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THE ANALYSIS OF GROUNDWATER QUALITY AND THE IMPACT OF REMEDIAL MEASURES ADOPTED BY THE WHEAT GROWERS: USING ENDOGENOUS SWITCHING REGRESSION MODEL APPROACH

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ABSTRACT

Groundwater pollution is a serious problem, posing severe problems on many economic activities. The study's main objectives were to access the groundwater quality in the study area and analyze the role of farmers in improving the groundwater quality. Total 108 groundwater samples were collected from different locations along the 11-L distributary located in District Sahiwal, Punjab-Pakistan. Samples were tested to analyze the quality of groundwater for agriculture and livestock. The parameters included pH, Ec, and TDS, were tested. Results showed that 14 samples were found to be fit, 23 were marginally fit and 71 were declared unfit for agricultural consumption. The results of CCME water quality index were also in favour of lab reports. Most wheat-growing farmers were using gypsum as a remedial measure to minimize the side effects of poor groundwater quality. Few farmers were using farmyard manure to improve groundwater quality. There are many factors that influence the adoption of remedial measures to compensate for the poor groundwater. Farmers were facing a few limitations that compelled them to avoid incurring any further costs in order to improve groundwater quality. The financial constraint was the main issue. The endogenous switching regression model was used for data analysis. The findings revealed that family workers, experience, education, and soil quality positively impact remedial measures adoption. The study recommended that proper groundwater quality monitoring is required on a regular basis. Farmers should be educated regarding the proper use of gypsum. The sewerage system was absent in many villages of the study area. To avoid the further leaching of hazardous materials into groundwater, it is critical to construct an effective waste management system.

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INTRODUCTION

Pakistan has the world's leading irrigation system; meanwhile, it is the second-largest groundwater user in the South Asian region (Naeem and Ghazal, 2021). Groundwater resources are really valuable natural resources. It is the main supplier of fresh water, especially in those areas where infrastructure is not available for transportation of surface water, so the quality of groundwater is a serious concern (Deeba et al., 2019). Groundwater in the agriculture sector is used to grow fruits, vegetables, crops and rearing livestock. Shortage of surface water turned the majority of the farmers to underground water resources for irrigation as a supplemental source. Informal underground water market provides an opportunity for farmers who do not have their own tube wells to buy groundwater (Basharat, 2019).

Groundwater is the most dependable source of water. It is fulfilling not only the agricultural water needs but also provides sufficient water for domestic and industrial use. Groundwater used to be deemed safe for agriculture in the past, but it has recently become much polluted (Awais et al., 2017). Punjab is the main province of Pakistan from an agricultural perspective. It uses more than 50 percent of groundwater for irrigation (Ishaq and Javaid, 2015). The intensification in groundwater usage is now posing serious threats to its quality and is also becoming responsible for diminishing the resource at a much faster pace. The groundwater tables declined to the inaccessible limit in Punjab (Adnan et al., 2019). In Punjab, 23 percent of the area is badly affected by poor groundwater quality (Muzammil et al., 2020). Deep drilling of groundwater alters the water quality in terms of varying salinity levels (De-Greef et al., 2019). Rapidly growing population, increasing urbanization and heavy use of fertilizers and pesticides in agriculture, poor sanitation system, and inappropriate industrial discharge are brutally damaging groundwater resources' quality (Lytton et al., 2021;

Shoemaker et al., 2017; Ran et al., 2016). The quality of groundwater is negatively affecting the crop yield. Different parameters are used to realize the groundwater quality (Saleem et al., 2017). Electric conductivity (EC) is the most important parameter for water quality for irrigation. Sodium absorption ratio (SAR), total dissolved solids (TDS) and residual sodium carbonate (RSC) are also mostly used for analyzing the groundwater quality for agriculture (Malik et al., 2021; Qurashi, 2021).

Groundwater pollution is a serious problem because of its impact on numerous economic activities (Solangi et al., 2019). For the agrarian economy, water pollution is a major concern (Reddy and Behera, 2006). Water makes about 70 percent of a livestock's body. Water consumption is more vital to animals as compared to other food consumption. The amount of water intake is determined by the weather and the foods eaten. Animal happily takes the clean water and reduces the quantity of intake in case of poor quality water. When animals do not consume the recommended amount of water may experience stress or even dehydration. Lower water intake also negatively impacts animals' productivity (Dobes et al., 2021). Animal losses are demonstrated when nitrate levels in groundwater are high (Soomro et al., 2017).

High salt in irrigation water significantly reduces the wheat yield (Oad et al., 2001). Wheat production in Pakistan is quite low in the salt-affected areas, and yield losses up to 65 percent have been recorded in moderately saline. However, if genetic variability in wheat is explored extensively, the productivity of these saline areas would increase greatly (Abbas et al., 2013). Salinity affects the overall performance of the plant. High salt levels lower germination rates, resulting in lower crop yields (Hossain et al., 2021).

Gypsum aids in the leaching of excess salts and the preservation of soil micronutrients necessary for crop growth (Khan et al., 2007). Farmers can reduce the water requirement by using advanced technology. This will help to improve the groundwater quality (Levidow et al., 2014). The aim of the current study was to analysis the current groundwater quality situation. The existing quality of groundwater is evaluated by analyzing groundwater samples for various EC, TDS, and pH. The study also analyzed the farmer's response to dealing with poor groundwater quality. This research was required, especially in light of recent droughts that have resulted in a drop in agricultural productivity. The study's findings are useful in improving the management of deteriorating groundwater supplies.

METHODOLOGY

Study Area

In terms of agriculture, the district of Sahiwal is crucial. The district has a total size of 3201 km^2 and a population of approximately 7.3 million people. The weather is hot, with 177 mm of rainfall on average. Wheat, corn, sugar cane, and cotton are among the most important crops (Khalid et al., 2017). In the district, groundwater quality ranges from acceptable to salty. For this study, an 11-L distributary was chosen. The quality of the water varies greatly along the distributary. Wheat yields also fluctuated along the distributary. Farmers keep dairy animals to mitigate farm losses. However, poor groundwater quality also has a negative impact on the dairy industry.

Data Collection

The current study used experimental data as well as cross-section data for analysis. Experimental data includes the results of the water samples collected from 108 different locations along the 11-L distributary. These 108 farmers were further interviewed for data collection. A simple random sampling technique was used for groundwater sampling and data collection. Cross-sectional data were collected from 108 farmers through a survey from the farmers in the selected study area. The sample size was selected using the formula for unknown population as shown;

$$n = \frac{(z_{\alpha/2})^2}{4e^2} \quad (1)$$

The Z value is 1.64 and the e value is 0.01 with a 10 percent confidence interval. The calculated sample size was 67. To analyze the quality of the groundwater for crops, groundwater samples were taken from 67 tube wells. Only 26 respondents were provided tube-well water to their dairy animals, while 41 used turbines and manual pumps to provide water to their animals. As a result, the study's overall sample size was 108 people. The number of samples collected from the head, middle, and tail was 40, 39, and 29 respectively, as shown in Table 1. The availability and condition of roads were not satisfactory that acted as a hurdle in collecting more samples from the tail location. The samples were collected at the head with an average distance of 6.63 Km distance from the distributary. The average distance of collected samples from the distributary at the middle and the tail location was 4.62 and 1.35 km respectively.

Table 1. Groundwater samples and their distance from distributary (N=108).

Items	Head	Middle	Tail
Villages	4	4	4
Samples	14+8+8+10=40	16+8+4+11=39	5+6+7+11=29
Distance from distributary (Km)	6.63	4.62	4.35

Water Quality Index (WQI)

An index is a single value that can be calculated easily and used for overall description (Dede et al., 2013). Different methods were used to calculate the water quality index. Canadian Council of Minister of the environment developed an index (CCME) for water quality measurement in 2001. Surface water quality was measured using CCME method by (Munna et al., 2013). Lamare and Singh (2016) analysed the water quality of limestone mining areas using CCME. An index was developed using CCME by Dede et al. (2013) for groundwater quality. The current study also used CCME for calculating WQI for groundwater quality on three different locations of 11-L distributary. Seven parameters were considered for calculating WQI in the current study like Ec, TDS, pH, SAR, RSC, Cadmium and Arsenic. Following is the detailed procedure to calculate WQI using CCME method.

CCME water quality index consists of three elements.

F1= Scope
F2= Frequency
F3= Amplitude

Here;

$$F1 = \frac{Numbers\ of\ failed\ variables}{Total\ numbers\ of\ variables} * 100 \quad (2)$$

Numbers of failed variables are those variables in which the observation crosses the standard limits.

$$F2 = \frac{Numbers\ of\ failed\ test}{Total\ numbers\ of\ test} * 100 \quad (3)$$

Here numbers of the failed test are the total number of those observations that cross the limits of the standard. The total numbers of observations are the total number of tests.

F3 represents the difference between failed test values and the standards. There involved three steps for the calculation of F3.

Step 1: Calculation of excursion values in case when test limits must not exceed the standards.

$$\text{Excursion values} = \left(\frac{Failed\ test\ values}{Standards}\right) - 1 \quad (4)$$

Calculation of excursion values in case when test limits must not fall below the standard

$$\text{Excursion values} = \left(\frac{Standards}{Failed\ test\ values}\right) - 1 \quad (5)$$

Step 2: calculation of normalized sum of excursion value (NSE).

$$NSE = \frac{Sum\ of\ all\ excursion\ values}{Total\ numbers\ of\ test} \quad (6)$$

Step 3: Calculation of F3.

$$F3 = \frac{NSE}{0.01*NSE+0.01} \quad (7)$$

The values of all three elements have been calculated, so the WQI will be calculated using their three elements.

$$WQI = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right) \quad (8)$$

The value of WQI lies between 0-100. The following Table 2 shows the different categories of water quality status.

Table 2. Classification of water quality status.

Water quality status	CCME WQI
Excellent	95-100
Good	80-94
Faire	65-79
Marginal	45-64
Poor	0-44

Source: (Munna et al., 2013; Dede et al., 2013).

Endogenous Switching Regression (ESR)

There are different techniques used in impact studies, but they may give an inconsistent standard error. ESR is a parametric technique that solves the issue of biasedness and missing unobserved factors that have distinct effects on two different regimes, such as adopter or non-adopter. The model estimates the selection equation in the first step to assess the impact of adaptation determinates. To account for selective bias, the outcome variable is estimated using inverse mill ratios in the second stage (Naqvi et al., 2020). Two-stage estimation using the endogenous switching regression model yields consistency standard errors. The complete Information Maximum Likelihood approach is utilized for the best simultaneous equation estimation (Adela and Aurbacher, 2018).

$$\ln Y_{1i} = X_i\beta_1 + \mu_{1i}$$

$$\ln Y_{2i} = X_i\beta_2 + \mu_{2i}$$

$$K_i^* = \theta(\ln Y_{1i} - \ln Y_{2i}) + Z_i\text{U} + \omega_i \quad (9)$$

The K_i^* determines the adaptation or non-adaptation of an individual i. Y_{ji} is the wheat yield of individual farmer i in sector j; Zi is a vector containing all other variables that influence the adaption decision regarding remedial measures. Xi contains all other variables that influence individual yield. β_1, β_2, and U are coefficients, and u_{1i}, u_{2i}, and ω_i are the residual terms. The individual i is adopted remedial measure or not have the following form (Lokshin and Sajaia, 2004);

$$K_i = 1 \qquad \text{If } K_i^* > 0$$
$$K_i = 0 \qquad \text{Otherwise}$$

The current model assumes that the adaption of remedial measures is endogenous to yield. Some other unobserved variables that influence the likelihood of selecting a specific remedial measure may also affect the wheat yield. If these selectivity effects are ignored, the yield will be misconstrued (Tesfay, 2020). The simultaneous ML estimation is used to correct the issue. The functional form of the system is given below;

$$\ln L = \sum\left(K_i w_i\left[\ln\{F(\lambda_{1i})\} + \left\{\frac{f\left(\frac{\mu_{1i}}{\sigma_1}\right)}{\sigma_1}\right\}\right] + (1-K_i)w_i[\ln\{1 - F(\lambda_{2i})\} + \ln\{f(\frac{\mu_{2i}}{\sigma_2})/\sigma_2\}]\right) \quad (10)$$

In the above equation F is a cumulative normal distribution function, f *is* a normal density distribution function, w_i is an optional weight for observation I, whereas;

$$\lambda_{ij} = \frac{(\theta Z_i + \rho_j\mu_{ij} / \sigma_j)}{\sqrt{1-\rho_j^2}}$$

Where $\rho_1 = \sigma^2{}_{1u}/\sigma_u\sigma_1$ is the correlation coefficient between u_{1i} and ω_i and $\rho_2 = \sigma^2{}_{2u}/\sigma_u\sigma_2$ is the correlation coefficient between u_{2i} and ω_i.

Unconditional prospects:

$$E(y_{1i}/x_{1i}) = x_{1i}\beta_1$$

$$E(y_{2i}/x_{2i}) = x_{2i}\beta_2$$

Conditional prospects:

$$E(y_{1i}/K_i = 1, x_{1i}) = x_{1i}\beta_1 + \sigma_1\rho_1 f(\upsilon Z_i)/F(\upsilon Z_i)$$

$$E(y_{1i}/K_i = 1, x_{1i}) = x_{1i}\beta_1 - \sigma_1\rho_1 f(\upsilon Z_i)/\{1 - F(\upsilon Z_i)\}$$

$$E(y_{2i}/K_i = 1, x_{2i}) = x_{2i}\beta_2 + \sigma_2\rho_2 f(\upsilon Z_i)/F(\upsilon Z_i)$$

$$E(y_{2i}/K_i = 1, x_{2i}) = x_{2i}\beta_2 - \sigma_2\rho_2 f(\upsilon Z_i)/\{1 - F(\upsilon Z_i)\}$$

RESULTS AND DISCUSSIONS

The groundwater quality is affected by the reactions that take place in the surroundings daily. Different natural and human activities were responsible for poor groundwater quality (Deeba et al., 2019). Groundwater quality improves due to the continuous recharge of comparative freshwater, which is becoming scarce day by day (Arshad and Shakoor, 2017). A total of 110 samples were collected from the study area. Two samples were wasted during transportation. Samples were collected from tube-wells, hand-pump, and motors. Few farmers were not offering tube-well water to their animals because their mobility was difficult, that's why samples were collected from hand-pump and motor to analysis the water quality for animals. The collected samples were analysed from the certified Ayub Agriculture Research Centre. The results in Table 3 showed that the groundwater quality was poor at the head reach of the distributary.

Table 3. Quality analysis groundwater samples.

Items	Agriculture			Livestock		
	Ec (µS/cm)	TDS (ppm)	pH	Ec (µS/cm)	TDS (ppm)	pH
Samples results from labs (N=108)						
Head						
Mini	932	596.48	7.4	932	596.48	7.4
Max	2189	1400.96	8.7	2189	1400.96	8.7
Average	1648.57	1055.08	7.94	1627.92	1041.87	7.94
Middle						
Mini	882	564.48	7.7	882	564.48	7.7
Max	1390	889.6	8.8	1390	889.60	8.8
Average	1179.75	755.04	7.99	1194.39	764.41	7.95
Tail						
Mini	303	193.92	7.6	276	176.64	7.6
Max	963	616.32	8.5	958	613.12	8.5
Average	756.37	484.08	7.90	704.5	450.88	7.91

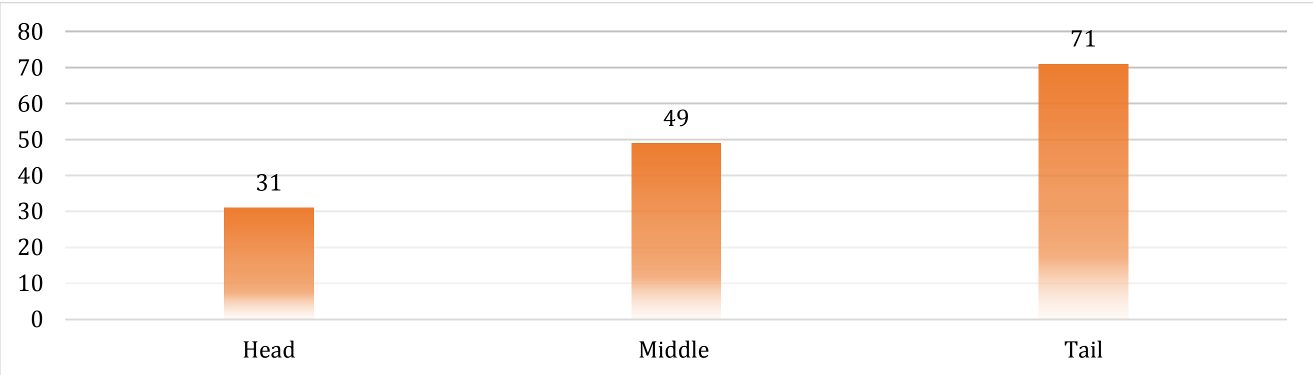

Figure 1. CCME index result.

The water quality index was also calculated using CCME methodology to analyse the overall groundwater quality status in the study area. The WQI value for the head was 31, for the middle was 49, and for the tail was 71. The index value also supported that the groundwater quality was poor at the head, marginal at the middle, and fair at the tail reaches of the distributary as described in Figure 1.

Improving GW Quality by Using Different Interventions

The use of gypsum, micronutrients, and farmyard manure (FYM) helps to mitigate the impacts of saline water. It is used to restore soil quality that has been altered as a result of poor groundwater quality. For soil reclamation, gypsum is efficient. The use of gypsum or FYM significantly increased wheat production (Yaduvanshi and Swarup, 2005). FYM improves the chemical composition of saline and sodic soil (Kharche et al., 2010). Table 4 showed that to maintain the soil properties and overcome the side effects of poor irrigation water, 35, 31, and 29 percent of respondents used gypsum at the head, middle and tail, respectively. The use of micronutrients was very limited in the whole study area. The availability of farmyard manure was limited; that is why very few respondents were using FYM at large scale, particularly to maintain groundwater quality. Only 12, 9, and 11 percent of respondents at the head, middle, and tail, respectively, were using FYM.

Table 4. Quality management practices specifically for GW.

Name of practices	Head (%)	Middle (%)	Tail (%)
Use of gypsum	35	31	29
Use of micronutrients	4	6	5
Use FYM (Trolley)	12	9	11
No practice used	49	54	55

Measures Taken to Reduce the Groundwater Use

Groundwater is a finite natural resource that is exploited over time. The only way to protect the groundwater resources is to reduce extraction. The lack of effective groundwater extraction regulations has resulted in overexploitation (Vandenbohede et al., 2009; Razzaq et al., 2019). In order to minimize hunger, the capacity of farmers to cope with drought is essential (Traore et al., 2020). Different technical steps were adopted to reduce the depletion of the water table. To safeguard water supplies, drip and sprinkling irrigation are the best options (Fishman et al., 2015). There were no farmers currently using drip irrigation in the study area. Few farmers have tried it, but they reported that it was a very expensive and time taking process. The job of maintaining the drips was very difficult. In areas where the water supply is insufficient to sustain agricultural productivity, fewer water-loving crops can be grown. In the study area, farmers were switched from more water-intensive crops (Rice and sugarcane) to less water-intensive crops (Wheat and maize). Table 5 shows that 45, 53, and 36 percent of respondents, at the head, middle, and tail, respectively, altered their crops from more water-intensive to less water-intensive ones. Drought resistance verities were grown by 14, 5, and 11 percent of farmers at the head, middle and tail, respectively. To decrease the accumulation of irrigation water in the soil, Proper land leveling is required. About 27 percent of the water used can be saved by precise land leveling (Sattar et al., 2003; Hussain et al., 2018). In the study area, 66, 55, and 61 percent of respondents were practicing lesser land leveling at the head, middle, and tail, respectively.

Table 5. Type of measures taken to maintain GW table.

Major adopted measure to protect table	Head	Middle	Tail
Drip irrigation	0	0	0
Change in cropping pattern (water saving crops)	45	53	36
Use of drought resistant varieties	14	5	11
Laser land levelling	66	55	61
Improving farm layout	4	6	6
Change in cropping pattern (Low delta crops)	14	4	6
No method used	10	28	15

Main Constraints Faced by the Farmers to Adopt New Technologies

The financial status of the respondent has a positive relationship with technological adoption (Melesse, 2018). Most farmers were facing financial constraints, as shown in Table 6. Farmer prefers to borrow from informal sources if they need money. It was difficult for many farmers to fulfill the financial borrowing requirements. The profitable technologies may not be widely disseminated due to the absence of a successful agricultural extension program (Takahashi et al., 2020). People were unaware of the new technology and preferred to use conventional cultivation methods. In the study area, the farm size is reducing due to inherence distribution. The use of modern technology on a small farm is difficult.

Table 6. Main constraints faced by the farmers for adopting of new technology.

Name constraints	Head	Middle	Tail
Financial constraints	39	38	29
Lack of information	25	27	28
Lack of skill	12	20	25
Lack of availability of new technology (No.)	24	15	18
Total	100	100	100

The findings of ESR model are depicted in Table 7. The findings demonstrated that a variety of explanatory variables could assist farmers in taking corrective action to increase wheat yield. Both adopters and non-adopters have a positive significant age impact on the wheat yield coefficient; the results are in accordance with the finding of Naqvi et al. (2020). Similarly, the family size has a positive impact on adopting remedial measures, but it is negative for non-adopters. Family workers are those members of the family who devote sufficient time to farming, and this variable has a substantial impact on both adopters and non-adopters. Farm size shows negative and significant relation for adopters and a positive non-significant impact for non-adopters. For both adopters and non-adopters, experience has a substantial positive impact. Education also has a positive impact in both cases. Soil quality shows a positive impact on wheat yield for the adopter and a negative impact on non-adopters. The groundwater quality variables and dummy variables were kept as instrument variables. The instrument variables were highly correlated with wheat yield.

Table 7. Results of full information likelihood ESR model.

Independent variables	Select		Adopters		Non-Adopters	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Age	0.010 (0.129)	0.434	0.129 (0.045)	0.411	0.146 (0.032)	0.000
Family size	-0.034 (0.344)	0.324	0.233 (0.147)	0.207	-0.168 (0.105)	0.005
Family worker	-0.016 (0.119)	0.889	1.024 (0.441)	0.020	2.196 (0.418)	0.004
Farm size	0.224 (0.028)	0.342	-0.127 (0.016)	0.003	-0.155 (0.105)	0.245
Experience	-0.227 (0.017)	0.206	0.186 (0.073)	0.000	0.136 (0.049)	0.000
Education	0.258 (0.050)	0.000	0.185 (0.230)	0.011	0.301 (0.097)	0.160
Constant	-3.625 (1.068)	0.001	21.02 (3.134)	0.000	38.181 (2.634)	0.000
Soil quality	0.217 (0.189)	0.010	1.444 (0.623)	0.021	-0.211 (0.626)	0.735
Financial constraints	-2.919 (0.480)	0.000	-	-	-	-
Information/skill constraints	-1.145 (0.660)	0.000	-	-	-	-
Ins0	-	-	-	-	1.235 (0.034)	0.012
Ins1	-	-	1.234 (0.035)	0.021	-	-
r0	-	-	-	-	0.235 (0.100)	0.039
r1	-	-	0.149 (0.124)	0.056	-	-

The results, as shown in Table 8, reveal that remedial adaptation increases wheat yields in a positive and significant way for wheat growers. T-test was used to analyse the treatment effect. It is applied after taking inverse mills ratio. Results shows that the adaptation of remedial measures increased the wheat yield.

Table 8. Results of T-test.

Variable	Obs.	Mean	Std. error	95% conf. interval	
Adopter	54	43.87	0.450	42.91	44.77
Non-adopter	54	31.73	0.505	30.72	32.75
Combine	108	37.80	0.676	36.46	39.14
Difference			0.567	10.79	13.47
H0: Mean adopter and non-adopter = 0					
Ha: Mean difference ≠ 0					
Pr(T>t) = 0.000	Pr(T=t) = 1.00		Pr(T≠t) = 0.000	t = 17.92	

CONCLUSIONS

Agricultural productivity is mainly dependent on the quality of groundwater. Groundwater is a vital supply of water, not just for agricultural purposes but also for other human requirements. The quality of groundwater varies by location and depth. The sample analysis results revealed that around 70 percent of the groundwater samples were unfit for agriculture. Water analysis revealed that the quality of groundwater improves when moving from head to tail of the distributary. The availability of canal water is comparatively better at the tail, so the extraction of groundwater is comparatively lower at the tail; that is why the quality of groundwater is better at the tail. The CCME results were also supporting that the groundwater quality is better at tail reaches of the distributary. Farmers used a variety of low-cost methods to combat the negative consequences of poor groundwater quality to improve farm productivity. Gypsum is one of the cheap methods to minimize the side effect of poor groundwater quality. But only 39 percent of farmers were using gypsum as a remedial measure against poor groundwater quality. Financial constraint was the reason for the non-adoption of the remedial measure. Adoption of remedial treatments was also influenced by different other factors such as experience, education, and soil quality. The majority of farmers relied on groundwater without assessing its suitability. The study concluded that proper groundwater quality monitoring is required. Gypsum is a low-cost way to minimize some of the negative consequences of poor groundwater quality. Farmers should be educated regarding the proper use of gypsum. The sewerage system was absent in many villages of the study area. To avoid the leaching of hazardous materials into groundwater, it is critical to construct an effective waste management system.

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