance of Ca(Mg)HCO3 and Na(K)Cl(SO4) type type as elucidated by the diamond plot (Liu et al. 2021) (Figure 4.59).

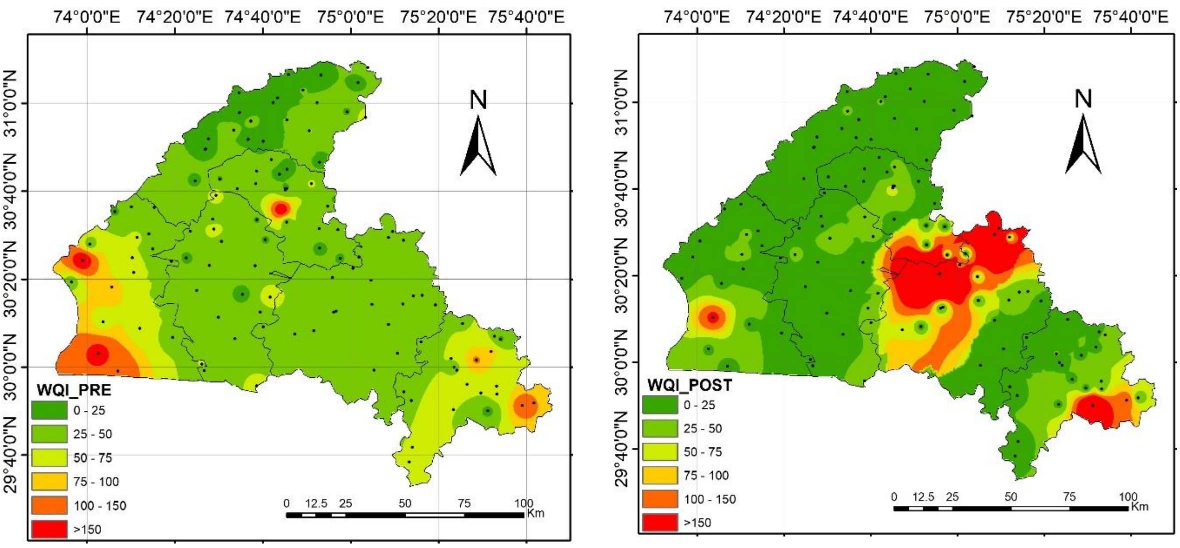


(a) (b)

Fig. 4.59. Piper trilinear plot for groundwater during (a) pre & (b) post monsoon

4.3.Suitability of Water for Drinking Purpose

The water quality indices for drinking water purpose was computed with reference value prescribed by BIS (2012) for drinking water and the values for parameters not mentioned in BIS (2012), the values prescribed by WHO (2017) was considered. The water quality indices of groundwater for drinking purpose ranges from 11.5 - 234 and 2.3 – 2448.8 during pre and post-monsoon respectively (Figure 4.60). During the pre-monsoon period, 28.6%, 45.9%, 17.3%, 2.0%, and 6.1% samples were observed in excellent, good, fair, poor, and very poor categories respectively. Similarly, during post monsoon period, 74.6%, 18.3%, 0.8%, and 6.3% samples were observed in excellent, good, fair, and very poor categories respectively. The groundwater was observed more deteriorated during the pre-monsoon period with almost 8% samples unfit for drinking and 74.5% samples in the excellent and good category. The parameters responsible for the poor water quality were both carcinogenic (Hg, As, Se, U, Cd, Pb, Ni, Cr, and NO3) and non-carcinogenic (Al, Mn, Fe, B, Cu, and F). Most of the samples were observed to be unfit for drinking purposes in pre-monsoon due to increased U, As, Se, Hg, and Cd concentration.



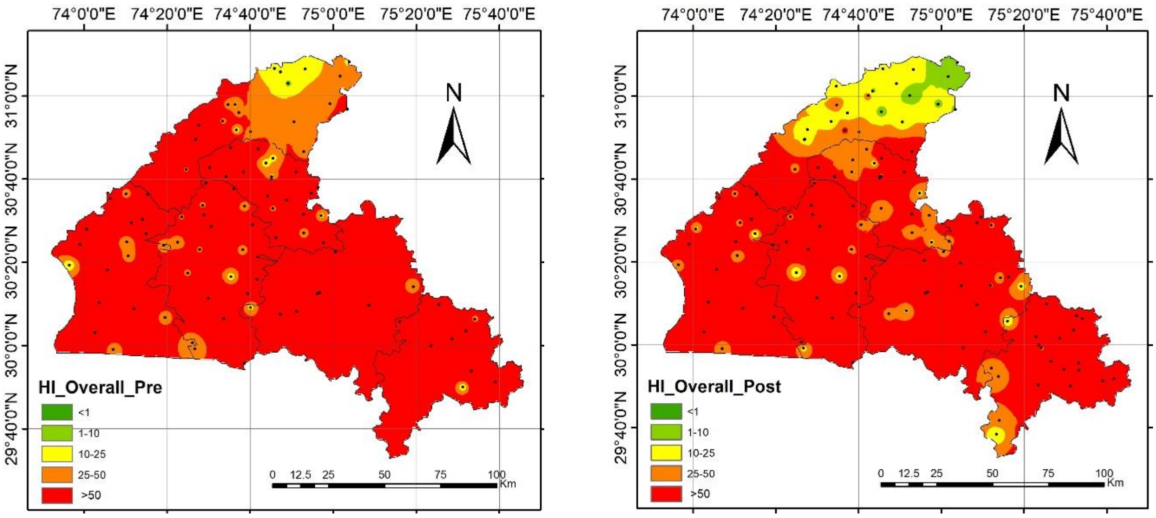
(a) (b)

Fig. 4.60. WQI for domestic application (a) pre & (b) post monsoon

4.4.Health Risk Assessment

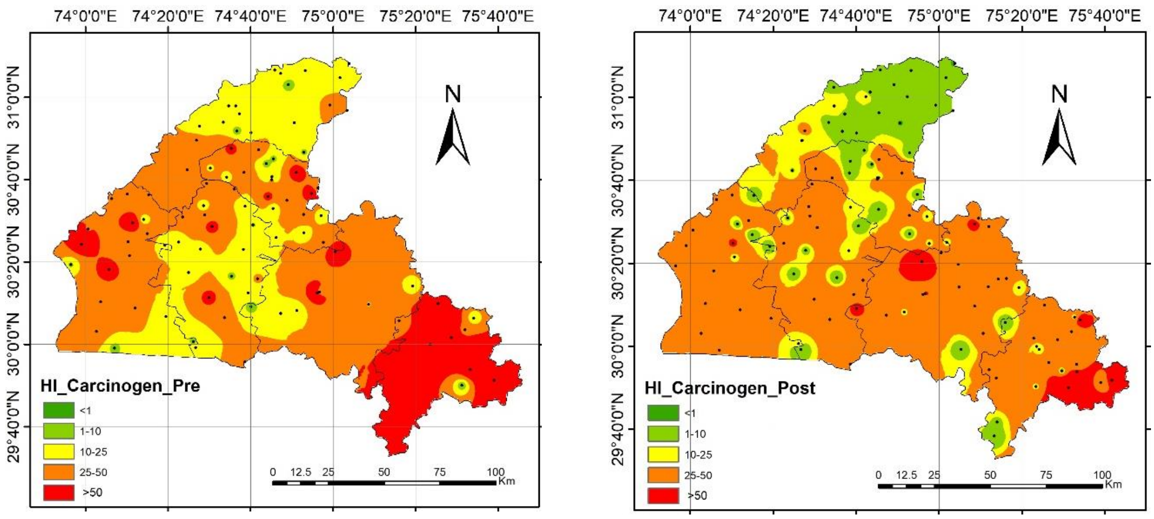
Health risk assessment is the potential of development of health-related side effects on the exposure to chemicals based on a unique set of exposure, model, and toxicity assumptions. It is generally a comparison of a receptor's potential exposure relative to a standard exposure level that poses no adverse health effects to the potential receptors over a similar exposure period (USEPA 2005). Based on the hazard index (HI), the water samples can be classified as non-hazardous (<0.1), low hazardous (0.1-1.0), moderately hazardous (1.0-10.0), and highly hazardous (>10) to human health. The health risk was computed using major ions and trace metals concentration in the analysed samples which are detrimental to human health. Pesticides and PAHs concentration was not considered for computing the health risk because their concentration was significantly lower than the prescribed guideline values.

The spatial distribution of associated overall health risk and cancer-related health risk due to the consumption of groundwater is depicted in Figures 4.61 (a & b) and 4.62 (a & b) respectively. The overall health risk is calculated based on F, NO_3, NO_2, SO_4, Li, B, Fe, Co, Ni, Pb, Be, As, Se, Hg, U Al, As, Cr, Cu, Fe, Mn, Pb, and Zn concentration in drinking water. The average individual health risk for the pre-monsoon and post-monsoon samples were in the order U>As>Li>F>Cr>Pb>Fe>Se>B>NO_3>NO_2>Zn>Hg>Mn>Co>Fe>Ni>Al>Cu>Be and U>Pb>F>Cr>As>Li>Co>B>NO_3>Hg>Zn>Be>Se>Fe>Mn>Cu>Ni>Al respectively. The groundwater of the study area poses moderate to high risk to the consumers and the health risk got elevated for the pre-monsoon period samples due to a significant increase in U, As, Cr, Li, and F concentrations. During the pre-monsoon period, 96.9% of samples were in the high-risk category which reduced to 88.1% in the post-monsoon period (Figure 4.61). The cancer-associated risk based on Ni, Pb, As, Hg, U, Cr, Be, Co, Se, Cd, and NO_3 was computed and around 83.7% of samples were in the high-risk category during pre-monsoon which got reduced to 61.1% in the post-monsoon period (Figure 4.62). Removal of U from the water samples will change the status of 90.2% samples in the pre-monsoon and 76.9% samples in the post-monsoon from high-risk category to low-risk category. Removal of U, As, Cr, and Pb from the groundwater samples will result in 93.9% and 98.4% groundwater samples under low-risk category for pre-monsoon and post-monsoon period respectively.



(a) (b)

Fig. 4.61. Health risk assessment based on all the observed parameter posing threat to health: (a) Pre-Monsoon period (b) Post-Monsoon period

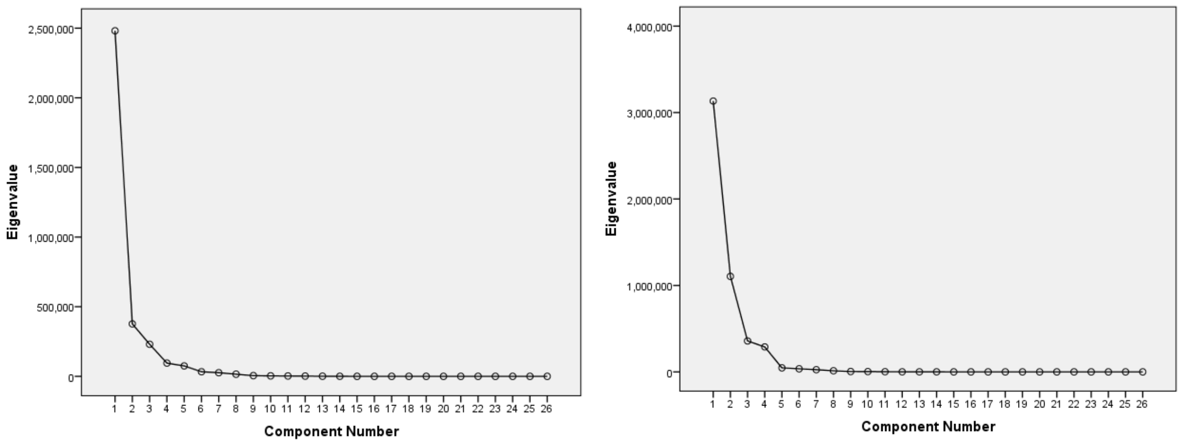


(a) (b)

Fig. 4.62. Health risk assessment based on observed carcinogenic parameter: (a) Pre-monsoon period (b) Post-monsoon period

4.5.Sources of pollutants in Groundwater

Principal component analysis (PCA) is a multivariate statistical analysis for reducing the dimensionality of large datasets often difficult to interpret for increasing the interpretability without losing information (Jolliffe and Cadima, 2016). The PCA has helped in the identification of the major variable factors responsible for the pollution (Varol and Davraz 2015; Ismail et al. 2016; Zhang et al. 2016; Chabukdhara et al. 2017). In this study, Principal component (PC) extraction was done with minimum acceptable Eigen value as 1 (Kaiser 1958) and the components with eigen value <1 were discarded as noise data (Yong and Pearce 2013; Ledesma et al. 2015). The priority to define the informative factor was based on the factor loading: strong (>0.75), moderate (0.75-0.50), and weak (<0.50) (Varol and Davraz 2015). In this study, B, Cu, Co, Ni, Pb, Be, Se, Hg, U, Al, As, Cr, Fe, Mn, Zn, pH, F, Cl, NO_3, SO_4, NH_4, K, Ca, Mg, and Na were considered for PCA. The PCA analysis revealed 3 principal components (PC) for pre-monsoon samples and 4 principal components (PC) for post-monsoon samples (Figure 4.63).



(a) (b)

Fig. 4.63. Scree Plot: (a) Pre-monsoon period (b) Post-monsoon period

In pre-monsoon, extracted principal component, PC1, with Eigen value >1 account for 74.15 % variance of the total variance with strong loading of SO_4 (Table 4.2). High variance is an indicator of sporadic distribution and anthropogenic origin (Zhang et al. 2016), and the same was observed in this case indicating the source of SO_4 as anthropogenic. The main contributor of these ions may be fertilizers used in agriculture (Adimalla 2020; Adimalla and Venkatayogi 2017). Component 2, PC2, is having the 11.25 % of covariance of the total with strong loading of Fe, moderate loading of B, Co, Al, and Na, and weak loading of Pb, Se, U, Cl, and Alkalinity. PC3, is having the 6.88 % of covariance of the total with moderate loading of B, Cl, Na, Ca, and Mg, and weak loading of Se, U, K, and alkalinity (Table 4.3). The low variance is an indicator of even distribution and originated from natural sources, therefore, Fe, B, Co, Al, Na, Pb, Se, U, Cl, Ca, Mg, and K in the groundwater may have originated from the dissolution of aquifer sediment (Zhang et al. 2016; Wang and Lu 2011).

Table 4.3. Principle component, Co-variance and contribution principal component analysis

	Pre-monsoon			Post-monsoon			
Component	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**	**PC4**
% of Variance	74.15	11.25	6.88	62.474	22.031	7.132	5.758
Cumulative %	74.15	85.41	92.29	62.474	84.506	91.638	97.396

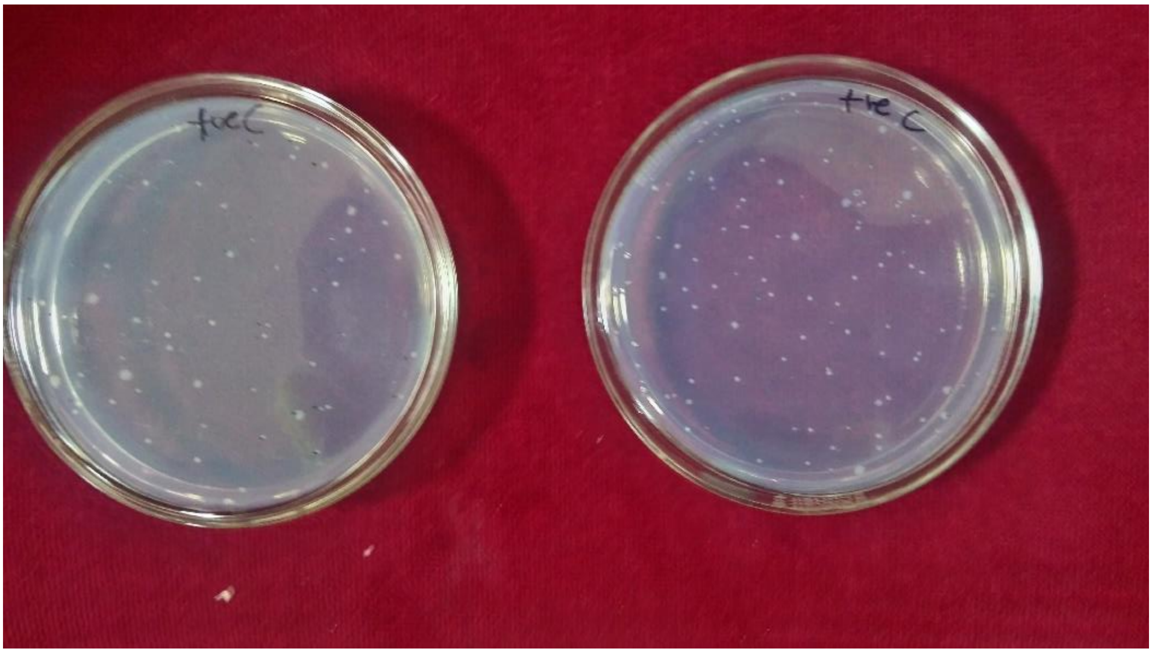
Table 4.3 Matrix of the principal component analysis loadings of heavy metals

Component Matrix							
Element	**Pre-monsoon**			**Post-monsoon**			
	1	**2**	**3**	**1**	**2**	**3**	**4**
B	0.12	0.61	0.58	0.09	0.77	-0.52	-0.35
Cu	-0.01	0.14	0.02	0.26	-0.16	0.19	-0.02
Co	0.06	0.61	-0.14	0.22	-0.15	0.23	-0.04
Ni	0.02	0.17	-0.12	0.22	-0.15	0.22	-0.04
Pb	0.02	0.33	-0.15	0.27	-0.14	0.20	-0.04
Be	-0.02	0.14	-0.22	0.22	-0.15	0.23	-0.04
Se	0.07	0.36	0.37	0.23	-0.07	0.20	-0.06
Hg	0.00	0.07	0.08	0.24	-0.15	0.22	-0.05
U	0.03	0.39	0.39	0.21	0.39	-0.35	-0.18
Al	-0.01	0.60	-0.47	0.78	0.04	-0.07	-0.04
As	0.02	0.13	0.08	0.40	-0.12	0.27	-0.01
Cr	0.00	0.19	0.04	0.18	0.27	-0.11	-0.03
Fe	0.05	0.87	-0.41	1.00	-0.01	0.04	-0.03
Mn	0.07	0.18	0.20	0.23	-0.11	0.13	0.09
Zn	-0.04	0.15	-0.06	0.42	-0.06	-0.58	0.69
pH	-0.05	-0.04	-0.16	0.47	-0.25	-0.10	-0.11
F	-0.04	0.24	0.15	0.03	0.21	-0.07	-0.03
Cl	0.24	0.42	0.67	0.01	0.84	0.36	0.24
NO_3	0.09	0.23	0.24	0.06	0.39	-0.07	0.26
SO_4	1.00	-0.02	-0.02	-0.02	0.94	0.24	0.18
Na	0.22	0.62	0.71	0.05	0.91	0.20	0.20
NH_4	0.09	0.22	0.26	0.25	0.77	0.22	0.18
K	0.09	0.17	0.46	0.13	0.43	0.07	0.18
Ca	0.22	0.23	0.51	-0.03	0.75	0.35	0.28
Mg	0.18	0.29	0.61	-0.04	0.81	0.36	0.24
ALK	0.02	0.45	0.43	0.13	0.38	-0.08	0.01

The principal components PC1, PC2, PC3, and PC4 for the post-monsoon samples account for 62.47%, 22.03%, 7.13%, and 5.76% variance of the total respectively. PC1 was influenced by the strong loading of Al and Fe, and weak loading of As, Zn, and pH. PC2 was having strong loading for B, Cl, SO_4, Na, NH4, Ca, and Mg, and weak loading for U, NO_3, K, and alkalinity. PC3 was having weak loading for Cl, Ca, and Mg. PC4 was having medium loading of Zn (Table 4.2 & 4.3). As, Al, Fe, Zn, and pH were observed to be of anthropogenic origin or influenced by anthropogenic inputs. The CV of other PCs was less than 50% indicating even distribution and from geogenic origin.

4.6. Mutagenicity Test

The mutagenicity test was conducted using Salmonella typhimurium TA100 (MTCC 1252), for detecting base-pair substitution obtained from Microbial Type Culture Collection and Gene Bank (MTCC), IMTech, Chandigarh. Attempt was made to prepare a mutagenicity scale using



known mutagens like Ethidium Bromide and Acridine orange (Figure 4.64).

Fig. 4.64. Colonies observed in positive control tests

Based on the number of colonies observed with the addition of mutagen, a mutagenicity scale was prepared for estimation of mutagenicity of drinking water of the study area (Figure 4.65). The experiments were repeated several times with the mutagens but the results were not consistent and therefore, the results of mutagenicity could not be estimated with the desired accuracy and it requires comprehensive investigation.

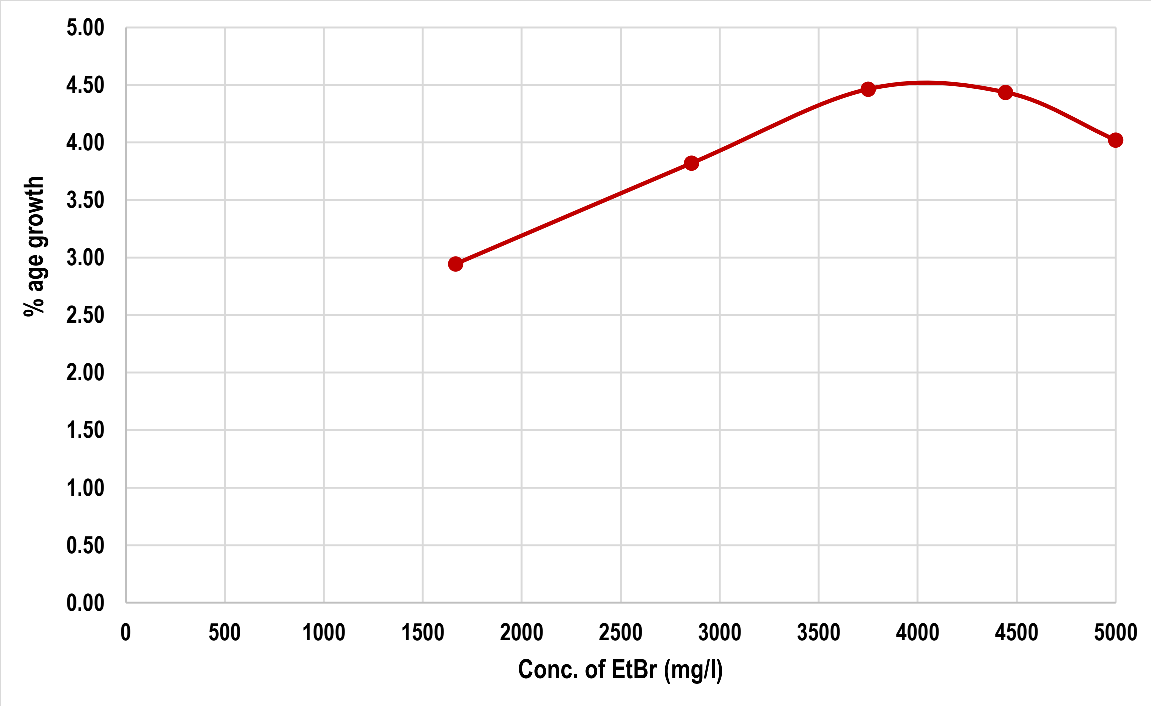


Fig. 4.65. Mutagenicity scale w.r.t. Ethidium bromide

4.7.Radon Estimation

Drinking water samples, mostly groundwater, were collected from different sources such as hand pumps (shallow) and submersible pumps (deep). The radon was analyzed onsite, using continuous online radon monitor RAD7 (Durridge Company Inc., USA), to avoid decay of radioactive gas. The instrument uses solid state silicon detector for analysis of radon gas.

The proposed maximum radon levels in community water supply by USEPA (NRC, 1999) is 11 Bq/l (≈300 pCi/l). WHO (2011) has recommended the guideline value of 100 Bq/m^3, and considering 1:10000 air-water transfer factor (Yang et al., 2014), the domestic supplies should be restricted for 1000 Bq/l (≈27000 pCi/l) radon if radon in ambient air is absent. In case the ambient radon concentration increases, the radon concentration in domestic water supply should be minimized to ensure the ambient radon concentration remains below 100 Bq/m^3. The concentration of radon in the shallow groundwater (depth: 25-150 ft bgl) ranges from 11.1 pCi/l to 209 pCi/L, with average concentration 95.02±2.91 pCi/l. Maximum concentration of radon was observed in the shallow groundwater of Jhanda Kalan, Mansa. The radon concentrations in the deep groundwater (>150 ft bgl) of the study area ranges from 37.5 pCi/l to 319 pCi/L, with average concentration 104.5±6.6 pCi/l (Figure 4.66 and 4.67). Maximum concentration of radon was observed in the deep groundwater of Jalalabad, Fazilka. The average radon concentration in the shallow and deep aquifers of the study area was observed in the order Ferozepur<Fazilka<Bathinda<Fardikot<Muktsar<Mansa and Muktsar<Ferozepur< Fardikot< Bathinda<Mansa<Fazilka respectively.

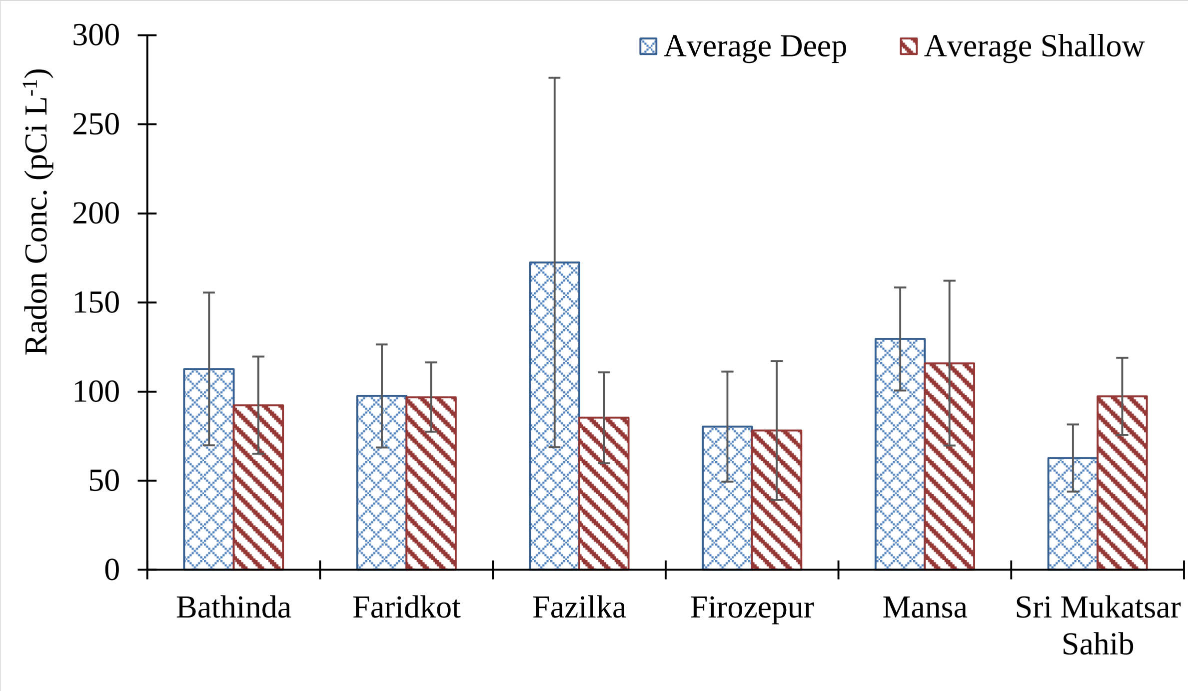


Fig. 4.66. Radon concentration in shallow and deep groundwater samples of SW Punjab

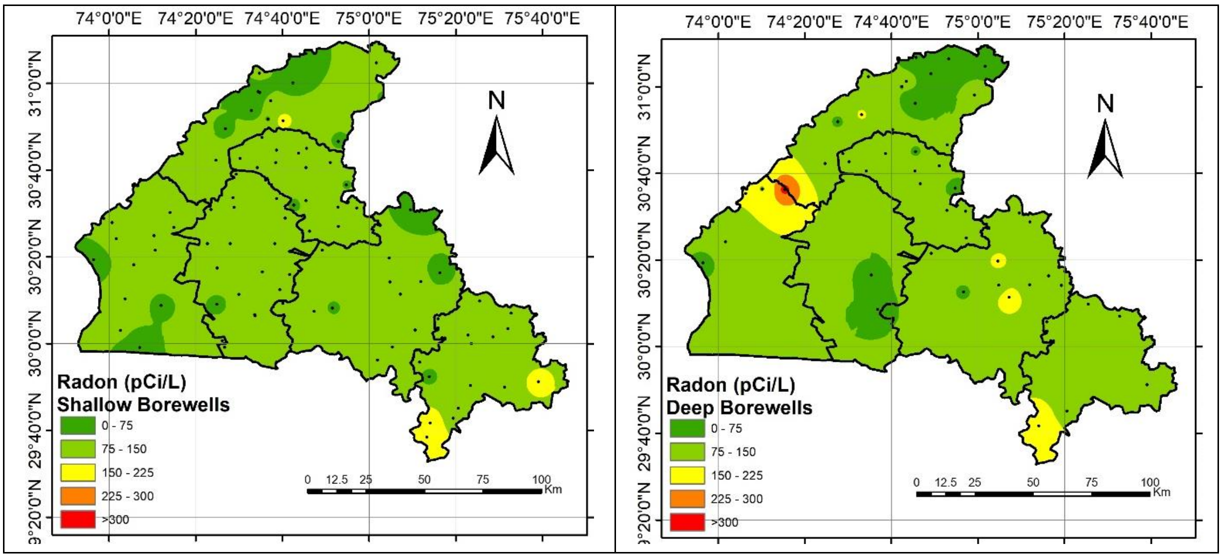


Fig. 4.67. Spatial variation of Radon in shallow and deep bore wells

4.7.1. Radon Associated Carcinogenic Risk Assessment

Excess Cancer Risk (ECR) is defined as the number of deaths per million of person per year from lung cancer due to the exposure to radon and its progeny (Nonka et al. 2017). The carcinogenic risk due to radon in drinking water can be calculated as excess cancer risk (ECR) by using the following relation -

$$ECR = AC \times R \tag{4.1}$$

Where, AC is the activity concentration of radon in pCi L^{-1} and R is the risk factor, which is the product of risk coefficient of radon, r (5.13 x 10^{-11} L pCi^{-1}), and per capita activity intake of radon in drinking water, I (liters). After incorporating r and I in equation (4.1), the given equation becomes –

$$ECR = AC \times (r \times I) \tag{4.2}$$

Where I = life expectancy of 70 years (25,550 days) x daily intake of water as 4 l/day which is upper bound level of Indian adult as per climate of India. Now, equation becomes-

$$ECR = AC \times [(5.13 \times 10^{-11}) \times (4.00 \times 25550)] \tag{4.3}$$

$$ECR = AC \times (5.24 \times 10^{-6}) \tag{4.4}$$

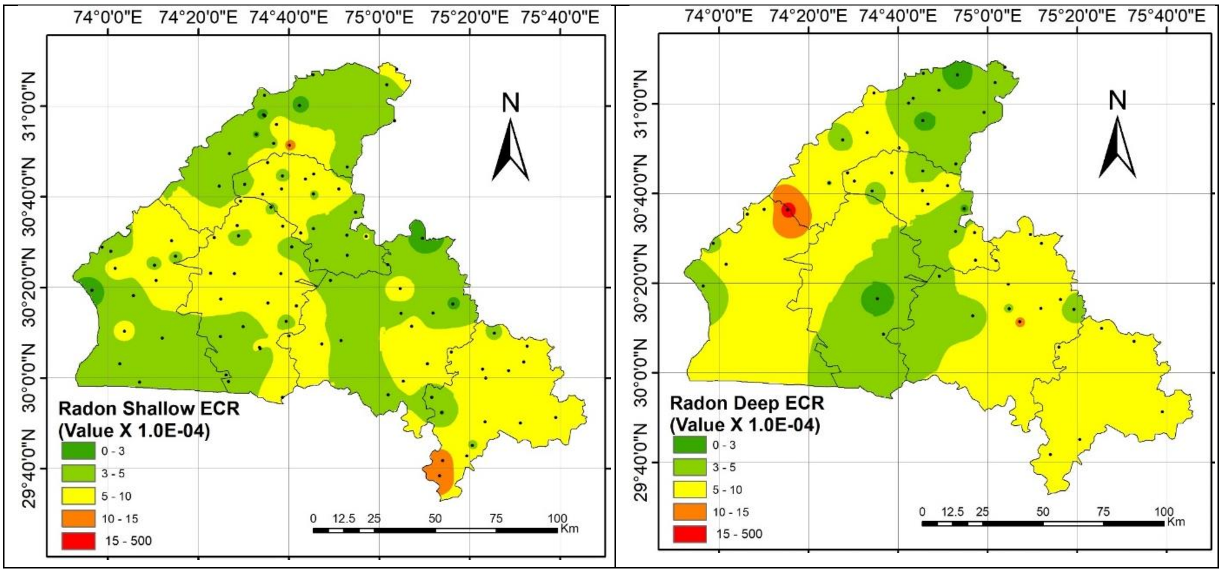


Fig. 4.68. Spatial variation of ECR due to radon in shallow and deep bore wells

Carcinogenic risk assessment due to radon intake through drinking water, excess risk has been calculated and shown in the figure 4.68. The value of ECR due to radon and its progeny in deep borewell groundwater indicates possible number deaths/million population/year in the range from 197 to 1670 with average value of 548. Similarly, the possible number of deaths/million population/year due to ingestion of shallow borewell water of the study area may be in the range from 58.2 to 1100 with average value 498. People using water from deep borewells of Jalalabad city in Fazilka district are at higher risk due to exposure with radon and its progeny with highest having excess value of ECR are at high risk and from shallow borewells of these districts are at normal to moderate risk.

5. CONCLUSIONS AND SCOPE OF FUTURE WORK

Water is most precious natural resource on this planet Earth, and the life on the Earth depends on the presence of water. However, population explosion, industrialization, urbanization, unmanaged waste management and modern agricultural activities have resulted in pollution of the ground as well as surface water. The contaminated water consumption is the main source of human health problem in this twenty first century. The south-western districts of Punjab are witnessing high per capita cancer cases, almost twice of national average. With the above background, this study is being carried out to identify the amount of carcinogenic contaminants present in the groundwater of South-Western districts of Punjab, India and following conclusions can be drawn from the work carried out till date-

- **Organoleptic parameters:** Around 1.6% samples exceeded the maximum permissible limit for pH (8.5) during pre- and post-monsoon period. The TDS of the samples were on significantly higher side 23.5% and 23.3% samples exceeded the prescribed maximum permissible limit of 2000 mg/l for TDS in drinking water.

- **Major Ions:** In the study area, Ca, Mg, Na, NH_4, F, Cl, NO3, NO2, SO4, and alkalinity content in the analyzed drinking water samples exceeded the permissible limit for 6.1%, 11.2%, 49%, 78.5%, 19.6%, 3.1%, 22.7%, 2.9%, 34.7%, and 12.2% pre-monsoon samples, respectively. Similarly, during post-monsoon period, around 10.3%, 20.6%, 53.2%, 35.7%, 31%, 7.1%, 24.6%, 38.1%, and 6.4% samples exceeded the maximum permissible limits for Ca, Mg, Na, NH_4, F, Cl, NO3, SO4, and alkalinity respectively.

- **Trace Metals:** The samples were analysed for B, Fe, Co, Ni, Pb, Be, As, Se, Hg, U, Al, Cr, Cu, Mn, and Zn concentration. Around 11.2%, 23.5%, 1.0%, 4.1%, 41.8%, 1.0%, 76.5%, 11.2%, and 1.0% samples exceeded the maximum permissible limits for B, Fe, Ni, As, Se, Hg, U, Al, and Cr during pre-monsoon respectively. During post monsoon, around 42.1%, 2.4%, 7.1%. 2.4%, 1.6%, 4.8%, 3.2%, 61.9%, 9.5%, and 27.8% samples exceeded the permissible limits for B, Ni, Pb, Be, As, Se, Hg, U, Al, and Fe respectively.

- **Pesticides & PAHs:** The samples were analysed for alachlor, atrazine, butachlor, chlorpyripos, DDT, DDE, DDD, ethion, isoproturon, HCH, malathion, phorate, naphthalene, acenaphthene, phenanthrene, anthracene, fluoranthene, pyrene, and chrysene. All the pesticides and PAHs were observed to be below the recommended limits for drinking water.

- **Hydrogeochemical Facie:** The groundwater was observed to be Ca(Mg)Cl(SO4) type and Na(K)Cl(SO4) type during pre-monsoon and mix type with dominance of Ca(Mg)HCO3 and Na(K)Cl(SO4) type during post-monsoon. A significant change in the groundwater composition was observed for pre- and post-monsoon samples. The pre-monsoon samples were mostly of no-dominant type for cations and anions with some samples sodium or potassium and Magnesium type, and chloride type. Similar trend was observed for the post monsoon samples with more samples in no-dominant type.

- **Suitability for Drinking Purpose:** Around 28.6%, 45.9%, 17.3%, 2.0%, and 6.1% pre-monsoon samples were observed in excellent, good, fair, poor, and very poor categories respectively. Similarly, during post monsoon period, 74.6%, 18.3%, 0.8%, and 6.3% samples were observed in excellent, good, fair, and very poor categories respectively. The parameters responsible for the poor water quality were both carcinogenic (Hg, As, Se, U, Cd, Pb, Ni, Cr, and NO_3) and non-carcinogenic (Al, Mn, Fe, B, Cu, and F).

- **Human Health Risk:** The overall health risk was calculated based on F, NO_3, NO_2, SO_4, Li, B, Fe, Co, Ni, Pb, Be, As, Se, Hg, U Al, As, Cr, Cu, Fe, Mn, Pb, and Zn concentration in drinking water respectively. During the pre-monsoon period, 96.9% of samples were in the high-risk category which reduced to 88.1% in the post-monsoon period. The cancer-associated risk based on Ni, Pb, As, Hg, U, Cr, Be, Co, Se, Cd, and NO_3 was computed and around 83.7% of samples were in the high-risk category during pre-monsoon which got reduced to 61.1% in the post-monsoon period.

- Removal of U, As, Cr, and Pb from the groundwater samples will result in 93.9% and 98.4% groundwater samples under low-risk category for pre-monsoon and post-monsoon period respectively.

- The PCA analysis indicated SO4 in the pre-monsoon samples and As, Al, Fe, and Zn in post-monsoon samples as a result of anthropogenic activities.

- **Radon:** The concentration of radon in the shallow groundwater (depth: 25-150 ft bgl) ranges from 11.1 pCi/l to 209 pCi/L, with average concentration 95.02±2.91 pCi/l and in the deep groundwater (>150 ft bgl), it ranges from 37.5 pCi/l to 319 pCi/L, with average concentration 104.5±6.6 pCi/l. Maximum concentration of radon was observed in the groundwater of Jalalabad, Fazilka. Carcinogenic risk assessment due to radon intake through drinking water, indicates possible number deaths/million population/year in the range from 197 to 1670 with average value of 548 for deep borewells, and 58.2 to 1100 with average value 498 for shallow borewells.

Although, this study resulted in comprehensive water quality status of the south west Punjab districts w.r.t. cancer cases in the study area and the health risks associated with ingestion of the groundwater of the area, following research questions needs to be further investigated-

1. The factors/mechanism responsible for the dissolution of U and other trace metals in the groundwater to minimize their concentration through in-situ measures.
2. Estimation of indoor radon concentration for holistic estimation of overall cancer risk.
3. Mutagenicity of water samples through cell line culture study.

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APPENDIX-A Project summary

Table A.1: Summary

<table>
<tr><td colspan="4">Project objectives</td></tr>
<tr><td>Objectives as per project document</td><td>Revised objective</td><td colspan="2">Reasons for revision</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Manpower deployed (against sanctioned manpower)</td></tr>
<tr><td colspan="2">Sanctioned</td><td colspan="2">Deployed</td></tr>
<tr><td>Designation</td><td>Person months</td><td>Designation</td><td>Person months</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Infrastructure/ equipment</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Developed/ procured</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Field work</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Completed</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Workshop/ Capacity building/ technology transfer</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Organized</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Study area</td></tr>
<tr><td colspan="2">Planned</td><td colspan="2">Extended</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="4">New data generated in the project</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Achievement</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Envisaged contribution of the project</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Contribution made</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">How research outcome benefited the end user department and society</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Benefit derived</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">End-of-project deliverables</td></tr>
<tr><td>Planned (as per project proposal)</td><td>Achieved</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Outsourcing (>1 lakh)/ consultancy (All)</td></tr>
<tr><td>Consultant (name and qualifications), organization / outsource agency</td><td>Work assigned</td><td>Estimated cost Rs</td><td>Actual cost Rs</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Financial achievement</td></tr>
</table>

S No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.				
2	Travelling Expenditure				
3	Infrastructure/Equipment				
4	Experimental Charges/Field work/Consumables				
5	Capacity building/Technology transfer				
6	Contingency				
7	Outsourcing/ consultancy				
	Total				

Table A.2: Quantitative outcome

i. Research papers published/ submitted		
S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/ seminar)	Impact factor for Journal

Reports/Monographs/Internal publications brought out	
S. No.	Reports/Monographs/Internal publications

ii. New techniques/models/ software/ knowledge developed, if any

iii. Web site/ application developed				
Name	Web address	Server location	Launch date	Details of information available

iv. Patents filed/awarded, if any

Workshop/ conferences/ seminars/capacity building programmes organised			
S. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)

v. Stake holders feedback and action taken on constructive feed back		
S No.	Feedback received	Action taken
Stake holder meet (Topic and date)		

vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)			
S No	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring/ sea-water	Number (planned)	Numbers (measured)

vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.)					
S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
viii. Equipment/ software purchased					
a. Equipment purchased					
S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
b. Software purchased					
S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
ix. Plans for utilizing the equipment facilities in future					
S. No.	Installation/ equipment		Planned future use		
x. Data dissemination policy for data generated in the project					
xi. Number of post-graduate/doctoral candidates completed their courses (Please give a list of such candidates)					
xii. Foreign deputation/visit of PI/Co-PIs/students, if any					

A.3 Activity chart

Include activity chart/ modified activity chart, reasons for modification of activity chart.

Appendix B Supplementary results

Sampling Location Details

Sr. No.	Location	Latitude	Longitude	Picture
Bathinda				
1	Akalia Jalal	30.512	75.1467	
2	Gurusar	30.4905	75.1397	
3	Goniana Khurd	30.2531	74.9114	

4	Khemuana	30.3764	75.0007	
5	Dyalpura Bhaika	30.4843	75.2009	
6	Ganga	30.3161	75.0782	
7	Rampura Phul	30.3079	75.2387	

8	Gill Kalan	30.2809	75.2692	
9	Bathinda City	30.2268	74.9554	
10	Bhucho Kalan	30.2401	75.0852	
11	Kotra Korianwala	30.2431	75.2122	

12	Badlala	30.2357	75.3152	
13	Ghudda	30.1224	74.7909	
14	Ghudda (Cw)	30.1273	74.8078	
15	Jai Singhwala	30.1344	74.8578	

16	Jai Singhwala (Cw)	30.1468	74.8593	
17	Jhanduke	30.1625	75.1467	
18	Ghuman Khurd	30.0941	75.2635	
19	Talwandi Sabo	29.9891	75.0921	

20	Barkhandi	30.3803	74.8376	
21	Mari	30.054	75.1865	
22	Lool Bai	30.1514	74.664	
Mansa				

1	Joga	30.1602	75.4203		
2	Khiwa Kalan	30.1018	75.5667		
3	Thuthianwali	30.0365	75.3862		
4	Dalel Singhwala	30.0243	75.4609		

5	Bhikhi	30.0694	75.5348		
6	Mansa	30.0214	75.3969		
7	Budhlada	29.9275	75.5484		
8	Kalipur	29.8969	75.5521		

9	Tandian	29.8753	75.2286	
10	Chhachhohar	29.8399	75.3943	
11	Barah	29.8976	75.479	
12	Sangreri	29.8981	75.665	

13	Bareta	29.8576	75.6844		
14	Boha	29.8441	75.5299		
15	Sardulgarh	29.6969	75.2393		
16	Kalehri	29.9488	75.4908		

17	Malkan	29.8092	75.4453		
18	Perron	29.91	75.2027		
19	Kulrian	30.1133	75.5525		

<table>
<tr><td>20</td><td>Patta Mulake</td><td>30.1523</td><td>74.6688</td><td></td></tr>
<tr><td colspan="5">Faridkot</td></tr>
<tr><td>1</td><td>Faridkot</td><td>30.3959</td><td>74.4536</td><td>
</td></tr>
<tr><td>2</td><td>Pakhi kalan</td><td>30.4508</td><td>74.4536</td><td>
</td></tr>
<tr><td>3</td><td>Pipli</td><td>30.4352</td><td>74.44</td><td>
</td></tr>
</table>

4	Jaito	30.2702	74.5258	
5	Dhimanwali	30.3552	74.4417	
6	Kot kapura	30.3528	74.4841	
7	Khachran	30.2555	74.4618	

8	Dhudi	30.4144	74.5107	
9	Kingra	30.4035	74.3415	
10	Golewala	30.4713	74.42	
11	Panjgarain kalan	30.3637	74.5448	

12	Mumaru	30.4733	74.3522	
13	Mehmuana	30.4145	74.3829	
14	Gobindgarh	30.2441	74.574	
15	Bargari	30.3115	74.571	

16	Wara daraka	30.3259	74.453	
17	Ghaniewala	30.3759	74.5623	
18	Sarawan	30.5221	74.8806	
19	Ramana	30.7458	74.6416	

<table>
<tr><td>20</td><td>Ahail</td><td>30.3912</td><td>74.4206</td><td>
</td></tr>
<tr><td colspan="5">Sri Muktsar Sahib</td></tr>
<tr><td>1</td><td>Mahuana</td><td>30.0323</td><td>74.3344</td><td>
</td></tr>
<tr><td>2</td><td>Khokhar</td><td>30.2857</td><td>74.4041</td><td>
</td></tr>
<tr><td>3</td><td>Saddarwala</td><td>30.3123</td><td>74.2857</td><td>
</td></tr>
</table>

4	Gurusar	30.1631	74.3524	
5	Dohak	30.3743	74.3609	
6	Doda	30.2301	74.3818	
7	Sri Muktsar Sahib	30.2813	74.3105	

8	Malout	30.1121	74.3019	
9	Gidderbaha	30.1226	74.3927	
10	Ratta khera	30.1724	74.2459	
11	Motlewala	30.3329	74.3842	

<table>
<tr><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td>12</td><td>Gulabewala</td><td>30.3339</td><td>74.2838</td><td>
</td></tr>
<tr><td>13</td><td>Akalgarh</td><td>30.3053</td><td>74.2335</td><td>
</td></tr>
<tr><td>14</td><td>Kot bhai</td><td>30.1555</td><td>74.4144</td><td>
</td></tr>
<tr><td>15</td><td>Jagat singhwala</td><td>30.3905</td><td>74.2923</td><td>
</td></tr>
</table>

16	Bhangchari	30.2306	74.2754	
17	Lal bai	30.0835	74.3649	
18	Gander	30.245	74.224	
19	Tarmala	30.3306	74.3242	

20	Waring Khera	30.3354	74.311	
Ferozepur				
1	Lehra Bet	31.0819	75.0267	
2	Talwandi Jalle Khan	30.9479	75.0604	

3	Khai	30.905	74.5517	
4	Bandala	31.1093	74.774	
5	Naraingarh	30.8969	74.8441	
6	Mallanwala	31.0489	74.8122	

7	Madhre	30.9664	74.5794	
8	Jamaitpur Dheru	30.9388	74.7563	
9	Firozpur	30.9574	74.6113	
10	Mannu Machhi	31.1364	75.0015	

11	Chak Ghobai Alias Tangan	30.88	74.4557	
12	Guru Har Sahai	30.7136	74.4053	
13	zira	30.9758	74.9857	
14	Aku Mastu Ke	31.0012	74.7084	

15	Killi Gudha	31.1023	74.8911		
16	Mudki	30.7862	74.8784		
17	Ruknewala	31.0845	74.7882		
18	Kasubegu	30.8578	74.6632		

19	Lakho ke behram	30.8234	74.4487	
20	Jhoke hari har	30.8703	74.6115	
Fazilka				
1	Pakan	30.2403	74.1916	
2	Chak Bazida	30.3522	74.0622	

3	Baghe Ke Hithar	30.3626	74.101		
4	Muhammad Pira	30.2417	73.591		
5	Islamwala	30.2131	74.1041		
6	Chak Kherewala	30.3084	74.1407		

7	Jalalabaad	30.3617	74.1583	
8	Chak Lakhowali	30.2951	74.1143	
9	Chak Kheowali	30.2453	74.1023	
10	Abohar	30.0843	74.1157	

11	Dhaban Kokarian	30.0642	74.1932	
12	Dalmir Khera	30.0513	74.0447	
13	Patti Amra Urf Patti Sadiq	29.9844	74.1181	
14	Kawanwali	30.2745	74.0058	

15	Khanwala	30.192	73.567	
16	Halimwala	30.2651	74.15	
17	Khui Khera	30.3005	74.0613	
18	Panjkosi	30.1828	73.5947	

19	Khuban	30.1701	74.0823	
20	Fazilka	30.4008	74.0259