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IWMI- TATA
Water Policy Program

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Water Policy Research

Highlight

Groundwater Markets and Water Use Efficiency:
The Case of Karnataka

S. C. Deepak,
M. G. Chandrakanth
and
N. Nagaraj

This study, based on primary data collected from 120 groundwater users in eastern dry zone of Karnataka compares the water use efficiency among different categories of water users, viz. well owners who do not sell water, well owners who sell water either for agricultural or non-agricultural use and water buyers (both agricultural and non-agricultural). Some of the important findings are-

- The cropping pattern varies between categories, with both the sellers and buyers preferring low water intensive mulberry crop, while the self user's category grew more water intensive crops.
- Farmers who sold water for non-agricultural purposes earned the highest return (because of higher end-use price) and also made the most efficient use of water. Thus, making a point that end-use pricing is a key in shaping marginal productivity of water.
- Compared to the self-users, farmers selling water for either agricultural or non-agricultural purposes realized higher marginal productivity. Thus, groundwater markets acted as an effective tool in enhancing efficient use of a scarce resource.

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GROUNDWATER MARKETS AND WATER USE EFFICIENCY: THE CASE OF KARNATAKA[1]

RESEARCH HIGHLIGHT BASED ON A PAPER TITLED: "GROUNDWATER MARKETS PROMOTING EFFICIENCY IN WATER USE IN AGRICULTURE IN KARNATAKA"

This study explores efficiency and equity in groundwater markets in the hard rock areas of Karnataka. It compares the water use efficiency of farmers using groundwater for irrigating their land and also selling it for agricultural purpose (WS_A, n=30), farmers using water for irrigating their land and also selling for non-agriculture purpose (WS_{NA}, n=15), farmers who do not either sell or buy water but use it on their farms (W_O, n=30), farmers who are buying groundwater for agriculture purpose (WB_A, n=30), and buyers of water for non-agriculture purpose (WB_{NA}, n=15). The Nash equilibrium framework describing the bargaining power of buyers and sellers of groundwater is used. Sidlaghatta taluk in eastern dry agroclimatic zone (EDZ) of Karnataka is chosen because it supports intensive groundwater markets. The objective of the study is to find out water use efficiencies among different groups of water users with the hypothesis that WS_{NA} obtain higher water use efficiency than WS_A, WB_A, and W_O.

METHODOLOGY

Borewell is the predominant groundwater extraction structure in the study area as all the 93 functioning wells in the sample were bore wells. Yield of bore well was estimated by recording the number of seconds to fill a bucket (of known volume) of water (expressed as gallons per hour, GPH) and it was then linearly extrapolated. For WS_A total groundwater extracted includes water used on their farm plus water sold to buyers for agriculture. For WS_{NA}, total water extracted includes water used on their farm plus water sold for non-agriculture purposes. The following method was used to calculate the volume of extraction (in acre-inches).

Volume of water sold by $WS_A = (Y \times In \times Cd) \div 22611$ = Volume of water bought by WB_A

Where,
Y = yield of bore well (GPH)
In = number of irrigation per month supplied to the buyer
Cd = duration of buyers' crop in months

Volume of water sold by $WS_{NA} = (Tn \times Tc \; Wsn \times Mn \times$ 4.54 litres/gallon) $\div$ 22611

Where,
Tn = number of tankers filled per day
Tc = tanker capacity in litres
Wsn = number of days water sold in a month
Mn = number of months in a year when water was sold

Theoretically, the variable cost of irrigation for farmers was almost nil, as they seldom paid electricity charges. The only variable cost they incurred was that of repair and maintenance. However, owing to frequent failure of irrigation wells occasioned by cumulative interference externality and other factors, farmers were forced to invest on additional wells. Thus the annual cost of irrigation (Ic) is calculated as:

$Ic = Cw + Cc + Cp + Cr$
Where,
Cw = amortized cost of irrigation well
Cc = amortized cost of conveyance
Cp = amortized cost of pump set and electrical installation
Cr = annual cost of repairs and maintenance

Amortization is over the average life of irrigation wells. Labor cost of irrigation was merged with cost of other agricultural operations. Annual cost

[1] The research covered by IWMI-Tata Highlight and Comment is carried out with generous support from Sir Ratan Tata Trust, Mumbai under the IWMI-Tata Water Policy Program. However, this Highlight is based on an invited paper authored by S.C. Deepak, M.G. Chandrakanth and N. Nagaraj who are associated with the Department of Agricultural Economics, University of Agricultural Sciences, GKVK, Bangalore. We are grateful to authors for allowing us to publish this for wider circulation as an IWMI-Tata Water Policy Research Highlight. The research paper can be downloaded from the IWMI-Tata Website http://www.iwmi.org/iwmi-tata

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of irrigation pertains to single irrigation well and was added across all the wells on the farm. This total cost of irrigation was then appropriated over individual crops according to the volume of groundwater used for each crop. Thus, cost of irrigation per acre-inch = (total amortized cost of irrigation on the farm)/(total acre-inches of water used in that year). The cost of irrigation for each crop is the cost per acre-inch of water multiplied with the number of acre-inches of water applied to that crop. Negative externality (per well) is considered as amortized cost per functioning wells minus amortized cost per well.

Water buyers were more likely to grow crops that needed less water so as to economize their total irrigation costs. Water sellers, on the other hand, too preferred low water intensive crops on their farm so that they could cover greater area through water sales.

Results and Discussion

Economic Profile of Farmers in Groundwater Market

Among the category of WS_A, 40 percent were marginal and small farmers. Thus, groundwater for agriculture is sold by both large farmers (60 percent) and marginal and small farmers (40 percent). However, among WS_{NA}, 70 percent were small farmers. Among WB_A, 70 percent were marginal and small farmers. Thus, agricultural water buyers were predominantly small and marginal farmers. Average land holding size for all categories of players in the water market was below 5 acres: 4.71 acres for WS_A, 3.45 acres for WB_A and 2.17 acres for WS_{NA} (Table 1).

There were sharp differences in area irrigated among different categories; while WS_A and WB_A irrigated 2.03 acres and 0.37 acres respectively; the WS_{NA} irrigated around 0.42 acres. But in percentage terms, WS_{NA} achieved irrigation coverage of over 73 percent, while WS_A could irrigate only 43 percent of their operational holding. This figure was abysmally low at around 10 percent for WB_A. W_O, on the other hand, irrigated about 2.3 acres or 36 percent of their holding. Thus, it seems that both WS_A and WS_{NA} could achieve higher irrigation intensity possibly from the income they derived from selling water. WS_{NA} were invariably located on urban outskirts and tapped the increasing demand for water for non-agricultural purposes.

Cropping Preferences among Various Categories

Mulberry, a hardy low water demanding perennial, is the crop preferred by farmers in the groundwater market. WB_A had 87 percent of irrigated area under mulberry followed by WS_A (70 percent), WS_{NA} (64 percent) and W_O

Table 1: Land Holding by Farmers in Water Markets

Particulars	W_O (N=30)	WS_A (n=30)	WB_A (n=30)	WS_{NA} (n=15)
Total land holding size (acres)	6.12 (100)	4.71 (100)	3.45 (100)	2.17 (100)
Dry land area (acres)	3.00 (49.00)	2.00 (42.46)	2.87 (83.18)	0.42 (19.35)
Area irrigated by irrigation well (acres)	2.23 (36.43)	2.03 (43.09)	0.37 (10.72)	1.60 (73.73)
Area under orchards (mango/eucalyptus)	0.89 (14.54)	0.68 (14.43)	0.21 (6.08)	0.15 (6.91)
No. of marginal farmers (holdings below 2.5 acres)	2 (6.67)	4 (13.34)	8 (26.67)	3 (20)
No. of small farmers (holdings 2.5 to 5 acres)	8 (26.67)	8 (26.67)	13 (43.34)	9 (60)
No. of large farmers (holdings above 5 acres)	20 (66.66)	18 (60)	09 (30)	03 (20)
Total	**30 (100)**	**30 (100)**	**30 (100)**	**15 (100)**

Note: Figures in parentheses show percentage to total.
Source: Based on Primary Survey

Table 2: Sources of Net Farm Income

Source of income per farm	W_O (n=30)	WS_A (n=30)	WB_A (n=30)	WS_{NA} (n=15)
From farming (irrigated agriculture)	47149 (30.98)	41584 (24.58)	10683 (14.90)	43783 (20.96)
From dairying	26884 (17.67)	29485 (17.42)	32965 (46.01)	9154 (4.38)
From sericulture	61426 (40.37)	58691 (34.69)	20431 (28.51)	45500 (21.78)
From sale of ground water	-----	29069 (17.18) from selling 1396 acre-inches for irrigation	-----	85000 (40.69) from selling 368.46 acre-inches for non agriculture purpose
From other sources (business, job)	16666 (10.95)	10334 (6.10)	7563 (10.56)	25428 (12.17)
Total annual income per farm	152125 (100)	169163 (100)	71642 (100)	208865 (100)

Note: Figures in parentheses show percentage to total.
Source: Based on Primary Survey

(56 percent). Area under other crops such as tomato, chilies, carrot, beetroot and potato, which require relatively more water, was higher for W_O over other categories of farmers. Thus, water buyers were more likely to grow crops that needed less water so as to economize their total irrigation costs. Water sellers, on the other hand, too preferred low water intensive crops on their farm so that they could cover greater area through water sales.

Features of Irrigation Wells

Features of irrigation wells, such as rate of well failure, gross irrigated area across wells, and average life of wells varied across categories. WB_A suffered the highest failure rate of wells and eventually resorted to buying groundwater from neighboring farmer-sellers. Thus, 30 WB_A among themselves reported only 8 functioning wells, and 30 W_O reported 46 functioning wells. Though gross irrigated area per well was 5 acres and the average age of wells was 9 to 10 years, there were inter-group variations. Negative externality per well was the highest for WB_A (Rs. 4,061) while for others it ranged from Rs. 1,500 to Rs. 1,900. The amortized cost per well ranged from Rs. 13,483 to Rs. 15,547 for different categories and that of functioning wells ranged from Rs. 15,725 to Rs. 17,544.

Sources of Income in Groundwater Market

For WS_A, W_O, and WS_{NA}, income from irrigated farming ranged from 20 to 30 percent of the annual income, while for WB_A, irrigated farming

Table 3: Economics of Irrigation (2003-04)

Particulars	W_O (N=30)	WS_A (n=30)	WB_A (n=30)	WS_{NA} (n=15)
Cropping intensity (percent)	174.8	201.7	163	244.2
Gross irrigated area per farm (acres)	6.38	6.20	3.65	5.54
Groundwater sale per acre of GIA (acre-inches)	-	7.50 sold	10.77 purchased	5.04 sold
Water extracted per well (acre-inches)	107.58	127.16	74.00	81.55
Groundwater used on per farm basis (acre-inches)	164.96	131.53	66.26	36.66
Groundwater used per acre of GIA (acre-inches)	25.91	21.21	15.41	15.64
Amortized cost of irrigation per acre-inch of groundwater from owned irrigation well (Rs.)	131	122	182	189
Amortized cost per well (Rs.)	14058	15547	13483	15427
Net returns per farm (Rs.)	108575	100275	31114	89283
Net returns per acre inch of groundwater used (Rs./acre-inch)	658	762	470	1217
Net returns per acre of GIA (Rs.)	17009	16173	7208	18345

Source: Based on Primary Survey

Table 4: Net Returns from Water Sale (2003-04)

Particulars	WS_A (n=30)	WB_A (n=30)	WS_{NA} (n=15)
Net returns per farm (Rs.)	100275	31114	89283
Net returns per farm including returns from sale of groundwater (Rs.)	129344	-	174283
Net returns (per farm) from selling groundwater per year (Rs.)	29069	-	85000
Net returns per acre inch of water from farming (Rs./acre inch)	563	470	912
Net returns per acre inch of groundwater from farming and sale of groundwater (Rs/acre inch)	726	-	1780
Addition to the net returns per acre inch of groundwater extracted (Rs.)	163	-	868
Net returns per acre inch from using own water in farming (Rs./acre inch)	762	-	1217
Notional price realized per acre inch of groundwater sold (Rs./acre inch)	624*	-	6910**

Source: Based on Primary Survey

contributed 15 percent to their income (Table 2). WS_A and WS_{NA} realized 17 and 41 percent of their income from sale of groundwater respectively. WS_A sold higher volume of water (47 acre-inches) per farm for agriculture, and realized lower returns (of Rs. 29,069 per farm), compared to WS_{NA} who sold half the volume (25 acre-inches) but realized an income (Rs. 85,000) more than twice that of WS_A. This was because groundwater for non-agricultural purposes like silk filatures and domestic use fetched higher price compared to water sold for agricultural purpose. Thus, end use price of groundwater and not so much the volume of water sold is the key in shaping marginal productivity of groundwater.

Economics of Irrigation

The net return per acre of gross irrigated area (GIA) was highest for WS_{NA} (Rs. 18,435), followed by W_O(Rs. 17,009), WS_A (Rs. 16,173) and WB_A (Rs. 7,208) (Table 3). WB_A are relatively more efficient in using water for irrigation than WS_A, using 15.41 acre-inches compared to 21.21 acre-inches used by WS_A per acre of gross irrigated area. Thus, both WS_{NA} and WB_A made the most efficient use of groundwater at the rate of 15 acre-inches per acre.

As far as economics of water selling is concerned, WS_A realized Rs. 762 per acre-inch of groundwater used for own use, and Rs. 624 for every acre-inch of groundwater sold, hardly a difference of Rs. 138 per acre-inch—a margin not substantial to cover the additional risks and uncertainty in groundwater extraction (Table 4). Notional price realized by WS_A and WS_{NA} per acre-inch of groundwater is Rs 624 and Rs 6,910 respectively. This whopping difference of Rs 6,286 is owing to end use pricing, which is much higher for non-agricultural purposes.

The cost of purchased water for agriculture forms about 50 percent of the net return. WB_A's gross irrigated area under purchased water was 3.5 acres, and realized a net return of Rs. 470 per acre-inch of purchased water which translated to a net return of Rs 7,208 per acre of gross irrigated area. For WB_A irrigation cost is two to four times higher than the cost incurred by other categories.

Groundwater price ranged from one-third to one-fourth of the gross value of produce cultivated

Table 5: Estimated Price of Water in Different Crops (2003-04)

Crop and crop share	Yield of the crop (tonnes/ acre)	Ground water bought and used per acre (acre inches)	Estimated value of ground water used per acre = Market value of crop share quantity (Rs)	Estimated price of groundwater sold for agriculture (Rs per acre inch)	Amortized cost per acre inch of ground water(Rs.)	Estimated price - amortized cost ratio
Mulberry (1/3)	8.56	5.4	3420	633	122	5.19
Tomato (1/4)	23.30	19	12460	656	122	5.37
Potato (1/4)	6.21	12	6800	567	122	4.65
Carrot (1/4)	6.06	11	6795	617	122	5.06
Beetroot (1/4)	6.82	9.5	6014	633	122	5.19

Source: Based on Primary Survey

Table 6: Price of Groundwater Purchased for Non-agricultural Purposes (2003-04)

Groundwater buyers	Number of groundwater buyers in the sample (n=15)	Ground-water purchased in liters per day	Ground-water bill (Rs/ day)	Price per 100 liters of ground - water (Rs)	Justification regarding the groundwater price
Silk filatures	08 (53.66)	1400	95	6.90	Power tiller driven tankers are the main mode of transporting water with tanker capacity ranging from 1,400-1,500 litres
Hotels	04 (26.34)	1100	70	6.40	Bullock drawn, cart mounted tankers are the main mode of transport, the tanker capacity ranging from 250 to 375 liters.
House holds	03 (20)	400	20	4.00	Bullock drawn, cart mounted tankers are the main mode of transport with tanker capacity ranging from 250 to 375 liters

Note: Price of water transported by mounted tankers ranges from Rs. 90 to 100 per load.
Source: Based on Primary Survey

using purchased groundwater. In crop share basis, the estimated price of groundwater in agriculture ranged from Rs. 567 to Rs. 656 per acre inch (Table 5). At the amortized cost of Rs. 122 per acre-inch of groundwater, the price to amortized cost ratio ranged from 4.65 to 5.37 across different crops. Price of groundwater for non-agriculture purposes, ranged from Rs. 4 to Rs. 6.9 per 100 litres for purposes like household use, hotels and silk filatures (Table 6).

Both WS_A and WS_{NA} sold about 25 percent of groundwater extracted by them but realized differential net return owing to the price differential obtained which is, in turn, a strong function of the end use. The estimated price realized by WS_A is Rs. 624 per acre-inch as they sold water for irrigation while WS_{NA} realized ten times this price, since they sold groundwater for non-agricultural purposes (Figure 2). WS_{NA} extracted around 45 percent less groundwater than WS_A, but realized 192 percent higher net return. Thus end use and end use price play a key role in determining volume of groundwater extracted, sold, and revenue realized.

Nash Equilibrium Model of Groundwater Pricing

The Nash equilibrium framework was used to model the bargaining power of water sellers and buyers. The model assumes that water buyers and sellers are highly rational with equal bargaining skills, each has full knowledge of the tastes and preferences of the other, and each individual wishes to maximize his utility. Bargaining power of seller is assumed in terms of GIA of sellers and total water extracted by them, while bargaining power of buyer is assumed to be GIA of buyers. As crop share is one-third to one-fourth of crop value, water price per acre-inch tends to remain uniform and this was chosen as the dependent variable after it was standardized by amortized cost

Figure 2: Groundwater Extracted and Sold in Groundwater Market (2003-04)

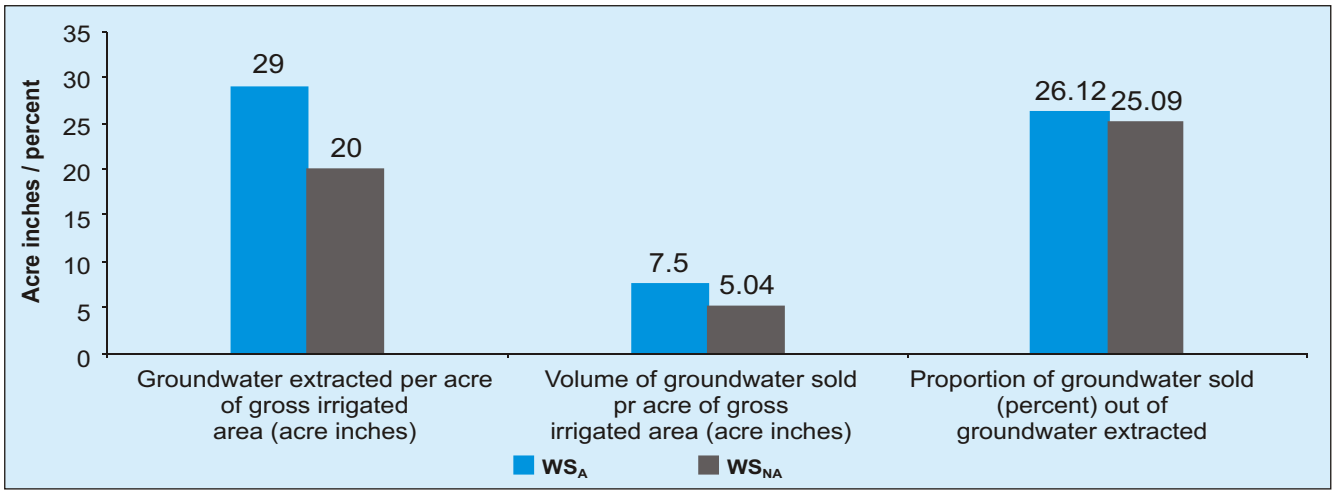

Table 7: Nash Bargaining Model of Groundwater Niche Market
Dependent variable: Ratio of groundwater price to its amortized cost (n=30)

		Inputs						R^2
	Intercept	GIA of seller (X_1)	Total water extracted seller (X_2)	GIA of buyer (X_3)	X_1^2	X_2^2	X_3^2	
Estimated Co-efficient	-1.0938	2.6861 (1.7440)	-0.1334 (0.0884)	4.1523 (2.1150)	-0.208 (0.1064)	0.0004 (0.0002)	-0.4928 (0.245)	0.7328
t value		1.5402	-1.5079	1.963	-1.960	2.313	-2.009	

Note: Figures in parentheses are standard errors.
Source: Based on Primary Survey

Farmers who sold water for either agricultural or non-agricultural purposes realized higher marginal productivity of water than farmers who did not sell water. Thus, groundwater markets were an effective tool in enhancing efficient use of a scarce resource.

incurred by sellers for extracting every acre inch of water. This price-cost ratio is assumed as a surrogate for monopoly power.

Surrogate price of groundwater (Y) = f (x_1, x_2, x_3)

Where,
x_1 = gross irrigated area of seller
x_2 = total water extracted by seller
x_3 = gross irrigated area of buyer

This Nash bargaining model is assumed to follow the quadratic function:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + c_1x_1^2 + c_2x_2^2 + c_3x_3^2$$

The elasticity of price-cost ratio with respect to each of the explanatory variables is considered as

$$(b_i + 2c_{ix}i)\, xi / y_i$$

The results of the Nash Equilibrium model show that for one percent increase in GIA of the seller, the price-cost ratio increased by 0.098 percent. For one percent increase in total water extracted by sellers, the price-cost ratio increased by 0.85 percent and for one percent increase in GIA of buyer, the ratio increased by 0.3 percent. Thus, total water extracted by seller and GIA of buyer are the key explanatory variables in price determination in groundwater market. Total water extracted by seller gives greater bargaining power to the seller in price determination than GIA of buyer and GIA of seller. By judiciously distributing the extracted water between own farm and neighboring buyer farms groundwater sellers are able to reap larger benefits, to the tune of Rs 29,069 per farm.

Conclusion and Policy Implications

Groundwater markets help farmers in using the scarce groundwater more efficiently. About 70 percent of water buyers are marginal and small farmers. Thus the groundwater market helps spreading access to irrigation for those who do not own well. Water buyers are also found to be using water sparingly and thus have achieved higher water use efficiency. Farmers who sold water for either agricultural or non-agricultural purposes realized higher marginal productivity of water than farmers who did not sell water. WS_A and WS_{NA} respectively realized 17 percent and 41 percent of their total net return from sale of water. This is an additional income over and above the returns from agriculture. Farmers participating in the groundwater market are more efficient in water use in addition to conserving groundwater than those who are not participating. Thus, far from enhancing resource depletion in hard rock areas as many scholars aver, water markets promote efficient use of a scare resource. Groundwater markets are thus promoting efficiency in groundwater use and, in addition, are a conservation strategy for scarce groundwater in hardrock areas.

HEADQUARTERS
127, Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Mailing Address : P. O. Box 2075, Colombo, Sri Lanka
Telephone : +94 11 2787404, 2784080
Fax : +94 11 2786854; E mail : iwmi@cgiar.org

REGIONAL OFFICE FOR SOUTH ASIA
C/o ICRISAT, Patancheru 502324
Andhra Pradesh, India
Telephone : +91 40 30713071
Fax : +91 40 30713074; E mail : iwmi-southasia@cgiar.org

NEW DELHI
South Asia Liaison Office
2nd Floor, NASC Complex, DPS Marg
PUSA Campus, New Delhi 110012, India
Telephone : +91 11 25840811-2
Fax : +91 11 25841294; E mail : b.sharma@cgiar.org

NEPAL
Department of Irrigation, Room # 412 and 413
Jawalkhel, Lalitpur
GPO 8975 EPC 416, Kathmandu, Nepal
Telephone : +977 1 5542306
Fax : +977 1 5536219; E mail : d.pant@cgiar.org

CHINA
Center for Chinese Agricultural Policy
Chinese Academy of Sciences
Building 917, Datun Road, Anwai
Beijing 100101, China
Telephone : +86 10 64889440
Fax : +86 10 64856533; E mail : i.makin@cgiar.org

REGIONAL OFFICE FOR CENTRAL ASIA (Pakistan)
12KM, Multan Road, Chowk Thokar Niaz Baig,
Lahore 53700, Pakistan
Telephone : +92 42 5410050-53
Fax : +92 42 5410054; E mail : iwmi-pak@cgiar.org

REGIONAL OFFICE FOR CENTRAL ASIA (Uzbekistan)
Apartment No. 123
Home No. 6, Murtazaeva Street,
Tashkent 700000, Uzbekistan
Telephone : +998 71 1370445
Fax : +998 71 1370317; E mail : m.hassan@cgiar.org

REGIONAL OFFICE FOR SOUTHEAST ASIA
P. O. Box 1025, Kasetsart University,
Bangkok 10903,Thailand
Telephone : +66 2561 4433
Fax : +66 2561 1230; E mail : iwmi-sea@cgiar.org

REGIONAL OFFICE FOR AFRICA
Private Bag X813, Silverton 0127, Pretoria, South Africa
Telephone : +27 12 845 9100
Fax : +27 12 845 9110; E mail : iwmi-africa@cgiar.org

SUB REGIONAL OFFICE FOR WEST AFRICA
IWMI Ghana, PMB CT 112, Cantonments, Accra, Ghana
Telephone : +233 21 784752-4
Fax : + 233 21 784752; E mail : iwmi-ghana@cgiar.org

IWMI-Tata Water Policy Program

The IWMI-Tata Water Policy Program was launched in 2000 with the support of Sir Ratan Tata Trust, Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations.

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IWMI-Tata Water Policy Program
Elecon, Anand-Sojitra Road
Vallabh Vidyanagar 388120, Gujarat, India
Telephone: +91 2692 229311-13
Fax : +91 2692 229310
E-mail: iwmi-tata@cgiar.org
Website: http://www.iwmi.org/iwmi-tata

IWMI International Water Management Institute

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