Depletion, Degradation, Desertification
Responses to Irrigation in Punjab, India

Figure 1: Punjab Administrative Divisions in 1986 and, inset, Punjab's location within India (from Brar 1999)
Introduction

Punjab is an agrarian state in northwestern India (see Figure 1), in the northwestern part of the Indo-Gangetic plain, a deep crustal trough filled with Quaternary sediments, a flat alluvial plain at an elevation ranging between 180 and 300 meters (Srivastava, nd; Brar 1999: 8). The name “Punjab” means five rivers, and the state, before the partition of India and Pakistan in 1947, was irrigated by five tributaries of the Indus River, three of which, the Ravi, Beas, and the Sutlej, remain in Indian Punjab. Land use in Punjab is overwhelmingly dedicated to agriculture (see Figure 2) with nearly 85% sown as of 1978 (Shiva 1991:87). The climate is semi-arid and subtropical with 80% of the rainfall occurring between July and September in the form of monsoons from the southeast and the majority of the rest falling between December and February from western cyclones (Brar 9).

Figure 2: Land use in Punjab 1978 (Shiva 1991)
I have read that Punjab may become a desert by 2025. Newspaper reporters and popular authors also cite 2025 as the year that the aquifers under Punjab will run dry if current groundwater extraction rates are maintained. Calls for conservation, reports on India’s food security and critiques of the Indian government’s hostility towards religious minorities like Sikhs, who live in large number in Punjab, seem to conflate two different scenarios of land degradation that are going on in Punjab in different regions at the same time. Looking at land degradation in Punjab through the lenses of space and time reveal that a simple cause and effect chain from groundwater depletion to desertification is not only incorrect, but also glosses over the diversity of land, soil and groundwater profiles in different regions within Punjab, ignores the fact that different irrigation methods are practiced in these different regions, and disregards differences in soil and aquifer responses based on these contexts.

Desertification

There is also some debate over what constitutes desertification. To Monique Mainguet at the laboratoire de géographie zonale pour le développement, université de Reims–Champagne-Ardenne, it is a socially constructed phenomenon based on economics and time more than it is a standardized geomorphic process. In Desertification: Natural Background and Human Mismanagement, she refers to “the myth of the encroaching desert” (Mainguet 1994: 12). A creeping desert was indeed how I had imagined desertification progressing toward Punjab, somehow scheduled to arrive over the border precisely in 2025.

Desertification, in Mainguet’s eyes, is instead “the ultimate step of land degradation: irreversibly sterile land, meaning irreversible in human terms and with practicable economic limitations.” There
is, then, a continuum of land degradation that ends with desertification, which leads me to believe that the process we need to examine is land degradation rather than simply the final step of desertification. The point at which degradation becomes desertification depends on humans and their technical ability and economic means to reverse the degradation process. Mainguet compares the degradation of the Aral Sea in Central Asia to the degradation of the San Joaquin Valley in California and concludes that the agricultural industry of the United States has far more resources to protect the Valley from desertification than the poorer former Soviet states, now independent nations, that used the Aral for irrigation. Thus, while much of the degradation in California is reversible, in Central Asia, it is not. So Mainguet calls the conditions in the San Joaquin Valley “dryland degradation” and the conditions in Central Asia “desertification” (Mainguet 129).

After proclaiming that “controversy, both informed and uninformed, inevitably surrounds and confounds discussions of land degradation in the drylands,” H. E. Dregne gives a short history of how scientists and official bodies like the United Nations have meant the word “desertification” over since its first use in 1927 by French biologist Louis Lavauden to describe grasslands in southern Tunisia (Dregne 2002: 99–100). Neither Lavauden nor Aubreville, a French forester working in humid West Africa, defined the term, but Aubreville referred to severely water eroded land as being “like a desert, abandoned and useless” (Dregne: 100). This “empty desert” idea runs completely contrary to how I have learned to look at vast expanses like deserts and oceans—as complex ecosystems, the workings of which humans understand so little.

Before the United Nations Conference on Desertification in 1977, desertification scenarios were usually centered on grazing, grasslands, and the actions of pastoralists in degrading the land. The 1977 conference, however, according to Dregne, legitimized a much-expanded paradigm that
included croplands and irrigated land (99). At the conference, the concept was broadened to specifically include conditions of salinization and waterlogging as well as heavy metal pollution of soils. None of these definitions conjures up in my mind the picture of a desert, which has to do with aridity rather than degradation. The 1992 United Nations Conference on Environment and Development defined desertification as “land degradation in arid, semiarid, and dry subhumid areas” and as the “diminution or destruction of the biological productivity of the land” with land meaning soils, plants, and water resources (100). The United Nations Environment Programme calls desertification processes that have had a “severe effect on land productivity”: vegetation degradation, water erosion, wind erosion, salinization, and soil compaction (100). In discussing the issue of the potential of reversibility as a criterion, as discussed above regarding Mainguet, Dregne notes that wind and water erosion tend to cause irreversible degradation, while salinization and compaction rarely produce irreversible effects. Thus, the jury is out on whether or not Punjab is actually being desertified.

Irrigation

Anthropologist Murray Leaf describes his confusion upon returning to Punjab in 1978 after doing initial fieldwork in 1965:

This late in the hot season the fields should all have been cleared, plowed, and leveled to preserve moisture. Some crops would have been sown; others would await the rains that were due to arrive shortly. Yet many of the fields appeared to have been only recently cleared and were as yet unbroken by the first summer plowing. Other fields were full of what appeared to be young rice, a crop almost never grown in this area during my first stay (Leaf 1984: 10).

The Green Revolution had come to Punjab in the years that Leaf was away. In 1963, the Rockefeller Foundation sponsored geneticist and plant pathologist Norman Borlaug, who had been working on
breeding higher-yielding wheat in the Sonoran desert of Mexico, to travel to India at the Indian government’s request. He found that conditions in India and Mexico were similar and sent 100 kilograms of improved wheat seed (Johnson 1972: 165). By 1965, India and Pakistan had ordered 600 tons of this high-yielding dwarf wheat seed from Mexico (Shiva 1991: 62).

Before other states in India had even heard of the Green Revolution, by the 1968–69 growing season, “Punjabi farmers had planted 80% of the land with ‘miracle’ varieties; consumption of fertilizers increased four-fold; yields doubled; the number of tubewells for irrigation rose from 7,000 to over 100,000. . . . By 1960–70 Punjab was producing one-quarter of India’s total wheat tonnage” (Johnson 174). Murray Leaf stresses that the farmers knew the risks of adopting a completely new agricultural methods (Leaf 54), and another author, Himmat Singh, also lauds Punjabi farmers for their willingness to take risks in their quest for profit and their ability to move up the learning curve with new technologies (Singh, 79).

The vast increase in the number of tubewells that Johnson cites points to the importance of irrigation to the new seed varieties, and Leaf takes note that rice, a crop that grows in puddles of water, had almost never been grown in Punjab, with its semi-arid climate, pre–Green Revolution. Irrigation, on the other hand, was not new to the state. The Persian wheel, buckets of water attached to a large wheel that raised water from streams, became popular in the 13th century (Brar 1999: 32) (see Figure 3), and inundation canals, ditches cut parallel to rivers on a floodplain, were also operated by individual farmers (Cantor 1970: 15). The inundation canals flowed for less than half the year and could serve as drainage channels during non-monsoon times (Shiva 122).
Canal Irrigation, Waterlogging and Salinity

When the British colonized Punjab in the mid-19th century, they stimulated agricultural development by building a large-scale canal system, starting with the Upper Bari Doab Canal (“MB Upper” in Figure 4) in 1860–61, which irrigated the districts of Amritsar, Gurdaspur, and Lahore, most of which corresponds with the region called Mahja in Figure 5, except that Lahore is now over the border in Pakistan. The Sirhind Canal (see Figure 4) was built in 1887 and irrigated Ferozepur and Ludhiana along with parts of Patiala, Nabha, Faridkot, Jind, Malerkotla, and Kalsia (Brar 35). This is in the Malwa region in Figure 5, and all of the subregions listed above may be identified in Figure 1.

Canals tend to cause waterlogging. First, in areas with poor drainage, canal water used to irrigate crops has nowhere to go once it has been applied. Additionally, unlined canals seep, which allows the percolation of canal water into groundwater, raising the water table. Waterlogging, then, has
Figure 4: Surface water system, Punjab, Shiva (1991)

Figure 5: Punjabi cultural regions, defined by rivers (from Brar)
been a problem in the canal command areas since well before the Green Revolution. In fact, according to Dregne, “salinization and waterlogging of irrigated land in the Indus watershed has been a big problem for a hundred years” (Dregne 115). The water table in the area of the Upper Bari Doab Canal rose five meters between 1865 and 1914 and, in 1925, it lay just 2.5 to 3 meters below the surface (Brar 64–65). See figure 6 to see waterlogging conditions in the Mahja region over time.

Figure 6: Waterlogging Mahja from irrigation and percolation from canals (from Brar)

Too much water, according to Diane Ward Raines, is “as damaging as too little, chokes off oxygen and life from the root systems of plants, interferes with the rotting of organic materials, reduced nitrogen, and encourages the accumulation of toxins in the ground” (Raines 2002: 107). Salinity
occurs whenever water does not get flushed past the root zone of crops but instead flows back upwards (see Figure 7). Even the best water has some salt in it—between 200 and 500 parts per million. Applying a typical irrigation amount of 10,000 cubic meters per hectare per year adds two to five tons of salt to the soil (Postel 1989: 15). A soil with enough soluble salts in the root zone to impair the growth of crop plants is considered saline, so there is no precise definition that works everywhere. Mainguet offers a succinct description of the effects of salinization on crops and the land itself:

If the salty perched water table comes within 1–1.6 meters of the roots, some of the water can rise through capillarity and cause damage because it inhibits the plant’s ability to absorb moisture. The plants become stunted and die, depending on the salt concentration. If the salty groundwater reaches the surface, it evaporates and leaves salt crystals on the surface of the fields and if the quantity of salty water reaching the surface is great enough, a relatively impermeable salt crust will form over the soil, diminishing infiltration and natural leaching (Mainguet 157).

Figure 7: Too much water is as bad as too little. Only with adequate drainage (C) is saline water flushed from the root system. Whenever irrigation water flows up rather than down, salinization occurs. From Seelig (2000).
Saline soil has high electrical conductivity, which is one way to measure salinity (Shahid 2003). New technologies are being used to map salinity in order to plan cropping patterns around salty soils of different intensities: for example, fruit trees are less tolerant to salt than vegetables, which are less tolerant than forages (Shahid, np). Mobilized soil assessment systems (MSAS) are one such tool and include soil conductivity sensors, a GPS receiver, a computer and a tractor or platform on which to mount the sensors (Lower Colorado Region Salinity Assessment Network, nd).

To recognize salinity in the field, look for salt efflorescence; reduced plant vigor; salt stains on dry soil surface; small to large bare areas; worsened conditions after high seasonal rainfall; high water tables of usually less than two meters; erosion; foundations weakened by high salinity water tables; and collapse of green belts, buildings, and roads due to the corrosive effects of salinity (Shahid, np). I wonder if the last two symptoms represent salinity or subsidence, both of which depend on the type and amount of clay in the soil. I was not sure exactly what Shahid meant by “collapse of green belts,” but collapse of buildings and roads would almost certainly point to subsidence. Canals might also be affected by subsidence, which would cause them to crack or fracture and leak even more water into the ground, creating more saline conditions. On the other hand, a water table so close to the surface could also cause the ground to be wobbly.

My research uncovered virtually nothing about land subsidence in Punjab. The one reference to subsidence in India that I uncovered was H. E. Dregne’s 2001 statement that “Salinization is common in the irrigated flood plains of the tributaries of the Indus River. Little is known about the extent of soil compaction” (Dregne 2001: 114). I am very curious to find out whether compaction and subsidence is an issue in Punjab or not. Brar remarks that driving heavy farm machinery like tractors over the land “leads to the formation of a layer of high bulk density, especially in the case of wet soils under paddy cultivation. Such a later restricts root development, affects profile water
recharge, and has an adverse effect on the leaf area, size of ear and quality of grains” (Brar 91, citing Sur and Singh 1989). Clay type is also a factor: montmorillonite clays tend to swell and disperse more than illite and kaolinite clays with the introduction of sodium. In Poland and Lofgren’s assessment of land subsidence in California’s San Joaquin Valley, the presence of montmorillonite clay was a factor in the tendency of the land to subside, along with the structure of underground aquifers and aquatards (Poland and Lofgren 1984: 271). I plan to explore the topics of clay content and underground structure in Punjab further in the future.

Hydraulic engineer William Wilcocks, who worked on the British colonial Ganges Canal, warned in 1904 that future irrigation systems must be preceded by drainage systems in the form of tile drains to take excess water out of the fields (Raines 109). However, this advice was not followed, in India or elsewhere: according to one expert on salinization, about 7% of the surface of the world is covered by salt-affected soils with 38% of Australia, 14% of Africa, 1.7% of North America, 0.5% of Central America, and 5.4% of Europe affected (Mashali 1989 cited in Shahid 2003). Notably, Asia does not appear among Mashali’s statistics. Shahid goes on to remark that, as of 2003, “similar information in other countries is still incomplete.”

The absence of alluvium resulting from salinization creates a situation where wind erosion is effective at picking up lighter, less dense soil constituents like organic matter, clays, and silts (Mainguet 71 and US Department of Agriculture Wind Erosion Research Unit). The Dust Bowl on the southern plains of North America is one dramatic case of wind erosion, and dust storms occur in Punjab. Ironically, the dust storm situation has actually been improving in terms of frequency and intensity since the Green Revolution because more crops hold more soil down (Krishan in Brar np).
Attempts to reclaim saline soil include the physical techniques of land leveling and salts scraping as well as the introduction of tile drains. Where saline soils have also become sodic, or alkaline, with a pH between 8.5 and 11, increasing the amount of calcium in the soil by adding gypsum helps clay form clusters, or flocculate (Shahid, np) and recover.

Another remedy for waterlogging is the use of tubewells to suck irrigation water out of the soil once it passes the root zone of crops. Then the water is used again. This is first of all very expensive, one of the chief advantages over surface water from canals over tubewell-pumped irrigation being that costs are lower because the canals, unlike tubewells, do not require electricity or diesel fuel to operate. Salinity, also, is building up faster as water is used and re-used.

**Salinity, Sodicity and Degradation**

Condom et al. discuss the diversity of quality of irrigation water, particularly the differences between canal and tubewell water and assess the effect of four different water qualities and whether they produce salinity, alkalinity, or sodicity hazards by measuring the electric conductivity and the residual alkalinity of the soil (Condom et al. 1999: 123). Their conclusion is that sodicity is a big hazard with tubewell-derived water in canal-irrigated zones, which creates soil degradation that negatively impacts agricultural production. The farms where they based their fieldwork were on the Pakistan side of Punjab, but in an area resembling Majha very closely. The same types of crops were grown as on the Indian side of the border as well: cotton, rice, and fodder in the summer and wheat and fodder in the winter (124).
Alkalinity is the sum of cations that may accept protons. Residual alkalinity is the alkalinity minus any cations and anions involved in mineral precipitation, so in this study, residual alkalinity was determined by concentrating a soil solution until minerals like calcite, sepiolite, and gypsum precipitate out. If the remaining soil solution has a negative residual alkalinity, the soil tends toward salinization, and if calcium and magnesium increase, in relative terms, then the soil may become alkaline. On the other hand, if the residual alkalinity is positive, mineral precipitation causes an increase in alkalinity and pH, and calcium and magnesium decrease. This process leads to salinization with sodification (125).

The indicators they used to test soil degradation in the top level of the soil were morphological indicators like the type of crust formed, the crust strength as tested with a hand-held penetrometer, chemical indicators, and farmers’ perceptions about the relationship between a surface crust and the infiltration rate (125–126). They found that there were structural crusts, which were porous, and runoff depositional crusts created from structural crusts whose pores were filled in with deposition, making them flat and causing the particles to sort out into layers. Structural crusts were found on cultivated soils, and depositional crusts on barren land. Structural crusting occurred within one crop season and could even appear after one or two irrigations, which was described in this case by farmers as ponding occurring after a second irrigation (127). A depositional crust would represent fairly serious degradation.

They found that the tubewell water in which salt was the most concentrated produced sodification, while canal water was clean of salts and produced no sodification. The soil tried to act as a buffer for the salt in the water and released divalent cations, which began mineral precipitation and reduced the alkalinity, leading to sodification (134). Soil texture played an important role: Fine- to medium-
textured soils tended toward neutral salinization followed by alkalinization. Coarse-textured soils tended toward sodification through alkalinization, which were especially susceptible to erosion by wind and water (135). Condom et al. call for the Pakistani government to revise their standards around the critical limit of soil degradation as measured in exchangeable sodium percentage, the ratio between the concentration of exchangeable sodium to the sum of the concentrations of other exchangeable cations. The government was using an ESP of 15% as the high limit, while their research showed degradation at levels as low as 4% (138). This is another indicator that using tubewells to re-use canal irrigation water rather than to build expensive tile drains is causing degradation of the land.

Rice, Tubewells, and Groundwater Depletion

One important development of the Green Revolution was that double cropping of wheat and rice became popular, with new seeds and other new inputs like chemical fertilizers and pesticides, as a strategy to get the most out of the land over the course of the year. Traditional agricultural practices were abandoned, like following wheat crops with crops of pulses or legumes to fix nitrogen in the soil or leaving fields fallow for a season to recover.

Leaf remarked that rice was almost never grown in the village he visited before the Green Revolution. According to Himmat Singh, prior to 1965–66, rice cultivation was limited to “small pockets” where the soil was hard clay and irrigation was in place (Singh 2001: 60). Now rice is a popular crop in southwestern Punjab, which borders on the Thar Desert in Rajasthan, so the soil there is very sandy and prone to salinization. Rice is also popular near Amritsar and Gurdaspur, where the soil is quite clayey (Punjab Environment, nd).
Rice became a viable crop for market in Punjab—it is very rarely eaten in the state—once electricity became available in the 1970s. Electricity for farmers is subsidized, and rates are fixed at a flat monthly rate. This encourages farmers to get the most water they can each month with electrified tubewells instead of trying to economize as they would with water charged per unit of volume (Leaf 48–49). To grow rice in the groundwater-irrigated village where Leaf did his research, it was necessary to deliberately create hardpan in order to “puddle” the fields above this impermeable layer. After each crop, the field needs to be plowed very deeply in order to break up the hardpan (Leaf 49). When Dregne notes that soil compaction and associated land degradation can be “reduced or eliminated rather easily by changing plow depth,” he may not be taking the plowing requirements for puddling on rice fields into account.

![Figure 8: Canal and tubewells over time (from Brar)](image)

Toward the beginning of the Green Revolution, the percentage of land irrigated by canals and the percentage irrigated by tubewells flip-flopped (see Figure 8). There were 190,239 tubewells in Punjab.
in 1971 and 760,291 in 1985–86 (Brar 71). These are used not only to extract excess water from canal-irrigated zones but also to extract groundwater in non-canal-irrigated regions.

A tubewell is a pipe 15 to 18 cm in diameter that is driven around 15 meters below the groundwater level. According to Leaf, “the pipe ends either in a long, perforated strainer or an underground tank, depending on the soil. Within the main pipe is a smaller one, which is attached to the pump proper. The large pipe is open at the top to allow air to enter the chamber that collects water; water is drawn up the inner pipe.” For firm soil, you would use the version with the tank. The other kind, with the strainer, can be used almost anywhere, but they cost more, and they only last around seven years. All are run with diesel or electric motors (Leaf 67).

I only read mention of salinization as a result of groundwater in depletion in one article (Shah et al. 2003: 133). I am not sure if this is actually an issue or not. The obvious effect of groundwater depletion through overpumping is a lowering of the water table. Shah et al. suggest that “the problems of groundwater depletion in the Punjab, India could be erased if the region’s export of ‘virtual’ groundwater—in the form of rice—could be reduced or stopped” (136). I could not find consistent evidence of any geomorphic effect of groundwater overpumping in Punjab. It could be that no one is looking for it when groundwater pollution by pesticides and fertilizers is such an important and life-threatening effect. Or it could be a hidden danger that does not leave its mark on the land.
Figure 9: Water table change over time (from Brar)

A typical estimate is that the water table in Punjab is dropping one meter per year, in the areas where it falling rather than rising as a result of waterlogging. Figure 9 shows how the same regions may experience water table rise and fall over time. It also shows, though, that the water table in Bist Doab and eastern Malva has been falling without respite since the Green Revolution began in 1966. Ironically, it is where there is the least water from rainfall, the southwest of Punjab, where waterlogging is a problem, and the northeastern part of the state, where rainfall is more plentiful, where the aquifers are in danger of running dry.

The United Nations released a study in 2002 that asserted that at that time, 40% of the world population faced water shortages and predicted that by 2025m the figure would rise to 50%. Another reason for the looming date of 2025 is that, according to Sandra Postel, “a slowdown in
world grain yields at the same time as a projected doubling of food demand between 1995 and 2025. Grain yields were 2 to 2.5% per year between 1950 and early 1990s, when it dropped to 1.1% per year” (Postel 1998). Desertification or degradation resulting from causes like salinization may account for some of the lost grain yields, and groundwater depletion may account for still more. But a lowered water table does not make a desert. And yields can depend on variables like fertilizers, pesticides, and genetically-engineered seeds, not simply geomorphic responses to irrigation.

Salinization and groundwater depletion are both responses of the land to irrigation. While both of these problems occur in Punjab, they are occurring in different regions and have predominated over different time periods: canals have been an issue for over one hundred years, while the water table only began to drop at an alarmingly quick rate at the time of the Green Revolution. Groundwater depletion, salinization, and sodification absolutely threaten the productivity of the land. Salinization threatens the parts of Punjab with the least rainfall. Waterlogged areas, though, would be more properly described as “reverting” to desert since they are reclaimed wastelands in the first place. The depletion of groundwater, while making regions where this is happening much dryer, is not cited in the desertification literature even though water resources are included in one of Dregne’s definitions of “the land,” which can be degraded. The most important lesson I learned from my research was that it in discussing desertification or land degradation in Punjab, it is important to sort out the different threads of time and space in order to tell the story in all of its complexity.
Works cited


