A multi-criteria analysis of management solutions for mitigation of groundwater loss in Gujarat, India

Final Paper, Water and Sustainability
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October 17, 2008

Abstract

Half of the western Indian state of Gujarat is under cultivation. 82% of this land is irrigated with groundwater. The current status of deep aquifers is such that the livelihoods of much of rural Gujarat is in peril. Towns dependent upon groundwater for life and sanitation are under an even greater threat. This paper explores the history of groundwater management in Gujarat with an eye towards performing a multi-criteria analysis of management solutions. Eight alternatives are considered using ten criteria, all described within. Weighted summation is used to provide a subset of appropriate alternatives. Three of the best scoring alternatives are then discussed further in the Gujarati context. The study concludes that tradeable private property rights and appropriate electricity pricing for agriculture hold the best promise if they can be combined with a process of engaging farmers in a cooperative dialogue.

1 Introduction

Gujarati groundwater is being extracted at a rate much higher than nature is capable of recharging, with reports of the water table dropping 3 to 5 m in a given year (Mudrakartha (1999) cited in Diwakara (2006)). This semi-arid region of western India relies heavily on groundwater for agriculture. Heavy dependence juxtaposed with dwindling aquifers is cause for concern. This paper begins by discussing some of the recent management history and the obstacles to successfully mitigating groundwater loss. With this context in mind, the paper aims to identify the most appropriate management solutions by using a multi-criteria analysis.

Multi-criteria analysis is a general sustainability assessment tool (Herwijnen 2007) that has been used for addressing water management issues in other contexts. Multi-criteria analysis (MCA) has been conducted in simulating irrigation markets in Spain (Gomez-Limon and Martinez 2006) and also in Jordan to assist in ranking various water projects for aid money (Al-Kloub et al. 1997). The aim in this paper is to use an MCA to compare various management solutions using disparate criteria, such as farmer's willingness to cooperate, cost to the farmer, and technological complexity. By performing a *weighted summation* type of MCA, each of the disparate criteria can be assigned a unique weight and normalization scheme thus enabling the combination and comparison of all criteria into a single analysis.

Section 2 reviews the scale of groundwater loss, recent management history, and political climate in Gujarat. In section 3, the criteria and weighting used in the MCA are presented in greater detail, followed by a section devoted to methodology. Section 5 presents the management solutions to be analyzed along with the actual implementation of the MCA. The paper wraps up with a kilometer high view of the results and outcomes of the weighted summation method and the applicability of the results in Gujarat.

2 Background

Gujarat State lies along the west coast of India. Its northern border is shared by Pakistan while nearby to the south is the megalopolis of Mumbai (See Figure 1). Gujarat is religiously diverse by Indian standards and has experienced its share of religious turmoil as a result. The region is semi-arid and dependent upon groundwater to maintain rural and medium scale agriculture. There are also several established surface water diversion and distribution projects that serve the needs of cities and agriculture.

Over fifty million people make Gujarat their home, roughly 5 times the population of Sweden, yet Gujarat is only 10th in population of Indian states. Such a large population places significant demand on finite resources. Rainfall ranges from $573 mm/year$ in the northern part of the state to around $1,100 mm/year$ in the central and southern part of the state, the plains. While the geology and climate endow the state with $17.3 km^3/year$ of replenishable groundwater, a 2002-2003 report from India's Ministry of Water Resources reports extraction rates of $10.2 km^3/year$. This puts statewide development of groundwater resources at 59%. While this is a tolerable average level of groundwater development, individual observation wells paint an even bleaker picture: of 184 monitoring districts, 89 are considered to be at critical or worse with respect to their extraction rates. Thirty-one districts are classified as 'over-exploited': where annual draw exceeds recharge. (Data from www.indiastat.com as cited in Mukherji (2006))

The state spans just under $200,000 km^2$. About 9,443,000 of these hectares was cultivated in 2001, 48% of the total land mass of the state. Approximately 82% of this land is irrigated with the use of groundwater. (Mukherji 2006) Irrigation is the dominant consumer of groundwater in the region, and therefore this paper focuses on agricultural use of groundwater.

The political atmosphere of Gujarat is complex. Policy is immensely motivated by emotion and vote 'buying'. Gujarat's religious turmoil has helped to feed almost fanatic support for the Bharatiya Janata Party (BJP) and competition with a powerful opposition party: the Congress party. This political landscape has aided the creation of a strong farmers' lobby entrenched as a radical peasant wing of the BJP. Tight political contests have parties playing favors to strong voting blocks, such as the farmers' lobby, thus preventing deployment of policies that would fairly price and promote more efficient use of groundwater. The Indian

Figure 1: The state of Gujarat highlighted in India.

government's Central Groundwater Board has tried to advise Gujarat state on the pending threat, but politics between national and state level are such that this advice was readily ignored and openly chastised. An attempt in 2003 to hike electricity tariffs for agriculture met a similar fate. Such a tariff hike could have helped reduce groundwater extraction rates as most groundwater is from deep tube wells requiring electrical pumping. (Mukherji 2006)

In 1987, as a result of farmer protest, the Gujarat government transitioned to a very low, flat rate fee for electricity. The rapid rise in groundwater development from 1984 to 1997 has been shown by the 6X increase in exploited and overexploited groundwater monitoring districts (Mukherji 2006). (See section 5.1.8 for further discussion on electricity pricing.) It must be mentioned that this benefited many rural farmers, poor and affluent alike. But at what cost to the future? The same poor and affluent who have benefited here may pay a significantly worse price in the near future.

There are several possible explanations for the lack of pragmatism on the part of Gujarati farmers: lack of understanding of the grave groundwater situation, a power play, interest only in short term gains, and others. It should be noted that the Gujarati farmers who stand to benefit the most from a lack of regulation over groundwater are the large land owners. Historically, groundwater has been of relatively open access. "Groundwater belongs to all who have land overlaying it." (Singh (1995) cited in Kumar (2000)) Precedent combined with the politics add to the difficulties of introducing pricing schemes or restrictions to what has effectively been an open access right.

Another contributing factor for such resistance is the historical context. For decades, Indian agriculture has never actually had to pay *for* water. The philosophy (and arguably vague legal framework) of groundwater as a right (Nagaraj et al. 1999) has provided the classical issue of open access. Farmers are charged for water via proxy through the electricity fees. These are relatively low, flat rates based only on the size of the pump (in HP). Appropriate agriculture can not be encouraged, and effective management of water use is not feasible with merely a flat rate system incapable of accounting for volumetric extraction.

3 Analytical Framework

This analysis takes advantage of the weighted summation method as outlined by Marjan van Herwijnen in the SustainabilityA-Test project. It provides an excellent web portal enumerating Advanced Tools for Sustainability Assessment.(Herwijnen 2007) Weighted summation is a specific type of multi-criteria analysis. Multi-criteria assessment (MCA) allows both subjective analysis and objective data to be combined into a single normalized comparison. The weighted summation method has several advantages including allowing good scores in one category to counter bad scores in an alternative weighting category. The MCA results in a ranking of management solutions in order of most appropriate and effective strategies based on the criteria outlined.

A preliminary step in the weighted summation method requires that the causes of groundwater loss be explored and refined as was done in section 2. Subsequently, alternative management solutions and selection criteria are identified and iterated. A normalization scheme for each criteria must also be developed. Finally, each criteria must have a weight attached to it before the actual process of valuation can begin.

Once the parameters have been identified and described, a matrix is constructed where each alternative is assessed for each evaluation criteria. After the entire matrix has been populated, the weighted summation computation is used to rank the most appropriate management solutions. See appendix A for a step by step listing of the MCA as outlined by (Herwijnen 2007). Once the MCA has been offered, the results are presented and discussed.

The various management solutions for groundwater recharge and use reduction will not be described in great detail here. These strategies are harvested from the library of work on groundwater as well as academic research into methods that hold promise but have not been tried in practice. Through the multi-criteria analysis, these strategies are vetted against the reality of the Indian context: cash poor, full of corruption, difficult to educate, and even more difficult to regulate. Opportunities for further information on each management solution are provided through referencing.

3.1 Discussion of weighting criteria

This section details the weighting criteria along with the motivation for including each criteria. Table 1 shows the criteria names and method of quantification. Subsequent sections provide the justification for inclusion of each of the listed criteria. Table 3 provides the weighting and normalization method for each criteria. Normalization is required in order for the disparate criteria to be summed fairly (Herwijnen 2007).

3.1.1 State Cost and Farmer Cost

Within the Gujarati context, real cost and perceived cost are both important components of the potential for a management solution to succeed. The government is reluctant to spend Gujarati coffers on water resource conservation nor are farmers willing to carry a proportional burden of their water usage.(Mukherji 2006) Barring a shift towards a more

Criteria Name	Criteria Description and Quantification
State Cost	Estimated annual cost of implementation for the state of Gujurat
Farmer Cost	Estimated annual cost of implementation the farmers
Difficulty for the State	Rate the implementation difficulty for the state
Difficulty for the Farmer	Rate the implementation difficulty for the farmer
Susceptibility to Corruption	Susceptibility to evasion and / or corruption. Quantified as likelihood 10% of farmers would evade. 0%-100%
Lobby Cooperation	Willingness of farmers' lobby to cooperate with solution 0(least) - 100(most)
State Cooperation	Willingness of Gujurat state government to cooperate with solution 0(least) - 100(most). Assumes measure is sourced at either national or community level
Organizational Complexity	Organizational complexity of the solution 0(least) - 100(most)
Technical Complexity	Technological complexity of the solution 0(least) - 100(most)
Mitigation Potential	The potential reduction of groundwater use 0(least potential) - 100(most potential)

Table 1: Weighting Criteria

independent and visionary government or a change in the farmers' understanding of the issues, cost will remain an irrationally strong issue in the consideration of any management solution.

3.1.2 Implementation Difficulty

Refers to the complexity of implementation for each group. These categories are used to help weigh if the implementation burden is more on the State side or the responsibility of farmers.

3.1.3 Susceptibility to Corruption

India is infamous for its widespread corruption at virtually every level of society. What typically constitutes blatant bribery and fraud in Western contexts is often relegated to the normal order of business and life. (MISRA 2007, BERTRAND et al. 2007) Gujarat is no exception. My own experiences in Gujarat, interacting with constables and relatives, have helped to confirm this widely observed phenomena.

3.1.4 Farmers' Lobby Cooperation and State Cooperation

With regards to water management, there has been a virtual free for all. Institutional cooperation is desperately needed in Gujarat. In this politically charged atmosphere, solutions that do not invite cooperation and seek support from the farmers as well as the state politicians will have limited success. History has shown that neither national or state agencies have been very successful in establishing a cooperative environment through traditional command and control efforts. (Mukherji 2006)

3.1.5 Complexity

Organizational complexity and technical complexity are also important. The Gujarat state government is not capable of handling a significantly increased bureaucracy for water management. Nor is it likely that such a bureaucracy would withstand corruption pressures. Technical complexity of management solutions must be sensitive to the level of education of farmers and civil servants who might be charged with deploying the management solution. Technical complexity also includes technological complexity. Metering water or electricity would be examples of technically complex solutions. They demand infrastructure as well as capital.

3.1.6 Mitigation Potential

This criteria is at the heart of the matter and asks how much water loss mitigation will be experienced with successful deployment of a given management solution. An effort accepted by all parties that results in little mitigation of groundwater loss has been a failure.

3.2 Criteria Weighting

For the purposes of weighting and valuing criteria, this paper considers the stakeholders. A top-level view of stakeholders includes farmers, the state, the residents (especially rural) of Gujarat, and the national government. Interactions with the national government are not addressed within the scope of this study. Additionally, 2nd order consequences and systems affects of the management solutions are not directly considered.

A large number of criteria can make their relative weighting difficult. Herwijnen (2007) suggests grouping the criteria and weighting the groups first, followed by weighting of each of the criteria separately using the first stage as guidance. The criteria chosen are easily grouped into Costs, Difficulty, Cooperation, Complexity, and Corruption. The potential to mitigate groundwater loss is the overarching objective of any management solution.

The weightings represent the relative importance of a given criteria. A larger magnitude number carries a larger weight, or influence. Weightings can be negative or positive. Positive criteria represent forces consistent with the overarching goal and help to increase the final score of a given management solution. Negative weights, on the other hand, are considered hurdles that the management solution must overcome. Negative criteria are deducted from the final score.

Having ranked the general categories, we may proceed to rank the criteria themselves and present a method of normalization as shown in table 3 on page 8. In this MCA, linear

General Category	Category Weight	Reasoning
Cost	-70	State cost should be more heavily weighted than farmer cost.
Implementation Difficulty	-30	Difficulty of implementing should be isolated mostly to the state as groundwater is a community resource the state is charged with protecting.
Suscept. Corruption	-80	Corruption is capable of negating any mitigation potential.
Cooperation	+50	State Cooperation gets lower points / Lobby cooperation should be more heavily weighted
Complexity	-60	Technical complexity can be a huge hurdle, while organizational complexity maybe is smaller.
Mitigation Potential	+200	

Table 2: Preliminary ranking of criteria in categories

normalization, also known as interval standardization, is the most preferred method of normalizing. It dynamically sets the range of a criteria between the smallest and largest values given across all of the management solutions. Then, the relative position of individual valuations is calculated as a fraction of one. After normalization, *one* corresponds to the largest value provided for a single criteria amongst all the management solutions. In equation form, linear normalization is rather straight forward:

$$\begin{gathered} V_{iNorm} = \frac{V_i - \min(V_{ij})}{\max(V_{ij}) - \min(V_{ij})} \\ \text{where } V_{ij} = \text{ all values for a given criteria} \\ \text{where } V_i = \text{ only the current value being normalized} \end{gathered} \tag{1}$$

4 Methodology

This paper is effectively a quantitative analysis heavily dependent on subjective valuation. The analysis is based on literature covering both the groundwater and political situation in Gujarat. Additionally, my personal experiences with relatives during the summer of 2004 help to provide context. These interactions are limited in relevance as my family is not directly engaged in agriculture, although they are familiar with the political landscape and left strong impressions. Through analyzing the literature on political ecology, I hope to place myself sufficiently in the Gujarati context in order to subjectively rank the management solutions within some reasonable level of reality. A couple criteria have more readily available objective data and these are used when possible. Meanwhile, most of the remaining criteria are weighted and valued based on this immersion into the literature I have attempted. Subsequent work along the lines of this study would benefit greatly by collection of interview and

Criteria Name	Criteria Weight	Method of Normalization
State Cost	-70	linear normalization*
Farmer Cost	-65	linear normalization*
Difficulty of Implementation for the State	-10	linear normalization*
Difficulty of Implementation for the Farmer	-30	linear normalization*
Susceptibility to Corruption	-80	linear normalization*
Lobby Cooperation	+60	linear normalization*
State Cooperation	+20	linear normalization*
Organizational Complexity	-60	linear normalization*
Technical Complexity	-65	linear normalization*
Mitigation Potential	+200	linear normalization*

Table 3: Individual criteria weighting and normalization (*also known as interval standardization)

survey data to more scientifically back and fine tune the valuation and weighting performed here.

5 Analysis

Analysis begins with a description of management solutions, followed by criteria details and justification for their inclusion. The multi-criteria analysis is then presented along with the outcome of the analysis.

5.1 Presentation and Discussion of Management Solutions

5.1.1 Tradeable private property rights

Kumar and Singh (2001) propose allocating tradeable private property rights according to the landholding size for landed farmers and based on subsistence for landless farmers. These rights would automatically help to price groundwater into other markets, for example tanker delivery of water to cities whose water rates are capable of higher returns than agriculture.

Provencher (1993) suggests a slightly different sort of private property rights regime in which private shares to the groundwater stock would be offered by the state. The permit holder would not actually hold particular units of groundwater. Instead, the holder of the permit is granted the right to pump or sell some units of groundwater stock as it deems appropriate. Both Kumar's and Provencher's private property schemes attempt to create a marketable, tradeable, unit value to the groundwater.

Water markets are not unheard of in Gujarat. Diwakara (2006) sites trends of groundwater markets developing in north Gujarat. These self-organized markets are similar to the community tube wells discussed below in that they formed without government or outside intervention. The tradeable private property rights management scheme evaluated here seeks to legitimize and equitably distribute such a groundwater market.

5.1.2 Participatory institutional management regime

Nagaraj (1999) takes lessons from France and attempts to understand the potential for their application in the Indian context. In France, management has proceeded successfully in a distributed fashion and within a participatory framework that engages the users. Rather than a top down approach, this participatory scheme tries to engage the users so their sphere and time-horizon of concerns is broadened. It attempts to make farmers better aware of the groundwater situation beyond their day to day operations concerns. Farmers need water, but they also need to understand the realities of their groundwater predicament. Nagaraj envisions the formation of Water Users Associations that would host workshops in rural areas and engage in negotiations with Gujarat Water Board representatives to arrive at pricing schemes and other measures that are acceptable to the farmers as well as achieve some level of groundwater loss mitigation. (Nagaraj 1999)

5.1.3 Community tube well organisations

Self-organized community managed tube well organizations exist throughout rural Gujarat, but mostly in the Mehsana district. These organizations have been born out of necessity, not out of a philosophy of precautionary action. The communities began experiencing acute groundwater depletion and thus formed community organizations to manage their tube wells. These wells are presently pumping from depths between 120 and 150 meters. The organizations are capable of monitoring withdrawal rates and planning irrigation improvements. These organizations are predicated on a certain degree of trust between independent actors, and are basically viewed as existing out of necessity. (Diwakara 2006) It is important to make the connection between trust and necessity. It may be that such organizations operate less effectively without the trust that comes out of necessity.

5.1.4 Volumetric pricing of groundwater

This solution would require significant infrastructure to monitor and bill based on quantity of water extracted. With over 138,000 tube wells dispersed throughout Gujarat (Mukherji 2006), monitoring would be logistically complicated and costly, if not virtually impossible. Along with the logistical complexity comes a technical complexity and large investment into infrastructure for metering. Volumetric would most likely be open to corruption. As with canal irrigation, an additional hurdle would be the actual collection of fees.(Kumar 2000) Either due to shortage of civil servants or corruption or a combination of the two, the collection of canal irrigation fees currently falls far short of the actual fees due. If volumetric pricing were successfully implemented, it could be effective in deploying a rational water pricing scheme to promote more appropriate and efficient use of water.

5.1.5 Water game

I include the *water game* as envisioned in the MATISSE project here as it is a strategy that holds some promise in the EU and is currently under further research at Lund University's Center for Sustainability Studies (LUCSUS) (Tabara et al. 2007). The water game is an IT enabled stakeholder participation effort. Stakeholders engage each other via computers in a game that includes agent behavior and hydrological models to simulate future conditions based on present decisions. It attempts to educate, immerse, and predict simultaneously. The water game also seeks to enlarge the geographic scope of the stakeholder community. Whereas traditional communities have a small geographic sphere, contemporary water issues take on a much larger geographic scope (i.e. a water basin, an alluvial aquifer, etc). A complete discussion of the promise and pitfall of the water game is not warranted here, but a brief discussion of its applicability in the Gujarati context is:

Rural Indian farmers typically do not have access to computers or developed computer skills. Attempting to engage rural farmers would be a two-fold project of IT education and stakeholder participation, a tall order in any region. Add the lack of infrastructure and resources for such a project, and this study concludes that the water game would be extremely challenging to implement in Gujarat.

5.1.6 Appropriate cropping strategies

Since farmers are effectively not charged for water use (but rather a flat fee levied based upon the size of the pump), farmers readily extract as much water as required and select cash crops with higher rates of return. These cash crops, like banana and sugarcane, are typically heavy water crops and do not reflect the true cost of their groundwater extraction or externalities that result from their cultivation in a semi-arid region. (Kumar and Singh 2001).

Appropriate cropping strategies would entail several components: an information dissemination campaign with an educational component focused on crop choice, crop layout with topographic considerations, irrigation practices, and crop selection. Appropriate cropping strategies could also include providing direct financial subsidies to farmers who convert agriculture land from high to low water demand crops.

5.1.7 Appropriate disincentives

The drivers for disincentives are similar to those in the cropping strategies management solution. Instead, this strategy offers disincentives for water heavy crops. The disincentive would take the form of a tax or surcharge placed on heavy water crops. This levy would most likely have to be imposed in the groundwater extraction electricity fee. In addition, it would require surveillance of crop choice, which might be achieved wholesale via aerial and satellite photography in order to minimize the required labor resources and logistical hurdles involved with ground based monitoring.

5.1.8 Appropriate electricity pricing

In 2003, a large electricity hike of Rs 760/HP (from Rs 500/HP to Rs 1,260/HP) was attempted by the Gujarat Electricity Board. Announcement of the hike prompted protests headed by the farmer wing of the BJP. The electricity tariff was eventually trimmed down to just 850 Rs/HP, a hike of 350 Rs/HP. The farmer lobby still considered this hike a blow in negotiations and a threat to their influence within the BJP. Farmers moved their allegance *en masse* to the Congress party. (Mukherji 2006)

It is critical to note that the original tariff of Rs 500/HP had existed since 1987 until 2003. In 1987, farmer protests demanded the removal of the already *existing* metering of electricity. The Gujarat government conceeded and in a clever and appropriate move created a two tier system: large pumps ($>$ 10HP) had a flat rate that exceeded the typical metered fee and small pumps ($<$ 10HP) were levied a flat rate significantly lower than their metered outcome. Since this scheme impacted the more influential and affluent large landholders, protests and agitation continued under the guise of peasant farmers. A bad drought hit that year and the government caved in to demands. Flat rate tariffs were then fixed at the longstanding rate of Rs 500/HP (in 1987). (Mukherji 2006)

Appropriate electricity pricing is kept here as a management alternative because of its effective nature. The incantation proposed for multi-criteria analysis involves the actual metering of electricity consumed, as opposed to the flat rate currently levied against farmers (based on the size of their pump). Such metering of electricity would act as a proxy for metering volumetric usage of water. Metering electricity would be cheaper and perhaps more effective than metering of water extraction itself, although electricity metering could still be susceptible to corruption by motivated farmers.

5.2 Multi-Criteria Analysis: Weighted Summation

Having presented the management solutions and the criteria by which they will be measured the paper begins the weighted summation. The weighted summation was carried out using a basic spreadsheet. The spreadsheet implements the normalization scheme as well as the summation. The summation follows as would be expected:

$$\begin{gathered} \text{Score}_i = \sum (\text{Weight}_{ij} * \text{Normalized Value}_{ij}) \\ \text{where subscripts } ij \text{ refer to specific criteria for a specific management solution} \\ \text{where subscript } i \text{ alone refers to a specific management solution} \end{gathered} \tag{2}$$

Time only permitted for the MCA valuation to be carried out a handful of times. Ideally, the valuations would be performed by a group of researchers more familiar with the Gujarati context. These researchers working together with community and government representatives would then debate each weight and valuation. Figure 2 presents the concluding MCA valuation for this paper.

Figure 2 is divided into three sections: 1) the white background indicates where the raw valuations determined by this paper are shown for each management solution for each

CRITERIA	MANAGEMENT SOLUTIONS:	Tradable private property rights	Participatory institutional management regime	Community tube well organizations	Volumetric pricing of ground water	Water Game	Incentives for appropriate cropping strategies (subsidies)	Disincentives for poor cropping choices (taxes)	Appropriate electricity pricing
	WEIGHT								
Cost to State	*-70*	1,000,000	10,000	1,000	10,000,000	1,000,000	10,000,000	10,000	10,000
Cost to Farmer	*-65*	10,000	1,000	10,000	10,000,000	10,000	1,000	1,000,000	10,000,000
Implement. Difficulty(farmer)	*-10*	0	10	70	0	0	0	0	0
Implement. Difficulty(state)	*-30*	60	80	0	100	100	50	50	30
Corruption Susceptibility	*-80*	5	20	10	60	30	30	30	60
Farmer Lobby Cooperation	*60*	90	30	30	5	10	60	10	10
State cooperation	*20*	80	70	20	60	60	30	90	100
Organizational Complexity	*-60*	90	100	60	40	100	70	70	40
Technical Complexity	*-65*	10	20	10	70	100	40	40	40
Mitigation Potential	*200*	60	30	50	100	50	65	50	90
NORMALIZED	**Method**								
Cost to State	linear	0.0999	0.0009	0.0000	1.0000	0.0999	1.0000	0.0009	0.0009
Cost to Farmer	linear	0.0009	0.0000	0.0009	1.0000	0.0009	0.0000	0.0999	1.0000
Implement. Difficulty(farmer)	linear	0.0000	0.1429	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Implement. Difficulty(state)	linear	0.6000	0.8000	0.0000	1.0000	1.0000	0.5000	0.5000	0.3000
Corruption Susceptibility	linear	0.0000	0.2727	0.0909	1.0000	0.4545	0.4545	0.4545	1.0000
Farmer Lobby Cooperation	linear	1.0000	0.2941	0.2941	0.0000	0.0588	0.6471	0.0588	0.0588
State cooperation	linear	0.7500	0.6250	0.0000	0.5000	0.5000	0.1250	0.8750	1.0000
Organizational Complexity	linear	0.8333	1.0000	0.3333	0.0000	1.0000	0.5000	0.5000	0.0000
Technical Complexity	linear	0.0000	0.1111	0.0000	0.6667	1.0000	0.3333	0.3333	0.3333
Mitigation Potential	linear	0.4286	0.0000	0.2857	1.0000	0.2857	0.5000	0.2857	0.8571
	WEIGHT SUM:	**71**	**-97**	**37**	**-88**	**-138**	**-34**	**-49**	**-1**

(linear normalization refers to interval standardization)

Figure 2: Multi-Criteria Analysis Scenario

criteria; 2) the light grey background indicates the section where the valuations have been normalized. This area allows for one to more easily compare the various criteria for a given management solution; 3) the dark grey background and white font indicate the weighted summation results. These results account for both the normalization and the weighting as described in previous sections.

6 Results

Of the 8 management solutions evaluated, the multi-criteria analysis highlights three top solutions: tradeable private property rights, community tube well organizations, and appropriate electricity pricing. With scores ranging from -138 to +71, tradeable private property rights and community tube well organizations were in the positive range, while appropriate electricity pricing was effectively even at -1. A positive result suggests that the positive attributes outweigh the negative attributes.

The top choice of this MCA: a tradeable private property rights scheme (score = +71) would have to be implemented by the state or perhaps even at the national level. It would have to be enabled by a supporting legal framework and some sort of distribution of groundwater property rights. Kumar and Singh (2001) suggest an approach that would provide equitable distribution between poor and more affluent farmers. While the State would not sell these rights, it would be obligated to organize their distribution in such a way to guarantee that the sum of rights distributed met a reasonable level of groundwater extraction. Additionally, this distribution of groundwater rights would have to be carefully controlled such that their distribution was localized. Trading groundwater rights from a groundwater rich locale to a region experiencing over-exploitation would completely defeat the purpose of the tradeable rights. Ideally, the state would thus set up the trading scheme within something akin to the management districts. Management districts could be combined (based on groundwater development rates) in order to create larger and more flexible markets.

The second choice of this MCA is a more tricky management solution. Community tube well organisations get a high score (37) in this ranking. The reason they are tricky is that they are not a management solution that the state can enforce. Perhaps even encouraging their formation is a difficult task. Recall in the discussion on tube well organisations that most of them were born out of necessity. They require a level trust that is achieved out of common need and shortage. As a preventative strategy, community tube well organisations would be difficult create from outside. If the state is not truly capable of creating community tube well organisations, perhaps the state could provide inducements to encourage their development from the bottom up. Such inducements could be in the form of assistance, education, and funding to support community based tube well organisations. In some ways, it would be similar to the state inducing the formation of user groups as Nagaraj et al. (1999) suggest. The key difference would be that while user groups would be encouraging the formation of an educated body to represent farmers in negotiations with the state, the tube well organisations would be created in order to better manage groundwater resources at community based, local level. This level of management has the advantage of self-determination, but the disadvantage of insight into the broader conditions of groundwater at the regional or aquifer level.

Appropriate electricity pricing (Score = -1), the third choice of this MCA, is not a surprise. Metered electricity pricing has been in effect in Gujarat in years past and it's success can be inferred by the impact they had on farmers to protest. Thus, it's logistical and technical hurdles are manageable, and as had been observed in most economies, metered pricing improves efficiency of use and better planning of agriculture. As the past has shown, hurdles to appropriate pricing of electricity have been primarily political. One of the drivers of these political forces might include a lack of awareness of the consequences of relentless pumping. A short-term horizon and lack of pragmatism seems to pervade the rural agricultural community. To be effective, a metered electricity pricing scheme must be accompanied by, at the very least, an outreach effort to engage the farmer community and lobby in what has historically been a strict command and control approach that has failed to achieve management goals.

With metered pricing, many affluent farmers might choose to upgrade their pumps to gain more efficient pumping at the same electricity cost. While not bad a decision overall, this shift would fail to mitigate groundwater concerns. Additionally, metered pricing introduces the problems of complete tariff collection as well as corruption.

There is also the realities of farmer suffering, and this can not be ignored. This paper envisions potential success with the introduction of metered pricing: a graduated pricing regime combined with a graduated time line in the increases of tariffs. This allows flexibility for subsistence and peasant farmers to continue making a living. In fact, for them, the metered pricing might even be more affordable. The graduated time line for increasing metered tariffs (should be proposed for at least 5 years into the future) provides the larger scale farmers a window of opportunity and planning horizon to migrate away from heavy water crops and towards more efficient irrigation techniques.

7 Limitations

The methodology used in this paper is significantly dependent on subjective valuation and as a consequence the results are certainly subject to debate. This subjectivity is a documented characteristic of the weighted summation method (Herwijnen 2007). What this method lacks in objectivity, it makes up for with transparency.

Analysis is also limited by the nature of being heavily dependent on existing literature. Such literature is not particularly abundant for the case of Gujarat, and available literature does not focus on the questions posed by the MCA. There is insufficient literature to provide good insight into the prospects of all the management criteria used above. Hence, this MCA lacks significant representation of the voices of real people: real farmers, real politicians, and members of the water board. Despite these limitations, this exercise is still a fruitful analysis that is capable of highlighting the direction Gujarat groundwater management needs to begin exploring.

This study would also benefit from a sensitivity analysis. With such an analysis, it would be possible to determine the valuation points that most easily change the overall outcome. Sensitivity analysis could also provide insight into where the real-life results of a management solution might be most likely to deviate from determinations of this MCA.

The lens of a single researcher is not adequate for an MCA. Ideally, this process would have engaged other researchers, farmers, and civil servants in Gujarat. Their engagement would have provided a forum for discussion over the weighting and valuation. Additionally, such a group would be able to more dynamically iterate through the weighting and valuation procedure of the MCA to arrive at different scenarios based on different outlooks. Such an analysis would generate a more thorough and strongly founded MCA as well as an entry point into a more participatory process.

8 Conclusion

Groundwater resources in Gujarat are beginning to approach critical conditions while the farmers who are capable of preventing this calamity are pumping without caution. The government of Gujarat has had a very difficult time affecting policies to better manage this shared resource. This paper attempted to provide focus towards management strategies with better chances for success by performing a multi-criteria analysis (MCA). The MCA provided three top choice management strategies: tradeable private property rights, community tube well organisations, and appropriate electricity pricing. This paper favors the property rights and metered electricity pricing schemes as the best opportunities for a State introduced management solution. These solutions allow the flexibility to engage farmers and maintain control at a higher levels. Engaging farmers in the introduction of these solutions could help to calm the political landscape and preempt protests, thus paving the path towards more successful management of Gujarat groundwater.

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A Steps of weighted summation

The steps of a weighted summation MCA as laid out by Herwijnen (2007):

- Definition of alternatives: identify the policy alternatives to be compared with each other.
- Selection and definition of criteria: identify the effects or indicators relevant for the decision.
- Assessment of scores for each alternative: assign values to each effect or indicator for all alternatives.
- Standardization of the scores in order to make the criteria comparable with each other.
- Weighting of criteria, in order to assign priorities to them.
- Ranking of the alternatives. A total score for each alternative is calculated by multiplying the standardized scores with its appropriate weight, followed by summing the weighted scores of all criteria