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# Chapter 9

# Groundwater Extraction for Use Efficiency in Crop Production under Different Water Market Regimes: A Case Study of Uttar Pradesh State (India)

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**Abstract.** Tube well irrigation, through modern water extraction mechanisms (WEMs) has been vital to food security and sustainable livelihoods in India due to reliable and comparatively better efficiency than canal irrigation. Since such mechanisms are largely under the private domain, its distribution is highly skewed towards large farmers. Small and marginal framers have to rely on owners of WEMs for irrigation water, resulting into an emergence of an informal water market. Thus, the present study was an attempt to examine the groundwater extraction and water use efficiency under different water market regimes (buyer, self-user, self-user + buyer and self-user + seller) in Central Plain Zone (CPZ) of Uttar Pradesh, which has well developed water market and water intensive cropping pattern. The primary data was collected through multi-stage random sampling from hundred farmers-households of Central Plain Zone in the year 2007. By examining the source–wise development of irrigation, it was found that share of canal irrigation in total irrigated area of Central Plain Zone has decreased during last four decades while that of tube well has increased about three times during the same period indicating that region was heavily depending upon groundwater as a source of irrigation. Moreover, most of the farmers in the study domain were predominantly small and marginal having less than 2 hectares (ha) of land. These resource poor farmers buy water from the WEM owners, thus, groundwater market provided them easy accessibility to irrigation water and helped in realizing better yield. Accessibility to secure irrigation was reflected by cropping pattern, which was skewed towards water intensive crops like wheat, paddy, sugarcane, potato, etc. To know the water use efficiency for different water market regimes, production function approach was used and it was found that for buyers, water was most limiting

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factor for farming due to uneconomic land holding and they were found to be under utilizing water resource. For self-user, and self user + seller, having their own water extraction facilities, over utilization of the water resource was found due to injudicious use of it while, self user + buyer were using groundwater economically resulting in almost optimum utilization of irrigation water. Thus although groundwater market helped in better realization of their resources to both the groups (sellers and buyers), but have various efficiency and equity considerations. In most of the cases, the water-buyers could get irrigation water only after the irrigation on own land was over by the owners/ sellers.

**Keywords:** Tube well irrigation, Canal irrigation, Groundwater market, Water market regimes, Water productivity, Water use efficiency.

## Introduction

The heat of water crisis for all usable purposes is being felt nowadays all over the world. India is also not an exception and therefore, lot of farmers' protest against state government, struggle between two state governments over controlling rights of river water, civil unrest in the urban areas, plight of villagers from one place to another, etc. have been reported in the recent pasts. Development of groundwater, at present, is the major concern at the national level on account of some inherent weaknesses (maintenance and operational inefficiencies) in canal irrigation (surface water irrigation) system, as former accounts for about two-third of India's net irrigated area (Kumar *et al.,* 2003). Water conveyance loss in canal irrigation is estimated at 40-50 per cent which is twice than that of well irrigation (Sivanappan, 1995) and about 20 per cent of canal irrigated area currently is seriously affected by water logging and/or salinity problem (Dhawan, 1988). This has resulted into the emergence of a groundwater market, which has various efficiency and equity considerations. It offers an opportunity for equitable access to groundwater irrigation for resource poor farmers and marginal farmers, as well.

In the recent years, most of the groundwater developments have taken place in the private domain through modern Water Extraction Mechanisms (WEMs) i.e. tube-wells (From here on, these two terms have been used synonymously). Possession of these WEMs/ tube-wells is highly skewed in favour of large farmers due to huge capital investment needed and relatively better consolidation of land holdings among them, as they install the tube-wells primarily for their own irrigation. Though, water market benefits buyers and sellers across the farm sizes, particularly benefiting more to small and marginal farmers as they could irrigate their crops without making huge initial investment (Singh and Singh 2003). Water market also helps farmers using the scarce groundwater resource more efficiently (Deepak *et al.,* 2003). However, it is widely accepted that the water buyers face problems like inadequate and untimely irrigation of their crops. Thus, the present study is an attempt to examine and analyze the groundwater accessibility, its productivity in terms of output per unit of irrigation (ground) water and irrigation efficiency at micro level under different water market regimes in the Central Plain Zone (CPZ) of Uttar Pradesh. The Zone has significant place in the agricultural economy of the state, since farmers in this region are exclusively engaged in water intensive crop production (e.g. Paddy, Wheat, Sugarcane, Potato etc).



## Study Location and Data Collection

Uttar Pradesh state is situated in northern plains of India, which falls between 23°52' and 31°28' north latitude and between 77°4' and 84°38' east latitudes. It ranks fourth (after separation of Uttarakhand state from it) with respect to geographical area among the Indian states but have largest (17 % of total) population. The state is divided into 70 administrative districts which are broadly classified into four economic regions viz., the Eastern, Western, Central and Bundelkhand regions comprising 27, 26, 10, 7 districts, respectively. In the plains, the average temperature vary from 12.5 to 17.5°C in January to 27.5 to 32.5°C in May and June. Average rainfall in the state ranges from 40-80 inches in the east to 24-40 inches in the west. About 90 percent of the rainfall occurs during the southwest monsoon, lasting from about June to September.

The Central Plain Zone has distinguished characteristics as more than two-third of area is irrigated by groundwater/ tube-well. Multistage random sampling for field survey of 100 farmers was used in two randomly selected districts (Lucknow and Sitapur) of the CPZ. From each district, two clusters of 2-3 villages, each and from each cluster, 25 sample farmers were drawn randomly, thus making a total sample size of 100 farmers having different size of land holdings.

## Conceptual Framework and Methodology

### *Water Market*

Water markets are informal institutions, in which private tube-well owners sell irrigation water after their own use to the farmers who doesn’t have their own WEMs in the vicinity of their land. Such markets provide easy access to groundwater irrigation particularly to the small and marginal farmers, who can’t afford their own WEMs. The water markets are very crucial, where state machinery for (groundwater/ canal) irrigation are nonexisting or has failed to deliver the promises to the resource poor farmers. From *prima facie* evidence, marginal and small farmers have relatively little access to groundwater resources for irrigation, although according to the Indian Easement Act of 1872, groundwater rights are appurtenant to land owner *de jure*. But *de facto*, these rights are ambiguous (Chandrakanth and Arun, 1997; Chandrakanth and Romm, 1990), as they can not afford to invest themselves to construct water extraction structure for irrigating their small land holding. There are no well delineated property rights for this resource and hence, there is no control over the resource pertaining to extraction, use and market.

In the present study, efficiency of groundwater use has been studied in four water regimes such as (a) Self-users, under which farmers have their own water extraction installation for irrigating their own land only and do not participate in water market; (b) Self-user + Buyer, are large farmers with fragmented land holdings which necessitates them to buy water in addition to their own sources (tube-well); (c) Only Buyer, primarily small and marginal farmers with poor resource base, who depend on others to buy water for irrigating their crops; and (d) Self-user + Seller, includes those farmers who sell groundwater after meeting their own irrigation requirement. In the study area, there was not a single household who was Only Seller.

### *Extent of Groundwater Extraction and Accessibility*

The amount of groundwater extracted and accessibility to irrigation water has been examined through personal interview with farmers in the study domain. Implication on groundwater accessibility on cropping pattern was examined through comparing the choice of crops under different water regimes. The volume of ground water exploitation/ extraction (in liters) was estimated by using following formula (Bhamoriya, 2005):

$$Q = t*129574.1 * BHP / (d + ((255.5998 * BHP^2) / d^2 * D^4)) \quad ...(1)$$

Where,

Q = Quantity of groundwater extracted (in liters) t =

Total duration of irrigation (in hours)

BHP = Engine power of pump (in HP) d =

Average depth of the well (in meters)

D = Diameter of the suction pipe (in inches)

### *Water use Efficiency: Production Function Approach*

For estimating water use efficiency, production function approach was used and out of several functions, log linear production function (Cobb-Douglas version) was used as it gave best fit to the observed data. Functional form of the log linear production function can be given as:

$$Y = A X_1^{b1} X_2^{b2} X_3^{b3} e^{Ui} \quad … (2)$$

Where,

Y = Annual gross return per farm (Rs/ha)

$X_1$ = Quantity of water used on the farm for all the crops (liters/ha)

$X_2$ = Value of seed used in irrigated crops (Rs/ha)

$X_3$ = Amount of fertilizer (NPK) applied in irrigated crops (kg/ha) $U_i$ =

Random error term

Since the production function was fitted to whole farm data, in order to avoid aggregation problem of output for different crops, gross farm income was taken into consideration and variables showing multicollinearity problems were dropped out from the model. Aggregation of all the outputs was done due to the insufficient number of observations for all the crops under four different water regimes for doing functional analysis (Appendix I). For example, if a farmer is growing paddy, wheat and sugarcane in a particular water regime, then the number of pooled observation of output-input data for the same farmer became three. In this case, revenue from each crop has been taken as dependent variable, while other inputs were taken in physical term to estimate the VMP, except for seed as improved seed costs very high but required less in quantity as compared to traditional varieties and thus underestimated while taking in physical term.

The value of marginal product (VMP) of water was computed at its geometric mean level of both dependent (Y) and independent variable ($X_1$) and the elasticity coefficient $b_1$ by using the formula:

$$VMPx_1 = b_1 * \bar{Y} / \bar{X}_1 \qquad \dots (3)$$

Where,

$VMPx_1$ = Value marginal product of $X_1$ coefficient. $b_1$ = The regression coefficient (elasticity coefficient) of $X_1$ variable, water $\bar{Y}$ = Geometric mean of gross return.

$\bar{X}_1$ = Geometric mean of $X_1$ variable.

In order to examine the Water Use Efficiency, the $VMPx_1$ was compared with its factor cost. For the resource to be optimally allocated necessary condition is,

$$VMPx_1 = Px_1 \text{ or } VMPx_1 / Px_1 = 1 \qquad \dots (4)$$

If the ratio is equal to unity, the resource will be said to be optimally allocated. If the ratio is more than one, it implies that the particular resource is under used, and *vice versa*. Water use efficiency estimated for different water market regimes indicate whether the particular group of farmers under respective water regime is efficient water user or not. Certainly, it would not explicitly explain in which crop, water is being used efficiently by the farmers.

## Result and Discussion

### *Land Utilization Pattern of Study Domain*

Uttar Pradesh, the fourth largest state of India, is having gross cropped and net cropped area of 25.42 and 16.75 million hectares (m. ha), respectively. Around 52.03 per cent of gross cropped area is under irrigation with the irrigation and cropping intensity of 140.04 and 151.79 per cent, respectively. Among several sources of irrigation, tube well is predominant and irrigate about 70 per cent of net irrigated area (Table 1). Similarly, Central Plain Zone is having gross cropped and net cropped area of 5479.90 and 3695.39 thousand hectares, respectively with irrigation and cropping intensity of 132.77 and 148.69, respectively. In this Zone too, tubewell is the predominant source of irrigation.

**Table 1.** Land utilization of study domain (2003-04)

| Particulars | Central Plain Zone | Uttar Pradesh |
|---|---|---|
| Gross cropped area (‘000 ha) | 5479.90 | 25424.61 |
| Net sown area (‘000 ha) | 3685.39 | 16749.53 |
| Cropping Intensity (%) | 148.69 | 151.79 |
| Net irrigated area (‘000 ha) | 2984.83 | 13227.33 |
| Gross irrigated area (‘000 ha) | 3963.07 | 18523.95 |
| Irrigation intensity (%) | 132.77 | 140.04 |
| % of gross irrigated area to gross cropped area | 72.32 | 72.85 |
| Share of different sources of irrigation (%) | | |
| Canal | 25.13 | 20.92 |
| Tubewell | 73.97 | 70.74 |
| Others | 0.89 | 0.44 |

Source: Indian Agricultural Statistics, Ministry of Agriculture, Government of India

## *Socio Economic Characteristics of Sample farm Households*

Socio economic characteristics of the sample farms showed that majority of the farmers in the study domain were small and marginal farmers (Table 2). Marginal category (0-1 hectare) included 57 per cent of the farmers with average family size of 9 and average 2.2 fragments of irrigated land. Small category included 24 per cent of sample farmers (100) with average 12 members in the family and 2.9 fragments of irrigated land. Farmers with more than two hectares of land had family size of 12 and 3.5 fragments of irrigated land.

**Table 2.** Socio-economic characteristics of sample farm households

| Particulars | Marginal (0-1 ha) | Small (1-2 ha) | Others (> 2 ha) |
|---|---|---|---|
| No. of farmers 57 | 24 | 19 | |
| Average size of family (No) | 9 | 12 | 12 |
| Education of head of household (% of total) | | | |
| Illiterate | 35.7 | 30.3 | 21.1 |
| Primary | 37.5 | 34.3 | 31.6 |
| Secondary | 23.2 | 29.3 | 36.8 |

| | | | |
|---|---|---|---|
| Higher | 3.6 | 6.1 | 10.5 |
| Proportion of adult family members having education | | | |
| At primary level | 36.68 | 46.84 | 40.15 |
| Above primary level | 14.04 | 18.99 | 22.63 |
| Average no. of fragments of irrigated land | 2.2 | 2.9 | 3.5 |
| Average no. of fragments of total land | 2.6 | 3.1 | 3.7 |

Source: From field survey, 2007

Education status especially higher education, one of the major factors for decision making, was skewed towards the farmers with more than two hectares of land holding. Majority of the small and marginal farmers were illiterate having education only up to primary level. Only 3.6 per cent of marginal and 6.1 per cent of small farmers were having higher education.

## *Share of Different Sources of Irrigation*

Canal and tube-wells are the main source of irrigation in Uttar Pradesh state of India. Other than these two, some minor sources of irrigation are tank and wells. Due to technological advancement and more reliability of groundwater, tube-well irrigation has grown more rapidly than canal irrigation. The decadal pattern on share of different sources in total irrigation area showed that share of canal irrigation has consistently declined from 35.42 per cent during 1965-75 to 25.18 per cent during the period 19952003. On the other hand, during the same period, share of tube-well in total irrigated area has increased significantly from 30.37 to 66.94 as it is considered as more reliable and efficient than canal (Table 3).

**Table 3.** Share of different sources of irrigation in total irrigated area

| Decade | Central Plain Zone | | | | | Uttar Pradesh state | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Canal | Tube Well | Other | Total | GIA* | Canal | Tube Well | Other | Total | GIA* |
| 1965-75 | 51.96 (1.29) | 22.64 (15.59) | 25.40 (-0.87) | 100 (3.23) | 1160 | 35.42 (1.76) | 30.37 (13.4) | 4.13 (2.15) | 100 (3.09) | 6879 |
| 1975-85 | 46.52 (2.64) | 42.89 (5.95) | 10.59 (-7.14) | 100 (2.82) | 1808 | 33.68 (2.07) | 51.40 (6.09) | 3.38 (-0.78) | 100 (2.56) | 9230 |
| 1985-95 | 40.53 (-0.57) | 55.67 (4.94) | 3.80 (-12.3) | 100 (2.06) | 2171 | 29.38 (-0.81) | 61.96 (2.66) | 3.21 (4.03) | 100 (1.35) | 11517 |
| 1995-03 | 30.12 (-1.65) | 69.27 (3.69) | 0.60 (-4.30) | 100 (2.10) | 2530 | 25.18 (-0.95) | 66.94 (2.42) | 2.65 (2.67) | 100 (2.50) | 12099 |

*Gross irrigated area (GIA) in '000 ha figures within parentheses are compound growth rates of irrigated area by different sources during respective decades.

Source: Indian Agricultural Statistics, Ministry of Agriculture, Government of India, Various issues.

## *Access to Groundwater Irrigation of Sample Households*

The sample households in the study area were predominantly small and marginal farmers and therefore majority of the sample households (51 per cent) were included in buyer category. Availability of groundwater market provided these resource-poor farmers accessibility to irrigation water and helped in realizing better crop yield (Table 4). Had such groundwater markets not developed in the region, about 27 percent of land would have remained un-irrigated. It was also evident that as farmers' land holding increased, they shifted from buyer to owner category. This shift may be due to the fact that, at large scale, for the farmers, it is more economical to install their own water extraction devices as the opportunity cost of reliance on sellers for irrigation water was a bit high.

**Table 4.** Accessibility of sample households and farmers' area under different water market regimes

(Per cent)

| Category of water market regimes | Avg. Holding (ha) | Farm category: Marginal | | Small | | Others | |
|---|---|---|---|---|---|---|---|
| | | No. of House-holds | Farm area | No. of House-holds | Farm area | No. of House-holds | Farm area |
| Buyer | 0.82 | 68.42 (39) | 57.31 | 37.50 (9) | 29.32 | 15.79 (3) | 15.37 |
| Self-user | 1.64 | 15.79 (9) | 19.72 | 25.00 (6) | 16.14 | 21.05 (4) | 20.06 |
| Self-user + buyer | 2.75 | 3.51 (2) | 5.22 | 20.83 (5) | 25.00 | 42.11 (8) | 41.82 |
| Self-user + seller | 2.00 | 12.28 (7) | 17.75 | 16.67 (4) | 29.54 | 21.05 (4) | 22.75 |
| Overall | 1.46 | 100 (57) | 100 (30.64) | 100 (24) | 100 (35.2) | 100 (19) | 100 (80.16) |

Figures within parentheses for households are number of respondents under respective category while for farm area, those are total area cultivated by the respective categories of farmers together. Source: From field survey, 2007

## *Mechanism of Groundwater Extraction in the Study Domain*

Extraction of groundwater, which determines the accessibility to water, depends on water level, engine capacity and size of outlet. From primary data collected in the Central Plain Zone of the state, it was found that the average depth of water was 36.7 metres. To lift groundwater for irrigation, on an average of 9 horse power (H.P.) capacity pump with diesel engine was being used by the farmers as electricity supply was very much erratic and unreliable in the rural area. With 4.13 inch diameter of outlet, 34950 litres of groundwater per hour was being extracted in the region. (Table 5). On the other hand, the average annual net precipitation in the region is about 100 centimeter. Hence, in the study, only water applied through irrigation has been accounted to estimate the water productivity as the water applied through precipitation is assumed same for all the farmers in the region. It may be noted that the water requirement of the crops under study may differ from the water applied.

**Table 5.** Mechanism of groundwater extraction in the study domain

| | |
|---|---|
| Average depth of water level (meter) | 36.7 |
| Average size of outlet (inch) | 4.13 |
| Engine capacity (HP) | 9.1 |
| Water extracted (litres/ hr of irrigation) | 34950.04 |

Source: From field survey, 2007

## *Groundwater Extracted by Tube-well Owners*

Total groundwater extracted by tube-well owners either for irrigating their own crops or others were estimated (Table 6), which may also be further used to estimate the net draft of groundwater in the region. The results showed that self-users extracted 2.287 million litres of water to irrigate 1.64 hectares land in a year and due to low water level in their vicinity. It is also interesting to note that the farmers with large land holding (self-user) tried to ensure their irrigation by installing high power bore-well with deeper depth as frequent failure of tube-wells have been reported by the respondents in the recent past. On the other hand, in case of self-user + buyer, ratio of area irrigated by own tube-well to that of others' was about 2:1 and the total groundwater extracted was estimated to be 1.54 million litres. Total water extracted by self–user + sellers was 2.491 million litres to irrigate their own 2.0 hectares land and the proportion of irrigating their own area to other's area was 2.73:1.

**Table 6.** Groundwater (GW) extracted by tube-well owner in the study year

| Water | Avg. depth | Avg. size | Engine | Number of | Average | Duration of | Total |
|---|---|---|---|---|---|---|---|

| regimes | of water level (meter) | of outlet (inch) | capacity (HP) | irrigations applied to all crops | irrigated farm area (ha)* | rrigation (hours/ irrigation/ ha) | GW extraction (million litres) |
|---|---|---|---|---|---|---|---|
| Self user | 44.20 | 4.00 | 10.00 | 14.13 | 1.64 | 26.17 | 2.287 |
| Selfuser + buyer | 30.08 | 4.00 | 8.44 | 13.98 | 1.58 | 36.93 | 1.540 (1.97:1) |
| Selfuser + seller | 32.52 | 4.00 | 9.16 | 14.92 | 2.00 | 29.4 | 2.491 (2.73:1) |

*****This area is irrigated by own tube-well only
Source: From field survey, 2007

## *Cropping Pattern of Selected Farm Households Under Different Water Regimes*

Cropping pattern within an agro-climatic area is mainly influenced by a number of factors such as soil type, size of holding, availability of irrigation facilities and other resources, level of investment, public policy, marketing facilities, etc. In the study area, although, there was not any significant trend for choice of crops by the farmers under different water regimes, but number of farmers growing different crops varied very much across the groups. For all the farmers, wheat has dominated the cropping pattern, while paddy seems to be grown only for household consumption. It was also surprising to note that self-user or tube-well owners, who were also relatively large farmers, were also growing vegetables on significantly large areas (Table 7). This may be due to assured irrigation facilities available to them. On the other hand, buyer and exclusive self-user were allocating about 8 per cent of area to pulse crops.

**Table 7.** Cropping pattern of selected farm under different water regimes

| Crops | Buyer | Self-user | Self-user + buyer | Self-user + seller | Overall |
|---|---|---|---|---|---|
| Paddy | 7.51 | 8.12 | 4.20 | 3.20 | 6.43 |
| Wheat | 36.26 | 34.37 | 35.47 | 38.93 | 38.28 |
| Maize | 0.71 | 3.01 | 3.66 | n.a. | 2.00 |
| Sorghum | 4.43 | n.a. | n.a. | 2.00 | 1.93 |
| Pealmillet | 3.43 | 0.60 | 2.74 | 4.53 | 2.95 |
| Mustard | 2.14 | 3.01 | 2.65 | 1.87 | 2.58 |
| Pulses* | 8.49 | 8.42 | 4.93 | 4.4 | 6.51 |
| Sugarcane | 20.34 | 32.36 | 19.47 | 19.20 | 18.80 |
| Potato | 4.28 | 3.51 | 15.54 | 8.27 | 8.18 |
| Vegetable** | 6.27 | 4.21 | 10.15 | 13.20 | 8.50 |

| | | | | | |
|---|---|---|---|---|---|
| Others | 6.14 | 2.40 | 1.19 | 4.40 | 3.87 |
| Total | 100 (1.10) | 100 (2.10) | 100 (2.27) | 100 (2.14) | 100 (1.60) |
| **Cropping intensity** | **130.05** | **115.98** | **100.43** | **114.05** | **120.29** |

Figures within parentheses are the gross cropped area for the respective group of farmers. **n.a.** = Respective crops are not being grown by the farmers in corresponding group.
*Pulses include pigeon pea, rape seed, and black gram.
**Potato is not included in vegetable group. Source:
From field survey, 2007

## *Water Productivity Under Different Water Markets Regimes*

Water productivity has been expressed in terms of amount of water required to produce unit quantity of grain output of a crop. It may be observed from table 8 that farmers belonging to buyer category were more efficient user of irrigation water in wheat and sugarcane crops, which were major water consuming crops, as they applied less amount of water as compared to other categories to produce one unit of output. The reason for the low ratio in case of buyers in wheat and sugarcane may be due to the fact that buyers were predominantly small and marginal farmers with small land holding size and thus they were engaged in intensive cultivation with proper utilization of resources.

**Table 8.** Water productivity for major irrigated crops under different water markets regimes
(Litres of water/ Kg of output)

| Category | Wheat | Paddy | Sugarcane | Potato |
|---|---|---|---|---|
| Buyer | 759.66 | 1000.58 | 40.27 | 161.02 |
| Self user | 1081.60 | 929.45 | 87.66 | 185.70 |
| Selfuser + buyer | 1087.52 | 1030.56 | 82.54 | 132.55 |
| Selfuser + seller | 933.33 | 581.39 | 72.55 | 160.54 |
| Overall | 965.53 | 885.50 | 70.76 | 159.95 |

Source: From field survey, 2007

In case of paddy (rainy season crop), selfuser + seller applied least irrigation water for producing one kg of paddy. This is mainly due to the fact that there were only few sample farmers, (three in numbers) under this category, growing paddy and most of them had low land area, where they had access to seasonal surface water accumulated in small ponds from rainfall for quite reasonable period. Besides, with balanced use of fertilizer, they could harvest better crop yield (5 t/ha) as compared to other farmers.

Magnitude of water productivity ratio was the lowest in case of sugarcane because yield of sugarcane, as compared to other sample crops, was very high. Similarly, in case of potato, although self-user + buyer emerged to be more water use efficient, but the number of observations under such categories being very small, it is difficult to reach to such conclusion. Again self-users with assured irrigation facilities were found to be using irrigation water injudiciously with 185.7 litres of water to produce one kilogram of potato. It is worth to note that amount of water used to produce one kilogram of output is a part of irrigation requirement of crop and it does not include rainfall water.

## *Incremental Water – Output Ratio*

Incremental water-output ratio shows the amount of water required to produce additional value in exchange of the output. This ratio is the replica of water productivity, with the difference in denominator term used where value of output in terms of Indian Rupees (INR) has been used instead of physical quantity. Results (Table 9) were found to be similar to that of above section, with buyers more efficient in wheat and sugarcane while in case of potato, selfuser +buyer were found to be efficient due to the reasons explained as above. One more interesting thing appeared from the result from sustainability point of view. Contrary to farmers' perception, potato and sugarcane emerged as better remunerative crop as far as water use is concerned as these crops required about onethird quantity of water to give a return of INR 1.00 as compared to paddy and wheat.

**Table 9.** Incremental water – output ratio for major crops grown under different water regimes

(Litres of water/ INR of value of output)

| Category | Wheat | Paddy | Sugarcane | Potato |
|---|---|---|---|---|
| Buyer | 107.70 | 209.05 | 40.74 | 45.05 |
| Self user | 163.23 | 172.10 | 69.44 | 45.86 |
| Selfuser + buyer | 157.77 | 196.78 | 75.85 | 36.77 |
| Selfuser + seller | 126.14 | 148.02 | 64.61 | 42.26 |
| Overall | 138.71 | 181.49 | 62.66 | 42.49 |

Source: From field survey, 2007

## *Regression Estimates for Irrigated Crop Production*

Cobb-douglas production function was fitted for the whole farm under different water regimes to see the major determinants and factors explaining the variation in value of crop output. Revenue from output of various crops was chosen as dependent variable and seed cost, fertilizer quantity and water uses were dependent variables.

Among all the four major factors explaining the variation in the dependent variable (revenue), seed cost was found to be highly significant for all the water regimes except self-user+ seller, where it was found insignificant with negative value (Table 10). Fertilizer quantity was also observed to be significant for self user+buyer and self user+seller category. For small and marginal farmers, who mainly came in buyer category, water- use was most significant factor as compared to other. For self-user and self-user+seller, the coefficient was negative showing water as not an important variable for farmers in this category. For self-user + buyer water regime also, water was not a significant input.

However, it is worth to note that less number of observations in this category could not capture the variations in the pooled data of different crops, giving rise to low value of $R^2$.

**Table 10.** Regression estimates for irrigated crop production under different water market regimes

| Variables | Buyer | Self user | Self user + buyer | Self user+ seller |
|---|---|---|---|---|
| Intercept | 2.607 (2.1370) | 12.57 (2.4797) | 0.7724 (4.5402) | 9.7657 (6.3300) |
| Seed cost (Rs/ha) | 0.312*** (0.0512) | 0.531*** (0.0734) | 0.369*** (0.0859) | -0.1675 (0.1225) |
| NPK (Kg/ha) | 0.0208 (0.1737) | -0.340 (0.2920) | 0.534* (0.3194) | 1.0917** (0.4449) |
| Water-use (litre/ha) | 0.342** (0.1436) | -0.301* (0.1658) | 0.245 (0.3418) | -0.2944 (0.4369) |
| Adjusted $R^2$ | 0.4175 | 0.5941 | 0.5298 | 0.1178 |
| No. of observations | 68 | 36 | 32 | 26 |

Dependent variable: Revenue from output of different crops (Rs/ha), figures with a prenthesis are standard user of estimated coefficient.

***, ** and * indicate significance at 1, 5 and 10 per cent probability level, respectively. Source: From field survey, 2007

## *Water use Efficiency for Different Category of Water Market Regimes*

Regression coefficients estimated from the regression analysis for irrigation water for different group of farmers were further used to estimate the water use efficiency under different water market regimes with the details presented in table 11. For buyers, ratio of VMPx and Px (price per unit of irrigation water) obtained was 1.361 (more than one) which indicated that buyers were under utilizing water resource. For them water was a significant and most limiting factor for the farming due to their small and uneconomic land holding. For self-user, having their own water extraction facilities, water was found to be least significant and the negative VMPx to Px ratio of –1.140 showed over utilization of the water resource due to injudicious use of it.

For self-user + buyer category, almost optimal utilization of water resource was observed as VMPx to Px ratio was almost equal to one. Farmers under this category had fragmented but large land holdings and therefore, in addition to their own irrigation sources, they also had to purchase water from others for the plots without water extraction facilities. Thus, although, water was not the significant factor for the land with its own facilities, but, purchased water was found to be used economically resulting into optimal utilization of water.

**Table 11.** Water use efficiency for different category of water market regimes

| Category | $VMP_X$ | $P_X$ (Rs/litre) | $VMP_X / P_X$ | Remark |
|---|---|---|---|---|
| Buyer | 0.00365 | 0.00268 | 1.361 | Under utilisation |
| Self user | –0.00247 | 0.00216 | –1.140 | Over utilisation |
| Selfuser + buyer | 0.00234 | 0.00225 | 1.039 | Almost optimal utilisation |

| | | | | |
|---|---|---|---|---|
| Selfuser + seller | –0.00211 | 0.00239 | –0.881 | Over utilisation |

Source: From field survey, 2007

Self-user + sellers, although VMPx to Px ratio was less than one (-0.881), but farmers under this category were found to be operating in third zone of the production process as shown by negative VMPx. Over utilization of water for this category might be the result of farmers' business behavior for the water market resulting in injudicious use of irrigation water.

## Conclusions and Policy Options

From the above discussion, it was observed that over the years, irrigation development in the Uttar Pradesh got planners' attention and therefore, irrigation potential has increased many folds. However, declining share of canal (surface) irrigation in total irrigated area of Central Plain Zone during last four decades and increasing share of groundwater (tubewell) irrigation (around three times) indicated that the region is heavily depending upon groundwater as a source of irrigation. The repercussion of such trend is emerging in the recent past in terms of frequent failure of tube-wells and drying up of wells/ hand-pumps in the summer season, on which most of the rural poor depend for drinking water. It was also evident that more than three-fourth of the farmers did not get enough water on time in the study area as they depended on large farmers for buying the irrigation water. Easy access to irrigation water due to emergence of water market also led to shifting of cropping pattern toward water intensive crops as majority of the households (78 per cent) observed that in last decade, gram, pigeon pea, groundnut nut and green gram got substituted by water intensive crops like rice, wheat and sugarcane. Furthermore, water-buyers were under utilizing water resource as for them, water was the most limiting factor for farming implying ample scope of enhancing crop productivity through optimum allocation of irrigation water. In the lack of clear-cut policy direction, large and resourceful farmers are installing higher capacity tube-wells and extracting more waters than their requirements to cultivate water-exhaustive crops like sugarcane, as it is more remunerative for them. Keeping above facts and findings in view, following policy suggestions are being made for equitable and sustainable development of agriculture in the region understudy: Firstly, due to lack of concerted efforts in canal irrigation development in the region, farmers have no options other than to opt for groundwater irrigation. Keeping in view the recent trends of groundwater depletion in this zone, there is a need to make investment in canal irrigation for conjunctive use of groundwater and surface water for irrigation purposes, which will also reduce the cost of production for poor farmers. With development of groundwater market, small and marginal farmers also got benefited as they could access to irrigation.

However, due to lack of assured electric supply, all the farmers have to largely depend on diesel-operated tube-wells, which cost them dearly and hit on the bottom-line (net profit) in the wake of rising crude prices in global market. Therefore, attempts should be made to provide assured electricity for irrigation purposes with economic electricity charges.The region has witnessed cropping pattern upheavals especially in the past two decades favoring water intensive crops at the cost of pulses, which needs to be corrected, not only for reducing reliance on import of pulses for domestic supply but also to arrest the depletion of groundwater resources. This requires adequate policy support for bringing required changes. Finally, since, water-buyers are under-utilizing water resources leading to lower crop productivity in the region, although having better water productivity, the optimal utilization through proper irrigation development and awareness will go a long way in helping these poor farmers in realizing higher yield and thereby better returns from agriculture in the region.

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**Appendix I.** Choice of crops across different water market regimes in study area

(No. of farmers)

| Crops | Buyer | Self-user | Self-user + buyer | Self-user + seller | Overall |
|---|---|---|---|---|---|
| Paddy | 11 | 8 | 4 | 3 | 26 |
| Wheat | 45 | 18 | 15 | 13 | 91 |
| Maize | 1 | 2 | 2 | **n.a.** | 5 |
| Sorghum | 6 | **n.a.** | **n.a.** | 2 | 8 |
| Pearlmillet | 9 | 1 | 4 | 5 | 19 |
| Mustard | 3 | 2 | 4 | 2 | 11 |
| Guar | 4 | **n.a.** | 1 | 2 | 7 |
| Pulses | 23 | 9 | 6 | 7 | 45 |
| Sugarcane | 9 | 8 | 5 | 4 | 26 |
| Potato | 5 | 3 | 8 | 5 | 21 |
| Vegetable | 13 | 5 | 7 | 7 | 32 |
| Others | 5 | 1 | **n.a.** | 1 | 7 |
| **Total** | **134** | **57** | **56** | **51** | **298** |

* Pulses include pigeon pea, lentil, and black gram.

**Potato is not included in vegetable group.

**n.a. =** Respective crops are not being grown by the farmers in corresponding group.