Irrigation in the Indus basin: A history of unsustainability?

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Abstract The Indus basin civilization (3000–1500 BC) is thought to have collapsed due to the Indus river shifting its course, and unchecked salinization of the irrigated land. Though modern irrigation practices in the Indus basin do not have to worry about the river shifting its course, a priority concern should be the basin’s salt profile. Despite attempts to deal with the problem since the 1960s, the net result is still an increasing salt balance which threatens the system’s sustainability. This paper explores what it means to manage risk, and then applies these insights to a narrative history of the Indus basin. Particular focus is placed on the basin’s current management since it will shape how irrigation is managed in the future. A key lesson to derive is that given the short-term nature of decision-making in the basin, any significant change has to address the political reality whereby politicians exert influence over water allocations in order to safeguard their political lives.

Keywords Indus basin; irrigation; risk; salinity; sustainability

Introduction

A key feature of irrigation is its expansionist tendencies. Countries that rely on irrigation for their agricultural production, and economic growth, tend to want to maximise their ability to reap the benefits by expanding the area under irrigation. Most development loans for irrigation focus on increasing the irrigable area by capturing and delivering more water to more land. Although it is understandable that countries want to maximise their agricultural and economic returns, the emphasis on increasing irrigated area is often detrimental to productivity in the long term. This is because they are focusing on irrigation’s positive results, and ignoring its negative consequences – waterlogging and salinization. Given many countries’ dependency on irrigated agriculture, it would appear foolhardy to ignore the system’s inherent risks. Yet, it is common for countries to do so.

Whilst the productivity benefits of irrigation are well established, there has long been an awareness that the advantages come at a price (Mulcahy, 1983). Questions about the sustainability of irrigation practices have been raised (e.g. by Khan et al., 2006) and a re-evaluation of irrigation’s cost-benefit balance has been called for by Hillel and Vlek (2005), who ask, ‘is irrigation sustainable, and if so, where, how, and under what conditions?’

The Indus basin has a long history of irrigation stretching back more than 4000 years to the Mohenjodaro and Harappa civilizations. Does the existence of irrigation for so many years in the Indus basin mean that the system has found a way to deal with the risks inherent in irrigation? This paper will explore this question by first examining what it means to manage risk, and then apply the approach to the Indus basin’s history. Particular interest will be paid to current management since its actions will shape how the basin’s irrigation will be managed in the future.
Managing risk

The risk management literature (e.g. Balamir, 2002; Hensgen et al., 2003; Elsubbaugh et al., 2004) tells us that every system has some inherent risk of failure that will threaten its sustainability. Therefore, it is wise to tackle this risk upfront before a failure occurs, in order to ensure the system’s longevity. However, most systems are managed in ways that ignore these risks, and tend to be caught off-guard when an event causes a breakdown. Risks are often ignored because short-term benefits are traded off against problems that may happen in the future. As time passes and the system functions without a crisis occurring, people begin to believe that the system is infallible and fall into a ‘blissful ignorance’. This ignorance may be a deliberate construct in which managers refuse to acknowledge that risks exist, or an unintended result of a lack of knowledge.

When a crisis does occur, the response is often reactive, dealing only with the immediate causes of the event rather than a full evaluation of the underlying issues and tackling of the accompanying risks. Consequently, the system is ‘managed’ in such a way that it lurches from crisis to crisis until it fails altogether. In some cases the events that signal system failure are not specific issues but actions that wear the system down over time. If we take this notion that every system carries, as part of its make-up, its own risk of failure, it would suggest that irrigation systems also carry inherent risks.

Irrigation is essentially about controlling the amount of time soil is in contact with water. Being able to control this interaction at will leads to considerable positive benefits vis-à-vis a society’s ability to develop agricultural products. In agricultural societies this has implications for their economic and social stability and longevity.

Irrigation also has negative consequences that usually stem from excessive use of water over time – waterlogging and salinization (Postel, 1992). This is aside from the environmental and social impacts arising from the infrastructure needed to control the water used for irrigation. The primary cause is inadequate drainage. If excess water cannot drain away from the soil once it has been applied, it collects below the surface, raising the water table over time, making the soil waterlogged. Since mineral salts are present naturally in soil and water, the application of water increases the amount of salts being applied to the soil. If the water remains stagnant in the soil, when it evaporates, salts leach out causing salinization. Natural salinity is called primary salinity, whereas salt increases due to human intervention is called secondary salinity (Prathapar et al., 2005). In both cases, the irrigated area is eventually unable to support agriculture. (A related issue is the amount of water applied to the soil to begin with. If less water is applied, less needs to be drained away).

Irrigated agriculture is a major human activity that leads to secondary salinity of land and water. The risk from waterlogging and salinization is that irrigated land will be driven out of production, threatening the system’s sustainability. Approximately 25 percent of irrigated land worldwide is currently salt affected to the extent that agricultural productivity is impaired, with 223,000 ha going out of production each year altogether (Prathapar et al., 2005). An obvious consequence, if left unchecked, is the collapse of irrigated agriculture. Depending on a society’s reliance on irrigated agriculture, this could also lead to societal collapse.

Managing this risk means developing an irrigation system that applies only the water needed for crop production to the soil, and has good drainage to take excess water away (Michel, 1972). However, the focus is often on maximising economic returns on large investments as quickly as possible by concentrating on storage and distribution of water to kickstart agricultural production. Even though effective drainage will underpin the system’s longevity, it is often postponed until the land’s productivity is severely damaged. This is usually for two reasons: (i) like storage and distribution networks,
Drainage is expensive and a government facing budgetary constraints will usually prefer to concentrate on infrastructure that will yield tangible economic results; and (ii) it takes time for the consequences of poor drainage to emerge, and political decision-making timeframes are much shorter.

In order to explore how the development of irrigated agriculture is often pursued despite rather than in full knowledge of the risk profile, we turn to an historical case study. The following section traces the history of irrigation in the Indus basin as a precursor to drawing out those aspects of irrigation practice which compromise sustainable food production and damage local ecosystems.

**Sustaining irrigation in the Indus basin**

In Pakistan, the Indus basin (with its five major tributaries – Sutlej, Beas, Ravi, Chenab and Jhelum) today houses over 140 million people and contains two million farms. It also contains the largest contiguous irrigation system in the world with 16 million ha receiving approximately 172 km³ of high quality river water annually (Prathapar et al., 2005). Despite lacking a continuous history of irrigation in the Indus basin, we know that it is one of the oldest agricultural production systems in the Indian subcontinent. Annual floods have shaped agricultural development for more than 4000 years. Pastoralism was the main form of livelihood due to space and unreliable rainfall.

Changes to the dominant way of life came with technical innovations that increased water availability, and have been vital to the region’s agricultural history (Gilmartin, 1994). The people of the Indus basin prospered on with an agricultural system that capitalised on the river’s silt-bearing floods which sustained irrigation and soil fertility (Hawkes, 1973). Wheat and six-row barley were grown, as were melon seeds, oil crops like sesame and mustard, and dates (petrified dates have been found in archaeological excavations in the valley). As for vegetables, the only apparent source was the field pea.

The earliest traces of cotton known anywhere in the world have been found in the valley (Wheeler, 1976).

**Mohenjodaro and Harappa period (Indus civilization)**

Based on excavations in the early twentieth century, it emerged that the Indus civilization had two main centres that are located in today’s Pakistan. Harappa in the province of Punjab, and Mohenjodaro in Sindh. Harappa was an urban centre in the second millennium BC, on an old bed of the River Ravi (a tributary of the Indus). It provided the first clues of the ancient Indus Valley civilizations. The Harappa culture was part of a continuing evolution of the Vedic culture which had developed on the banks of Saraswati river. Harappan urban form, with its characteristic grid pattern, has also been correlated with various other functional requirements of a city, such as drainage, sewage disposal and transport systems. The city’s economy was thought to rely on trade and agriculture. A variety of crops were grown including grain (Wheeler, 1976).

Located next to the Indus river, Mohenjodaro is probably the best known Indus Valley site. Here a great bathhouse, uniform buildings and weights, hidden drains and other hallmarks of the civilization were discovered in the 1920s. Almost all houses had a form of bathroom with a pipe leading down either into storage jars or cisterns or into covered brick street sewers. The sewers had manhole covers, and sometimes flowed into storage pits. It is not known where the waste eventually wound up, but these cities would have been far cleaner than almost any before the modern period. From the excavations, indicating their strong economies, it is evident that the civilizations were powerful and advanced (Wheeler, 1976: 76–9).
Nearing the end of the Indus civilization, the cities began to wither and their strong economies slowly deteriorated. Though it is unknown what actually ended the civilizations, a number of factors are thought to have contributed. Their society suffered as a result of a series of floods and droughts, and from the River Indus changing its course. Wheeler suggests that intermittent floods would have wiped out the irrigation system that supplied water to the crops, and destroying many of the buildings. As the irrigation system deteriorated over time, so would have social order resulting in the cities falling into disrepair and increasing more vulnerable to attack. If it is true that the Aryans invaded the Indus Valley when the civilization was waning, it would explain the ease with which they were able to vanquish and drive people out of the area. Possehl (1997) questions previous hypotheses including Wheeler’s floods and proposes that there was no general collapse or eclipse, just a process of de-urbanisation and shift eastwards of the population. Other hypotheses concerning the collapse of the early Indus civilizations have proposed eco-disasters arising from overexpansion of population causing deforestation and agricultural abuse (Saier, 2004). Though the exact nature of the civilizations’ demise remains unknown, the vibrancy of their agricultural production systems was clearly dependent on irrigation.

**Mughal period**

There is a gap in the history of irrigation in the Indus basin. Wescoat (1991) describes how canal systems were developed in Kashmir during the 8th century, and in Punjab and Sind during 13–16th centuries. The introduction of the Persian wheel in the later periods increased the ability of people to draw larger amounts of well water using animal power. As agricultural production increased, it encouraged large-scale migration and settlement in central Punjab. Similarly, as inundation canals were built they influenced local agricultural production. The availability of more controlled crop watering means opened areas that could be independent of the rivers’ floods.

Inundation canal building during this period went beyond technical innovation, and was linked to the political imperatives of power. As the Mughal empire declined in the late 18th and early 19th centuries, local rulers used inundation canals to consolidate their own power. Brief periods of large scale irrigation were punctuated by military conquests, court intrigues and frequent political restructuring. During periods of instability and decentralisation, well irrigation was used. By the mid-1800s, the only significant canal irrigation was provided by small inundation canals serving the floodplain areas along the Sutlej river, and the middle and lower Indus river. Well-fed irrigation was predominant mainly in the foothills where the water table was within 100 feet of the surface (Michel, 1972). As in the Indus civilization, irrigation was also important to the Mughal empire and its socio-economic structures.

**British period**

The British conquered Sind and Punjab provinces in the 1830s and 1840s. Punjab was formally annexed in 1849, when they began to transform irrigation practices using new technology. British irrigation policy prioritised returns on investments, and protection against famine. From the 1850s onwards, British canal building took on a distinctive political and ideological significance with the aim of strengthening imperial control, and rewarding allies (Gilmartin, 1994, 2003). With the Indus’ heavy silt-bearing load, irrigation development had to clear the silt annually to keep the canals operational. When statute labour (chher) was outlawed in 1870, the Sind provincial government realised that 25 percent of its revenue would be needed to pay for labour to clear the canals annually (Gilmartin, 1994). Despite the large operational costs, the British continued with their
expansion of the irrigation systems. In the 1880s, interlinking irrigation canals were constructed that would eventually make millions of acres accessible for agricultural production, and settlement (Table 1).

**Pakistani period**

By 1995, the net irrigated area, nationally, was 17.2 million ha, with 80 percent of arable land irrigated. Many parts of Pakistan use fixed scheduling to provide water – the quantity is consistent, and the timing pre-determined (Sarwar and Perry, 2002). Called the land of five (punj) rivers (ab), the Punjab, understandably has the largest concentration of irrigation in Pakistan. Groundwater currently provides over 40 percent of total crop water requirements in the densely populated province, which produces 90 percent of Pakistan’s food. Surface irrigation and drainage problems have stimulated massive groundwater development involving hundreds of thousands of public and private tube wells. The number of wells in Punjab alone has increased from barely a few thousand in 1960 to half a million in 2000 (Shah et al., 2003). The Tarbela dam, which was completed in the mid-1970s and is a significant storage and electricity generator, is already silting up. With increasing water and power demands there is growing pressure for the government to build more dams (Westcoat, 1991). Yet, with the heavy silt-loads of the Himalayan rivers, it is questionable how long any new dams will remain productive. Despite its nuclear armoury, Pakistan’s economy remains largely agrarian and heavily dependent on a sustained irrigated system.

**A history of unsustainability?**

As described above, although it is unclear why the early Indus Valley civilizations collapsed, there is evidence for both river bed migration and salinization being contributory factors. Our primary focus hereon, however, is to trace more recent history which illustrates an inability to manage the risk highlighted in our opening section. Pursuing the benefits provided by water (primarily irrigation) has increased the system’s overall vulnerability to shock. There is little doubt that irrigation in the Indus basin has disturbed the hydrologic equilibrium between recharge and discharge of groundwater (Prathapar et al., 2005). Seepage from the canals, distributaries and watercourses, and deep percolation from irrigated lands have increased the natural recharge rates.

Several authors (e.g. Michel, 1972) have pointed out that modern irrigation technology was used without anticipating its ecological impact, and that communities are now paying the price. British rule focused on extending the command area so that new regions could be settled and taxed, creating a granary in the Punjab to offset famine elsewhere in British India, and increasing cotton production in Sindh. Cropping patterns at this time were dominated by cash-crops – wheat and cotton which spread water thinly. Sugarcane production was limited, and rice discouraged until the water tables rose.

As early as 1859, waterlogging and salinization were apparent close to the Western Jumna Canal in the Ganges basin, however, it was not until 1925 that the problem was given wider recognition with the Waterlogging Enquiry Committee’s establishment. Yet, rather than attributing the problem to irrigation, other infrastructure that interfered with surface runoff was seen as responsible. It was also suggested then that the Punjab was

**Table 1 Development of irrigated area (in millions of acres) (Gilmartin, 1994)**

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<th>1880s</th>
<th>1918</th>
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<td>Punjab</td>
<td>1.32</td>
<td>9.06</td>
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<td>Sind</td>
<td>1.5</td>
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simply in a ‘rainy cycle’, despite the fact that by 1908 the Lower Chenab Canal had serious waterlogging having only opened in 1892. There was also a strong anti-drainage lobby that regarded high water tables as advantageous because it helped to operate hundreds of Persian wheels and allowed the water to be utilised during the dry season.

By 1949, water tables had risen close to the surface and even intersected with surface waters during the latter part of the summer (kharif) growing season. Since modern irrigation practices were introduced, the water table has risen on average between 0.6–1.0 feet per year. By 1959, 5 million acres were seriously waterlogged or salinized, out of 23 million acres annually irrigated, with 50–100,000 acres being affected each year. In the worst districts, 40–50 percent of cultivated land was severely damaged and barely productive. Since the 1960s, various drainage programmes have been initiated, but these initiatives are extremely complex and costly. Between 1965–75, Michel (1972) estimated the initiatives would cost US$1,100 million (approximately the cost of the Tarbela dam).

As Michel (1972: 263) points out, the “lure of adding new acreage was still strong, and few were interested in reclamation when lost acreage could be replaced elsewhere” even though the costs of bringing water to new land was higher, and the soil quality poorer. Farmers responded by growing rice where the land was waterlogged and where it was salinised they grew only one crop or to reduce the amount of water used. However, as gross area cultivated increased, so less water was available to flush the salts out of the soil, which made the situation worse and lead to salt accumulation until land had to be abandoned. Lessons from elsewhere were neither sought out nor adopted and “there is no evidence that anyone, even within the same political jurisdiction, really learned from, or paid attention to, experience with waterlogging and salinity” (ibid: 265).

Many of today’s water problems in the Indus basin have their roots in the colonial period – salinity, drainage, inadequate water pricing, poor maintenance, provincial conflict, and ineffective bureaucratic organisation. For example, water pricing has often been promoted as a way of improving water efficiency and system maintenance, but governmental inability to introduce it stems back to colonial times when it was repeatedly considered and then dropped for political and practical reasons. More than 100 years later circumstances still do not favour water pricing reforms. Many existing systems are well overdue for rehabilitation and renovation, raising a real challenge for moving to a more sustainable water management regime (Sarwar and Perry, 2002).

Indeed, the frequency with which water management problems return and the sluggishness with which solutions have been implemented appear to be unaffected by modernity. As Westcoat (1991: 392) muses, “the sobering lesson from the colonial period is that a problem may be well understood, and potential solutions may be well known, but it may take decades or centuries before the problem can be resolved.” This reflection is echoed by Michel’s (1972: 272) comment, “[w]hat amazes me about the history of agriculture is that the lessons of field cropping in semiarid margins have to be learned again and again, from place to place and from time to time.” Given what we know about the cumulative effects of irrigation in inducing high water tables and soil salinity there is a real danger that these same fields may cease production for a second time due to declining fertility prompted by waterlogging and salinization.

Conclusions
As noted above, risks are an inherent part of any system and are particularly characteristic of large scale, highly connected systems. Whilst we cannot expect ancient societies to have applied modern approaches to understanding and mitigating against risk, we can expect both communities and governance bodies to learn from the past. Such learning
can be utilised in two ways. It can be incorporated into an understanding of how to better utilise the resource, or it can provide evidence for the limits to which the resource can be managed in order to generate benefits.

The dangers of a ‘command and control’ approach to irrigation in the Indus basin have been articulated elsewhere (Faruque, 1996). Whilst our analysis supports Faruque’s critique, we only partially concur with his conclusions. Although incentive or market-based policies are an additional, and often effective, tool to achieve change they still emerge from a management paradigm premised on a full and complete understanding of how the socio-natural system works. Though such approaches can reduce the apparent risk to the system from single events, given the complexity of issues that are usually interlinked, this can create a false sense of security which result in greater vulnerability overall.

This study has shown that, despite four thousand years of irrigation experience, the Indus basin continues to suffer from the negative impacts of poor management. By taking a long term historical perspective we are able to demonstrate that, in the case of irrigation in the Indus basin, the future is like the past in that the risks inherent to irrigation are inadequately mitigated for. But is this failing due to ignorance (a lack of knowledge or incapacity to learn), an inability to intervene in appropriate ways (lack of resources), or wilful convenience (a lack of political will to fully address the totality of the problem)?

Our own interpretation of this repeated inability to learn from the past is that successive regimes have two elements. Firstly, we conjecture that the incumbent societies have not handled the accompanying risks. Though there have been advances in technology and understanding of how water impacts soil through irrigation, and large amounts of money have poured in to develop the irrigation system, the risks have not been properly addressed. It has been a case of either ignoring the risks, or doing too little too late. A key lesson to derive is that given the relatively short-term nature of political decision-making, any significant change has to address the political reality whereby politicians exert influence over water policy. Yet, the timescales over which risks to a system may emerge, such as climate change, do not match political schedules and cycles, and can be ignored until a crisis has occurred.

Secondly, we argue that irrigation itself has an organizing effect on society, economy and governance. The allocation of water rights, scheduling of water use, construction, maintenance and defence of infrastructure from hostile neighbours, are all forces at work within hydraulic societies. This thesis, more elegantly laid out by Wittfogel (1957), premises that while irrigation can be carried out by small groups on an informal basis, it is more efficient and leads to greater growth if there is central management. Large scale, centrally managed systems are poor at responding to change and rely on command and control management styles to legitimize planning and intervention.

These tensions between the benefits and costs of coordination, collaboration and scale characterise many water management systems. We should be concerned that the lessons of the past appear not to have been learned in the Indus basin. But equally we should be optimistic that we are better armed than ever to create new realities which decouple some of the socio-natural couplings which create seemingly impassable challenges to more sustainable use of water resources.

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References


