In: Contaminants in Agriculture and Environment: Health Risks and Remediation
DOI: 10.26832/AESA-2019-CAE-0152-012

Chapter 12

Groundwater pollution, causes, assessment methods and remedies for mitigation: A special attention to Indian Punjab

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Chapter contents

Abstract

In parallel to over-exploitation of groundwater resources of Indian Punjab, water pollution has turned out to be another serious challenge chiefly due to increased use of Agrochemicals (fertilizers, pesticides, insecticides, fungicides, herbicides, etc.). The Malwa region of the state consumes about 75% of the total pesticides used in Punjab. Nitrogen and phosphorus use of the state is nearly twice of that at national level. About 80% groundwater of Malwa region has

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become unfit for drinking containing high levels of pesticides, nitrate, magnesium, fluoride and heavy metals or trace elements. Under such a situation, the precision agricultural tools such as Leaf Colour Chart (LCC) and N-sensors for need based fertilizers application require their promotion in the state. Use of pesticides can be replaced through adoption of Integrated Pest Management (IPM), bio-pesticides, organic manures and crop diversification. There is a need to review and fortify the community programs for safe use of the chemicals through improved pesticide policies. The soilless cultivation of vegetable crops can also be adopted to have reduced water and soil pollution through controlled use of fertilizers. There arises a need for timely understanding and identification of sources of pollution and detection of contaminants associated with groundwater through appropriate measures such as complete blood analysis, physical and chemical analysis of water separately for pre- and post-monsoon seasons.

Keywords: Groundwater pollution, Heavy metals, Pesticides, Nitrate, Management

Introduction

Punjab occupies only 1.57% (50,362 km^2) of geographical area of the country having 83% of its land in agriculture compared to national average which is only 40.4% (Gupta, 2009). At present, the total sown area of the state is about 2.5 times of that during late sixties and the cropping intensity more than 190%. Out of the total cropped area of the state, 72.5% area is irrigated through tube wells, 26.2% through canals and the rest 1.3% by others (GoI, 2009). The agriculture in the state has become intensive in terms of land, capital, energy, nutrients, agricultural water and other agricultural inputs.. The population of the state has also increased from 27,704,234 (approx. 27.7 million) in 2011 to 30,452,879 (approx. 30.5 million) in 2018 (Anon, 2019a). Previously, during the retro of Green Revolution (supported jointly by institutional and technological factors), Punjab witnessed an incredible increase in the agricultural production and named as “Food Basket of the Country” and “Granary of India” due to its significant contribution for rice and wheat production to central pool.

However, the groundwater pollution in the state has become an uninviting challenge as a result of direct factors (extreme use of fertilizers, pesticides, over-pumping, injudicious dumping of wastes, mining activities industrial effluents, pharmaceuticals, sewage wastes and others) and indirect factors (prolonged urban development, local climatic conditions, water basins, river network interruption etc.). A fast variation in groundwater quality with respect to time and space is consistently being recorded in alluvial aquifers of the state. The use of insecticides in Indian agriculture has already crossed 76% compared to the world which is 44% (Mathur *et al.*, 2005). India has become the second largest manufacturer of pesticides in Asia after China with 12th rank in the world (Mathur, 1999; Yadav, 2010). The main use of pesticides in India is for cotton crops (45%) followed by paddy and wheat. The states of Punjab, Haryana and Uttar Pradesh consume more than 5000 MT pesticide annually and come under category-I.

The dissolution of minerals and ion exchange processes during pre-monsoon affect the groundwater quality (Stagnitti *et al*., 1994). However, during post-monsoon season, the rainwater loaded with salts from the unsaturated zone contributes to the groundwater pollution. Thus, monitoring of alluvial aquifers has become imperative due to their vulnerability to anthropogenic pollution (Kumar *et al*., 2009; Sidhu *et al*., 2013) and to assess the suitability of the groundwater for irrigation and drinking. The route of pesticide contamination of surface and ground water resources has been indicated through Figure 12.1 (Stagnitti *et al*., 1994). The parameters viz. electrical conductivity (EC), Kelly's ratio (KR), magnesium adsorption ratio (MAR), soluble sodium percentage (SSP), permeability index (PI), sodium adsorption ratio (SAR), soluble sodium percentage (SSP) and residual sodium carbonate (RSC) can be used to assess the quality or suitability of water (or groundwater) for irrigation (Table 12.6).

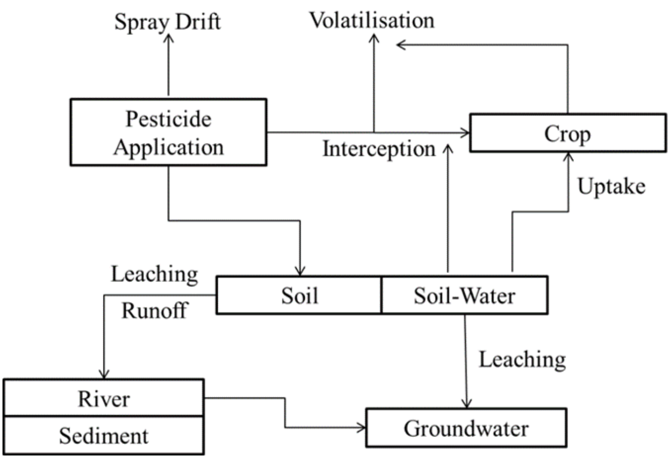

Figure 12.1. *Route for groundwater contamination through pesticide application.*

Likewise, the suitability of groundwater for drinking can also be assessed through computation of parameters such as pH, total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), nitrate (NO_3^{-}), fluoride (F^{-}), alkalinity (as $CaCO_3$), water quality index (WQI) and others (Table 12.7). The heavy metals viz. lead (Pb), chromium (Cr), arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), copper (Cu), cobalt (Co) and nickel (Ni) are responsible for inorganic chemical hazard in water (Jarup, 2003) as a result of their concentrations beyond the limit in the shallow and deeper aquifers. Among these, Pb, Cr, As, Cd and Hg are reported to be the key pollutants in Malwa region of Indian Punjab. A heavy metal like As which comes under first 20 most hazardous metals can cause acute and chronic health effects in human (Gray *et al*., 1989; Saha, 2003) as reported worldwide (Smedley *et al*., 2002; Bhattacharya *et al*., 2002; Bhattacharya *et al*., 2011). However, the establishment or socioeconomic development of a stable community is highly dependent on the availability of safe and reliable fresh water resources such as groundwater. Thus, assessment of groundwater quality (chemical, physical and biological parameters) and timely detection of pollutants has become essential for its suitability for drinking, irrigation and taking effective remedial measures for its improvement (Raju *et al*., 2009). This chapter demonstrates the current scenario of water pollution in Indian Punjab, possible causes, sources, long-term effect of water pollution on mankind and remedial measures for its control.

Routes of water pollution through point and non-point sources

The contaminants can enter water bodies through (i) direct discharge of domestic and industrial waste water, (ii) surface runoff and seepage, (iii) river flow transport, (iv) reaction and transport through the water-sediment interface and (v) reaction and transport across the air-water interface (Anon, 2019b). The transport of pollutants through unsaturated zone is encouraged by hydraulic and mass transport factors such as hydraulic conductivity and gradient, soil moisture content, degree of homogeneity of soil, relative portion of active pore spaces, boundary conditions of the unsaturated zone and climatic conditions of the region. The active pore space traps the pollutants through restricting the movements of water by conveying water to dead end space. The boundary conditions of the unsaturated zone influence the amount of moisture available for percolation and evapotranspiration. However, the transport of contaminants through saturated zone is carried by convection and dispersion processes. Convection (advection) refers to contaminant transport by moving water with same velocity and direction.

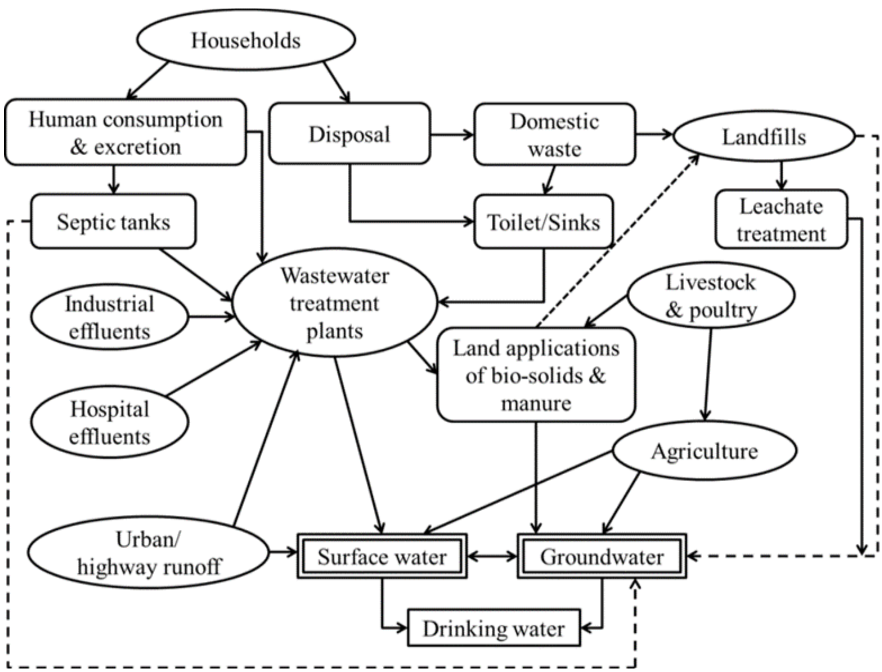

Figure 12.2. *Water pollution (surface and groundwater) through point and non-point sources.*

While, dispersion refers to spreading of contaminants dissolved in the water by local variations in velocity of water. There are several sources of surface and groundwater pollution which can be categorized as point and non-point (diffuse) sources of pollution. Figure 12.2 demonstrates the routes through which the different point and non-point sources of pollution contribute to the water pollution (surface and groundwater). The groundwater pollution is directly related with surface water pollution as indicated in Figure 12.2 (Stefanakis *et al*., 2015). In structured soils, the macro pore flow often causes rapid non uniform leaching via preferential flow paths, where a fraction of the contaminant percolates into ground water before it can degrade or be adsorbed by the soil (Sharma *et al*., 2016). Water undergoes changes in its chemical composition through different chemical processes and reactions after percolation in soil, vadose zone and movement in saturated zone (Anon, 2019b). Those processes and reactions include, acid and base reaction, bio-chemical reactions, heavy metal reactions, ion exchange and adsorption, oxidation and reduction, solubility and precipitation, and volatility. However, some processes such as biological degradation, buffering of pH, dilution, mechanical filtration, membrane filtration, precipitation, oxidation-reduction reaction and volatilization may help in controlling the groundwater contamination.

The present study was planned with the following objectives:

- To identify the contaminants and routes of water pollution through human interventions
- To discuss the extent of water pollution through different contaminants and their major causes

Table 12.1. *Abbreviations used in this study.*

Abbreviation	
MT	Million tonne
DDT	Dichlorodiphenyltrichloroethane
BHC	Benzenehexa Chloride
HCH	Hexachlorocyclohexane
BIS	Bureau of Indian Standards
CGWA	Central Ground Water Authority
CGWB	Central Ground Water Board
EPA	Environment protection Act, 1986
GoI	Government of India
GoP	Government of Punjab
MoEF	Ministry of Environment and Forests
MoWR	Ministry of Water Resources
PAU	Punjab Agricultural University
PSFC	Punjab State Farmers’ Commission
PWRED	Punjab Water Resources and Environment Directorate
TERI	The Energy Resource Institute
WHO	World Health Organization

- To identify the health hazards due to water pollution
- To understand how to identify the sources of contaminants and problems associated
- To review and demonstrate the different techniques for computation of water quality indices for irrigation and drinking water suitability.
- Remedies for management or control of water pollution.

General description

Indian Punjab is situated between 29´30´´ N to 32´32´´ N latitude and 73´55´´ E to 76´50´´ E longitude with an altitude in the range of 230-700 m from the mean sea level. Agro-climatologically and hydrologically Punjab has been divided into three zones viz. North-East, Central and South-West comprising of 19, 40 and 41% respectively of the geographical area of the state. North-East zone of the state is facing a problem of soil erosion mainly due to water (80 t/ ha/year). Central and South-West zones of Punjab are facing acute depletion of fresh ground-water resources and water logging with poor quality water respectively. Punjab has three perennial rivers viz. Beas, Satluj and Ravi and a seasonal river Ghaggar. It has a canal network of about 14,500 km for supplying water from these rivers. Average annual rainfall of the state ranges from 1250 mm in the North to 350 mm in the South-West. More than 70% of the annual rainfall occurs during the monsoon season (July to September). However, a decline in rainfall in the range of 40-50% has been recorded during last two decades between 1994 and 2014 (PWRED, 2014). The fresh groundwater resources of the state has gone under threat from last few couple of decades in terms of over-exploitation leading to depleted water resources.

Extent of groundwater pollution in Punjab

Apart from the critical groundwater depletion, pollution of water (surface and groundwater) has become another serious issue at present in the state. The sources of groundwater pollution include heavy metals (Cd, Cr, Cu, Pb, Hg & others), inorganic compounds (NO_2^-, NO_3^-, PO_4^{-3} and others), toxic compounds (Se, CN^- etc.), radioactive substances (radon caused by uranium and thorium series decay), synthetic organic compounds (chlorinated hydrocarbons, detergents, paint colors, petroleum products, pesticides, phenols etc.) and pathogenic micro-organisms (bacteria and viruses) which can origin diseases such as diarrhoea and dysentery. The fresh groundwater water resources have been now badly contaminated, particularly the Malwa region of the state through entry of toxic chemicals (e.g. pesticides, etc.) and heavy metals (e.g. arsenic, fluoride, etc.) moved down into groundwater from soil or rock layers as well as through direct contamination from poorly designed hazardous waste sites and industrial sites (Table 12.2). There exists an interaction of poor quality surface water with the good quality fresh groundwater through leaching or percolation (preferential flow) as indicated in Figure 12.1. For an example, the water being pumped through hand pumps from shallow aquifers particularly near Buddha Nallah in Rural Ludhiana (Bhamian Kalan, Khasi Kalan and Wallipur) is now degraded both physically and chemically as a result of direct discharge of untreated industrial effluents including dyes, tanning, nickel and chrome plating units (Kaur *et al*., 2014); which in turn polluting the surface water resources (Satluj river) and thereby the groundwater resources. A deliberated industrial discharge of about 50000 m^3day^{-1} of most toxic industrial effluents into the Buddha Nallah in Ludhiana district has been reported, which is further responsible for recharge of the groundwater aquifers in the city (CGWB, 1998). According to CGWB, the concentrations of heavy metals viz. Cd, CN, Pb and Cr was beyond the limit in the shallow aquifers with a small amounts of these heavy metals in the deeper aquifers too.

Causes of water pollution (point and non-point sources) prevalence of deadly diseases

- Prompt increase in population and urbanization
- Agricultural practices
  - ∗ Introduction of high yielding crop varieties.
  - ∗ Excessive use of pesticides (fungicides, insecticides and weedicides or herbicides etc.).
  - ∗ Exposure interval and levels to agrochemicals, toxicity and persistence of agrochemical used, and several environmental conditions are also responsible factors for acute and chronic poisoning on human health and the environment.
  - ∗ Lack of awareness, training and adequate knowledge for using the agrochemicals.
  - ∗ Deliberately extensive use of fertilizers for the sake of improving crop productivity.
  - ∗ Leaching of salts in the unsaturated zone, contribution of water soluble fertilizers and livestock excrement play a substantial role in groundwater contamination (shallow aquifers).
  - ∗ Over irrigation in crops like rice, creates a scope for nitrate contamination in the groundwater through leaching due to its high solubility in water and less retention by soil particles.
  - ∗ In addition to nitrate, DDT is another major hazardous chemical responsible for groundwater pollution.
  - ∗ Untreated wastewater (containing industrial chemicals) being used for irrigation contains heavy metals (e.g. As, Cr, Cd, Co, Pb, etc.).
- Industrialization
  - ∗ Injudicious disposal (or dumping) of untreated industrial chemical waste contaminates the shallow aquifers, rivers and streams leading to groundwater pollution. Example: direct discharges of wastewaters containing chemicals to Buddha Nallah of district Ludhiana in Punjab and Yamuna River in Delhi.
  - ∗ Disposal of untreated mercury contaminated effluent from caustic manufacturing into groundwater aquifers.

   * Lack of proper drainage systems for treated effluents in industries which again leach down to meet groundwater.

- Inappropriate approaches for artificial groundwater recharge (in-situ RWH) through abandon bore wells. Example: directing untreated wastewater or runoff water containing several hazardous contaminants such as agricultural chemicals, and heavy metals directly into the bore wells.
- Surface water contamination through direct disposal of untreated sewage waste (human and animal) into rivers. Example: Satluj River between Ludhiana and Jalandhar in Punjab and Yamuna River in Delhi.
- Fluoride and arsenic contamination due to over-exploitation of groundwater.
- Disposal of liquid and solid wastes into open water bodies
- By-products and waste from of mining activities
- Dumping of wastes (e.g. lubricants) from the service centres of motor vehicles.
- Disposal of wastes from hospitals in open environment (water) and dumping into soils.
- Disposal of nuclear energy wastes
- River network interruption
- Mineral processing of radioactive substances
- Cemeteries

Table 12.2 *Districts affected with groundwater pollution through heavy metals, salinity and trace elements.*

Heavy metal	Location	
Arsenic (>0.05 mg/L)	Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, Ropar According to recent study: Bathinda, Faridkot, Ferozpur, Mansa, moga and Muktsar (Sharma and Dutta, 2017)	
Flouride (>1.5 mg/L)	Amritsar, Barnala, Bathinda, Faridkot (Sharma *et al*., 2016), Fatehgarh Sahib, Ferozpur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Patiala, Ropar, Sangrur, Tarn-Taran According to recent study: Barnala, Bathinda, Faridkot, Mansa and Muktsar (Kaur *et al*., 2017)	
Iron (>1.0 mg/L)	Bathinda, Faridkot, Fatehgarh Sahib, Ferozpur (Sharma and Dutta, 2017), Gurdaspur, Hosiarpur, Mansa, Moga (Sharma and Dutta, 2017), Ropar, Sangrur	
Nitrate (>45 mg/L)	Amritsar, Barnala, Bathinda(Sharma *et al*., 2016), Faridkot (Sharma *et al*., 2016), Fatehgarh Sahib, Ferozpur (Sharma *et al*., 2016), Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Mansa, Moga, Muktsar, Nawan Shahr, Patiala, Ropar, Sangrur, Tarn-Taran	
Salinity	Bathinda, Faridkot, Ferozpur, Gurdaspur,Mansa, Moga, Muktsar, Patiala, Sangrur (Chopra and Krishan, 2014)	
Trace elements	Se	Nawan Shahr, Hoshiarpur and Tarn-Taran (Dhillon and Dhillon, 1991)
	Rn	Bathinda, Gurdaspur (Virk *et al*., 2001)
	U	Barnala, Bathinda, Fazilka, Ferozpur, Ludhiana, Moga, Sangrur

Further, similar to fresh water pollution through seawater intrusion process, the depleting groundwater level in Central Indian Punjab and rising water table in South-Western Punjab may further create a potential gradient for bad quality water to flow and enter into fresh groundwater resources of the state. Thus, a regular assessment of quality of groundwater for different purposes (agricultural and domestic) is of great importance (Raju *et al.*, 2009).

Quality of irrigation water in Punjab

At present, the assessment of groundwater to check its suitability for irrigation and drinking has become imperative through computation of different quality parameters (reported above). Considering EC and RSC values of groundwater as criteria for checking its suitability for irrigation, about 95.6% water was found unfit in Muktsar district followed by Mansa (73.0%) and Bathinda (66.9%) (Table 12.3) (Chopra and Krishan, 2014). The EC and RSC values of groundwater of the districts viz. Bathinda, Faridkot, Mansa and Muktsar were recorded to be more than 4000.0 µmho/cm and 5.0 meq/L respectively. Out of the total area of Punjab, the groundwater in 24.8% area was not found suitable for irrigation, 21.9% as marginally fit and 53.3% as fit for irrigation. However, the groundwater in Hoshiarpur district was 100.0% groundwater fit for irrigation followed by Gurdaspur (99.6%), Nawan Shahr (98.0%) and Ropar (92.1%). For Amritsar,

Table 12.3. *District-wise categorization of groundwater quality for irrigation (45-60 m depth).*

District	Area (km²)	Fit (%)	Marginal (%)	Unfit (%)
Amritsar	2647	78.8	21.2	0.0
Barnala	1410	27.7	51.1	21.3
Bathinda	3385	2.5	30.6	66.9
Faridkot	1469	2.9	37.7	59.4
Fatehgarh Sahib	1180	73.9	26.1	0.0
Ferozepur	5303	27.2	24.4	48.3
Gurdaspur	3564	99.6	0.4	0.0
Hosiapur	3365	100.0	0.0	0.0
Jalandhar	2632	88.6	10.5	0.9
Kapurthala	1632	83.1	12.3	4.6
Ludhiana	3767	88.7	10.6	0.7
Mansa	2171	4.1	23.0	73.0
Moga	2216	30.0	46.3	23.7
Muktsar	2615	0.0	4.4	95.6
Nawan Shahr	1267	98.0	2.0	0.0
Patiala	3218	64.1	27.3	8.5
Ropar	1369	92.8	7.2	0.0
Sangrur	3610	33.1	40.3	26.6
SAS Nagar Mohali	1093	76.2	23.8	0.0
Tarn Taran	2449	25.8	53.8	20.4
Total area (km²)	**50362**	**26847**	**11041**	**12474**
EC (µmho/cm)	-	<2000	2000-4000	>4000
RSC (meq/L)	-	<2.5	2.5-5.0	>5.0

Table 12.4. *Concentration of heavy metals in drinking water in Malwa region of Indian Punjab.*

District	**Mean concentration of heavy metal and essential element in drinking water (mg/L)**						
	As	*Cd*	*Cr*	*Fe*	*Hg*	*Pb*	*Zn*
Barnala	0.03	0.005	0.00	0.32	0.002	0.02	0.84
Bathinda	1.28	0.013	0.00	0.40	0.200	15.11	0.99
Faridkot	1.35	0.006	1.55	0.15	0.186	14.62	0.52
Ferozpur	1.16	0.005	2.10	1.52	0.170	14.73	0.92
Mansa	2.13	0.005	1.03	0.45	0.003	15.22	1.03
Moga	0.99	0.004	0.52	1.03	0.210	1.07	2.73
Muktsar	1.25	0.004	2.66	0.14	0.200	1.55	5.64
Sangrur	0.03	0.005	0.00	0.31	0.002	0.01	1.17
Average	1.03	0.006	0.98	0.54	0.122	7.79	1.73

Fatehgarh Sahib, Jalandhar, Kapurthala, Ludhiana and SAS Nagar, the groundwater was recorded to be suitable for irrigation (73.9-88.7%). Districts, Tarn Taran and Barnala were found more than 50.0% in marginally fit category. Keeping EC and RSC as quality criteria, groundwater was found fit in 53% and marginal to fit in 47% (Chopra and Krishan, 2014).

Water pollution through heavy metals and trace elements

There are several heavy metals or trace elements responsible for inorganic chemical hazard in water (Jarup, 2003). Among those, Pb, Cr, As, Cd and Hg are reported to be the key pollutants. Furthermore, the trace elements such as Se (Dhillon and Dhillon, 1991) and radioactive elements such as Rd are also being reported in the groundwater (Virk *et al*., 2001). The above mentioned heavy metals have been categorised as strong pollutants by the International Agency for Research on Cancer and their presence in water can create many health issues such as intellectual and developmental disabilities (Sarkar, 2002). As per the news by "The Tribune" on 6th February 2018, Indian Punjab accounts for about 88% of the total habitations in the country adversely affected through presence of heavy metals in groundwater (Anon, 2019c). All the samples collected for analysis for Pb concentration in drinking water from districts viz. Muktsar, Faridkot, Feropzpur, Mansa and Moga were found 100% unsafe (Table 12.4) (Sharma and Dutta, 2017). The mean concentration of Pb was recorded to be beyond the permissible limit (≤0.01 mg/L) as per BIS standards for all districts in the following order, Mansa > Bathinda > Ferozpur > Faridkot > Muktsar > Barnala > Sangrur. The sample taken for analysis of As in drinking water from districts viz. Bathinda, Muktsar, Faridkot, Feropzpur and Moga were found unsafe beyond 50%. The mean concentration of As was beyond the permisible limit (≤0.05 mg/L) as per BIS standards for all districts except Barnala and Sangrur with the following order, Mansa > Faridkot > Bathinda > Muktsar > Ferozpur > Moga > Barnala = Sangrur (Table 12.4).

The samples taken for analysis of Fe in drining water from Ferozepur district were 100% unsafe followed by Barnala and Sangrur with unsafe concentration of 60% each. The mean concentration of Fe was beyond the permissible limit (≤1.0 mg/L) as per BIS standards for Ferozepur and Moga districts and the concentration of Fe in drinking water was in the following order, Ferozepur > Moga > Mansa > Bathinda > Barnala > Sangrur > Faridkot > Muktsar. The Cd concentration in drinking water for all the districts was also beyond the safe limit (≤0.003 mg/L). The drinking water from the districts viz. Bathinda, Barnala and Sangrur were found safe for chromium concentration (Table 12.4). However, the concentration of Cr in drinking water for the districts viz. Muktsar, Faridkot, Ferozepur, Moga and Mansa was reoprted to be beyond permissible limit (≤0.05 mg/L). The concentration of Cr in drinking water samples from different districts was in the following order, Muktsar > Ferozepur > Faridkot > Mansa > Moga > Bathinda > Barnala > Sangrur. The concentration of Hg in drinking water samples from all the districts was recorded to be beyond the permissible limit (≤0.001 mg/L) with the following order, Moga > Bathinda > Muktsar > Faridkot > Feorzepur > Mansa > Barnala > Sangrur. The mean concentration of Zn in drinking water samples from all the districts was found within safe limit except for Muktsar and the order was, Muktsar > Moga > Sangrur > Mansa > Bathinda > Ferozepur > Barnala > Faridkot. Groundwater contamination through high levels of uranium (trace element) in south-western Punjab has also been reported in past. The drinking water quality characteristics have been demonstrated in Table 12.7. Contamination of groundwater through presence of arsenic (As) has been reported in Amritsar, Kapurthala and Ropar districts of Indian Punjab. As concentration of more than 10 µg/L has been reported at several locations in Muktsar-Malout belt in south west region of the state (Singh *et al.*, 2015). The mean concentrations of arsenic of 9.37 and 11.01µg/L were recorded in groundwater during summer and winter season respectively (Kaur *et al.*, 2017).

Groundwater pollution through fluoride and iron

Groundwater (drinking water) pollution through excessive concentrations of fluoride, nitrate and iron has also become a serious challenge in Malwa region particularly in Bathinda, Faridkot and Ferozepur districts. In a study (Sharma *et al.*, 2016), about 95 and 59% samples of groundwater were reported to have nitrate and fluoride content. The maximum concentration of fluoride has been recorded to be 10.6 mg/L at Faridkot. The mean value of fluoride was obtained to be 3.03 mg/L with standard deviation of 10.32. Most recently, 75% groundwater samples in Malwa region (Barnala, Bathinda, Faridkot, Mansa and Muktsar) were found to have fluoride concentration beyond permissible limit (Kaur *et al.*, 2017). The fluoride concentration was found in the range of 1.29-3.74 mg/L and 0.81-2.98 mg/L during summer and winter season respectively with mean values of 2.31 and 1.97 mg/L. Fluoride in groundwater which was beyond the permissible limit (>1.5 mg/L) (BIS, 1991) causes health hazards of Fluorosis. Likewise, the iron (Fe) concentration in groundwater was recorded to be in the range of 0.009-5.41mg/L and 0.074 to 7.7mg/L during summer and winter respectively with mean values of 0.05 and 1.08 mg/L.

Groundwater contamination through use of pesticides and fertilizers

Malwa region is the cotton belt of the state and has the highest pesticide consumption density in

Table 12.5. *Cancer cases in Indian Punjab due to pesticide contamination.*

District	Number of cancer patients per million population					Cancer deaths in last 5 years (2013)
	2001	*2002*	*2005*	*2009*	*2013*	
Bathinda	359	353	592	750	1258	2058
Faridkot	261	257	280	446	1346	1112
Mansa	-	-	574	498	1348	1212
Muktsar	246	242	547	751	1363	1791
Patiala	349	336	-	235	868	1498

the country consuming nearly 75% of the total pesticides used in Punjab. This region has been described as India's "cancer capital" due to abnormally high number of cancer cases (Table 12.5) (Mittal *et al*., 2014), which have increased three folds in the last 10 years (Mittal *et al*., 2014). Nearly 80% water of Malwa region has been reported as unfit for drinking containing high levels of pesticides, fertilizers (nitrate), magnesium, fluorine, phosphates along with the chemicals such as magnesium and fluoride which were naturally found in groundwater (Anon, 2019d). Two types of bad effects (chronic and acute) are possible on human health due to pesticide exposure (Kumar *et al*., 2013). Chronic effects of pesticide exposure include reduced attention span, memory disorders, abridged co-ordination, and reproductive problems including miscarriages, birth defects, reduced infant development, depression and cancer. While the acute effects of pesticide exposure include headaches, blurred vision, salivation, diarrhea, vomiting, nausea, wheezing, eye problems, coma, seizure and even death.

The prevalence and symptoms of cancer as well as deaths due to cancer have been reported highest in Malwa (followed by Doaba region) region of Punjab compared to Doaba and Majha regions (Figure 12.3). The key reason for spread of cancer in Indian Punjab is excessive use of pesticides and fertilizers. In India, the largest consumer of pesticides is cotton crop (45%) followed by paddy and wheat. Alachor, Aldicarb, Carbofuran, Chlorpyrifos, Lindane, Malathion and Methoxychlor are the different pesticides used in Punjab. In Indian Punjab, the traces of the banned pesticides viz. BHC, Endosulfan, DDT and HCH have been found in the most safe and sacred mother's milk in many cases. The use of Endosulfan has resulted in increased birth rate of mentally retarded children. Above 20% of Indian food products contain pesticides residues above the tolerance level compared to only 2% globally. Punjab has just 2.5% of total agricultural land in India and consumes nearly 18% of the total pesticides used in the nation (Dutt, 2008). Consumption of pesticides and insecticides (Technical Grade) has augmented from 3200.0 MT in 1980 -81 to 6150.0 MT in 2011-12. Industrial waste and sewage waste from urban area are other major factors responsible for cancer in Malwa region of Punjab. The fertilizer consumption particularly nitrogen (N) and P_2O_5 has significantly increased in Punjab compared to the country. Punjab alone uses nearly twice of the fertilizers (N and P_2O5) used at national level. The total consumption of chemical fertilizers (NPK) has increased from 213 thousand tons (37.5 kg/ha) in 1970-71 to 1936 thousand tons (246.0 kg/ha) in 2011-12. As per GoI (2014), the national fertilizer consumption was 84.54, 33.44 and 10.36 kg respectively for N, P_2O_5 and K_2O in 2012-13.

Whereas, it was 188.47, 58.67 and 3.05 kg respectively for N, P_2O_5 and K_2O in Punjab. In Punjab, N and P_2O_5 applications were nearly 2.3 and 1.8 times of that of India in 2012-13. However, the application of potash was nearly one third of that at national level. Groundwater (drinking water) pollution through excessive concentrations of nitrate has also become a serious challenge in Malwa region particularly in Bathinda, Faridkot and Ferozepur districts. From the water samples taken from wells before monsoon, 32%, 48%, 16%, and 4% presented NO_3-N concentrations of <10, 10-15, 15-20 and >20 mg/L respectively and after monsoon, 16%, 49%, 29%, and 6% respectively (ICAR, 1998). In a study (Sharma *et al*., 2016), about 95% samples of groundwater were reported to have nitrate content. The maximum concentration of nitrate was recorded to be 90 mg/L at Bathinda. The mean values of nitrate was obtained to be 25.14 with standard deviation 1.317. The extent of prevalence, symptoms and spread of cancer in Punjab due to the above discussed reasons is demonstrated in Figure 12.3 (GoP, 2013).

Problem identification and precautions

- A complete blood analysis can be an appropriate practice for examining the exposure of a spray man to environmental pollutants mainly pesticides and the analysis can be carried out using a Gas Chromatograph Mass Spectrometer (GC-MS) multi residue analytical technique (Hayat *et al*., 2010).
- Analysis for physical and chemical properties of groundwater samples for pre and post-monsoon seasons can help to assess the suitability of groundwater for drinking and irrigation.

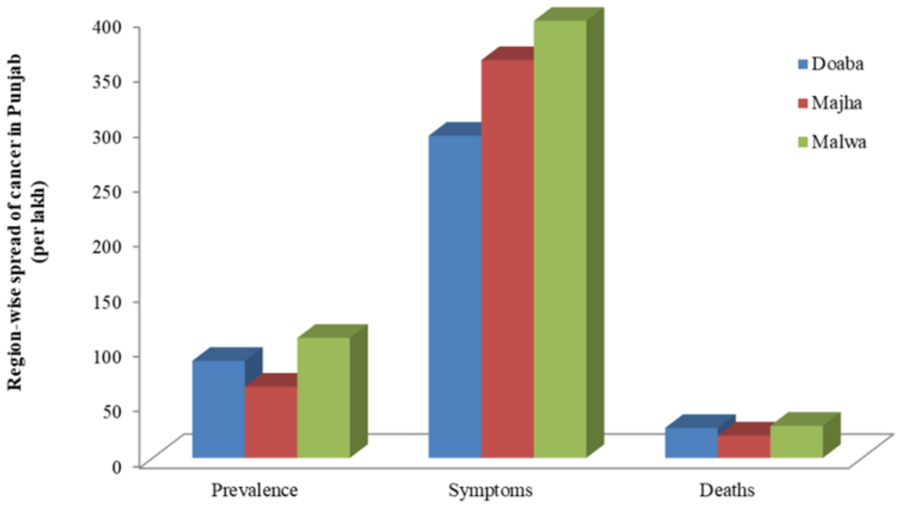

Figure 12.3. *Spread of cancer in Indian Punjab.*

Following precautions are required to be taken while application of toxic agricultural chemicals:

- Using a proper protecting kit during application of agrochemicals to a crop.
- Regular monitoring of groundwater is essential to avoid environmental threats.

Water treatment and computation of water quality parameters (physio-chemical)

There are three methods of water treatment viz. primary, secondary and complete treatment. The primary treatment includes chlorination, membrane filtration, ozone treatment and ultraviolet treatment. Secondary treatment includes sedimentation and filtration followed by chlorination. There are four types of filtration systems viz. cartridge filtration, multimedia sand filtration, up-flow filtration and rapid sand filtration. The complete treatment comprises of flocculation, coagulation, sedimentation and filtration followed by disinfection. Flocculation and coagulation can help in removing contaminants through addition of lime to make the water slightly alkaline, followed by addition of coagulants like aluminium sulphate (Alum), ferric chloride or ferric sulphate. The precipitate hence formed can be removed through sedimentation and filtration. Further, to reduce the extreme levels of manganese, iron and organic matter, chemical treatment may be required followed by clarification.

The EC value of water can be determined using digital water proof testers or EC meters. SAR, MAR, RSC, SSP, PI and KR can be computed using the formulae listed in Table 12.6 for examining the suitability of groundwater for irrigation (Table 12.6). The pH of drinking water can be measured using digital waterproof pH meters. Similarly, TDS, TH and WQI can be computed using the methods (formulae) listed in Table 12.6. The suitability ranges for all these parameters (EC, MAR, RSC, SSP, PI, KR, TDS, TH and WQI) have been also reported in Table 12.6. The computation methods for other parameters for testing drinking water suitability include Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, NO^{3-}, F^{-} and as $CaCO_3$ and others including heavy metals or trace elements (Pb, Cr, As, Cd, Hg, Zn, Cu, Co, Ni etc.) have been listed in Table 12.7. Quality characteristics for drinking water (desirable and permissible limits standardised by BIS, WHO and EPA have been presented in Table 12.8. Biological test can be performed by Most Probable Number (MPN) method. The maximum permissible COD level for industrial effluents is 250 mg/L (Singh, 2001). The methods for removal of several contaminants from drinking water are suggested in Table 12.9.

Remedies for controlling water pollution through use of pesticides, fertilizers, industrial wastes and other sources

- Adoption of precision agricultural practices or resource conservation techniques for optimal use of input resources such as fertilizers.
    - Use of LCC (rice, wheat and maize) recommended by PAU Ludhiana for supplying

Table 12.6. *Formulae for computation of different quality indicators of water and their range.*

Parameter	Abbreviation	Formula/gadget	Unit of measurement	Suitability of groundwater for drinking/irrigation
Electrical conductivity	*EC*	Digital waterproof testers of Hanna Instruments	µS/cm	<250 (excellent), 250-750 (good), 750-2000 (permissible), 2000-3000 (doubtful) and >3000 (not suitable) (Sharma *et al.*, 2016; WHO, 2008)
Sodium absorption ratio	*SAR*	$\frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$ (Richards, 1954)	-	<10 (excellent for irrigation), 10-18 (good), 18-26 (doubtful) and >26 (not safe) (Richards, 1954; Das and Nag, 2015)
Magnesium ratio	*MR*	$\frac{Mg^{2+} * 100}{(Ca^{2+}+Mg^{2+})}$ (Paliwal, 1972)	-	<50 (suitable for irrigation) >50 (not suitable for irrigation)
Residual sodium carbonate	*RSC*	$(HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+})$ (Eaton, 1950; Raghunath, 1987)	mg/L	<1.25 (suitable), 1.25-2.5 (marginally suitable) and >2.5 (not suitable for irrigation) (Lloyd and Heathcote, 1985)
Soluble sodium percentage	*SSP*	$\frac{(Na^+ + K^+) * 100}{Ca^{2+}+Mg^{2+}Na^+ + K^+}$ (Raghunath, 1987; Wilcox, 1948)	-	<20 (excellent for irrigation), 20-40 (good), 40-60 (permissible), 60-80 (doubtful) and >80 (not safe)
Permeability index	*PI*	$\left(\frac{Na^+ + \sqrt{HCO_3}}{Ca^{2+}+Mg^{2+}Na^+}\right) \times 100$ (Doneen, 1964)	-	<80 (good), 80-100 (moderate) and 100-120 (poor) (Das and Nag, 2015)
Kelly's Ratio	*KR*	$\frac{Na^{2+}}{Ca^{2+}+Mg^{2+}}$ (Kelly, 1963)	-	<1 (suitable) and >1(not suitable) (Das and Nag, 2015)
Total dissolved solids	*TDS*	Constant factor (CF)×EC (µS/cm) Where, CF=0.65 (Shakha, 2016) or 0.67 (Sharma *et al.*, 2016)	mg/L	<500 (desirable), 500-1000 (permissible), 1000-3000 (useful for irrigation) and >3000 (unfit for drinking and irrigation) (Sharma *et al.*, 2016)
Total hardness	*TH*	$2.497 \times Ca^{2+} + 4.115 \times Mg^{2+}$ (Todd, 1980)	mg/L of $CaCO_3$	<75 (soft), 75-150 (moderately hard), 150-300 (hard) and >300 (very hard) (Sawyer and McCarty, 1967) OR <60 (soft), 60-120 (moderately hard), 121-180 (hard) and >180 (very hard) (Sharma *et al.*, 2016)
Water quality index	*WQI*	$WQI_A = \sum_i^n w_i q_i / \sum_i^n w_i$ $q\_i = 100 \times (V_i - V_{id})/(S_i - V_{id})$ Where, n is number of variables, w_i is the relative weight of i[th] parameter, q_i *is the water quality rating of the* i[th] parameter, V_i, S_i and V_{id} are the observed, standard permissible and ideal value of i[th] parameter (Horton, 1965; Brown *et al.*, 1972)	-	0-25 (excellent), 26-50 (good), 51-75 (poor), 76-100 (very poor) and >100 (not fit for drinking) (Brown *et al.*, 1972; Chaterjee and Raziuddin, 2002)

Table 12.7. *Methods of determination of water quality parameters for drinking water.*

Parameter	Abbreviation	Method (s) for determination	Unit of measurement
Aluminium	Al	Graphite Furnace Atomic Absorption Spectrometry	mg/L
Anionic detergents	MBAS	Spectrophotometric Method or Crystal Violet Method	mg/L
Arsenic	As	Graphite Furnace Atomic Absorption Spectrometry	mg/L
Boron	B	Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), Spectrophotometric Method	mg/L
Cadmium	Cd	Graphite Furnace Atomic Absorption Spectrometry	mg/L
Calcium	Ca	Titremetry (EDTA as titrant and murexide as indicator)	mg/L
Chlorides	Cl^-	Titremetry (AgNO3 with Potassium Chromate as indicator)	mg/L
Chromium	Cr^{6+}	Gas Chromatography, Polarography and Spectrophotometry	mg/L
Copper	Cu	Atomic absorption spectroscopy or spectrophotometry	mg/L
Cyanide	CN	Ion Chromatography Method with Pulsed Amperometric Detection , GC/MS Headspace Analysis	mg/L
Fluoride	F	Spectrophotometer (SPADNS reagent)	mg/L
Iron	Fe	Spectrophotometric Method or Atomic Absorption Spectrometry	mg/L
Lead	Pb	Graphite Furnace Atomic Absorption Spectrometry	mg/L
Magnesium	Mg	Titremetry (EDTA as titrant and erichrome black T as indicator)	mg/L
Manganese	Mn	Extraction-photometric methods	mg/L
Mercury	Hg	Cold Vapor Atomic Absorption Spectrometry,	mg/L
Mineral Oil		Gas-chromatographic analysis	mg/L
Nitrate	NO_3^-	Spectrophotometer (Phenol disulphonic acid)	mg/L
Pesticides		Solid Phase Extraction and Capillary Column GAS Chromatography/Mass Spectrometry	mg/L
Phenolic Compounds	C_6H_5OH	Alternating-Current Oscillopolarographic Titration, Solid Phase Extraction and Capillary Column GAS Chromatography/Mass Spectrometry	mg/L
Potassium	K	Flame Photometer	mg/L
Residual, free chlorine		Iodometric Back Titrations, Amperometric Direct and Back Titrations, DPD Titration, DPD Colorimetric Method and Orion 97-70 Chlorine Specific Ion Electrode Method	mg/L
Selenium	Se	Atomic Absorption Spectrometry with Hydride Generation	mg/L
Sodium	Na	Flame Photometer	mg/L
Sulfate	SO_4^-	Turbidimetric Method	mg/L
Turbidity	Turb	Nephelometer	NTU
Zinc	Zn	Atomic Absorption Spectrometry	mg/L

Table 12.8. *Drinking water quality criteria (desirable and permissible limits) by different international standards.*

Substance or Characteristic	**BIS (1991)**		**EPA (2018)**		**WHO (1971)**	
	Desirable (mg/L)	*Permissible (mg/L)*	*Desirable (mg/L)*	*Permissible (mg/L)*	*Desirable (mg/L)*	*Permissible (mg/L)*
Alkalinity	200	600	×××	×××	×××	×××
Aluminium (Al)	0.03	0.2	0.05	0.2	×××	×××
Anionic detergents (MBAS)	0.2	1	×××	×××	0.2	1
Arsenic (As)	0.01	××	0.01	××	0.05	××
Boron (B)	1	5	3	6	×××	×××
Cadmium (Cd)	0.01	××	0.005	××	0.01	××
Calcium (Ca)	75	200	×××	×××	75	200
Chlorides (Cl)	250	1000	250	×××	200	600
Chromium (Cr^{6+})	0.05	××	0.1	××	×××	×××
Copper (Cu)	0.05	1.5	1	×××	0.05	1.5
Cyanide (CN)	0.05	××	0.2	××	0.05	××
Dissolved solids	500	2000	500	2000	500	1500
Fluoride (F)	1	1.5	2		0.6	1.7
Iron (Fe)	0.3	1	0.3	×××	0.1	1
Lead (Pb)	0.05	××	0.015	××	0.1	××
Magnesium (Mg)	30	100	×××	×××	30	150
Manganese (Mn)	0.1	0.3	0.05	×××	0.05	0.5
Mercury (Hg)	0.001	××	0.002	××	0.001	××
Mineral Oil	0.01	0.03	×××	×××	0.01	0.3
Nitrate (NO_3)	45	××	10	××	×××	×××
Pesticides	×	0.001	×××	×××	×××	×××
pH	6.5-8.5	××	6.5-8.5	××	7.0-8.5	6.5-9.2
Phenolic Compounds (C_6H_5OH)	0.001	0.002	0.001	0.002	0.001	0.002
Residual free chlorine	0.2	×××	3	3.5	0.1	×××
Selenium (Se)	0.01	××	0.05	××	0.01	××
Sulfate (SO_4)	200	400	250	×××	200	400
Total Hardness ($CaCO_3$)	300	600	-	×××	100	500
Turbidity (NTU)	5	10	5	10	5	25
Zinc (Zn)	5	15	5	15	5	15

required quantity of nitrogen to be applied in crops at right time to get the maximum productivity (Kumar *et al*., 2018).

* Use of sensors to determine fertilizer requirement by observing and recording various indices for different crops and taking soil samples.
* Example: Using a tractor mounted N-sensor (Yara International make) to predict nitrogen (N) requirement for wheat.

- Efficient use of agro-chemicals such as pesticides (insecticides, nematicides and fungicides etc.)

Table 12.9. *Methods (or remedial measures) for removal of contaminants from drinking water.*

Parameter	Source	Method/technique for removal of contaminant
Aluminum (Al^{+3}) Low water solubility 0.1-9.0 ppm (natural water) Desirable: 0.05-0.2 mg/L (US EPA)	Earth's surface Use of aluminum sulfate (alum) as a coagulant in water treatment plants	Reverse Osmosis (removal by more than 98%) Distillation (removal more than 99%) Electro-dialysis
Arsenic (As) Difficult to dissolve in water Classified as a carcinogen (US EPA) Desirable: ≤ 0.05 mg/L	Mining or metallurgical operations Runoff from agricultural	Reverse osmosis (removal rate up to 90%) Activated alumina Ion/anion exchange (removal rate of 90-100%) Activated carbon (removal rate of 40 - 70%) Distillation (removal rate of 98%)
Barium (Ba^{+2}) Desirable: ≤ 2.0 mg/L	Surface and ground waters Oil and gas drilling muds, waste from coal-fired power plants, automotive paints and jet fuels	Sodium form cation exchange units (softeners) Reverse Osmosis Electro-dialysis
Bromine or bromide (Br^{-}) Widely used in pharmaceutical industry. Used to disinfect swimming pools and cooling towers Desirable: ≤0.05 mg/L	Found in seawater and exists as the bromide ion (65 mg/l) Occurs normally in blood (1.5 to 50 mg/l)	Reverse Osmosis (removal rate of 93-96%) Activated Carbon Ultrafiltration or Electro-dialysis
Cadmium (Cd) Desirable: ≤0.005 mg/L (US EPA)	Found in zinc as an impurity Found in by-products from mining, electroplating, pigment, smelting and plasticizer production	Sodium form cation exchange units (softeners) Reverse Osmosis (removal rate of 95-98%) Electro-dialysis
Calcium (Ca^{+2}) It is the major component of hardness in water (5-500 mg/L as $CaCO_3$)	Derived from rocks, but mainly found in limestone and gypsum	Sodium form cation exchanger (softener) Reverse Osmosis (removal rate of 95-98%) Electro-dialysis Ultrafiltration Using hydrogen form cation exchanger
Chloride (Cl^{-}) Chloride content in water ranges from 10 to 100 mg/L Desirable: ≤250 mg/l (US EPA)	Major anions found in water (combined with calcium, magnesium and sodium)	Reverse Osmosis (removal rate of 90 - 95%) Electro-dialysis Distillation Strong base anion exchanger
Chromium (trivalent: Cr^{-3}/ hexavalent: Cr^{-6}) Cr^{-3} (slightly soluble in water) is essential for efficient lipid, glucose and protein metabolism in living beings Cr^{-6} is considered toxic Desirable: ≤0.005 mg/L (US EPA)	Found in drinking water entered from industrial waste contaminants	Cr^{-3}: strong acid cation resin regenerated with hydrochloric acid Cr-6: strong base anion exchanger regenerated with caustic soda (sodium hydroxide) NaOH Reverse osmosis (removal rate 90-97%) Distillation

***Table 9.** Continued...*

Copper (Cu^{+}/Cu^{+2}) Its range for drinking water is 2-5 mg/l Desirable: ≤1.3 mg/L (US EPA)	Derived from rock weathering Corrosion of copper and brass piping and addition of copper salts for algal control	Sodium form strong acid cation resin (softener) Reverse osmosis (removal rate of 97-98%) Activated carbon filtration
Cyanide (CN^{-})	Normally found in waste water from metal finishing operations	Chlorine feed, retention and filtration Reverse osmosis (removal rate of 90-95%)
Fluoride (F^{-}) Desirable: ≤4 mg/L (US EPA)	Waste water from the manufacture of glass and steel Foundry operations	By anion exchange Activated carbon Reverse osmosis (removal rate of 93-95%)
Iron (Fe^{+2}/Fe^{+3})	Occurs naturally in ground waters as: Ferrous Iron i.e. clear water iron Ferric Iron i.e. red water iron Heme Iron i.e. organic iron	Ferrous Iron : using a softener (provided it is <0.5 ppm and the pH of the water>6.8) If the ferrous iron>5.0 ppm, it must be converted to ferric iron before its removal by mechanical filtration Heme iron: using an organic scavenger anion resin or by oxidation with chlorine followed by mechanical filtration
Lead (Pb^{+2}) Desirable≤0.05 mg/L	Metallurgical wastes or from lead-containing industrial poisons Primarily from the corrosion of the lead solder used to put the copper piping together	Water softener Activated carbon filtration Reverse osmosis (removal rate of 94-98%) Distillation
Magnesium (Mg^{+2})	Found in minerals including dolomite, magnesite and clay In sea water (five times the amount of calcium)	Using a softener or purification exchanger in hydrogen form (to <1 mg/l)
Manganese (Mg^{+2}/Mn^{+3}) Found in groundwater (2-3 mg/L) Desirable: ≤0.05 mg/L	Found in soils Sediments Rocks	Ion exchange (sodium form cation-softener) Chemical oxidation-retention-filtration
Mercury (Hg^{+2}) Desirable: ≤0.002 mg/L	Occurs as an inorganic salt or an organic compound (methyl mercury)	Activated carbon filtration Reverse osmosis (removal rate of 95-97%)
Nickel (Ni^{+2}/ Ni^{+3})	Exists in almost 85% of the water supplies (about 1 ppb)	By a strong acid cation exchanger Activated-carbon filtration Reverse osmosis (removal rate of 97-98%)
Nitrate (NO_3^{-}) Desirable: ≤10 mg/L (US EPA)	Comes into water supplies through the nitrogen cycle It is one of the major ions in natural waters Septic systems, feed lots and agricultural fertilizers	Reverse osmosis (92-95%) Anion exchange resin Distillation
Pesticides Pesticides are common synthetic organic chemicals (SOCs)	Water supplies (surface and groundwater) from the runoff in agricultural areas	Activated carbon filtration Ultrafiltration Reverse osmosis (removal rate 97-99%)

Table 9. *Continued…*

Potassium (K^+)	-	A cation exchange resin (softener) Reverse osmosis (removal rate of 94-97%)
Radium (Rn) Used in the treatment of cancer and some skin diseases Desirable: ≤5 pCi/L (US EPA)	Pitchblende and other uranium minerals Naturally or man-made processes	By sodium for cation exchange resin (softener) Reverse osmosis (removal rate of 95-98%)
Radon (Rn) Desirable: ≤15 pCi/L (US EPA)	Formed through atomic disintegration of radium Radionuclide (e.g. Radon 222) is of most concern	By aeration Carbon filtration
Selenium (Se^-) Desirable: ≤0.05 mg/L	Found in drinking water and comes from natural minerals Copper mining or smelting	Anion exchange (removal rate of 60-95%) Reverse osmosis
Silica (SiO_2) Found in surface and groundwater (1-100 mg/L)	It is an oxide of silicon present in almost all minerals	Anion exchange portion of the demineralization process Reverse osmosis (removal rate of 85-90%)
Silver (Ag^+) Desirable: ≤ 0.1 mg/L (US EPA)	Found in natural and finished water supplies	Distillation (removal rate of 98%) Activated carbon filtration (removal rate of 60%) Cation/anion exchange (removal rate of 90%) Reverse osmosis (removal rate of up to 90%)
Sodium (Na^+) Desirable: ≤20 mg/L (US EPA)	All water supplies contain some sodium depending on local soil conditions Corrosive nature of water increases with sodium content	Hydrogen form cation exchanger Reverse osmosis (removal rate of 94-98%) Distillation
Sulfate (SO_4^{2-}) Desirable: ≤250 mg/L (US EPA)	Occurs in almost all natural water Mostly originate from the oxidation of sulfite ores, the presence of shales and existence of industrial wastes	Reverse osmosis (removal rate of 97-98%) Using a strong base anion exchanger
Total Dissolved Solids (TDS) Desirable: ≤500 mg/L (US EPA)	Total Dissolved Solids (TDS) consist mainly of carbonates, bicarbonates, iron, chlorides, sulfates, nitrates, phosphates, calcium, magnesium, potassium, sodium, manganese, etc.	Reverse osmosis Electro-dialysis
Uranium (U) Desirable: ≤15 pCi/L (US EPA) pCi/L stands for picoCuries per liter	Naturally occurring radionuclide	Reverse osmosis (removal rate of 95-98%) Ultrafiltration Activated alumina

Significant information has been taken from https://www.aquapurefilters.com/contaminants/150/

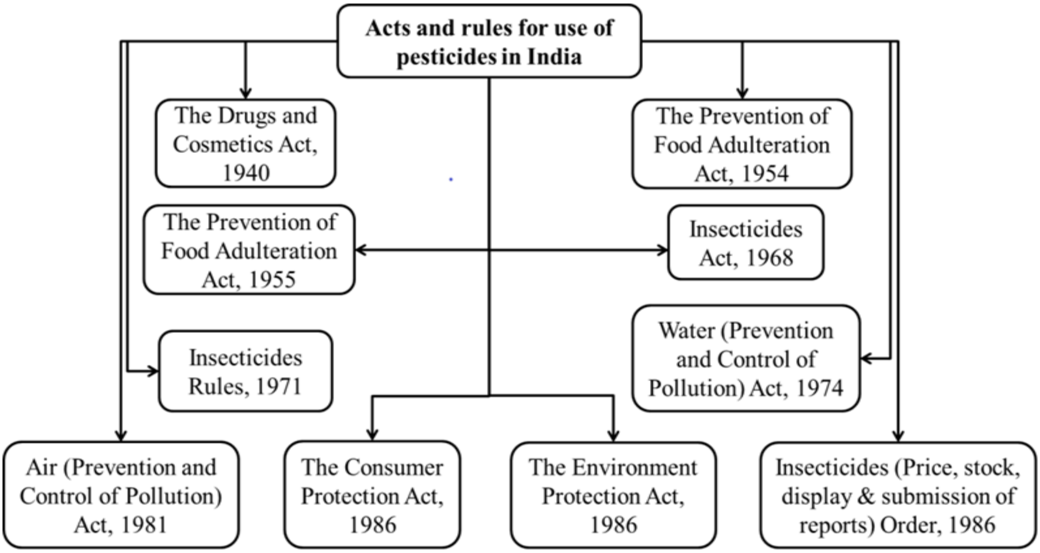

Figure 12.4*. Acts and rules for monitoring use of pesticides in India.*

- Promotion of organic manures with a significant reduction on use of artificial chemical fertilizers.
- Promotion of soilless cultivation practices (substrate culture cultivation, hydroponics and aeroponics etc.) particularly in vegetable crops (e.g. tomato, capsicum, cucumber, etc.) and fruit crops (e.g. strawberry). This technology can help to reduce the water pollution through controlled (re-circulation of nutrient solution) and reduced use of fertilizers (no wastage) along with saving in water use and improved crop yields (Singh *et al.*, 2018a, Singh *et al.*, 2018b; Singh *et al.*, 2019a; Singh *et al.*, 2019b).
- The chemical pesticides can be replaced with the following practices to control pollution:
    - IPM: Mechanical and biological control with greater emphasis on use of crop rotation, bio-pesticides and pesticides for plant origin like neem formulation.
    - Bio pesticides: The pesticides derived naturally from the waste materials from animals, plants, bacteria and minerals. It includes neem and the plant based formulations alike Indene, Repline, Neemmark and Guava family.
    - Organic farming: It is dependent upon crop rotation, animal manures, crop residues, off-farm organic wastes, mineral grade rock additives and biological system of nutrients mobilization and plant protection.
    - Crop diversification: Shifting from one particular cropping system to a diverse and multi cropping system to stabilize farm income in order to protect the natural resources.
- Use of class-I pesticides (as classified by WHO and other agencies) which are found highly

dangerous to human health should be banned with immediate effect.

- Active participation of the ministries through different mediating agencies or Acts (e.g. MoWR, MoEF, CGWA, CGWB, EPA Act 1986 and PPSW Act, 2009) is highly needed at present to protect the water resources (surface and groundwater) both in terms of quality and quantity through developing operational policy guidelines not as usual. The various acts and rules for regulating the use of pesticides in India are listed in Figure 12.4. The full names of above abbreviations are given in Table 12.1.
    - On 10th December 1996, Supreme Court of India directed the Union MoEF to authorize the CGWB under the EPA Act, 1986, against overexploitation of ground-water resources of the country through formation of the CGWA. However, not much success was achieved in managing the further over-exploitation of ground-water resources and quality.
    - Recently in February 2018, in order to stop the continued pesticide pollution in drinking water and food, the department of Agriculture, Punjab Government has banned the sale of 20 pesticides (insecticides) including Endosulfan based on the recommendations of Registration Committee, PAU and PSFC. The banned insecticides included Benfuracarb, Bifenthrin, Chlorfenapyr, Carbosulfan, Dicofol, Endosulfan, Ethofenprox, Tricholorofon, Methomyl, Phosphamidon, Thiophanate Methyl, Phorate, Triazophos, Dazomet, Diflubenzuron, Fenitrothion, Metaldehyde, Kasugamycin, Alachor and Monocrotophos (Anon, 2019e). Among these pesticides, Methomyl, Monocrotophos, Phosphamidion, Phorate, Triazophos are considered in class I by World Health Organization (WHO).
- Every individual should be encouraged to save water and retain its quality through proper waste (domestic, agricultural and industrial) management for sustainable quality food production and mankind. The community participation can play a great role in making the public aware of the current situation of depleting and polluting water resources of the state and their bad outcomes which may make the future darker.

Conclusion

The establishment or socioeconomic development of a stable community is highly dependent on the availability of safe and reliable fresh water resources such as groundwater. However, the quality of groundwater is extremely dependent on several anthropogenic factors (direct and indirect) that origin the pollution. The urban runoff, agricultural fertilizers including agro-chemicals (e.g. pesticides) and leaching from polluted industrial discharge and sewage disposal (containing heavy metals) sites have been identified to be the main causes of groundwater pollution in the state. The deadly illness to people of Malwa region due to pesticide contamination through direct contact with pesticide or drinking groundwater (80% contamination) has become a serious challenge for the modern and future Indian Punjab. The drinking water of this particular region contains high levels of pesticides, nitrate, magnesium, fluoride, iron, phosphates. The long-term excessive use of pesticides seems to be a main origin for prevalence of different deadly diseases in Malwa region of Punjab (cotton belt). Thus, to prevent the further health hazards to the people of the region through chemical contamination, there is a need to review and fortify the community programs for safe use of the chemicals through improved pesticide policies. Due to ineffectiveness of pollution control authorities in dealing with the groundwater crisis; it has become very important to involve the local people and society to evaluate the pollution status of groundwater. Thus, for improved and safe water supply, effective public policies, plans and technologies should be implemented in addition to political, socio-economic and other factors. Furthermore, the diminishing groundwater level in central zone and increasing water table in south-western zone may lead to gradient of flow from south-western to central zone thereby polluting the precious fresh water resource of central Indian Punjab in near future. It is obvious that there is a lack of proper monitoring of water quality and utilization of groundwater resources of the state. Thus, there arises a need for timely understanding and identification of sources of pollution and detection of contaminants associated with water (surface and groundwater) through appropriate measures such as complete blood analysis, physical and chemical analysis of water separately for pre and post-monsoon seasonal basis.

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Cite this chapter as: Singh, M.C. (2019). Groundwater pollution, causes, assessment methods and remedies for mitigation: A special attention to Indian Punjab. In: Kumar, V., Kumar, R., Singh, J. and Kumar, P. (eds) Contaminants in Agriculture and Environment: Health Risks and Remediation, Volume 1, Agro Environ Media, Haridwar, India, pp. 148-172, https://doi.org/10.26832/AESA-2019-CAE-0152-012