Chapter 10
Groundwater Crisis: A Crisis of Governance?

Fazilda Nabeel

Abstract This chapter delves into Pakistan's groundwater situation by engaging in a historical case study of the province of Punjab from the colonial to the contemporary period. Drawing on archival research, document analysis and interviews conducted as a part of the author's doctoral research, Punjab's groundwater crisis is analysed to make two key arguments. First, despite Punjab's endowment of surface water, the province is heavily dependent on groundwater for meeting its agricultural, domestic and industrial water demand. Second, in contrast to a conventional narrative that characterises Pakistan's groundwater crisis as one arising from the absence of groundwater governance, this chapter argues that the crisis was brought about by the *very nature of groundwater governance* in this region over time. Through a careful historical analysis of the techniques of groundwater governance in colonial, post-colonial and contemporary Punjab, the chapter highlights the strategic importance of groundwater to achieve Pakistan's development goals, and in turn how this has shaped the nation's approach towards groundwater use and management over time. The paper concludes that the nature of groundwater governance in Pakistan over time has been focused on groundwater exploitation for agricultural expansion and economic development, with little emphasis on sustainable management of the resource.

Keywords Groundwater governance · Governance challenge · Depletion and contamination · Management approaches · Groundwater use

F. Nabeel (✉)
Department for International Development, University of Sussex, Brighton, UK
e-mail: f.nabeel@sussex.ac.uk

M. A. Watto et al. (eds.), *Water Resources of Pakistan*, World Water Resources 9,
https://doi.org/10.1007/978-3-030-65679-9_10

10.1 Pakistan's Groundwater Crisis in the Global Context

Groundwater accounts for about 97% of the available global non-frozen freshwater resources (IGRAC 2015), contributing over 40% of global food production, and 50% of global drinking water requirements (IGRAC 2015). Global groundwater consumption is continuously growing with a 1–3% increase in annual use. Between 1960 and 2000, groundwater use more than doubled, from 312 km^3 to 734 km^3 per year (Fienen and Arshad 2016). Pakistan's dependency on groundwater follows the global trend, increasing from 8% of total irrigation water use in 1960 to 40% in 1996, and reaching 60% in 2006 (Briscoe et al. 2005). While these numbers are averages for the whole of Pakistan, groundwater dependency for irrigation varies considerably across the country based on surface water availability and groundwater quality. In areas where surface water supplies are intermittent or unreliable, groundwater forms up to 80% of irrigation water requirements.

Pakistan has become the fourth largest abstractor of groundwater globally, primarily withdrawing from the Indus Basin aquifer, the second most overstressed groundwater basin in the world (Margat and van der Gun 2013; Buis and Wilson 2015). Groundwater in Pakistan is primarily used for agriculture (94%) with 6% for domestic use and the industrial sector. It provides a buffer against variability in the monsoon rainfall, which occurs for a short period in summer. In 2016, there were 1,385,000 tube-wells in Pakistan, predominantly located in the Punjab province (Ministry of Finance 2019). Existing studies highlight rapidly deteriorating groundwater in some areas of Pakistan, both because the annual rate of abstraction exceeds recharge and because of the rampant contamination of aquifer systems (Wescoat et al. 2000; MacDonald et al. 2016; Raza et al. 2017). To further add to the groundwater crisis, climate change and variability in rainfall affect the recharge of water stored in aquifers, while also leading to an increased demand for groundwater (Taylor et al. 2013). The improvement in well-drilling techniques and tube-well technology has further improved the accessibility of groundwater as a resource. In addition, rapidly proliferating solar pumps have increased the independence of groundwater users, not having to rely on intermittent electricity supplies from the state grid or recurring costs of fuel for diesel-powered tube-wells.

Contamination of groundwater systems from agricultural, industrial and urban sources of pollution creates environmental hazards and risks to life. A principal source of groundwater contamination in Pakistan occurs through secondary salinisation resulting from irrigation. The extent of salinity varies greatly between provinces. Almost half of the farmland in Sindh and Balochistan is affected, while 10% of the farmland in Punjab and KPK is affected by salinity (Zulfiqar and Thapa 2017). Excessive flood irrigation also results in water from the root zone of crops leaching into the groundwater and contaminating underlying aquifers with fertilisers, pesticides and salts. Untreated industrial effluent from water-polluting industries such as textile, leather and several others contains heavy metals such as cadmium, cobalt, copper, mercury, nickel, lead, tin and zinc, which also leaches into the groundwater. Another critical aspect of groundwater pollution in Pakistan is arsenic contamination, which is estimated to affect about 50 million people in the Indus Basin who are at risk of poisoning from the high level of arsenic in the soil (Ravenscroft et al. 2009; Podgorski et al. 2017).

10.2 Growing Dependency on Groundwater: A Case of Pakistan's Punjab Province

Punjab presents an intriguing case to analyse the problem of groundwater governance in Pakistan, not least because the province has the majority of the country's tube-wells. Punjab is also the most populous province, with 53% of the country's population (Punjab Bureau of Statistics 2019), and accounts for 60% of Pakistan's agricultural exports. The province is heavily dependent on groundwater to support its agrarian and industrial economies. In 2014–15, more than three quarters (76.8%) of the total irrigated area in Punjab was dependent on groundwater for irrigation, whether exclusively by wells and tube-wells, or in combination with water from canals (Fig. 10.1).

Despite being the land of five rivers, Punjab, as Pakistan's breadbasket, is the most dependent on groundwater for irrigation compared to other provinces (Young et al. 2019, and see Fig. 10.2). Groundwater is the main irrigation source for Punjab's major agricultural crops, accounting for between two-thirds and three-quarters of total irrigated area for wheat, rice, cotton and sugarcane when taking into account exclusive and conjunctive use of tube-wells (Punjab Bureau of Statistics 2017). In the year 2015–16, an overwhelming 78.4% of the total irrigated areas under wheat was irrigated partially or solely with groundwater sources. Similar statistics for rice,

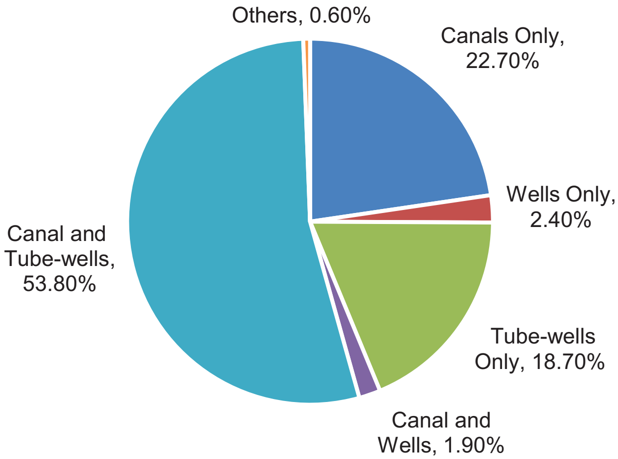

Fig. 10.1 Source of irrigation water in Punjab, Pakistan. (Source: Punjab Bureau of Statistics 2014–2015)

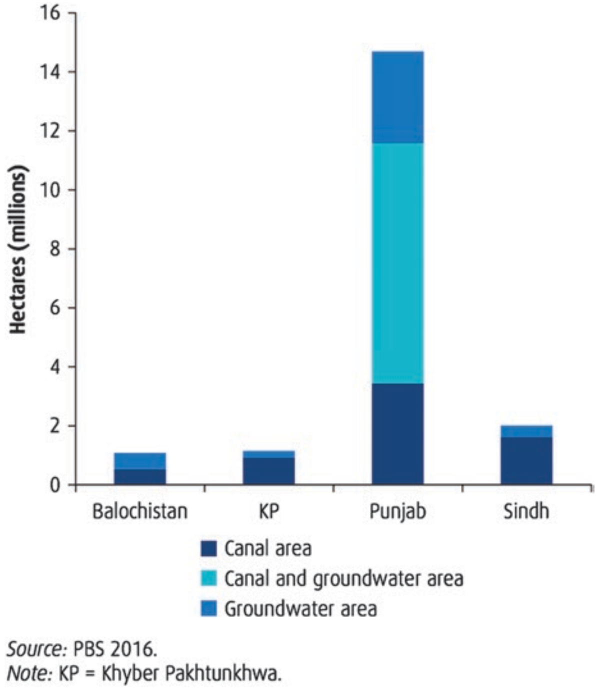

Fig. 10.2 Punjab's groundwater use in comparison to other provinces. (Source: Young et al. 2019, p. 16)

sugarcane and cotton show an overwhelming 88.7%, 69% and 68.6% of total irrigated area was dependent on groundwater irrigation (Punjab Bureau of Statistics 2017).

Punjab's growing dependence on groundwater is partly in response to overall variability and unpredictability in total inflows over time, and partly due to inflexibility in weekly rotations of its distribution at the farm level (Watto and Mugera 2016). Most of Punjab lies within the Indus Basin Irrigation System, which is the largest contiguous surface irrigation system in the world, developed through massive investments in large-scale surface infrastructure under British rule and in the early post-colonial period. Recent studies have shown a significant decline in average annual inflows in the Indus Basin in both the eastern and western tributaries (Cheema 2012; Cheema and Pawar 2015).

The problematic distribution of surface water is a key reason for Punjab's increased dependency on groundwater. Canal water is distributed through the *warabandi* system, which was established under colonial rule to distribute available surface supplies in proportion to farm size in fixed weekly rotations. In practice, the rigidity of the *warabandi* system, bureaucratic corruption and inequitable distribution between head and tail-ends of canals means farmers are increasingly reliant on groundwater pumped through tube-wells for timely access to irrigation water at crucial times in the cropping season (Jacoby and Mansuri 2018; Zardari and Cordery 2009). Since the *warabandi* system was established, cropping intensities have more than doubled from 70 to more than 150% (Shah 2007). Some areas of Punjab's sugarcane-wheat zone support crop intensities of 234% due to groundwater use (Mirza and Latif 2012). This was in particular due to the introduction of high yielding seeds and fertilisers during the Green Revolution of the 1960s.

The 1960 signing of the Indus Waters Treaty also induced a gradual transition to groundwater use. The Treaty was an agreement on the division of the Indus River system following partition between India and Pakistan. Under the Treaty, the three western tributaries of the Indus (Indus, Jhelum, Chenab) were given to Pakistan and the three eastern tributaries (Ravi, Bias and Sutlej) to India. However, the Treaty also gave rights to India for power generation and non-consumptive use on the three western tributaries before they entered Pakistani territory. In the last few decades, intensive hydropower development upstream by India on the western tributaries has substantially reduced downstream flow to Pakistan, thus making users more dependent on groundwater (Mustafa 2010).

Punjab also has a sizeable industrial sector, with more than 48,000 plants that together contribute 24% of the province's GDP (Planning and Development Department 2015). These include water intensive and water-polluting industries such as textiles, leather, pulp, chemicals and light manufactured goods. Pakistan's textile industry contributes 54% of the country's overall exports, with a water footprint of 12,251 million cubic metres of water (Linstead et al. 2015), with a sizeable proportion of the industry located within Punjab. Groundwater is also the main source of drinking and domestic water use for 87% of Punjab's population, with many districts (such as Bhakkar, Gujranwala, Gujrat, Hafizabad, Jhang, Kasir, Mandi Bahauddin, Nankana Sahib, Narowal, Okara, Sheikhupura and Sialkot) entirely dependent on groundwater as their sole source of drinking water (Tahir et al. 2010).

The groundwater crisis in Punjab manifests itself in the form of persistent decline in the depth of the aquifer due to over-abstraction, as well as groundwater pollution due to seepage from agricultural and industrial effluents. According to a recent study, groundwater levels across most of Punjab are falling by 16–55 centimetres per year, with large urban centres such as Lahore experiencing higher depletion rates of 40–150 centimetres per year (Basharat et al. 2015). In parts of Punjab with historically good quality groundwater such as the Rechna Doab, agricultural and industrial activity as well as urban growth has meant that groundwater levels are falling by two to three metres annually. Falling groundwater levels due to over abstraction necessitate deeper drilling to pump from the underground aquifers, thus marginalising poorer farmers due to increased costs of drilling and pumping (Nabeel 2020).

In addition to declining quantity, there is degradation of quality of groundwater resources. Punjab has many of the hotspots where people are at risk of arsenic poisoning (Podgorski et al. 2017), which is especially alarming given groundwater is often the main source and sometimes the only source of drinking water. Pesticide seepage and industrial pollution has contaminated shallow groundwater aquifers

Fig. 10.3 A factory in Sheikhupura that has built unlined wells for the disposal of untreated effluent

with hazardous chemicals and metals. Industries routinely discharge untreated effluent, often via open drains, while those located away from the drainage network find other ‘creative’ ways for effluent disposal. During the fieldwork that informed this chapter, the author found unlined wells or ‘*khuwas*’ being used in Sheikhupura to discharge untreated effluent, which slowly percolated down into the underlying shallow aquifer (see Fig. 10.3). This resulted in severe contamination of groundwater used in adjoining areas, making the water unfit for drinking and even for irrigation. Poor farmers at the tail-end of canals bear a disproportionate burden of polluted groundwater aquifers, as compared to wealthier farmers who often live near the head of canals where plentiful surface water seepage continues to replenish groundwater reserves. This is worrying because farmers at the tail-ends are more dependent on groundwater for their irrigation requirements, as opposed to farmers at the head who have ready access to surface water (Nabeel 2020).

10.3 A Crisis of Governance? Insights from the History of Groundwater Governance in Punjab, Pakistan

Existing studies have identified that groundwater crises result from governance arrangements that are weak (e.g. Faysse et al. 2014) or lacking (e.g. van Steenbergen 1995). These include analyses of the situation in Punjab and Pakistan generally, which have pointed to the absence of or weaknesses in legal, institutional and regulatory policies governing groundwater use, and the need to strengthen these to achieve resource sustainability (Qureshi et al. 2010; Khair et al. 2015; Watto and Mugera 2016). A recent World Bank report also takes a similar view about water governance: "The governance challenges relate to inadequate legal frameworks for water at federal and provincial levels, and the incompleteness of policy frameworks and the inadequacy of policy implementation" (Young et al. 2019, p. xviii). This chapter builds on existing studies, but presents a refined view. Instead of attributing the groundwater crisis due to the absence of, or weak, governance of the resource, the crisis is attributed to the very techniques of groundwater governance occurring in Punjab over time.

The chapter uses a historical analysis of the techniques and mechanisms of groundwater governance from the colonial to the contemporary period to highlight the role of the state in creating Punjab's groundwater crisis. The chapter finds that through each historical period, groundwater is needed for the state to fulfil its developmental goals, and in turn the significance of groundwater shapes the state's approach towards its governance, ultimately leading to the contemporary groundwater crisis. The analysis begins with an overview of groundwater governance in the colonial period (Sect. 10.3.1), before highlighting the role of the state in initiating large scale public groundwater development in the post-colonial period (Sect. 10.3.2), and finally reviewing the mechanisms of governance that drive contemporary governance of groundwater (Sect. 10.3.3). The chapter ends with reflections on significance of groundwater to Pakistan's economy as well as the complex nature of historical groundwater governance that has led to the contemporary crisis (Sect. 10.4).

10.3.1 Colonial Approach to Groundwater Governance

The use of dug wells for irrigation and domestic purposes has been recorded in the Indus Basin as early as the fourteenth century, when access to subsoil water was made possible through the use of the Persian wheel. Babur, the founder of the Mughal Dynasty, made reference to Persian wheels being used in 1519 for irrigation of profitable crops such as rice and sugarcane in Bhera and Khoshab, areas which are part of present day Punjab in Pakistan (Siddiqui 1986). However, the small-scale nature and yield of such irrigation, powered by animals, meant that well irrigation was for the most part managed by individual cultivators. Upon British annexation of Punjab in 1849, the colonial state continued to encourage this form of irrigation through (subsidised) *tuccavi* loans for well construction, a practice that had also been used earlier by pre-colonial rulers.

In the early colonial period, dug wells remained the dominant form of irrigation across the north western provinces of British India, particularly in Punjab and Uttar Pradesh. In the year 1885, about 16% of the total cultivated area in Punjab was irrigated by wells (*chahi*) – whether as the sole source of irrigation or in conjunction with other sources. By comparison, the area irrigated by canals (*nahri*) in Punjab

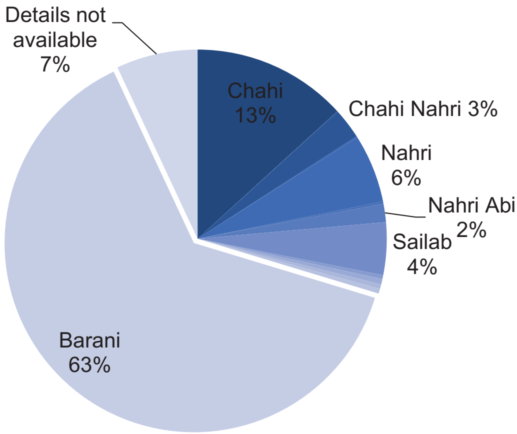

Fig. 10.4 Cultivated area in Punjab by source of irrigation in 1885. (Source: Statistical Abstract Relating to British India, 1885. Area labelled *barani*: rain-fed, *chahi*: well-irrigated, *nahri:* canal-irrigated)

constituted about 11% of the total cultivated area including area irrigated by inundation canals. As shown in Fig. 10.4, most of Punjab's agriculture was still rain-fed *(barani)* until the end of the nineteenth century.

Despite the British Government's efforts to expand the canal network in the latter half of the nineteenth century, groundwater use through wells remained an integral part of the irrigation mix in Punjab, for three key reasons: First, well irrigation was critical for areas not supplied by the canal network. As over half of Punjab's agriculture was rain-fed for most of the nineteenth century, the variability and lack of rainfall frequently led to distressed crop outcomes. The colonial government's construction of large-scale engineered canal works was ambitiously pursued to reduce such fluctuations in output. However, the only areas that benefitted from canal irrigation were those that could be commanded by gravity flow. Canal irrigation was not suitable for upland terrains, areas above canal heads and other areas thought to be inaccessible. Hence wells represented a suitable method to irrigate uplands, and to allow an increased and more flexible allocation of water and cultivation intensity (Ali 1988).

Second, wells provided supplementary irrigation in canal command areas for *Rabi* (winter) crops, when canal flows were inadequate. Well irrigation was particularly crucial for wheat, which was the "most important of all Punjabi crops" occupying up to one-third of total cropped area in the province by the turn of the twentieth century (Annual Report of the Department of Land Records and Agriculture 1908, p. 5). The strategic importance of wheat as an export crop for Britain's global imperial economy underscores the significance of well irrigation for the colonial government at that time. Wheat comprised 4 per cent of the value of exports out of the province in the year 1900, with United Kingdom being the top recipient of the produce (Statistical Abstracts Relating to British India 1899–1900).

Third, well irrigation had been declared as a form of 'protective irrigation' under the evolving colonial irrigation policy, helping to prevent famine in times of drought (Report of the Indian Famine Commission 1880). The devastating outcome of periodically occurring famines in British India, such as the ones that occurred in Madras in 1877–78, had compelled the colonial government to look towards encouraging forms of irrigation that would serve to "prevent" famines, rather than incurring expenditure on post-famine relief efforts. In British Punjab more than half of the cultivated area was rain-fed until the end of the nineteenth century, making the fate of agriculture highly dependent on rainfall distribution. Well irrigation (together with perennial canals) provided a resilient means of irrigation during times of droughts when other methods such as tanks and inundation canals would "dry up" (Danvers 1877).

It is interesting to chart the colonial approach to groundwater governance, which evolved over the course of British rule from the mid-nineteenth to mid-twentieth century. Until the early twentieth century, apart from its role to provide 'protection', groundwater was primarily a small-scale method of irrigation managed by individual cultivators, at their own expense, in areas not supplied by canals or for use as supplementary irrigation during winter months. Mechanisation and tube-well technology at the turn of the twentieth century showed promise of increased yield of groundwater for irrigation. The freedom from dependency on animal power to extract groundwater allowed by tube-wells meant that groundwater was no longer to be limited as a small-scale means of irrigation. This enabled the colonial government to consider large-scale sponsorship of public tube-well schemes in Punjab, not just for agriculture but also for municipal water supply. It represented a paradigm shift in the colonial government's approach towards groundwater, enabling the government to charge tube-well users for groundwater, in a manner similar to irrigation dues paid by users of canal irrigation.

From the beginning of the twentieth century, the colonial state used a two-pronged approach to groundwater development: (a) activities supporting farmers to enhance yields of existing dug wells by mechanically deepening them; and (b) exploring technological and economic feasibilities of private and public tube-well irrigation schemes. The colonial state offered expertise on both fronts through the Punjab Department of Agriculture's Engineering Section in the first half of the twentieth century. The colonial state also incentivised uptake of tube-wells by private cultivators by encouraging them to cultivate government wasteland through installation of tube-wells (Ali 1988). Tube-well installation subsequently became a pre-condition for granting of tenure – lessees were required to construct tube-wells as a part of the lease obligations.

Despite the colonial state's efforts to promote groundwater exploitation and uptake for irrigation, groundwater irrigation did not achieve a breakthrough by the end of the colonial rule. Part of the reason lay in the broader political economy situation during British rule – the two World Wars, budgetary constraints, and high prices of obtaining imported materials for tube-well boring and installation stymied the progress in groundwater development. Also, because cultivators had to bear (subsidised) costs of installation of wells and tube-wells, the high prices and lack of availability of materials during war years deterred the demand for groundwater irrigation. Another important set of factors hindering groundwater development despite the colonial state's intent concerned the difficulty in achieving a breakthrough in generating hydroelectric power for running tube-wells. The availability of low cost hydroelectric power was critical to improving the economic feasibility of tube-wells as opposed to higher cost diesel-powered pumps. In addition, technical issues with tube-well technology and high maintenance expenses deterred farmers from installing tube-wells for groundwater irrigation (Punjab Department of Agriculture 1938).

Notwithstanding the limited success of tube-well irrigation during colonial rule, the colonial state's policies towards groundwater development have left lasting impacts on the way the resource is governed in the region. In particular, the legal and administrative changes in the governance for groundwater brought about during the colonial period completely re-configured the groundwater-society dynamic in Punjab, sowing the seeds for the explosive growth in post-colonial use of groundwater, and in many ways contributing to the current crisis. In the pre-colonial period, the rights to sub-soil water were largely customary, arising from local social relations, kinship and "tradition", and usually determined by the share of investment in jointly owned wells within communities. This system of customary rules governing groundwater rights, along with social and economic relations at the village level were studied by the colonial administration and carefully recorded in village administration papers called "*shart wajib-ul-arz*".[1] The shares in investment of jointly constructed wells determined precisely when each shareholder's bullocks had to be yoked and unyoked at certain times of the day to allow the cattle for another shareholder to draw water for irrigation (Gilmartin 2015). In 1882, groundwater rights were formally tied to private property rights over land after passing of the Indian Easements Act based on common law principles of England (Gilmartin 2015, p. 109). According to the Easements Act, owners of land have the right to "collect and dispose within his own limits of all water under the land which does not pass in a defined channel and all water on its surface which does not pass in a defined channel" (Indian Easements Act 1882, Section 7). The change in legal entitlement to water meant that those who held titles to the land could sell their property rights to land and water without consideration of others in the community (Singh 1991). These changes, along with parallel improvements in mechanisation improving the volume and ease of groundwater extraction, meant that groundwater was effectively rendered as a resource that could be extracted to a cultivator's desire, without consideration or dependency on others in the community.

Despite the colonial state's policies and strong intent to pursue large-scale groundwater development in Punjab, it could not be materialised by the eve of independence in 1947. As the next section will illustrate, it was only after independence and the creation of Pakistan that large-scale state-owned schemes sponsored by international agencies such as USAID and the International Bank for Reconstruction and Development were established. Though these 'public tube-wells' were initially installed with the intention to alleviate the problem of waterlogging and salinity, within a decade there was a rapid and concomitant rise in installation of private tube-wells by individual cultivators as tube-well technology became commonplace and tube-wells started to be manufactured locally. The explosive growth of

[1] The *shart wajib ul arz* regulated the management of the village commons or *shamilat* in the villages ranging from cultivation of *shamilat* by proprietors and tenants, grazing rights by proprietors and non-proprietors of the village, the use of wells, the right to plant and cut trees in the *shamilat*.

tube-well irrigation, accompanied by the availability of high-yielding variety of seeds, fertilisers and mechanisation of agriculture, led to the post-colonial ‘Green Revolution’. Yet, in many ways, the post-colonial approach represented continuity in the prior colonial approach to groundwater governance, as detailed in the next section (Sect. 10.3.2).

10.3.2 Post-colonial Groundwater Development

After the partition of the Indian subcontinent and independence from British Rule in 1947, the newly established state of Pakistan sought to invest in public groundwater development to fulfil three key objectives: (a) to increase water availability for food self-sufficiency and reduction of foreign exchange spent on imported grains; (b) to relieve waterlogged and saline soils which had rendered about a quarter of West Pakistan’s area uncultivable at the time; and (c) to enhance the agricultural growth rate for its predominantly rural-based economy.

Pakistan’s first decade after independence was politically and economically unstable. In the early 1950’s, the economy was provided with a temporary boom during the Korean War due to increased demand for jute products from East Pakistan (now Bangladesh). After the end of the Korean War, the decline in foreign exchange earnings in Pakistan and unfavourable monsoons led to a shortage of food, medicine and essential consumer goods. This was resolved with the help of foreign aid by bringing in food grains as well as aid from development programs. In the country’s first five-year national development plan period, Pakistan had to pursue extensive import of food grains, consuming a significant $700 million in foreign exchange, in addition to freight charges paid on food grains received as aid.

The partition of the subcontinent in 1947 also involved a separation of both land and water resources across the Indus Basin. In the aftermath of the Indus Waters Treaty of 1960 that divided the surface waters of the Indus, the Pakistani state sought to replenish water ‘lost’ to India by constructing massive diversion works for water from the western rivers to the fields that the eastern rivers formerly irrigated. The Indus Basin Development Fund made this possible, which was a financial agreement between Pakistan, the World Bank and a group of capitalist states including Australia, Canada, New Zealand, UK and USA (Akhter 2015, p. 70). The Indus Basin Project was the largest integrated irrigation project in the world at the time, with funding of about $1200 million (Michel, 1967).

On one hand, Pakistan struggled with the need to secure its share of surface waters of the Indus, while on the other hand the growing problem of waterlogging and salinity presented a sizeable constraint for agricultural growth and the problem of food security. Groundwater levels and the loss of land to waterlogging and salinity had been recognised as a growing problem even under colonial rule as early as 1908 when the first comprehensive survey of water table in the Chenab colony was conducted. However, even as the colonial government sought to understand and ameliorate the problem by propagating the value of tube-wells as a vertical drainage solution, there was "little progress" on the issue of waterlogging by the eve of independence in 1946 (Gilmartin 2015, p. 237).

After independence, a series of programs were initiated by the Pakistani government to control waterlogging via vertical tube-well drainage, but with inconclusive results, perhaps because of the limited scope of these scattered projects (Johnson 1989, p. 2). The Rasul Scheme, originally proposed as a tube-well irrigation and drainage scheme by the colonial government in 1927, was finally sanctioned in 1944. The scheme had been delayed first because of jurisdictional issues of where the power supply would come from, then because of financial stringency during World War 2, and finally due to chaos created by the partition. When the project was finally functional, it was deemed a 'failure' (Michel 1967, p. 460). In addition to the Rasul scheme, the 495 tube-wells installed in the Chaj Doab were so close to the canals that, rather than relieve waterlogging, they accelerated seepage. Most of the 762 tube-wells installed in the Rechna Doab failed or declined in yield due to blockage of strainers and incrustation (when deposits of carbonates build up on well strainers).

After a series of lukewarm efforts at ameliorating waterlogging and analysing prospects for groundwater development by the newly independent Pakistani state, it was international expertise and financial assistance that came to the rescue and initiated large-scale groundwater development in Pakistan. In 1953, the Pakistani government reached an agreement with the predecessor of USAID for "technical assistance in soil and water resources investigation" initiating the "West Pakistan Groundwater Survey" nicknamed "Project 035" whose immediate objective centred on the "the provision of soils and water data essential for agricultural development, improved irrigation, salinity control, and land reclamation in West Pakistan" (Taylor Jr 1976, p. 87). As a result of Project 035, a Pakistani counterpart for managing project activities was established as the Groundwater Development Organisation (GWDO) within the West Pakistan Department of Irrigation. GWDO was later transferred to West Pakistan Water and Power Development Authority (WAPDA) in 1960 where it was reorganised in the form of Water and Soils Investigation Division (WASID).

The production of knowledge resulting from Project 035 in the form of soil data and maps, water table maps and hydrographs, exploratory well logs, water quality analysis and maps and technical reports eventually fed into the design and construction of the first Salinity Control and Reclamation Program (SCARP 1) in 1961, a pilot project in the Chenab colony funded by a low interest American loan. The SCARP program's logic was simple and something that had been advocated as a solution to waterlogging and salinity even in the colonial period – installation of public tube-wells for vertical drainage that would lower the water table, while providing additional water for irrigation. The West Pakistan Water and Power Development Authority (WAPDA), an institution created to manage the construction of surface infrastructure under the Indus Basin Plan, was also given charge of designing, monitoring and implementing the public tube-well programs drawing on the advice of many foreign consultants readily assigned to the project (Michel, 1967).

This was a time immediately after the signing of the Indus Water Treaty of 1960 when foreign donors committed huge sums of money to construct dams and barrages on the western rivers allocated to Pakistan as compensation for the loss of water from the eastern rivers allocated to India under the treaty. The post-treaty Cold War environment provided the perfect opportunity for the then President Ayub Khan of Pakistan to visit the US to lobby for more funding highlighting his "concern with waterlogging and salinisation which threatened the future of Pakistan's agriculture" (Taylor Jr 1976, p. 89). President Kennedy responded by appointing a special scientific presidential panel headed by Richard Revelle, the then Science Advisor to the US Secretary of Interior. The knowledge products from the Revelle Report led to a massive expansion of SCARP programs in the 1960s and 1970s. With up to 15,000 state owned and managed tube-wells, this was the most comprehensive response to the issue of waterlogging and salinity in Punjab ever attempted. These public tube-wells were usually installed at the head of a tertiary water channel, thus supplementing and compensating for irregular canal water supplies to village watercourses (Gilmartin 2015, p. 239).

The investment in public tube-wells through SCARP Projects was consciously planned by the state, but the parallel growth of private tube-wells mushroomed almost unnoticed until a survey was done in 1964. In 1950, the Department of Agriculture reported only 177 private tube-wells, all of which had been installed with assistance from the Department from 1939 onwards (Johnson 1989, p. 1). In subsequent decades, private tube-wells had a greater share than public ones in increasing the role of groundwater in overall irrigation mix. By 1996, there were about 300,000 private tube-wells, most of which were in Punjab. Groundwater accounted for 8% of total irrigation water in 1960, rising rapidly to 40% in 1996 and reaching 60% in 2006 (Briscoe et al. 2005). As seen in Fig. 10.5, the province of Punjab led the private tube-well "revolution" in Pakistan.

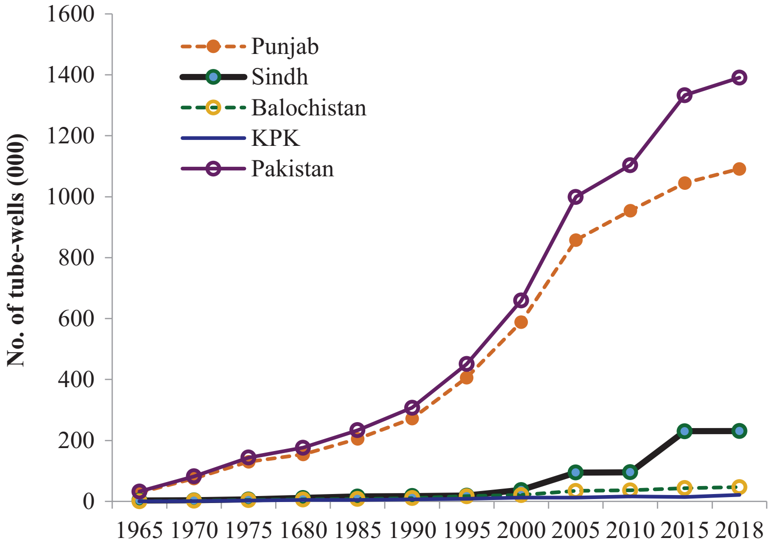

Fig. 10.5 Private tube-well growth in the post-colonial period. (Source: FWM 2019)

Most accounts of private tube-well development in Punjab document it as a silent revolution often attributing its phenomenal growth to the individual incentives of the rational farmer (Watto and Mugera 2016; Molle et al. 2003). While the improved economic feasibility of tube-wells in the post-colonial period improved their uptake, the analysis in this section suggests that the techniques of formal governance of groundwater played an active role in bringing about this breakthrough in tube-well irrigation. The Pakistani state offered subsidies for private tube-well construction, power connection, drilling, and electricity tariffs during the 1960s and 1970s as incentives to increase cropping intensity and to fulfil targets for agricultural growth (Government of Pakistan 1978). During this period, a tube-well construction subsidy was given to small and marginal farmers on tail-ends of canals and rain-fed areas, in addition to a separate subsidy on connection to the electricity grid, as well as a subsidy on drilling costs. A diesel subsidy of 20% was also introduced in 1972, benefiting farmers with diesel-operated tube-wells. By April 1979, the scheme supported 11,500 tube-wells at a total cost of Rs. 132 million (Anson 1984, 34). Agricultural tube-wells extended a subsidised electricity rate of 0.35 per kilowatt per hour, compared to non-agricultural customers who paid 66% more than the subsidised rate. Apart from direct subsidies, the Agriculture Development Bank of Pakistan (ABDP) provided institutional credit for private tube-well development. Between 1964 and 1981, the total number of tube-wells increased from 23,000 to 186,000, with an average increase of 9500 tube-wells each year. ABDP's loans contributed to an approximate 20% of the tube-well units installed each year within this period (Anson 1984, p. 135).

Perhaps farmers would have invested in private tube-wells even without the subsidies. However, state subsidies clearly indicate the state's intent to harness groundwater resources for agricultural production and economic growth. Another reason for subsidising and incentivising private tube-well development was the high operation and maintenance costs of the public tube-well SCARP program. It was evident within the first few years of operation that the SCARP tube-wells suffered from persistent problems with the design, maintenance, and high operating costs, as well as staff absenteeism of public tube-well operators. In addition, the institutional coordination between the Federal Government, WAPDA, foreign consultants and provincial governments during project life did not play out well. WAPDA, together with consultants, was responsible for planning, design and construction of SCARP tube-wells, after which these were handed over to the provincial irrigation departments for maintenance. The provincial irrigation departments found themselves to be ill-equipped to handle the maintenance of public tube-wells both from expertise and budgetary perspectives. Thus, as early as 1965, merely 5 years from the start of the SCARP program, the Government of Pakistan had started encouraging private tube-well development in its official development plan:

> Construction of private tube-wells has been accelerating rapidly and is now estimated to be running at 6500 per year, of which two thirds are diesel-operated. The rapid development of private tube-well now requires a new tactic – a strategy of public-private development. It is

> proposed to give private tube-wells every assistance in the form of imports, credit and electrical connections. With such assistance, some 40,000 new tube-wells can be expected during the plan period (Government of Pakistan 1965, p. 294).

While SCARP tube-wells had strong operating and maintenance issues during the 1970s, the government assisted private tube-well development programs were doing quite well at the time. Up to 1982–83, a subsidy of Rs. 211.6 million had been given to farmers against which 19,433 private tube-wells have been installed. In the Sixth Five Year Plan, an additional Rs 102 million were to be allocated for private tube-well subsidy for installation of 8195 additional private tube-wells, the majority of which were to be located in Punjab (Government of Pakistan 1983). In the Eighth Five Year Plan it was decided that no new public tube-well program would be initiated in fresh groundwater zones. From then on, SCARP tube-wells to alleviate waterlogging and salinity would only be installed in saline groundwater zones after the 1990s (Government of Pakistan 1983), and soon afterwards the existing SCARP tubewells were also ushered into a World Bank sponsored privatisation program. The Pakistani state's subsidies for groundwater irrigation are an important part of the explanation of the post-colonial "tube-well revolution" in Pakistan. This was accompanied by concomitant efforts at improvements in tube-well technology and rural electrification after the construction of the Tarbela dam.

The centralised development of groundwater through publicly owned and operated tube-wells, and the private groundwater boom that followed suit, considerably transformed the post-colonial groundwater-society dynamic. Perhaps the most profound effect of the state's intervention in development of centralised groundwater schemes was the demonstration effect to the farmers. Public tube-wells transformed the way society valued groundwater. Whereas private tube-well development had been repeatedly found to be economically unfeasible by adopters in the colonial period, technological improvements and the availability of the locally made pumps transformed this relationship in the post-colonial period.

Many of the legacies of colonialism inherited by the post-colonial state had of course contributed to the boom in atomistic tube-well development. As discussed in the previous section, the legal rights to groundwater defined in the colonial period held groundwater entitlement as linked to rights to private properly over land. Treating groundwater as a private resource linked to rights over land, with little or no state oversight, effectively meant that the only cost to using groundwater was the cost of pumping it from the ground. While the cost of pumping groundwater was higher than the fixed *abiana* farmers paid for their canal water allocation, they did not have to wait for their turn to get water to irrigate their crops. The lack of flexibility in surface water supplies, and the on-demand nature of private groundwater pumps, meant farmers were willing to invest, leading to the private pump boom.

10.3.3 Historical Contingency and the Contemporary Groundwater Governance Problem

Techniques and mechanisms of formal governance of groundwater in the colonial and post-colonial period have been instrumental in the making of Punjab's current groundwater crisis. While governance mechanisms towards groundwater have changed between historical periods, formal governance of groundwater has consistently focused on exploiting groundwater for agricultural expansion, as this chapter has shown. For the colonial state, tube-wells were promoted as an additional means of irrigation, especially for areas not served by canals and for important winter crops such as wheat. In the post-colonial period, the loss of productive land to waterlogging led the state to carry out large-scale public groundwater development, serving twin objectives of increasing the water budget for agricultural intensification and relieving waterlogging and soil salinity. The post-colonial state also offered sustained incentives and subsidies that eventually led to a revolution in Punjab's private tube-well uptake. This section shows how, even in the contemporary period, state policies indirectly incentivised increasing dependence on groundwater as surface water supplies become more unpredictable. Further, the section highlights how the legal entitlement to groundwater and the institutional responsibility for its management is currently muddled because of the blend of old and new institutions and laws created by successive policy regimes.

Contemporary groundwater governance in Punjab indirectly incentivises groundwater overexploitation for agricultural and industrial use. The agricultural sector has held strategic importance for Pakistan and Punjab's economy during the historic past as well as in the contemporary period. Keeping in mind the importance of the rural electorate that comprises nearly half of the total population, successive political governments have subsidised agricultural inputs such fertilisers, pesticides, tube-wells, tractors and improved seeds (Dorosh and Salam 2007; Pursell et al. 2011). In the contemporary period, the agriculture sector contributes about 21% to the country's GDP, but employs 45% of the labour force, and contributes a staggering 80% to Pakistan's export earnings (including forward linkages to agro-based industries such as textiles) (Ministry of Finance 2018). Wheat, rice, cotton and sugarcane are key crops for Pakistan's economy, accounting for two thirds of the total cropped area in Pakistan and contributing one-third to the total agricultural GDP (Ministry of Finance 2018). As has already been pointed out, between two-thirds and three-quarters of the area under these crops is irrigated by groundwater, whether exclusively or conjunctively with canal water. What is even more worrying is the very low water use efficiency of these crops, with 80% of the country's water being used to generate less than 5% of its GDP (Ministry of Finance 2018). In addition to the heavy water footprint of major agricultural crops, livestock production (dairy, poultry, sheep and goats), accounting for nearly half of the agricultural GDP, is also water intensive. State policies have incentivised the uptake of water intensive crops, and subsidised farm inputs that increase water requirements such as fertilisers, both historically as well as in the contemporary period. For instance, the fertiliser subsidy is the single largest subsidy in the total subsidies budget, with wheat and sugar subsidies falling at the second position (Government of Pakistan 2017). Rice, another water intensive crop, is Pakistan's second largest export commodity, and yields the government about $2 billion in foreign exchange annually (The Express Tribune 2017).

Favourable wheat and sugar subsidies benefit capitalist interests of ruling political elites, particularly sugar mill owners in Pakistan. Cotton growing districts in Punjab such as Rahim Yar Khan, Bahawalpur and Multan have documented a shift in cropping pattern towards growing sugarcane because of the artificially inflated support price of sugar, despite the heavy water requirement of the crop (Arif Nadeem, Former Secretary for Agriculture Punjab, pers. comm., 2017). The crop water requirement for sugarcane is almost double the requirement for cotton; hence the recent expansion in the area under sugarcane, and the concomitant decline in the area under cotton, is bad news for groundwater over abstraction (Ebrahim 2020). Pakistan's sugarcane production is highly water inefficient, having the second highest total water footprint in the world compared to the world average, with 69% of the total sugarcane growing in Punjab province (Scholten 2009). In addition to price support mechanisms for primary produce, the government supports key water intensive agro-based export sectors of textile, leather, sports goods, surgical goods and carpets through its "zero rated regime" (The News 2017). Pakistan's government has also made efforts to increase exports of highly water intensive halal meat to gulf countries and to China (Dawn Newspaper 2018). It is estimated that the total water footprint of beef can be up to six times the water footprint of rice.[2] Agricultural and economic policies place considerable emphasis on water intensive agribusiness production and export, facilitating allocation of precious groundwater resources based on users' ability to extract.

Thus, the state's techniques for groundwater governance in the contemporary period have largely drawn on a mix of state subsidies and trade policy incentives – policies that have over time made Pakistan emerge as the top groundwater exporter in the world (ahead of the United States and India) (Dalin et al. 2017). Dalin et al. (2017) show that about 11% of global non-renewable groundwater use for irrigation is embedded in international food trade, of which two-thirds are exported by Pakistan, USA and India alone. For Pakistan, the cultivation and export of crops such as rice account for a major share of the non-renewable groundwater use.

The rise of powerful agro-industrial corporate interests in contemporary Punjab's increasingly globalised economy are also shaping groundwater governance processes in the later post-colonial and contemporary period. Notwithstanding the significance of agriculture to Pakistan's economy, industry is an equally important sector with a 21% contribution to the country's GDP (Ministry of Finance 2017). While the contribution of industry to GDP is similar to that of agriculture, official estimates suggest that industrial water use is "negligible" or between 1 and 2% of

[2] Beef requires the most water, at 1847 gal./lb., followed by sheep at 1248 gal./lb. Chicken at 518 gallons of water per pound. Milk by itself uses only 122 gallons of water per pound. Rice requires an average of requiring 299 gallons of water per pound of processed rice. (www.waterfootprint.org)

total water use while agriculture consumes more than 90% (Basharat et al. 2015). These official government estimates of industrial water use (which is not currently metered or measured in Punjab), and the consequent corporate water footprint, are questionable in the light of other studies. A recent WWF Pakistan study estimates the total blue, green and grey water footprint of four key industrial sectors of Punjab (textile, leather, sugar and paper) to be 30,000 million cubic metres annually. This represents a significant water requirement when put in perspective of total Indus river flows (Linstead et al. 2015). While this study does not isolate groundwater footprint from overall water footprint, these estimates are indicative of the water intensive nature of Pakistan's agribusiness and manufacturing industries.

The legal apparatus of the state for groundwater governance is a critical part of the governance puzzle, with contemporary legislation on groundwater based on colonial law and a jumble of post-colonial amendments. As noted above, the most decisive historical change in legal entitlements to groundwater was brought about by the colonial state in the Indian Easements Act, which tied groundwater entitlement to property rights over land. The post-colonial Pakistan state issued a series of legal provisions to support groundwater management, but none of the post-independence legislation around groundwater has been fully or consistently implemented (van Steenbergen and Gohar 2005). The Punjab Soil Reclamation Act of 1952 set up a Soil Reclamation Board to control problems of waterlogging and salinity that affected fertile lands in the newly independent country. The key responsibilities of the Soil Reclamation Board also included issuing licenses to landowners to install private tube-wells for the pre-determined land reclamation areas. However, the Board was suspended after a few years, with these responsibilities shifting to the provincial irrigation departments. After the establishment of WAPDA under the Pakistan Water and Power Development Authority Act (1958), the responsibility for groundwater development and monitoring rested with WAPDA under the World Bank sponsored SCARP programs.

There is also confusion between federal, provincial, and local responsibility for groundwater governance between various levels of government. Water management falls under provincial jurisdiction in Pakistan, though it can be developed and regulated by two federal bodies - the Council of Common Interests and the Water and Power Development Authority (WAPDA). The Water and Power Development Authority Act of 1958 gives the federal body a mandate to develop water resources in Pakistan with consent from the provinces. In the provinces, the control over groundwater, pollution, and overexploitation lies with the respective provincial irrigation departments. In principle, local governments in rural and municipal areas also have the right to regulate the use of private water sources and tube-wells for drinking water (Local Government Ordinance 2001). However, this mandate of the local government impinges on the rights of property granted by the Indian Easements Act of 1882, which effectively grants unchecked private ownership of the common pool groundwater resource flowing under the land to which one has ownership rights. Further, a 2006 Amendment to the Canal and Drainage Act of 1873 allows the provincial government to intervene in case of groundwater overexploitation. In practice this provision has hardly been deployed by provincial governments, implying little recognition or effort on the part of the government to counter groundwater depletion.

The recently passed Punjab Water Act of 2019 stipulates radical changes in the way entitlements to use groundwater are administered. According to the Act, a 22 member Punjab Water Resources Commission controls surface water resources, water in lakes or reservoirs, water in drains, *as well as groundwater resources* (Punjab Water Act 2019) (http://punjablaws.gov.pk/laws/2743.html). Thus, the Act makes the Commission responsible for conserving, "controlling" and allocating effectively all the water resources in Punjab. For groundwater use, this specifically means that the Commission has the authority to issue licenses for abstraction and disposal of groundwater for agriculture, domestic, industrial and mining purposes. The implications of the recent legislation for groundwater users or the groundwater crisis are not clear yet. It is not clear how the state will set up a system of licensing and abstraction for the sustainable use of the resource under the new law, which awaits implementation.

10.4 Implication for Water Policy and Groundwater Governance in Pakistan

The chapter has analysed the historical importance of groundwater using a case study of Punjab province in Pakistan over the last 150 years to emphasise how groundwater has supported the state's developmental goals in each period. The analysis underscores groundwater's critical contribution to colonial hydrology and the post-colonial Green Revolution, and presents compelling evidence on groundwater's role in Punjab's contemporary water intensive export economy. It highlights how throughout Punjab's history groundwater has helped to fulfil critical development objectives, in turn shaping governance policies that incentivised exploitation of the resource. The chapter shows how governance techniques and mechanisms have focused on groundwater exploitation for agricultural expansion. Whether in an effort to control waterlogging by vertical drainage or as a supplementary source of irrigation, groundwater has been critical in doubling cropping intensities from the colonial to the contemporary period. State policies over time have been instrumental in transforming the groundwater-society relationship in Punjab. Large scale public tube-well development in the post-colonial period changed the way the society valued groundwater, paving the way for the explosion in private tube-well investments. At the same time, the combination of agricultural subsidies in both the post-colonial and contemporary periods mean that the dependency on tube-well irrigation is deeply entrenched. The character of state policies towards groundwater so far has been focused on groundwater exploitation to foster economic development, without groundwater sustainability concerns.

By highlighting the indispensable historical contribution of groundwater to Punjab's economy, the chapter demonstrates why there needs to be a higher policy priority on groundwater conservation. In the contemporary scenario, the water resources policy debates in Punjab (and Pakistan) are dominated disproportionately by surface water development, primarily the need to increase storage by the construction of dams on western tributaries of the Indus in a race against upstream India. Securing transboundary surface waters shared with India, and the use of the rivers as issues of 'national security' has placed an overwhelming pressure on successive governments to prioritise surface water infrastructure development, especially given the context of mounting development and population pressures. While there has been recent recognition of groundwater overexploitation, and a mention of the need for sustainable groundwater management in the country's first ever national water policy in 2018, there has been little follow up in terms of implementation. This chapter focuses on the historical analysis of the importance of groundwater for the region's development, and an emphasis on its current role as the major contributor to the agro-industrial economy, thus emphasising the need to focus on groundwater conservation. Incorporating historical analysis into groundwater policy will bring attention to the legacies of colonialism and the contribution of post-colonial policies and programs by the state embedded in specific political economy issues of each era. This chapter has highlighted the many ways in which the current groundwater crisis in Punjab is historically contingent on the colonial approach to groundwater governance. The techniques of groundwater governance used in the colonial period – particularly the legal, administrative and institutional changes – have left behind strong legacies for post-colonial and contemporary governance approaches. An appreciation of the history of groundwater development and the role of state in Punjab will also lead to an appreciation of the blend of old and new institutions created by successive governance regimes. This will bring attention to the need to clearly demarcate responsibilities for groundwater between various levels in the state – federal, provincial, local – as well between institutions at the same level.

The chapter also highlights the need for reviewing and engaging with the production of knowledge around groundwater. The dominant rhetoric in most technical and policy studies is to blame the traditional agriculture sector as "inefficient" and "wasteful". At the same time, industrial water use is deemed as negligible, and multinational companies are increasingly advertising their water use efficiency by subscribing to international standards of water efficiency such as the Alliance for Water Stewardship (AWS) and Sustainable Rice Partnership (SRP). It is worth noting that subscription to international standards of water efficiency can merely represent a "greenwashing" of operations for many businesses, while making little difference to the actual water footprint. There is a need to engage in critical knowledge production to review and measure industrial water use in order to effectively manage demand for sustainable groundwater development.

This chapter does not make the usual recommendations for groundwater policy and governance in Pakistan. It also refrains from defining conceptions of what "good" groundwater governance is, in order to appreciate its complex and messy nature. The experience of other countries dependent on groundwater illustrates that there is no magic formula that "works" for sustainable groundwater management (Mukherji and Shah 2005). Hence the analysis in this study does not emphasise a particular approach to groundwater governance over another. Rather the aim is to bring to light how Pakistan's experiences with various techniques of governance have actively contributed to the contemporary groundwater crisis. Perhaps the implementation of the Punjab Water Act 2019 and the control of groundwater by the state will be decisive for the governance trajectory of this resource. It is also possible that little will change on ground, as the reality of countries like Mexico and Spain that have re-centralised the ownership of groundwater to be controlled by the state shows. Pakistan first needs to unpack and put its policies and legislation concerning groundwater into careful implementation, before we find out the impact of these on the suitability of this precious resource.

References

Akhter M (2015) The hydropolitical cold war: the Indus Waters Treaty and state formation in Pakistan. Polit Geogr 46:65–75. https://doi.org/10.1016/j.polgeo.2014.12.002

Ali I (1988) The Punjab under imperialism, 1885–1947. Princeton University Press, Princeton. https://doi.org/10.1515/9781400859580

Anson R (1984) Public and private tube-well performance: emerging issues and options. World Bank. http://documents1.worldbank.org/curated/en/648291468287749149/pdf/multi-page.pdf

Basharat M, Sultan SJ, Malik AS (2015) Groundwater management in Indus Plain and integrated water resources management approach (IWASRI Publication No. 303). International Waterlogging and Salinity Research Institute (IWASRI), Lahore, Pakistan

Briscoe J, Qamar U, Contijoch M et al (2005) Pakistan's water economy: running dry. World Bank, Washington, DC

Buis A, Wilson J (2015) Study: third of big groundwater basins in distress. NASA, Washington, DC. https://www.nasa.gov/jpl/grace/study-third-of-big-groundwater-basins-in-distress

Bureau of Statistics Punjab (2017) Punjab development statistics 2017. Bureau of Statistics, Planning and Development Department, Government of Punjab. http://bos.gop.pk/developmentstat

Bureau of Statistics Punjab (2019) Punjab in figures 2019. Bureau of Statistics, Planning and Development Department, Government of Punjab

Dalin C, Wada Y, Kastner T, Puma MJ (2017) Groundwater depletion embedded in international food trade. Nature 543(7647):700–704. https://doi.org/10.1038/nature21403

Danvers FC (1877) A century of famines, being particulars of all famines that have visited India since the year 1770 and an inquiry as to the best means of providing against them. IOR/V/27/830/15. India Office Records and Private Papers, British Library, London

Dawn Newspaper (2018, June 4) Meat exports begin to grow again. https://www.dawn.com/news/1411794

Department of Land Records and Agriculture (1908) Annual report, Punjab Department of Land Records and Agriculture. India Office Records and Private Papers, British Library, London

Dorosh PA, Salam A (2007) Distortions to agricultural incentives in Pakistan. World Bank. http://documents.worldbank.org/curated/en/155531468313744488/pdf/560780NWP0PK0v1UBLIC10Pakistan10508.pdf

Ebrahim Z (2020) Pakistan abandoning cotton for water guzzling sugar cane. The Third Pole. April 9. https://www.thethirdpole.net/2020/04/09/pakistan-sugarcane/

Faysse N, Errahj M, Imache A et al (2014) Paving the way for social learning when governance is weak: supporting dialogue between stakeholders to face a groundwater crisis in Morocco. Soc Nat Resour 27(3):249–264. https://doi.org/10.1080/08941920.2013.847998

Fienen MN, Arshad M (2016) The international scale of the groundwater issue. In: Jakeman A et al (eds) Integrated groundwater management: concepts, approaches and challenges. Springer, Cham, pp 21–48. https://doi.org/10.1007/978-3-319-23576-9_2

FWM (2019) Federal Water Management Cell. Ministry of National Food Security and Research, Islamabad

Gilmartin D (2015) Blood and water: the Indus River Basin in modern history. University of California Press, Oakland

Government of Pakistan (1965) The third five year plan 1965–70. WAPDA Library, Lahore

Government of Pakistan (1978) The fifth five year plan 1978–83. WAPDA Library, Lahore

Government of Pakistan (1983) The sixth five year plan 1983–88. WAPDA Library, Lahore

Government of Pakistan (2017) Federal Budget 2017–18: Budget in Brief. Finance Division, Government of Pakistan, Islamabad. http://www.finance.gov.pk/budget/Budget%20in%20Brief%202017-18.pdf

IGRAC (2015) Transboundary aquifers of the World Map 2015. International Groundwater Resources Assessment Centre (IGRAC, UNESCO-IHP, Delft. https://www.un-igrac.org/resource/transboundary-aquifers-world-map-2015

Jacoby HG, Mansuri G (2018) Governing the commons? Water and power in Pakistan's Indus Basin. World Bank policy research working paper no. 8351. https://doi.org/10.1596/1813-9450-8351

Johnson RL (1989) Private tube well development in Pakistan's Punjab: review of past public programs/policies and relevant research. IIMI Country Paper Pakistan No. 1, International Irrigation Management Institute (IIMI), Colombo

Khair SM, Mushtaq S, Reardon-Smith K (2015) Groundwater governance in a water-starved country: public policy, farmers' perceptions, and drivers of tubewell adoption in Balochistan, Pakistan. Groundwater 53(4):626–637. https://doi.org/10.1111/gwat.12250

Linstead C, Sayed AH, Naqvi SA (2015) Water footprint of key industrial sectors in Punjab Pakistan. WWF-Pakistan, Lahore http://67.222.34.53/wsp/pdf/WFK_industrialSector.pdf

MacDonald AM, Bonsor HC, Ahmed KM et al (2016) Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. Nat Geosci 9(10):762–766. https://doi.org/10.1038/ngeo2791

Margat J, van der Gun J (2013) Groundwater around the world: a geographic synopsis. CRC, Boca Raton

Michel AA (1967) The Indus Rivers: a study of the effects of partition. Yale University Press, New Haven

Ministry of Finance (2017) Pakistan economic survey 2016–17: agriculture. Ministry of Finance, Government of Pakistan http://www.finance.gov.pk/survey_1718.html

Ministry of Finance (2018) Pakistan economic survey 2018–19: agriculture. Ministry of Finance, Government of Pakistan. http://www.finance.gov.pk/survey/chapters_18/02-Agriculture.pdf

Ministry of Finance (2019) Pakistan economic survey 2018–19. Ministry of Finance, Government of Pakistan. http://www.finance.gov.pk/survey/chapters_19/Economic_Survey_2018_19.pdf

Mirza GM, Latif M (2012) Assessment of current agro-economic conditions in Indus Basin of Pakistan. In Proceedings of international conference on water, energy, environment and food nexus: solutions and adaptations under changing climate, Lahore, Pakistan. 4–5 April 2012

Molle F, Shah T, Barker R (2003) The groundswell of pumps: multilevel impacts of a silent revolution. Paper presented at the ICID Asia regional workshop, Taipei, Taiwan, November 10-12

Mukherji A, Shah T (2005) Groundwater socio-ecology and governance: a review of institutions and policies in selected countries. Hydrogeol J 13(1):328–345. https://doi.org/10.1007/s10040-005-0434-9

Mustafa D (2010) Hydropolitics in Pakistan's Indus Basin. US Institute of Peace, Washington, DC

Nabeel F (2020) Political ecology of groundwater governance in Pakistan's Punjab. Unpublished thesis, University of Sussex, Brighton UK

Planning and Development Department (2015) Punjab growth strategy 2018: accelerating economic growth and improving social outcomes. Planning and Development Department, Government of Punjab, Lahore

Podgorski JE, Eqani SAMAS, Tasawar K et al (2017) Extensive arsenic contamination in high-pH unconfined aquifers in the Indus Valley. Sci Adv 3(8):e1700935. https://doi.org/10.1126/sciadv.1700935

Punjab Department of Agriculture (1938) Report on the operations of the Department of Agriculture, 1938/39–1940/41. IOR/V/24/11. India Office Records and Private Papers, British Library, London

Punjab Water Act (2019) This Act was passed by the Punjab Assembly on 20 November 2019; assented to by the Governor of the Punjab on 10 December 2019; and was published in the Punjab Gazette (Extraordinary), dated 13 December 2019, pages 2507–2529

Pursell G, Khan A, Gulzar S (2011) Pakistan's trade policies: future directions. IGC working paper 11/0361. International Growth Centre (IGC), London School of Economics and Political Science, London

Qureshi AS, McCornick PG, Sarwar A, Sharma BR (2010) Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan. Water Resour Manag 24(8):1551–1569. https://doi.org/10.1007/s11269-009-9513-3

Ravenscroft P, Brammer H, Richards K (2009) Arsenic pollution. Wiley-Blackwell, Oxford doi: https://doi.org/10.1002/9781444308785

Raza M, Hussain F, Lee J et al (2017) Groundwater status in Pakistan: a review of contamination, health risks, and potential needs. Crit Rev Environ Sci Technol 47(18):1713–1762. https://doi.org/10.1080/10643389.2017.1400852

Report of the Indian Famine Commission (1880) Part I, Famine relief. IOR/L/E/6/12, File 551. India Office Records and Private Papers, British Library, London

Scholten W (2009) The water footprint of sugar and sugar-based ethanol. Thesis report, Department of Water Engineering and Management, Univerity of Twente, Enschede, The Netherlands. http://essay.utwente.nl/58701/1/scriptie_W_Scholten.pdf

Shah T (2007) The groundwater economy of South-Asia: an assessment of size, significance and socio-ecological impacts. In: Giordano M, Villholth KG (eds) The agricultural groundwater revolution: opportunities and threats to development. CABI, Wallingford, pp 7–36

Siddiqui IH (1986) Water works and irrigation system in India during pre-Mughal times. J Econ Soc Hist Orient 29(1):52–77. https://doi.org/10.1163/156852086X00036

Singh C (1991) Water rights and principles of water resources management. Indian Law Institute, New Delhi

Statistical Abstract Relating to British India (1885) Nos. 27–30. IOR/L/PARL/2/291. India Office Records and Private Papers, British Library, London

Statistical Abstract Relating to British India (1899–1900) Nos. 31–34. IOR/L/PARL/2/292. India Office Records and Private Papers, British Library, London

Tahir MA, Rasheed H, Imran S (2010) Water quality status in rural areas of Pakistan. PCRWR publication no. 143-2010. Pakistan Council of Research in Water Resources (PCRWR), Islamabad

Taylor GC Jr (1976) Historical review of the international water-resources program of the US geological survey 1940–70. United States Government, Washington, DC

Taylor RG, Scanlon B, Döll P et al (2013) Ground water and climate change. Nat Clim Chang 3(4):322–329. https://doi.org/10.1038/nclimate1744

The Express Tribune Rice (2017, February 1) Exporters: commerce minister promises 50% subsidy for brand promotion. https://tribune.com.pk/story/1313170/rice-exporters-commerce-minister-promises-50-subsidy-brand-promotion/

The News (2017, May 18) Govt assures exporters zero rating regime for 5 major sectors. https://www.thenews.com.pk/print/205036-Govt-assures-exporters-zero-rating-regime-for-5-major-sectors

van Steenbergen F (1995) The frontier problem in incipient groundwater management regimes in Balochistan (Pakistan). Hum Ecol 23(1):53–74. https://doi.org/10.1007/BF01190098 van Steenbergen F, Gohar S (2005) Groundwater development and management. In: Briscoe J, Qamar U (eds) Pakistan water economy running dry – background papers. Oxford University Press, Oxford

Watto MA, Mugera AW (2016) Groundwater depletion in the Indus Plains of Pakistan: imperatives, repercussions and management issues. Int J River Basin Manag 14(4):447–458. https://doi.org/10.1080/15715124.2016.1204154

Wescoat JL, Halvorson SJ, Mustafa D (2000) Water management in the Indus Basin of Pakistan: a half-century perspective. Int J Water Res Dev 16(3):391–406. https://doi.org/10.1080/713672507

Young W, Anwar A, Bhatti T et al. (2019) Pakistan: getting more from water. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/31160

Zardari NH, Cordery I (2009) Water productivity in a rigid irrigation delivery system. Water Resour Manag 23(6):1025–1040. https://doi.org/10.1007/s11269-008-9312-2

Zulfiqar F, Thapa GB (2017) Agricultural sustainability assessment at provincial level in Pakistan. Land Use Policy 68:492–502. https://doi.org/10.1016/j.landusepol.2017.08.016