Chapter 12
Impacts of Water Quality on Human Health in Pakistan

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Abstract Pakistan is ranked third among countries facing severe water shortage. Yet the country's water resources are being depleted with such intensity that it has become a country with physical water deficiency, with water contamination another contributing factor. Most of the population is exposed to hazards of drinking unsafe and polluted surface and groundwater due to unavailability of clean water. Over 60% of the population get their drinking water from hand or motor pumps, with the figure in rural areas being over 70%. Inadequate quantity and quality of potable water and poor sanitation facilities and practices are associated with a host of illnesses such as diarrhoea, typhoid, intestinal worms and hepatitis resulting in national income losses of Rs. 25–28 billion annually, or approximately 0.6–1.44% of the country's GDP. Studies conducted by national and international agencies suggest that all key quality parameters for Pakistan's drinking water are exceeding acceptable limits. This chapter provides an updated review of literature on water quality issues in Pakistan, sources of contamination, and health impacts. The review leads to a set of strategies that Pakistan could adopt to reduce the level of waterborne health impacts.

Keywords Water contamination · Carcinogenic · Waterborne diseases · Heavy metals · Microbial pathogens

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12.1 Introduction

12.1.1 Water Quality Definition and Global Context

"Water quality" is a term used to express the suitability of water for various purposes or to sustain various water-dependent processes. Any specific use of water requires measurement against acceptable levels of physical, chemical, and biological properties of water. In particular, drinking water must clear global standards of limits on the concentrations of these elements. The quality of water bodies is thus assessed in terms of their hydrology, physico-chemistry, and biology. A range of variables are used to reduce threats to human health, food production, ecosystem functions and economic benefits (Bartram and Balance 1996). Because of the complexity of factors determining water quality and large choices of the variable used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition but in broader terms, water quality can be defined as follows:

> "Set of concentrations, speciations, and physical partitions of inorganic or organic substances, or composition and state of aquatic biota in the water body, or description of temporal and spatial variations due to factors internal and external to the water body" (Chapman 1996, p. 6).

Water quality can be assessed in relative terms as it not only depends on the function of its conditions or components but also its usefulness and usability (WWAP 2015). It is for these reasons that the World Health Organisation (WHO) has established a world standard set of water quality guidelines (e.g. WHO 2008) that is regulated by different countries according to the specific conditions.

In the global context, 785 million people lack basic drinking water services, out of which 144 million people use surface water for drinking purposes. Globally at least 2 billion people use drinking water contaminated with faeces resulting in transmission of diseases such as diarrhoea, cholera, dysentery, typhoid, and polio. Out of these diseases, diarrhoea counts for 485,000 deaths every year. By 2025, half of the world's population will be living in water-stressed areas. In the least developed countries, 22% of health care facilities have no water service, 21% no sanitation service, and 22% no waste management service (WHO and UNICEF 2014).

12.1.2 Water Quality and Anthropogenic Impacts

Water is essential for human survival. Once it is contaminated, it is difficult and expensive to remediate. Natural processes and anthropogenic activities influence the quality of both surface and groundwater resources. Natural essential components of good quality water include dissolved substances, insoluble particulate matter, and microbes which help to maintain biogeochemical cycles as well. Exceptionally, there are possibilities that naturally occurring substances trigger any water quality changes detrimental to human health. But anthropogenic activities such as domestic use, agricultural production, mining, industrial production, power generation, and other factors alter the natural composition of water which threaten its safe use. For example, industry is responsible for dumping an estimated 300–400 million tonnes of heavy metals, solvents, and toxic sludge into water each year (UN Water 2011). Therefore, every contaminant entering the water body has an impact on water quality.

Increasing population and industrialisation has increased the demands of water, especially good quality water for drinking, personal hygiene, agriculture, and other industrial activities. Each water use leads to a considerable impact on water quality and several human activities have undesirable impacts on water quality. For example, around 80% of the global wastewater produced due to human activities goes untreated, containing everything from human faeces to highly toxic industrial discharges (van Vliet et al. 2017). Managing water quality will become the main challenge societies will face during the twenty-first century, as most human activities that use water ultimately produce wastewater (WWAP 2017). Untreated wastewater poses significant risks of diarrhoea, microbial infections, and malnutrition, accounting for 1.7 million deaths annually, of which over 90% are in developing countries and almost half are children (Fig. 12.1) (WHO 2002).

12.1.3 Water Quality Status of Pakistan

Although Pakistan arguably had adequate surface and groundwater resources at the time of independence, population growth, unsustainable urbanisation, and excessive water use has placed stress on quality as well as quantity of water resources in the

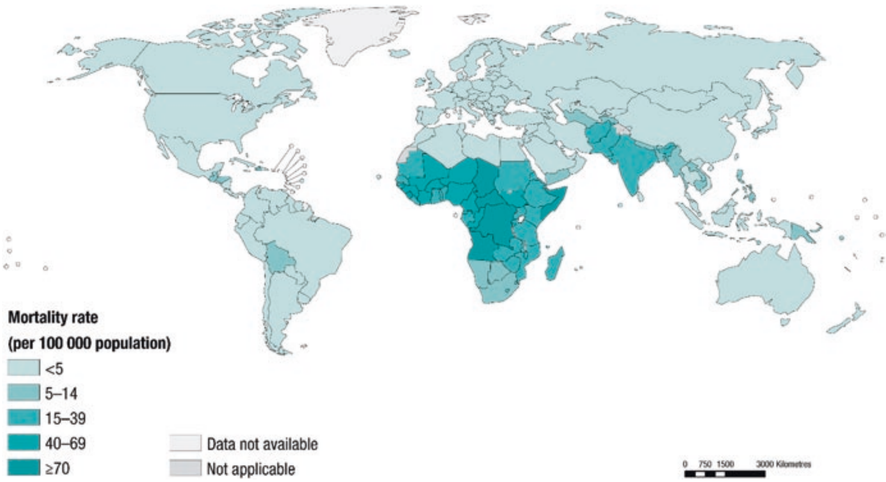

Fig. 12.1 Deaths from unsafe water, sanitation and hygiene (WHO 2016, p. 73). (Reproduced with WHO permission from http://gamapserver.who.int/mapLibrary/Files/Maps/Global_WASH_Mortality_2012.png)

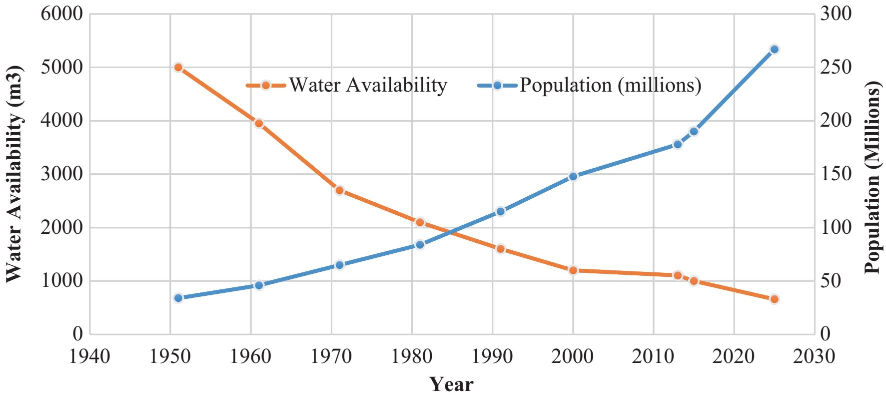

Fig. 12.2 Water availability per capita in Pakistan. (Authors, using data from Jabeen et al. 2015, Table 12.1, p. 1517)

country (Kamran and Omran 2020). Total and per capita water availability is continuously declining in Pakistan (Fig. 12.2). The quality of water is directly related to the quality of human health due to its routine consumption. Most of the population in the country is exposed to the hazards of drinking unsafe and polluted water from both surface and groundwater sources (Daud et al. 2017).

According to UK-based charity WaterAid, providing basic water services in a rapidly urbanising and populous country like Pakistan is extremely challenging – a situation which the charity describes as a crisis (https://www.wateraid.org/pk/the-crisis). Like most developing countries, Pakistan has failed to supply safe drinking water to its citizens resulting in an increase in water-borne diseases. Provision of safe drinking water, sanitation, and hygiene are becoming serious public health issues in Pakistan (Amin et al. 2019). Millions of people in the country have no access to safe drinking water, making Pakistan one of the worst ten countries for people living without safe water (Cooper 2018). Results from various studies showed that the water quality in Pakistan in almost all high-density populated areas and/or sources are not fit for drinking (Podgorski et al. 2017). It is estimated that 21 million people in Pakistan do not have access to safe drinking water (Daud et al. 2017). Moreover, water-borne diseases are the leading cause of mortality in Pakistan especially in infants and children (WHO and UN Water 2017). The Pakistan Council for Research on Water Resources (PCRWR) concluded in their five-year project that 84% of the water samples collected from 23 major cities of Pakistan were contaminated and hence not fit for drinking (Kahlown et al. 2002). This chapter provides an updated overview of water major contamination issues in Pakistan and their impacts on human health.

12.1.4 Major Pollutants in Water Resources of Pakistan and Their Sources

Water pollution can be categorised as point source and non-point source. Point sources are those which discharge effluents into water bodies directly e.g. from industrial units, factories, power plants, etc. Non-point source pollutants mainly come from agriculture run-off, drainage, seepage, etc. In the case of Pakistan, industrial effluents, solid wastes, and agriculture runoff are the major sources of water contamination. Almost 90% of domestic and industrial wastes in Pakistan are dumped into water bodies which can ultimately leach to groundwater (Mustafa et al. 2013). Around 92% of sewage is disposed of untreated and about 50% of human excreta produced in urban areas goes directly into water bodies (Pakistan Economic Survey 2013). These untreated waste effluents not only add toxic contaminants but also result in widespread disease incidents.

Poor living conditions and mismanagement are the main reasons for water contamination. Industrial waste in Pakistan often receives minimal treatment resulting in increased contamination of surface as well as groundwater. For example, Sial et al. (2006) found that of over 6000 industries registered in Pakistan's two largest industrial estates in Karachi, 1228 were highly polluting because they discharged heavy metals, oils, and other contaminants. The Ministry of Environment (2005) reported that 80,000 m^3 of industrial effluents were being discharged directly into the Kabul River posing a serious threat to human health (as cited by Mulk et al. 2016).

The agriculture sector is also another source of pollutants in water bodies in Pakistan, including from agriculture runoff. Agricultural pollutants mainly comprise sediments, pesticides, nutrients, nitrates, phosphorous and heavy metals. Runoff from livestock farms directly into water bodies is also an important contributor to water contamination, a matter of particular concern given that livestock farms can be closely located to populated areas. These point and non-point contaminants make drinking water unsafe for human consumption. As a result, the drinking water quality is deteriorating in both urban and rural areas (Ashraf 2016). Major pollutants prevailing in Pakistan's water resources are discussed in the following sections.

12.2 Status of Microbial Pathogens in Water Resources of Pakistan and Their Health Impacts

The consumption of contaminated water with human and animal faeces in drinking water is a major threat. Pathogenic bacteria, viruses, and parasites are responsible for the most common infectious diseases, as detailed in Table 12.1. One of the main reasons for this type of contamination is the breakdown of water supply safety which leads to large-scale disease outbreaks, especially diarrhoea. While significant efforts have been made to reduce diarrheal diseases, diarrhoea remains a leading cause of global mortality and morbidity, causing an estimated 1,655,944 deaths in

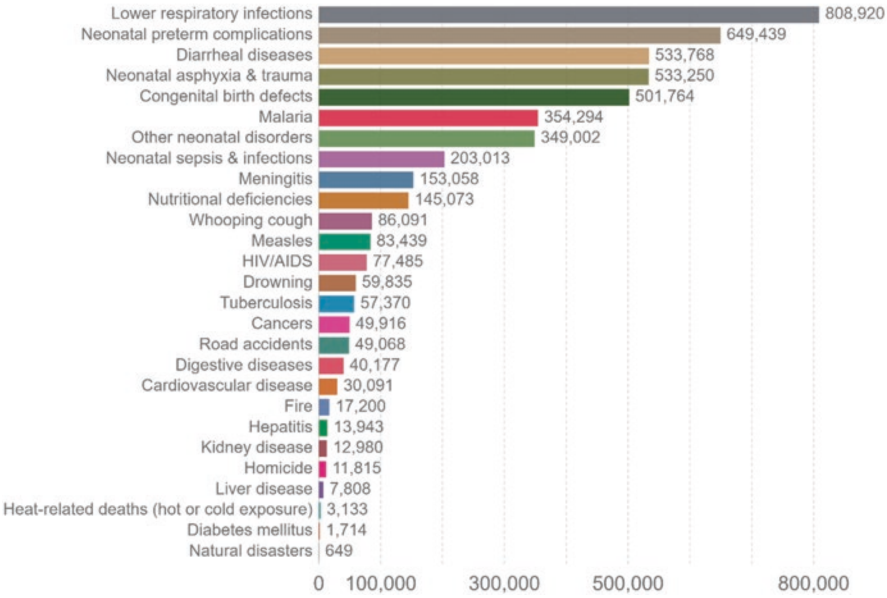

Fig. 12.3 Cause of death globally in children under the age of 5 in year 2017. (Reproduced from Ritchie and Roser (2018) https://ourworldindata.org/causes-of-death)

2016 globally, out of which 533,259 were children under the age of 5 (Troeger et al. 2018, and see Fig. 12.3). These deaths were mainly due to drinking unsafe water. Epidemics caused by waterborne pathogens and health hazards in developing countries are mainly associated with improper management of water resources. Waterborne diseases cost an estimated 12 billion dollars globally (Ramírez-Castillo et al. 2015).

The poor quality of Pakistan's municipal water supply, especially in small towns and rural areas, is due to main sewers being laid at depths of 30–50 feet and are only 10–15 feet away from drinking water supply lines (Arshad and Imran 2017, citing a 2011 conference paper by Benjamin). Their poor management results in contaminated water mixing with drinking water supplies as well as groundwater contamination. Citing a World Bank report, Cooper (2018) also noted that 42% of households in rural Punjab and 60% in rural Khyber Pakhtunkhwa have no drains, and that where drains exist, they are open and managed without treatment. This ultimately increases the risks of water contamination.

Out of different water pollutants, microbial contamination has been regarded as a serious threat to public health in Pakistan. While there are few investigations to determine overall status of microbial pathogens in Pakistan, many individual studies have identified microbial contamination in Pakistan's drinking water (see Table 12.1). Studies conducted in major cities of Pakistan reveal coliform and faecal coliform are frequently found in drinking water (Kahlown et al. 2002). Ahmad et al. (2018) found high levels of enteroviruses in river water samples that had been

Table 12.1 List of pathogens distributed through drinking water with reports confirming their presence in Pakistan

Pathogen	Health Effects	Persistence in water supplies	Disease	Reported in Pakistan	Identified in
Bacteria					
Burkholderia pseudomallei	High	May multiply	Melioidosis	Naureen et al. (2010)	Affected equine
				Shabbir et al. (2015)	Soil samples
				Ali et al. (2017)	Soil samples
Campylobacter jejuni, *C. coli*	High	Moderate	Diarrhoea	Noreen et al. (2020)	Children with diarrhoea
				Nisar et al. (2018)	Retail meat
				Mahmood et al. (2009)	Retail milk
				Kanwal et al. (2019)	Wastewater & bird droppings
Escherichia coli – Pathogenic	High	Moderate	Serious food poisoning, septic shock, meningitis, urinary tract infections	Shah et al. (2016)	Tap water
				Huma et al. (2019)	Children with diarrhoea
E. coli – Enterohaemorrhagic	High	Moderate	Diarrhoea or haemorrhagic colitis	Bano and Ali (2019)	Sewage waste
				Iqbal et al. (2017)	Drinking water
Legionella spp.	High	May multiply	Legionnaires' disease	Zahir et al. (2016)	Dental water flush
Non-tuberculous mycobacteria	Low	May multiply	Non-tuberculous mycobacterial (NTM), lung disease	Iqbal et al. (2016)	Lung disease patients
Pseudomonas aeruginosa	Moderate	May multiply	Pneumonia, urinary tract infections (UTIs), bacteremia	Saleem and Bokhari (2019)	Hospital patients
Salmonella typhi	High	Moderate	Typhoid	Tagg et al. (2020)	Hospital patients
Other salmonellae	High	May multiply	Diarrhoea, stomach cramps, abdominal pain	Yasmin et al. (2019)	Poultry
Shigella spp.	High	Short	Shigellosis	Nisa et al. (2020)	Human faeces

(continued)

Table 12.1 (continued)

Pathogen	Health Effects	Persistence in water supplies	Disease	Reported in Pakistan	Identified in
Vibrio cholerae	High	Short to long	Cholera	Sarwar et al. (2016)	A child
				Hussain et al. (2020)	Tap water
Yersinia enterocolitica	High	Long	Versiniosis	Ullah et al. (2019)	Sheep & goats
				Mengal et al. (2019)	Salad & water
Viruses					
Adenoviruses	High	Long	Common cold, conjunctivitis, bronchitis, pneumonia	Ahmad et al. (2016)	Drinking water
Enteroviruses	High	Long	Poliomyelitis	Ahmad et al. (2016)	Drinking water
				Ahmad et al. (2018)	Drinking water
Hepatitis A	High	Long	Liver disease	Ahmad et al. (2018)	Drinking water
Hepatitis E	High	Long	Liver disease	Butt and Sharif (2016)	Jaundice patients
Noroviruses and Sapoviruses	High	Long	Gastroenteritis	Alam et al. (2016)	Children with diarrhoea
Rotavirus	High	Long	Gastroenteritis	Yousuf et al. (2017)	Drinking water
Protozoa					
Acanthamoeba spp.	High	May multiply	Granulomatous amoebic encephalitis (GAE)	Tanveer et al. (2013)	Drinking water
				Yousuf et al. (2017)	Tap water
Cryptosporidium parvum	High	Long	Cryptosporidiosis	Iqbal et al. (1999) and Khan et al. (2017)	Children with diarrhoea
				Haseeb et al. (2017)	Tap water
				Aslam et al. (2014)	Tap water
Cyclospora cayetanensis	High	Long	Cyclosporiasis	Haseeb et al. (2017)	Tap water

(continued)

Table 12.1 (continued)

Pathogen	Health Effects	Persistence in water supplies	Disease	Reported in Pakistan	Identified in
Entamoeba histolytica	High	Moderate	Amoebic dysentery (bloody diarrhoea)	Tasawar et al. (2010) and Zeb et al. (2018)	Human faeces
				ul Akbar et al. (2014)	Tap water
Giardia intestinalis	High	Moderate	Giardiasis	Tayyab et al. (2017)	Tap water
Naegleria fowleri	High	May multiply	Primary amoebic meningo-encephalitis (PAM)	Naqvi et al. (2016)	Affected patients
				Tanveer et al. (2017)	Drinking water
				Yousuf et al. (2017)	Tap water
Toxoplasma gondii	High	Long	Toxoplasmosis	Khan et al. (2013a) and Ayaz et al. (2011)	Tap water
				Ajmal et al. (2013)	Tap water, food & soil
Helminths					
Dracunculus medinensis	High	Moderate	Dracunculiasis	Eradicated in Pakistan (Shah et al. 2017)	
Schistosoma spp.	High	Short	Snail fever, bilharzia	Asghar (2017)	Livestock

The first three columns are reproduced with permission from Table 7.1 in WHO 2017, p. 119

polluted from sewerage in Lahore (40%), Islamabad (29%) and Rawalpindi (33%). These pathogens are responsible for digestive, diarrheal, liver and kidney diseases, which were among the top ten causes of death during the year 2017 (Fig. 12.4). A study in 2006 found that 20–40% of bed occupancy in Pakistan hospitals was a result of waterborne diseases, and accounted for one-third of deaths (Pak-SECA 2006).

Diarrheal disease is a threat associated with contaminated water, especially in children under the age of five. During the year 2017, diarrheal and digestive diseases associated with contaminated water use accounted for 74,647 and 59,787 deaths respectively in Pakistan in total (Ritchie and Roser 2018, and see Fig. 12.4). Almost 50% of deaths associated with diarrhoea were of children under the age of five from 2007–2017 (Ritchie and Roser 2018, and see Fig. 12.5). Several studies reported occurrence in food products of the kinds of microbial pathogens in Pakistan that cause diarrhoea (e.g. Mahmood et al. 2009; Nisar et al. 2018), while Nisa et al. (2020) identified a link between such pathogens and patients with

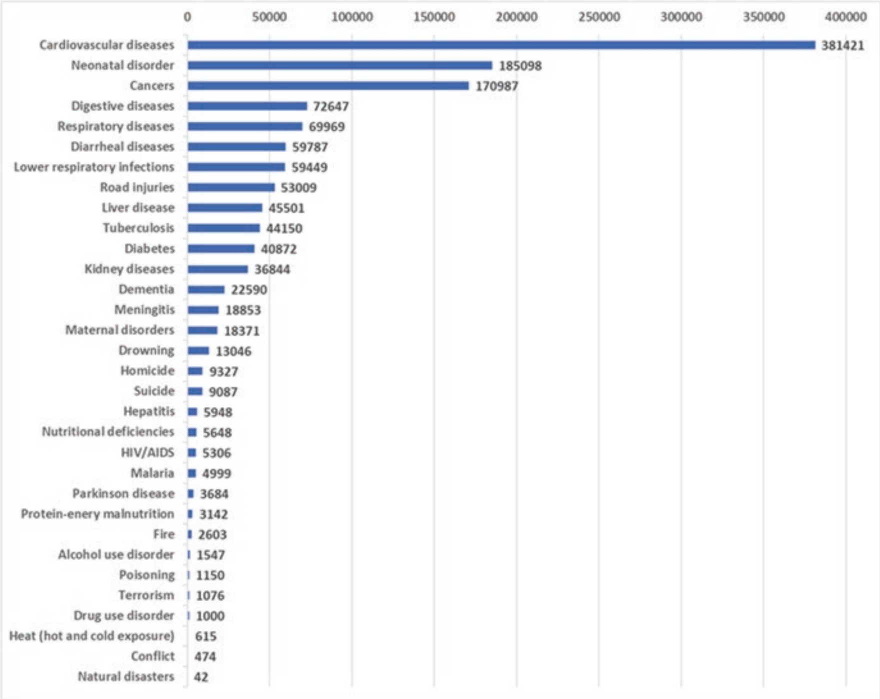

Fig. 12.4 Causes of death in Pakistan during the year 2017. (Reproduced from Ritchie and Roser (2018) https://ourworldindata.org/causes-of-death)

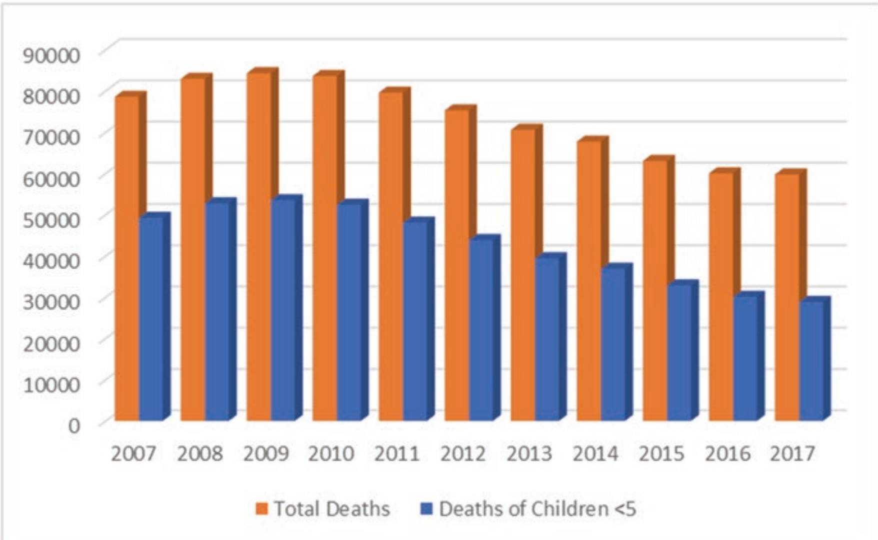

Fig. 12.5 Deaths in Pakistan due to diarrhoea during 2007–17 (Ritchie and Roser 2018)

diarrhoea. The survey conducted by Pakistan Council for Research in Water from 24 major cities found that more than 80% of samples of drinking water were unsafe for human consumption, with most samples positive for coliform bacteria (Ashraf 2016).

Various individual studies conducted in different parts of the country support the findings of PCRWR. Water quality is serious even in Pakistan's main cities. A study conducted in Islamabad found that 14.5% of the water resources in Islamabad did not meet safe limits for microbial pathogens in its drinking water as 21 samples out of 55 were found contaminated with total coliform (Ahmed et al. 2015a). Even microbial contamination was detected in water from filtration plants in Islamabad (Hisam et al. 2014). Similarly, water samples from pumping stations at the twin cities of Islamabad and Rawalpindi were positive for microbial pathogens (Farooq et al. 2008) as were samples taken from food snacks and drinking water in Islamabad schools (Saddozai et al. 2009).

An investigation in a particular riverside community in Lahore found 92% of 50 drinking water samples contained pathogens and were unfit for drinking, with the most common illness in the area being diarrhoea (Qureshi et al. 2011), while another larger sampling of Lahore city as a whole identified 37.2% of 530 samples were unfit due to the presence of microbial pathogens, especially coliform (Anwar et al. 2010). Other Lahore-based investigations revealed similar findings (Hannan et al. 2010; Haydar et al. 2016), with Yousaf and Chaudhry (2013) and Syed et al. (2014) even finding pathogens in bottled water. Other parts of Punjab were also found to have unfit levels of pathogens in drinking water, including Gujrat (Ahmed et al. 2017), Jampur (Rafique et al. 2014), Alipur (Shehzadi et al. 2015), and the Salt Range Wetlands (Ullah et al. 2012). An earlier study involving residents of Gujrat found that 90% of people interviewed suffered from water borne diseases frequently (Tanwir et al. 2003).

Like other big cities of Pakistan, the quality of drinking water is very poor in Karachi. An investigation in five administrative districts in Karachi found that 96% of the samples collected were positive for microbial pathogens, especially total coliform, with a related high prevalence of waterborne diseases: diarrhoea and vomiting, skin problems, malaria, prolonged fever, eye problems and jaundice in that order (Amin et al. 2019). Similarly, an investigation into six of Karachi's filtration plants reported *Acanthamoeba* spp. in 35% of drinking water samples collected (Yousuf et al. 2017). A recent study of drinking water in Sindh schools found around half of samples to be contaminated with *Escherichia coli*, *Shigella* spp., *Salmonella* spp., and *Vibrio cholerae*, and an associated varying risk of infection and illness across the province, with schoolchildren in Karachi experiencing the highest probability of waterborne illnesses (Ahmed et al. 2020).

Water is also not safe in the provincial capital of Khyber Pakhtunkhwa province due to the presence of bacterial pathogens (Nabeela et al. 2014), including in samples taken from drinking water in schools (Ali et al. 2011), and in its surrounding rural areas where 50% of handpump water samples were contaminated with *E. coli* (Ali et al. 2013a). Similar results were found in the province's Hazara division and in the city of Kohat, where high loads of pathogens were found in wells used for drinking, including *Shigella spp*. fecal coliform and *staphylococci* (Muhammad et al. 2017). A prevalence of waterborne diseases was found in Abottabad, north of Islamabad, including diarrhoea, skin infections, typhoid and hepatitis in the urban population (Jabeen et al. 2011), and among students of various academic institutes (Ahmed et al. 2015b). In both cases these illnesses were found to be linked to drinking contaminated water.

The above-mentioned accounts of widespread microbial contamination in drinking water pose a great threat to public health in Pakistan, with digestive diseases and diarrhoea being the fourth and sixth major causes of deaths in Pakistan (see Fig. 12.4). Pakistan has also faced epidemics associated with water-borne pathogens, including an outbreak of drug-resistant typhoid fever in Sindh from 2016 (WHO 2018), and of Hepatitis C, where the estimated 7 million people found to be chronically affected in Pakistan in 2013 represented one-tenth of the global Hepatitis C burden (Lim et al. 2018).

12.3 Status of Toxic Metals in Water Resources of Pakistan and Their Health Impacts

Heavy metals and potentially toxic elements are among the chemicals posing a great threat to humans when present in water (Martin and Griswold 2009). Like microbial contaminations, heavy metals and other toxic elements pose a great threat to the water resources of Pakistan. Heavy metal contamination in surface water and groundwater has increased due to increased population, industrialisation and urbanisation. Because of the grave threats being faced in Pakistan, numerous studies have investigated heavy metal presence in drinking water sourced from both groundwater and surface water. A selection of these studies is summarised in Table 12.2.

Arsenic is a major threat to public health in Pakistan, where many regions have arsenic concentration in drinking water above safe limits (10µg/L) recommended by the World Health Organization (WHO). A meta-analysis of 43 published studies in Pakistan revealed 73% had mean arsenic levels above the WHO limit, and 41% were higher than Pakistan's much less strict limit of 50 mg/L (Shahid et al. 2018b). Podgorski et al. (2017) estimated that 50–60 million people in the Indus Bain use groundwater with a high concentration of arsenic (see Fig. 12.6). Several studies have reported serious health impacts on the human population exposed to high concentrations of arsenic in water in Pakistan (Nickson et al. 2005; Shakoor et al. 2015), including cancer (Wadhwa et al. 2013; Waqas et al. 2017), melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsum, non-pitting oedema, gangrene (Ali et al. 2013b), decrement in lung function (Nafees et al. 2011) and skin problems (Hussain et al. 2016).

Chromium is another threat to the human population in Pakistan and has been reported extensively in Pakistan's water resources (Azizullah et al. 2011), with several studies identifying chromium concentrations above safe limits set by WHO

Table 12.2 Concentration of heavy metals in groundwater used for drinking in selected cities across Pakistan

	Concentrations in groundwater sourced drinking water		
Metal	City	Concentration (μg/L)	References
Arsenic (As)	Jamshoro	13–106	Baig et al. (2009)
	Lahore	5.2–80	Bibi et al. (2015)
	Mailsi	11–828	Rasool et al. (2016a)
	Sheikhupura	40–65	Abbas and Cheema (2015)
	Tharparkar	523–2350	Brahman et al. (2016)
	Vehari	32.5–61.5	Shahid et al. (2018a)
Chromium (Cr)	Karachi	18–145	Ul Haq et al. (2009)
	Kasur	50–9800	Tariq et al. (2008)
	Sialkot	1048-3182	Rafique et al. (2010)
	Swat	244–606	Khan et al. (2013b)
Lead (Pb)	Chitral	0.3–32	ur Rehman et al. (2020)
	Karachi	14–320	Ul Haq et al. (2009)
	Mailsi	10–230	Rasool et al. (2016b)
	Muzaffarabad	ND-665	Ali et al. (2019)
	Zhob	1–63	Chandio et al. (2020)
Nickel (Ni)	Lahore	4–7190	Hussain et al. (2019)
	Sialkot	10–220	Ullah et al. (2009)

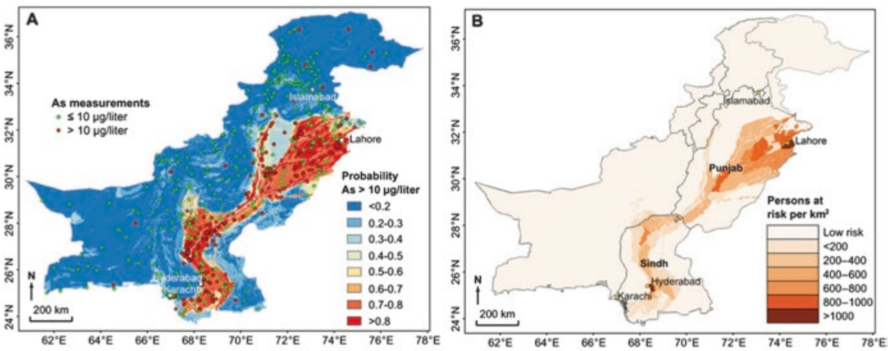

Fig. 12.6 Arsenic prediction and risk models. (**a**) Probability (hazard) map of the occurrence of arsenic concentrations in groundwater exceeding the WHO as guideline of 10μg/litre along with the aggregated arsenic data points used in modelling (n = 743). (**b**) Density of population at risk of high levels of arsenic in groundwater using the WHO As guideline of 10μg/litre. (Reproduced from Podgorski et al. 2017 with permission of American Association for the Advancement of Science (AAAS). © Podgorski et al. 2017, some rights reserved; exclusive licensee AAAS. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC) http://creative-commons.org/licenses/by-nc/4.0/)

(Table 12.2). Hexavalent compounds from chromium cause various diseases including cancer, skin irritations and those associated with the digestive, excretory, and reproductive system (Azizullah et al. 2011). Contact with nickel creates allergic reactions, with WHO recommending safe limits in drinking water being below 20μg/L whereas Pakistan has cases well above these levels (see Table 12.2).

Lead occurs naturally and it is normal to have traces of lead in drinking water. However, anthropogenic activities have led to toxic concentrations of lead in water. In Pakistan lead is often found to be above safe limits recommended by WHO (10μg/L) (see examples in Table 12.2).

The status of heavy metals in water resources of Pakistan is highly variable in concentration and frequency. Poor sanitation, improper management and lack of treatment facilities are major issues which expose the human population to various disease-causing contaminants. In addition to the above-mentioned contaminants, nitrate in groundwater has also been found to be higher than permissible limits, and this can lead to blue baby syndrome in infants (Soomro et al. 2017).

12.4 Impact of Water-Borne Diseases on the Pakistan Economy

Pakistan not only has issues of drinking water contamination with industrial wastes and municipal sewage, but also a lack of water disinfection practices and quality monitoring at treatment plants, which ultimately result in waterborne diseases. Lack of record maintenance in hospitals makes it hard to quantify the burden of waterborne diseases in Pakistan. One estimate of the cost to the economy relates to inadequate sanitation being Rs. 343.7 billion equivalent or 3.94% of the country's GDP (Khalid and Khaver 2019), while another suggests water-linked diseases result in income losses of Rs 25–28 billion annually, or about 0.6–1.44% of the country's GDP (Khwaja and Aslam 2018).

12.5 Environmental Regulations in Pakistan

Pakistan's 1983 Environmental Protection Ordinance established an institution to develop the country's environmental program. This institution later became the Pakistan Environmental Protection Council with environmental protection agencies at federal and provincial levels. Negligence in the implementation of environmental legislation is evident in that it took 10 years to organise the first meeting of the Pakistan Environmental Protection Council after its establishment (i.e. in 1993). After this meeting, the National Environmental Quality Standards (NEQS) were established to develop permissible limits for municipal effluents and industry discharges. It took another seven more years to bring them to the implementation phase. But still, governments were hesitant to implement such laws either due to lack of monitoring capacity or in response to political pressure. After devolution in 2010, the environment became a provincial responsibility. All provinces established a water and sanitation policy but implementation and legislation regarding water safety are still lingering.

Pakistan's National Water Policy was approved in 2018, yet its implementation and shortcomings are still a huge debate between policymakers and stakeholders. There are several challenges related to the financial stability of service delivery organisations in the water sector (Khalid and Khaver 2019). Water supply schemes became dysfunctional as the provincial government did not allocate sufficient resources to their operation and maintenance (World Bank 2016). While laws and regulations on wastewater treatment and disposal have been formulated, the actual problem is the implementation of these laws and regulations due to lack of resources and workforce skills. As a result, their effectiveness in practice, despite the existence of adequate and necessary administrative capacity on paper, is significantly weakened due to these shortcomings.

12.6 Recommended Strategies to Reduce Water-Borne Health Issues

Pakistan requires strategic planning to reduce the health impacts associated with water contamination. Water-borne diseases are a huge burden on Pakistan's economy and the health sector in Pakistan. Pakistan has made significant progress in improving access to safe drinking water and sanitation, with 90% of Pakistan's population having access to safe drinking water (UNICEF Pakistan 2018). However, reality is on the ground, with UNICEF finding that around 70% of households drink contaminated water (https://www.unicef.org/pakistan/wash-water-sanitation-and-hygiene-0).

Another major issue is the sustainability of existing water supply systems in Pakistan, where lack of proper maintenance of pumps and supply systems results in deterioration of supplied water quality. Acute water shortages and unreliable water supply has left communities with little option other than to buy water at high cost or to drink contaminated water, causing an increased disease burden in the country. Another factor is that management and governance of water and sanitation has been allocated through the 18th amendment to provincial councils and corporations, who in turn have devolved responsibility to lower levels of district administration, who have failed to implement policies due to severely limited budgets and capacity (Khalid and Khaver 2019). This makes Pakistan off-track to meet the UN Sustainable Development Goal of universal access to safe water and sanitation services.

Given the gravity of the problem and the level of investment required, a targeted and multi-tiered approach is required to cope with this serious issue. There is an urgent need for national-level actions including allocation of specific public sector budget allocations for safe water supply and sanitation programs. The national government must establish a separate ministry to monitor the progress of provincial governments to improve people's access to safe water, sanitation, and hygiene services. Pakistan's long-term aim must be adequate and safe piped water supply with metering, realistic tariffs and the safe removal of faecal waste away from human settlements.

Pakistan can learn from case studies in other countries where water and sanitation services have been improved (e.g. Salian and Anton 2010). A community-based natural resource management program can help to keep water resources safe from contamination. This can be implemented with the concepts of sanitation improvement, income generation, poverty alleviation, and sustainable resource management. Such an approach can also incorporate ecological sanitation systems, where treated urine and dry faecal matter is used as fertiliser for agriculture and kitchen gardening. This approach can also be combined with composting of organic wastes, rainwater harvesting, use of grey water, thus ultimately reducing the burden of contaminants on the surface as well as groundwater resources.

Agricultural nutrients and other essential elements recovered from wastewater has gained increased attention in recent years (Ye et al. 2020). Countries like Pakistan, which is already importing huge amount of fertilisers, can gain substantial economic return by adopting this technique to treat wastewater. Wastewater contains nutrients essential for human food production (nitrogen, phosphorous and potassium, or NPK) allowing agriculture to reduce its dependence on the use of mineral NPK fertilisers. It has been documented that the rate of phosphorous recovery from wastewater influent plants is 10–60%, from wastewater slug 35–70% and from sludge 70–98% (Cornel and Schaum 2009). Thus, this approach must be implemented in water management policies and strategies at local as well as national levels for economic gain and to keep water resources safe from contamination.

12.7 Conclusion

Water resources in Pakistan are highly contaminated and not fit for human consumption as most of the disease-causing agents are present. Biological as well as chemical contamination is a great threat to human health in Pakistan. One of the main reasons for water quality deterioration in Pakistan is the mixing of sewerage water with drinking water, which results in the occurrence of disease-causing pathogens and chemicals. The second source of water contamination is industrial effluents which introduce toxic chemicals and elements in drinking water resources. Thus, to reduce the impact of water-borne diseases there is a need to upgrade and maintain regular monitoring campaigns from source to end-user levels and strict compliance of the environmental legislation is required to reduce contaminant burden in water resources. Severe economic impacts can be quantified if regular records are maintained in hospitals and diagnostic facilities are improved. The Pakistan Government must conduct comprehensive surveys and continuous monitoring campaigns to assess the severity of water-borne diseases and their possible sources.

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