International Growth Centre

Patterns of migration, water scarcity and caste in rural northern Gujarat

Ram Fishman[a], **Meha Jain**[b] and **Avinash Kishore**[c]

[a] George Washington University (contact: rfishman@gwu.edu), [b] Columbia University (contact: mj2415@columbia.edu), [c] International Food Policy Research Institute (contact: avinash.kishore@gmail.com)

Working Paper
February 2013

International Growth Centre
London School of Economics and Political Science
4th Floor,
32 Lincoln's Inn Fields
Houghton Street
London WC2A 2AE
United Kingdom

For media or communications enquiries, please contact Mazida Khatun
mazida.khatun@theigc.org

Directed and Organised by
LSE
University of Oxford

www.theigc.org

Patterns of Migration, Water Scarcity and Caste in Rural Northern Gujarat

Report Submitted to the IGC India Country Program

Ram Fishman[1], Meha Jain[2] and Avinash Kishore[3] *

Abstract

We document patterns of rural-urban migration and employment shifts in a region that is facing ongoing depletion of groundwater resources in Northern Gujarat, India. Given that migration typically does not occur due to one singular risk, our study assessed the multi-factorial drivers of migration. Survey results revealed migration and employment shifts were dominated by the Patel caste, which is the dominant landowning caste in the region. Migration by younger males in this group is highly prevalent, and is correlated with the degree of water depletion, land scarcity, and family ties to workers who have previously migrated to urban areas. Among castes with traditionally little or no land ownership, migration rates are much lower. These results suggest that social and economic factors, including caste type, land holding size, and social networks, mediate the ability of households to respond to groundwater depletion via migration to urban centers.

---

[1] Department of Economics, George Washington University
[2] Department of Ecology, Evolution, and Environmental Biology, Columbia University
[3] International Food Policy Research Institute, India

* This study was conducted under a grant from the International Growth Centre (IGC) India Country Program. We are grateful for IGC's financial support and helpful comments from anonymous reviewers. We are also grateful for the logistical support of SaciWaters, and in particular to Anjal Prakash and Sreenivasulu Chedubavi. We thank Abhishek and Nandish Kenya for their dedicated fieldwork. We thank the Columbia Water Center India for their support, in particular Shama Perveen, Dishant Patel, Nikunj Patel, Ankur Patel, Anil Kumar and Sandeep Mahajan. We thank Anjal Prakash and Prabhat Barnwal for insightful comments and suggestions.

I. Introduction and Background

Environmental migration is an old phenomenon: for millennia, human populations were driven to migrate away from areas affected by different forms of environmental and climatic stress (McLeman and Smit 2006). It is also widely projected that future environmental stress including growing water scarcity and climate change will result in mass migration due both to push factors, like agricultural income shocks caused by increasing climate variability, and pull factors, including higher and more stable salaries from urban professions (IPCC Report 2007, World Development Report 2009, Warner 2010). While possible environment-related migration has been widely discussed in the academic and policy literature, there is little quantitative evidence by which to assess these claims.

In this study we document spatial correlations between rural-to-urban migration rates, rural employment shifts out of agriculture, and environmental stress associated with groundwater depletion in the Indian state of Gujarat.

Increasing water scarcity is expected to threaten the livelihoods of hundreds of millions of farmers in semi-arid, developing countries (Vörösmarty et al 2000). One particular form of water stress arises from the depletion of groundwater resources (Konikow and Kendy 2005, Wada et al 2010) and India, the world's largest consumer of groundwater, is the country probably most vulnerable to this threat (World Bank, 1998; World Bank, 2010; Shah, 2010; Fishman et al, 2011; Fishman, 2011). Our study took place in the northern districts of the state of Gujarat, where agriculture is critically reliant on groundwater irrigation but where depletion has been a concern for decades (UNDP, 1976; Postel, 1999; Moench, 1992).

Water tables in our study area have been rapidly falling over the last 3-4 decades (figure 2), but the rates of decline have been spatially uneven. Our survey results indicate migration and employment shifts tend to be more common in locations that experience more extreme groundwater depletion (deeper water tables). On average, we estimate that an additional 100 feet of water table decline is associated with an increase of about 15% in the odds ratio that a household will have at least one migrant son, as well as at least one son shifting out of agriculture (but remaining in the village). However, we find that these adaptive responses are much more prevalent among the dominant socio-economic groups (land-owning castes), and are much less common amongst the landless and marginal land owning castes.

The correlations we find hold when other candidate drivers of migration are controlled for, including land scarcity and access to social networks in cities. As expected, households with less available land per son, larger overall land holding (a proxy for wealth), relatives in cities and migrant brothers (brothers of the male head of household) are more likely to have sons migrating. However, additional data is required to interpret this correlation casually and to rule out the possibility that unobserved confounding factors are driving the results (such as spatial patterns in water table declines, which we address partially by including regional fixed effects in our regressions), and future drafts of this paper will attempt to address this. At this stage, we can suggest two possible mechanisms.

Respondents in some of the most water-scarce villages in the area claimed the high rates of migration from these villages were the result of water stress, and local well drillers we interviewed reported that the deep water tables in these villages were a result of highly localized geological conditions. According to this interpretation, environmental stress is acting as a "push factor", driving those who can (especially those who have social networks in cities)[4] to migrate to cities in search of better employment. Migration here is therefore an adaptive response to the growing problem of water scarcity by relatively well-off and proactive households. The poor remain in the village and continue to rely on agriculture as their main source of income (Burke and Moench, 2000), and our survey shows that they often lease or sharecrop (but not buy) land "left behind" by migrant landowners.

However, an alternative possible explanation of the correlations we observe is that those farmers, or communities, who have extracted their groundwater resources more effectively and rapidly, had invested the associated rents in ways (e.g. higher education) that facilitated the observed employment shifts and migration.[5] These rents were almost

[4] As one young respondent from these castes groups explained:

> *"Wage rates are not much higher in Ahmedabad [the near big city] than in the village for low-skilled workers while room rents and food prices much higher. Unlike Patels [Land Owning Caste], we do not have close relatives in the city who would let us live with them for free. Nor can we expect any financial support from our families in the village in the first few years when we are working on low-pay jobs."*

This is consistent with the important role of the social network, especially caste networks, in facilitating migration to cities. Most migrants seek and receive help from member of their own extended family and caste and not from their co-villagers of a different caste. Banerjee (1983) in his survey of immigrants to Delhi and Munshi and Rosenzweig (2007) in their nationally representative survey also find family and caste networks to be the most important in facilitating or restricting migration.

[5] For example, evidence from Kerala suggests that remittances contributed to higher water consumption for agricultural purposes, thereby potentially intensifying water stress (Pohle and Knerr, 2010).

entirely captured by the land and bore-well owning dominant caste, which explains why landless castes are unable to migrate.

In any case, we do not suggest that water stress and groundwater depletion are the major drivers of migration. Groundwater depletion and the associated migration is taking place against a background of equally rapid economic and social changes in this economically fast growing state that are also likely to be stimulating migration.[6] A rough estimate from our data is that some 20% of migration may be attributed to the decline in water availability for irrigation. Consistently, respondents attributed about 20% of their sons' migration to water scarcity. Looking beyond north Gujarat, however, this finding suggests migration may be an important mode of response to depletion in the many other parts of India where water tables are falling, but are still "trailing behind" north Gujarat in depth.

This paper contributes to the emerging empirical literature on environmental migration. Much of the discussion on environmental migration is based on qualitative investigations and case studies (Warner et al 2009, Feng, Krueger and Oppenheimer, 2010), but several recent studies have attempted to provide systematic, causal quantitative evidence relating environmental stress to migration. Hornbeck (2012) shows that the "dust bowl" of the 1930s in the American west resulted in large population declines in affected areas. Feng, Krueger and Oppenheimer (2010) find that rainfall induced production shocks result in increased immigration from Mexico to the U.S.

Migration related to groundwater depletion is a comparatively recent development (Brown, 2004) but there is some anecdotal evidence indicating out-migration from areas where water and other natural resources are becoming degraded (Chopra and Gulati, 2001; Vighneswaran and Ranjini 2006; Nair and Chattopadhyay 2005)[7] The relation between groundwater depletion and migration in North Gujarat is suggested by Moench (2002), and explored in depth in a study of a few villages in the area by Prakash (2005). As far as we are

---

[6] For example, respondents from land-owning castes commonly reported the difficulty of marrying off sons that are still engaged in agriculture, a reflection of changing social attitudes and increasing economic prospects. Similarly, almost all land owning respondents saw no future in agriculture for their sons and wished a "better life" for them, both in light of the disappearing water resources but also more generally.

[7] Much of this evidence, however, is qualitative in nature. Moench (2002) contends that it is not possible to quantitatively document the extent of migration occurring in India as a result of groundwater overdraft mainly because aquifers often transcend administrative units (villages, blocks, and districts) for which demographic and economic data are collected.

aware, however, our paper is the first to document a systematic correlation between groundwater depletion and migration over substantial spatial scales.

Our results are also related to the relationship between agricultural productivity and structural transformation and economic diversification (Foster and Rozensweig 2008). They suggest that declines in agricultural productivity (as a result of water scarcity) lead to increased labor shifts away from agriculture. This is broadly consistent with Foster and Rosensweig (2002), who find that rural industrial growth in India was faster in villages that experienced relatively low rates of agricultural growth, and with Hornbeck and Keskin (2012), who find no evidence for a long-term expansion of non-agricultural sectors in areas of the great plains of the U.S. that benefitted agriculturally from improved groundwater access in the 1930s.

The literature on migration distinguishes between voluntary migration to urban areas based on "pull" factors, like better income opportunity and quality of life in cities[8], from involuntary migration based on "push" factors like drought and other short-term income shocks. [9] Our results also confirm the important role played by social networks in India in enabling migration to cities, but also show that push (water and land scarcity) and pull factors (contacts in cities) can operate in parallel.

---

[8]Work on rural-urban migration which is focused on "pull" factors often builds upon the Harris-Todaro model (1970) which, explains migration as a function of expected rural-urban wage difference adjusted by the probability of finding a job in the urban area.

[9] Rhoda (1983) explored push factors of rural-urban migration and found that rural interventions that increase cultivable land, and redistribute land and income tend to reduce migration while interventions that increase inequality, improve access to cities, commercialize agriculture, and raise education and skills lead to increases in migration. Banerjee (1981) found that caste networks play an important role in facilitating migration to Delhi from other parts of India. Munshi and Rosenzweig (2008) propose that rural caste networks, which provided insurance against shocks for centuries in an economy where markets did not function well, restrict geographical mobility in India. Bird and Deshingkar (2009) explore circular migration and find that rates of migration are higher among the poor and more socially marginalized (the "scheduled castes", "scheduled tribes", and Muslims), especially in drought prone regions. In a survey of seasonal migrants in 70 villages in Gujarat, Rajasthan, and Madhya Pradesh, Coffey, Papp and Spears (2012) find that less educated people are more likely to migrate than more educated people and people from poorer households are more likely to migrate than people from richer households. A study of immigrants in Bangalore by Sridhar, Reddy and Srinath (2010) finds that the lower the level of education of the migrant, the greater the importance of the push factors whereas with increasing level of education of the migrant, pull factors become more important in migration.

II. Methodology and Data

Our surveys were carried out in a region of Northern Gujarat known for its groundwater depletion (Jain et al., in prep.; Columbia Water Center 2010). Interviews with local well drillers identified a group of about 15 villages that were especially water scarce due to unique geological conditions. In addition, we randomly selected about 50 additional villages in the surrounding areas, that included seven *talukas* (sub-district administrative units) in three districts (figure 1). In each village, about 10% of household were then randomly selected for the survey.

The surveys included questions on agricultural practices, assets and household demographics, and heads of households were asked about the primary activities and places of residence of each of their sons and brothers. We focused on migration of male family members because female family members mostly migrated out of villages generally due to marriage and not because of the drivers, including groundwater depletion, that are of interest in our study.

III. Summary Statistics

Access to Water. About 88% of the household surveyed reported that the male head of the household was engaged in agriculture. Agriculture in this semi-arid area is highly dependent on irrigation, and groundwater provides the principal source of irrigation water. Table B1 displays some of the characteristics of irrigation and agriculture in the sample region. Because of the deep water tables prevailing in the region, bore-wells tend to be extremely deep (typically 300-1000 feet, with an average depth of 580 feet) and use powerful pumps (53 HP on average).

Access to water in this area is determined by a rather complex matrix of cooperative well ownership and water markets. As shown in table B1, a typical farmer obtains water from 1.7 borewells, either as a share-holder in the well or as a water buyer. Shareholders are members of a bore-well cooperative, where anywhere from two to one hundred farmers share the initial cost of constructing a well, and then receive a percentage of the irrigation provided by the well equal to the percent paid for the initial investment. Water buyers, on the other hand, are farmers who are not a part of this cooperative and instead pay for irrigation depending on usage (effectively, per hour) when shareholders are willing to sell surplus water from their borewells.

The confined aquifers on which the region's agriculture is crucially dependent have a very low rate of natural recharge and have been mined by local farmers for several decades. Data from monitoring wells maintained by the Government of Gujarat provide dramatic evidence of the fall of local water tables (figure 2), at an average rate of 3 meters per year for the last three decades. This is probably one of the highest rates of water table decline in India (Fishman 2011).

To cope with falling water tables, farmers have mostly resorted to deepening wells and the use of more powerful pumps. Table B1 shows that farmers recall current wells to be 220 feet deeper than they were a decade ago, and pumps to be more powerful by 20 HP. However, the possibility of adapting through increased energy use is limited, and water scarcity has become a real constraint on agricultural cultivation. This is manifested in the reduced water flow from wells. As table B1 shows, farmers report an average increase of 2.3 hours in the time required to irrigate one wheat parcel of a given size over the last decade, which is an increase of about 60%. The decreased availability of water seems to have forced farmers to reduce the area under cultivation in the rainless winter and summer seasons, when irrigation is critical for cultivation, by about 7% and 17% respectively.[10] There are also indications of reductions in the number of irrigations applied to crops, but in smaller relative amounts.

Differences among Caste Groups. We divided the multiple castes present in the area into two caste-based land owning categories: the major *land-owning* castes, essentially *Patels*, who traditionally own the majority of land, and the marginal or landless castes, who traditionally own no or little land and work as agricultural laborers. The marginal castes sometimes own small parcels of land, especially in villages where *Patels* are absent.

As tables B2 and B3 show, a farmer's land tenure of cultivated land (ownership vs. rental) and the borewell he gets irrigation water from (co-ownership vs. water buying) are correlated with caste. Among land-owning castes, 96% own the land that they cultivate, whereas among marginal land-owning castes, 8% are share-croppers and 19% are landless agricultural laborers. Similarly, among land-owning castes, 77% of cultivators own a share in a well, and 20% purchase water as their primary water source. Among the marginal land-owning castes, an approximately equal share of farmers are share-holders (49%) and water buyers (47%). This distribution does not seem to have changed substantially over the last decade (based on recall).

---

[10]In some parts of our study area, called *dark zones*, where depletion is extreme, the public utility company has enacted strong limitations on the ability to get new electrical connections for groundwater pumps, and in such area, increasing access to water through the drilling of new bores is not an available adaptation strategy to farmers.

Table B4 reports additional differences between the two caste categories. Land-holding caste members have higher asset holdings in every single category other than buffaloes, which are considered an inferior livestock to cows because of the lower amount of milk they produce. Respondents belonging to land-owning castes were also substantially more likely to have sons that have exited from agriculture while residing in the village, and more likely to have brothers (32% vs. 15%) and sons (43% vs. 12%) that have migrated from the village to larger cities compared to marginal land-holding castes. In other words, like assets and land, migration and labor shifts are dominated by the large land-owning castes.

Exit from Agriculture. Our surveys requested heads of households to report the primary activity of each of their sons and brothers. Results are displayed in tables B6 for brothers, and B10 for sons. Of sons (table B10), 34% are working in non-agricultural related activities, but again, the rate is much higher for large land-owners (55%) than for the marginal land-owning castes (24%). Furthermore, even within agriculture, as expected, almost all land-owners are cultivators, while 23% of marginal land-owning castes are landless agricultural laborers. Land-owners' sons are also slightly more likely to be receiving education over the age of 15. A similar pattern hold for respondents' brothers (tables B6), but less so. Overall, 21% are not farming, with 32% for land-owners and 17% for marginal land-owning castes.

Migration. Our approach to the measurements of migration rates consisted of requesting information about the place of residence of the brothers and sons of each head of household we interviewed. The main drawback is that we miss households where all family members have migrated, probably resulting in an underestimate of the extent of migration.

Table B9 displays summary statistics about the place of residence of all sons of households we sampled. In the entire sample, about 16% have left the village, almost all of them for urban areas, rather than to other villages. However, here too, we see strong differences along caste lines. Among the larger land-owners, almost 38% of sons have migrated, whereas among the marginal land-owning castes, only 7% migrated. A similar pattern holds for brothers of household heads sampled, although the extent is smaller (Table B5). Overall, about 16% of brothers have left the village, with a rate of 28% for land-owners and 11% for the marginal land-owning castes.

Interestingly, the stated reasons for migration also differ between the two caste categories. As tables B8 (brothers) and B12 (sons) show, the most prominent reason stated is better employment opportunities, which is a "pull" factor. Push factors like land scarcity (17%) and water scarcity (13%), on the other hand, are less dominant but still significant causes of migration for the sons of land-owning castes; it is likely that push factors are more prominent in the generation of sons than brothers given that water scarcity is a more recent phenomenon. Of course, reasons reported by the respondents may not be accurate and the real reasons may be a combination of several factors. The regressions that follow will attempt to assess the importance of these various push and pull drivers for migration out of agriculture in this region.

IV. Regression Results

To assess the importance of various push and pull drivers for migration and employment shifts, we regressed the rates of migration of respondents' brothers and sons on indicators of water scarcity, land scarcity, social networks, and wealth.

Tables B15 and B16 report regressions of the prevalence of non-agricultural employment among those brothers and sons of the survey respondents who have remained in the village – i.e. have pursued non-migratory employment shifts. Tables B13 and B14 report similar results for the prevalence of migration. In each table, columns 1-5 report logistic regressions of a dummy variable indicating whether any of the respondent's brothers or sons engage in non-agricultural work as their primary activity, but are still residing in the village (tables B15-B16) or migrate (tables B13-B14). Columns 6-10 report linear regressions where the dependent variable is the (continuous) percentage of brothers or sons that pursue non-agricultural work as their primary activity (B15-B16), or migrate (tables B13-B14). In each group, the second column includes *taluka* (sub-district administrative unit) fixed effects and the third column includes village fixed effects. The fourth column restricts the sample to the land-owning castes and the fifth column restricts the sample to the landless or marginal land owning castes.

In the regressions for brothers (tables B13 and B15), the explanatory variables include the reported change in the water table during the last decade (a proxy of water scarcity), land holding (a proxy of household wealth), the presence of any relatives in a big city (social networks), and an indicator for the land-owning caste (in the first three regressions only). In the regressions for sons (tables B14 and B16), we also include the amount of household land available per son (land holding of the household head divided by the number of sons) as an indicator of land scarcity, and a dummy indicator of whether any of the respondent's brothers (the sons' uncles) have exited agriculture or migrated.

Starting with migration (tables B13 and B14), we see that for the older generation of respondents' brothers (tables B13), the only statistically significant association of migration is the presence of relatives in a big city – confirming the importance of social networks.

For the younger generation (sons), however, all other drivers show statistically significant impacts that align with our predictions. Households are more likely to have at least one son migrating if they have relatives in the city or an uncle that has already migrated, if they are wealthier (have larger land holdings), if there is less land available per son (land scarcity), and if they belong to the land holding class – in fact, the above associations are only statistically significant for that group. Moreover, households are more likely to have migrant sons if they report higher rates of water table declines (this estimate does not survive village fixed effects, perhaps due to the lower variation in water depth within the same village). The more conservative point estimate of 0.13 suggests that the average reported water table drop of 220 feet was responsible for a 28% increase in the frequency of households that have migrant sons. In terms of the percentage of migrant sons, the 0.02 point estimate suggests water table drops increased migration by a more modest 4.5%.

Moving to employment shifts (exit from agriculture), we see that for brothers, none of these factors have a statistically significant effect. As we have seen, non-migratory employment shifts are uncommon among this generation. For the younger generation (sons), water scarcity emerges as the only variable with a statistically significant impact. The point estimate suggests that every additional 100 feet of decline in water tables is associated with a 15% increase in the likelihood of employment shifts for a household.

V. Conclusion

Adaptation to environmental stress, and water scarcity in particular, can take many forms. Within the agricultural domain, farmers may be able to adapt farming practices and technologies that would allow them to maintain their production even while reducing their water usage. Alternatively, farmers may also choose to shift away from agriculture and migrate from areas that face severe water decline.

In this study, we find evidence to suggest that the primary modes of adaptation pursued by socially advantaged (dominant castes) farmers in an increasingly water-scarce region of India are migration to cities and employment shifts away of agriculture. The ability to migrate and to shift income sources may have been instrumental in avoiding some of the more pessimistic predictions about the eventual impacts of water depletion, for which we find no evidence in the study area (but we do not claim to be able to provide an accurate assessment of the wealth or welfare of the household we surveyed).

The sort of environmental stress we study here is a gradual process, not a short-term shock. The fact that young farmers are choosing to migrate rather than to adapt agricultural practices may be an indication that such adaptation strategies are not readily available to them. Furthermore, our results suggest that migration opportunities may be largely available only to the dominant land-holding castes that have access to enough social and economic capital to transition away from agriculture. When and if groundwater depletion occurs over a larger geographical scale, migration possibilities may be crowded out, and the implications for agricultural production may be substantially negative. This case study does not allow us to predict the general equilibrium effects of such a process, but it can be a source of concern from the broader policy perspective on food security in India. In particular, we note that the great majority of migrant land-owners were reported to lease out their land, rather than sell it. This raises the concern that increasing amounts of land will be cultivated by individuals with few incentives to invest in that land's productivity or in agricultural infrastructure. The full impacts of migration on agricultural productivity are, however, beyond the scope of this seed study.

The difficulty of assessing the welfare impacts of groundwater depletion and of associated migration make it difficult to draw conclusive policy lessons from our study. Economists mostly consider the permanent movement from the agricultural sector into the non-agricultural sector and from rural to urban areas as an essential aspect of economic development (Todaro, 1969; Harriss and Todaro, 1970). However, among developing countries, India stands out for its remarkably low levels of occupational and geographic mobility.[11] The World Development Report (2009) argues that policy barriers to internal mobility in India are imposed by omission rather than by commission and that negative attitudes held by government and ignorance of the benefits of population mobility have caused migration to be overlooked as a force in economic development. Indeed, the government of Gujarat, for example, declares the reduction of rural to urban migration to be a prominent policy goal, and attempts to achieve it through infrastructural investments in rural areas.

Our results suggest that government policies to sustain irrigation in the region may have indeed reduced the rates of migration to cities and economic diversification. If it were not for the state government's long standing subsidization of electricity for groundwater pumping, falling water tables would have most likely constrained agriculture in the area years ago (Columbia Water Center 2010). Similarly, current plans already under

[11] India lags behind other countries with similar size and levels of economic development in this respect (Munshi and Rosenzweig, 2007). For example, only one-fifth of the urban growth in India between 1961 and 2001 is accounted for by net rural to urban migration and the process has not accelerated even in the last two decades of rapid economic growth (Mitra and Murayama, 2008, Kundu 2011). The gross decadal inflow of rural to urban migrants as a percentage of total urban population in 2001 was only around 7 percent (*ibid*). Also the majority of labour movement in India is not rural-urban migration, but from rural areas in poor states to those in relatively well-off state like Punjab, Gujarat and Maharashtra to work on the farm (World Development Report, 2009).

implementation to bring surface irrigation canals to this area through energy intensive lift irrigation programs may also relieve water scarcity. Our results suggest these policies, in addition to the high energy related costs they incur, may also slow down processes that are usually considered to be integral to economic growth. However, an estimate of the impacts of migration and diversification rates on overall growth is beyond the scope of this seed study and additional research will be needed in order to rigorously evaluate them.

References

Banerjee, B. (1983). Social Networks in the Migration Process: Empirical Evidence on Chain Migration in India. The Journal of Developing Areas, Vol. 17, No. 2 (Jan., 1983), pp. 185-196

Brown, Lester R. (2004). New flows of environmental refugees. http://www.peopleandplanet.net/doc.php?id=2134

Burke, J., Moench, M. (2000). Groundwater and Society: Resources, Tensions, Opportunities. Sales no. E.99.II.A.1. United Nations, New York.

Chopra, K., Gulati, S.C. (2001). Migration, Common Property Resources and Environmental Degradation.Sage, New Delhi.

Coffey, D., Papp, J. and Spears, D. (2012). Dual Economies or Dual Livelihoods? Short-Term Migration from Rural India and Non-Agricultural Employment.RICE Working Paper.http://riceinstitute.org/wordpress/wp-content/uploads/downloads/2012/12/nimns_paper.pdf

Columbia Water Center (2011). Addressing the Water Crisis in Gujarat, India. Columbia Water Center White Paper.

Deshingkar, P. (2006). Internal migration, poverty and development in asia. Technical report,ODI Briefing Paper.

Deshingkar, P. and E. Anderson (2004). People on the move: New policy challenges for increasingly mobile populations. Natural Resources Perspectives 92.

Fishman, R. M., Siegfried, T., Raj, P., Modi, V. and Lall, U. (2011), Over-extraction from shallow bedrock versus deep alluvial aquifers: Reliability versus sustainability considerations for India's groundwater irrigation, Water Resources Research, Vol 47.

Fishman, R.M. (2011), Falling Water Tables in India - a Review of the Evidence, Columbia Water Center Working Paper.

Foster, A., and M. Rosenzweig (2004). Agricultural Productivity Growth, Rural Economic Diversity, and Economic Reforms: India, 1970–2000. Economic Development and Cultural Change 52.3 (2004): 509-542.

Foster, A. and M. Rosenzweig (2002). Household division and rural economic growth. The Review of Economic Studies 69 (4), 839-869.

Foster, A. and M. Rosenzweig (2008). Economic development and the decline of agricultural employment. Handbook of Development Economics 4, 3052-3083.

Harris, J. and M. P. Todaro (1970). Migration, unemployment and development: A two sector analysis. American Economic Review 60 (1), 126{142.

Hornbeck R. (2012) The Enduring Impact of the American Dust Bowl: Short- and Long-run Adjustments to Environmental Catastrophe. American Economic Review [Internet]. 2012;102(4):1477-1507.

Hornbeck, R., and Keskin P. (2012) Does Agriculture Generate Local Economic Spillovers? Short-run and Long-run Evidence from the Ogallala Aquifer. No. w18416. National Bureau of Economic Research.

Konikow, L. F., and Kendy, E. (2005) "Groundwater depletion: A global problem." *Hydrogeology Journal* 13.1: 317-320.

Kundu, A. (2011) Politics and Economics of Urban Growth. Economic & Political Weekly, Vol. XLVI, No. 20, 10:12.

McLeman, R. and Smit, B. (2006). Migration as an Adaptation to Climate Change. Climatic Change. 76: 31-53.

Mitra, A. and Murayama, M. (2008), "Rural to Urban Migration: a district level analysis for India" IDE Discussion Paper No. 137, Institute of Developing Economies, Japan.

Moench, M. (1992). Drawing down the buffer. Economic and Political Weekly, XXVII (13): A7–A14.

Moench, M. H. (1992). Chasing the Watertable: Equity and Sustainability in Groundwater Management." Economic and Political Weekly: 171-177.

Moench, M. (1993). Preface to Groundwater Management: The Supply Dominated Focus of Traditional, NGO and Government Efforts. VIKSAT, Ahmedabad.

Moench, M. (2002). Water and the potential for social instability: Livelihoods, migration and the building of society, Natural Resource Forum, 26(2002), page 195-204.

Moench, M., Burke, J., Moench, Y. (2001). Through a Different Lens: The Question of Groundwater, Food Security, Uncertainty, Variability and Risk. FAO, Rome.

Munshi, K. and Rosenzweig, M. (2007). Why is Mobility in India so Low? Social Insurance, Inequality and Growth, IPC Working Paper Series Number 68, University of Michigan.

Pohle, A. and Knerr, B. (2010). Exploring Interactions between Water Resource Depletion and Remittances from Labour Migration: The Case of Kerala, Tropentag, September 14-16, Zurich

Postel, S. (1999). Pillar of Sand: Can the Irrigation Miracle Last? Norton, New York.

Prakash, A. (2005). The dark zone: groundwater irrigation, politics and social power in North Gujarat. Orient Blackswan

Rhoda, R. (1983) Rural Development and Urban Migration: Can we keep them down on the Farm? International Migration Review, 17 (1) (Spring): 34-64.

Shah, T. (2010), Taming the anarchy: Groundwater governance in South Asia, Resources for the Future Press Washington, DC

Sreedhar, K. S., Reddy, A. V. and Srinath, P. (2010). Is it Push or Pull? Recent Evidence from Migration in India. SANEI Report 10-04.

Todaro, M.P. (1969). A model of labor migration and urban unemployment in less developed countries, The American Economic Review, Vol 59: 138-49

United Nations Development Programme (1976) .Ground-water surveys in Rajasthan and Gujarat, United Nations Development Programme.

Vörösmarty, C. J., et al. (2000). Global water resources: vulnerability from climate change and population growth. *science* 289.5477 (2000): 284.

World Bank (2009). World Development Report: Reshaping Economic Geography, Washington, DC: World Bank.

World Bank (2010). Deep wells and prudence: Towards pragmatic action for addressing groundwater overexploitation in India. World Bank Technical Report.

World Bank and GOI (1998). India-Water Resources Management Sector Review: Groundwater Regulation and Management Report. World Bank, Washington, DC

Wada, Yoshihide, et al. (2010) Global depletion of groundwater resources. *Geophysical Research Letters* 37.20 (2010): L20402.

Warner, K. (2010). Global environmental change and migration: Governance challenges. *Global Environmental Change* 20.3 (2010): 402-413.

Appendix A. Figures

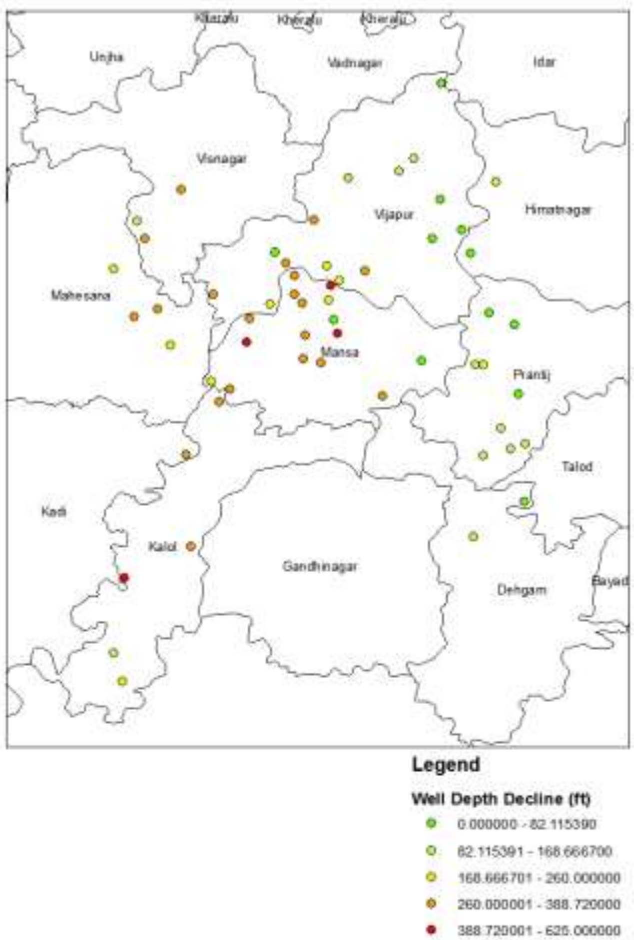

Figure 1. Map of the study area. Lines show the administrative boundaries of the sub-districts of Gandhinagar, Mahesana and Sabarkanta districts. Villages included in the survey are indicated in dots, and the mean reported decline in well depth is indicated by the colors.

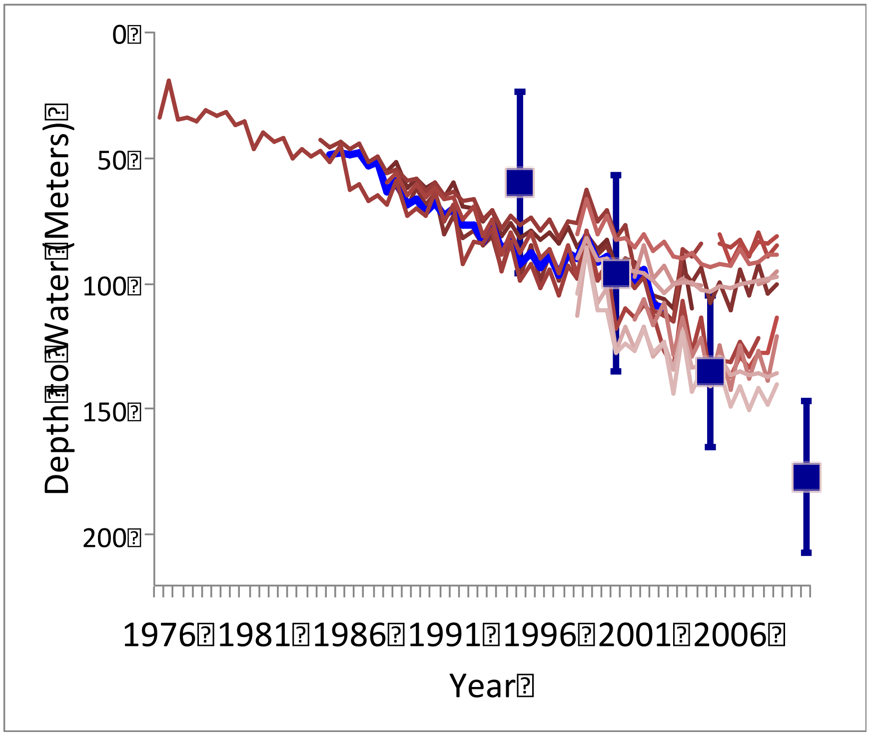

Figure 2: Depth to water, over time (red curves), in a collection of observation wells located in the study area (Vijapur Taluka). Blue error bars represent farmers' recall of the depth to water currently, and 5, 10, and 15 years ago.

Appendix B – Tables

Table B1: Changes in Irrigation and Agriculture Indicators and Assets over the Last Decade (2001-Present)

	N	Now	Past	Diff.	p
Time to Irrigate a Parcel	1088	5.8	3.5	2.3	0.00
Frequency of Access (Days between)	1080	16.3	11.8	4.5	0.00
Bore HP	985	53.2	33.2	20.0	0.00
Bore Depth (100 ft)	1034	5.8	3.6	2.2	0.00
No. Bores Used	1062	1.7	1.6	0.0	0.72
No. Bores, Has Share	675	1.5	1.5	0.0	0.97
No. Bores, Buys From	532	1.4	1.4	-0.0	0.98
Land Cultivated, Rainy	1166	6.9	7.0	-0.1	0.77
Land Cultivated, Winter	1166	5.2	5.6	-0.4	0.11
Land Cultivated, Summer	1166	2.3	2.8	-0.5	0.00
No. Irrigations, Rainy	1022	5.8	5.5	0.3	0.02
No. Irrigations, Winter	1068	6.1	6.4	-0.2	0.09
No. Irrigations, Summer	837	6.5	6.8	-0.3	0.11
Yield, Rainy	1100	25.0	34.6	-9.6	0.00
Yield, Winter	1056	55.4	65.6	-10.2	0.00
Yield, Summer	768	36.3	42.3	-6.1	0.00
Owned Land (Bigha)	1529	5.1	5.5	-0.4	0.18
Permanent House	1503	0.6	0.5	0.1	0.00
Ceiling Fans	1529	2.1	2.1	0.0	0.34
Cows	1529	1.0	1.4	-0.4	0.01
Buffaloes	1529	1.2	2.0	-0.7	0.00
Livestock	1529	2.3	3.3	-1.0	0.00
Tractors	1529	0.1	0.1	0.0	0.05
Motorcycles	1529	0.4	0.2	0.2	0.00
Cars	1529	0.1	0.0	0.0	0.00

Table B2: Type of Cultivation, by Caste Category

	Land Owning Castes	Marginal and Landless Castes	Total
Cultivates Own Land	96	72	78
Cultivates Leased Land	3	1	2
Share-Crops	0	8	6
Agricultural Laborer	1	19	14
Total	100	100	100

Table B3: Main Source of Water, by Caste Category

	Land Owning Castes	Marginal and Landless Castes	Total
No Access to Irrigation	3	4	3
Share in a Bore	77	47	58
Buys Water	20	49	38
Other	0	1	0
Total	100	100	100

Table B4: Land Owning Castes vs. Marginal and Landless Castes

	N	Land Owning Castes	Marginal and Landless Castes	Diff.	p
Migration and Exit from Agriculture					
Percentage of Adult Migrating Sons	373	0.37	0.08	0.29	0.00
Did Any Sons Migrate?	373	0.43	0.12	0.31	0.00
Percentage of Migrating Brothers	334	0.26	0.12	0.14	0.00
Did Any Brothers Migrate?	334	0.32	0.15	0.17	0.00
Percentage of Adult Non-Farming Sons	253	0.27	0.19	0.08	0.00
Did Any Sons Exit Agri.?	253	0.32	0.22	0.10	0.00
Percentage of Non-Farming Brothers	263	0.08	0.09	-0.01	0.59
Did Any Brothers Exit Agri.?	263	0.10	0.10	-0.00	0.87
Relatives in City	438	0.41	0.08	0.33	0.00
Assets					
Land (Bigha)	459	8.54	3.62	4.92	0.00
Permanent House	445	0.94	0.44	0.50	0.00
Ceiling Fans	459	2.72	1.90	0.81	0.00
Cows	459	1.40	0.88	0.52	0.03
Buffaloes	459	1.27	1.24	0.03	0.72
Livestock	459	2.67	2.12	0.55	0.03
Tractors	459	0.14	0.04	0.10	0.00
MotorCycles	459	0.61	0.29	0.32	0.00
Cars	459	0.14	0.04	0.09	0.00
Changes in Assets					
Change in owned land (bigha)	432	-0.01	-0.00	-0.01	0.69
Change in number of ceiling fans	442	0.05	0.14	-0.09	0.09
Change in number of cows	393	-0.27	-0.21	-0.06	0.81
Change in number of buffalos	412	-1.15	-0.37	-0.78	0.00
Change in Livestock	377	-1.30	-0.54	-0.76	0.01
Change in number oftractors	342	0.08	0.02	0.05	0.00
Change in number of two wheelers	350	0.51	0.21	0.29	0.00
Change in number of cars	340	0.11	0.04	0.08	0.00
Access to Water					
Borewells, Has Access to	401	2.06	1.40	0.67	0.00
Borewells, Has Share in	340	1.72	1.19	0.53	0.00
Borewells, Buys from	167	1.47	1.42	0.05	0.52
Shortage of Water?	369	0.84	0.88	-0.05	0.04

Table B5: Place of Residence of Brothers, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Village	74	89	84
Other Village	0	1	1
Town/City	26	10	15
Total	100	100	100

Table B6: Primary Activity of Brothers , By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Cultivation	66	55	58
Ag. Labor	1	25	18
Cattle Rearing	1	3	2
Non-Farming	32	17	21
Education	1	0	0
Total	100	100	100

Table B7: Place of Work of Brothers, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Village	70	86	81
Other Village	2	3	3
Town/City	28	11	16
Total	100	100	100

Table B8: Stated Reason for Brother's Migration, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Land Scarcity	9	9	9
Water Scarcity	3	2	3
Better Employment	87	83	85
Marriage	0	2	1
Other	1	3	2
Total	100	100	100

Table B9: Status of Migrant's Land, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Fallow/Rainfed	2	1	1
Leased Out	19	11	15
Sharecropped out	22	8	16
Managed by Brother	57	80	66
Sold	1	0	1
Total	100	100	100

Table B9: Place of Residence of Sons, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Village	62	92	84
Other Village	0	1	1
Town/City	38	7	16
Total	100	100	100

Table B10: Primary Activity of Sons (Above 16), By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Cultivation	28	39	35
Ag. Labor	1	23	16
Cattle Rearing	1	3	2

Non-Farming	55	24	34
Education	15	11	12
Total	100	100	100

Table B11: Place of Work of Sons, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Village	46	82	71
Other Village	4	4	4
Town/City	51	14	25
Total	100	100	100

Table B12: Stated Reason for Son's Migration, By Caste Category (Percent)

	Land Owning Castes	Marginal and Landless Castes	Total
Land Scarcity	17	4	12
Water Scarcity	13	2	9
Better Employment	63	88	72
Marriage	2	1	2
Education	5	0	3
Other	0	4	2
Total	100	100	100

Table B13: Migration of Brothers of HH Head

	Any Migration (Logistic)					Percent Migrated				
Sample	(1) ALL	(2) ALL	(3) ALL	(4) Land-Own	(5) Marginal and Landless Castes	(6) ALL	(7) ALL	(8) ALL	(9) Land-Own	(10) Marginal and Landless Castes
Well Depth, Change	0.03	0.00	-0.03	0.04	0.01	0.00	-0.00	-0.01	-0.00	0.00
	(0.51)	(0.98)	(0.69)	(0.46)	(0.89)	(0.92)	(0.52)	(0.44)	(0.93)	(0.81)
Land Holding	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	(0.34)	(0.25)	(0.46)	(0.47)	(0.70)	(0.41)	(0.31)	(0.46)	(0.60)	(0.60)
Relatives in City	1.58^{***}	1.51^{***}	1.79^{***}	1.16^{***}	2.33^{***}	0.29^{***}	0.28^{***}	0.29^{***}	0.23^{***}	0.42^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Land Owning Caste	0.31	0.17	0.06			0.03	0.02	0.01		
	(0.21)	(0.47)	(0.83)			(0.33)	(0.47)	(0.76)		
Constant	-2.06^{***}	-2.59^{***}	-1.72	-1.55^{***}	-2.14^{***}	0.08^{***}	0.01	0.01	0.15^{***}	0.07^{***}
	(0.00)	(0.00)	(0.26)	(0.00)	(0.00)	(0.00)	(0.62)	(0.97)	(0.00)	(0.01)
Taluka FE	No	Yes	No	No	No	No	Yes	No	No	No
Village FE	No	No	Yes	No	No	No	No	Yes	No	No
Observations	765	750	645	290	475	765	765	765	290	475

p-values in parentheses
$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

Table B14: Migration of Sons of HH Head

	Any Migration (Logistic)					Percent Migrated				
Sample	(1) ALL	(2) ALL	(3) ALL	(4) Land-Own	(5) Marginal and Landless Castes	(6) ALL	(7) ALL	(8) ALL	(9) Land-Own	(10) Marginal and Landless Castes
Well Depth, Change	0.21^{***}	0.13^{**}	0.02	0.17^{**}	0.10	0.02^{***}	0.01^{*}	-0.00	0.04^{***}	0.01
	(0.00)	(0.02)	(0.79)	(0.03)	(0.29)	(0.00)	(0.09)	(0.95)	(0.01)	(0.10)
Land Holding	0.12^{***}	0.14^{***}	0.15^{***}	0.20^{***}	0.10^{*}	0.01^{***}	0.01^{***}	0.01^{***}	0.02^{***}	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.08)	(0.00)	(0.00)	(0.00)	(0.00)	(0.54)
Relatives in City	1.08^{***}	0.98^{***}	1.21^{***}	1.32^{***}	0.38	0.19^{***}	0.18^{***}	0.18^{***}	0.22^{***}	0.09
	(0.00)	(0.00)	(0.00)	(0.00)	(0.46)	(0.00)	(0.00)	(0.00)	(0.00)	(0.22)
Did Any Brothers Migrate?	0.92^{***}	0.84^{***}	0.94^{***}	1.24^{***}	0.55	0.15^{***}	0.14^{***}	0.13^{***}	0.27^{***}	0.04
	(0.00)	(0.00)	(0.00)	(0.00)	(0.20)	(0.00)	(0.00)	(0.00)	(0.00)	(0.38)
Land per Son	-0.16^{***}	-0.17^{***}	-0.18^{***}	-0.27^{***}	-0.09	-0.01^{***}	-0.01^{***}	-0.01^{**}	-0.03^{***}	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.13)	(0.01)	(0.01)	(0.02)	(0.00)	(0.94)
Land Owning Caste	1.28^{***}	1.17^{***}	1.11^{***}			0.17^{***}	0.17^{***}	0.15^{***}		
	(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)		
Constant	-3.13^{***}	-4.41^{***}	-4.68^{***}	-2.29^{**}	-2.77^{***}	-0.03	-0.11^{***}	-0.20	0.08^{*}	0.02
	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.15)	(0.00)	(0.52)	(0.09)	(0.32)
Taluka FE	No	Yes	No	Yes	Yes	No	Yes	No	No	No
Village FE	No	No	Yes	No	No	No	No	Yes	No	No
Observations	578	578	492	230	335	578	578	578	235	343

p-values in parentheses
$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

Table B15: Exit from Agriculture, Brothers of HH Head

	Any Exit (Logistic)					Percent Exit				
Sample	(1) ALL	(2) ALL	(3) ALL	(4) Land-Own	(5) Marginal and Landless Castes	(6) ALL	(7) ALL	(8) ALL	(9) Land-Own	(10) Marginal and Landless Castes
Well Depth, Change	-0.05	-0.05	-0.00	-0.05	-0.05	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.41)	(0.45)	(0.97)	(0.55)	(0.60)	(0.28)	(0.34)	(0.86)	(0.63)	(0.36)
Land Holding	0.00	-0.00	0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	0.00
	(0.86)	(0.87)	(0.88)	(0.78)	(0.86)	(0.85)	(0.84)	(0.91)	(0.90)	(0.90)
Relatives in City	0.35	0.36	0.23	0.16	0.79	0.03	0.03	0.02	0.02	0.07
	(0.40)	(0.41)	(0.61)	(0.74)	(0.22)	(0.33)	(0.33)	(0.42)	(0.62)	(0.34)
Land Owning Caste	0.03	0.05	-0.23			0.00	0.01	-0.01		
	(0.93)	(0.89)	(0.61)			(0.95)	(0.82)	(0.75)		
Constant	-2.37***	-2.72***	-0.35	-2.26***	-2.37***	0.07***	0.02	-0.01	0.07***	0.07***
	(0.00)	(0.00)	(0.75)	(0.00)	(0.00)	(0.00)	(0.29)	(0.96)	(0.01)	(0.00)
Taluka FE	No	Yes	No	No	No	No	Yes	No	No	No
Village FE	No	No	Yes	No	No	No	No	Yes	No	No
Observations	659	628	416	228	431	659	659	659	228	431

p-values in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table B16: Exit from Agri., Sons of HH Head

	Any Exit (Logistic)					Percent Exit				
Sample	(1) ALL	(2) ALL	(3) ALL	(4) Land-Own	(5) Marginal and Landless Castes	(6) ALL	(7) ALL	(8) ALL	(9) Land-Own	(10) Marginal and Landless Castes
Well Depth, Change	0.15***	0.15***	0.19**	0.25**	0.10	0.02**	0.02**	0.02*	0.03	0.02*
	(0.00)	(0.01)	(0.04)	(0.02)	(0.17)	(0.01)	(0.03)	(0.06)	(0.11)	(0.08)
Land Holding	0.05	0.04	0.05	0.06	0.04	0.00	0.00	0.00	0.01	-0.00
	(0.16)	(0.32)	(0.23)	(0.35)	(0.46)	(0.76)	(0.92)	(0.91)	(0.51)	(0.85)
Relatives in City	0.37	0.35	0.22	-0.10	1.40***	0.08	0.08	0.06	-0.01	0.27**
	(0.35)	(0.39)	(0.60)	(0.82)	(0.01)	(0.29)	(0.30)	(0.34)	(0.91)	(0.02)
Did Any Brothers Exit Agri.?	0.69*	0.57	0.33	0.64	0.52	0.13	0.11	0.08	0.13	0.13
	(0.07)	(0.15)	(0.52)	(0.28)	(0.34)	(0.10)	(0.17)	(0.30)	(0.35)	(0.17)
Land per Son	-0.08	-0.08	-0.08	-0.11	-0.08	-0.00	-0.00	-0.00	-0.01	0.00
	(0.17)	(0.18)	(0.18)	(0.29)	(0.19)	(0.69)	(0.64)	(0.86)	(0.49)	(0.86)
Land Owning Caste	0.64**	0.63**	0.36			0.09**	0.09*	0.04		
	(0.02)	(0.03)	(0.39)			(0.05)	(0.05)	(0.44)		
Constant	-1.84***	-1.06*	-1.51	0.05	-1.46***	0.10***	0.12***	0.91**	0.22***	0.10**
	(0.00)	(0.06)	(0.32)	(0.89)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)
Taluka FE	No	Yes	No	Yes	Yes	No	Yes	No	No	No
Village FE	No	No	Yes	No	No	No	No	Yes	No	No
Observations	441	441	375	143	296	441	441	441	143	298

p-values in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table B17: Asset Changes Associated with Migration

	(1) Change in owned land (bigha)	(2) Change in number of ceiling fans	(3) Change in number of cows	(4) Change in number of buffalos	(5) Change in Livestock	(6) Change in number oftractors	(7) Change in number of two wheelers	(8) Change in number of cars
Percentage of Adult Migrating Sons	-0.01	-0.04	-0.83**	-1.22***	-2.10***	-0.02	0.00	0.06**
	(0.62)	(0.57)	(0.04)	(0.00)	(0.00)	(0.47)	(0.99)	(0.03)
As above, with Village FE	0.01	-0.04	-0.60	-1.03***	-1.79***	-0.01	-0.01	0.06**
	(0.71)	(0.64)	(0.18)	(0.00)	(0.00)	(0.72)	(0.88)	(0.04)
Observations	863	1098	981	1037	964	913	929	912
Land Owning Castes	0.01	0.00	-1.33*	-1.28***	-2.82***	-0.10**	-0.33***	0.04
	(0.17)	(0.97)	(0.08)	(0.00)	(0.00)	(0.01)	(0.00)	(0.36)
Observations	360	367	324	344	313	280	288	279
Marginal and Landless Castes	-0.05	-0.00	-0.16	-0.39	-0.62	0.03	0.14*	-0.02
	(0.37)	(0.98)	(0.77)	(0.37)	(0.42)	(0.32)	(0.10)	(0.61)
Observations	503	731	657	693	651	633	641	633

p-values in parentheses
$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$