CHAPTER 21
Groundwater and poverty: exploring the connections

M. Moench
Institute for Social and Environmental Transition, Boulder, Colorado, USA
mmoench@i-s-e-t.org

ABSTRACT: Access to groundwater, the most reliable source of irrigation, can be a major mechanism enabling farmers to transition out of poverty. State-level data from India indicate that groundwater extraction rates and declines in poverty between 1956 and 1991 are closely correlated. In conjunction with field level information document the importance groundwater plays in reducing agricultural risks while also increasing productivity. This enables small farmers to accumulate assets, move out of poverty and often develop new, non-agricultural livelihoods. Loss of access to groundwater due to over-extraction or water quality problems can be a major factor increasing poverty. The impact of groundwater problems on poverty may depend, however, as much on the presence or absence of alternative livelihoods within the wider economy as on the direct implications for agriculture. This chapter explores the connections between the intensive use of groundwater and poverty using data from South Asia, Yemen and the USA.

1 OBJECTIVE OF THE CHAPTER

The objective of this chapter is to explore the linkages between access to groundwater and rural poverty. Groundwater access has key benefits for rural farmers in that it increases agricultural productivity and reduces the risk of loss due to drought or the variability of supplies from surface sources. As a result, groundwater access can be a major factor enabling rural farmers to increase income and, thus, move out of poverty. Access to groundwater can also have other poverty reducing benefits such as reducing the amount of time people (typically women) must spend obtaining water for domestic uses and improving health by reducing the spread of water-bourn diseases.

This chapter starts by outlining some of the conceptual linkages between groundwater and poverty. Direct evidence of the benefits access to groundwater generates for income is outlined next section. The following two sections shift focus and explore the consequences loss of access to groundwater and declines in groundwater quality have for the wealth of rural populations. Core observations are synthesized in the final concluding section. Because the chapter synthesizes much of my earlier research it draws heavily on previous publications.

2 CONCEPTUAL FRAMEWORK

In their classic book written in the mid-1980s, *To the Hands of the Poor, Water and Trees*, Chambers, Saxena and Shah (Chambers *et al.* 1987) argue that access to basic productive resources, in specific water and trees, is central to rural poverty alleviation. This has also been suggested in other more recent research in India and Nepal (Shah 1993, Rao 1996, Gyawali & Dixit 1999). Secure access to basic resources enabled through rights represents a foundation on which rural farmers and other inhabitants can build to work their way out of poverty. Where water is concerned, much of book by Chambers, Saxena and Shah focuses on lift irrigation because of the direct control pump owners are able to exert over their own access to water and because of the opportunities lift irrigation creates for water sale by well owners to others who may be unable to afford pumps of their own. It is this element of reliability and control by individual users that lies at the heart of the benefits groundwater creates for poverty alleviation.

Now let us put this into an internally consistent conceptual framework that relates groundwater access to poverty: groundwater access provides a foundation for an asset pyramid. It enables access to higher yields while also reducing the risk of losses. This foundation opens access to a much larger pool of entitlements (physical, economic and social assets) than farmers would otherwise have.

The conceptual relationship between groundwater access is simplistically outlined in a cartoon in our recent book *Rethinking the Mosaic* (Moench *et al.* 1999). Increases in yields and reductions in risk associated with groundwater enable farmers to generate surpluses far more consistently than when they depend on surface irrigation or precipitation. These surpluses are then reserved as savings or invested in any of a multitude of ways –from improvements in health care to education, land or any other form of physical, economic or social capital. Because losses are reduced, the capital stock held by groundwater users tends to accumulate over time and people who were once marginal farmers move out of poverty. They become, to use the entitlements terminology developed by Sen and others (Drez *et al.* 1995, Sen 1999), *entitled* to a much wider pool of assets than they would have been without access to groundwater. Furthermore, the impact of groundwater access extends beyond the narrow set of individuals who own wells to other farmers who purchase water and to the wider regional economic base. It also contributes to poverty reduction in other ways –for example via reductions in morbidity (through access to clean drinking water) and by reducing the amount of labor that must otherwise be expended, generally by women, to obtain water for domestic uses. Groundwater access, it could be argued, lies at the root of a virtuous cycle of accumulation at both the individual family and regional levels that can help rural populations to move out of poverty.

Loss of access to groundwater, through over development, pollution, quality declines or reallocation, undermines the conceptual foundations underlying the above virtuous cycle. As irrigation becomes less reliable, productivity declines and the risks of loss increase. Losses may, in fact, be even more severe than those that existed prior to groundwater development because economies in groundwater irrigated areas have shifted to more intensive production techniques requiring higher inputs and associated cash, labor and other capital investments. If groundwater over development or other problems become severe, agricultural production may decline and the overall economic future of regions becomes uncertain. This has been an explicit concern in the context of water transfers (many of which involve groundwater) in the Western USA. As I wrote over a decade ago (Moench 1991):

> "Major transfers of water out of basins or regions are often perceived as undermining the local socioeconomic base (MacDonnell & Howe 1986, Checchio 1988, Nunn & Ingram 1988, Woodard 1988, Oggins & Ingram 1990). This has become known as the *area-of-origin* problem. When water is transferred out of a region, the economic activity it supported can go with it. The retirement of agricultural lands can have secondary effects on local labor and agricultural supply markets. It can also have direct and indirect effects on the local tax base leading to impoverishment of local governments. Furthermore, the economic development potential of a region can be impaired –water transferred out of a region is no longer available to support the initiation of high value activities in the source area. Overall, market based transfers are often seen as threatening the economic viability of source areas. Since most transfers are from agricultural to municipal uses, the division tends to fall along rural-urban lines".

The fear in the Western USA is that water transfers will create rural areas where economic opportunities are few and remaining populations become (or remain) impoverished. This type of dynamic is, to some extent, conceptually parallel to areas where groundwater over-development or related problems become severe in the less industrialized parts of the world[1]. As a box prepared by

[1] It should be recognized, however, that while parallels do exist, there are also fundamental differences. In areas suffering from groundwater depletion, for example, farmers are being forced out of agriculture by the absence of a resource essential for production. In the USA, in contrast, low producer prices are the primary factor undermining much agriculture and encouraging farmers to sell their water rights.

Dr. Tushaar Shah in an our earlier publications suggests for several locations in India, groundwater depletion can lead to declines in agricultural production, out-migration and poverty (Burke & Moench 2000).

The above conceptual links between groundwater and poverty are relatively clear but, as Burke (this volume) suggests, actual connections may be far less direct. As in most *real life* situations, numerous factors influence the relative wealth or poverty of individuals and access to groundwater is only one among them. Furthermore, linear cause and effect relationships are rare. As Shah (1993) points out: "It has been argued, for example, by Dhawan (1982), that the spread of the green revolution technology in the northern plains was fueled by the tubewell revolution. The two *revolutions* have, however, complemented each other: it can be argued equally well that the tubewell revolution was spurred by the opening up of the green revolution technology". As a result, it is important to look more closely at the limited –but telling– empirical evidence that more directly relates groundwater access to poverty.

3 EMPIRICAL EVIDENCE OF BENEFITS FOR INCOME

Recent reports by IFAD (International Fund for Agricultural Development) draw attention to broad relationships between access to irrigation and poverty. As they indicate: "One third of cropland is irrigated in Asia (growing about two thirds of its crops by value), but less than 5% in sub-Saharan Africa. This partly explains Africa's generally lower yields, cropping intensity and food security" (IFAD 2001). This leads to their conclusion that: "Some control by the poor over water is essential if they are to realize the full benefits from farmland. East and South Asia's facts poverty reduction and farm growth owe much to the 30–35% of irrigated cropland –and the persistence of rural poverty and agricultural stagnation in most of sub-Saharan Africa to its mere 1%–5%" (IFAD 2001). IFAD also notes that: "The green revolution of 1965–85, which induced huge falls in rural and urban poverty, has had much more impact on production and poverty in irrigated areas than elsewhere".

The above types of comparisons can also be made within regions. In India, many of the least developed and most poor states such as Rajasthan and Bihar are those where groundwater resources are either limited or remain undeveloped while other states, such as Punjab have booming agricultural economies based largely on irrigated, groundwater dominated, agriculture. As the analysis below indicates, the decline in the incidence, depth and severity of poverty between many states over the period 1957–58 to 1991–92 is, in fact, highly correlated with 1991 figures for the level of groundwater extraction (a good proxy for groundwater development over the full 1957–1991 period).

3.1 *Poverty declines and state level groundwater use in India*

Data on the decline in the incidence, depth and severity of poverty[2] in a series of states in India are shown in Table 1 from Morris (1997).

Table 1. Trend of change in rural living standards, 1957–58 to 1991–92. Morris 1997, using data from Datt & Ravalon (1996).

State	Change in		
	Squared poverty gap index (severity)	Poverty gap index (depth)	Head Count Index (incidence)
Andhra Pradesh	-4.22719	-3.19518	-1.847
Bihar	-1.5656	-0.8459	-0.009
Gujarat	-3.38126	-2.47739	-1.353
Haryana	-3.28239	-2.90517	-2.491
Karnataka	-1.02348	-0.70595	-0.3448
Madyha Pradesh	-2.37474	-1.5417	-0.4485
Mararashtra	-1.89022	-1.47214	-0.894
Orissa	-3.83885	-2.73323	-1.524
Punjab	-6.42747	-4.66962	-2.687
Rajasthan	-1.31608	-0.92812	-0.468
Tamil Nadu	-2.98289	-2.25434	-1.337
Uttar Pradesh	-1.79855	-1.27927	-0.695
West Bengal	-3.91729	-2.96017	-1.85

[2] Morris cites and uses the Foster, Greer and Thornbecke index (Foster *et al.* 1984), which he defines in the following manner: $P_a = 1/n\sum[(z-y_i)/z]^a$ where z = the poverty line, y_i = the income of the i[th] household; and a = a given weight depending on policy considerations.

If a = 0, then P_a = the headcount index; if a = 1, then P_a = the poverty gap index (depth); if a = 2, then P_a = the squared poverty gap index or severity of poverty.

Citing the planning commission, Morris identifies the poverty line underlying the above data as: "based on a nutritional norm of 2,400 calories per day, and is defined as the level of average per capita expenditure at which this norm is typically obtained. The poverty line was thus determined at a *per capita* monthly expenditure of Rs. 49 (US$ 1 = Rs. 48.6, so it is roughly equivalent to US$ 1) at October 1973-June 1947 all India prices" (Morris 1997).

Groundwater extraction data along with rural and total population levels are given below in Table 2 for each of the above states. Table 3 gives correlations and R^2 values indicating the correspondence between the amount of groundwater use and poverty reduction between the mid-1950s and 1991. The data presented in Table 3 suggest that a relatively strong relationship exists between reductions in number, depth and severity of poverty at a state level and *per capita* groundwater use. The correlations are slightly (though not significantly) stronger when only the rural population is considered. The fact that correlations do not decline significantly when the urban population is included is interesting and could be interpreted as indicative of the wider economic benefits associated with groundwater development. Correlations improve very substantially when the three eastern states of Andhra Pradesh, West Bengal and Orissa are excluded. Precipitation in these states is higher and somewhat less variable than in other areas. Furthermore, they obtain substantial amounts of rain in both the north-west and south-east monsoon periods. As a result, it is logical that the reliability of groundwater would have far less implication for agricultural production and risk (and by implication for poverty reduction) in these states than in other, more arid, regions. Data for these states are also graphed in Figures 1 and 2.

Table 2. Groundwater extraction and population. (Census of India 1991, Central Ground Water Board 1995).

	Groundwater Extraction (Mm^3) (1991)	Rural Population (1991)	Total Population (1991)	Rural per capita Groundwater Extraction (m^3/person)	Total per capita Groundwater Extraction (m^3/person)
Andhra Pradesh	10,132	48,620,882	66,508,008	208	152
Bihar	7,811	75,021,453	86,374,465	104	90
Gujarat	10,243	27,063,521	41,309,582	378	248
Haryana	8,685	12,408,904	16,463,648	700	528
Karnataka	6,144	31,069,413	44,977,201	198	137
Madyha Pradesh	10,187	50,842,333	66,181,170	200	154
Mararashtra	11,058	48,395,601	78,937,187	228	140
Orissa	2,045	27,424,753	31,659,736	75	65
Punjab	22,511	14,288,744	20,281,969	1,575	1,110
Rajasthan	7,748	33,938,877	44,005,990	228	176
Tamil Nadu	19,368	36,781,354	55,858,946	527	347
Uttar Pradesh	38,336	111,506,372	139,112,287	344	276
West Bengal	6,779	49,370,364	68,077,965	137	100

Table 3. Correlations between poverty and groundwater extraction levels.

	All states with data				Excluding eastern states (West Bengal, Orissa, Andhra Pradesh)			
	Per capita rural population		*Per capita* total population		*Per capita* rural population		*Per capita* total population	
	Correlation	R squared	Correlation	R squared	Correlation	R squared	Correlation	R squared
Head count	-0.654	0.428	-0.654	0.428	-0.876	0.767	-0.873	0.763
Depth	-0.679	0.461	-0.673	0.453	-0.944	0.891	-0.934	0.873
Severity	-0.672	0.452	-0.665	0.442	-0.942	0.888	-0.931	0.867

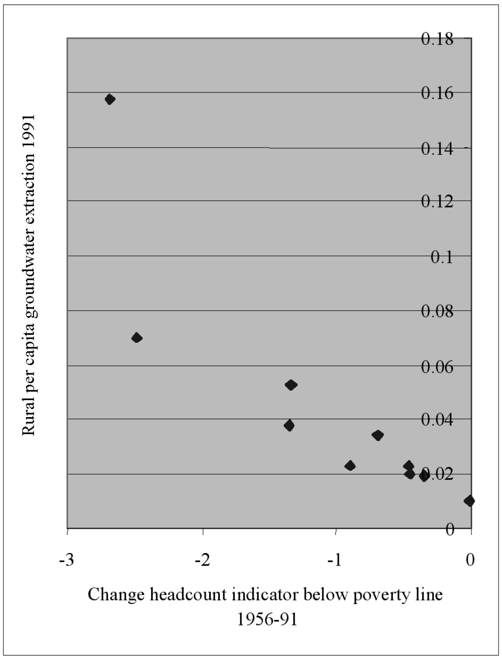

Figure 1. Groundwater and population below poverty line, selected states, India.

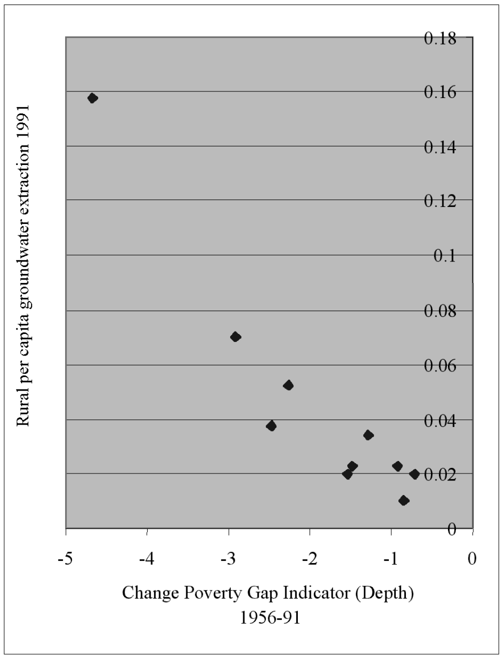

Figure 2. Groundwater and depth of poverty, selected states, India.

The correlations and graphs strongly suggest a close relationship between levels of groundwater extraction and the progress states in India have made in reducing both rural and urban poverty. Increases in groundwater access both stabilize and increase agricultural production, thus leading to reductions in poverty. Correlations such as the above can, however, be misleading. As the earlier quote from Tushaar Shah (1993) on the spread of green revolution technologies illustrates, the increases in groundwater extraction could be as much a result of (as opposed to a factor underlying) poverty reduction. As wealth increases, people can afford pumps and, as a result, increases in groundwater extraction could be a consequence of as opposed to a cause of poverty reduction. In addition, correlations such as the above ignore major regional differences in cultures, organizational capacities, history, economic integration and so on. To investigate the relationships further it is important to look much more closely at the micro level where direct links between access to key resources, such as groundwater, and the wealth or poverty of people can be documented.

3.2 *Poverty and groundwater: micro-level evidence*

At a micro level, many of the basic arguments behind the impact of groundwater on agricultural productivity and through that on poverty have been made many times and this section, which reiterates much earlier writing, reflects that. The fundamental difference between groundwater and other sources of irrigation is that, as Shah (1993) argues: "In comparison to tanks and canals, extensive evidence suggests that wells offer better quality irrigation service and therefore help generate a larger irrigation surplus".

Irrigation was the *lead* input that enabled increases in agricultural productivity during the so-called *green revolution*. Without assured water supplies, other inputs such as improved seeds, fertilizer and pesticide, have little impact on yields. Water control alone can bridge the gap between potential and actual yields by about 20% (Herdt & Wickham 1978). Reliability rather than just the volume of water available is one of the most important factors. Yields can be affected even if adequate water supplies are available following periods of shortage because many crops are highly vulnerable to moisture stress at critical points in plant growth (Perry & Narayanamurthy 1998). Water stress at the flowering stage of maize, for example, can reduce yields by 60%, even if water is adequate during all the rest of the crop season (Seckler & Amarasinghe 1999). Similar impacts on onions, tomatoes and rice have also been documented (Meinzen-Dick 1996). In addition to the direct impact of water availability on crop growth, the reliability of supplies is a major factor inducing investment in other inputs to production such as labor, fertilizers, improved seeds and pesticides (Kahnert & Levine 1989, Seckler & Amarasinghe 1999). This is where groundwater excels and results in, what is called in India "the dynamic effect of groundwater irrigation on crop yields" (Dhawan 1993). The reliability of other sources depends not only on precipitation but also on an array of social and institutional factors that determine the operation of surface systems and ultimately whether or not farmers actually receive water when they need it. Groundwater sources are inherently less vulnerable to seasonal or annual fluctuations in precipitation and are also less vulnerable to social or institutional points of instability since access is often under the direct control of individual well owners.

Groundwater can be accessed *on-demand* just at the time crops require or that is most convenient to the farmer. The results of this reliability are clearly demonstrated by the fact that agricultural yields in India are generally higher –by one-third to half– in areas irrigated with groundwater than in areas irrigated with water from other sources (Dhawan 1995). As the reliability of irrigation water supplies increases there is multiplier effect on yields. For low rainfall regions in India, "a wholly irrigated acre of land becomes equivalent to 8 to 10 acres of dry land in production and income terms" (Dhawan 1993).

Small farmers benefit particularly heavily from groundwater irrigation. Although available data for India are over a decade old, they indicate that while 76% of the operational land holdings are of small and marginal farm category (less than 2 ha), they operate only 29% of the area. Their share in the net area irrigated by wells is, however, 38.1% and they also account for 35.3% of the tubewells fitted with electric pump sets (GOI 1992). Thus, in relation to operational area, small and marginal farmers have far better access to groundwater irrigation than larger farmers. In Bangladesh IFAD has found that: "Irrigation can both improve yields and reduce rural poverty. The IFAD-supported Southwest Rural Development Project in Bangladesh installed tubewells and provided input credits to the poor; after five years, net returns to a typical small (one-acre) farm rose by over 50%" (IFAD 2001). [1 acre = 0.4047 ha].

The impact of groundwater irrigation extends beyond yields and those who actually own wells. Citing Datt & Ravalon (1996), IFAD (2001) states that: "The much lower cost per workplace in agriculture, and its tendency to employ the poor and increase the reliability of their food, suggest that giving aid to agriculture and rural development is good for the poor if it raises output. Indian evidence that only agricultural growth is associated with substantial poverty reduction supports this". Following this general trend, recent findings from Andalusia in Spain indicate that irrigated agriculture from groundwater is economically over five times more productive (in terms of €/m^3) and generates more than three times the employment in comparison to by surface irrigated agriculture (Hernández-Mora *et al.* 2001). In South Asia, the importance of groundwater irrigation to non-well owners was documented in several early studies in Pakistan (Meinzen-Dick 1996), and in Gujarat and Eastern Uttar Pradesh in India (Shah 1993). These studies indicated that while farmers owning wells generally achieve the highest yields, those purchasing water from well owners achieve yields higher than farmers dependent on canal irrigation alone. In addition, those purchasing water tended to have higher fertilizer, pesticide and quality seed inputs than those dependent on canal water alone. This stabilizes the demand for these associated inputs, and leads to the spread of support services for pumps, wells, etc., creating a base for small scale rural industries (World Bank 1998). The demand for agricultural labor also increases. According to the Report of the Working Group on Minor Irrigation for Formulation of the Ninth Plan (1997–2002) additional indirect employment created on every hectare of irrigated land through increased agricultural activity is approximately 45 d/ha (GOI 1996). As Shah (1993) notes, "the increase in the costs of these inputs rises less rapidly than does the value of the output". As a result, intensification enabled by groundwater access increases the net income farmers generate and helps to lift both them and others out of poverty. Overall, therefore, expansion of groundwater irrigation can be seen as a major catalyst for rural development via the creation of a broad rural economy that enables increases in production and contains a spectrum of job opportunities.

While the ability to increase yields and the creation of demand for associated products and services is one important dimension in the poverty alleviation equation, risk reduction is equally important. For farmers, droughts can be catastrophic events forcing the loss or mortgaging of core assets such as land. When crops fail, farmers generally face loss of cash investments in agricultural inputs in addition to receiving no return on their labor or other non-cash inputs. Marginal farmers who depend on credit to finance agricultural inputs (or even their own food between harvests) are particularly vulnerable. Such farmers are often forced to dispose of virtually everything they own at a fraction of its long-term value to pay creditors and survive when drought hits. This creates a vicious cycle of drought and poverty. Assets accumulated during good years evaporate when crops are lost and farmers stay mired in poverty. Irrigation helps to reduce such risk. An analysis carried out for eleven major states in India for the period 1971–84 reveals, for example, that the degree of instability in irrigated agriculture is less than half of that in unirrigated (Rao *et al.* 1988) (see Table 3)[3].

Access to groundwater can play a particularly important role in stabilizing agricultural production and breaking the cycle described above because it substantially reduces the risk of catastrophic losses. Production from irrigated land may be more reliable than unirrigated, but land irrigated by groundwater is even more reliable. Research in the Negev desert and in California has, for example, documented the substantially higher value of groundwater in comparison to surface sources because of its reliability (Tsur 1990, 1993). Groundwater access in essence provides insurance that other water-dependent investments will not be lost. This has tremendous practical value. During the early 1990s, for example, the economic impacts drought in California were minimal largely because farmers had access to groundwater and were able to shift away from less reliable surface supplies (Gleick & Nash 1991).

A recent study on the treadle pumps being promoted in South Asia by International Development Enterprises, a development NGO, provides some of the best micro-level information on the relationship between groundwater access and poverty (Shah *et al.* 2000). Treadle pumps are small, affordable, manually operated pumps that can be used to economically irrigate the small landholdings commonly held by marginal farmers in South Asia. The review by Shah and others found that access to groundwater via the treadle pump raises "the net annual incomes of adopter households by US$ 50–500, with the modal value in the neighborhood of US$ 100" and that "less enterprising adopters achieve fuller employment at an *implicit wage rate* that is 1.5–2.5 times the market rate". Gross income increases of US$ 750–1,000 per hectare are common. Furthermore, the treadle pump enables farmers to both give *crop-saving* irrigation to large parts of their holdings while also establishing a *priority plot* devoted to high-yielding rice or vegetable cultivation (Shah *et al.* 2000). All this translates into more income and less livelihood vulnerability for some of the most marginal farmers in the world.

Access to groundwater through treadle pumps, enables farmers to grow crops, such as vegetables and prized varieties of rice, they were not able to grow before. Furthermore, as Shah (1993) comment: "the most significant impact of treadle pumps irrigation occurs probably through increases in crop yields. Harvests of treadle pumps irrigators are almost always significantly higher than harvests of the pumpless, and often exceeds harvests of diesel pump owners". Based on discussions with users, yields are greater because it is easier to control the water output from the small pump which enables better control over application of other inputs such as fertilizer and avoids water damage to crop plants. This, once again, points to the core advantage of groundwater with respect to productivity and risk. Water application through surface systems is difficult to precisely control. Control and reliability both increase when groundwater is accessed through mechanized pumping technologies. They increase still further when pumping can be done manually. As a result, technolo-

[3] Data requirements for this type of analysis do not permit inclusion of more states.

gies such as treadle pumps that enable the poor to access groundwater and exercise detailed control over its application result in the largest production bounce.

The large impact of treadle pumps on rural poverty depends on the affordable nature of the technology. The least expensive bamboo models cost as little as US$ 12 while more expensive metal and concrete models with bore hole and frame cost US$ 25–35 (Shah 1993). This contrasts hugely with the US$ 200 or more required to purchase most diesel pumps. In addition, treadle pump users can rely on their own labor while diesel and electricity must be purchased. As a result, before treadle pumps became available, access to groundwater depended on the financial ability of farmers to purchase a diesel or electric pump along with the fuel to run it. In addition to the difficulty marginal farmers face in making a large capital investment of this nature, many land holdings in locations such as India and Bangladesh are too small make purchase of such a pump economic. As Shah *et al*. (2000) comment citing government of India data, in the Ganga-Bhramaputra-Meghna basin "over half the total farmlands are operated by marginal farmers owning an average of 0.8–0.9 ha of farmland". Furthermore, in locations such as Bihar and West Bengal, the average plot size in the mid-1980s was only 0.11 ha (Rao 1996). In situations such as this, access to groundwater depends either on the development of water markets such as those discussed by Shah (1993) or on access to more affordable pumping technologies. As a result, prior to the advent of treadle pumps, a large portion of the poor could not obtain direct access to groundwater.

Overall, the ability to reduce poverty by increasing access to groundwater depends heavily on the nature of available technologies. Many pumping technologies are relatively capital intensive and tend to disproportionately benefit more wealthy sections of the rural population. While the most poor do often benefit indirectly through increased opportunities to purchase water or increases in the demand for labor and other agricultural services, direct impacts depend on technologies, such as treadle pumps that provide the smallest land owners with reliable access to water.

3.3 *Synthesis*

Increasing access to groundwater is a major factor reducing rural poverty. On a macro-level there is a relatively strong correlation between regional poverty reduction and groundwater access. At a micro-level, evidence indicates that access to groundwater enables increases in yields and reductions in risk. This, in turn, enables rural populations to increase income, avoid losses and gradually increase their stock of physical and social capital assets. In addition, because groundwater enables agricultural intensification, it often benefits third parties by increasing the demand for labor and other agricultural services. This, in turn, contributes to reductions in rural poverty.

The above benefits for rural populations from groundwater access depend heavily on available technologies. In many areas, the cost of drilling and equipment excludes the poorest sections of the agricultural community from direct groundwater access. Technologies, such as treadle pumps, which reduce access barriers, are, as a result, important for extending the poverty reduction benefits of groundwater to the more marginal sections of the rural population.

4 IMPLICATIONS OF LOSS OF GROUNDWATER ACCESS

Groundwater overdraft, pollution and quality declines can represent major threats to the economic base of rural agricultural populations. Take the situation now emerging in parts of Yemen. As Table 4 below documents, groundwater extraction substantially exceeds recharge in many parts of the country. This said, except in the highland

Table 4. Abstraction and recharge in Yemen (WRAY-35 1995).

Aquifer complex	Approximate abstraction (Mm^3/yr)	Approximate average recharge (Mm^3/yr)	Fresh groundwater stored (Mm^3)
Tihama quaternary aquifer	810	550	250,000
Southern coastal plains (West of Mukalla)	225	375	70,000
Extended Mukalla complex	575	500	10,000,000
Highland plains	500	100	50,000

aquifers, stored groundwater is sufficient to meet existing demands for generations. As a result, time may be available for populations to transition away from water intensive livelihoods.

The decentralized management study conducted for the World Bank documented the impacts of groundwater overdraft on communities near Ta'iz in Yemen during the late 1990s (unpublished). In that area groundwater overdraft was substantial in many rural locations. Municipal supplies for the Ta'iz urban area were also insufficient and efforts were being made to expand existing well fields to supply more water to the urban area. The section below is drawn from the final, unpublished, report of the study which I authored.

4.1 *Findings of the decentralized management study, Yemen*

Water levels in many *wadis* near Ta'iz have declined substantially due to groundwater pumping. In some cases the lower portions have dried out completely. Lower Al Hima *wadi* –below the Ta'iz municipal well field– illustrates the impact of water scarcity on local populations. In the 1980s, lower Al Hima was a vibrant agricultural community. Local inhabitants grew a wide variety of irrigated crops and there was a small horticultural station run by the Department of Agriculture. Now the area is dry. Dead trees surround the deserted agricultural extension office. Drying Qat plants struggle to survive in fields irrigated through expensive purchases of water brought in by tanker from distant locations. Most agriculture now depends on rain. Drought resistant millet, which produces only a small crop of grain and fodder, has replaced the high value fruit, vegetable and qat crops that provided the economic base for local villages. Even drinking water is in very short supply. Children, women and men travel long distances by donkey or camel to collect water at the few tap stands that still run.

In upper stretches of the *wadi* running through Al-Hima and Habeer, irrigated agricultural fields contain a rich array of qat and other crops. The municipal wells for Ta'iz urban supply are also actively diverting large amounts of water from the *wadi* bed and underlying formations. The supplies that fulfilled agriculture and domestic needs in the lower *wadi* have been diverted to other uses.

With the decline in agriculture, populations in the lower Al Hima area have been forced to depend on other activities to support themselves. Many families survive from hand to mouth. Income from a brother, son or father working abroad or in the city is the primary basis for survival. Most of the men remaining in the village travel out to Ta'iz city daily and seek work as casual laborers. Poverty has become a way of life and few see avenues to improve their condition.

Wadi Bani Khawlan also in Ta'iz governorate presents a similar picture. The upper part of the *wadi* is covered with crops and lush fruit trees. The lower area, once also a rich agricultural zone is now desolate. Dry wells dot the fields. In some areas, pipes still cross the ground ready to transport water to waiting fields should water return to the wells. In most areas, however, the pipes have been removed –sold since they no longer serve any purpose. Where wells still operate in the lower *wadi* (mostly at points where minor side *wadis* enter the main one), women now wait for 6–7 hours to fill up plastic containers of water for domestic use. As with lower Al Hima, most men have migrated in search of work. A few remain, spending their time and the remittance money sent by others in the small dusty stores that are remnants of more prosperous days in the valley.

There is no urban demand on water supplies in *Wadi* Bani Khawlan. Extensive development of wells for irrigation in the upper *wadi* has, however, captured all available supplies in the *wadi* alluvium. Little now trickles down to the lower *wadi*.

4.2 *Other regions and parallels with water transfers*

The above example from Yemen is typical of many situations where groundwater overdraft is reported as a problem in developing countries. The impacts of loss of water can be directly observed in relatively small areas on specific communities. While substantial anecdotal evidence exists, few, if any, detailed studies have been carried out that actually document the impact of groundwater problems on poverty in rural or urban communities.

The situation in Gujarat is illustrative of this. Groundwater overdraft and water quality declines in North Gujarat have been documented as a major concern since the 1970s (United Nations Development Program 1976, Moench 1992, 1993). This has led to regional declines in water levels that exceed one meter annually over large areas. Problems related to groundwater overdraft only, however, become intense in the context of drought years. Much of Northern Gujarat sits on top of a deep alluvial aquifer where, despite dramatic declines in pumping heads over the past three to four decades, water remains available in many wells. Our field work in Gujarat over the last decade suggests that during normal rainfall years groundwater overdraft is causing a gradual transition. Farmers have already shifted from water intensive crops such as rice and cotton to cropping patterns dominated by oil seeds and other less water intensive crops. Furthermore, although agriculture has declined in some areas as wells go out of service, the transition has, to a large extent been gradual allowing farmers to move into other activities. North Gujarat has, for example, reportedly developed into a major source area supplying teachers as families invest in education and transit out of agriculture (Tushaar Shah, pers. comm.). This picture changes in drought periods.

In the spring of 2000, news reports documented the impact of drought on rural communities in North Gujarat. In a survey, conducted by the Times of India (2000), of 1,131 individuals from drought hit portions of Northern Gujarat, the following impacts were documented: "it was found that 59.65% had lost all avenues of work; 50% had migrated with their starving cattle; 70% had been pushed to deeper hole of indebtedness". A large number of migrants had to sell lands in order to survive. Furthermore, the survey documented particularly large impacts on manual laborers. The drought was wide spread and numerous news reports and regional experts directly attributed the large impact of the drought to groundwater overdraft in preceding years (Srinivas Mudrakartha & Shashikant Chopde, VIKSAT, Ahmedabad, pers. comm.). Declining groundwater levels led to a boom in the drilling of new wells to try to access whatever remained of the resource. During the same period in Ahmedabad city it was estimated that over 200 new deep wells were being drilled each month and at least 50% of these were needed to replace existing dry wells (Chavda 2000). Farmers in rural areas reportedly couldn't afford to replace dry wells and, as a result, had to migrate, depend on food for work programs or subsist on resources accumulated during previous years (Times of India 2000). Articles on droughts in Gujarat often directly link poverty and other drought impacts to groundwater over-extraction (Bavadam 2001). The groundwater supply that served as a buffer in previous droughts was, as predicted (Moench 1992), no longer available. Overall, there is widespread, but not systematically documented, evidence that groundwater overdraft in locations such as North Gujarat is substantially increasing drought vulnerability and, as a result, poverty. No systematic studies of the impact of groundwater overdraft on poverty –or for that mater rural economic activity in general– have been done that I am aware of.

Despite the absence of studies on the impact of groundwater overdraft, some indication of likely effects can be found in research on water transfers in the Western USA. Water transfers are somewhat similar to groundwater overdraft in that they represent a, generally gradual, loss of access to reliable water supplies for agricultural users on a regional basis. Recent studies of such transfers do provide evidence relating reductions in water availability to declines in rural incomes. Take, for example, recent studies in the Arkansas Valley conducted by Charles Howe at the University of Colorado. As Table 5 below indicates, water transfers are inversely related to output, personal income, employment, and the local tax base.

Table 5. Arkansas Valley (1979–1995). Transfer of selected large water rights. (Charles Howe, pers. comm.).

Transfers	Loss of	Direct impact of transfer	Direct + Indirect
Average area: 10,088.94 ha	Output/Mm^3	US$ 721.29	US$ 948.70
Average size of transfer: 1,253.92 Mm^3	Tax impact/Mm^3	—	US$ 99.23
	Pers. income/Mm^3	US$ 145.04	US$ 230.89
	Employ: Number/10^3 Mm^3	16.38	20.84
	Output/capita	US$ 14.11	US$ 18.51
	Tax impact/capita	—	US$ 1.72
	Pers. income/capita	US$ 2.63	US$ 4.27
	Employ/100,000 population	35.26	43.49

The above effects of water transfers are the types of economic impacts that would also be expected to occur as water availability declines in areas where overdraft or quality declines reduce access to groundwater. Declines in personal income and declines in the amount of employment are the types of changes that directly affect rural poverty levels.

It is important to recognize that the above impacts do not necessarily imply that poverty at a societal level has actually increased. In the USA, water transfers to urban areas may be a factor enabling job creation in those areas. While some remaining residents in areas of origin may be worse off, other sections may have gained. In addition, as may be the case in Gujarat, gradual reductions in water availability can lead to a variety of coping strategies, including migration and livelihood shifts that maintain most of the original inhabitants above poverty levels. If the educated and all others who can end up migrating, however, populations remaining in areas affected by groundwater overdraft are likely to represent a residual pool of poverty. The area will, as a result, be dominated by poor populations who have been unable to migrate to areas with better opportunities.

5 GROUNDWATER QUALITY AND POVERTY

Although this chapter has focused heavily on the association of groundwater availability with rural poverty, groundwater quality conditions can also affect poverty levels. One of the more direct links may occur where quality deterioration affects agricultural production. This is, for example, the situation in coastal Gujarat where saline ingress due to groundwater over-extraction has led to the abandonment of villages and affects water supply availability in hundreds (Barodt 1996). As much as two fifths of India's irrigated area is affected by salinization and alkalinity (Repetto 1994). This has major, though undocumented, implications for the income of people living in affected areas.

Health implications associated with groundwater quality concerns may have even larger implications for poverty. Access to good quality groundwater supplies for drinking is a major factor reducing the incidence of water borne diseases. This can, in turn, have a major impact on poverty because disease is a major factor reducing productivity and the ability of people to engage in a wide variety of economic activities. As a result, groundwater was initially developed in many areas in order to provide a clean source of domestic water supply and reduce disease.

The health benefits of groundwater development are in many areas now being undermined by water quality problems. The case of arsenic in Bangladesh, India and to a lesser extent Nepal is illustrative. In West Bengal, high levels of arsenic are found in water supplies underlying nearly 39% of the state and, within the affected area, millions of people may be affected (Bhattacharya *et al.* 1996). Arsenic problems are even more well-known in Bangladesh where perhaps 21 million people are currently estimated to be at risk and some 200,000 cases of arsenic poisoning are known (British Geological Survey 1999). Arsenic from geological sources has caused poisoning outbreaks in Mexico, Argentina, Chile, Taiwan, Inner Mongolia, China, Japan, India and Bangladesh (Nordstrom 2000). Health problems associated with arsenic and other contaminants such as fluoride in groundwater can contribute substantially to poverty. In the case of fluoride, for example, skeletal fluorosis causes joints to stiffen and can severely cripple affected individuals. It has been a well known problem associated with groundwater in parts of India since the early 1980s (Centre for Science and Environment 1982). In villages where fluoride levels are high in, for example, Gujarat, many working age people are severely affected and their ability to contribute economically is greatly reduced (Moench & Matzger 1994).

As the above example illustrates, there is clearly a connection between emerging groundwater quality problems, health and poverty. That connection has not, as far as I have been able to determine, been systematically documented. It is important to recognize, however, that the health and human productivity dimensions of poverty associated with access to groundwater are probably equally important as the availability and reliability of water supplies for agriculture and other economic activities.

6 CONCLUSIONS

There is relatively strong empirical evidence linking improvements in groundwater access for rural agricultural communities to reductions in poverty. Improvements in groundwater access reduce agricultural risk and increase productivity. As a result, they generally increase the income of farm families. Technologies such as treadle pumps that enable very small landowners to obtain direct access to groundwater can have a particularly large impact on poverty. Benefits extend beyond well owners to the wider regional economy through increases in demand for labor and other agricultural support services. In addition, increasing access to groundwater can reduce the prevalence of water bourn diseases and, through health improvements, reduce poverty. Data from India strongly suggest that groundwater development has been a major factor contributing to poverty reduction over the last five decades in many states.

While reductions in poverty associated with groundwater development are relatively clear, the impact of groundwater problems (over-extraction and quality declines) on poverty is less so. On a local scale, there are clear cases in locations such as Yemen, where groundwater overdraft has caused the impoverishment of local communities. Such relatively clear-cut cases tend, however, to occur in areas where opportunities to shift out of agriculture and into other forms of economic livelihood are limited. For many communities in Yemen, agriculture is the only obvious form of economic activity. As a result, loss of a key productive resource is devastating.

The impact of groundwater overdraft in other areas is less clear. While over-extraction and associated quality problems are affecting large areas, such as the coastal belt and deep aquifers of Gujarat, economies in most such regions are much better connected with regional and global economies than in Yemen. Research on water transfers in the USA clearly indicates that loss of access to water does have a significant economic impact on the affected area *–but this does not necessarily imply a net increase in poverty*. In this type of situation, those losing access to water for agricultural uses may be able to migrate or develop other forms of livelihood. The affected rural area may develop into a *pocket of poverty* but it is unclear whether this is because only the poor remain behind when others migrate or whether the entire original population faces a reduction in income and living standards. Much more direct impacts on poverty probably occur in when drought suddenly affects areas where groundwater overdraft has already resulted in significant water level or quality declines. Under these circumstances, communities can face major reductions in income and production forcing them to migrate or sell accumulated assets and, thus, substantially increasing poverty.

The association between groundwater quality deterioration, health and poverty is, in most cases, similar to the overdraft situation. Local impacts in specific cases (arsenic in Bangladesh, fluoride in Gujarat) have been documented relatively clearly. Larger scale impacts could be present but have not been systematically investigated.

Poverty is one of the largest challenges facing the world in the coming century. Increasing access to groundwater has had a major impact on poverty in parts of the world and could contribute substantially to poverty reduction in other areas. This said, emerging over-exploitation and quality concerns may threaten some of the poverty alleviation benefits that have already been achieved. Reductions in poverty associated with groundwater development occur due to the confluence of many factors –reductions in risk, increases in productivity, improvements in health, reductions in labor expended to obtain water for domestic uses, and so on. Potential increases in poverty associated with emerging groundwater problems would also occur through similar complex pathways and would depend on the interaction between numerous seemingly unrelated factors. If the world is to be successful in reducing poverty –or managing groundwater– better understanding of the links between groundwater and poverty will be required. As this chapter has documented, systematic documentation and understanding is lacking in many key areas.

The world now faces massive migrations of refugees fleeing war and drought from locations such as Afghanistan. Stabilizing these countries will require the development of sustainable livelihoods for their populations. As IFAD (2001) comments, agriculture tends to employ the poor, increase their food security and has a low cost per workplace in comparison to other livelihoods. Sustainable development of groundwater could, as a result, contribute substantially to creation of livelihoods and help to address the instability created by poverty and migration. Unsustainable development leading to depletion of available water resources and the decline of agricultural livelihoods could, on the other-hand, contribute substantially to the instability.

What does all this imply for groundwater management? The standard interpretation would probably be that the link with poverty highlights the importance of managing aquifers on a sustainable basis. In many locations, however, unsustainable use patterns on the short-run are an important strategy enabling communities to move first out of poverty and ultimately into non-agricultural livelihoods. Furthermore, in many parts of the world *management* in the traditional sense of an ability to control or regulate groundwater use may be unachievable (Moench 2002). As a result, instead of emphasizing the need for regulatory forms of management, the role of groundwater in social transition implies that a wider focus may be required.

If populations can be assisted to transition successfully from water intensive agricultural livelihoods to less water intensive livelihoods, then many groundwater problems may, in effect, resolve themselves. Furthermore, if such wider social transitions can be achieved, remaining groundwater problems may prove far more amenable to traditional forms of groundwater management. Instead, for example, of attempting to manage the hundreds of thousands of individual wells owned by individual farmers that tap aquifers in South Asia, reductions in the population dependent on agricultural livelihoods could lead to smaller –more highly educated– groups involved in the day to day business of agriculture. This could, in turn, create the social basis for more direct forms of groundwater management.

REFERENCES

Barodt, J.M. 1996. Occurrence of salinity in Gujarat. *Reaching the Unreached: Challenges for the 21st Century*, New Delhi, WEDC, Loughborough University, Leicestershire.

Bavadam, L. 2001. Dealing with drought. *Frontline*. 18, June 9–22, 2001.

Bhattacharya, P.; Chatterjee, D. *et al*. 1996. Safeguarding groundwater from arseniferous aquifers. *Reaching the unreached: Challenges for the 21st Century*, New Delhi, WEDC, Loughborough University, Leicestershire.

British Geological Survey 1999. *Groundwater Studies for Arsenic Contamination in Bangladesh*. Phase 1: Rapid Investigation Phase. Final Report. Dhaka London, British Geological Survey and Mott MacDonald Ltd., in cooperation with the Government of the People's Republic of Bangladesh, the Ministry of Local Government, Rural Development and Cooperatives, the Department of Public Health Engineering, and the Department for International Development (UK).

Burke, J. & Moench, M. 2000. *Groundwater and Society: Resources, Tensions, Opportunities.* New York, United Nations.

Central Ground Water Board 1995. *Groundwater Resources of India*. Faridabad, Central Groundwater Board, Ministry of Water Resources, Government of India, June 1995.

Centre for Science and Environment 1982. *The State of India's environment 1982: a citizens' report. Centre for Science and Environment*. New Delhi, Ambassador Press.

Chambers, R.; Saxena, N.C. & Shah, T. 1987. *To the Hands of the Poor, Water and Trees*. New Delhi, Oxford and IBH publishing company.

Chavda, D. 2000. Drying borewells take contractors deeper. *Indian Express*. Ahmedabad, January 15, 2000.

Checchio, E. 1988. *Water Farming: The Promise and Problems of Water Transfers in Arizona*, Issue Paper Number Four. Tucson, Water Resources Research Center, University of Arizona.

Datt, G. & Ravalon, M. 1996. *Macroeconomic Crises and Poverty Monitoring: A case study for India*. Washington, D.C., World Bank.

Dhawan, B.D. 1982. *Development of tubewell irrigation in India*. New Delhi, Agricole Publishing Academy.

Dhawan, B.D. 1993. *Trends and new tendencies in Indian irrigated agriculture*. New Delhi, Commonwealth Publishers.

Dhawan, B.D. 1995. *Groundwater depletion, land degradation and irrigated agriculture in India*. New Delhi, Commonwealth Publishers.

Drez, J.; Sen, A. *et al*. (eds.) 1995. *The Political Economy of Hunger*. New Delhi, Oxford University Press.

Foster, J.; Greer, J. & Thornbecke, E. 1984. A class of decomposable poverty measures. *Econometrica* 52: 761–766.

Gleick, P. & Nash, L. 1991. *The Societal and Environmental Costs of the Continuing California Drought*. Oakland, Pacific Institute for Studies in Development, Environment and Security.

GOI 1992. *All India Report on Agricultural Census, 1985-86*. New Delhi, Government of India, Ministry of Agriculture.

GOI 1996. *Report of the Working Group on Minor Irrigation for Formulation of the Nineth Plan (1997-2002) Proposals*. New Delhi, Government of India, Ministry of Water Resources.

Gyawali, D. & Dixit A. 1999. Fractured Institutions and Physical Interdependence: Challenges to Local Water Management in the Tinau River Basin, Nepal.

Rethinking the Mosaic: Investigations into Local Water Management. M. Moench, E. Caspari & A. Dixit. (eds.) Kathmandu, Nepal Water Conservation Foundation, Institute for Social and Environmental Transition: 57–123.

Herdt, R.W. & Wickham, T. 1978. Exploring the gap between potential and actual rice yields: the Philippine case. *Economic Consequences of the New Rice Technology*. Los Baños, Philippines, International Rice Research Institute.

Hernández-Mora, N.; Llamas, M.R. & Martínez Cortina, L. 2001. *Misconceptions in aquifer overexploitation: implications for Water Policy in Southern Europe*. Workshop SAGA (FAIR-CT97-3673), Milan. Fondazione Enni Enrico Mattei: 107–126.

IFAD (International Fund for Agricultural Development) 2001. *Rural Poverty Report 2001: the challenge of ending rural poverty*. Oxford University Press.

Kahnert, F. & Levine, G. 1989. *Key Findings, Recommendations, and Summary.* Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin, Washington, D.C., The World Bank.

MacDonnell, L.J. & Howe, C.W. 1986. Area-of-Origin Protection in Transbasin Water Diversions: An Evaluation of Alternate Approaches. *University of Colorado Law Review* 57: 527–548.

Meinzen-Dick, R. 1996. *Groundwater Markets in Pakistan: Participation and Productivity.* Washington, D.C., International Food Policy Research Institute.

Moench, M. 1991. *Social Issues in Western U.S. Groundwater Management: An Overview*. Oakland, Pacific Institute.

Moench, M. 1992. Drawing Down the Buffer. *Economic and Political Weekly* XXVII(13): A-7-A-14.

Moench, M. 1993. Preface. *Groundwater management: the supply dominated focus of traditional, NGO and Government Efforts*. M. Moench. Ahmedabad, VIKSAT: 1–4.

Moench, M. 2002. *When management fails: evolutionary perspectives and adaptive frameworks for responding to water problems*. Boulder, Working Paper, Institute for Social and Environmental Transition.

Moench, M. & Matzger, H. 1994. Groundwater availability for drinking in Gujarat: quantity, quality and health dimensions. *Economic and Political Weekly* XXIX(13): A-31-A-14.

Moench, M.; Caspari, E. *et al*. (eds.) 1999. *Rethinking the mosaic: investigations into local water management. Kathmandu.* Nepal Water Conservation Foundation and the Institute for Social and Environmental Transition.

Morris, M. 1997. *Social capital and poverty in India.* IDS Working Paper 61, Brighton, Institute of Development Studies.

Nordstrom, K. 2000. An overview of mass-poisoning in Bangladesh and West Bengal, India. *Minor Elements 2000, Processing and Environmental Aspects of As, Sb, Se, Te, and Bi.* Young and Courtenay, Society for Min. Metall. Expl.: 21–30.

Nunn, S.C. & Ingram, H.M. 1988. Information, the decision forum, and third-party effects in water transfers. *Water Resources Research* 24(4): 473–480.

Oggins, C.R. & Ingram, H.M. 1990. *Does anybody win? The community consequences of rural-to-urban water transfers: an Arizona perspective*. Tucson, Udall Center for Studies in Public Policy, May 1990.

Perry, C.J. & Narayanamurthy, S.G. 1998. *Farmer response to rationed and uncertain irrigation supplies*. Colombo, International Water Management Institute: 15.

Rao, D.S.K. 1996. Treadle Pumps: Boon to marginal farmers in the eastern region. *Economic and Political Weekly* XXI(30).

Rao, C.H.H.; Ray, S.K. *et al*. 1988. *Unstable agriculture and droughts: implications for policy*. New Delhi, Vikas Publishing House.

Repetto, R. 1994. *The second India revisited: population, poverty, and environmental stress over two decades*. Washington, D.C. World Resources Institute.

Seckler, D. & Amarasinghe, U. 1999. *Water supply and demand, 1995 to 2025: Water scarcity and major issues*. Colombo, International Water Management Institute: 40.

Sen, A. 1999. *Poverty and famines*. Delhi, Oxford University Press.

Shah, T. 1993. *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*. Bombay, Oxford University Press.

Shah, T.; Alam, M.; Dinesh Kumar, M.; Nagar, R.K. & Singh, M. 2000. *Pedaling out of Poverty: Social Impact of a Manual Irrigation Technology in South Asia.* Colombo, International Water Management Institute: 36.

Times of India 2000. Debt and migration, but no relief. *Times of India*. Ahmedabad: 3.

Tsur, Y. 1990. The Stabilization Role of Groundwater when Surface Water Supplies are Uncertain: The Implications for Groundwater Development. *Water Resources Research* 26(5): 811–818.

Tsur, Y. 1993. *The economics of conjunctive ground and surface water irrigation systems: basic principles and empirical evidence from Southern California*. Department of Agricultural and Applied Economics, Report Number P93-15, Staff Paper, University of Minnesota.

United Nations Development Program 1976. *Groundwater surveys in Rajasthan and Gujarat*. New York, United Nations Development Program.

Woodard, G.C. 1988. *The water transfer process in Arizona: analysis of impacts and legislative options*. Tucson, Division of Economic and Business Research, College of Business and Public Administration, The University of Arizona.

World Bank 1998. *India-water resources management sector review, groundwater regulation and manage-*

ment report. Washington D.C., New Delhi, World Bank, Goverment of India.
WRAY-35 1995. *The water resources of Yemen*. Sana'a, General Department of Hydrology, Republic of Yemen, TNO Institute of Applied Geoscience, and Kingdom of the Netherlands, March, 1995.