Enhancing resilience or furthering vulnerability? Responses to water stress in an urbanizing basin in Southern India[1]

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Abstract

Urbanizing areas in developing countries face multiple stressors, including climate induced ones. We examine the case of water stress in agriculture in Arkavathy sub-basin in Southern India, a rapidly urbanizing landscape, including a part of the megacity of Bangalore. Drawing upon a farm household survey, supplemented by long term data on climate, we show that water stress in agriculture is not driven by climate change, but by the rapid increase in groundwater irrigation, followed by dropping water tables. Groundwater use may help maintain welfare of farmers in the short run, but over extraction reduces sustainability of the resource, furthering vulnerability in the long run. We caution that the exclusive focus on climate change might distract us from paying attention to the multiple stressors that trigger changes. Further, resilience and vulnerability analysis should address the underlying normative concerns as they matter to specific problem contexts.

Keywords: Climate change, multiple stressors, urbanization, groundwater, agriculture, sustainability

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1. Resilience, vulnerability and the climate debate

The ideas of 'resilience' and 'vulnerability' have gained increasing attention in academic literature and policy circles. In recent years, the discussions on resilience and vulnerability seem to be increasingly centred around the issue of climate change. However, both these ideas have been part of debates on sustainability and development for the last three decades. On the face of it, it would seem that resilience is the opposite of vulnerability; increasing resilience is tantamount to decreasing vulnerability and vice-versa. However, a closer inspection reveals subtle differences in the genesis, framing and scale of these terms.

Resilience had its origins in the ecological sciences, as a response to the equilibrium centric stability perspective of ecological systems. Resilience emphasized the ability of ecosystems to absorb shocks and stresses and "still persist" (Holling, 1973: 17). In this view, resilience can be seen as one temporal attribute of the broader concept of ecological sustainability (Lele, 1988, Lélé, 1998). In the context of climate change, resilience has been defined as a characteristic of 'social ecological systems' or SES (Folke, 2006). Such systems also include social actors, institutions and their interests, and emphasise capacities of these integrated systems to absorb change, self-organize and learn (Nelson et al, 2007).

In contrast, vulnerability had its genesis largely in the social sciences, with the livelihoods/development stream focusing on smaller scales, such as households and communities (Chambers, 1989), whereas the disasters/geography stream looking at larger scales, such as region or basin (Blaikie et al, 1994). Applied to climate analysis, vulnerability studies can be classified into two broad approaches; the 'systems thinking' approach (Füssel and Klein, 2006) which takes climate as an entry point and explains the multiple dimensions of impacts, and the 'critical approach' that traces the socio-structural and political economic causalities of climate impacts (Ribot, 1995).

Attempts have been made to link resilience and vulnerability analyses in the context of climate change. Sustainability science and systems thinking proponents tend to find synergies between resilience and vulnerability research (Turner II, 2010). Integrated frameworks of vulnerability (Füssel, 2007), exemplified in 'coupled human environment systems' or CHES (Turner II et al, 2003), attempt to combine the socio-political contexts of households or communities with the biophysical side of exposure and impact, and across scales. The policy impacts of these ideas have been tremendous. Successive reports of the Intergovernmental Panel on Climate Change (IPCC) have drawn upon the systems approach to defining resilience and vulnerability. The scale of action and policy has been large, such as the Asian Cities Climate Change Resilience Network (ACCRN) and the 100 Resilient Cities Challenge by the Rockefeller Foundation.

There are, however, limitations in the current approach. Critics see a shift in the climate debate towards resilience and systems thinking in a way that relegates the 'social' dimensions to the backstage (Cannon and Müller-Mahn, 2010). This they argue depoliticizes the causal analysis (Ribot, 2009) that vulnerability thinking seeks to highlight. There has been inadequate attention to normative questions (Tyler and Moench, 2012). For instance, cities may import water from other basins or states, enhancing their own resilience at the cost of others. Finally, in the current thinking, the emphasis is on climatic variations and shocks, overlooking specificities of problem contexts (Dodman and Mitlin, 2011), and mismatches between scales of climate analysis and action, for sustainability (Wiens and Bachelet, 2010) as well as for livelihoods.

This article is framed against the backdrop of these debates. While the focus on climate change has expanded the original ideas of resilience and vulnerability, we caution in this article that an exclusive focus on resilience can distract us from more pressing normative concerns, and the overwhelming attention to climate-induced stresses might make us inattentive to other stressors that are equally important, or more relevant in specific locational settings. We do this using observations from an ongoing socio-hydrological research project in an urbanizing region in Southern India, viz., the Arkavathy sub-basin that includes part of the megacity of Bangalore, and four smaller towns. We make a case for looking at multiple stressors that trigger changes and for anchoring discussions on resilience and vulnerability in the wider normative concerns as they matter to specific problem contexts.

The rest of the article proceeds as follows. The next section describes the study area and research methods. Subsequently, drawing upon a household survey on farm livelihoods and groundwater use, supplemented by evidence on climate, we show that the water stress in agriculture in Arkavathy sub-basin is not driven by climate change. The changes are driven by rapid increase in groundwater irrigation through the expansion of borewell technology. Based on this, we reflect upon the implications for thinking about resilience and vulnerability in the final section.

2. Study area and research methods

The Arkavathy sub-basin (Figure 1) with a catchment area of 4,169 sq. km. is a part of the Cauvery river basin, which cuts across three different states in Southern India. The sub-basin is rapidly urbanizing and includes roughly a third of Bangalore city and four small towns (Lele et al, 2013). The growth of Bangalore city itself has been phenomenal with the total area expanding from 291 sq. km. in 1992 to 663 sq. km. in 2011, with the portions inside the Arkavathy sub-basin as well contributing significantly to this increase. Nevertheless, the sub-basin still has more than 1000 villages, which are dependent on agriculture, although increasingly being supplemented by city based occupations. This article focuses on the northern portion of this rural segment of the sub-basin.

INSERT FIGURE 1 HERE

The Arkavathy river originates in the Nandi Hills and is joined by three major streams, Kumudavathy, Vrishabhavathy and Suvarnamukhi before it joins Cauvery. Of these, Kumudavathy at present flows just during the peak wet season. A reservoir was built along the stream at TG Halli in 1935 to provide water for Bangalore. The TG Halli catchment in the northern part of the sub-basin has an area of 1447 sq. km. and comprises of another water supply reservoir at Hesaraghatta, and a series of 'tanks' (smaller water storage structures) built as a 'cascading system' (overflows feeding downstream). The second major river Vrishabhavathy (catchment area, 561 sq. km.), which might have been dry otherwise, is a perennial stream fed by wastewater flows, both industrial and domestic, from Bangalore city, eventually joining Cauvery (Jamwal et al, 2014). And the third stream, Suvarnamukhi (a smaller catchment with area of 286 sq. km.) flows during most part of the year except peak dry season. Hesaraghatta and TG Halli reservoirs used to supply water for Bangalore, but with changes in land use and urbanization, which we shall examine in detail in the next section, Hesaraghatta has become completely dry and the supply from TG Halli to Bangalore has been minimal. Most other irrigation tanks in the sub-basin are also either dry or only filling to a fraction of their capacity. Agriculture in villages has become heavily groundwater dependent, with water sourced by deep groundwater wells (borewells), and borewell failures are common. Thus, several villages in the sub-basin experience significant or severe water stress, except those in the Vrishabhavathy catchment and to some extent the smaller Suvarnamukhi catchment.

The research under the project 'Adapting to Climate Change in Urbanizing Watersheds' (http://www.atree.org/ACCUWa) on which this article is based involves detailed climatic, hydrological, water quality, institutional and socio-economic analysis pertaining to the Arkavathy sub-basin as a whole and the three river catchments in particular. This article is based on climate and hydrological analysis and a stratified random sample household survey covering the entire sub-basin, conducted between November 2013 and January 2015. The sub-basin level stratification for the household survey was based on farm (groundwater) and domestic water availability as well as agricultural labour availability. The survey covered 16 villages, and in this article, we use data from 11 villages which fell in the TG Halli catchment (Figure 1), where detailed climate and hydrological analysis was also conducted.

In the household survey, we defined irrigated farmers as farmers who irrigated at least some fraction of their land from borewells, given that groundwater is the main source of irrigation, and randomly selected 20% of the borewell farmers in each village with a minimum of 10 households. In addition, we selected a random sample of 20% from the rainfed farmers, i.e., farmers who had no irrigated land. The TG Halli sample comprised 245 households, with 161 rainfed and 84 irrigated farmers. The household survey collected detailed information on land use and cropping patterns over the 1993-2013 period, demographic profile and labour availability, as well as information on borewells, both functioning and failed, pertaining to depth and usage. Before undertaking surveys in each village, we verified using existing climate data and cross checked with villagers whether these (2013, 2003 and 1993) were normal years for the respective villages.

3. Investigating sources of water stress in the Arkavathy sub-basin

Despite lack of clear evidence on the possible impact of climate change on Arkavathy sub-basin, there is a popular perception among policy actors and the local communities themselves that climate change is the cause of water stress in the sub-basin. This was evident from the consultations that we held with representatives of water agencies, as well as interactions with the farmers during the course of the study. The alternative hypothesis would be that water stress was directly anthropogenic, i.e., induced by changes in water use in agriculture. In this section, we examine empirically the trends in climatic parameters over time, specifically trends in rainfall between 1934 and 2010, and in estimated evapotranspiration between 1961 and 2010, to explain the role of temperature. We then present evidence on trends in agricultural change and water availability for agriculture over the last 20 years (1993-2013) using household survey data to examine the role of direct human actions in creating water stress.

3.1 Climate trends in Arkavathy sub-basin[3]

Climate change typically affects the quantity of stream flow in a river through two factors, rainfall and evapotranspiration. Rainfall controls the amount of water entering the catchment, while evapotranspiration influences how much water plants transfer out of the soil back into the atmosphere.

Changes in rainfall patterns could induce changes in the amount of stream flow and groundwater recharge. Both the total quantity and the intensity of rainfall matter. In general, if two storms which have the same amount of water falling on a catchment, a short intense rainfall event will result in greater runoff and less recharge as compared to longer-duration, moderate rainfall, which will generate less runoff but more recharge. Thus even if annual rainfall patterns were to remain unchanged, changes in the intensity of rainfall could alter the amount of stream flow generated and groundwater recharge.

Several factors influence actual evapotranspiration by the vegetation in a catchment including temperature, humidity, solar radiation, and wind speed. Of these, it is known that temperature has been increasing in South India over the past century, while solar radiation and wind speed have been decreasing.

To assess if these factors could have contributed to declining surface runoff in Arkavathy basin, we examined daily rainfall data over 75 years (1934-2010) in four rain gages. After performing appropriate quality control, we computed annual rainfall over the water year (June to May). To identify changes in rainfall intensity, the number of days per year in which rainfall volumes exceeded 10 mm, 25 mm and 50 mm were determined for the 1934-2009 period. Trend detection was undertaken for each of the above datasets.

[3] This section is based on Srinivasan et al (2015).

INSERT FIGURE 2 HERE

Figure 2 (panel B) shows the area-averaged monthly and annual rainfall over the basin for the years 1934-2010. With an average of 830 mm/year and standard deviation of 210 mm/year, the monthly rainfall time series does not show any trend, and no statistically significant trend emerges in the annual rainfall. No significant changes are visible in the pre- and post- 1970 in mean annual and monthly rainfall totals or the daily rainfall intensities.

Although the temperature data exhibit a rise in temperature of about 0.6 to 1 degree C (100 years, from 1901 to 2001), the estimated potential evapotranspiration averaged to the annual scale (Figure 2, panel C) does not show a statistically significant trend within the Arkavathy basin. So, there is no evidence to show that increase in temperature has increased potential evapotranspiration leading to a decline in stream flow in Arkavathy.

Thus, climatic factors cannot explain the loss in surface runoff and water stress in Arkavathy sub-basin.

3.2 Farm household trajectories and responses

As noted earlier, Bangalore city started experiencing tremendous expansion, both in terms of its geographical spread as well as in its economic and industrial activities, beginning from the early 1990s. In response, there was a predictable move away from agriculture, especially among the younger generation in the villages. Survey data showed that mean age of working age population (defined as between age 18 and 65 years) involved in agricultural jobs including farming, agricultural labour and animal husbandry, as primary occupation is higher than that for non-agricultural jobs, indicating a clear preference for the latter among the younger generation. Mean age of currently rainfed (henceforth RF) farmers is 45 years and that for currently irrigated (henceforth IR) farmers is 42 years. In comparison, the mean age of members involved in non-agricultural jobs is 31 and 28 years respectively for RF and IR households. There has been paucity of agricultural labour in general. 75% RF and 89% IR respondents reported difficulty in getting agricultural labour.

This was accompanied by massive increase in irrigated agriculture with the advent of borewell technology. Irrigated area as a proportion of net cultivated area showed an increase during the 1993-2013 period, among IR farmers (Table 1). During the same period dependence on groundwater increased. This increase, however, did not come from open wells. In fact, area irrigated by open wells also declined. Borewell irrigation which was just 18% for IR and 12% for RF farmers in 1993 increased to 48% and 16% respectively by 2003 (Table 2). Among IR farmers more land was brought under borewell cultivation by 2013 showing an increase to 54% of net cultivated area (Table 2). As much as 15% of cultivated land of IR farmers and 13% of RF farmers was irrigated by stream or canal in 1993, but absolutely no land could be irrigated by surface water by 2013.

The combined result of shortage of agricultural labour and increasing demand for commercial crops was a dual shift towards rainfed plantation crops like eucalyptus and irrigated plantation crops such as coconut. Table 3 reveals the dramatic shift towards plantation crops. The crop area under eucalyptus increased from 1% to 10% for RF farmers and roughly by the same proportion for IR farmers during the 1993-2013 period. This is corroborated by satellite image analysis that indicates a tripling of the area under eucalyptus in the TG Halli catchment during 2001 to 2013 (Lele, unpublished data). Area under coconut and areca also exhibited a similar trend. On the other hand, none of the IR or RF respondents in TG Halli catchment were cultivating paddy in 2013 which had constituted 7% of IR area and 5% of RF area in 1993. It should be noted that replacing rainfed coarse millets such as sorghum or finger millet with eucalyptus increases water stress significantly because of the deep-rooted and fast-growing nature of eucalyptus.

INSERT TABLES 1, 2 AND 3 HERE

What was the impact of these cropping changes on the hydrological system? First, groundwater levels declined rapidly. During the period we found more and deeper borewells being drilled even as several and increasing number of borewells reported failure in yielding any water for agricultural purposes (Figure 3). Several of the RF farmers had borewells earlier, which failed during the period between 2003 and 2013. The mean depth of borewells increased from 195 ft. in 1989 to 938 ft. in 2013, and mean depth of sighting water increased from 130 ft. to 688 ft. during the same period (Figure 4). These results from household survey in TG Halli catchment matches inferences emerged independently from hydrological analysis in the region. The decline in groundwater was reflected in a steady decline in baseflow since the 1980s, with there not being a single month since 1992 when there was baseflow into the TG Halli reservoir (Figure 2, panel D).

INSERT FIGURES 3 AND 4 HERE

Our consultations with villagers during fieldwork revealed that lack of water for agriculture is forcing villagers to diversify livelihoods, especially to non-farm occupations. This is particularly the case with poorer RF farmers who do not have sufficient resources to invest in borewells[4], and those RF farmers, who had borewells in the past which have now failed.

RF farmers, on average, tend to be poorer than IR farmers. This is evident from the assets that the two groups own and their livelihoods. Mean landholding of IR farmers (4 acres) is more than double of that of the RF farmers (1.5 acres). Being poorer, RF farmers also undertake labour, both agricultural and non-agricultural, which occupies 17% of their total income, compared to just 2% for IR farmers. Agricultural activities (agriculture and dairying combined) contributed to 64% of the income of IR farmers, but just 28% for RF farmers. RF farmers also receive a substantial portion of their income from salaried jobs (35%) and small

[4] Drilling borewells is a highly expensive activity that only the well off farmers can afford to undertake. The average cost of drilling a borewell estimated from household survey was close to INR 265,000 (USD 4,250).

scale businesses (14%). Thus, RF farmers are seen to diversify their livelihoods into non-agricultural activities much more than IR farmers. Disaggregated data for RF farmers who had borewells in the past and who never had borewells tell a similar story. While both groups seem to have fairly diversified livelihoods, the proportion of income from agricultural activities is higher among those who had borewells in the past (41%) than who never had (23%). Further, just 6% of the income for the former comes from labour, whereas agricultural and non-agricultural labour together constitute 21% of income of those RF farmers who never had borewells. The case of RF farmers who had borewells in the past seem to signify the transition to largely non-agricultural livelihoods, driven by water stress.

The next section discusses the results and provides a conceptual summary of the Arkavathy sub-basin experience. We will also reflect on the implications that this has on thinking about vulnerability and resilience in the context of the climate debate.

4. Discussion

It is clear from the results presented in the previous section that 'climate change induced vulnerability' and 'building resilience to climate change' are highly inadequate descriptive and normative framings respectively of the problem in the upper Arkavathy or TG Halli catchment. Starting from the normative end, the 'problem' in the catchment is hardly one of 'inability to bounce back from climate or other shocks'. Indeed, it can be argued that, on average, resilience of rural households has improved, as households have become richer either by mining groundwater for cash crops or by engaging with a variety of non-farm activities. Even in biophysical terms, irrigation buffers farming (makes it 'less vulnerable') from failures induced by erratic monsoons that are common under purely rainfed conditions. The problem in the TG Halli rural catchment, however, is one of steady declines in groundwater that might eventually make irrigated farming impossible, and of increasing inequality due to the unfair mining of theoretically open-access groundwater by a few who had the resources to invest in borewells, once the shallow aquifer (accessed by open wells) was drawn down. And finally, the problem is also that of the loss of in-stream environmental values as stream after stream dried up as a consequence of a declining water table.

INSERT FIGURE 5 HERE

While several of the irrigated farmers may experience an increase in household welfare and feel less vulnerable, at present, the trend is going to be reversed, if the current rate of extraction of ground water in the region is to continue. If observations from our field study are any indication, this trend reversal has begun already. Respondents in TG Halli catchment villages mentioned to us that eucalyptus is on the decline, especially during the last few years, as the soil does not seem to support it anymore, and there are no more new eucalyptus coming up. Similarly areca has been drying up because of lack of water. To sum up, it is a combination of 'pull factors' from the burgeoning city (such as urbanization leading to changes in labour and commodity markets) and 'push factors' from the villages (such as shortage of labour in agriculture resulting in a preference for plantations, and borewell technology, both leading to declining groundwater) that has led to the current water stress in upper Arkavathy sub-basin. As water levels drop further and borewells fail to yield water, household welfare will be adversely affected. Added to this, any future climate change will just compound the woes of the region. Figure 5 provides a conceptual summary of our argument.

5. Final remarks

This article has attempted to contribute to three inter-related topics.

First, there is a recent tendency to approach environmental problems such as water stress or floods primarily through the lens of climate change and disasters. The critical stream of vulnerability analysis has cautioned us against looking at climate change as producing undesirable outcomes, instead of socio-structural inequities resulting in differential climate impacts. We added another dimension to this argument illustrating that all purportedly climate impacts need not necessarily be so, and the role that non-climatic factors play also have to be carefully looked at. Even when climate might be a factor, the role of multiple stressors need to be given more attention than now.

Second, the climate debate has provided strong impetus for extension of the ideas of resilience and vulnerability, especially in bridging and linking the social and biophysical, and triggering thought on and action towards sustainability and adaptation. The long-term impacts of shifts to eucalyptus or groundwater irrigation can only be ascertained by careful hydrological investigations. On the other hand, the shift in farmer preferences towards plantation crops and non-farm jobs requires an understanding of how labour and commodity markets affect crop-choice. Thus, neither the biophysical nor the socioeconomic analysis alone can provide insights into farmer vulnerability in the Arkavathy sub-basin. We suggest that such a perspective be applied in approaching environmental problems in general, in conjunction with (Srinivasan et al, 2013) or independent of climatic factors.

Finally, there is a crucial difference between climate and other local stressors. While global climate change occurs at the planetary scale and is 'exogenous', i.e., not influenced by what occurs in a small catchment in India, stressors such as urbanization, technology and land use changes are 'endogenous' to the area. The very process of individual households responding to these stressors may cumulatively result in the transformation of the system as a whole. Improved resilience today might be achieved at the expense of sustainability (abstracting groundwater thereby reducing the endowments for future generations), or equity (wealthier farmers 'adapt' by investing in borewells, while poorer ones are forced to pursue alternate livelihoods). Resilience and vulnerability analyses, as they are applied to the climate debate, need to be anchored in and reflect the normative concerns of equity, sustainability or justice as may be applicable to specific problem contexts.

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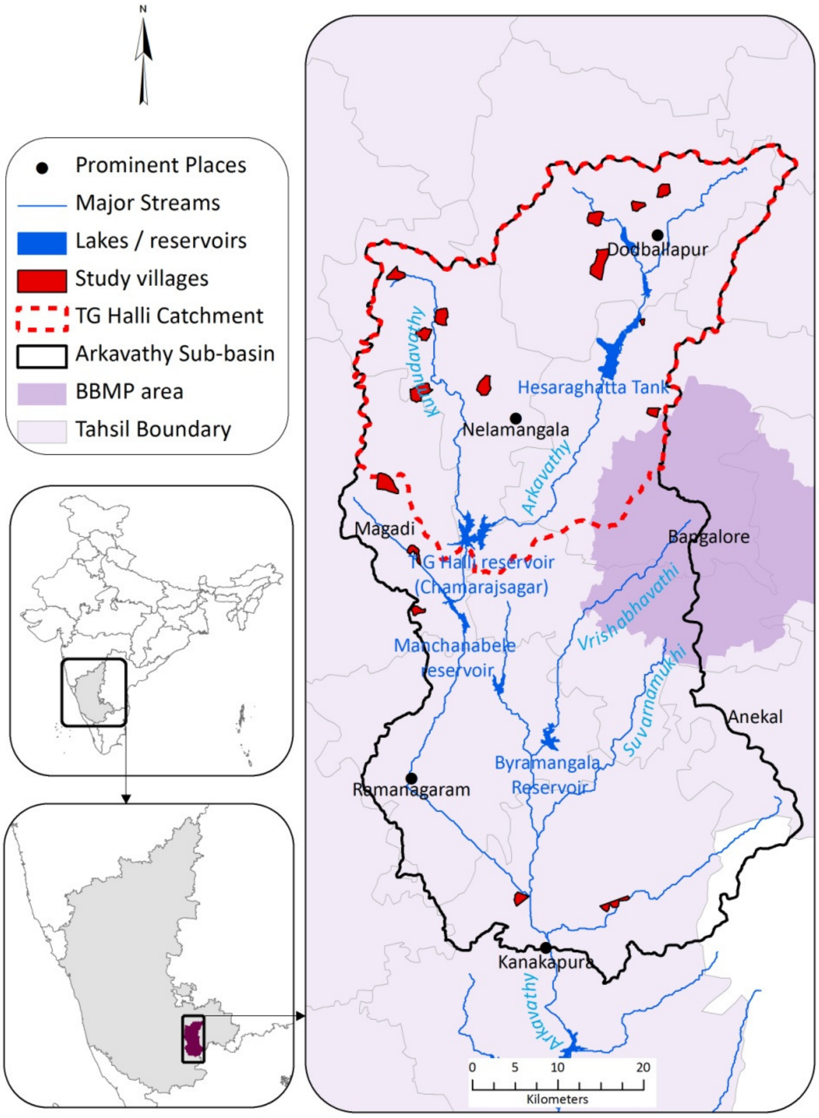
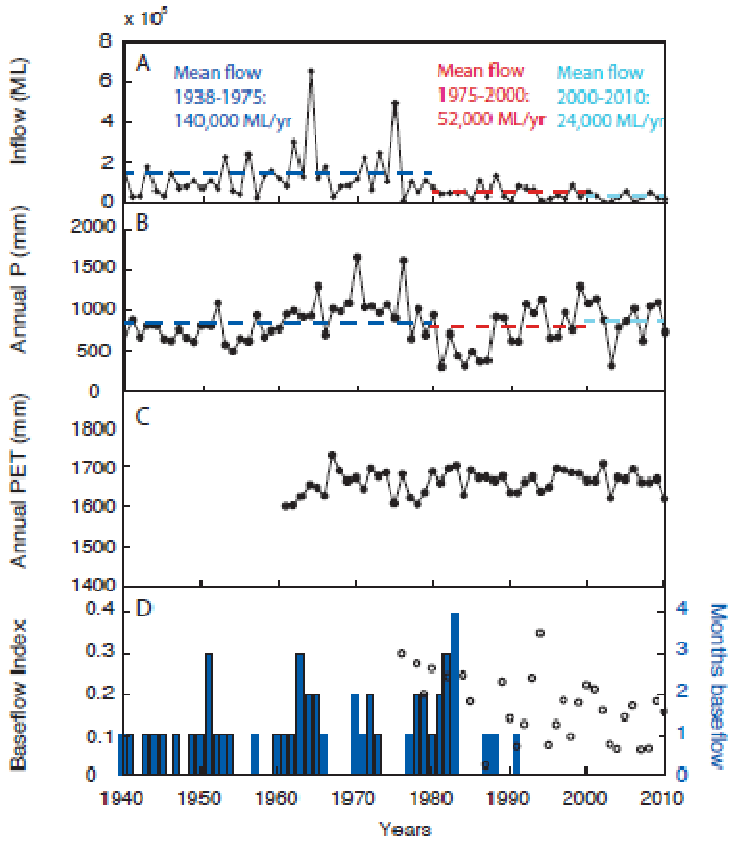
Tables and figures

Figure 1: Study area



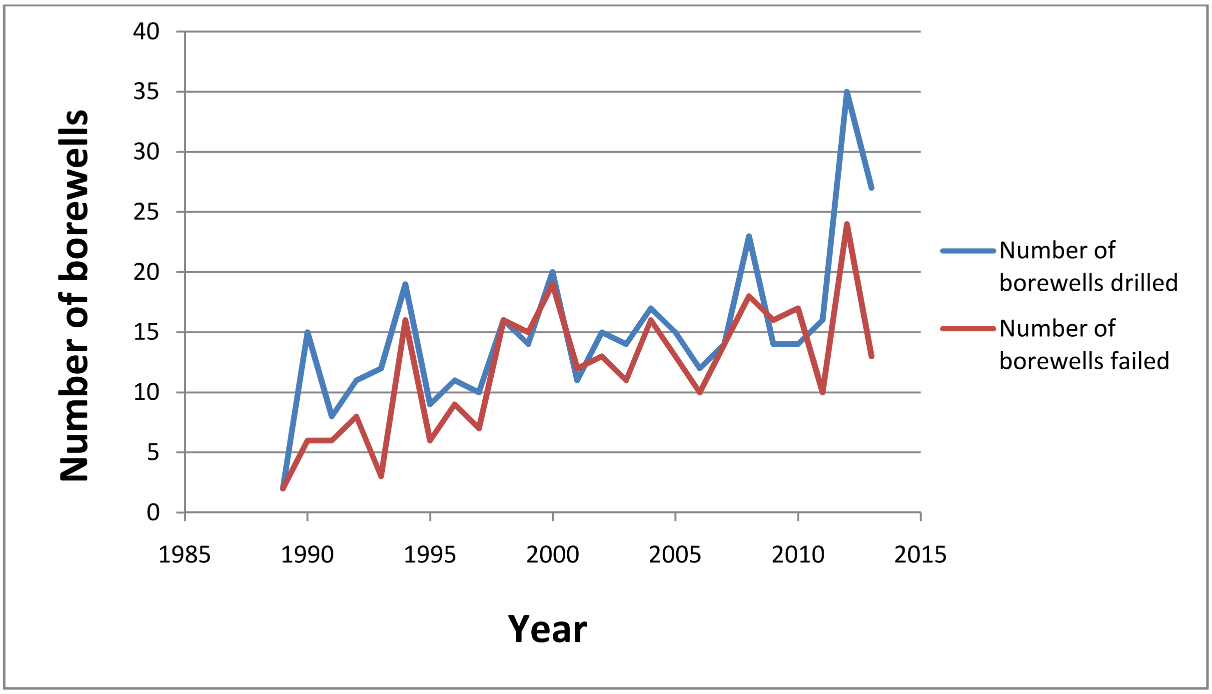
Source: Eco-informatics lab, ATREE.

Figure 2: Trends in area averaged annual rainfall, 1934-2010, and estimated potential evapotranspiration, 1961-2010



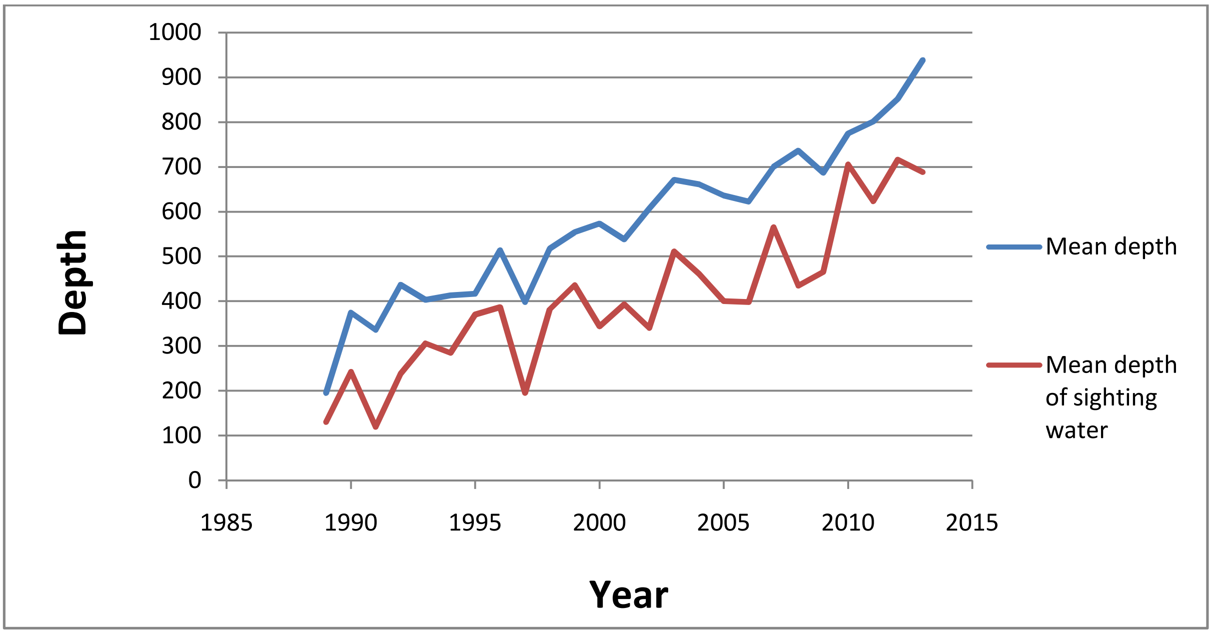
Note: Reproduced from Srinivasan et al (2015: 64). Panel B shows area averaged annual rainfall over 7 talukas in the TG Halli catchment. Panel C shows estimated potential evapotranspiration for TG Halli catchment.

Figure 3: Drilled and failed borewells, 1989-2013



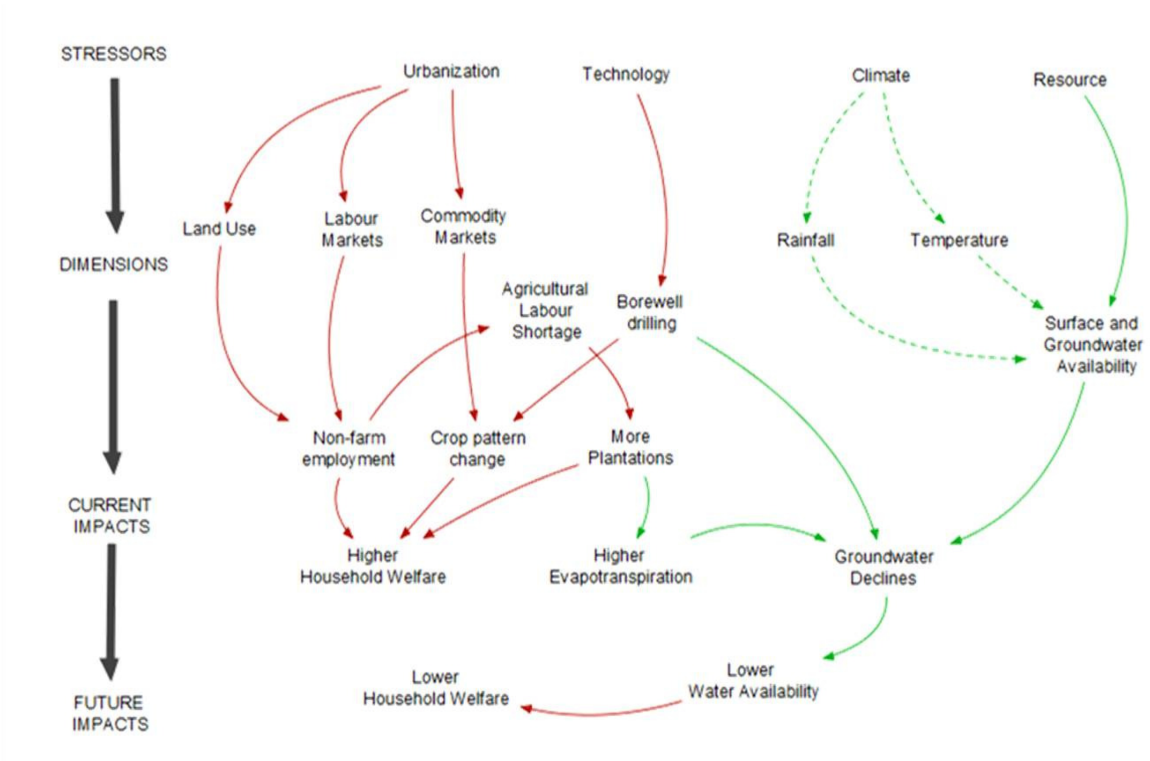
Note: IR and RF samples combined.

Figure 4: Depth of borewells, 1989-2013



Note: IR and RF samples combined. Depth in ft.

Figure 5: Summary of the argument



Note: Red indicates socio-economic linkages and green indicates biophysical linkages. Dotted lines represent weak linkages.

Table 1: Changes in irrigated area, 1993-2013

	2013		2003		1993	
	IR	RF	IR	RF	IR	RF
Net cultivated area	324.1	228.5	321.5	233.2	316.4	234.0
Irrigated area	176.8 (54.5)	4.4* (1.9)	175.1 (54.5)	38.0 (16.3)	119.8 (37.9)	65.3 (28.0)

Note: Area in acres. Percentage of net cultivated area in brackets. Due to the nature of our sampling (refer section 2), the areas of IR and RF cannot be added up. * Irrigated using sources other than borewell (our sampling definition was IR=borewell irrigated farmers).

Table 2: Changes in sources of irrigation, 1993-2013

Source of irrigation	Area irrigated					
	2013		2003		1993	
	IR	RF*	IR	RF	IR	RF
Borewell	175.8 (54.2)	0	155.2 (48.3)	36.3 (15.5)	56 (17.7)	28.3 (12.1)
Purchased water	0	4.4 (1.9)	0	0	0	1.3 (0.5)
Open well	1 (0.3)	0	6.8 (2.1)	0	15.3 (4.8)	4.8 (2.0)
Canal or stream	0	0	13.0 (4.0)	1.8 (0.8)	48.5 (15.3)	30.21 (13.0)

Note: Area in acres. Percentage of net cultivated area in brackets. * Irrigated using sources other than borewell.

Table 3: Changes in cropping pattern, 1993-2013

Crop	2013		2003		1993	
	IR	RF	IR	RF	IR	RF
Ragi (finger millet)	64.2 (13.6)	99.1 (27.2)	98.6 (15.3)	135.8 (26.7)	174.9 (27.2)	184.6 (23.7)
Maize	71.6 (15.0)	89.2 (24.4)	51.4 (8.0)	33.5 (6.6)	26.7 (3.4)	12.6 (1.9)
Eucalyptus	49.8 (10.5)	37.7 (10.3)	34.3 (5.3)	22.3 (4.4)	9.9 (1.3)	5.5 (0.9)
Coconut	35.3 (7.5)	0.75 (0.2)	33.9 (5.3)	1.6 (0.3)	15.5 (2.0)	2.1 (0.3)
Vegetables	95.9 (20.3)	7.4 (2.0)	128.1 (19.9)	38.7 (7.6)	56.7 (7.3)	49.1 (7.6)
Pulses	50.0 (10.6)	74.4 (20.4)	129.9 (20.2)	171.5 (33.7)	242.2 (31.1)	213.5 (33.1)
Areca	26.4 (5.6)	0.6 (0.2)	27.1 (4.2)	9.2 (1.8)	4.1 (0.5)	4.8 (0.7)
Jowar (sorghum)	5.8 (1.2)	19.2 (5.3)	29.6 (4.6)	48.3 (9.5)	60.8 (7.8)	46.0 (7.1)
Paddy	0	0	17.2 (2.7)	3.6 (0.7)	55.7 (7.2)	35.0 (5.4)

Note: Area in acres. Percentage of gross area in brackets.