INTRODUCTION

The rapid rise in population growth, improvement in living standards and climate change are the reasons of soaring global water requirements manifold in the next few decades. In many countries of the world, the per capita availability of water has been declining sharply especially in countries having low rainfall such as Pakistan (Chatha et al., 2015; Irfan et al., 2014; Shakoor et al., 2012). The available data suggests that most of our basins are over exploited and hence water table has been depleting rapidly (Shakoor et al., 2018). The reality is quite bitter, and it can be easily guessed that with the existing rate of groundwater use, the water will be no longer available for use in the near future. Groundwater has been in use since ancient times. More than 50% of the crop water requirements are being fulfilled using groundwater, which is producing most foods in Pakistan (Arshad et al., 2013). The development of private tubewells has strong relation with the declining rate of water table depth in terms of installation cost (Shakoor et al., 2015). The farmers using tubewell water get 41% more yield as compared to those farmers who only depends on canal water, type of tubewell, cropping patterns and agro-climatic conditions are the major factors which influence the utilization factor of tubewell. During Kharif season, use of tubewell is almost double as compared to Rabi season (Qureshi et al., 2003). The increasing trend of tubewells in Pakistan from 1960 to 2010 and then forecasted for future is shown in Figure 1.

Figure 1. Tubewells growth rate in Pakistan (Source: Shakoor, 2015; PES, 2009).

Mostly private tubewells are installed in the months of May, June and July due to more crop water requirement in Kharif season and extraordinary shortage of water is observed in this period which is the major factor to enforce the farmers to invest for tubewells at this time of the year (Malik and Strosser 1993). The groundwater over exploitation and its
mismanagement is more in arid regions and poses a major threat to water table (Shakoor et al., 2015). The groundwater level decreasing rapidly more than 4 to 5 meters per annum in many of the aquifers of Pakistan (Khair et al., 2010; Chandio, 2009). Due to natural recharge in space and time domain, it is very necessary to analyze the seasonal groundwater depth fluctuation which is the best management strategy for groundwater development (Buchanan and Triantafilis, 2009). Thus, the objective of the research was to delineate the temporal and spatial fluctuation in groundwater level by using GIS software and to evaluate the impact of lowering water table on tubewell energy nexus district Hafizabad, Pakistan.

MATERIALS AND METHODS

Study area: The research work was carried out at Hafizabad district using GIS in 2013, the boundary and the piezometers are shown in the Figure 2. The research site has area of 2503 km² with flat topography and located at 32.07° N latitude and 73.68° E longitude. The North-West boundary of the study area touches the river Chenab. The entire study area is being irrigated by lower Chenab canal (East) by branch canals. The rainfall of the study area is 790.9 millimeter with a higher average of up to 250 millimeters during the moon soon season in July and August (Tariq, 2009). The climate of the study area is hot and dry during the summer and moderately cold in the winter. The maximum summer temperature in the month of June was 48°C, while in winter (January) the lowest minimum temperature was 7°C. In 2011-12, the area irrigated by tubewells in Pakistan and Punjab was 3.79 and 2.94 million hectares, respectively while, by both canal and tubewells was 7.60 in Pakistan (Ahmad et al., 2007).

In order to study spatio-temporal variation in water table depth, the eleven years (2003-2013) groundwater depth data were obtained from Punjab Irrigation Department (PID) Faisalabad and only 3 years data were compared (2003, 2008, and 2013). The Geographic Information System software was utilized to delineate the variation in groundwater level for making the maps and geographic analysis. Both ordinary and universal kriging methods were used to prepare thematic maps but ordinary kriging gave best results. The exponential semivariogram model in ordinary kriging method was found best fitted to interpolate groundwater level data. For the interpolation of groundwater data, many researchers used kriging method and found the satisfactory results (Rahmawati et al., 2013; Karatas et al., 2013; Jiazhong et al., 2011). Under the boundary of study area, the “Extraction by Mask” method was used to extract the data. GIS is a computer-based tool for making the maps and analyzing the spatial and raster data. GIS technology integrates common database operations such as queries and statistical analysis with the geographic analysis and visualization benefits offered by maps (Ehsan et al., 2005). GIS is being considered as one of the most important new technologies, with the potential to revolutionize many aspects of research by the increased ability to make decisions and to solve the problems (Khalid et al., 2013; Batelaan and Smelt, 2007).

Field survey: The field surveys were conducted to find the causes of water table variation and to estimate the installation and operation cost of tubewells in district Hafizabad. The data were collected through questionnaires from different villages that were selected on the basis of irrigation type and the location of farms from water courses, distributaries and canal. The 100 respondents were selected randomly who were the male head of households and farms.

Cost analysis: Cost of the tubewell is the major factor affecting on the farmer’s total expenditure and net benefits. The impact of increasing tubewells on the total expenditure of the farmer on a farm was estimated by calculating both the operational and constructional cost. The construction cost was calculated by the summation of cost of material, pump and the labor; while the operational cost was calculated using Equations 1-3 (Raghunath, 2007).

Power of the pump required:

$$P_p = \frac{\rho g Q H}{1000 \times \text{Efficiency of pump}} \quad \text{Eq-1}$$

Power of the motor;

$$P_m = P_p / \text{efficiency of motor} \quad \text{Eq-2}$$

Operational Cost (Rs.)

$$P_m = P_m \times \text{pumping hours} \times \text{unit price} \quad \text{Eq-3}$$

Where, ρ is density of water (1000kg/m³), g is 9.81 m²/s, H is head (m), Q is discharge, Pump efficiency is 60%, Motor efficiency is 85%, (Choudhary, 2008). Unit price of electricity is Rs. 25. Pumping hours are 12 per day.

Figure 2. Boundary and location of piezometers in study area
RESULTS AND DISCUSSION

The spatial and temporal maps were created with GIS using ordinary krigging method with spherical semivariogram model for the interpolation of the groundwater level variation. The piezometric values were used for GIS analysis for the years of 2003, 2008 and 2013. The water table depths were distinguished in three zones i.e. shallow (<10 m), moderate (10 to 15 m) and deep (>15 m). It was found that water table was shallow on north-east boundary, medium on the Centre and deep on west-south boundary as shown in Figure 3-5.

It was observed that the area of shallow water table is going to short while deep water table area is expanding rapidly. In 2003, shallow water table area was 9.6578*10^2 km^2 which decreased to 8.1734*10^2 km^2 in 2008 and further decreased to 5.7433*10^2 km^2 in 2013. Moderate area was 1.30952*10^3 km^2 in 2003 which decreased in 2008 as 1.27897*10^3 km^2 and then increased to 1.48143*10^3 km^2 in 2013. The deep water table area was expanding rapidly from 2.2769*10^2 km^2 (2003) to 4.067*10^2 km^2 (2008) and 4.4724*10^2 km^2 in 2013. The total study area was 2503 km^2 and the % increase in deep groundwater level area and % decrease in shallow groundwater level area is shown in the Table 1.

Qureshi et al. (2008) observed that the depletion of groundwater is more prominent in non-canal command areas of Punjab, where surface water supplies are very low and the only source for agriculture was groundwater. Latif and Ahmad (2009) observed that the areas having deeper groundwater depths generally were existed in tail reaches of the canal system. This increasing depth of groundwater in non-canal command areas was caused considerably decrease in the net income of farmers from head to tail direction. The fluctuation in water table was due to increase in cropping intensity and population area is becoming under cultivation to fulfill the requirements of food and fiber. The numbers of tube wells were also increasing with the passage of time, which is threat to groundwater. Through farmers interviews it was found that 70 to 80% of crop water requirement in the study

Table 1. Change in percent area of groundwater levels.

| Zones   | Area (%) | Area (km^2) | Area (%) | Area (km^2) | Area (%) | Area (km^2) |
|---------|----------|-------------|----------|-------------|----------|-------------|
| Shallow | 3.858*10^3 | 9.658*10^2 | 3.265*10^3 | 8.173*10^2 | 2.295*10^1 | 5.743*10^2 |
| Moderate| 5.232*10^3 | 1.310*10^3 | 5.110*10^3 | 1.279*10^3 | 5.919*10^1 | 1.481*10^3 |
| Deep   | 9.100*10^3 | 2.277*10^2 | 1.625*10^3 | 4.067*10^2 | 1.787*10^1 | 4.472*10^2 |
area is being fulfilled by groundwater which was due to limited canal water supply. In the study area, rice crop was grown and to meet high demand of water for rice, groundwater was utilized and it was also found that a sufficient quantity of groundwater was wasted due to land division from forefather to their generation.

**Energy nexus:** Cost analysis shows the increasing trend of operational and constructional cost with the increasing trend of no. of tubewells to abstract the more deep water. It was found that material and labor costs are major factors in cost calculation. The operational cost increased linearly as the groundwater depth increased. As the groundwater depth increased from 25 m, pump capacity also increased. Therefore, the constructional cost rapidly increased after 25 m groundwater depth. The increasing trend of total cost has same trend as in constructional cost (Fig. 6).

![Figure 6. Impact of groundwater level on tubewell cost.](image)

**Conclusions:** It was observed that the spatial and temporal fluctuations in groundwater depth in the study area. Groundwater level was shallow near the canals and rivers and deep in the areas which were away from the water bodies. Groundwater level gradually decreased from north-east to west-south boundary. The deep groundwater level area was increased 8.77% and shallow groundwater level area decreased 15.63% from 2003 to 2013. The 90% of farmers consider that the groundwater level decreased due to over pumping. The farmers mostly used groundwater because of shortage of canal water and almost 70 to 80% irrigation is from groundwater resources. It was also found that declining of water table increased the constructional and operational cost. The operational and constructional cost of tubewells below 36 meters depth become 2.65 and 4 times, respectively as compared to that area where water table is shallow (9 meters). It was recommended that regulatory infrastructure and groundwater management should be assured for balancing the utility of groundwater and the pumping rate of groundwater should be controlled.

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**REFERENCES**

Ahmad, A., H. Iftikhar and G.M. Chaudhry. 2007. Water resources and conservation strategy of Pakistan. Pakistan Institute of Development Economics, Islamabad. 46: 997–1009.

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.

Ashfaq, M., G. Griffith and I. Hussain. 2009. Economics of Water Resources in Pakistan: Water and poverty. Pak. TM Printers, Pakistan.

Batelaan, O and F.D. Smedt. 2007. GIS based recharge estimation by coupling surface- subsurface water balances. J. Hydrology 337:337-355.

Buchanan, S. and J. Triantafilis. 2009. Mapping water table depth using geophysical and environmental variables. Groundwater 47:80-96.

Chandio, N.H. 2009. Fluctuation of ground water, its causes and impacts on soil and agriculture in Kamber, Sindh, Pakistan. Sindh Univ. Res. J. (Sci. Ser.). 41:47-54.

Chatha, Z.A., M. Arshad, A. Bakhah and A. Shakoor. 2015. Statistical analysis for lining the watercourses. J. Agric. Res. 53:109-118.

Choudhary, M.R. 2008, Irrigation and Drainage practices for Agriculture, 8th Ed. Study Aid Foundation for Excellence (SAFE), city and country????

Erhan, S., A. Davraz and M. Ozcelik. 2005. An integration of GIS and remote sensing in groundwater investigation: A case study in Burdur, Turkey. Hydrogeology J. 13:826-834.

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.

Jiazhong, P., S. Jianhua., F. Qi and C. Zongqiang. 2011. The spatial heterogeneity of groundwater level depth in Ejina oasis based on Geostatistics. J. Arid Land Resour. Environ. 04:17-pages???

Karatas, B.S., G. Camoglu and K. Olgen. 2013. Spatio-temporal trend analysis of the depth and salinity of the groundwater, using geostatistics integrated with GIS, of the Menemen irrigation system, Western Turkey. Ekoloji 22:36-47.
Ground water irrigation

Khalid, M., A.D. Rana., S. Tariq., S. Kanwal., R. Ali., A.H. Ali and T. Tahseen. 2013. Groundwater levels susceptibility to degradation in Lahore Metropolitan: Sci. Int. (Lahore) 25:123-126.

Latif, M. and M.Z. Ahmad. 2009. Groundwater and soil salinity variations in a canal command area in Pakistan. J. Irrig. Drain. 58:456-468.

Malik, S.M. and P. Strosser. 1993. Management of private tubewells in a conjunctive use environment: a case study in the Mananwala Distributary Command Area, Punjab, Pakistan. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI). vii, 38p. (IIMI Working Paper 027) doi: http://dx.doi.org/10.3910/2009.133.

PES. 2009. Pakistan Economic Survey. 2008-09. Agriculture. Federal Bureau of Statistics, Statistics Division, Ministry of Economic Affairs and Statistics, Govt. of Pakistan, Islamabad, Pakistan 107:171-172.

Qureshi, A.S., T. Shah and M. Akhtar. 2003. The groundwater economy of Pakistan. Working Paper 64. Lahore, Pakistan country series No. 19: International Water Management Institute.

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

Raghunath, H.M. 2007, Ground Water, 3rd Ed. New Age International Publishers. City, country

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

Shakoor, A., M. Arshad., R. Ahmad., Z.M. Khan., U. Qamar., H.U. Farid., M. Sultan and F. Ahmad. 2018. Development of groundwater flow model (MODFLOW) to simulate the escalating groundwater pumping in the Punjab, Pakistan. Pak. J. Agri. Sci. 55:635-644.

Shakoor, A., M. Arshad, A. Bakhsh and R. Ahmad. 2015. GIS based assessment and delineation of groundwater quality zones and its impact on agricultural productivity. Pak. J. Agri. Sci. 52:837-843.

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.

Khair, S.M., R.J. Culas and M. Hafeez. 2010. The causes of groundwater decline in upland Balochistan region of Pakistan: Implication for water management policies. Paper presented at the 39th Australian Conference of Economists (ACE 2010) Sydney, Australia 27-29 September 2010.

Tariq, M. 2009. Pre-investigation study district Hafizabad, directorate of industries, Punjab, Lahore, Pakistan.