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Toward Managing Rural Drinking Water Quality in the State of Punjab, India

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This report was prepared by a team led by Pratibha Mistry and Srinivasa Rao Podipireddy. The team consisted of the Water Quality Division of the Drinking Water Supply and Sanitation, led by Veenakshi Sharma, and Albert Tuinhof, Koos Groen, Prasad Modak, Anjali Chikersal, Subhash Verma, Simmi Mishra, Kedar Dash, Carter Borden, Anupama Kumar, Amit Nair, Qiong Lu, Pyush Dogra, Charu Jain and Sunita Singh. This report has benefitted greatly from formal reviews and comments from Nagaraja Rao Harshadeep, Susanna Smets, Miguel Vargas-Ramirez and Janardan Prasad Singh.

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Executive Summary

Rural drinking water quality is an emergent issue in the State of Punjab. In response to health concerns related to children being exposed to metals in some regions, and reports of higher incidence of cancers in the State, the Department of Drinking Water Supply and Sanitation conducted blanket testing of all its water supply sources. The groundwater, which was generally considered to be of good quality, appeared to contain various minor chemical components or trace elements that exceeded the standards for drinking water. These included heavy metals lead, chromium, cadmium, nickel, aluminum, arsenic, and uranium.

The objective of this study was to systematically examine the drinking water quality issue and provide practical guidance to the State on possible responses. The State's commitment to addressing this issue is highlighted by its allocation of $59 million for a component to improve water quality through the Punjab Rural Water and Sanitation Sector Improvement Project, financed by the World Bank (US$248 million, approved in 2015).

While the study seeks to provide an analytical basis for understanding the occurrence and impact of the contamination, practical actions have been explored and demonstrated to allow the State to begin actively managing the water quality issue. The study is designed around three key areas:

- **Understanding the problem.** The first is understanding the scope and scale of the problem, the reasons why pollution is appearing in the deeper aquifer in which water supply tube wells are located, where the pollution is coming from, and what are the attributable health impacts on the rural population.
- **Taking appropriate action.** The second explores the actions the state can take to manage the water quality issue, including managing its water supply sources, ensuring that communities engage in safe water use behaviors, and continuously monitoring water quality to continue to understand the pollution characteristics and guide the ongoing management actions.
- **Institutional sensitization and action.** The third is around of the institutions responsible for water quality and its effects, their understanding of this emerging issue, and their ability to take coordinated action.

Groundwater contaminants have been divided into three groups based on the consistency of occurrence, known sources, and health impacts.

- **Group 1** contaminants arsenic, uranium, and fluoride have geogenic origins, with overabstraction of groundwater increasing the mobilization of these contaminants.
- **Group 2** contaminants are anthropogenic, namely lead, selenium, mercury, nickel, chromium, aluminum, iron, nitrate, total dissolved solids and pesticides. These contaminants show (i) there is a low statistical frequency of exceeding the permissible limit; (ii) the pattern of high concentrations is not consistent between the monitoring phases, indicating possible analytical errors; (iii) health risks may be low based on the concentrations reported; or (iv) the contaminants can easily be removed by simple treatment measures.
- **Group 3** are biological contaminants or pathogens, which continue to be a major health risk.

Arsenic and fluoride present the most urgent risk, surpassing the risk of uranium, with the duration of exposure increasing the health impacts. The origin of uranium, arsenic and fluoride is the erosion products of the Himalayas that make up the Indo-Gangetic sedimentary basin. High alkalinities from irrigation return flows are enhancing the mobilization of arsenic, uranium, and fluoride. The problem of geogenic contaminants is therefore aggravated by anthropogenic activities. The potential adverse health impacts due to arsenic are higher than those due to uranium. The impacts of uranium on human health are related to the isotope of the metal to which the population is exposed. The common form of uranium in drinking water—natural or depleted uranium—is not radioactive, and its impacts are due to its chemical nature, not radioactivity. Arsenic is carcinogenic and the priority contaminant to be managed. It takes several years for the effects of chronic exposure to be exhibited; and once the effects are present, they are irreversible. Arsenic risk depends to a large degree on the type of arsenic. Inorganic arsenic in the water supply and taken up by crops via irrigation is much more toxic than the organic form. The speciation of arsenic in Punjab should be tested as a matter of priority. Fluoride is rapidly absorbed in the body and distributed throughout, with deposition in the teeth and bones. Infants and young children absorb proportionately greater amounts. Dental fluorosis develops early, and is associated with damage to the enamel and continued higher levels lead to skeletal fluorosis. Once exposure has occurred, these effects cannot be reversed.

High levels of heavy metals, such as lead, selenium, mercury, nickel, and chromium, exceeding permissible limits, have been found across the State, but do not occur consistently in space and time. Results were not reproducible, and repeated sampling did not yield consistent results. Sample preparation and procedural or analytical errors may be contributors to these results. Higher levels of nitrate concentrations are found everywhere in Punjab, indicating that groundwater contains anthropogenic nitrate from agricultural practices. The occurrence of nitrates points to the possibility of pesticides, which should be tested across Punjab.

Acute diarrheal disease remains a major health concern in Punjab. Over the last decade, on average, more than 200,000 cases of acute diarrheal disease have occurred every year, and multiple cholera outbreaks have occurred annually. Pathogens have not been measured and the occurrence of water-borne diseases indicates potential contamination of drinking water from sources, distribution systems, and household storage and handling. Water-borne diseases are largely preventable when appropriate disinfection is a part of the standard operating procedures for the water supply systems, and communities are encouraged to practice safe hygiene behaviors. There is limited awareness among water users of water quality and its potential to impact health. Even diseases such as diarrhea, which have a direct link to unsafe water, are not on the radar of mothers with young children.

Management action centers on the management of water sources. The priority is for the DWSS to develop and find safe alternative sources as a long-term solution. The construction method used for the drinking water wells is creating a preferential flow path for polluted water from the surface entering the deeper aquifer. Contamination could be avoided by redrilling wells with geophysical logging and improved designs, ensuring that wells are sealed from ingress of surface contaminants and deep sources are protected by sufficient clay layers. Deeper wells exceeding 300 meters could be a viable long-term alternative that should be a priority option. Riverbank infiltration systems should also be piloted as a priority. Groundwater yields are likely to be sufficient to support multivillage schemes from new sources. In areas with local contamination, neighboring safe sources could be expanded. New groundwater sources do not require treatment and can connect into existing distribution systems, resulting in reduced operations and maintenance costs compared with treatment plants. Treatment technologies should be a last resort, after exhausting groundwater and surface water options.

The communications strategy emphasizes behavior change at the individual, community, and institutional levels. Priority behaviors include the use of the piped water supply for drinking and cooking and ensuring that water is stored and handled appropriately. The Gram Panchayat Water and Sanitation Committees should understand water quality risks and actively participate in the management of the water supply systems, particularly ensuring adequate disinfection. Targeted interpersonal communications, facilitated by information and communication technology tools, are powerful alternatives to traditional approaches.

Strategic water quality monitoring allows the State to actively manage drinking water quality. It requires monitoring systems, processes and controls, reporting and decision-making frameworks to guide ongoing management decisions. DWSS has established three modern laboratories since this study was completed in 2017. There is a need for improved sample handling and preparation; testing, data organization and analysis; and general laboratory management. Risk-based monitoring will require dedicated resources and expertise, and active day-to-day management.

Technology is an important enabler for water quality management. The integration of scheme and water quality data into a consistent database is an important resource. Information, communication and technology can be used to conduct household surveys, monitor water quality, and create and disperse behavior change communication. The app developed under this study allowed field staff to collect data and engage with household members. Using simple water quality tests, householders were educated on water quality issues, water safety planning, and discussion on sanitation and hygiene. An app designed specifically to customize behavior change and communications assisted social staff to implement behavior change communication and water safety planning by classifying household status on awareness and compliance; providing targeting messaging; documenting engagements with the households, and tracking progress made for each household in the villages.

Water quality management is a dynamic process integral to daily operations of the Department of Drinking Water Supply and Sanitation. The responsibility is fundamental to the supply of safe drinking water and is inherent in every aspect of its operations. Standard operating procedures for the development of new wells and operation of water supply schemes are required. The DWSS needs to adopt a learning mindset and culture to actively manage the water quality issue, and to establish constructive, ongoing knowledge sharing arrangements with key institutions.

The current report is a first step toward understanding and managing water quality issues in the State. It provides an analytical basis for moving forward, and has demonstrated approaches that have yielded valuable lessons for scale-up. The next steps are for the State to identify key actions and develop detailed action plans for implementation.

Abbreviations

BARC	Bhabha Atomic Research Centre
BCC m-App	Behavior Change Communication m-App
BRIT	Board of Radiation and Isotope Technology
CEM	Community Engagement and Mobilization
CGWB	Central Groundwater Board
DoA	Department of Agriculture
DPSIR	driving force, pressures, state, impact, and response
DWSS	Department of Drinking Water Supply and Sanitation
EC	electrical conductivity
EPA	Environmental Protection Agency
ESOP	Economic and Statistical Organization of Punjab
GIS	Geographic Information System
GoI	Government of India
GoP	Government of Punjab
GPWSC	Gram Panchayat Water and Sanitation Committee HH Survey m-App Household Survey m-App
IARC	International Agency for Research on Cancer
ICT	information and communication technologies
ICMR	Indian Council of Medical Research
IEC	information, education, and communication
IPC	interpersonal communication
IRIS	Integrated Risk Information System
NABL	National Accreditation Board for Testing and Calibration Laboratories
NAQUIM	National Deep Aquifer Mapping project
NIH	National Institute of Hydrology
NPPCF	National Program for Prevention and Control of Fluorosis
NRDWP	National Rural Drinking Water Program
O&M	operations and maintenance

PBTI	Punjab Biotechnology Incubator
PCA	principle component analysis
PRSC	Punjab State Remote Sensing Centre
SDG	Sustainable Development Goals
WHO	World Health Organization
WQ m-App	Water Quality m-App

Chapter 1
Introduction

1.1 Background

Punjab's alluvial aquifer is an abundant source of water that was a driving force of the green revolution and economic development in the State. Punjab is a northwestern state in India, bordering Pakistan to the west. Punjab was at the forefront of India's green revolution, which drove economic growth during the 1960s and 1970s, and made Punjab one of India's most prosperous and developed states. Intensive agricultural production was driven by the predominantly flat topography, fertile alluvial soils, a long-standing policy of free electricity and plentiful surface and groundwater resources.Extensive irrigation is from surface water from five tributaries of the Indus: Jhelum, Chenab, Ravi, Sutlej, and Beas from which the State derives its name, and about 1.25 million tube wells.[1] Dominant crops are rice (kharif) and wheat (rabi), and cotton is grown in the canal command areas in the southern districts. From the 1950s to 2011, the population has grown from 9 million to 27.7 million.[2] The State is largely rural, with 62 percent of the population living in rural areas in 2011.[3] The industrial sector is limited, contributing 26 percent (2012-13) of the State's economy,[3] largely due to limited availability of minerals and power resources, and its landlocked location on the border with Pakistan.[4] The State is home to manufacturing industries for textiles, sports goods, scientific instruments, electrical goods, and the processing of pine oil and sugar.[5]

Intensive agricultural production has led to overabstraction, falling groundwater levels, and excessive fertilizer and pesticide use. Overexploitation has caused continuous lowering of groundwater levels; groundwater withdrawal is 140 percent of recharge and could to grow to 200 percent in the middle of this century.[6] Groundwater levels have dropped more than 15 meters to 20 meters during the past 50 years.[7] Punjab consumes 9 percent of India's total fertilizers and is the highest user by gross cropped area per hectare (190.1 kilogram per hectare of gross cropped area compared to 88.2 kilograms per hectare in all India.[8] Factors driving fertilizer use include (i) the availability of credit; (ii) the fall in fertilizer prices; and (iii) greater use of high yielding varieties of rice and wheat. Cotton production, particularly in the southern Malwa region, is pesticide intensive. Excessive fertilizer and pesticide use is leading to declining productivity and soil fertility, and at the same time, farmers are increasing their use to increase yields.

Authorities discovered children who had been exposed to metals in some regions, and higher incidence of cancers were reported in the State. Media reports have focused on the issue with reports of the "cancer train" that transports poor cancer patients from Punjab to a charitable cancer specialty treatment hospital in Bikaner, in the neighboring state of Rajasthan. In 2009, concern about metal exposure arose when hair and urine samples of children in Faridkot had high amounts of barium, cadmium, manganese, lead, and uranium, signifying long-term exposure. In response, the Bhabha Atomic Research Centre (BARC) tested drinking water, in which 235 groundwater and surface water samples were collected from Bhatinda, Mansa, Faridkot, and Ferozpur. Forty-two percent of the groundwater samples had uranium concentration above 60 parts per billion, the Atomic Energy Regulatory Board (AERB) limit.

In 2010, the Department of Drinking Water Supply and Sanitation (DWSS), Government of Punjab (GoP), conducted blanket testing of all its water supply sources, including testing for metals. The DWSS operates more than 9,000 rural water supply schemes. Most are groundwater-based schemes, except for the southern districts, where groundwater salinity is too high for potable water use, and drinking water is supplied from irrigation canals. A typical groundwater-based rural water supply scheme consists of an average well that is 100 meters to 150 meters deep (depths range from less than 50 meters to 400 meters) with a submersible pump, a pump house with chlorination plant, and an elevated reservoir. The typical well services 1,000 to 3,000 consumers (one to three villages). A minority are drilled wells with a hand pump serving about 20 households. In general, the depths of the wells increase from the west to the east of the State. Testing found that the groundwater, generally considered to be of good quality, appeared to contain minor chemical components or trace elements that exceeded the standards for drinking water. These included the heavy metals like lead, chromium, cadmium, and nickel, and aluminum, arsenic, and uranium.

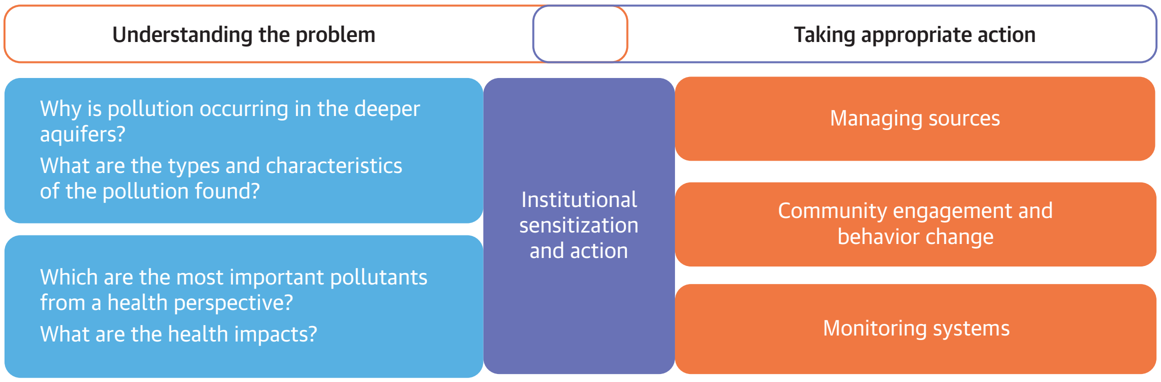
In response, the DWSS installed more than 1,000 reverse osmosis plants in affected villages. These were installed, operated, and maintained by private operators. Less than a fifth of villagers are reported to be using them. The lack of uptake is due to (i) availability of private water sources in the household; (ii) limited awareness of the water quality issue and its impacts on health; (iii) reverse osmosis plant supply times limited to two hours a day; (iv) inconvenience of fetching water at the point of reverse osmosis supply. There is currently limited oversight or regulation of these plants. Rejects are disposed directly into ponds, drains, open fields or special bore wells to inject rejects into the groundwater.

1.2 Objectives and Design

The GoP has an ongoing engagement with the World Bank and has committed US$59 million toward the management of drinking water quality. GoP has prioritized rural water supply and sanitation as a key area of its development agenda, and has invested significantly over the past decade. The first World Bank-financed Punjab Rural Water Supply and Sanitation Project (2007-14) for US$90 million saw the State investing predominantly in water supply systems using a community driven development approach. The subsequent Punjab Rural Water and Sanitation Sector Improvement Project for US$248 million, approved in 2015, focuses on improving water supply and sanitation service levels, reducing open defecation, and strengthening service delivery. Faced with the contamination of water sources, without a clear indication of the reasons and severity, the GoP committed US$59 million for a component to improve water quality. Through this component, the project aims to (i) strengthen water quality monitoring and develop mitigation measures; (ii) finance cost-effective retrofitting of water schemes with engineering solutions to treat arsenic, fluoride, iron, and so on (target: 150 villages); and (ii) construct surface water supply schemes to supply safe drinking water to more than 121 villages in the districts of Moga and Barnala, which have uranium and other heavy metal contamination.

This technical assistance study was designed to respond directly to the drinking water quality challenges faced by the DWSS. It provides strategic direction to the State to understand and manage the water quality issue. The study has three key areas, as illustrated in figure 1.1 and described below.

FIGURE 1.1 Water Quality Management Framework



- **Understanding the problem.** Understand the scope and scale of the problem, the reasons why the deeper aquifer was polluted, the source of the pollution, and the health impacts on the rural population.
- **Taking appropriate action.** Explore actions that can be taken by the State to manage the water quality issue, by managing its water supply sources, ensuring that communities engage in safe water use behaviors, and continuously monitoring water quality to continue to understand the pollution characteristics and the effectiveness of management actions taken.
- **Institutional sensitization and action.** Assist institutions in understanding water quality and its effects, and their ability to take coordinated action.

While the study seeks to provide an analytical basis for understanding the occurrence and impact of the contamination, practical actions were explored and demonstrated to allow the State to begin actively managing the water quality issue. The strategy set out an approach that the Punjab Water and Sanitation Sector Improvement Project can implement. Key elements were implemented on a small scale to demonstrate the concepts and test their effectiveness. With limited structured information, and the urgent need for the State to take action, the study simultaneously conducted research and analysis to understand the problem, and provided practical actions in the State context.

This synthesis report is structured around this framework. Chapter 2 summarizes the findings, providing an understanding of the pollution occurrence and flow paths, potential health impacts, and risks. Chapter 3 outlines ways to manage drinking water sources, engage with communities, improve monitoring systems, and change how government institutions work and cooperate to improve the flow of information and enable coordinated action. The study methodology is provided in appendix A. This study was informed by several focus areas presented as separate technical reports, as summarized in appendix B, table B.1.

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Chapter 2
Understanding the Problem

This section explores why contaminants are in the deeper aquifer in rural areas in Punjab, where they may be originating, and how they are making their way into the deeper drinking water wells. This section also explores the health effects of these contaminants and the health risk to the population in Punjab.

Key messages

- The origin of uranium (together with arsenic and fluoride) is the erosion products of the Himalayas that make up the Indo-Gangetic sedimentary basin. High alkalinities from irrigation return flows are enhancing the mobilization of arsenic, uranium, and fluoride. The problem of geogenic contaminants is therefore aggravated by anthropogenic activities.
- High levels of heavy metals, such as lead, selenium, mercury, nickel, and chromium, exceeding permissible limits, have been found across the State, but do not occur consistently in space and time. Results were not reproducible, and repeated sampling did not yield consistent results. Sample preparation and procedural or analytical errors may be contributors to these results.
- Higher levels of nitrate concentrations are found everywhere in Punjab, indicating that groundwater contains anthropogenic nitrate from agricultural practices. The occurrence of nitrates points to the possibility of pesticides, which should be tested across Punjab.
- The construction method used for the drinking water wells is creating a preferential flow path for polluted water from the surface entering the deeper aquifer.
- Acute diarrheal disease remains a major health concern in Punjab. Over the last decade, on average, more than 200,000 cases of acute diarrheal disease have occurred every year. From 2013 to 2016 there have been six deaths from cholera, an average of six cholera outbreaks per year, with an average of over 800 cases. Pathogens have not been measured and the occurrence of water-borne diseases indicates potential contamination of drinking water from sources, distribution systems, and household storage and handling.
- The greatest health risk is from arsenic and fluoride. The potential adverse health impacts due to arsenic are higher than those due to uranium. The impacts of uranium on human health are related to the isotope of the metal to which the population is exposed. The common form of uranium in drinking water—natural or depleted uranium—is not radioactive, and its impacts are due to its chemical nature, not radioactivity.
- Arsenic is carcinogenic and the priority contaminant to be managed. It takes several years for the effects of chronic exposure to be exhibited; and once the effects are present, they are irreversible. Arsenic risk depends to a large degree on the type of arsenic. Inorganic arsenic in the water supply and taken up by crops via irrigation is much more toxic than the organic form. The speciation of arsenic in Punjab should be tested as a matter of priority.

- Risks are higher for children than for other age groups, and safe concentrations for children should be considered in addition to guideline values. For example, fluoride is rapidly absorbed in the body and distributed throughout, with deposition in the teeth and bones. Infants and young children absorb proportionately greater amounts.
- Wells with a high risk from multiple contaminants have been identified and prioritized for monitoring. These wells should be prioritized for more frequent monitoring. If the exceedances are consistent over multiple sampling rounds, then appropriate action should be taken.
- There is limited awareness among water users of water quality and its potential to impact health. Even diseases such as diarrhea, which have a direct link to unsafe water, are not on the radar of mothers with young children.

2.1 Pollution Occurrence and Sources

Groundwater contaminants are divided into two groups based on the consistency of occurrence, known sources, and health impacts. Groundwater contaminants are divided into three categories. Group 1 are the geogenic contaminants arsenic, uranium, and fluoride. Group 2 are anthropogenic: lead, selenium, mercury, nickel, chromium, aluminum, iron, nitrate, total dissolved solids, and pesticides. Group 3 are biological contaminants or pathogens.

The most important input for this study were the databases of the DWSS and Punjab Remote Sensing Center (PRSC), which contain thousands of analyses on pollutants and major chemical constituents of water from wells in Punjab. The DWSS database comprises analyses of samples from about 7500 tube well schemes. Analyses were available from three monitoring phases: the first, second and ongoing third monitoring phase (2011-2017). The samples have been analysed for heavy metals fluoride, nitrate, iron, aluminium and TDS. Not all wells have been sampled and not all parameters have been analysed during the monitoring phases. For the various parameters the number of analyses varies between 100 and 6000 for each phase. The PRSC database was developed in 2009 during first World Bank-financed Punjab Rural Water Supply and Sanitation Project. It holds the results of a state wide sampling campaign (about 5800 analyses of all major constituents except for sodium) the database also contains the geographical coordinates and well construction information. A summary of the analysis of the three phases is shown in table 2.1.

2.1.1 Group 1: Geogenic Contaminants

Arsenic, uranium, and fluoride have geogenic origins, with overabstraction of groundwater increasing their mobilization. Most hydrogeochemical studies worldwide, as well as those in Punjab, attribute arsenic, uranium, and fluoride to geogenic origins. Some authors propose anthropogenic sources such as fertilizers (fluoride, uranium), pesticides (arsenic), and fly ash from coal incineration (uranium). Elevated nitrates in the deeper drinking water wells indicate anthropogenic contaminants. However, the lack of consistency between high concentrations of arsenic, fluoride, and uranium, and the pattern of nitrate occurrences, indicate the more likely source to be underlying sediments and the chemical conditions promoting their mobilization. Arsenic, fluoride, and uranium originate from the erosion products of the Himalayas that make up the Indo-Gangetic sedimentary basin. The irrigation return

TABLE 2.1 Occurrence of Contaminants in Rural Drinking Water, Phases 1, 2, and 3, Punjab, 2010–17

		No. wells above acceptable limit (phases)				No. wells above permissible limit (phases)						Health impacts	
Element	Acceptable limit (mg/l)	1	2	3	Permissible limit (mg/l)	1	2	3	Location in Punjab	Source G /A	Comments/ observations	known impacts	risk in Punjab[b]
Arsenic	0.01	736	687	435	0.05	84	90	88	NW	G	Consistent Holocene sediments	High	Moderate/ high
Fluoride	1.0	493	535	235	1.5	184	198	185	SW and E	G, A[a]	Consistent Link with TDS and EC	High,	Moderate/ high
Uranium	0.03	619	609	243	0.06	121	116	47	SW (center, SE)	G, A[a]	Link with TDS and EC Pathway impact	Milder (in DW)?	Unsure
Lead	0.01	320	141	23	0.01	320	141	23	Scattered	A	Analysis inconsistent	High	Limited
Aluminum	0.03	4,080	2,352	1,107	0.03	4,080	2,352	1,107	Scattered, focus on E	G	Why high number? Vert. flow (see nitrate)	Not significant	Limited
Selenium	0.01	141	95	81	0.01	141	95	81	Center and E	Unsure	Impact on rice	Moderate	Unsure
Nitrate	45	73	111	53	45	73	111	53	Scattered	A	Confirms vertical groundwater flow	High	Moderate
Mercury	0.001	20	7	4	0.001	20	7	4	Scattered	Unsure	Few wells	High	Limited
Cadmium	0.003	10	18	24	0.003	10	18	24	Moga and Ludhiana	A	Industrial sources	High	Limited
Nickel	0.02	50	8	82	0.02	50	8	82	Moga and Ludhiana	A	Analysis inconsistent Industrial sources	Moderate	Limited
Chromium	0.05	5	18	14	0.05	5	18	14	Scattered	A	Few wells Leather industry?	Moderate to high	Limited
TDS	500	n.a.	1,171	437	2,000	n.a.	20	10	S and E	G	South: salinity Why in east?	Salinity	Limited
Iron	0.3	731	929	337	0.3	731	929	337	Scattered	G	No health issue Attitude of users?	Aesthetic	Limited

Source: World Bank data.

Note: Phase 1 involved 7,170 samples; Phase 2, 7,600 samples; Phase 3, 3,670 samples (not yet completed). A = anthropogenic; G = geogenic; TDS = total dissolved solids; n.a.= not available.

a. Pathway accelerated by anthropogenic processes.

b. Probability of exposure determined by geographical extent, consistency of data and significance of high value.

flows and other effluents entering the groundwater lead to high alkalinities because of dissolved organic matter and nutrients. Part of this water has reached the screens of DWSS wells. Because this water enhances the mobilization of arsenic, uranium, and fluoride, the problem of geogenic contaminants is aggravated by anthropogenic activities. The presence and origin of Group 1 contaminants is summarized in table 2.2.

Arsenic predominantly occurs in the Tarn Taran, Amritsar, and Gurdaspur districts of northwest Punjab, and Rupnagar District in the east. Arsenic in drinking water is geogenic and related to organically rich Holocene sediments. High levels of arsenic concentrations above the acceptable and permissible levels of 10 micrograms per liter and 50 micrograms per liter, respectively, are clustered in two zones, as shown in figure 2.1, panels a–c. One zone comprises the districts of Tarn Tara, Amritsar, and Gurdaspur in northwest Punjab, and the other is the Rupnagar District in the east. In the latest, most extensive monitoring phase, 452 out of 3,665 wells exceed the acceptable limit. Fewer analyses were carried out in previous phases, but the same areas emerge as problematic.

Elevated fluoride levels are in the zones around the Patiala District in the north, Fategarh Sahib in the east, Sangrur and Firozepur in the south, and Fazilka in the north along the Pakistan border in southwest Punjab. High levels of fluoride above the acceptable and permissible limits of 1 milligrams per liter and 1.5 milligrams per liter, respectively, are mainly in three zones as shown in figure 2.3, panels a–c. Most conspicuous is the zone of Patiala (north) and Fatehgarh Sahib (east) in southeast Punjab. Concentrations in 487 out of 6,568 wells do not have acceptable levels in the most extensive monitoring of Phase 1. A similar pattern was found in subsequent monitoring phases.

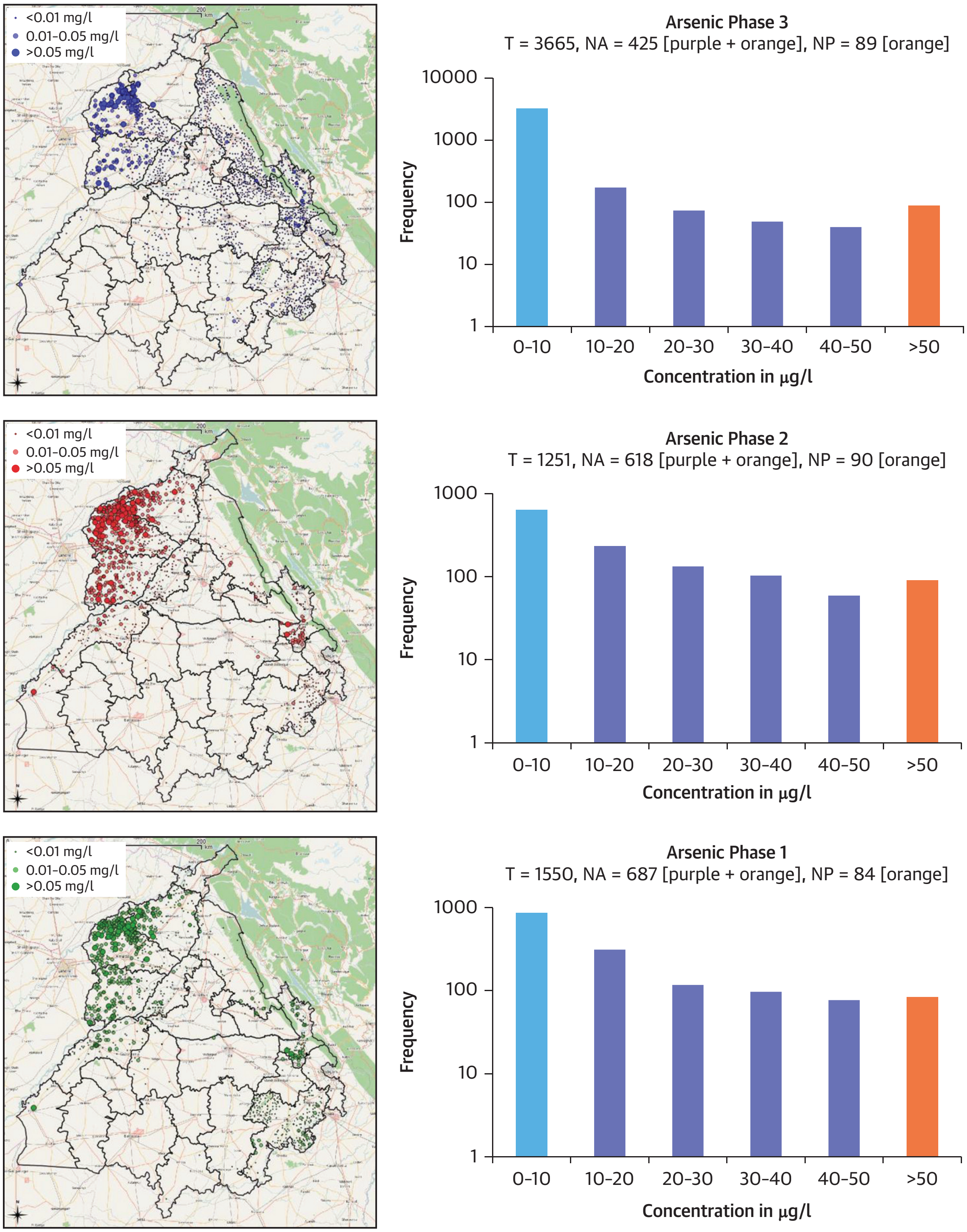
Uranium is in high concentrations exceeding the acceptable and permissible limits of 30 micrograms per liter and 60 micrograms per liter, respectively, in the southern districts of Punjab (figure 2.3, panels a–c): Fazilka (north), Ferozepur, Taran Taran, Moga, Barnala, Sangrur, Patiala, and Fatehgarh Sahib. Clusters of polluted wells occur particularly in the Moga, Ferozepur (south), and Fazilka (north) districts. Concentrations in 614 out of 6,686 wells have unacceptable levels in the most extensive monitoring of Phase 1. In the other phases the pattern is similar.

TABLE 2.2 Group 1 Geogenic Contaminants in Water Supply

Contaminant	Presence	Origin	Hypothesis
Arsenic	Amritsar, Gurdaspur, Taran Taran, Rupnagar	• Geogenic • Related to organic rich Holocene sediments	Groundwater from deeper aquifers may be arsenic free; needs to be reconfirmed by drilling exploratory wells to depths > 200 m and 300–500 m from existing well
Uranium	Fazilka, Moga, Sangrur, Barnala, F.G. Sahib, Patalia	• Geogenic • Related to TDS and EC	Possibility of avoidance by drilling wells deeper than 200 m
Fluoride	Fazil, Ferozpur, Moga, Barnala Sangrur	• Geogenic • Probably related to TDS and EC • Found in wells > 240 m	Aquifers with low EC and high resistivity probably have low uranium; possibly avoidable through resistivity logging of wells to find safe layers

Source: World Bank data.
Note: EC = electrical conductivity; TDS = total dissolved solids.

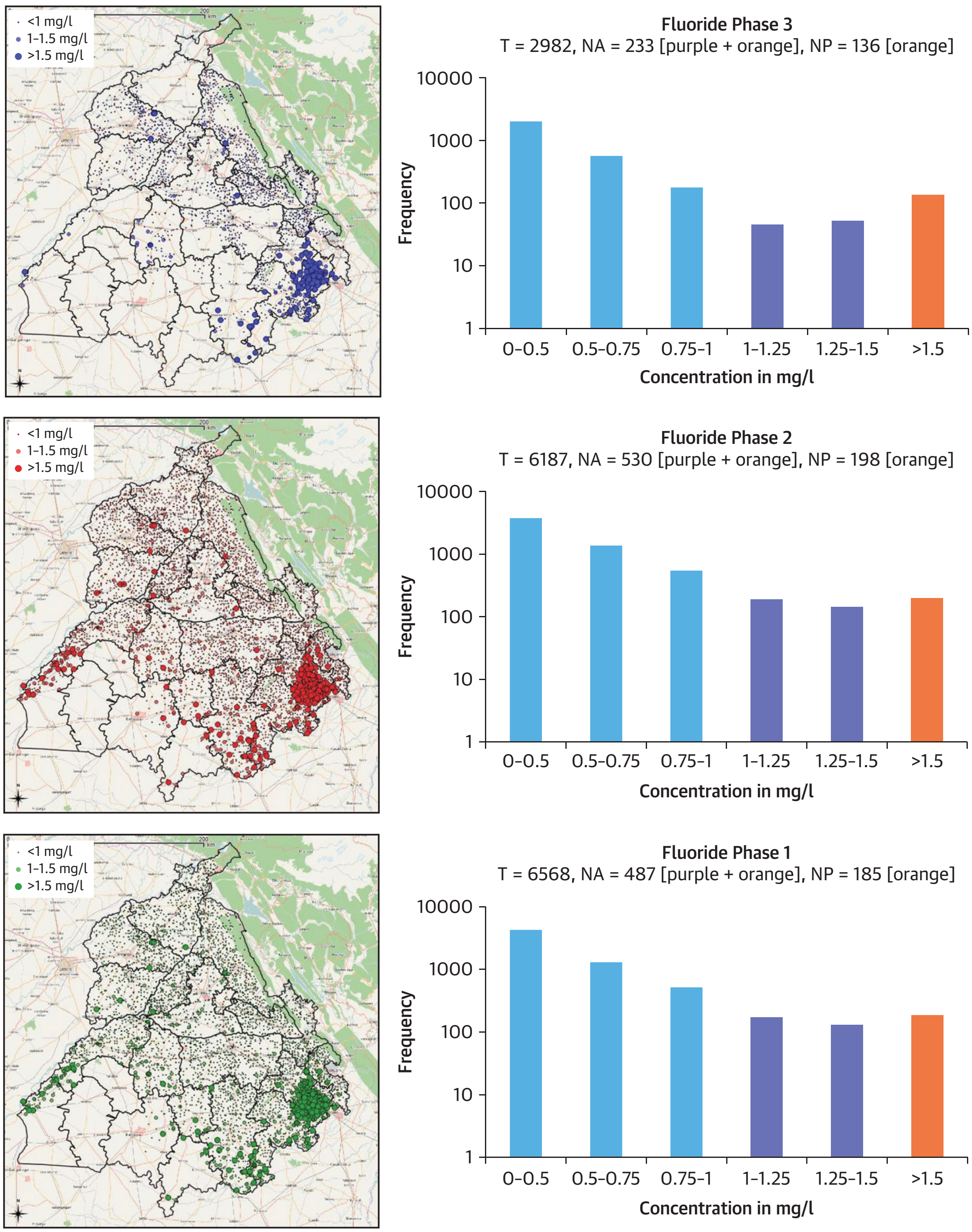
FIGURE 2.1 Arsenic Occurrence in Three Sampling Phases, State of Punjab, 2010–17



Source: World Bank.

Note: T = Total number of measurements, NA = Number within Acceptable Limit, NP = Number above Permissible Limit.

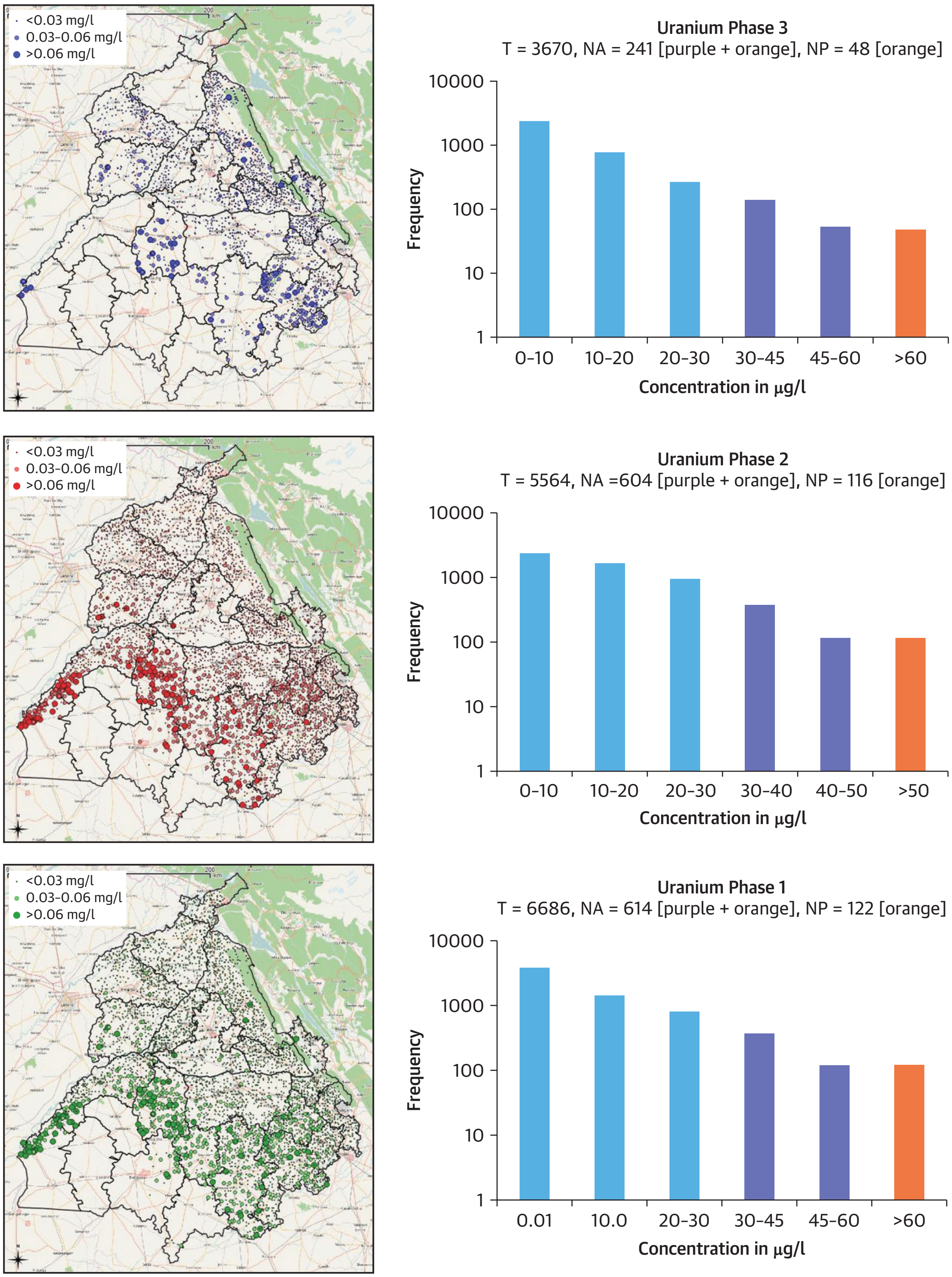
FIGURE 2.2 **Fluoride Occurrence in Three Sampling Phases, State of Punjab, 2010–17**



Source: World Bank.

Note: T = Total number of measurements, NA = Number within Acceptable Limit, NP = Number above Permissible Limit.

FIGURE 2.3 **Uranium Occurrence in Three Sampling Phases, State of Punjab, 2010–17**



Source: World Bank.

Note: T = Total number of measurements, NA = Number within Acceptable Limit, NP = Number above Permissible Limit.

2.1.2 Group 2: Anthropogenic Contaminants

Group 2 contaminants tend to be inconsistent in occurrence over the sampling rounds, have no clear sources in the rural area, or are detected at levels that have a low risk to human health. In this group, contaminants show (i) there is low statistical frequency of exceeding the permissible limit; (ii) the pattern of high concentrations is not consistent between the monitoring phases, indicating possible analytical errors; (iii) health risks may be low based on the concentrations reported; or (iv) the contaminants can easily be removed by simple treatment measures. The presence and origin of Group 2 contaminants is summarized in table 2.3.

High levels of heavy metals, such as lead, selenium, mercury, nickel, and chromium, exceeding permissible limits, have been found across the State, but do not occur consistently in space and time. A substantial proportion of wells were found to be contaminated in the first two rounds of sampling, but this reduced substantially in the third phase. Results were not reproducible, and repeated sampling did not yield consistent results. Sample preparation may be a factor. Samples are acidified in the field or

TABLE 2.3 Group 2 Contaminants to Water Supply, Phases 1, 2, and 3, Punjab, 2010–17

	% > permittable level				
Contaminant	Phase 1	Phase 2	Phase 3	Presence	Hypothesis
Heavy metals:					Source: industrial/urban areas (based on nickel pattern and literature)
lead (Pb),	45	52	0.7	Everywhere, but not consistent in space/time.	
selenium (Se),	23	40	2.0	Phase 3: low occurrence	Low occurrence
mercury (Hg),	5	11	0.1	Nonreproducible	Poss. avoidable: wells > 300 m from canals, *nullahs*, dumps, and factories
nickel (Ni),	3	10	0.5	Sampling impact[a]	
chromium (Cr)	0.4	4	0.4		
Nitrate (NO3)	1	2	2	Everywhere, but scattered	Source: fertilizers, latrines, septic systems and manure storage and spreading Avoidable: wells > 200 m from latrines
Iron (Fe)	9	13	9	Everywhere, but scattered	Treatment simple Low risk
Aluminum (Al)	4	6	3	Everywhere Sampling impact (note)!	Irrelevant
Salinity (TDS)	0.3	n.a.	0.3	In south related to uranium (U) and fluoride (F)	Low risk Avoidable: resistivity logging
Pathogens	n.a.	n.a.	n.a.	Possible everywhere if wells have no clay seals	High risk Source: latrines, waste (water), etc. Avoidable: proper well design
Pesticides	n.a.	n.a.	n.a.	Possible everywhere if wells pump young groundwater	High risk Source: agriculture Possible to avoid if wells > 200 m deep

Source: World Bank data.
Note: n.a. = not available; TDS = total dissolved solids.
a. Acidification of samples before filtering may give incorrect or high values.

in the laboratory, and then filtered, which is not standard procedure. Samples for ICP-MS analyses, or analyses on cations in general, are to be filtered first and acidified after.[1] Samples for Phases 1 and 2 were analyzed in a different laboratory than for those of Phase 3. Even though both are accredited laboratories, procedural or analytical errors may factor.

Pollution hotspots were analyzed by aggregating data using a water quality index for heavy metals and industrial pollution intensity indexes. Analysis of the spatial distribution of high occurrence of these two indexes showed that six blocks—Ajnala, Sujanpur, Nabha, Patiala, Sanaur, and Samana—have both high exceedances of heavy metals pollutants and presence of red industries. However, in many blocks there is no consistent direct correlation between the occurrence of large red industries and incidence of heavy metals. Polluted wells are in rural areas, and industries tend to concentrate in urban or peri-urban areas. Horizontal flow through the aquifer is very slow, with up to 30 years of travel time for water to travel 300m horizontally. The likely flowpath is vertically through the well screen. For wells closer to urban areas, it is prudent to ensure that wells are sited more than 300 meters from canals, nullahs, dumps, and factories, and tested more frequently. Urban wells are at greater risk, and an assessment of urban and peri-urban wells is recommended.

Pesticides have not been measured in the DWSS wells. The literature shows that some analyses have been carried out on surface water and in some wells, but pesticides have not been found. Many factors determine whether a pesticide will leach to groundwater. The pesticides most susceptible to groundwater leaching are those with high solubility in water, low adsorption to soil, and long-term persistence. When these pesticides are applied to sites with sandy soils, shallow depth to groundwater, and either a wet climate or extensive use of irrigation, the risk of groundwater contamination could be high. Since the source is at the surface, deep wells will likely have lower concentrations. However, the occurrence of anthropogenic nitrate in wells indicates agrochemicals may have reached the well screens. Further testing for pesticides is therefore recommended.

Higher concentrations of nitrates indicate humanmade influences such as the application of fertilizers in agriculture and discharge of domestic waste and sewage. Maps show wells with concentrations exceeding 10 milligrams per liter nitrate across the State, indicating that groundwater contains anthropogenic nitrate from agricultural practices. The occurrence of nitrates points to the possibility of pesticides, which should be tested across Punjab. High levels of nitrate concentrations above the acceptable and permissible level of 45 milligrams per liter are found everywhere in Punjab. High concentrations of the Phase 1 monitoring occur mainly below the line Ferozepur- Ludhiana-Chandigarh. In Phase 2, high concentrations are found in the northern districts. In Phase 3, high concentrations occur predominantly in the northern districts, but monitoring of this phase is not complete. Clusters with contaminated wells are not consistent. They are in Ferozepur in Phases 1 and 2 and in Hoshiarpur (north and south) in Phase 3. Exceedances are not frequent: they vary from 1 percent to 2 percent of the analyses. In pristine groundwater, nitrate generally occurs in concentrations less than 5 milligrams per liter.

The pattern of concentrations of selenium exceeding the acceptable and permissible limit of 10 micrograms per liter is comparable to that of lead. In Phases 1 and 2, 23 percent and 40 percent respectively, of the limited number of analyses exceed the limit. In Phase 3, about 2 percent of the analyses are higher than the limit. There are no clusters of contaminated wells apparent on the map. The worst affected districts are Jalandhar, Ludhiana, and SBS Nagar.

With respect to mercury's acceptable and permissible limit of 1 microgram of liter, the same pattern emerges as for selenium. In Phases 1 and 2, few wells have been analyzed. In Phase 1, 10 percent (2 out 19 wells) and in Phase 2, 5 percent (3 out of 61) of the analyses surpass the limit. In Phase 3, only 0.1 percent of the concentrations are not acceptable (4 out of 3,363). Clusters of contaminated wells cannot be identified. The highest observed value was 0.038 milligrams per liter in the Mansa District, followed by 0.02 milligrams per liter in a well in SAS Nagar.

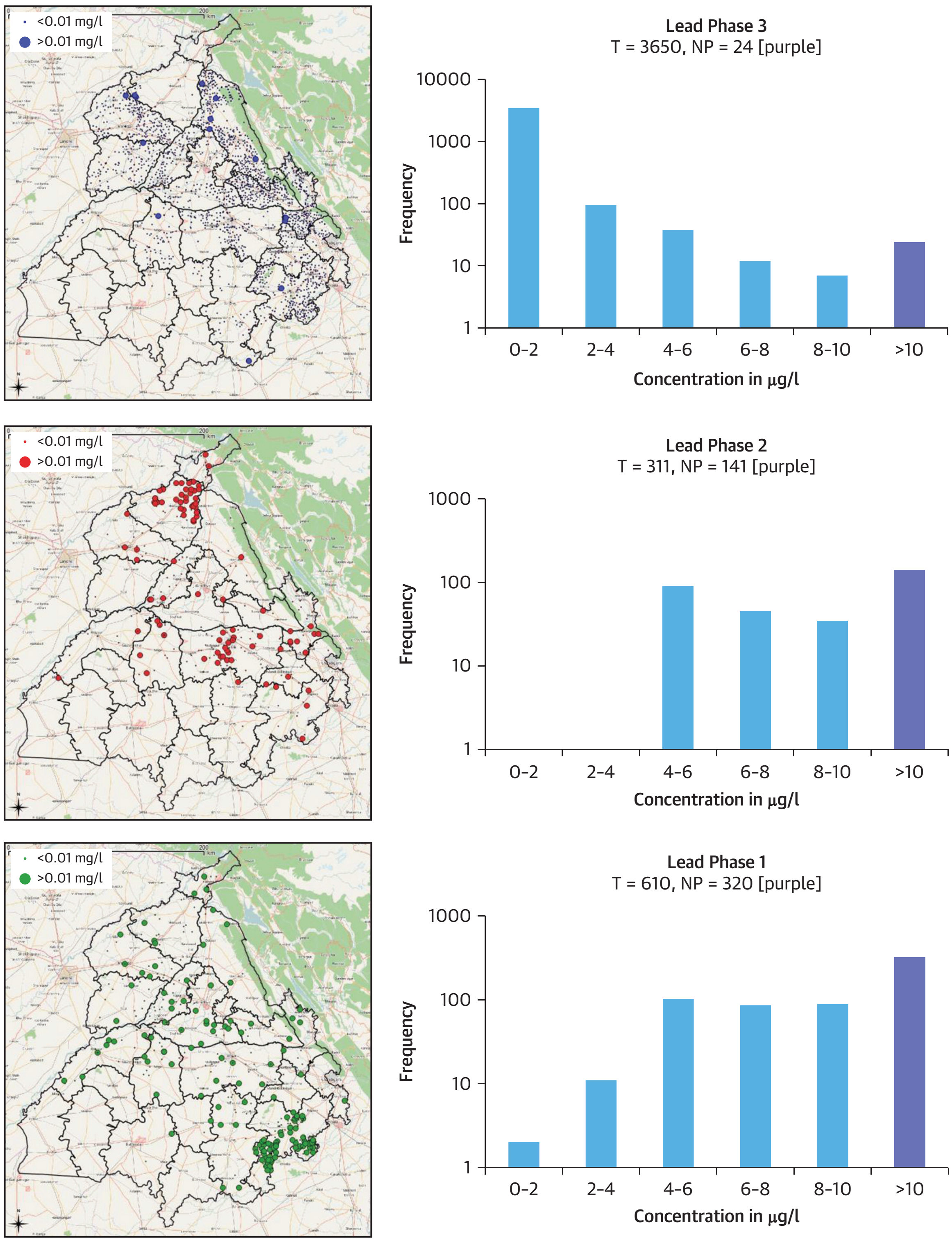
For lead, the number of analyses in Phases 1 and 2 is restricted compared to the number in Phase 3. Wells with concentrations exceeding the acceptable and permissible limits of 10 micrograms per liter are found everywhere in Punjab. Phase 1 displays a cluster of contaminated wells in Patiala District in the far southeast, while Phase 2 shows a cluster in Gurdaspur District in the north and in Ludhiana in the center, as shown in figure 2.4. About 50 percent of the analyses of Phases 1 and 2 exceed the limit. This seems to pose a serious problem, though the number of analyses is restricted. The exceedances in Phase 3, on the other hand, carried out by another laboratory, are less than 1 percent and are scattered all over Punjab. There was a negative correlation between the depth of the wells and the logarithm of the lead concentration, suggesting that the source could be from surface water.

Nickel has the same pattern as for the other heavy metals, apart from uranium. In Phases 1 and 2, respectively, 10 percent and 3 percent of the analyses exceed the acceptable and permissible limit of 20 micrograms per liter. In Phase 3, only 0.5 percent of the analyses have unacceptable concentrations. In Phases 1 and 2, there are no clusters of contaminated wells. In Phase 3, which is not yet complete, clusters appear around the major cities of Ludhiana and Moga in central Punjab. Fourteen of the 22 districts have at least one sample with a concentration that exceeds guidelines.

The pattern of chromium concentrations is similar to those of the other heavy metals, apart from uranium. In Phases 1 and 2, respectively, 0.4 percent and 4 percent of the analyses exceed the acceptable and permissible limit of 50 micrograms per liter. In Phase 3, 0.4 percent of the analyses have unacceptable concentrations. Only in Phase 2 is there a cluster of contaminated wells: Hoshiarpur District (north) in the north of Punjab. Other exceedances occurred in Amritsar, Gurdaspur, and Taran Taran districts.

In all three phases, aluminum concentrations in many wells throughout Punjab are higher than the acceptable and permissible limits of 0.03 milligrams per liter and 0.2 milligrams per liter, respectively. In Phases 1, 2, and 3, respectively, 61 percent, 57 percent, and 30 percent of the aluminum concentrations exceed the acceptable limit of 30 micrograms per liter. These high concentrations in groundwater are peculiar. Aluminum may occur in high concentrations only under very acidic conditions. However, the pH is generally almost neutral to slightly alkaline. The reason may be that groundwater samples containing colloidal particles with adsorbed aluminum have not been filtered before analysis. This may have led to erroneous results. Generally groundwater is filtered in the field with 0.45-micrometer pore filters. Aluminum is generally not considered a toxicant. If aluminum concentrations in groundwater are indeed high, simple treatment by aeration (oxidation) and sand filtration or cation exchange could be applied to reduce the concentrations.

FIGURE 2.4 **Lead Occurrence in Three Sampling Phases, State of Punjab, 2010–17**



Source: World Bank data.

Note: T = Total number of measurements, NA = Number within Acceptable Limit, NP = Number above Permissible Limit.

Iron is an element related to aluminum and shows a similar pattern. High concentrations exceeding the acceptable and permissible limit of 0.3 milligrams per liter occur everywhere in Punjab. In Phases 1, 2, and 3, respectively, 9 percent, 19 percent, and 13 percent of the samples exceed the limit. The limit is not as much related to health risks as to technical and aesthetic considerations. Dissolved iron contents higher than 2 milligrams per liter are quite common in anoxic groundwater. In this case about 0.5 percent of the samples in Phase 3 surpass this concentration. This means deep groundwater has relatively low concentrations. This may indicate oxic conditions in the aquifers. Another possibility is that samples have been oxidized during transport, which should have been apparent by the red coloration of the samples. In any case, high iron concentrations in groundwater are not too problematic because iron can be removed easily by aeration (oxidation) and sand filtration.

Wells with high levels of Total Dissolved Solids (TDS) above the acceptable and permissible limits of 500 milligrams per liter and 2,000 milligrams per liter, respectively, are mainly in the southern district of Ferozepur in Punjab. In Phases 2 and 3, respectively, 14 percent and 17 percent of the analyses exceed the permissible limit. The acceptable limit is exceeded in only 0.3 percent of the wells.

2.1.3 Group 3 Contaminants: Pathogens

Pathogens have not been measured in the DWSS wells over the three phases. It is generally assumed that the deep sources will not be contaminated, but leakage along the gravel pack of wells is not unlikely. Wells are often constructed without clay seals (around screens, at the depth of natural clay layers and at the well head), though well heads are well protected in the pump houses. The occurrence of water-borne diseases indicates potential contamination of drinking water from sources, distribution systems, and household storage and handling. Pathogen monitoring is part of the standard monitoring required at district laboratories. However, these tend to be poorly equipped and managed, and data are not readily available.

2.2 Contaminant Pathway

The DWSS water supply wells are generally deeper than agricultural or private wells and vary in depth from 120 meters to 150 meters. The annular space (space between the borehole wall and well casing) is entirely filled with gravel. The gravel pack forms a preferential flow path. It enhances the risk of polluted water from the surface (well head) or the shallow sand layers entering the gravel in the annular space and reaching the upper well screen. This flow path through the gravel pack is expected to be a much faster route than the normal vertical groundwater flow through the sand and clay layers. Little is known about the deeper parts of the alluvial sediments (greater than 200 meters). A provisional analysis of eight DWSS wells deeper than 250 meters shows that the wells are not polluted. Further research of the deeper aquifers is warranted. Improved construction of wells with adequate sealing is necessary.

2.3 Literature Review of Health Effects

A complete picture of health risks can be assessed only by considering all human exposure pathways and sources. Contaminants can enter the food chain from natural or anthropogenic sources, and uptake by plants and crops from groundwater used for irrigation. This study focuses on human health risk assessment based on the drinking water as a source of exposure to the contaminants.

2.3.1 Group 1: Geogenic Contaminants

Chronic effects of arsenic are most often seen after long-term exposure, generally greater than five years, and include both carcinogenic and noncarcinogenic effects. Arsenic effects, once initiated in the human body, are irreversible. Prevention of further exposure is a key recommendation by the World Health Organization (WHO). No case of arsenicosis has so far been reported from the State, though this may be due to the absence of surveillance. Human exposure to elevated levels of inorganic arsenic occurs through drinking contaminated water, using contaminated water for crop irrigation and food preparation, industrial exposure, and smoking tobacco grown in arsenic contaminated soils. By far the greatest risk of exposure is from drinking contaminated water. Arsenic has no smell and no taste; and it is not possible to tell if it is present in food, water, or air without special tests.

Adverse health effects of arsenic can occur in acute or chronic settings, though chronic exposure is of greater public health importance. Acute arsenic poisoning leads to abdominal pain, vomiting, diarrhea, muscular pain, and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping, and a rash. Chronic effects are most often seen after long-term exposure to high levels via drinking water and food for over five years, at the minimum. The occurrence of these effects is influenced by the status of nutrition of the exposed individuals; malnourished individuals show greater adverse impacts.

Chronic effects can be both carcinogenic and noncarcinogenic. A far greater proportion of the population that shows any effects presents with noncarcinogenic impacts. The signature symptoms are related to the skin, with pigmentation changes and hyperkeratosis (thickening of the skin). Dermal lesions include hyperpigmentation and hypopigmentation, and roughened and thickened patches on palms and soles. The skin lesions may be a precursor to skin cancer. Other effects of long-term exposure include lung cancers and peripheral vascular disease, bladder cancer, cardiovascular disease, diabetes, and neurotoxicity. Epidemiological studies are recommended to monitor the health of populations that are at high risk.

Fluoride has a mixed effect on humans: low levels are essential for proper development and strength of teeth and bones, while high levels have adverse impacts. Human exposure occurs mostly from drinking water contamination. Fluoride is rapidly absorbed in the body and distributed throughout, with deposition in the teeth and bones. Infants and young children absorb proportionately greater amounts. WHO has established a guidance value of 1.5 milligrams per liter for naturally occurring fluoride in drinking water, based on consumption of 2 liters of water per day. Levels higher than these over a prolonged period lead to dental and bone problems. Dental fluorosis develops early, and is associated with damage to the enamel and consequent staining, pitting, and opacity of teeth. Continued and higher levels lead to skeletal fluorosis, with deposition of the metal in the bones leading to brittle bones, increased fractures, denser bones, calcification of ligaments, stiffness of joints, joint pain, loss of mobility of joints, and a rigid spine. Once exposure has occurred, these effects cannot be reversed. The National Program for Prevention and Control of Fluorosis (NPPCF) data collection is operational in two districts: Sangrur and Ferozpur. Data inconsistencies are present, but cases of dental fluorosis have been recorded, with 25 cases of skeletal fluorosis confirmed. Screening or active surveillance have been inadequate. Less than 0.2 percent of the population has been screened.

Health impacts due to natural and depleted uranium, which are the common forms and comprise predominantly nonradioactive isotopes, occur due to the element's chemical nature. Most uranium entering the human body via the oral route is not absorbed; it is eliminated in the feces. Of that which is absorbed, most is excreted in the urine. The health effects of uranium are related to the isotope of the metal to which exposure occurs. The chemical toxicity is primarily affected through impacts on the kidney. Uranium exposure via oral route causes kidney dysfunction in some, but not in all, exposed people. Impairment of kidney function is transient and recovers once the source of exposure is removed. There is some evidence relating uranium exposure to respiratory illness, but at present this is inconclusive. Both the U.S. Environmental Protection Agency (EPA) and the International Agency for Research on Cancer (IARC) have not classified natural or depleted uranium with respect to carcinogenicity.

2.3.2 Group 2: Anthropogenic Contaminants

Besides pesticides, Group 2 contaminants show (i) low statistical frequency of exceeding the permissible limit; therefore, (ii) the pattern of the high concentrations is not consistent between the monitoring phases, indicating possible analytical errors; (iii) most of these contaminants can easily be removed by simple treatment measures. Some contaminants, for example lead, have significant health impacts. Because repeated sampling has yielded exceedances for this group, action should be taken to protect the health of the community.

WHO cites lead as one of the 10 leading chemicals of public health concern. Although no level is considered safe, for practical considerations the limit is set at less than 0.01 parts per million. Multiple organ systems are affected by lead, of which the chief are the nervous system, the hematological system, and the gastrointestinal system. Others include the cardiovascular system, kidneys, and immune systems. Lead toxicity can occur as an acute, severe, clinically obvious poisoning or a slow, chronic, unapparent toxicity. The latter is far more common, and most often seen in children. Children are especially susceptible due to their much higher intake of food and water proportionate to their body weight.

The most common route of human exposure is via ingestion, either due to pica in children, ingestion of contaminated ceramic glazes and paints, or through contaminated foods grown in polluted soil. In drinking water, the principal source of lead is use of lead solder in pipe fittings. Inhalation of small lead particles smaller than 10 micrograms in occupational settings can also be an important route. Lead is distributed to several organs such as the brain, kidneys, liver, and bones. It gets stored in the teeth and bones from where it may be remobilized into the blood stream. The typical effects of chronic exposure in children lead to neurobehavioral deficits such as poor concentration, lower IQ, and developmental milestone delays. Anemia is also typical. In cases with exposure during fetal periods or early life when the immune system is developing, lead poisoning leads to defective immune functioning. Recurrent or intermittent abdominal pain, vomiting, and constipation are other typical gastrointestinal symptoms of chronic lead exposure. Once exposure has occurred, it is uncertain if treatment can reverse many of the effects. Reversal of neurological deficits is not possible. Chelation therapy is suggested to limit the toxicity to other organs, along with eliminating further exposure.

Ingestion of high amounts of nitrates in acute settings causes oxidation of hemoglobin to methemoglobin, a form that is unable to bind and transport oxygen as required by the body. This effect is especially prominent in babies. High concentrations of nitrate in drinking water can result in a temporary blood disorder in infants called methemoglobinemia, commonly called "blue baby syndrome." This occurs when concentration of methemoglobin rises beyond 10 percent of total hemoglobin. Symptoms include irritability, lack of energy, headache, dizziness, labored breathing, and a blue-gray coloration around the eyes, mouth, lips, hands, and feet. Nitrate and nitrite poisoning or ingestion of large quantities can also cause violent gastroenteritis. Prolonged exposure to small amounts may produce anemia and nephritis (kidney disease). Long-term exposure to nitrate and nitrite is associated with formation of nitroso compounds, many of which are carcinogenic, especially to the urinary bladder. The major route of human exposure is via food intake. Vegetables such as spinach, celery, beets, lettuce, and root vegetables are the main sources. Nitrates are selectively transported to the salivary glands, in which almost 25 percent of the ingested nitrates get concentrated (a phenomenon called bioconcentration). The rest of the nitrates are distributed throughout the body. Excretion occurs via the urine.

The chief route of human exposure to cadmium is via food. Crops irrigated with polluted water or grown on contaminated soil contain increased concentrations, as does meat from animals that graze on contaminated grasslands. The main foodstuffs containing high cadmium are leafy vegetables, potatoes, grains, peanuts, and soybeans. In comparison, the intake from contaminated drinking water forms a much less significant source. Galvanized pipes can be a source of the metal contamination to some extent in drinking water. Upon entering the body, most cadmium is converted to a harmless form by the liver. A small proportion is slowly excreted via the kidneys in urine. The ability of the body to both convert the metal to this harmless form and excrete it are overcome when exposed to high concentrations, overloading the liver and kidney with the toxic metal form. Cadmium is a nonessential element with a slow excretion rate, and can become toxic at lower concentrations. Cadmium has been labeled a human carcinogen by the IARC and a probable human carcinogen by the U.S. EPA. The type of cancer seen due to the metal is usually lung cancer after exposure via inhalation. Oral exposure via food or water is known to lead to deposition in the kidney with renal disease. Bone disease with increased brittleness and fractures are also seen.

Drinking water is usually a very minor route of exposure for chromium. The most significant route of human exposure to chromium is via air. Occupational exposure in industries using the metal, in those living close to these industries or those around hazardous waste facilities, and smoking are major exposure pathways. Moderate amounts of the metal are naturally present in fruits, vegetables, nuts, beverages, and meats. This form of exposure increases when these foods are grown in soil contaminated with high concentrations of the metal or irrigated with polluted water. Food prepared in utensils that contain chromium may have increased concentrations. Small amounts of chromium III are essential for normal human bodily function; it is thus an essential trace metal. For this function, chromium VI is converted to chromium III in the body. Most of the metal that enters the human body is excreted via the kidneys within a week. Most commonly, cadmium affects workers exposed occupationally via the aerial route, causing breathing problems with cough, shortness of breath, irritation in nose, or asthma. Skin allergies are known to occur. Chromium compounds have been categorized as human carcinogens by the IARC lung cancers have been seen in those exposed occupationally via inhalation route.

Oral exposure to high levels of Nickel, either in food or drinking water, is not uncommon. There is no evidence linking this form of exposure to carcinogenesis in humans. The U.S. Department of Health and Human Services has concluded that nickel compounds are human carcinogens; the IARC states that some nickel compounds are carcinogenic; and the U.S. EPA similarly states that specific nickel compounds, such as in refinery dust, or nickel subsulfide are carcinogenic. There is no evidence that oral exposure to nickel causes any form of cancer. Most nickel taken in orally is excreted via the feces. Of that which is absorbed, most is quickly excreted by the kidneys in the urine, with only a fraction remaining in the body.

Although selenium is toxic to the human body when present in excess, small quantities of selenium are essential for normal functioning. It is thus an essential trace element. The main route of human exposure is via food such as cereals, meat, and fish. Humans can also be exposed to selenium dust via burning coal or oil. Selenium can be absorbed into the human body via the gastrointestinal tract, the skin, or the respiratory tract. WHO guidelines for drinking water quality for selenium are marked "provisional" and set at 0.04 parts per million (milligrams per liter) due to the lack of definite certainty in the levels that cause adverse health impacts. Short-term exposure to high levels can cause vomiting and diarrhea.Iron is an essential trace element; its presence is critical for normal functioning of the human body. It is required by hemoglobin in the blood for transporting oxygen to all cells in the body. The guideline limit is for reasons of palatability, aesthetics, and smell rather than any health concerns.

2.3.3 Group 3 Contaminants: Pathogens

Acute diarrheal disease remains a major health concern in Punjab. Over the last decade, on average, more than 200,000 cases of acute diarrheal disease have occurred every year. Weekly reported cases range from a few hundred to over 15,000 in each district. Jalandhar, Amritsar, Kapurthala, Ludhiana, Gurdaspur, Patiala, and SAS Nagar showing consistently high numbers of acute diarrheal disease cases from 2011–15. In terms of incidence of acute diarrheal disease (the number of cases proportional to the population) Kapurthala, SAS Nagar, Jalandhar, and Patiala remain districts of highest concern. Higher diarrheal disease in these districts may be due to increased exposure to domestic wastes and insufficient drinking water treatment. In some districts, improved disease surveillance systems may result in better data capture, compared with other districts. Acute diarrheal disease tends to be seasonal: generally higher in summer than winter due to the physiology of bacteria and viruses that thrive in water at higher temperatures. While there are several factors that can lead to diarrheal diseases, such as passage of infection from person to person due to poor hand hygiene, most cases can be prevented by supply of safe drinking water.

Water-borne disease outbreaks, including cholera, continue to be a concern, as shown in Table 2.4. On average there is at least one outbreak of the three major groups of water-borne diseases: diarrheal disease (including cholera), enteric fever (typhoid), and hepatitis (due both to hepatitis A and E viruses) every year. In the past decade, cholera epidemics have occurred every year. In the last four years, on average, there have been about six outbreaks, with an average of over 800 cases each year (table 2.4). Six deaths due to the disease have been confirmed in this period. Documentation of the number of deaths due to other water-borne diseases remains incomplete. Most occur in the summer and monsoon months between June and September. This indicates that targeted interventions and responses over this period

TABLE 2.4 Cholera Cases Reported under Integrated Disease Surveillance Program, Punjab, 2013–16

Year	No. outbreaks	No. cases	Districts affected
2013	6	916	Jalandhar, Ludhiana, Gurdaspur, SAS Nagar, SBS Nagar
2014	9	1,211	Ludhiana, Hoshiarpur, Patiala, Moga, SAS Nagar, Moga
2015	2	76	Hoshiarpur
2016	6	1,047	Hoshiarpur, Patiala, Moga, SAS Nagar, Jalandhar

Source: IDSP, Punjab.

will help prevent outbreaks and reduce morbidity and disease burden. Outbreaks in the health department require comprehensive investigation including early response, clinical confirmation, and laboratory assessment and confirmation of samples. Further responses in the DWSS are required, including water supply infrastructure maintenance, quality assurance mechanisms, and monitoring systems of wells. Outbreaks require coordination between the DWSS and health department, and between units of the same department responsible for various functions.

2.3.4 Assessment of Health Risks

Health risk in Punjab is a function of exposure and severity of the health impact, such as when large populations are at risk, or small populations are exposed to high concentrations for prolonged periods. This section may help guide decisions on prioritization of geographic areas for action. Contaminants can enter the food chain from natural or anthropogenic sources and uptake by plants and crops from groundwater used for irrigation. This study focuses on human health risk assessment based on the drinking water as a source of exposure to the contaminants. All exposure pathways and sources should be integrated to assess the potential human health risks.

Risk is defined as concentrations exceeding relaxed guideline levels. The wells have been classified as 'no risk' (less than half the guideline), between half and 0.75 of the guideline value (low risk), moderate risk (between 0.75 the guideline and the guideline, high risk between guideline and the relaxed guideline value and very high risk.

Arsenic is carcinogenic and the priority contaminant to be managed. As shown in table 2.5, the highest proportion of exceedances of guidelines by arsenic concentration occurred in Amritsar (40.2 percent, high risk; 13.2 percent, very high risk), Gurdaspur (24.2 percent, high risk; 4.3 percent, very high risk), and Taran Taran (38.1 percent, high risk; 3.1 percent, very high risk). Arsenic can lead to both acute and chronic effects, with the latter more common and significant from a public health perspective. It takes several years for the effects of chronic exposure to be exhibited; and once the effects are present, they are irreversible. Impacts include both noncancerous effects and cancers. The major changes are seen in the skin with increase or decrease in pigmentation (mottling) and roughening in palms and soles (hyperkeratosis). Skin and bladder cancers are well documented.

Arsenic risk depends to a large degree on the type of arsenic. Inorganic arsenic in the water supply and taken up by crops via irrigation is much more toxic than the organic form. Arsenite (trivalent arsenic, or As^{+3}), a form of inorganic arsenic, is the most toxic form; it is considered up to 60 times more toxic than the pentavalent form, or As^{+5}. The effects produced by both, however, are indistinguishable from each other. Occurrence of effects also depends on socioeconomic and nutritional status of the population,

TABLE 2.5 Share of Wells by Arsenic Concentration and Risk, Punjab 2010–2017

mg/l

District	No risk < 0.005 (%)	Low 0.005–0.0075 (%)	Moderate 0.0075–0.010 (%)	High 0.01–0.05 (%)	Very high > 0.05 (%)	Total no. wells
Amritsar	33.0	7.4	6.3	40.2	13.2	1,399
Barnala	100	0	0	0	0	231
Bathinda	97.7	1.6	0	0.8	0	129
Faridkot	85.7	14.3	0	0	0	14
Fatehgarh Sahib	97.7	1.2	0.3	0.8	0	601
Fazilka	90.9	5.3	1.2	1.6	0.8	243
Ferozepur	76.8	9.3	6.2	7.7	0.1	1,024
Gurdaspur	57.9	8.8	4.8	24.2	4.3	952
Hoshiarpur	91.2	4.3	2.3	2.2	0	1,712
Jalandhar	97.4	1.6	0.7	0.3	0	1,158
Kapurthala	80.6	11.4	4.3	3.7	0	1,076
Ludhiana	99.7	0.1	0	0.1	0	1,498
Mansa	83.3	2.8	8.3	5.6	0	36
Moga	95.0	4.0	0.7	0.3	0	702
Muktsar	95.3	2.7	0.7	0.7	0.7	148
Pathankot	90.1	3.5	4.5	1.9	0	312
Patiala	81.1	10.8	5.1	2.9	0	1,771
Roopnagar	75.5	6.6	5.8	11.6	0.6	1,037
Sangrur	98.5	0.8	0.2	0.4	0.1	921
SAS Nagar	99.3	0.3	0	0.3	0	606
SBS Nagar	97.5	1.1	0.9	0.5	0	875
Taran Taran	39.0	9.8	10.0	38.1	3.1	810
Total	81.4	5.4	3.2	8.5	1.5	17,255

Source: World Bank data.

and individual factors such as age, gender, and immune status. The speciation of arsenic in Punjab is not known, and the monitoring data are based on total arsenic concentrations.

Action should be taken as early as possible since the time of exposure increases the health risk. Amritsar and Tarn Taran have the maximum potential for causing noncancerous adverse health effects when the adult population is exposed to this drinking water for 10 years. Nine districts have a cancer risk value greater than 1 in 10,000 persons after exposure for 10 years. The maximum excess cancer risk is seen in Amritsar, which has the highest concentrations. If exposure lasts the entire life duration of the population, 11 districts are at risk of adverse impacts. In addition to Amritsar and Tarn Taran, these are Hoshiarpur, Kapurthala, Muktasar, Patiala, Roopnagar, Sangrur, SAS Nagar, and SBS Nagar. In absolute terms, less than 1 percent of the State's water schemes pose a potential health hazard due to arsenic if the population is exposed for 10 years. This percentage increases to over 12 percent if no mitigation measures are put in place for the entire lifetime. Population at excess risk of cancer from arsenic exposure similarly increases from 8.5 percent of the State's tested water schemes at 10 years to over 34 percent at lifetime exposure.

The potential adverse health impacts due to arsenic are higher than those due to uranium in both degree and spread. The worst affected districts are Bathinda, Fazilka and Moga districts. The impacts of uranium on human health are related to the isotope of the metal to which the population is exposed. The common form of uranium in drinking water—natural or depleted uranium—is not radioactive, and its impacts are due to its chemical nature, not radioactivity. The effects are seen predominantly on the kidney, in which the metal causes dysfunction; this however is not universal and is reversible on removal of exposure. Any potential carcinogenic effect is caused by genetic damage due to the radioactivity, which is present mainly in enriched uranium used in the nuclear power industry.

There were high levels of exceedances of guidelines by fluoride in Fazilka, Mansa, and Patiala districts. Human exposure occurs mostly from drinking water contamination. Fluoride is rapidly absorbed in the body and distributed throughout, with deposition in the teeth and bones. Infants and young children absorb proportionately greater amounts. Table 2.6 shows fluoride risk by district. The highest risks occur in the Fazilka, Mansa, and Patiala districts.

TABLE 2.6 Share of Wells by Fluoride Concentration and Risk, Punjab 2010–2017

mg/l

District	No risk < 0.5 (%)	Low 0.5–0.75 (%)	Moderate 0.75–1.0 (%)	High 1–1.5 (%)	Very high > 1.5 (%)	Total no. wells
Amritsar	91.3	5.5	2.0	0.2	0.9	1,271
Barnala	39.7	30.1	21.8	5.2	3.1	229
Bathinda	13.2	44.1	22.1	16.2	4.4	68
Faridkot	16.7	33.3	0	50.0	0	6
Fatehgarh Sahib	49.7	23.8	6.4	12.0	8.1	581
Fazilka	18.5	13.5	26.6	30.6	10.8	222
Ferozepur	55.4	23.4	14.8	5.8	0.6	949
Gurdaspur	87.3	9.1	3.1	0.2	0.2	900
Hoshiarpur	90.1	7.7	1.4	0.4	0.4	1,642
Jalandhar	59.2	26.3	12.0	2.4	0.2	1,059
Kapurthala	67.8	28.2	3.5	0.3	0.2	1,027
Ludhiana	69.8	25.3	3.5	1.3	0.1	1,412
Mansa	8.6	28.6	11.4	34.3	17.1	35
Moga	58.0	20.8	13.7	6.8	0.7	678
Muktsar	0	0	0	0	0	0
Pathankot	98.5	1.5	0	0	0	262
Patiala	21.7	26.5	15.6	16.7	19.5	1,675
Roopnagar	80.2	16.6	2.8	0.4	0	941
Sangrur	31.4	39.3	15.6	8.0	5.6	870
SAS Nagar	61.0	17.9	12.7	6.2	2.3	569
SBS Nagar	65.2	32.3	2.3	0.1	0	813
Taran Taran	84.1	9.6	4.8	0.8	0.8	773
Total	64.2	20.2	7.7	4.6	3.2	15,982

Source: World Bank data.

TABLE 2.7 Derived Safe Concentrations of Key Contaminants in Drinking Water for Children and Adults

mg/l

Toxicant	< 2 years	2-6 years	6-16 years	> 16 years	Guideline
Aluminum	N.A.	N.A.	N.A.	N.A.	0.03
Arsenic	0.003	0.006	0.004	0.008	0.010
Cadmium	0.005	0.009	0.007	0.013	0.003
Chromium	0.033	0.06	0.04	0.08	0.05
Copper	0.044	0.08	0.06	0.11	NA
Fluoride	0.657	1.1	0.9	1.6	1.0
Lead	0.004	0.007	0.005	0.009	0.010
Mercury	0.003	0.006	0.004	0.008	0.001
Methyl mercury	0.001	0.002	0.001	0.003	NA
Nickel	0.219	0.38	0.29	0.53	0.02
Nitrate	17.520	30	23	42	45
Selenium	0.055	0.09	0.07	0.13	0.01
Uranium	0.033	0.06	0.04	0.08	0.03

Source: World Bank data.
Note: n.a. = not applicable.

Wells with a high risk from multiple contaminants were also assessed and priortised. The number of exceedances of guidelines was used as an index to identify hazardous wells. Fifteen wells with the highest risk are spread across districts, indicating potential localized effects. These wells should be prioritized for more frequent monitoring. If the exceedances are consistent over multiple sampling rounds, then management should take action.

Risks are higher for children than for other age groups, and safe concentrations for children should be considered in addition to guideline values. Table 2.7 shows derived safe concentrations of the key contaminants in drinking water, based on the body weight and water intake per age group. The derived values vary with age group but are comparable to the current guideline values for Punjab. Having age-specific or social group specific guidelines has merit, but this would be difficult to administer. A more desirable method is to have water that does not present a risk to the most vulnerable group. Where this is not possible, an alternative water supply should be available for the most vulnerable group.

2.4 Rural Drinking Water Use Behaviors and Perceptions

Households tend to have access to private wells on premises. Rural Punjab is characterized by plentiful water resources and a long-term policy of free electricity. As a result, households tend to have private shallow bore wells on premises, either as hand pumps, or submersible pumps with storage tanks on the roof of the house. Generally, households display a preference for their private source, which is greatly vulnerable to contamination from nearby sanitation facilities and unclean storage tanks. Even though people display an awareness that water from deeper sources is likely to be cleaner, this does not translate to a consistent preference for using the DWSS managed piped water supply. Household-level reverse osmosis technology has been strongly marketed, and many households use this water for drinking.

There is limited awareness of water quality and its potential to impact health. The management of the water supply system was focused on the quantity of water supplied, specifically the duration and frequency of supply, rather than the quality of water and services. Householders do not understand the link between drinking unsafe water and poor health outcomes. People's understanding of what constitutes safe water are perceptual and subjective, such as appearance (visible clarity, lack of yellowness) followed by taste (neutral or fresh-tasting) and smell (neutral). Awareness of contaminants, whether bacteriological or heavy metals, is very low, since these are not visible to the naked eye. Good health is seen more as a function of nutrition and a full stomach, rather than safe water. Even diseases such as diarrhea, which have a direct link to unsafe water, are not on the radar of mothers with young children. There is no mention of boiling or filtering either piped or submersible water before using it for cooking and drinking. It is likely that, because of the low awareness of water-borne disease, households would view boiling as tedious and a waste of cooking fuel. Gender plays a role here, because the level of spending on cooking fuel is decided by the man of the house, and not the woman, who actually collects and handles drinking water. Chlorine is not usually preferred on account of its taste and smell.

Contamination of drinking water sources in the household is a major risk. Taps are not used in the piped water supply contributing to the well-established and fully acceptable practice of water running nonstop throughout the duration of supply. The piped water supply entry into the household is usually inside the bathroom or toilet, and therefore, a likely contributory factor for contamination. The household often does not have a correct protocol for disposing of child and animal feces, which are disposed in open drains in the household compound. Open defecation is practiced. Household-level practices related to water collection, storage, and handling are poor, and despite having some knowledge, this does not necessarily translate to consistent behaviors. Generally, water storage containers are not washed or covered, and water is not dispensed using appropriate utensils. Handwashing, particularly before handling water, is not common.

Even though decentralization of water supply and sanitation services is mandated by law, local governments and communities have limited involvement in service delivery. In communities that have not been actively and consistently involved in the process of development and management of water supply, there is a low sense of ownership of the water supply asset. Similarly, department staff and local committees are uninvolved when they lack the requisite knowledge about the operations and maintenance (O&M) of the water supply systems. Below-par functioning and capacities of the Gram Panchyat Water and Sanitation Committees (GPWSCs), politics and infighting, lack of gender representation, limited minority inclusion, lack of transparency, and nepotism in *panchayat* functioning exacerbate these factors. Community water supply is considered the government's responsibility, and there is limited involvement of community members, and limited interaction between the community and local government and the DWSS on matters relating to technical assistance and redressal of grievances. The line functionaries are often understaffed. In Punjab, as in most other parts of India, there is an acceptance of the status quo of insufficient availability of safe drinking water. The apathy and lack of dialogue around this issue have caused rural communities to manage with whatever standard of water supply and quality they can get, and limited awareness and attention to the potential health impacts.

Punjabi society is highly patriarchal, and women in rural areas are largely left out of household decision making. Rural Punjabi women, as their counterparts in other parts of India, tend to remain subservient and fulfill their roles and responsibilities within their families. From an early age, they are conditioned to live a life serving others, first parents, and then a husband. In many cases, they are not educated beyond primary school, since it is not considered that they would have an independent career. Only a third of women are reported to participate in household decisions, and a quarter have experienced at least one incidence of spousal violence. Implications of gender inequality in Punjab in the context of water safety are concerned primarily with the woman's ability to make decisions. The woman is the water collector and user, but she does not make decisions on water supply infrastructure and water safety issues in the household. Even when she has awareness and knowledge, her opinion does not count. The man of the household makes both financial and nonfinancial decisions, and is known to usually follow the advice of his peers. Thus, the woman's ability to incorporate better water safety and security behavior and practice is curtailed.

A corresponding aspect of the woman's lack of financial empowerment translates into an absence of health-seeking behavior. In many cases during the household interactions, although the woman may complain of pain symptoms, she is unwilling and unable to consider going for a formal health checkup or doctor's visit. She leaves it to the man of the household to decide if, and when, the medical visit would take place. It is likely that prevalence of disease is underreported. During fieldwork water testing, researchers found that despite evidence of water-borne diseases, as well as fecal coliform, in many household drinking water sources, the household would not confirm, or even acknowledge, the presence of illness.

Note

1. Pumped water samples may contain colloidal or particulate matter, which under normal conditions do not dissolve in drinking water or pose health risks. If the sample taken for laboratory analysis is acidified before it is filtered, this matter may breakdown and its chemical components dissolve. Once dissolved, these components pass through the filter and may lead to higher concentrations that are not representative of the original sample under normal pH conditions.

Chapter 3
Taking Appropriate Action

The study has provided a wealth of information and has increased the understanding of the pollution sources, origin, pattern, and pathways. Based on this information and the better understanding of the groundwater pollution risks, the DWSS can be more proactive in managing sources in affected areas to ensure safe drinking water, improve monitoring systems to ensure timely and effective action, and engage with local communities meaningfully to ensure that safe water is used and handled appropriately and to realize desired health benefits.

Key Messages

- New groundwater sources are the most viable and cost-effective clean sources for the state: Improve the design and construction of the DWSS wells and increase the depth to at least 200 meters, Increase depth to 300 meters to 400 meters at certain locations to reduce the risk for specific pollutants, and explore the development of riverbank infiltrating systems along the main rivers (Beas, Setluj, Ravi, Chenab Jhelum) to pump arsenic and fluoride-safe shallow groundwater. Improved well construction measures are recommended to minimize contamination risks
- Treatment technologies should be a last resort, after other groundwater and surface water options have been exhausted. Treatment technologies should be short- or medium-term solutions, with a view to ensuring the shift to safe surface or groundwater sources in the longer term.
- Consistent and correct chlorination is critical. Standard operating procedures for the development of new wells and operation of water supply schemes are required and key to reducing water borne diseases. This step alone will have significant health benefits in the State.
- The communications strategy emphasizes behavior change at the individual, community, and institutional levels. Priority behaviors include the use of the piped water supply for drinking and cooking and ensuring that water is stored and handled appropriately. The Gram Panchayat Water and Sanitation Committees (GPWSCs) should understand water quality risks and actively participate in the management of the water supply systems, particularly ensuring adequate disinfection.
- Strategic monitoring allows the State's to actively manage drinking water quality. It requires monitoring systems, processes and controls, reporting and decision-making frameworks to guide ongoing management decisions. The State should upgrade its lab infrastructure to be more effective. There is a need for improved sample handling and preparation, and testing, data organization and analysis, and general laboratory management. Risk-based monitoring will require dedicated resources and expertise, and active day-to-day management.
- Water quality management is a dynamic process integral to daily operations of the DWSS. The responsibility is fundamental to the supply of safe drinking water and is inherent in every aspect of DWSS operations. Standard operating procedures for the development of new wells and operation of water supply schemes are required. The DWSS needs to adopt a learning mindset and culture to

actively manage the water quality issue, and to establish constructive, ongoing knowledge sharing arrangements with key institutions.

Technology is an important enabler for water quality management. The integration of scheme and water quality data into a consistent database is an important resource. ICT is used to conduct household surveys, monitor water quality, and create and disperse behavior change communication.

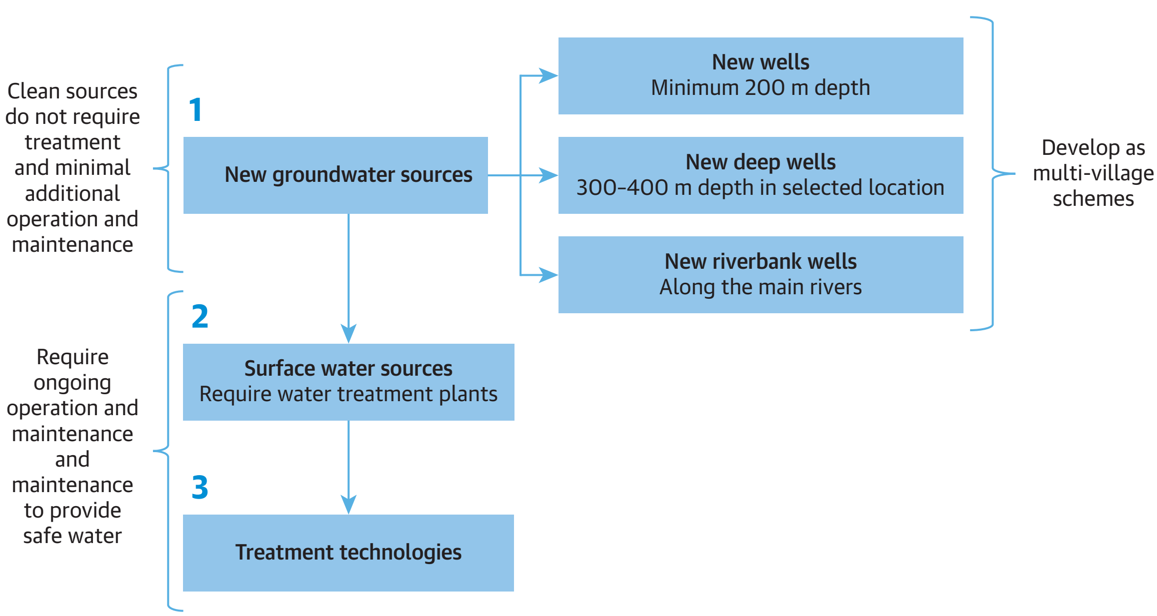
3.1 Managing Sources

The priority is to find safe alternative sources as a long-term solution. The Department of Drinking Water Supply and Sanitation (DWSS) can consider a number of options for developing alternative sources. Between the current spectrum of shifting to surface water sources, or installing reverse osmosis plants, there are additional options that can enable long-term use of deeper aquifers. This will allow the department to continue to use existing infrastructure, will not require any additional operations and maintenance (O&M) capacity, and provide a long-term solution to the water quality issue. Multivillage schemes will allow economies of scale. If these groundwater options are exhausted, then the feasibility of surface water or treatment technologies should be considered. Feasibility costing should be done on a life-cycle scale, to ensure that all costs are considered across the lifetime of the infrastructure. See figure 3.1.

3.1.1 Surface Water

The shift to surface water is a long-term solution endorsed by the Government of India (GoI), though contamination of surface water sources should be examined closely. The DWSS currently supplies surface water to the southwestern districts covering parts of Mansa, Bathinda, Faridkot, Moga, Ferozepur,

FIGURE 3.1 Prioritized Source Management Options



Muktsar, and Sangrur due to high salinity in the groundwater. The Punjab Rural Water Supply and Sanitation Project covers two multivillage surface water systems in Moga and Barnala (more than 120 villages). Future schemes in affected areas close to canals could be considered for the shift to surface water. Contamination of surface water could result from agricultural return flows and untreated domestic wastewater, particularly from more densely populated areas. In addition to the conventional set of chemical and bacteriological parameters, the quality of the surface water should be analyzed for a wider range of contaminants, including heavy metals, fertilizers, and pesticides.

3.1.2 Alternative Groundwater Sources

Recommendations and proposed measures focus on locating safe groundwater and improvement of the siting, design, construction, operation, and monitoring of the DWSS wells. The following measures can be considered in the order presented:

- **Redrill wells**. Improve the design and construction of the DWSS wells and increase the depth to at least 200 meters.
- **Drill deeper wells.** Increase depth to 300 meters to 400 meters at certain locations to reduce the risk for specific pollutants.
- **Drill riverbank wells.** Explore the development of riverbank infiltrating systems along the main rivers (Beas, Setluj, Ravi, Chenab Jhelum) to pump arsenic- and fluoride-safe shallow groundwater.

New tube wells can replace the existing tube wells, without increasing the O&M cost. The total cost of replacement is estimated to be about US$50,000, as shown in table 3.1. This option is financially viable because removal plants such as reverse osmosis, adsorption, or nano technology require incremental O&M costs (e.g., replacement cost of filters and media and the disposal of wastewater). The removal plants also treat drinking water, so the cost of running the polluted well will continue and should be added to the treatment cost. The cost of a 400-meter deep replacement well is estimated based on the Bill of Quantities and unit prices of existing DWSS wells. The cost of the deep well is estimated at US$35,000, compared with US$14,000 for existing wells. If the cost for submersible pumps, a new pump house, and connection to the existing overhead tank are added, then the total cost of a replacement well comes to US$50,000. This amount can be used to make a financial case for drilling a replacement well versus installation of a removal plant.

The hypothesis that deeper groundwater, up to 400 meters or more, will provide a source of safe drinking water needs to be confirmed by drilling a number of deep monitoring wells. A solution that has emerged from this study is the expected absence of most pollutants in the deeper groundwater. Deeper aquifers with fresh and good quality water are expected to be found below the present depth of DWSS wells. This counts not only for arsenic but also for other pollutants that originate from the surface or shallow groundwater. The fluviatile (clay and sand) deposits are likely to continue until at least 1,000 meters, but there is little information on the productivity of these layers and the water quality. The Central Groundwater Board (CGWB) has drilled a few deep monitoring wells, which confirm the presence of a deeper aquifer, and the National Deep Aquifer Mapping project (NAQUIM) will supplement this knowledge substantially

TABLE 3.1 Cost Estimate of Replacement Wells, Punjab 2017

Description	Quantity	Estimated cost	
		Rs, lakh	US$
Tube well, 650 mm with 200 mm screens and casing (based on pipeline for pumping main (110 mm) 2016 price level for drilling existing DWSS wells)	1	22.48	34,585
	45 meter	0.48	738
Chlorination unit for disinfection	1	0.86	1,323
Pump chamber with staff quarter	1	4.55	6,997
Pumping machinery (submersible pump)	1	2.20	3,385
Subtotal (A)		30.57	47,028
Environmental mgt charges @ 0.25% of (A)	n.a.	0.08	118
Price contingencies @ 1% of (A)	n.a.	1.00	1,538
Total		31.64	48,684

Source: World Bank data.
Note: Replacement wells are 300 meters to 400 meters deep. US$1 = Rs 65. N.a. = not applicable.

in the coming years. Details on the siting, design, and construction of deep monitoring wells is given in a supplementary technical report. A number of deep monitoring wells in the arsenic-affected areas in Amritsar and Gurdaspur will help answer the following questions:

- Are there contaminants (arsenic and others) in deeper parts of the groundwater?
- What are the contaminant sources in sediment minerals (geogenic)?
- How does the groundwater flow around a DWSS well (origin, pathway)?
- What is the vertical groundwater flow to deeper aquifers?
- Are there protecting clay layers below 150 meters to avoid vertical flow of polluted water?

The feasibility of riverbank infiltration systems should be investigated. Geogenic contaminants such as arsenic and fluoride are often found in shallow groundwater (less than 30 meters), but not in nearby surface waters in rivers and streams. River water, which infiltrates to the groundwater, remains free of these contaminants and has the advantage of being bacteriologically safe (if residence time in the aquifer is more than 60 days). Riverbank infiltration systems are designed on this principle and widely applied in Europe, including for large cities such as Berlin and Budapest. In Bangladesh, the wells near the Mohandan River (e.g., in the arsenic-affected town of Chapai Nawabganj) show low arsenic values. In Punjab, the research of TERI University (in cooperation with Columbia University) in Amritsar also confirms that the shallow groundwater near the Setluj River is free of arsenic. A systematic inventory of the feasibility of river bank infiltration system along the main rivers (Beas, Setluj, Ravi, and Chenab Jhelum) is recommended and will show many affected villages can be supplied through such a system.

The DWSS should consider these options from the perspective of developing multivillage schemes, and consider the benefits of not requiring water treatment plants. Table 3.2 summarizes the redrilling strategy for Group 1 contaminants: arsenic, uranium, and fluoride. The aquifers allow construction of wells with higher capacities than the present DWSS wells (12.5 cubic meters per hour). Present capacities

TABLE 3.2 Strategy to control the key contaminants to Water Supply, Punjab

Status	Strategy and redrilling[a]
Arsenic	
• Analyzed by DWSS. • Pattern: Gurdaspur, Amritsar, and Taran Taran districts • Geogenic source: adsorbed As(III) or As(V) to iron hydroxides, mobilized under ferric redox conditions (reductive dissolution of iron hydroxides) • Pathway: horizontal flow to aquifer and screens	• New deep well with seals and screens in a deep, fresh sand layer with sulphic redox conditions. • Sand layer must be protected by natural clay layers from previously exploited and polluted sand layers • Well design based on geophysical log
Uranium	
• Analyzed by DWSS • Pattern: south of Punjab and occasional wells elsewhere • Geogenic source: uranium calcites and reactive silicates, mobilized by alkaline leaching during long residence times; requires further research; related to high TDS and alkalinity • Pathway: horizontal flow to aquifer and screens	• New well with seals and screens in a sand layer with low salt content (high resistivity in geoph. log) and low content of reactive minerals. Might be also a shallower sand layer. • Sand layer must be protected by natural clay layers from the previously exploited and polluted sand layers. • Well design based on geophysical log.
Fluoride	
• Analyzed by DWSS • Pattern: south of Punjab (Patiala District, but all are very deep) and occasional wells elsewhere • Geogenic source: apathite and reactive silicates, mobilized by alkaline leaching during long residence times and calcite precipitation (requires further research); related to high TDS and alkalinity • Pathway: horizontal flow to aquifer and screens	• New well with seals and screens in a sand layer with low salt content (high resistivity in geoph. log) and low content of reactive minerals (low gamma ray in geoph. log); might be also a shallower sand layer. • Sand layer must be protected by natural clay layers from previously exploited and polluted sand layers. • Well design based on geophysical log.

Source: World Bank.
Note: DWSS = Department of Drinking Water Supply and Sanitation; TDS = total dissolved solids.
a. The new deep sand layer may get contaminated in future by downward flow or changes redox conditions. This may take 10 to > 100 years.

are based on demand only. DWSS could also consider a greater number of multivillage schemes with its new wells, which are likely to have sufficient capacity to supply more than three villages. Updated technical specifications for the tube wells, which include sealing to prevent contamination from shallower aquifers, is provided in the technical note. Further exploration of the technical, institutional, operational, and financial feasibility to serve more than three villages from one improved DWSS well—which will have larger capacity than the current DWSS wells—will provide economies of scale. These options can be evaluated against the installation of treatment plants. The advantage of improving the existing schemes is that O&M will not change. Multivillage groundwater schemes are likely to be financially viable and more robust compared to new treatment technologies, which may not be operated and maintained as required. Nearby surface water and alternate groundwater options should be investigated before treatment technologies are considered. The DWSS already operates treatment technologies, including reverse osmosis units for removal of arsenic. Other technologies are being piloted and tested under the Punjab Rural Water Supply and Sanitation Project, including nano filtration. However, this should be considered a last option if the other options are not feasible.

The study analyzed a strategy for managing Group 2 and Group 3 contaminants as summarized in table 3.3. Other pollutants have inconsistencies between the sampling rounds (some heavy metals), show a low frequency (some heavy metals), do not pose or pose only low risk to human health (iron, total dissolved solids) or are not (yet) analyzed (pesticides, pathogens). The table shows that that deep drilling may also be effective for pollution by nitrate, pesticides, and heavy metals (if not proven to be an artifact).

Geophysical well logging should be carried out as standard practice and include gamma ray. It is helpful to avoid mineralized layers (uranium- and fluoride-bearing zones) and find coarse sand layers without reactive minerals (low gamma ray), which are protected by clay layers (high gamma ray). To save costs and negative wells of deep well drilling, the DWSS could consider to drill first a deep small-diameter exploration borehole and then carry out geophysical logging. With this information it may be decided to design and complete the well after reaming the borehole with a larger diameter to required depth.

Well screens should not be distributed over many sand layers. One or two screens at the appropriate sand layer is sufficient. Well capacity is not a limiting factor, because the demand based production is now only 12.5 cubic meters per hour as an average. For that reason geophysical well logging is also important.

The standard depth of wells in areas affected by arsenic metals, nitrate, and pesticides should be 300 meters and 200 meters in areas with only uranium and fluoride contamination. The DWSS can go for 300 meters as standard depth. These kind of wells may be a bit more costly, but depreciated over the lifetime of a well, it is an almost negligible incremental cost

DWSS should issue tender documents with better bill of quantities or terms of reference for drilling contractors and do onsite supervision by trained hydrogeologists. The bill of quantities or terms of reference should include the procedure for sealing of clay layers and well head. Tender documents should provide clear instructions for a proper well completion report (including digital data of the pumping tests) to replace the current strata chart. The DWSS can immediately start a pilot phase by drilling 20 improved wells in each area affected by arsenic, fluoride, and uranium and then evaluate the experiences and results.

3.1.3 Treatment Technologies

Treatment technologies should be a last resort, after other groundwater and surface water options have been exhausted. Treatment technologies should be short- or medium-term solutions, with a view to ensuring the shift to safe surface or groundwater sources in the longer term. This section provides a framework that was applied for the selection of pilot arsenic treatment technologies in three villages. This approach can be applied for the selection of any treatment technologies.

The DWSS has developed criteria for evaluating technology and has applied it for selecting arsenic treatment technology for piloting. In January 2016, a multistakeholder workshop titled “Arsenic Removal Technology Assessment Framework Workshop” was organized in Chandigarh by the DWSS. The purpose was to develop and set the criteria for evaluation of treatment technology. DWSS staff scored options using a technology assessment framework. Participants developed a weighted set of

TABLE 3.3 Measures to Control Other Contaminants in Water Supply, Punjab

Contamination	Status	Strategy and drilling	Efficiency
Pathogens Not analyzed by DWSS	• Anthropogenic source; reported in literature • Pathway: leakage along gravel pack of wells and leaks in distribution system	• New identical well, but with improved well head seals • Ensure chlorination by simple, reliable chlorination system	• High • No-regret measure
Heavy metals (Pb, Ni, Se) Analyzed by DWSS	• Pattern: exceedances not consistent, only near Ludhiana and Moga • Probably anthropogenic (polluted canals, disposal wells, waste sites) • Sampling may have led to erroneous results • Pathway: leakage along well or groundwater flow to aquifer	• Compare present sampling with correct sampling (first filtrated, then acidified) • New deep well with seals and screens in deep, fresh sand layer[a] • Well design based on geophysical log	• If source is real and pathway is groundwater flow, deep aquifer may get polluted in future by downward flow • May take 10 to more than 100 years
Pesticides Not analyzed[b]	• New sampling and analyses proposed • Anthrop. source: storage sites (point) and agricultural fields (diffuse) • Pathway: leakage along well or downward flow to aquifer and screens	• New deep well with seals and screens in deep, fresh sand layer[a] • Well design must be based on geophysical log	• If pathway is groundwater flow, the new deep sand layer may get contaminated in future by downward flow • May take 10 to more than 100 years
Nitrate Analyzed by DWSS and PRSC	• Pattern: presence and exceedances everywhere and consistent. • Anthrop. source: storage/waste sites (point) and agricultural fields (diffuse) • Pathway: downward groundwater flow to aquifer and screens	• New deep well with seals and screens into deep, fresh sand layer[a] • Well design must be based on geophysical log	• Deep sand layer may get polluted in future by downward flow. • May take 10 to more than 100 years • May disappear over time due to denitrification

Source: World Bank data.
Note: DWSS = Department of Drinking Water Supply and Sanitation; PRSC = Punjab State Remote Sensing Centre.
a. Sand layer must be protected by natural clay layers from the previously exploited and polluted sand layers.
b. State report and literature report that pesticides are not found in surface water and groundwater. Needs verification.

criteria to assess the performance of the technology through its life cycle, including technical, economic, environmental, and social perspectives. The weighted criteria are summarized in table 3.4. The criteria were then applied for the evaluation of the technologies listed in table 3.5, through consultation and collaboration among DWSS engineers, external experts, and technology providers. The consultative process improved the legitimacy of the technology selection process by engaging with a broad set of stakeholders to ensure greater representation and incorporation of a broader set of experiences and perspectives. The workshop allowed participants to understand the technologies, analyze their effectiveness against multiple criteria, and understand the O&M requirements. The process produced a set of criteria that represents the shared values of the DWSS and can be used for the selection of any type of technology.

TABLE 3.4 Weighted Evaluation Criteria for Technology to Remove Contaminants from Water Supply

Rank	Criteria	Overall weights (%)
1	Compliance to standards	32.9
2	Reject/residue management	15.8
3	Operating costs	13.4
4	O&M repair and replacement	12.4
5	Capital costs	7.3
6	Energy requirement	6.1
7	Source and status of technology	3.3
8	Design and installation	3.1
9	Chemical requirements	3.1
10	Land requirement	2.6

Source: World Bank.
Note: O&M = operations and management.

TABLE 3.5 Technologies to Remove Arsenic from Drinking Water

Provider	Description
Centre for Environment Science and Engineering, IIT Mumbai	Based on ZVI (iron nails, reactive material); mechanism is co-oxidation, co-precipitation of arsenic in sequential manner along with iron
InnoNano Research Private Ltd., Chennai	Adsorption of colloidal iron and selective complexation of contaminants
IIT Kharagpur	Laterite-based filters for arsenic and heavy metal removal
Pureit, Unilever, Mumbai	Disinfectant for microbial purification and inorganic adsorbent for arsenic removal
Ion Exchange (India) Ltd., Mumbai	Modular design; resin-, membrane-, and media-based filters
Eureka Forbes, Delhi	Based on activated alumina, oxidation filtration, and membrane technologies; fitted with water ATM
Institute of Nano Science and Technology, Mohali, Punjab	Adsorption-based filters; was disqualified because it was still on pilot scale

Source: World Bank.
Note: These were evaluated during the Arsenic Removal Technology Assessment Framework Workshop, January 2016.

These technologies were shortlisted: (i) IIT Madras/InnoNano Research: adsorption on iron ferric oxyhydroxide; and (ii) IIT Kharagpur/Vas Brothers: adsorption on modified lateritic media. An additional technology adsorption using ferric hydroxide was also studied[1]. The technology options were evaluated from a life cycle analysis over a 15-year life cycle, including the mitigation and safe disposal of treatment residuals, such as sludge from the water treatment process. The objective was to have a robust, reliable, and sustainable pollutant removal technology that could provide affordable drinking water to rural citizens. Two service levels were evaluated for arsenic, uranium, fluoride, and lead technologies. three service levels were evaluated as shown in table 3.6: point of entry plant at 40 and 80 liters per capita per day with delivery to households using the existing pipeline; and point of use at 10 liters per capita per day and water supplied at the users door step in 20-liter containers.

TABLE 3.6 Life Cycle Costs of Arsenic Adsorption Technologies

	Option 1: point of entry	Option 2: point of entry	Option 3: point of use
Population	1,250	1,250	1,250
Water supply (lpcd)	40	80	10
Capacity (m^3/day)	50	100	12.5
Capacity (m^3/15-yr. life cycle)	198,750	397,500	49,687.5
Operation (hrs./day)	5	10	6
Average flow (m^3/hr.)	10	10	2
Design flow/average flow	1.5	1.5	2
Capacity (m^3/hr.)	15	15	4
Capex (plant + infrastructure) (Rs, lakhs) (A)	16.0	25.0	6.2
Annual operating cost (personnel + consumables + testing) (Rs, lakhs)	1.4	1.3	0.4
Annualized O&M cost (15 yrs. at 6% annual escalation) (Rs, lakhs) (B)	24.9	16.4	6.6
Media changes in 15-yr. life cycle	3–4	3–4	3–4
Media replacement cost (Rs, lakhs) (C)	11.3	36.2	29.2
Water life cycle cost (Rs, lakhs) (A) + (B) + (C)	52.2	77.6	42.0
Production cost of water (Rs/kl)	26	20	85
Production cost of water (Rs/day)	1,313	1,952	1,057
Water delivery cost per 20-l containers	0	0	1,250
Cost of water delivered (Rs)	1,310	1,950	2,310
Cost of water per capita (Rs/person)	1.05	1.56	1.85

Source: World Bank data.
Note: Capex = capital expenses; O&M = operations and maintenance.

A summary of treatment technologies and similar indicative costs were calculated for other Group 1 and some Group 2 contaminants. The DWSS can use this information at the prefeasibility level to assess the type of technologies appropriate for specific contaminants, assess their benefits and limitations, and assess indicative costs at the selected service levels. Table 3.7 is a technology selection matrix per contaminant. Indicative life cycle costs can be found in the technical note.

A cost comparison of replacement tube wells is shown in table 3.8. It analyses technologies at various service levels and shows that the cost of replacement tube wells is comparable to treatment. However, replacement tube wells provide additional benefits beyond what is currently monetized. Replacement tube wells are a safe source. They require no additional O&M capacity from what DWSS currently undertakes. Most importantly, it eliminates the risk of failure of the treatment plant, and the inadvertent supply of contaminated water through the water supply system. This is a real risk in the context of the required additional competencies required in DWSS to monitor the treatment efficiency of the technology, operate the plant, conduct routine maintenance, ensure timely media replacement and safe disposal.

TABLE 3.7 Groundwater Chemical Contaminant Selection Matrix

Chemical contaminant	Limits BIS 10500 (mg/l)	Treatment technologies
Ammonia	0.5	Biological filtration, ion exchange
Arsenic	0.05	Adsorption (activated alumina and granular ferric oxyhydroxide, reverse osmosis
Boron	1	Ion exchange and reverse osmosis
Chromium (total)	0.05	Ion exchange and reverse osmosis
Fluoride	1	Adsorption (activated alumina), coagulation filtration, capacitive
Hardness	No limit	Ion exchange
Heavy metals	Total	Ion exchange and reverse osmosis
Iron	0.3	Oxidation/coagulation, filtration
Manganese	0.1	Oxidation/coagulation, filtration
Nitrates	45	Biological filtration, ion exchange
Radium		Ion exchange
Selenium	0.01	Ion exchange and reverse osmosis
Sulfides/odor	0.05	Adsorption, ion exchange
Suspended solids	< 2	Filtration, ultra filtration
Total organic carbon/organics	< 1,500	Granular activated carbon
TDS	500	Capacitive deionization, reverse osmosis
Turbidity	5	Filtration, ultra filtration
Volatile organic carbon (soluble)	No limit	Adsorption activated carbon
Lead	0.01	Adsorption granular ferric hydroxide
Mercury	0.001	Adsorption granular ferric hydroxide
Uranium	0.03	Ion exchange, reverse osmosis

Source: World Bank data.
Note: TDS = total dissolved solids.

3.2 Community Engagement and Behavior Change

The communications strategy emphasizes behavioral change at the individual, community and institutional levels. This approach requires a commitment to coordination at all required levels that touches target groups with customized message content through strategically chosen media and tools. The detailed consultative and research-backed process helped identify the following fundamental principles: (i) convergence with existing GoI National Rural Drinking Water Program (NRDWP) and Swachh Bharat Mission frameworks and objectives, as well as Punjab Rural Water and Sanitation Sector Improvement Project communications and capacity building plans; (ii) commitment to coordination among all levels of government and relevant departments, as well as other stakeholders; (iii) identification and prioritization of only a select number of behaviors for intervention purposes;

TABLE 3.8 Costs of Arsenic Mitigation between New Source and Water Treatment 2017

Scheme type	Years	Consumers	Daily production (m^3)	Annual production (m^3)	Usage (days)	Water demand/ use (lpcd)	Capital cost (Rs)	ACR (Rs/yr.)	O&M cost/ price (Rs/yr.)	Total annualized cost			Water delivery cost (Rs/l)	Delivered water cost (Rs/ consumer)
										Rs/yr.	Rs/m^3	Rs/l		
Replacement well (depth 400 m) at 500 m from existing well	20	1,250	100	36,500	365	80	3,000,000	305,600	1,491,000	1,796,600	49.22	0.05	–	4.0
Replacement well (depth 300 m) at 25 m from existing well	20	1,250	100	36,500	365	80	2,500,000	254,600	1,295,000	1,549,600	42.45	0.04	–	3.0
Reverse osmosis plant + kiosk; cap 12.5 m^3/day; drinking water only	15	1,250	12.5	4,562.5	365	10	700,000	81,800	6,395,000	6,476,800	1419.57	1.42	0.10	15.0
Adsorption media plant kiosk; cap. 12.5 m^3/day; drinking water only	15	1,250	12.5	4,562.5	365	10	620,000	72,400	1,460,000	1,532,400	335.87	0.34	0.10	4.0
Adsorption media plant @ 80 lpcd	15	1,250	100	36,500	365	80	2,500,000	292,100	1,808,000	2,100,100	57.54	0.06	–	5.0
Adsorption media plant @ 40 lpcd	15	1,250	50	18,250	365	80	1,600,000	186,900	566,000	752,900	41.25	0.04	–	3.0

Source: World Bank data.
Note: ACR = alternate contribution rate; – = not applicable.

(iv) constant reinforcement of good hygiene and sanitation behavior through multiple channels for recall and adoption; and (v) dynamic monitoring and evaluation mechanism that gives detailed assessments on behavior change in real time.

Priority behaviors were identified and implemented in two phases: (i) creating awareness and (ii) intervention for social and behavioral change. First, people should draw their drinking and cooking water from the piped water supply. Families should ensure safe storage and handling of drinking water, including cleaning the carrying and storage vessels regularly; covering the vessel with a lid; using taps to regulate water flow and not waste water; using a tap or clean ladle to take water from the storage vessel; using separate vessels for transportation and storage; and not dipping hands in vessels holding drinking water. Hygiene behaviors such as washing hands with soap before handling food or water and after toilet usage are also included in the messaging.

Second, families should handle their drinking water appropriately, and treat their drinking water at the household level, by using boiling, filtering, using chemical disinfection, and so on. The treatment method will depend on the local practices, traditional methods of water treatment, the water quality risks (microbiological, arsenic, fluoride, iron, lead, and so on) and the local availability of the required method. Water testing should be the only method used to ascertain purity of water. Communities should actively participate in the management of their water source to ensure safe and adequate supply and quality, and help make the Gram Panchayat Water and Sanitation Committee (GPWSC) function with accountability and responsibility. They may see it as their right to request information on water quality issues and express grievances through the DWSS helpline.

For the communication strategy to be effective, target audiences were identified and segmented according to their capacities, and the messages intended for them. This allows for the communication, advocacy, engagement approaches, activities, and content to be tailor-made for the needs, and help them achieve the desired behavior. For this purpose, the target audience has been segmented into primary, secondary, and tertiary groups.

The primary group consists of men, women, and children as the first three subgroups. All subgroups will be directly addressed to change their behavior. It is expected that the household-level awareness and behavior change objectives will be fully achieved. The fourth subgroup consists of GPWSC members who have the responsibility of promoting good water supply, sanitation, and hygiene behavior in the community, and ensuring community participation in the process of planning and implementation of all activities related to ensuring safe drinking water.

The secondary group consists of individuals or entities who carry a cultural and social influence with the primary group, and operate within the same sociocultural milieu. It consists of such community leaders as *panchayat* members, front-line health functionaries, DWSS staff, local faith leaders, local teachers, and former and current armed forces personnel. They both support the communication activities and endorse the desired behavior.

The tertiary group consists of individuals and entities whose actions directly or indirectly influence—both positively and negatively—the primary and secondary groups. Policy makers and politicians, government officials, senior faith leaders, and arts, sports, media and other role models fall into this category.

The communications strategy integrated water safety planning, community based water testing, and the use of information and communication technology (ICT) tools to facilitate change.

- **Water safety planning** at community and household levels: awareness building of risk occurrence and mitigation through the application of service delivery recommendations and infrastructural changes.
- **Water testing** of basic parameters at household level to support water safety planning.
- **Development of ICT tools** to disseminate behavior change communication (BCC) in a customized manner, monitor impact through recording changes in household parameters, provide a log of activity and advice given, and allow for transparent recording since it is geo-tagged, and evidence-based, allow database to be updated in real-time, allow user to work off-line, and allow user and manager to check progress

The main communications approaches suggested for the primary and secondary target groups are interpersonal communication (IPC) and community engagement and mobilization (CEM), using ICT tools and testing for water quality data at the community level. For the tertiary group, a mix of advocacy and engagement is recommended. All communications will be supported and reinforced by mass media, ICT, and outdoor and folk media, as well as reminder support media.

IPC is the recommended approach to raise awareness, as well as encouraging behavior change and learning new behavior. It is based on the premise of one-to-one interaction, providing an enabling environment for the adoption and application of new knowledge and behavior. It provides a supportive environment within which to reinforce new behaviors. It provides an unassailable medium in which to demonstrate the promoted behavior. As IPC touches more families, it builds motivators and change agents within the community, drawn from the early adopters. Some examples of IPC are door-to-door canvassing and knowledge dissemination, peer focus group discussions, developing change agents and motivators at a peer level, peer-to-peer communication, address by faith leaders and other influencers, and family-based counseling.

CEM involves interpersonal communication in a broader context. Its objective is to motivate and galvanize communities to participate in the water safety and security planning and implementation process; to initiate commmunity-level dialogue and problem solving in dealing with water quality issues; and to provide a forum for community ownership of the water source asset. Water testing at household and community levels is vital. Examples of CEM are town hall meetings (addressed through *gurudwaras*), training of trainers and peer educators from the community, community pledges and signature campaigns, community events around cleanliness and other civic activities, appointment of *nigrani samitis* (watch committees), community-level water testing, and regular meetings with DWSS senior functionaries. Advocacy efforts are intended to influence and engage leaders and decision makers to provide policies, funding, and organizational support for safe drinking water, and provide direction and stability to existing programs. Some examples are evidence-based papers, fact-based reporting in media, and stakeholder consultations.

Digital, outdoor, and folk media can disseminate knowledge regarding water quality issues and programs and reinforce the desired behaviors on a large scale. Since the reach and recall is relatively high, these methods are an excellent support for infotainment and edutainment purposes. Examples of mass media include infotainment and edutainment programs (Punjabi and Hindi) on television; local cable TV content; human interest stories and citizen journalism showcased as five-minute shorts before news broadcasts; public service messages before film screenings; and consumer radio, community radio, and newspapers and magazines in Punjabi, including a water supply, sanitation and hygiene supplement. Digital media would include social media apps, text messages, helpline call centers, or mobile games apps, in addition to dissemination of water testing results. Outdoor media would include billboards, wall paintings, paintings on storage tanks, posters at banks or farm equipment dealers, and messages on buses. Folk media would be traditional forms of communication such as theatre, song, dance, or puppet shows. Reminder and training media would include posters, stickers, calendars, T-shirts, caps and bags, water bottles, backpacks, and digital and paper flip charts.

3.3 Monitoring Systems

The State currently has established lab infrastructure that should be upgraded and made effective. GoI supports water quality monitoring and surveillance through the NRDWP by establishing laboratories. Thirty-four laboratories have been set up under the program in Punjab: one regional advanced water testing laboratory in Chandigarh that is National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited; one state laboratory and research unit in Patiala; 21 district water testing laboratories; eight subdistrict water testing laboratories; and three mobile water testing laboratories. In addition, the DWSS has partnerships with the Punjab Biotechnology Incubator (PBTI), a partly government entity with advanced laboratory facilities; the Bhabha Atomic Research Centre (BARC) in Mumbai; and pesticide laboratories operated by the Agriculture Department. NRDWP guidelines require that each district- and subdivision-level water testing laboratory have facilities to test pH, coliforms, total hardness, iron, chlorine demand, residual chlorine, nitrate, fluoride, and arsenic when identified and detected. All sources are to be tested by the subdivisional laboratories, 10 percent of samples are to be tested (which include positively tested samples by the district laboratories), and routine cross-verification is to be conducted by the State laboratory. Chemical and physical parameters are to be tested once a year; bacteriological parameters, tested twice a year pre- and postmonsoon and when water-borne diseases are detected. Upgrading laboratories and laboratory systems, including capacity building of staff, should be prioritized.

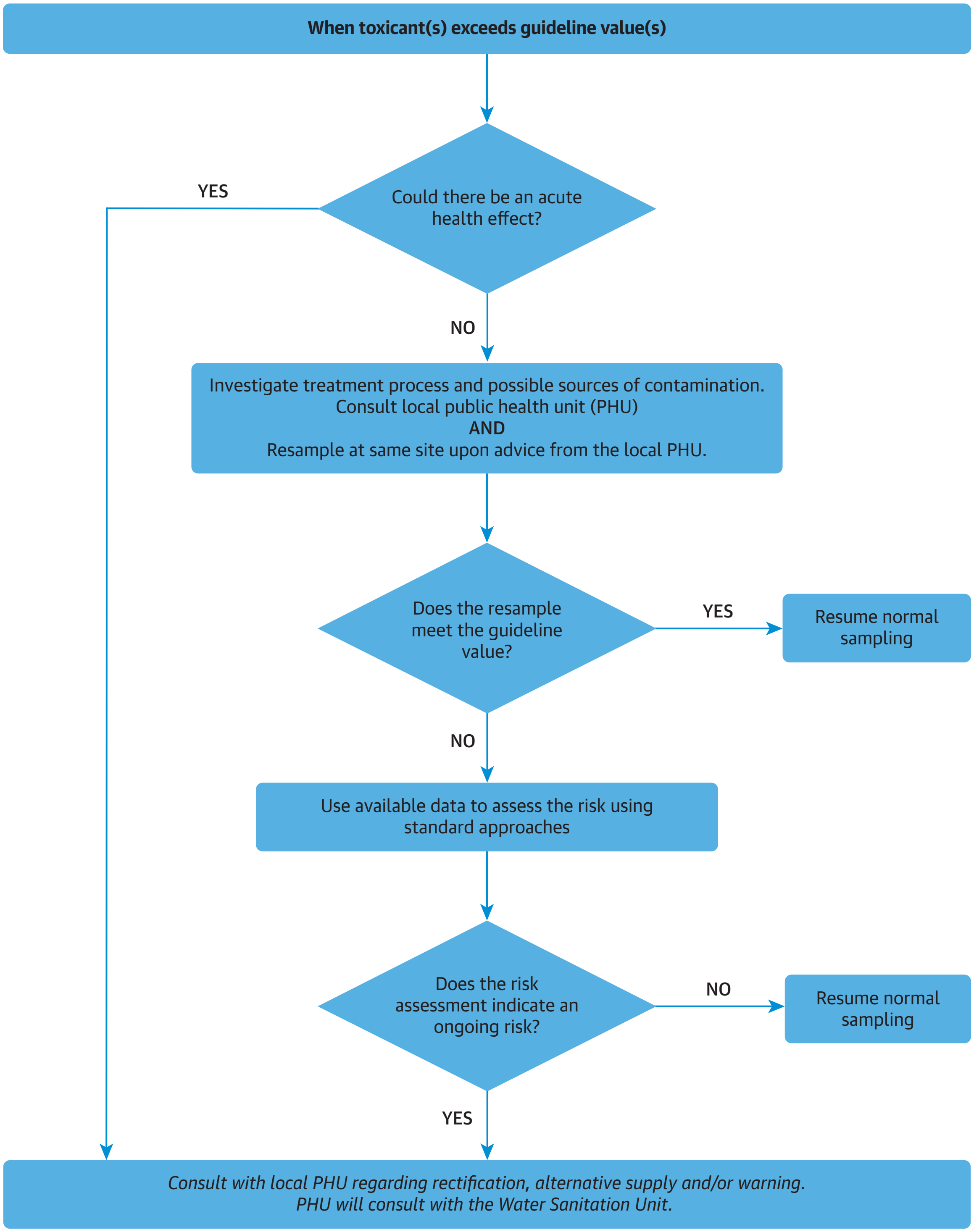
There is a need for improved sample handling and preparation. The DWSS regional advanced water testing laboratory is NABL accredited and functions to international standards, including chemical analyses on duplicate and blank samples, and determination of accuracy, precision, and detection limits. However, there is a need to improve sample handling and preparation procedures. Samples are taken by junior engineers in the field, who may not be fully trained on sampling procedures. Blank and duplicate samples are not taken in the field. Samples are acidified in the field or in the laboratory, and then filtered, which is not standard procedure. Samples for ICP-MS analyses or analyses on cations in general are to be filtered first and acidified after. Pumped water samples may contain colloidal or particulate matter, which under normal conditions do not dissolve in drinking water or pose health risks. Acidification before filtering may result in breakdown of this matter and dissolution of chemical components. Once dissolved these components pass the subsequent filtering and may lead to concentrations that are too high and not representative for the original solution under normal pH conditions. This may explain the abnormally high aluminum concentrations: under the general alkaline conditions (pH 7.5 to 8) of groundwater in Punjab the solubility of aluminum would be very low. The concentrations found here can occur only under acid conditions (greater than a pH of 6). In addition, the strengthening of quality control, as set out in table 3.9, will be beneficial.

When sampling for metals, care must be taken not to cause contamination during sampling. Avoid metal (including stainless steel) sampling equipment, using plastic wherever possible. If analyzing for trace metals, deionized water is recommended for decontamination rather than distilled. Distilled water may contain trace metals such as mercury. When sampling for metals it is important to determine prior to collection whether total or just the soluble phase is required. This will determine the preservation and filtration requirements. When soluble metals are required, samples may either be field filtered or sent to a laboratory for filtering. If sending to the laboratory for filtering, samples must not be acidified, but be cooled to 4 degrees Celsius, and filtered in the laboratory as soon as possible. Laboratory filtering is not appropriate when there is a risk of increased precipitation or mobilization of metals prior to analysis. Both vacuum and pressure filtration are suitable for metals. Table 3.9 provides suggestions for quality control in each step of the monitoring process.

TABLE 3.9 Quality Control in Monitoring Contaminants in Water Supply

Monitoring Step	Quality Control Protocols	Purpose
Develop monitoring plan	Various, including control sites, multiple sample locations, duplicate samples, sampling times	Ensure sample collected is representative of body from which it was taken.
	Review of monitoring plan	To ensure that monitoring plan meets monitoring objective
Sample Collection	Appropriate containers, filling and preservation techniques	Minimise changes to sample (physical and chemical)
	Sample blanks – field, transport, equipment and container	Quantify contamination of samples during sampling process
	Decontamination of sampling equipment	Minimise contamination
Sample filtration	Filtration procedures	Minimise physical and chemical changes to sample
	Filtration blanks	Quantify physical changes and contamination during filtration
Field Testing	Equipment calibration	Minimise and quantify bias and error in field equipment
Transport and storage	Appropriate preservation techniques	Minimise physical and chemical changes to sample
Analysis	Accredited laboratory for required analysis	Ensure laboratory undertakes appropriate QC including spikes, calibration of equipment
	Duplicate samples – intra (within) lab	Check variability in lab analysis
	Duplicate samples – inter (between) lab	Quantify differences between laboratories' analysis methods
Reporting	Peer review validation	Validate that sampling is undertaken as per monitoring plan and in accordance with sampling guidelines

FIGURE 3.2 Decision-Making Flow Chart: When Toxicant(s) Exceeds Guideline Value(s)



Monitoring can be done on a risk basis, rather than repetitive blanket screening of all wells. Wells with good chemical quality based on DWSS central laboratory analyses can be taken up in a low-level monitoring program. Chemical parameters can be measured with simple field equipment by DWSS district engineers during regular scheme inspections (electrical conductivity [EC], ion-specific field analyses). If parameter values change, DWSS laboratory personnel can take samples for laboratory testing. Wells with good quality water need only be analyzed every four years. Wells with a chemical parameter exceeding the permissible limit must be resampled two times within the following year and analyzed. If the concentration is consistently high, the well will have to be taken up in a mitigation program (redrilling and tapping other aquifers, water supply from another nearby scheme, or well with good water quality or water treatment). If water quality parameters are upward trending, then appropriate actions should be taken. A series of decision-making flowcharts can be developed to simplify the process, as shown in figure 3.2. In addition, baseline pesticide monitoring should be conducted, as well as speciation of arsenic.

There is a need to improve sampling, testing, data organization and analysis, and general laboratory management. A comprehensive monitoring and sampling manual should be developed. It should provide common techniques, methods, and standards for sample collection, preservation and storage, and secure transport to a laboratory. It should also include data management for use by government agencies, relevant persons, and other organizations. Procedures for making instrument-based measurements in the field must be covered. The environmental media covered—sample material collected—are water (surface and ground), soils and sediment, animal and plant tissues, and whole samples. The role of reference sites, replicate measures and samples, and blank samples should be covered in the manual along with workplace health and safety issues associated with collecting samples in the field. Use of the manual will help develop consistency and increased scientific rigor of sampling data available for interpretation.

Note

1. Adsorption of arsenic uses media Bayer Bayoxide 33; system is delivered by InNow, supported by AdEdge.

Chapter 4
Institutional Sensitization and Action

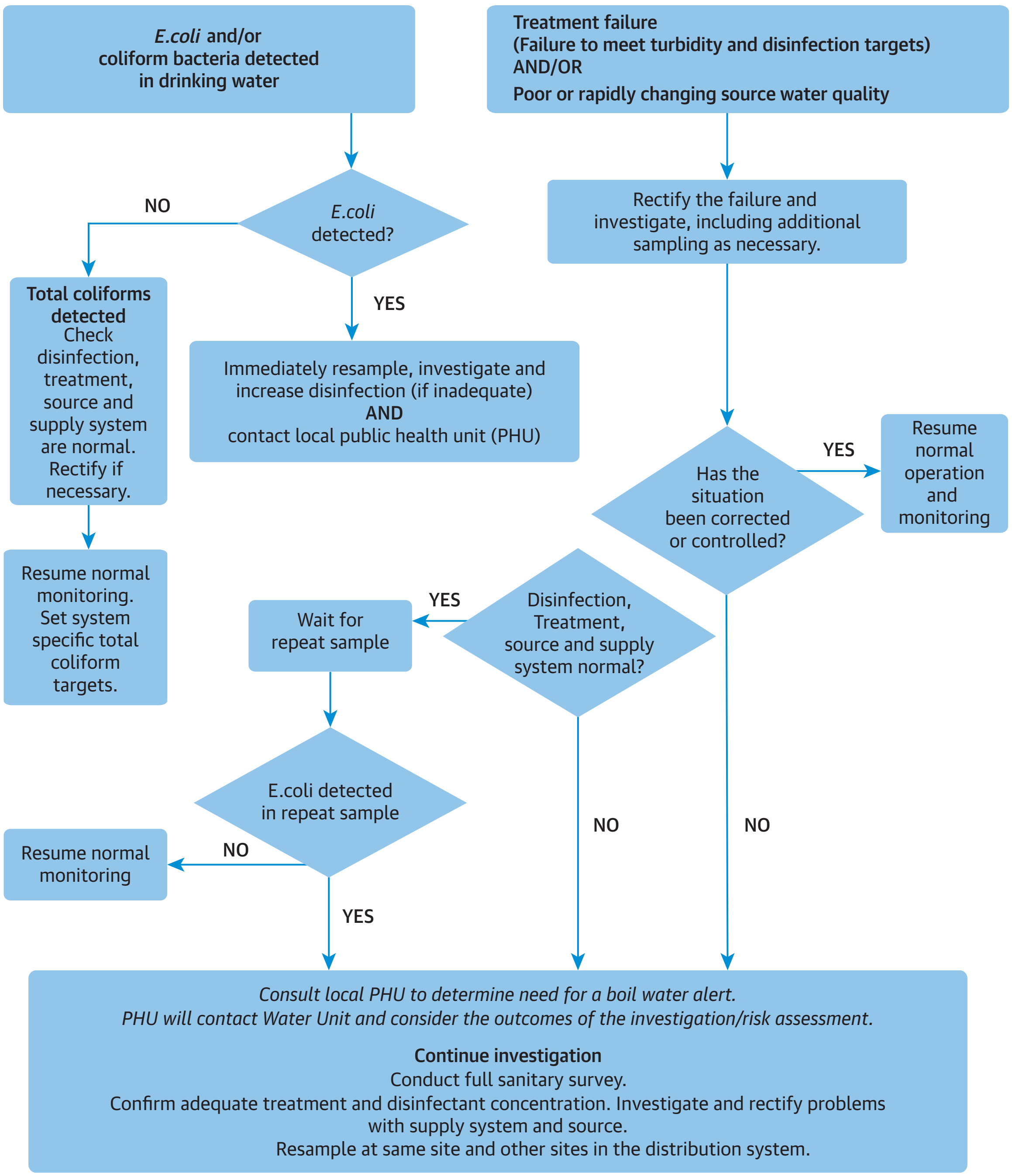
The central tenant of the framework is the institutional element, which requires the Department of Water Supply and Sanitation (DWSS) to make water quality an integral part of its commitment to deliver safe water to the rural population. Water quality management requires ongoing monitoring and understanding of the issue, and active management. Both functions and competencies are required within the DWSS going forward. As a multidisciplinary, multisector issue, water quality management requires coordination and action from different players, including the agriculture department, health department, pollution control board, and research institutes. The DWSS must have a central role in driving policy to provide safe drinking water. This study has shown that technology can be a significant institutional enabler by simplifying processes and functions, creating analytical capability, and creating accountability mechanisms. Using technology for key functions can be relatively simple to implement, and substantially increase the ability of the DWSS to dynamically understand and manage the water quality issue.

4.1 Service Delivery

Water quality management is an integral part of service delivery. Water quality management must be an integral part of the functioning of the DWSS to provide safe drinking water to rural citizens. Both sufficient water quantity for citizens' everyday use and water quality ensure a safe water supply. Training of all DWSS staff ensures that staff members are aware of water quality and its importance in assuring safe services. The impacts of sanitation on water supply, for example, is an important consideration. The proper construction of latrines is required at sufficient distance from drinking water sources to ensure that domestic sources remain safe. There is a need to develop clear roles and responsibilities for staff at all levels that integrates water quality into the everyday functioning of the DWSS. Technology, particularly mobile technologies, can enable learning, accountability, and more data-driven management. Oversight and incentive mechanisms can be easily built into mobile applications. All staff should be inspired to maintain a personal sense of responsibility and dedication to providing consumers with safe water, and should never ignore a customer complaint about water quality. DWSS staff should be empowered to respond quickly and effectively to monitoring flags.

Standard operating procedures for the development of new wells and operation of water supply schemes are required. Despite the proven benefits of chlorination of water supplies, this function is not being carried out routinely in most water supply schemes. Consistent and correct chlorination alone will have significant health benefits in the State. UV lamps are meant to be an integral part of the reverse osmosis plants, and should be properly installed and used. Correct construction of new wells by sealing will have a substantial impact on closing off a pathway of contamination of the deeper aquifer. Regular and correct use of field test kits and sample collection and testing at district labs should be part of the routine functions of the DWSS. Intensive training and application of these standard operating procedures will be required. Standard operating procedures include the decision-making process when exceedances of water quality parameters are found. For example, figure 4.1 outlines a process and decision-making framework when coliforms are in exceedance. Codified processes can enable institutional response and coordination, including coordination with other state department.

FIGURE 4.1 Decision-Making Flow Chart: When Coliforms Detected in Exceedance of Standards



4.2 Institutional Coordination

Actual health impacts on the population can be assessed only if active health surveillance systems are in place. Healthcare workers should be trained toward possible impacts to capture any early cases. There is a need to monitor levels regularly and assess risks periodically, especially in areas with marginal values. A detailed study of the health risks at the individual water source level is required to assess the impacts on the population given that each population is fed by water from specific schemes. Drinking water quality monitoring and health surveillance are closely related, requiring coordination between the DWSS and the health department.

Long-term regulation of irrigation wells will be required to assure the quality of drinking water wells. If deeper DWSS wells will provide safe drinking water, then irrigation wells should not be drilled deeper and cause polluted water to migrate vertically toward the screens of the DWSS wells. This will require coordination between departments responsible for agriculture and water resources.

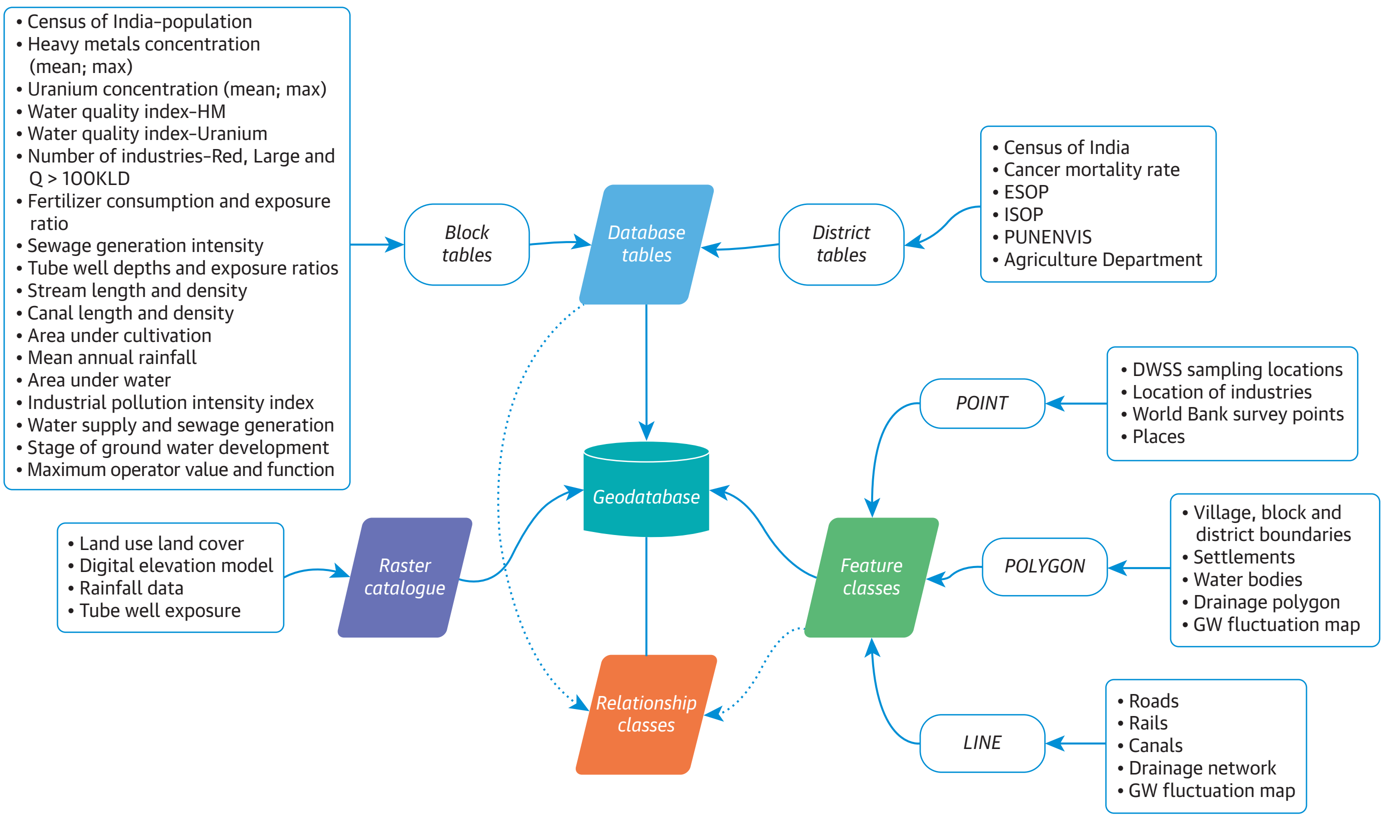
Water quality is best managed by regulating the sources of contamination. Suspected industrial pollution in urban areas is a serious concern and may pose an increasing threat to nearby rural wells. Groundwater pollution from infiltration of contaminated rivers, canals, and illegal discharge of wastewater (including through recharge wells) is a serious concern for ensuring safe drinking water. In addition, the regulation of agricultural practices related to fertilizer and pesticide use will have long-term benefits to ensuring source security. Cooperation with the urban local bodies, water utilities, the pollution control board, and the irrigation department will be required.

There is a need to adopt a learning mindset and culture to actively manage the water quality issue, and to establish constructive, ongoing knowledge sharing arrangements with key institutions. The understanding and investigation of redrilling sources will require knowledge of groundwater characteristics and proper well construction. Geophysical sampling and correct water quality sampling and testing will be required to determine the effectiveness of new sources. This has significant long-term cost and water quality management implications for the DWSS. The recent steps taken with the Central Groundwater Board (CGWB) should be maintained. The groundwater knowledge and experience of the CGWB is an essential input to systematically improve the successful siting and drilling of deeper and improved DWSS wells.

4.3 Technology as an Enabler

Develop geographic information system (GIS) capability in the DWSS to maintain a consistent database of all scheme and water quality data. The DWSS has been collecting and testing water samples across the State of Punjab since 2009. Water quality testing results for more than 13,500 samples collected from more than 7,400 locations have been compiled by the DWSS so far. To make this collected data structured and utilizable, a geodatabase has been developed with additional datasets. The geodatabase will help the DWSS develop a management strategy for solving water quality issues, optimizing monitoring efforts, prioritizing locations for interventions, and identifying curative and preventive measures. The structure of the geodatabase is shown in figure 4.2. The DWSS should continue populating and updating the geodatabase through a dedicated team. The Environmental Geodatabase is a tool to help strategize the management of water quality in rural areas of Punjab. It includes processed forms of spatial and

FIGURE 4.2 Design and Content of Geodatabase

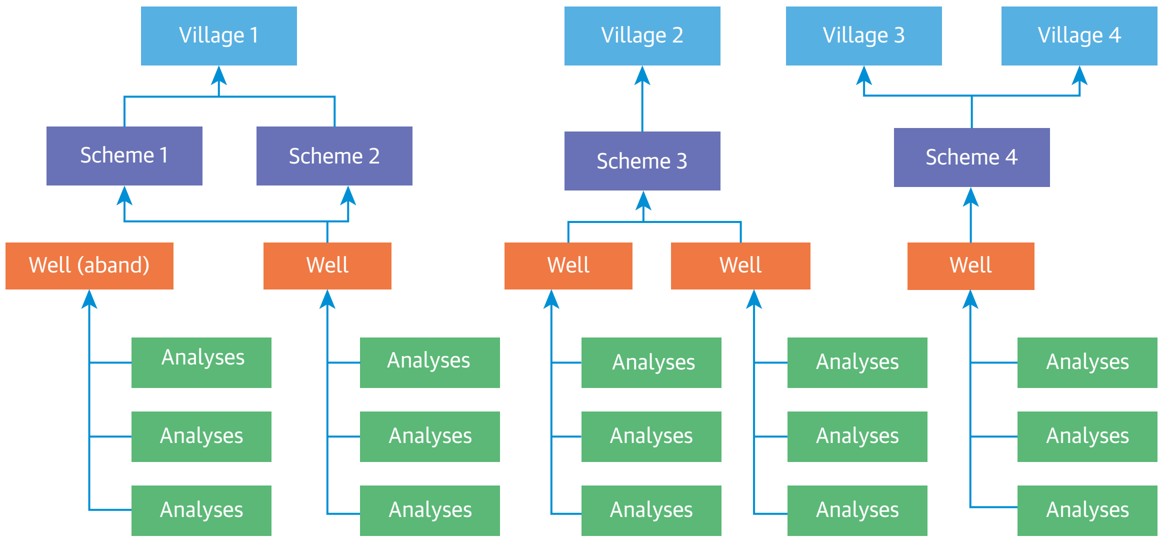


nonspatial datasets collected from such state agencies as the DWSS, Punjab State Remote Sensing Centre (PRSC), Indian Council of Medical Research (ICMR), Economic and Statistical Organization of Punjab (ESOP), and Department of Agriculture (DoA).

A robust well-structured database with input, output, and verification routines is necessary. Its structure could consist of a relational database of four datasets, connected to well-known identification codes. These datasets relate to (i) village (demography, administration); (ii) scheme (engineering data of the scheme components); (iii) well (layout, design); and (iv) water quality (analyses). Figure 4.3 shows how different combinations of villages, schemes, and wells are possible.

Information and communication technologies (ICT) use was demonstrated for conducting household surveys, monitoring water quality, and behavior change communication (BCC). Three mobile applications (m-Apps) were piloted as part of the communications strategy in three villages: Buddha Theh, Chak Kamal Khan, and Gorey Nangal, in which arsenic treatment plants were installed. The Household Survey m-App (HH Survey m-App) was used to inventory 358 households with respect to general socio-economic and demographic questions, water use and treatment sanitation practices (including use of toilet), and mobile or technology use. The Water Quality m-App (WQ m-App) was used by field staff for screening water quality in households and public water sources throughout the villages. Finally, the Behavior Change Communication m-App (BCC m-App) was deployed to assist field staff in delivering

FIGURE 4.3 Sample Combinations of Villages, Schemes, and Wells



water quality messaging, tracking water quality conditions and visits, and determining the progress made for each household in the villages. The WQ Reporting Portal and BCC Reporting Portal provided web-based access to review data collected and track communication activities. These technologies support the water quality communications strategy activities by characterizing conditions, screening water quality conditions, disseminating information to citizens and DWSS staff, and guiding BCC messaging.

The HH Survey m-App allowed field staff to collect data and engage with household members to answer survey questions and educate household on water quality issues, water safety planning, and discussion on sanitation and hygiene. For the pilot, the household survey data were used to develop an overall water quality sampling strategy, prioritize household visits, provide input to the WQ m-App, WQ Reporting Portal, and BCC m-App, and support the crafting of the community engagement and behavior change interventions. Data on socioeconomic, family health, water sources and handling, and sanitation hygiene practices information collected from 358 households provide in-depth social context. The interview questions engaged with household members to promote BCC messages, as well as ascertaining household members' knowledge water quality issues and sanitation and hygiene.

The WQ m-App was used to collect household level water quality data. This data were used to educate households on water quality issues and water safety planning. The WQ m-App enables users to screen and automatically log water quality results for six parameters in the field. For the pilot, the WQ m-App was used by DWSS field staff to screen the water quality of private and public drinking water sources (e.g., wells) as well as public water supply schemes (conditions of the water towers). The water quality data and the citizen engagement provide social and environmental context, provide input to the WQ Reporting Portal and BCC m-App, educate household on water quality issues and water safety planning, and support the crafting of the community engagement and behavior change interventions. The m-App guides users through the screening process by first prompting users to input basic information (e.g., water source, household members present) and then leading them through the steps for screening electrical conductivity [EC], pH, nitrate, total iron, free chlorine, and coliform (table 4.1). For screening, each analyte requires additional materials or equipment including probes (conductivity), test strips (pH, nitrate, total iron), and an Akvo Caddisfly chamber (free chlorine). With the exception of coliform, results are returned to the user within a minute and written to the Akvo Flow database. For the coliform test, the water sample is placed in a sampling container containing reagents, rested for 24 hours, then read by the user and manually entered into the WQ m-App.

Over a three-month period, DWSS social scientists and junior engineers collected 119 water quality screenings across the three villages, for example as shown in figure 4.4. The locations included piped and other sources (e.g., submersible, reverse osmosis) from both private (e.g., household screenings) and public water sources. The WQ m-App results provide three insights with respect to water quality: (i) aside from a few exceptions, EC, pH, nitrate, and total iron were within BIS drinking water standards (BIS 2012); (ii) chlorination was below the BIS drinking water standard of 0.2 milligrams per liter from all sources, including piped connections and water towers; and (iii) coliform was present in 65 percent of the water sources screened. Synoptic water quality of groundwater wells around Punjab indicate that the pilot villages contain elevated levels of arsenic. While originally included in the water quality screening, the test kits proved to be complicated (requiring reagents), the DWSS questioned the test kits' accuracy, and the WQ m-App was not set up to read the test strips. Thus, arsenic was not included in the analytes to examine. The WQ m-App allowed DWSS staff to engage in dialogue with household members regarding water quality issues and water safety planning. During the field campaigns, household members would observe the screening, ask questions regarding the results, and listen to staff response addressing potential sources of contamination and health risks associated with

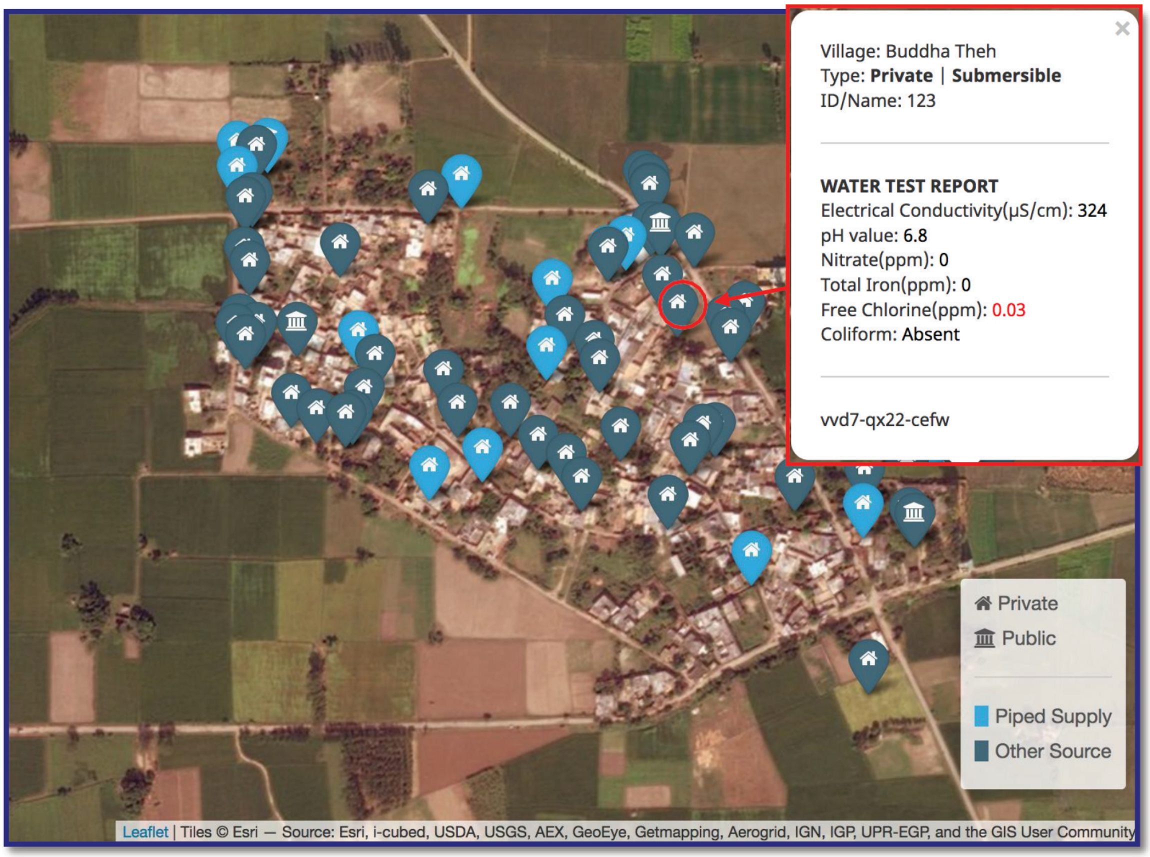
TABLE 4.1 WQ m-App Parameters and Appropriateness of Use by DWSS Staff and Citizens in Future Projects

Parameter	Analytical method	Crowdsourcing by DWSS staff	Crowdsourcing by citizens	Comments
Conductivity	Electro-conductivity probe (EC)	yes	no	External probe: feasible for DWSS staff to assess village conditions, but challenging for widespread distribution to citizens in crowdsourcing projects.
pH	Test strip	yes	yes	Test strips ideal for both DWSS staff and citizen use.
Nitrate	Test strip	yes	yes	Test strips ideal for both DWSS staff and citizen use.
Total iron	Test strip + reagents	yes	ltd.	Use of reagents with test strips are adequate for DWSS staff, but add complexity when given to citizens in crowdsourcing projects.
Free chlorine	Akvo Caddisfly chamber	yes	no	Feasible for DWSS staff to assess village conditions, but challenging for widespread distribution to citizens in crowdsourcing projects.
Coliform	Sampling container with reagents	ltd.	ltd.	Sampling method requires 24 hours and yields presence/absence. Does not provide real-time results, which may be a barrier to widespread distribution.

Source: World Bank.

Note: Ltd. denotes that the technology is available but has limitations for crowdsourcing. DWSS = Department of Drinking Water Supply and Sanitation; EC = electrical conductivity; WQ m-App = Water Quality m-App.

FIGURE 4.4 Water Quality Screening Locations (65) in Buddha Theh, Punjab 2016



Source: World Bank.
Note: Screening conducted by World Bank Team and DWSS field staff. Screenshot as reported in the WQ Portal. In the WQ Portal, WQ m-App results are available for any location in the pop-up window (outlined in red).

unsafe water. Staff also reported that citizens generally trusted the use of m-Apps to measure and receive water quality results.

The WQ m-App was an effective tool for screening water quality conditions in the field. Each month the DWSS collects one to two public drinking water sources, which are sent to the state laboratory for analysis. While laboratory analyses provides greater accuracy, limitations of this sampling regime include the delay in obtaining results (within days if not weeks), only a single point within the village is measured, and the action does not foster community awareness nor build DWSS field staff-community member relations. The WQ m-App addresses these limitations by providing real-time results of the drinking water sources, informing household members of water quality limited sources, enhancing interaction between the DWSS and community members, and creating opportunities to increase awareness of water contamination and its sources and how water quality links to health impacts. Furthermore, use of the WQ m-App with household members helps dispel the notion that clear and odorless water is always safe to consume. These factors empower individuals with information so they can choose to take appropriate actions (e.g., boiling water, using piped water), potentially preventing adverse impacts of consuming water of poor quality. This technology contributes to building community awareness, fostering transparency in water testing, and disseminating water quality data: factors that contribute toward improved water quality conditions and water safety and security practices.

The increased number and spatial distribution of water quality screenings throughout the community provide DWSS senior officials, DWSS field staff, and GPWSC members an overview of the drinking water quality conditions. These resource managers can use this information to address problems in infrastructure or its operations, poor water handling behavior by citizens, develop strategies for addressing the source of pollution, and link to the SNK system (DWSS's citizen engagement hotline). At US$31.98 per screening, the current screening routine is difficult to scale. The costs per sample will likely decrease substantially as the number of analytes screened is reduced, the required equipment eliminated, and the number of screenings conducted increased.

The WQ Reporting Portal is a dashboard for assessing the water quality screenings in the communities. Users are able to view village-based summary data from the HH Survey m-App and WQ m-App. A screen shot of the portal in shown in figure 4.5.

The BCC m-App assisted DWSS social staff to implement the BCC and water safety planning. It classifies household status on awareness and compliance; provides targeting messaging; documents DWSS engagements with the households, and tracks the progress made for each household in the villages. Built on an understanding of water quality communication strategy and challenges in its execution, the BCC m-App supports DWSS social staff to engage with community members. The BCC m-App incorporates and displays the results from the HH Survey m-App and WQ m-App and addresses shortcomings in previous messaging. In addition, it synthesizes BCC and water safety planning communications. According to field testing, the m-App is helpful. They enjoy not having to carry paper files, having greater amount of information readily available, and "watching the houses change from red to green" to indicate progress in changing household behavior. Features of the BCC m-App:

- **Map screen**. Maps of the village with color-coded house icons in red, yellow, or green based on the ranking protocol for compliance with the water safety planning and BCC protocols. Houses are identified if water quality screening has occurred. This screen provides a quick overview of water quality conditions of all the households in the village.
- **Household status screen**. For any house in the village, when selected, another screen displays salient household survey data, water quality results, and household status. For quick reference, icons indicate pipe connection status, presence of taps, presence of a toilet, and willingness to have water quality screening conducted. For households that have been experienced water quality screening, a pop-up window provides details results.
- **Communication overview**. Provides a list of safety planning actions to take, narrative and videos to provide, and measures appropriate for the household status. Check boxes allow field staff to track of activities and BCC observed by the household. The screen is accessed through the Communication Advice button on the Status screen.

FIGURE 4.5 **Summary of water quality screenings for Gorey Nangal, Punjab 2016**

Select Village: Gorey Nangal

Per Parameter Analysis

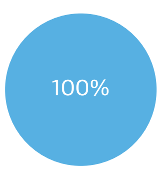
Village Gorey Nangal, 35 sources tested

	Piped supply	Other sources	
Public	1	1	2
Private	14	19	33
	15	20	35

Electrical Conductivity

How saline is the water?

? Learn More



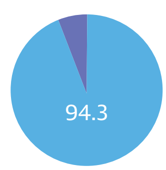
Sources beyond permissible limit:
Piped Supply Sources: 0 of 15
Other Sources: 0 of 20
Private Sources: 0 of 33
Public Sources: 0 of 2

● Within Permissible limit

pH

How acidic or alkaline is the water?

? Learn More



Sources beyond permissible limit:
Piped Supply Sources: 0 of 15
Other Sources: 2 of 20
Private Sources: 2 of 33
Public Sources: 0 of 2

● Within Permissible limit ● Beyond Permissible limit

Source: World Bank.
Note: This figure depicts the top portion of a website page within the WQ web portal.

- **Activity log.** DWSS staff can view a log of previous interactions with the household d for tracking communications and actions taken by the household. The screen is accessed through the View Log button on the Household Status screen.

While ICT tools were effective for the pilot, barriers to expansion need to be addressed when scaling to larger regions. The barriers include time required to conduct the survey, type of data collected, limited availability of DWSS social staff, and current software platform in which the HH Survey m-App has been developed. Solutions include limiting the survey questionnaire by removing data not deemed relevant to the DWSS WQ Communications Strategy (e.g., socioeconomic data), determining other sources of data, or limiting the density of surveyed household in the village. When moving forward, barriers and costs need to be weighed against the benefits. Benefits include having a social context to develop targeted BCC messaging, a basis for WQ screening prioritization lists, and supplies input to the WQ Reporting Portal and BCC m-App. In addition, HH Survey data are potentially beneficial to other departments (e.g., sanitation and hygiene communication, water supply scheme development) and state agencies (e.g., health department).

Costs of using the WQ m-App include fees for using the Akvo Flow APK and Dashboard and the cost of the screening test kits. For a yearlong license covering data collection, use, and access to Akvo Flow, the fee is US$4,251. For 10 cells phones; 10 EC probes; and 200 test kits for pH, iron, nitrate, residual chlorine, and fecal coliform, the cost is US$4,271. Assuming 200 samples and that the Akvo Flow fee is split evenly between the HH Survey m-App and WQ m-App, the combined fee for the technology and test kits is US$31.98 per screening. Because the phone and the probes are fixed costs, continued use of these test kits will lower the cost per survey. The test strips, reagents, and Akvo Caddisfly inserts will continue to be purchased. Because the test kits have the required sampling equipment and were passed out to the DWSS field staff and World Bank team, distribution costs and availability of additional supplies were not evaluated.

Costs to conduct the HH Screening m-App include fees for customizing and using the Akvo Flow APK and Dashboard. For a yearlong license covering data collection, use, and access to Akvo Flow, the service fee is US$4,251 for up to 4,000 forms (e.g., survey results, water quality screenings). Assuming this fee is split evenly with the WQ m-App, which also uses Akvo Flow, the fee is US$5.94 per survey. Because the annual service fee is fixed up to 4,000 forms, the cost per survey will reduce with the increasing number of surveys performed.

Chapter 5
Conclusion

As India moves toward the achievement of the Sustainable Development Goals (SDGs), the establishment of mechanisms for the delivery of safe and sustainable water supply in Punjab provides experience and direction for the country. Groundwater has been a safe and reliable source of water that has driven economic development for decades. However, overabstraction of the resource has significantly affected water availability and water quality. Alternative sources often tend to be less reliable, subject to droughts and contamination, and more expensive, requiring transport across longer distances, and operations and maintenance (O&M) of water treatment infrastructure.

This study provides the first step toward understanding and managing drinking water quality in the State. It provides an analytical basis for moving forward, and has demonstrated approaches that have yielded valuable lessons for scale-up. It combines the need to use knowledge with the need to make cost-effective management decisions, and the interconnection of these two aspects within the institutional home of the DWSS.

Water quality management is an integral part of service delivery, integrating source development and management, and operation of water supply systems. The emerging water quality issue presents an opportunity for the State, and the country, to take the lead and proactively understand and manage it. The problem is complex and the study highlights a multipronged approach that is practical and achievable within the State context. The next steps are for the State to develop a series of implementation plans to operationalize the highlighted elements. This synthesis report provides the overall framework for the State. Additional technical reports provide in-depth analysis and detailed recommendations that can be used by the State to advance its engagement on this issue.

Appendix A
Study Methodology

A.1 Literature Reviews

Literature reviews were carried out to understand the water quality context, deterioration of groundwater, groundwater flow characteristics, health impacts, and beneficiary behavior. These are detailed in the respective technical notes. They provide useful concepts and hypotheses for explaining the provenance, mobilization, and pathways of the pollutants and to identify and map the framework of water quality issues at the national and state levels.

A.2 Data Collection and Analysis

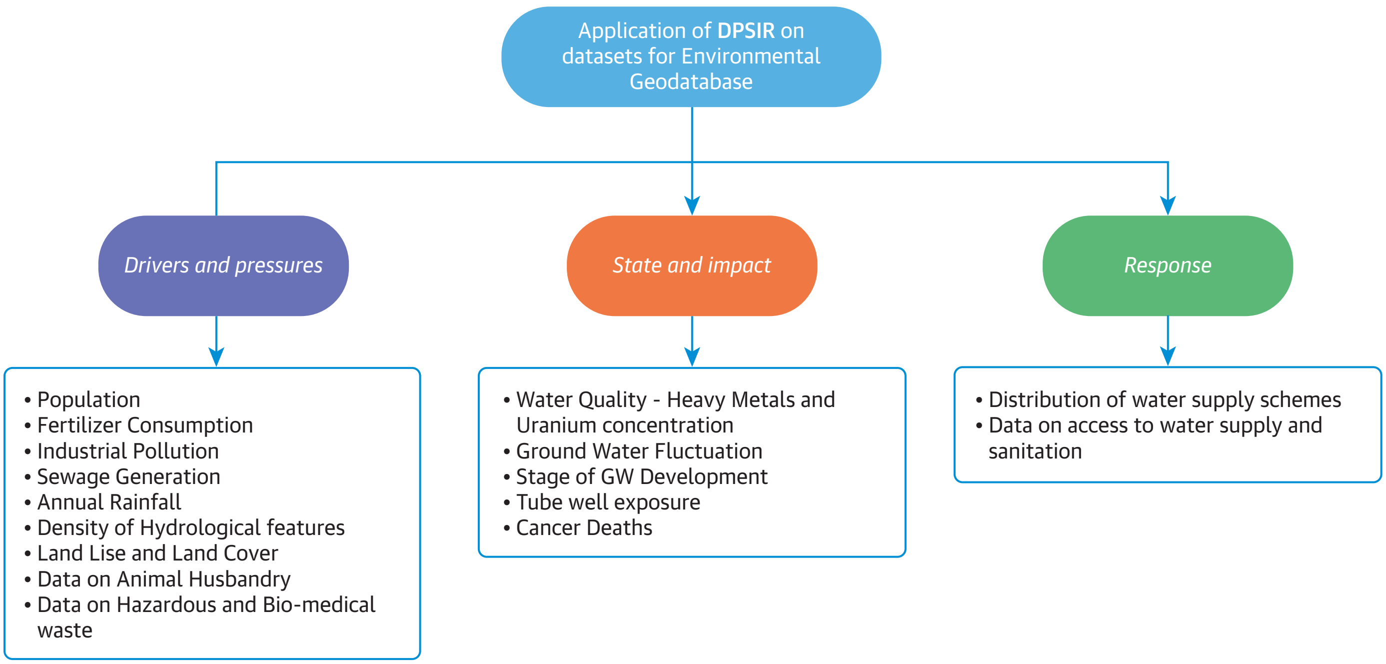
A.2.1 Development of a Geodatabase

The Punjab State Remote Sensing Centre (PRSC) developed the geodatabase in 2009, during the implementation of the Punjab Rural Water and Sanitation Project, in which DWSS water source was geotagged and tested for pollutants and major chemical constituents. The statewide sampling campaign included about 5,800 analyses of all major constituents, except for sodium. The geodatabase also contained geographical coordinates and tube well construction information.

This study updates the PRSC geodatabase with the most recent DWSS water quality testing, and includes processed forms of spatial and nonspatial datasets collected from state agencies, including the Indian Council of Medical Research (ICMR), the Economic and Statistical Organization of Punjab (ESOP), and the Department of Agriculture (DoA). The geodatabase is a single, comprehensive repository of spatial and nonspatial information. The sampling sites, administrative boundaries, hydrological features, settlements, roads, and railways are stored in a geodatabase feature class; land use, land cover, and digital elevation model are stored in a raster catalog; and nonspatial datasets are stored in tables and linked to corresponding features using a relationship class. The database is structured around the driving force, pressures, state, impact, and response (DPSIR) framework as shown in figure A.1.

The geodatabase contains data for: water supply schemes, water quality data, polluting industries, fertilizer consumption, estimated sewage generation, water resource vulnerability, census data, cancer statistics, household surveys. Data was first analyzed at the block level, then at scheme level. Pollution hotspots were analyzed by aggregating data using a water quality index for heavy metals and industrial pollution intensity indices. Spatial resolution was improved by matching coordinates available in the PRSC dataset with the scheme level data in the DWSS MIS and the water quality database. Extensive cleaning and aggregation of the database was required, which highlight the need for data protocols to be established in future to ensure consistent naming and spelling of schemes and their associated data. The geodatabase has presented a state-wide picture of water quality distribution for the first time.

FIGURE A.1 Application of DPSIR Framework to Geodatabase



Source: World Bank.
Note: DPSIR = driving force, pressures, state, impact, and response.

A.2.2 Water Quality Standards

The Bureau of Indian Standards (IS-10500-2012) is a voluntary drinking water quality standard with two limits: (i) acceptable limits and (ii) maximum permissible limits. These are provided in table A.1 for the key constituents studied. Drinking water is considered contaminated if it exceeds the permissible level. Permissible limits provide a relaxation of the limit when no other source of drinking water is available.

A.2.4 Water Quality Data

The study's analysis is based on the geodatabase and the DWSS water quality testing data. The DWSS Excel database contains analyses of samples from about 7,500 tube well schemes, available from the first, second, and ongoing third monitoring phases (2010-17). The samples have been analyzed for the heavy metals fluoride, nitrate, iron, and aluminum and TDS (total dissolved solids). The monitoring phases did not analyze all wells or all parameters. The number of analyses varies between 100 and 6,000 for each phase. The combined database contains the results of the PRSC statewide sampling campaign (about 5,800 analyses of all major constituents except for sodium), geographical coordinates, and tube well construction information. Substantial efforts were made to streamline and clean the DWSS database, including matching scheme data and resolving inconsistencies in naming, units, and numerical and text entries. The reliability of data (e.g., well depths) may still be questionable. The DWSS and PRSC databases are linked, and geographical coordinates from PRSC records have been added to the PRSC records, and input files have been created for geographic information system (GIS) mapping.

TABLE A.1 Standards for Drinking Water in India

mg/l

Parameters	Code	Acceptable limit	Permissible limit[a]
TDS	none	500	2,000
Fluoride	F	1.0	1.5
Nitrate	NO_3	45	100
Iron	Fe	0.3	No relaxation
Aluminum	Al	0.03	No relaxation
Lead	Pb	0.01	No relaxation
Selenium	Se	0.01	No relaxation
Chromium	Cr	0.05	No relaxation
Mercury	Hg	0.001	No relaxation
Arsenic	As	0.01	0.05
Nickel	Ni	0.02	No relaxation
Cadmium	Cd	0.003	No relaxation
Uranium	U	0.03	0.06

Source: World Bank data.
Note: TDS = total dissolved solids.
a. In the absence of alternative sources.

A.2.5 Data Analysis

After revision of the Excel databases, statistical analyses were carried out. Analyses of all pollutant parameters were depicted in histograms of various classes, showing the number of exceedances of acceptable and permissible levels according to the Bureau of Indian Standards (2012) and other criteria. The analyses were also subjected to correlation analyses using two-step clustering and the principle component analysis (PCA). The analyses of DWSS wells and other spatial information have been processed into base files for GIS projects (ARCGIS and QGIS). GIS maps have been prepared showing the state of pollution in the form of indexes aggregated at block and district levels. Maps display information on drivers such as sewerage, industrial activity, and fertilizer use. A well-established risk assessment approach to drinking water quality is the U.S. Environmental Protection Agency (U.S. EPA) Integrated Risk Information System (IRIS) approach was used to assess health risks.[1] Further details on data analysis are provided in the technical papers.

A.2.6 Targeted Sampling

During the course of the study, questions arose regarding the spatial and temporal consistency of the high concentrations of certain components in certain areas. One sampling campaign was conducted in Amritsar and Gurdaspur districts, in which a number of DWSS wells were sampled and analyzed to define the consistency of high arsenic contents. Two campaigns on uranium and lead were conducted in Hoshiarpur. In these campaigns, irrigation wells close to DWSS tube wells, which previously had high concentrations of these compounds, were sampled, as well as household wells. To get a better understanding of the provenance of the pumped groundwater isotope (tritium, stable isotopes),

TABLE A.2 Targeted Sampling Rounds during the Study, Punjab, January 2016 to May 2017

	Focus	No. samples	District	Period
1.	Lead	10 samples from various wells[a]	Jalandhar	Jan 2016
2.	Arsenic	69 samples from various wells[b]	Amritsar and Gurdaspur	May 2016
3.	Arsenic and lead	16 samples[a]	Amritsar and Jalandhar	June 2016
4.	Lead	50 samples[b]	Hoshiarpur	Oct–Nov 2016
5.	Lead	48 samples[b]	Hoshiapur, Ropar	Feb 2017
6.	Uranium	60 samples[b]	Various	Mar 2017
7.	Fluoride	50 samples, 10 locations[b]	Patalia	Mar 2017
8.	Water quality in deep wells	20 samples based on DWSS[b]	Mainly Patalia and Ropar, Hoshiapur	Mar 2017
9.	Isotopes	20 wells[c]	Various	Apr 2017

Source: World Bank data.
Note: DWSS = Department of Drinking Water Supply and Sanitation; NIH = National Institute of Hydrology.
a. By World Bank team.
b. By DWSS.
c. By NIH.

DWSS personnel carried out analyses on groundwater samples. The DWSS laboratory and PBTI laboratory in Mohali and the isotope laboratory of the National Institute of Hydrology (NIH) in Roorkee have carried also out analyses. See table A.2.

A.3 Exposure Visit to West Bengal

West Bengal is one of the first states in India in which arsenicosis was first reported; thereafter, studies have shown presence of high concentration of arsenic in groundwater. West Bengal has adopted comprehensive technological options, health and communication strategies, and actions to manage water quality issues related to arsenic. The objectives of the exposure visit were to (i) understand the role of the State in management of arsenic mitigation; (ii) understand the technologies explored and adopted by the State; (iii) understand problem of arsenic from public health perspective; (iii) to see clinical arsenicosis cases; (iv) determine the capacity requirements for surveillance of arsenicosis; and (iv) understand the information, education, and communication (IEC) strategy adopted by the State.

A.4 Formative Research

Formative research was conducted to understand the causes of attitudes and behavior regarding water use in villages. The research was conducted in five quality-affected villages in the districts of Amritsar and Gurdaspur. The schemes selected were Budha Theh, Chak Mishri Khan, Chak Kamal Khan, and Gorey Nangal in Amritsar District, and Rattar Chattar, a three-village servicing scheme, in Gurdaspur District. These villages were selected for the high concentration of arsenic, and because arsenic mitigation technologies were planned for piloting. These villages were selected to pilot the strategies for behavior change communication (BCC) as well as crowd-sourcing water quality data from the community.

The formative research was qualitative, informed by quantitative inputs from the end-line sector survey conducted at the close of the Punjab Rural Water Supply and Sanitation Project, and statistical studies in Punjab from the public domain. The findings were an input for the communications strategy. The methodology included personal interviews with adult women, who were considered the key respondents. Women generally collect water in the household and are most knowledgeable about water-related issues. In addition, focus group discussions were held in the community, including young women, men, youth, school children, *panchayat* members and other influencers, functionaries from the DWSS, and Gram Panchayat Water and Sanitation Committee (GPWSC) members. Participant observation and interviews provided additional insights. Key aspects investigated included the following:

- Piped water supply: functioning of the scheme; pattern of complaints by beneficiaries; issues such as illegal connections, metering, low pressure, *tullu* pumps; conservation through regular usage of taps; water safety planning; timely water bill collection; timely payment of electricity dues; operations and maintenance (O&M); reasons for low subscriptions to schemes; feedback mechanisms; and trust and transparency issues.
- Sewerage and sanitation at a household and village level, from the point of view of their impact on water supply safety and presence and use of toilets.
- Hygiene behavior relating to water collection, storage, and handling, as well as toilet usage, use of sanitation products, and sanitation behavior.
- Communication activities: interest in and acceptance of IEC, message recall from earlier campaigns, and media preferences and interest in information and communication technologies (ICT) tools and social media.
- Mindsets and attitudes of the identified target groups, including women and men.
- Identification of change motivators.
- Village water and sanitation committee: assessment of capacities and identification of development needs; issues of inclusion and transparency.

A.5 Pilot Implementation

Technology selection and implementation was demonstrated for arsenic affected areas. Arsenic affected areas, whose source is geogenic, were selected because of the known negative health impacts. It was therefore plausible to take management action. The DWSS selected three villages with high levels of arsenic to implement the pilot community scale water treatment plants. The multistakeholder Arsenic Removal Technology Assessment Framework Workshop was organized by the DWSS in Chandigarh to develop criteria for evaluation of technologies, and finalize the most appropriate technologies with the consultation and collaboration among experts and technology providers. Technologies were evaluated against the criteria, and two technologies were shortlisted. Life cycle costs for these two shortlisted technologies were analyzed. The DWSS procured and installed community-scale plants in these villages on a pilot basis. Nano technology was selected, and DWSS procured and installed treatment plants in the three villages in Amritsar District—Budha Theh, Gorey Nangal, and Chak Kamal Khan—to demonstrate community-scale water treatment. Up to now only small-scale community reverse osmosis plants have been used, and this project has provided demonstration of an alternative technology and scale. At the same time, a BCC strategy was piloted to ensure that communities understood the water quality issue and used the treated water. Water safety planning was integrated into the methodology.

A pilot to demonstrate use of ICTs to monitor water quality was included as part of the BCC process. Awareness generation was the first phase, by which knowledge relating to water quality issues—along with water supply, sanitation, and hygiene behaviors linked to water quality—were discussed with all households, using interpersonal communication (IPC). The households were categorized across parameters relating to behavior, ranging from extremely high levels of poor and harmful practice to relatively lower levels. The households then received customized messages at the later phase of the project. A custom, mobile-based application was designed to help the DWSS social staff conduct advocacy campaigns in selected villages. After advocacy, changes in household behaviors were monitored using the application.

A.7 Key Institutions Consulted

The Central Groundwater Board (CGWB) in Punjab is the focal point for knowledge and information on shallow and deep groundwater in Punjab. There was recognition of the need for closer cooperation and knowledge sharing between the DWSS and CGWB, particularly on improved tube well construction, monitoring, and exploration of deeper wells. The CGWB has drilled six deep monitoring wells and is about the drill 36 deep exploration wells under the National Deep Aquifer Mapping project (NAQUIM)[2]. These wells will provide valuable information for the understanding of the pollution pathways and the occurrence of the groundwater pollution below 150 meters to 200 meters. The CGWB and DWSS are exploring further cooperation for retesting deep monitoring wells, provision of guidance and advice to DWSS on the siting and drilling of deep monitoring wells, and the exchange of data and information on new wells.

The NIH conducted the stable isotopes and tritium analysis in their laboratories. NIH scientists have conducted work on groundwater quality and residence times in study areas in Punjab. NIH has also conducted training to DWSS engineers on sealing of wells. In addition, the Bhabha Atomic Research Centre (BARC) with the Board of Radiation and Isotope Technology (BRIT) have conducted research in Punjab on groundwater pollution and associated health risks of uranium contamination, and have laboratory facilities for specialized analyses, including of uranium and isotopes. Punjab University has facilities for sediment analyses on heavy metals, including arsenic and uranium, and can potentially make students available for fieldwork through MSc studies. Finally, Teri University with Columbia University are involved in an arsenic and fluoride research project in Amritsar and Gurdaspur to drill monitoring wells for mapping these elements. It was agreed to exchange this information and align the monitoring of the wells.

Notes

1. See the EPA website, https://www.epa.gov/iris.
2. The NAQUIM (MoWR started in 2012 with the objective to identify and map aquifers at the micro level, to quantify the available groundwater resources, and to propose plans appropriate to the scale of demand and aquifer characteristics, and institutional arrangements for participatory management.

Appendix B
Technical Reports

TABLE B.1 Technical Reports

Title	Author
Understanding the Pollution in the DWSS Rural Water Supply Wells State of Punjab—India (Volume I: Main Report)	Albert Tuinhof Koos Groen
This report has provided a wealth of information on the characteristics and pollution conditions of groundwater in Punjab. It assesses the pollution sources, origin, pattern, pathways, and risks of the various contaminants (including arsenic, fluoride, uranium, lead, aluminum, selenium, nitrate, mercury, cadmium, nickel, chromium, TDS, and iron). The report provides the type of measures that can be taken to reduce the pollution risk of the contaminants. These measures focus on locating safe groundwater and improvement of the siting, design, construction, operation, and monitoring of the wells.	
Understanding the Pollution in the DWSS Rural Water Supply Wells State of Punjab—India (Volume I: Main Report)	Albert Tuinhof Koos Groen
This report includes all the supporting information to the main report. The main contents include the strata chart and cost estimate of the DWSS tube wells, reference for the main report, maps and histograms of the contaminants, statistical analysis of the DWSS and PRWS water quality database, a review of the water sampling and analyses protocols, and the design and construction of the water production wells.	
Study Report on Drinking Water Quality and Health in Rural Punjab	Anjali Chikersal
This report studies the health impacts of the environmental pollution of drinking water sources under the Department of Water Supply and Sanitation, studies the surveillance systems in the State, and provides recommendations toward strengthening the institutional mechanisms for the same, with the broader aim of supporting the GoP in decision making regarding institution of mitigation measures, and strengthening institutional mechanisms. Health fact sheets of the contaminants in groundwater resources in Punjab are also included in the report.	
Workshop Report on Development of Technology Assessment Framework with Focus on Arsenic Removal Technologies	Prasad Modak
A multistakeholder workshop, Arsenic Removal Technology Assessment Framework Workshop, met on January 19, 2016, at PHD Chamber in Chandigarh, India. The report is the outcome of the workshop. The technology assessment framework was developed setting the criteria for evaluation of technologies. The workshop focused on finalizing the criteria, weights, and the scoring theme and capacitating DWSS officials on the evaluation process. The report includes suggestions made on the workshop to improve the technology assessment criteria.	
Groundwater Quality Monitoring Plan	Prasad Modak
This report reviews existing groundwater quality monitoring system. It formulates a groundwater monitoring plan for the DWSS. It also makes recommendations for the strengthening and optimization of the system.	
Potential Health Risks from Inorganic Chemical Contamination of Groundwater in Punjab, India	Anupama Kumar, Ray Correll
This report describes the human health risks from inorganic contaminants to drinking water quality in wells across the Punjab state of India. The data set is extensive and includes information on analyses from 18,509 wells.	
Technologies for Chemical Pollutants Mitigation in Ground Water	Subhash Verma
The report explores possible treatment options for the various chemical pollutants present in the water, basically arsenic, fluoride, uranium, lead, and other heavy metals.	
Communications Strategy	Simmi Mishra
The report describes the communications strategy for the water quality management in Punjab. It was developed based on a comprehensive literature review and formative research with the intention of ensuring that the present strategy is evidence-based and draws from work completed in the area.	

table continues next page

TABLE B.1. continued

Title	Author
Report on Environment Geodatabase for Water Quality Management in Punjab	Prasad Modak
The report provides information on the design and compilation of the geodatabase produced for strategizing the management of water quality in rural areas of Punjab. It discusses the processes followed for building the datasets. Illustrative applications of the geodatabase are also been included.	
Evaluation of ICTs to Support Water Safety and Behavior Change Communications	Carter Borden
This report gives detailed information on the pilot project that explored the use of ICT to improve information communication, foster conversations, and support citizen science programs. It also shows how ICT can support the DWSS in achieving the water quality communications strategy objectives of bringing greater awareness to the community with respect to water quality issues and water safety and security planning.	
Arsenic Mitigation in Water Supply—West Bengal Study Mission: March 9–11, 2016	World Bank
The team visited West Bengal in March 2016 to understand the water quality issues relating to arsenic and to study technology and communication strategies. The report introduces the main activities of the mission and shares the main findings.	

Note: DWSS = Department of Drinking Water Supply and Sanitation; GoP = Government of Punjab; ICT = information and communication technologies; n.a. = not applicable; PRWS = to come; TDS = total dissolved solids.

About the Water Global Practice

Launched in 2014, the World Bank Group's Water Global Practice brings together financing, knowledge, and implementation in one platform. By combining the Bank's global knowledge with country investments, this model generates more firepower for transformational solutions to help countries grow sustainably.

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