Pak. J. Agri. Sci., Vol. 52(3), 837-843; 2015
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

GIS BASED ASSESSMENT AND DELINEATION OF GROUNDWATER QUALITY ZONES AND ITS IMPACT ON AGRICULTURAL PRODUCTIVITY

Aamir Shakoor[1,*], Muhammad Arshad[1], Allah Bakhsh[1] and Riaz Ahmed[2]

[1]Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan;
[2]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.
[*]Corresponding author's email: aamirskr@yahoo.com

The utilization of groundwater for irrigation is rapidly increasing due to constrained canal water supplies. The spatial fluctuation of groundwater quality widely varies, so mapping has become necessary for better management of this precious resource. Therefore, to delineate groundwater quality zones in the Central East of Punjab-Pakistan, geographic information system (GIS) was used. A hydro-economic model was also developed to observe the impact of groundwater quality on agricultural economics. Three groundwater quality zones such as good (zone-1), marginal (zone-2) and hazardous (zone-3) were classified according to the available criteria. The final maps of pre and post-monsoon season showed that area of good, marginal and hazardous quality groundwater was ranged between 35.81 to 41.19%, 36.63 to 31.53% and 27.55 to 27.27% of the total area, respectively. It was found that the benefit cost ratio in zone-1 was 2.53, which was much higher than zone-2 (2.24) and zone-3 (1.88). The results also showed that with the 1% increase in the value of electric conductivity (EC), the gross value product (GVP) was decreased significantly by 0.080 and 0.526 % in zone-2 and 3, respectively.
Keywords: Cost benefit ratio, double log, hydro-economic, interpolation, water quality

INTRODUCTION

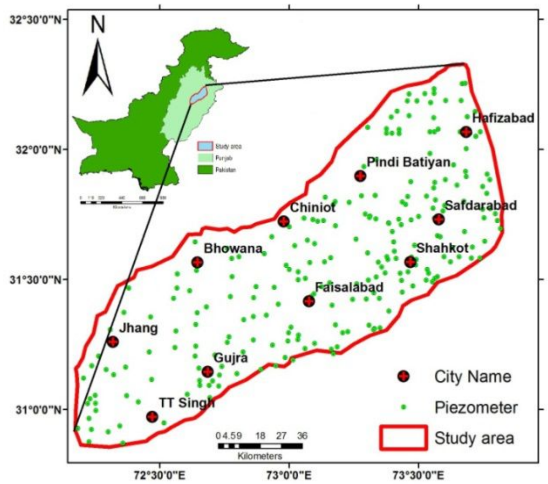
Groundwater plays a life sustaining role in the development of agricultural production and said to be a green revolution. The increasing demand of groundwater resources was due to limited canal water supply (Tariq *et al*., 2007; Scott and Shah, 2004). About 750-800 billion cubic meter (BCM)/year of global groundwater abstraction were used for irrigation (Shah, 2007) and groundwater significantly important in the agriculture based economy like Pakistan, where more than 50% of the total crop water requirements was met from this precious resource (Qureshi *et al*., 2010). Similarly, in Punjab-Pakistan, about 90% of the population depended on groundwater for their daily domestic needs (Qureshi *et al*., 2004; Shah, 2007).

In the Indus basin of Pakistan, the quality of groundwater varied spatially and was dependent upon the movement of groundwater in the aquifer (Qureshi *et al*., 2008). About 1.2 million small capacity private tubewells are working in Pakistan, out of which, more than 90% are used for agriculture (Qureshi, 2012). About 62BCM of groundwater is being pumped annually to supplement surface water supplies as food demand is increasing in Pakistan due to population growth (Arshad *et al*., 2013; Shakoor *et al*., 2012). The uncheck abstraction of groundwater is creating a number of management problems including salt water intrusion and increase in the soil salinity. In irrigated agriculture, the application of poor quality groundwater was considered as one of the major source of salinity in root zone and ultimately a reason of reduction in crops yield (Kijne, 1996). So, the identification of groundwater quality zones through mapping is necessary for efficient utilization, management and planning of poor quality groundwater. Therefore, this research was carried out to delineate and compare the groundwater quality and its effect on agricultural economics in the study area.

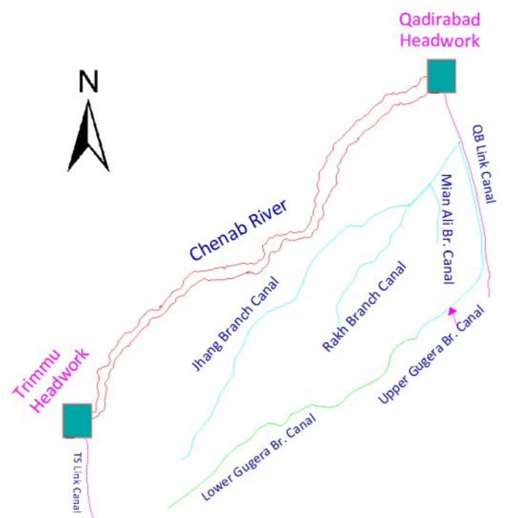
MATERIALS AND METHODS

***Study area*:**The research was carried out in the Central East of Punjab, Pakistan, which is bounded between the longitude of 73°50'43" E to 72°10'50"E and latitude of 32°18'56" N to 30°50'42" N as shown in Figure 1a. The study site has a surface area of 11576 km^2 with cultureable command area of 9761km^2. The River Chenab is lying on Northwest, Gugera Branch Canal on the Southeast, Qadirabad-Baluki on Northeast and Trimmu-Sidhnai Link canal on the Southwest side of the study area as shown in Figure 1b. The other canals in the study area are Mian Ali, Rakh and Jhang Branch canals.

Topography of study area is fair with semi-arid climate. The climatic data such as rainfall, reference evapotranspiration, minimum and maximum temperature were collected from Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad-Pakistan. The summer is hottest with maximum and minimum temperature of 50 and 27°C, respectively. The winter season is coldest having average maximum and minimum temperature of 23 and 6°C, respectively. The highest rainfall occurred in July to September (monsoon season) and average rainfall is 439 mm/year while maximum reference evapotranspiration was recorded in May and June with the average of 1257 mm/year.



(a)



(b)

Figure 1. (a) Location of study area and installed piezometers (b) Location of river and canal system in the study area.

***Groundwater data collection*:** The irrigation water quality is generally described by the three parameters such as electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC). So, the data of these parameters, from 256 piezometers, were collected from the Punjab Irrigation Department (PID), Faisalabad-Pakistan, for pre-monsoon (June) and post-monsoon (October) for the period of 2003 to 2013. But in this research, the spatial variation groundwater quality for June and October of 2013 was compared only because the crop data were collected for this period.

***GIS based zoning*:** Geographic Information System (GIS) is considered as one of the most versatile tools for capturing, integrating, analyzing, managing, manipulating and storing spatial data referenced to earth. The following two steps were used in GIS to delineate the spatial groundwater quality variation: Step-I; thematic maps were prepared and in step-II; groundwater quality zones were delineated.

***Step-I: Development of database*:** The boundary of the study area was drawn in the Google Earth software and saved in "kml" format, which was further converted into shape file to use in GIS. The canal network and groundwater sampling locations were also prepared (Fig. 1a and b). The data of groundwater quality i.e. EC, SAR and RSC were assigned to each piezometric location.

***Step-II: Interpolation and overlay analysis*:** In this step, the spatial layers of each water quality parameter were developed using the piezometeric data. The developed layers were classified according to the allowable limits described by WAPDA (1982) for each irrigation water quality parameters to know the spatial fluctuations of groundwater quality. To interpolate groundwater quality data, kriging method was applied. Several researchers were used kriging method for interpolation of groundwater data and found satisfactory results (Rahmawati *et al*., 2013; Nwankwoala *et al*., 2012; Ebrahimi *et al*., 2011; Nikroo *et al*., 2010).

The weights were attributed to each class of individual layers depending upon irrigation water criteria (Table 1). The most favorable class was attributed to high weightage, while less desirable or unsuitable class for irrigation aim was attributed to low weightage according to Bonham (1994) and Vijay *et al*. (2011). The layer of each water quality parameter was created and categorized by allocating the weights as described in Table 1.

The each layer was constituted of thousands of small cells of equal size depending upon the size of the study area. The procedure was repeated for all water quality parameters and finally all the layers were incorporated using weighted sum overlay analysis to delineate potential groundwater quality zones. The weight of each cell was computed as a sum of all the assigned weights. At the end, final layer was further classified and the standard for classification of groundwater quality zones into Good, Marginal and Hazardous was defined as weights of 9, 9-6 and <6, respectively.

***Hydro-economic model*:** A hydro-economic model was developed using Cobb-Douglas production function to find the effect of groundwater quality on crop production. Many researchers used extensively double-log production model in agriculture research and reported that it was satisfactory (Shahroudi, 2013; Ashfaq *et al*., 2009; Kamat *et al*., 2007). The double-log production model (Ashfaq *et al*., 2009) is given in Equation 1:

$$\ln GVP = \gamma_o + \gamma_1 \ln L.Hold + \gamma_2 \ln L.Prep. + \gamma_3 \ln S.Cst. + \gamma_4 \ln T.Well + \gamma_5 \ln Canal + \gamma_6 \ln Fert.Cst. + \gamma_7 \ln Exp. + \gamma_8 \ln EC + \varepsilon_r \quad \text{(Eq-1)}$$

Table 1. Weights and area under different irrigation water quality parameters.

Parameter	Quality	Criteria*	weight	Area km² (Percentage)	
				June	October
EC (dS/m)	Good	<1.5	3	4438.96 (38.34)	4910.06 (42.42)
	Marginal	1.5-2.7	2	3036.61 (26.23)	3471.19 (29.99)
	Hazardous	>2.7	1	4100.42 (35.42)	3194.74 (27.60)
SAR	Good	<10	3	6191.91 (53.49)	6210.53 (53.65)
	Marginal	10-18	2	3871.81 (33.44)	3960.92 (34.21)
	Hazardous	>18	1	1512.27 (13.06)	1404.54 (12.13)
RSC (meq/L)	Good	<2.5	3	5706.56 (49.29)	5918.74 (51.13)
	Marginal	2.5-5.0	2	4415.59 (38.14)	4033.23 (34.84)
	Hazardous	>5.0	1	1453.84 (12.56)	1624.03 (14.03)
Overall Quality	Good	9	-	4145.35 (35.81)	4768.01 (41.19)
	Marginal	6-8	-	4241.03 (36.63)	3650.87 (31.53)
	Hazardous	<6	-	3189.62(27.55)	3157.12 (27.27)

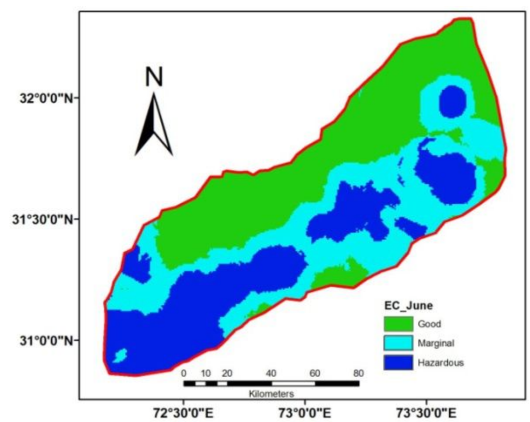
*WAPDA (1982)

Where, lnGVP= Log of gross value of wheat (Rs/ha), lnL.Hold= Log of holding size of the respondent (ha), lnL.Prep.= Log of cost of land preparation (Rs/ha), lnS.cst.= Log of seed cost (Rs/ha), lnT.Well= Log of cost of groundwater (Rs/ha), lnCanal= Log of cost of canal irrigation (Rs/ha), lnFert.Cst= Log of cost of fertilizer (Rs/ha), lnExp.= Log of farming experience of the respondent (years), lnEC = Log electrical conductivity (dS/m), γ_0= Intercept coefficient, γ_1- γ_8= Coefficients of respective inputs, ε_r= Random error term

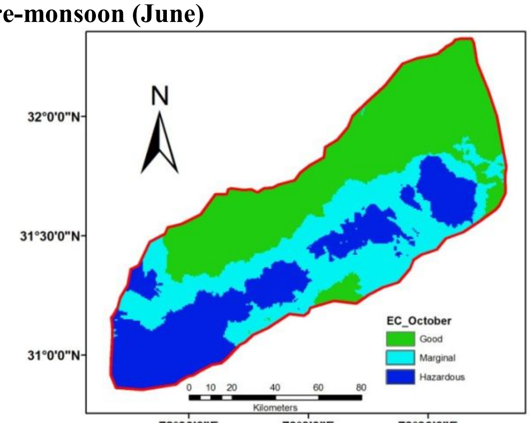
To obtain the data of hydro-economic model, a questionnaire was developed. The data of wheat crop, major crop in the study area, from 300 respondent farmers were collected through questionnaires. To observe the impact of groundwater quality on crop yield, electric conductivity (EC) was selected, which is the basic and most influencing parameter (Irfan *et al*., 2014). The other independent variables selected were land holding, cost of land preparation, seed cost, cost of groundwater irrigation, cost of canal irrigation, fertilizer cost and farming experience.

RESULTS AND DISCUSSION

Groundwater quality:GIS based individual water quality layers for each parameter were prepared and re-classed for both pre and post monsoon seasons, based on the criteria described in Table 1. The EC of groundwater in good quality range of the study area has covered 38.34% of area in June, which was increased to 42.42% after monsoon season. The marginal quality EC also has increased from 26.23 to 29.99% of the area and hazardous quality EC decreased from 35.42 to 27.60% of the area (Figures 2a and b). The area under good and marginal quality SAR laid in 53.49 and 33.44% in June and increased to 53.65 and 34.21% in October, respectively. The hazardous quality SAR reduced after monsoon season from 13.06 to 12.13% of area (Fig. 3a and 3b). The area under good quality RSC laid in 49.29% of area in June and increased to 51.13% in October. The marginal quality RSC reduced from 38.12 to 34.84% after monsoon. The hazardous quality RSC increased unexpectedly from 12.56 to 14.03% of area (Fig. 4a and b).

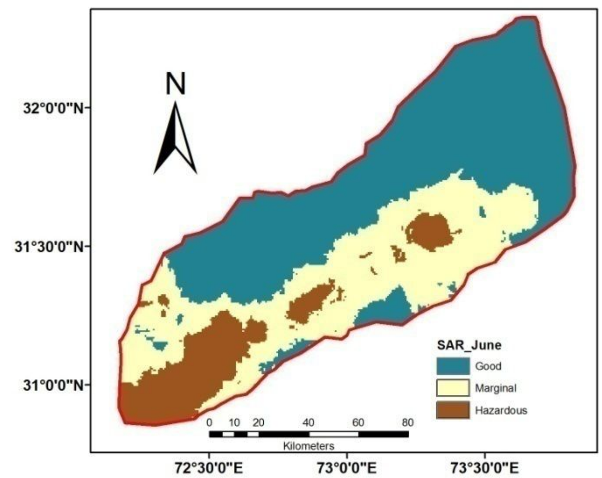


a. Pre-monsoon (June)

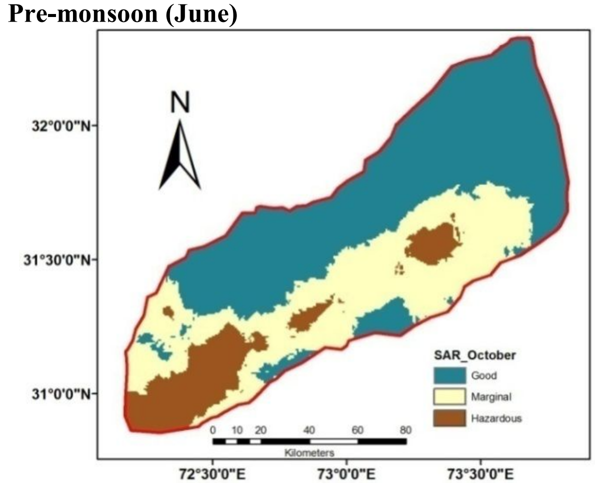


b. Post monsoon (October)

Figure 2. Spatial distribution of electric conductivity (EC).



a. Pre-monsoon (June)

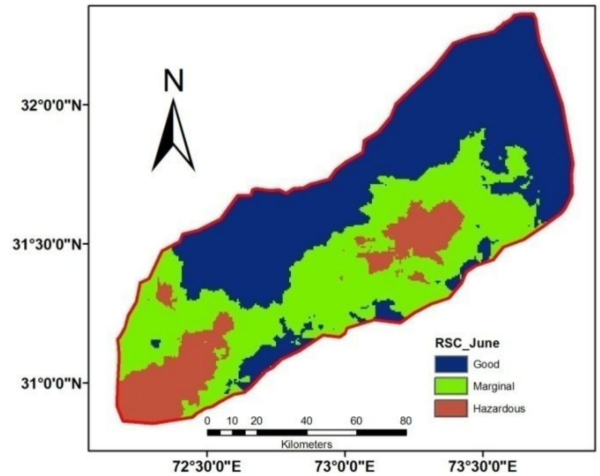


b. Post monsoon (October)

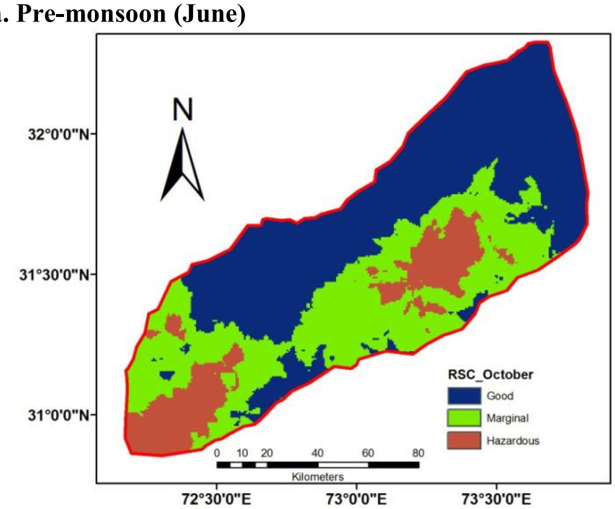
Figure 3. Spatial distribution of Sodium adsorption ratio (SAR).

It was observed that the good quality range of all irrigation water quality parameters was increased after monsoon season due to mixing of fresh rainfall water into groundwater. The contribution of recharge from rainfall to groundwater was from 17 to 22% of rainfall and the 15% of water delivered to field recharged to groundwater (Arshad *et al*., 2005).

The groundwater quality was distinguished in three category and their zones were delineated such as Good, Marginal and Hazardous (Table 1) and the spatial variation maps of groundwater quality after integration of each layer of water quality parameter for pre-monsoon and post-monsoon are shown in Figures 5a and 5b, respectively. The 35.81% of area has good quality groundwater in June and increased to 41.19% of area after monsoon. The good quality water existed on top of the study area and along the Chenab River; the strip is about 29km wide and 33.80km long. Rehman *et al*. (1997) said that the river and canal water coming from the snow melt and from rainfall runoff, having generally good quality water, when mixed with groundwater, makes it of suitable quality. Khan *et al*. (2008) reported that 24-48km wide belt along river had good quality water.



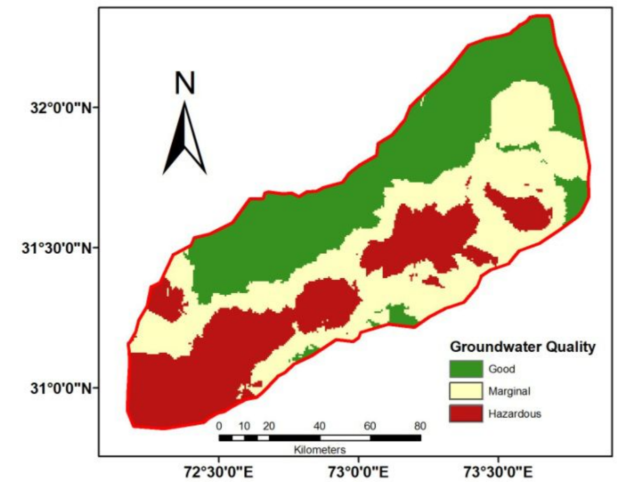
a. Pre-monsoon (June)



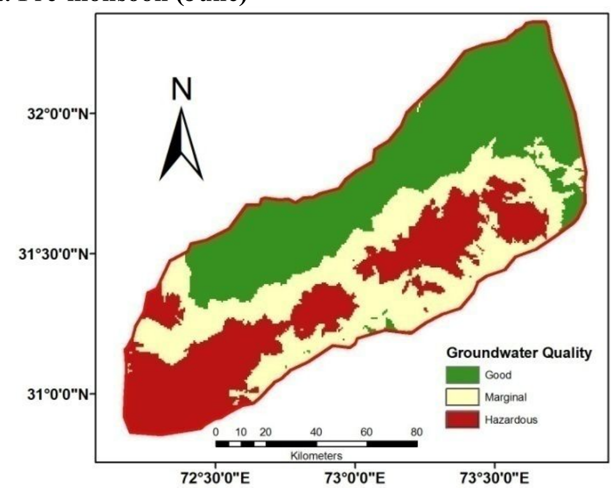
b. Post monsoon (October)

Figure 4. Spatial distribution of residual sodium carbonate (RSC).

After monsoon season, the marginal and hazardous quality groundwater reduced from 36.63 to 31.53% and 27.55 to 27.27%, respectively. The hazardous quality groundwater surrounded by marginal quality water and both consisted on about 33.80km wide and 181km long strip along the Gugera Branch canal. The most of the lower part of the study area had hazardous quality water, which is unsuitable for irrigation. Qureshi *et al*. (2004) reported that aquifer away from the river and less irrigation infrastructure had marginal to poor groundwater quality.



a. Pre-monsoon (June)



b. Post monsoon (October)

Figure 5. Spatial distribution of groundwater quality zones.

***Analysis of hydro-economic model*:** The impact of groundwater quality on agricultural productivity and farmer's income was observed using double log production function model. The 67% of the selected farmers applied five irrigations to grow wheat crop and groundwater was the main source of irrigation. The average rate of seed, 108kg/ha was applied to the field along with the average rates of Urea and Diammonium Phosphate (DAP) was 198 and 144kg/ha, respectively. The average cost of wheat production and income, according to groundwater quality zones for year the 2012-13 is given in Tables 2 and 3, respectively. The land preparation and fertilizer was the main cost of wheat production. The cost of land preparation for zone-1, zone-2 and zone-3 was 14167, 13137 and 11107Rs/ha, respectively. The average cost of fertilizer and chemicals was 20975, 20480 and 20185Rs/ha for zone-1, zone-2 and zone-3, respectively.

The huge contribution in land preparation was due to the high cost of diesel, while in fertilizer and chemicals, it was because of costly pesticide, weedicide, Urea and DAP application. The seed cost included the labor cost and chemicals used for disease dieses protection. The irrigation cost was included the cost of tubewell operation that was 8014, 6248 and 4483Rs/ha for zone-1, zone-2 and zone-3, respectively, which showed the high contribution of groundwater. Hence, the average total expenses occurred for the wheat crop production was little higher (59068Rs/ha) in zone-1 as compared to zone-2 (55676 Rs/ha) and zone-3 (51233 Rs/ha), mainly due to more land preparation (leveling, ploughing and rotavator) and abstraction of good quality water.

Table 2. Average cost of wheat crop production

Activity	Cost (Rs/ha)		
	Zone-1 (Good)	**Zone-2 (Marginal)**	**Zone-3 (Hazardous)**
Land Preparation	14167	13137	11107
Seed and seed treatment	8525	8491	8257
Fertilizer and chemicals	20975	20480	20185
Irrigation (canal + Ground)	8014	6248	4483
Harvesting	6095	6030	5967
Transportation	1292	1290	1234
Total expenses	59068	55676	51233

Table 3 shows the revenue generated by the farmers of the study area for wheat cultivation. The wheat yield in the good quality groundwater was significantly higher than the other zones. Hence, the higher average revenue generated was 149286Rs/ha for zone-1 over zone-2 (124830 Rs/ha) and zone-3 (96535Rs/ha). The benefit cost ratio resulted that 2.53 times income was generated over the investment in zone-1, which was much higher than zone-2 and zone-3.

Table 3.Average income from wheat crop.

Items	Zone-1 (Good)	Zone-2 (Marginal)	Zone-3 (Hazardous)
Wheat yield (kg/ha)	4447	3720	2865
Price of wheat (Rs/kg)	30	30	30
Net income without by product (Rs/ha)	133410	111600	85950
Yield of chaff (kg/ha)	4447	3706	2965
Price of chaff (Rs/kg)	3.57	3.57	3.57
Net income from chaff (Rs/ha)	15876	13230	10585
Gross income (Rs/ha)	149286	124830	96535
Total benefit (Rs/ha)	90218	69154	45302
Benefit cost ratio	2.53:1	2.24:1	1.88:1

Table 4.Regression analysis of each good groundwater quality zone.

Predictor	Zone 1 (Good)			Zone 2 (Marginal)			Zone 3 (Hazardous)		
	Coef.	**T. Value**	**Sig.**	**Coef.**	**T. Value**	**Sig.**	**Coef.**	**T. Value**	**Sig.**
Constant	2.73 (1.734)	1.578	0.120*	8.681 (0.503)	17.260	0.000***	7.849 (1.374)	5.710	0.000***
ln Hold.	0.016 (0.011)	1.372	0.176*	0.032 (0.012)	2.750	0.009***	0.002 (0.014)	0.140	0.892*
ln L.pre	0.28 (0.066)	4.250	0.000***	0.009 (0.041)	0.210	0.833*	0.264 (0.094)	2.810	0.008***
ln S.cst	0.186 (0.087)	2.143	0.036**	0.0304 (0.017)	1.780	0.082**	0.038 (0.021)	1.810	0.077*
lnIrrig.	0.106 (0.052)	2.036	0.046**	-0.027 (0.016)	-1.7	0.003***	-0.081 (0.025)	-3.180	0.009***
lnFerti.	0.296 (0.176)	1.678	0.048**	0.138 (0.056)	2.480	0.017**	0.596 (0.153)	3.900	0.007***
ln Exp.	0.019 (0.012)	1.607	0.113*	0.016 (0.014)	1.120	0.268*	0.005 (0.010)	0.530	0.602*
ln EC	0.094 (0.056)	1.671	0.100*	-0.080 (0.028)	-2.9	0.006***	-0.526 (0.099)	-5.350	0.000***

* Non-significant, **Significant, *** Highly significant

The results of double log (log-log) production function to determine the factors affecting the production of wheat for zones-1, 2 and 3 are shown in Table 4. In the zones, some independent variables had significant impact while, some had non-significant on crop yield and the values in parenthesis indicate Standard Error Coefficient. The coefficient of irrigation showed that with the increase of 1% cost of irrigation, there was 0.106% increase in gross value of wheat product in zone-1, while 0.027 and 0.081% decrease in crop yield in zone-2 and zone-3, respectively. Its positive impact in zone-1 was due to the good quality of both canal and groundwater. In zone-2 and 3, adverse effect was due to the use of poor quality groundwater for irrigation because of inadequate canal water. The effect was very small and highly significant due to salinity buildup in soil profile.

The results showed that with 1% increase in the value of EC, the GVP was increased by 0.097%. While, in zone-2 and 3 GVP was decreased by 0.080 and 0.526%, respectively, although the effect was very small but highly significant. With the increase in EC, water become unfit for irrigation and over utilization of that quality groundwater, destroyed the soil structure and plants could not grow healthy and resulted in low yield. The average value of coefficient of determination (R^2) was 0.707 and Adjusted R^2 was 0.691, showing that about 69% variation in the yield was explained by the predictor variables included in the equation. The results had good agreement with the previous research as Bakhsh and Awan (2002) concluded that groundwater application having EC between 1.50 to 4.70dS/m turned the top 300mm soil depth of a typical non-saline soil into saline conditions. Hussain *et al*. (2012) found that the salinity was a major obstacle in successful crop production in many semi-arid areas like Pakistan. Hill and Koenig (1999) resulted that the application of poor quality water reduced the expected yield of alfalfa to 60% of what it could be with good quality water.

Conclusions: It was concluded that groundwater in the study area had wide range from good to very poor and spatially varied. The good quality of groundwater existed on about 29km wide strip along the Chenab River whereas, marginal and hazardous quality groundwater existed along the Lower Gugera branch canal had about 33.80km wide strip. There was very little improvement in groundwater quality as observed after the monsoon season. The economic analysis of wheat crop indicated that the good quality zone had 11.46 and 25.69% more benefit than the marginal and hazardous quality zones, respectively. It is recommended that groundwater should be artificially recharged and more surface water should be applied to protect its quality in zone-2 and zone-3.

Acknowledgment: The authors acknowledged the financial support from Higher Education Commission (HEC), Pakistan under PhD Indigenous scholarship program and Punjab Irrigation Department (PID), Faisalabad for providing the groundwater data.

REFERENCES

Arshad, M., A. Shakoor, I. Ahmad and M. Ahmad. 2013. Vertical electric sounding method for hydraulic transmissivity determination in comparison with traditional methods for groundwater exploration. Pak. J. Agri. Sci. 50: 487-492.

Arshad, M., M.R. Choudhry and N. Ahmed. 2005. Estimation of groundwater recharge from irrigated fields using analytical approach. Int. J. Agri. Biol. 7: 285-286.

Ashfaq, M., M. Akram, I.A. Baig and A. Saghir. 2009. Impact of ground water on wheat production in District Jhang, Punjab, Pakistan. Sarhad J. Agric. 25: 121-125.

Bakhsh, A. and Q.A. Awan. 2002. Water issues in Pakistan and their remedies. In: National Symposium on Drought and Water Resources in Pakistan, 16th March 2002, CEWRE, University of Engineering and Technology, Lahore-Pakistan; pp.145-150.

Bonham, C.G. 1994. Geographical Information Systems for Geoscientists: Modeling with GIS. Pergamon Press, Oxford; p.398.

Ebrahimi, K., S. Feiznia , M.J. Rostami and K. Ausati. 2011. Assessing temporal and spatial variations of groundwater quality (a case study: Kohpayeh-Segzi). J. Rangeland Sci. 1: 193-202.

Hill, R. and R.T. Koenig. 1999. Water salinity and crop yield: Utah water quality. Res. Bull. AG-425.3; Utah Ag. Exp. Sta., Utah State University, Logan, UT, 84322.

Hussain, M., M. Farooq, M. Shehzad, M.B. Khan, A. Wahid and G. Shabir. 2012. Evaluating the performance of elite sunflower hybrids under saline conditions. Int. J. Agric. Biol. 14: 131–135.

Irfan, M., M. Arshad, A. Shakoor and L. Anjum. 2014. Impact of irrigation management practices and water quality on maize production and water use efficiency. J. Anim. Plant Sci. 24: 1518-1524.

Kamat, M.S., S.N. Tupe and M.M. Kamat. 2007. Indian agriculture in the new economic regime, 1971-2003: Empirics based on the Cobb Douglas Production Function. Munich Personal RePEc Archive. MPRA Paper No. 6150, posted 7. pp 1-13.

Khan, S., T. Rana, H.F. Gabriel and M.K. Ullah. 2008. Hydrogeologic assessment of escalating groundwater exploitation in the Indus Basin, Pakistan. Hydrogeo. J. 16: 1635–1654.

Kijne, J.W. 1996. Water and salinity balances for irrigated agriculture in Pakistan. Research Report 6, International Irrigation Management Institute (IWMI), Colombo, Sri Lanka, pp. 1-23.

Nikroo, L., M. Kompani-Zare, A.R. Sepaskhah and S.R.F. Shamsi. 2010. Groundwater depth and elevation interpolation by kriging methods in Mohr basin of Fars Province in Iran. Environ. Monit. Assess. 166: 387-407.

Nwankwoala, H.O., O.S. Eludoyin and A.A. Obafemi. 2012. Groundwater quality assessment and monitoring using Geographic Information System (GIS) in Port Harcourt, Nigeria. Ethiopian J. Environ. Studies & Manage. 5: 583-596.

Qureshi, A.S. 2012. Groundwater management in Pakistan: The question of balance. Centenary Celebration (1912 – 2012), Paper No.717:207-217.

Qureshi, A.S., M.N. Asghar, S. Ahmad and I. Masih. 2004. Sustaining crop production under saline groundwater conditions: A case study from Pakistan. Aus. J. Agri. Sci. 54: 421-431.

Qureshi, A.S., P.G. McCornick, A. Sarwar and B.R. Sharma. 2010. Challenges and prospects for sustainable groundwater management in the Indus Basin, Pakistan. Water Resour. Manage. 24: 1551-1569.

Qureshi, A.S., P.G. McCornick, M. Qadir and Z. Aslam. 2008. Managing salinity and waterlogging in the Indus Basin of Pakistan. Agri. Water Manage. 95: 1-10.

Rahmawati, N., J.F. Vuillaume and I.L.S. Purnama. 2013. Salt intrusion in coastal and lowland areas of Semarang City. J. Hydrol. 494: 146–159.

Rehman, G., W.A. Jehangir, A. Rehman, M. Aslam and G.V. Skogerboe. 1997. Principal findings and implications for sustainable irrigated agriculture: salinity management alternatives for Rechna Doab, Punjab, Pakistan. Vol. I, Research report R-21.1, Pakistan National Program, International Irrigation management Institute (IWMI), Lahore, Pakistan.

Scott, C.A. and T. Shah. 2004. Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico. Water Resour. Devel. 20: 149–164.

Shah, T. 2007. The groundwater economy of South-Asia: An assessment of size, significance and socio-ecological impacts. In: M. Giordano and K.G. Villholth (eds.), The Agricultural Groundwater Revolution: opportunities and threats to development. CABI Publications 7-36.

Shahroudi, S.M.M. 2013.Estimation of food substance small-scale production function. Intl. J. Agri. Crop Sci. 13: 1487-1489.

Shakoor, A., M. Arshad, A.R. Tariq and I. Ahmad. 2012. Evaluating the role of bentonite embedment in controlling infiltration and improve root zone water distribution in coarse soil. Pak. J. Agri. Sci. 49: 375-380.

Tariq, S.R., M.H. Shah, N. Shaheen, M. Jaffar and A. Khalique. 2007. Statistical source identification of metals in groundwater exposed to industrial contamination. Environ. Monit. Assess. 138: 159–165.

Vijay, R., D.R. Samal and P.K. Mohapatr. 2011. GIS based identification and assessment of groundwater quality potential zones in Puri City, India. J. Water Resour. Prot. 3: 440-447.

WAPDA. 1982. Revised Action Programme for Irrigation Agriculture, Final Report. Lahore: WAPDA (Water and Power Development Authority), Economic Research Section, Planning and Development Division.