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Short Communication

Suitability Analysis of Groundwater for Eco-friendly Agricultural Growths in Food Basket of Pakistan

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Introduction

Water is an important component of earth's atmosphere and it sustains ecosystems, agriculture and human settlements on earth (Samson et al., 2010). Salinity, sodicity and toxicity generally need to be considered for the evaluation of suitable quality of groundwater for irrigation (Khan et al., 2014; Cobbina et al., 2012; Todd and Mays, 2005). In Thal Doab Aquifer (TDA) groundwater occurs as a layer of fresh water over saline water and its availability is subjected to recharging potency of the Indus and Chenab rivers (Hussain et al., 2017 a, 2016 a). TDA is considered as a food basket of the country due to its major contribution in food production and resultant food security. The potability of groundwater reserves in the area is at stake due to extensive agricultural interventions and higher water abstraction rates. Irrigation practices with deteriorated water in Punjab province are the prime factor causing severe environmental degradation. Rapid and unplanned agricultural landuse change along with intense groundwater abstraction is adding environmental and ecological burdens including secondary salinity. Haphazard installation of tubewells is moderately fit and unfit groundwater zones are resulting in salinity problems (Hussain et al., 2017b). Use of saline water for irrigation triggers secondary salinity, evaporation and percolation in the area. The deposition of salt enriched water is changing the soil profile of the area by reducing its permeability. Long term exposure of land to the secondary salinity (irrigated with saline water) is ultimately resulting in irreversible soil degradation, crop damages and environment deterioration (Hadas and Frenkel, 1982). The problem of secondary salinity instigates disruption of soil fertility by reducing its permeability and porosity and ultimately turns it into totally barren one (Aslam et al., 2015), reduces food productions (Azpurua and Ramos, 2010) and disturbs food chain and ecosystem.

From hydrological perspective, SCARP-3 in 1986 is one of various hydro-climatological studies carried out in Thal Doab over a period of time. Greenman et al., (1968) did an extensive hydrogeological study in Punjab under USGS support. Akram et al., (2014) has divided the TDA into three recharging sources as rain, river and mixed recharge zones based on the isotropic concentration of O^{18}. Thal Doab Aquifer is recharged by both vertical and lateral flows. The Indus River is the main source of aquifer recharge. This fact has been confirmed by Akram et al., (2014) by using O^{18} isotopic study. The shallow groundwater is present near recharge sources like the Indus River and main canals. Hussain et al. (2017b) predicted that about 52% of entire Thal Doab has shallow water table at a depth of 6m. Results of such studies are quite supportive in recharge estimation of entire TDA and were used by Hussain et al., (2017a) to calculate recharge layer as one the seven DRASTIC hydrogeological layers for the vulnerability assessment of TDA. It was observed that intrinsic vulnerability of ground water to the surface contaminants is directly related to agricultural interventions. Another study on smaller portion of TDA was carried out by developing a source-pathway-receptor model under scarce data availability scenario (Hussain et al., 2017c). This study has also vulnerability with the Indus River.

In climate change impact modelling the correct estimation of rainfall is very crucial. From meteorological perspective, a GIS based drought index has been developed by Shaheen and Baig (2011) in the central drought affected areas of Thal Doab. Finally drought severity maps were generated by integrating the meteorological and agricultural drought severity maps, indicating the areas facing combined hazard condition. A comparative analysis of six Satellite Rainfall Estimates (SREs) products over Pakistan revealed high detectability of TMPA in TDA and other arid regions of Pakistan (Hussain et al., 2017d). Aslam et al., (2017) had applied a bottom up approach to simulate the effects of climate change extreme events on the economics of southern Punjab. Monthly mean precipitation under A2 scenario ranges from 12 to 15 mm and for A1B scenario it ranged from 15 to 19 mm. Frequency modelling of floods and droughts via Poisson distribution showed increased trends in recent decades posing serious threat on agriculture and livestock, food security, water resources, public health and economic status of the area.

Water quality of TDA is depleting in the area. Neckson et al., (2005) found high concentration of arsenic in the groundwater of Muzafarghar higher than World Health Organiszation (WHO) limits of 10 ppb. An interpolation of arsenic concentration was found related to recharge from the Indus River and with reported public health issues at local levels (Hussain et al., 2016b). The modeled vulnerability of groundwater to the surfacial contaminants has indicated high recharge with intensive agricultural interventions and high vulnerability (Hussain et al. 2016a, 2017a). From statistical analysis of tubewells installed in previous years, it was observed that number has increased fastly. The growths of such tube wells are unchecked, which also lead to installation of these wells in marginally fit quality groundwater. Hussain et al. (2017b) had used electrical resistivity sounding data to resolve implication for balanced and eco-friendly agriculture growths through the marked optimized groundwater quality for tube wells in Tehcil Kot Adhu, located in Thal Doab.

TDA has been divided in Upper Thal Doab consisting of four districts Bhakar, Layyah, Jhang and Muzaffurgarh. While Khushab and Mianwali are districts falling in command area of Lower Thal Doab. TDA is a hydrologically active area and the groundwater reservoir is composed of thick alluvium where replenishment is based on surrounding rivers and their tributaries and precipitation over it. Predominately coarse soil areas like Thal, Cholistan, Thar and barren areas of Balochistan are being cultivated to maintain food security of the region. Development of extensive irrigation system in TDA is in progress to meet food demand of growing population (Shakoor et al., 2012). TDA has been categorized as Mungbean-Wheat zone with total output growth of 3.47 acres per annum higher than other zones including cotton-wheat, rice-wheat and mixed zones of the province. The average farm size varies from 12.6 acres in Layyah to 18.4 acres in Bhakar. Apparently cropping intensity is relatively low showing inverse relationship between farm sizes and cropping intensity. Muzaffargarh and Khushab are districts with 49.9% and 48.3% food insecure population, while Layyah (37.4%), Jhang (38.7%), Bhakar (40.8) and Mianwali (44%) are also turning into food insecure districts. There are about 61.2% of Muzaffurgarh, 61% of Mianwali, 50.9% of Layyah, 68.2% of Bhakr, 51% of Jhang and 74.7% of Khushab katcha houses which reveals that TDA is economically deprived area (SDPI, 2009). Monthly income of households in the TDA is less than 1.25 USD making the situation worst (MoF, 2015).

The present study is focused on the management of secondary salinity problem through development of different groundwater quality zones via respective suitabilities for balanced agricultural growth in the three districts of Thal Doab (Layyah, Jhang and Muzafargarh). Managing secondary salinity using this approach is practical, economically feasible and socially viable choice for developing economies like Pakistan. In addition ArcGIS 10.1 provides various algorithms which are very supportive for hydrological studies like Inverse Distance Weighting (IDW), Spline, Trend Surface Analysis and Kriging. In this study automatic cartographic processing is done by IDW algorithm for the liner interpolation of the sampling points.

Geology of the Study Area

The study area lies in Thal Doab, a fertile part of land between Indus and Chenab. Three districts of Thal Doab (Layyah, Jhang and Muzafargarh) and their geographical location is presented in Fig. 1. The region is semi-arid, where rainfall is less than evapotranspiration. Mean annual rainfall is 195 mm with the dominance of summer monsoon (July, August), average mean annual temperature is 24^oC with average minimum of 17^oC and average maximum 32^oC. The night time relative humidity is 73% whereas the day time humidity is 41% (Hussain, 2014). There are two cropping seasons Rabi (October-December) and Kharif (March-April). Irrigation in the study area is done mainly by canal water combined with tubewells installed in upper zone of aquifer (about 50 meters in depth). The contribution of groundwater through pumping in total irrigation varies seasonally.

The greater Punjab Plain is a part of the Indo-Gangetic Plain and is drained by the Indus River and its tributaries (Jehlum, Chenab, Ravi and Sutlej). The plain is divided into four water flow systems as doabs (land between two rivers): Bari, Rachana, Chaj and Thal. All these doabs share similar hydrogeological characteristics with very little variations at a regional scale. The study area consists of alluvium deposits of Quaternary age, over thick basement rocks of unknown depth (Hussain, 2014). Geological characteristics of Thal Doab can be described by its physiograghic units (Khan et al., 2014). Physiograghic units of Thal Doab are active and abandoned flood plains and sand dunes. This classification is based on their relative distances from current positions of rivers, especially from the Indus River (Khan et al., 2014). The alluvium deposits

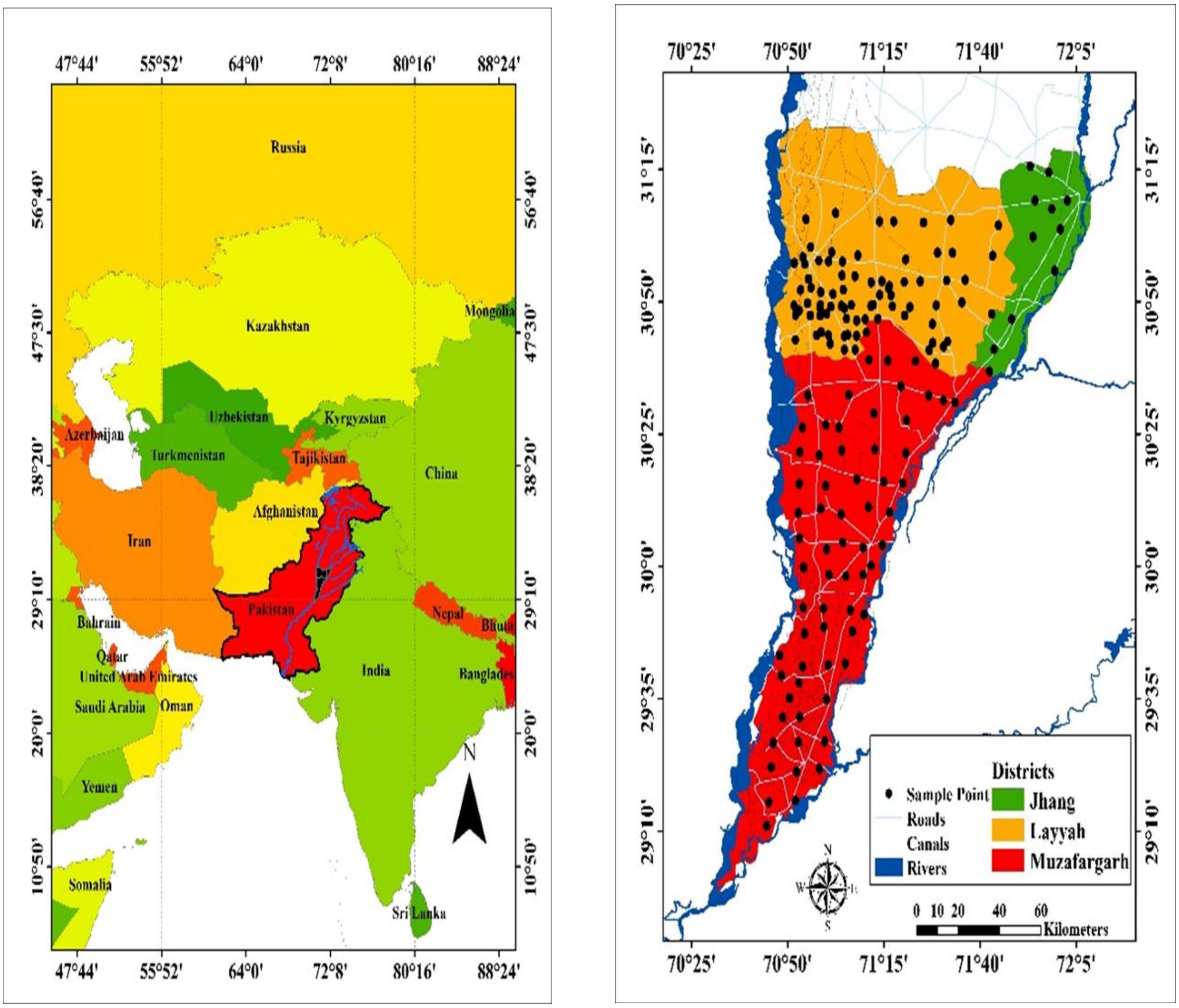

Fig. 1 Regional location of the study area on world map (left), administrative boundary of the study area including, roads, rivers and sampled wells locations (right).

consist of an inter-mixer of sand, slit, clay and gravels with major proportion of sand. There are two important geographic boundaries of Thal Doab, Salt Range at the northern side and *Koh-e-Sulaiman* ranges at western side. In northern part of the area there are piedmont fan deposits that are being eroded and redeposited by the action of seasonal streams generated at the foothills of Salt Range (Hussain et al., 2017a).

Methods and Materials

Groundwater quality was assessed by Pakistan Council of Research in Water Resources (PCRWR) through a campaign in entire Thal Doab from June 2003 to June 2008 to check the availability of fresh groundwater quality in these areas. Water samples were collected from the tube wells and hand pumps at the depth of water table (upper 50m) near the site of electrical resistivity survey probe. Further details of this survey can be accessed at www.pcrwr.gov.pk. The EC taken from groundwater samples are interpolated and then classified according to Water and Power Development Authority (WAPDA, 1981) water quality standards, using statistical approaches like Inverse Distance Weighting and Quartile Classification algorithms of ESRI ArcGIS 10.1 software.

Arranged PCRWR data are imported in ArcGIS 10.1 and assigned X, Y values to create a point shape file for all the sampled points. All the points were projected to UTM (Universal Transverse Mercator) at 42 North Zone with WGS 1984 datum using projection and transformation tool of ArcGIS 10.1 software. Results are interpolated using IDW technique. It works on the principle that value at unmeasured point can be predicted from neighboring measured points by assigning a weight factor, which varies inversely with the distance from measured point. The formula of application of IDW is similar like other interpolation techniques, the only difference lies in computing weight (Childs, 2003).

Results and Discussion

The results show that availability of fresh groundwater is a function of canal density and relative distances from the Indus River. As the study area has good hydrogeological characteristics, so canal and river water can easily percolate into saturated zone and can be pumped easily. The contribution of rainfall in groundwater recharge is very low, that's why the areas having low canal density have poor groundwater quality (Fig. 2). However there are small packets of hazardous water quality although there are very close to recharging agents. The possible cause of these anomalous zones may be because of recharge-extraction imbalance i.e. in these particular areas groundwater pumpage is more than recharge. Another possible cause is the presence of clay lenses that form a perched aquifer system, which hinders the recharge of fresh water.

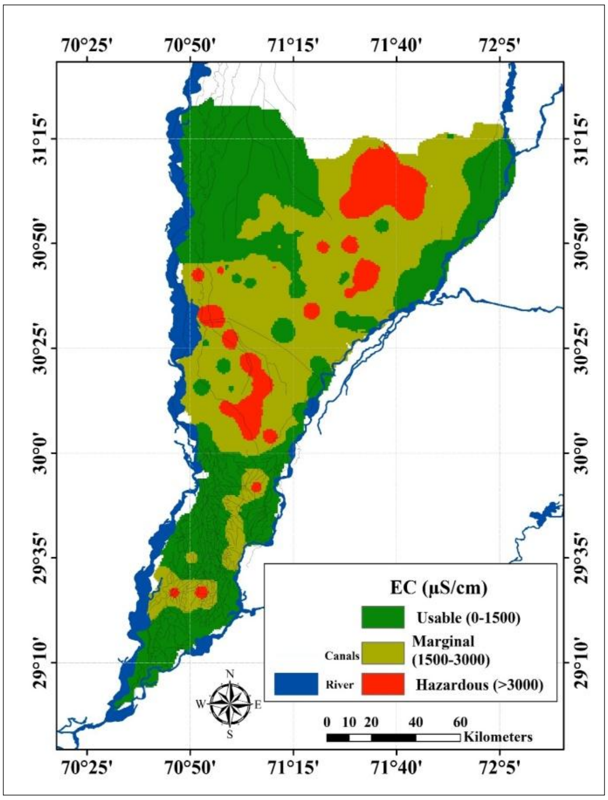

Fig. 2 Groundwater quality zonation based on EC ranges in accordance with WAPDA (1981) water quality standards for irrigation.

Major portion of projected area (34%) is under marginal fit groundwater zone showing alarming situation because majority of tube wells, which are prime source of secondary salinity belong to this zone. The possible reasons of poor water quality in these regions may be the disturbance in input-output groundwater equilibrium. Due to inadequacy in surface water availability more groundwater is being pumped than recharge. About 29.4% sampling wells fall in marginally fit groundwater where as 47% sample wells are fit for drinking. This zone needs to be properly managed for sustainable water abstraction and environmental conditions of the region. Small portion of the area under unfit for irrigation category with EC (> 3000 µS/cm) range is not a big problem, because usually there is no rapid tube wells installations in these regions. The upper north western part of district Layyah and lower parts (Tehsil Alipur) of district Muzafargarh have fresh groundwater reservoir. The electrical conductivity less than 1500 µS/cm, due to high canal density, shows great contribution in groundwater recharge (Fig. 2). Active flood plains of both rivers (Indus and Chenab) have fresh groundwater except central portion of the area which is because of groundwater over draft as described above. The overall water quality of lower parts of District Muzafargarh is fit for irrigation. A study conducted by (Hussain et al. 2016 b) reveals that active flood plain of the Indus River and its canal system is the major cause of groundwater contamination of district Layyah with arsenic (As). These two contaminants share a common transport agent (Indus River). But results of the present study show that areas near the Indus River have fresh groundwater in terms of EC.

Conclusion

This paper presents spatial interpolation of electrical conductivity (EC) taken from 160 groundwater samples in districts Layyah, Muzafargarh and some parts of district Jhang. Zonation of the study area is based on Water and Power Development Authority (WAPDA) guidelines (1981), into three groundwater salinity suitability zones as fit for irrigation with EC (0-1500µS/cm), moderately fit (1500-3000µS/cm) and unfit (>3000µS/cm) for irrigation.

Results show that the most parts of the study area near the Indus River and its canal system have good groundwater quality, because of lateral recharge and seepage. The central part of area has notions of significance (marginal fit and unfit for irrigation groundwater quality) because of disruption in groundwater equilibrium through extensive groundwater abstraction. Environmental problems particularly, secondary salinity requires special attention from policy makers through proper land use planning and sustainable water abstraction and agricultural interventions.

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References

Akram, W, Latif, Z, Iqbal, N, Tasneem, M. A. (2014). Isotopic investigation of groundwater recharges mechanism in Thal Doab. *Nucleus* **2** (2), 187–197.

Aslam, A. Q., Ahmad, S. R., Ahmad, I., Hussain, Y., Hussain, M. S. (2017). Vulnerability and impact assessment of extreme climatic event: A case study of southern Punjab, Pakistan. *Sci. Total Environ.*, **580**, 468-481.

Aslam, K., Rashid, S., Saleem, R., Aslam, R. M. S. (2015). Use of geospatial technology for assessment of waterlogging and salinity conditions in the Nara canal command area in Sindh, Pakistan. *J. Geogr. Inform Sys*., **7**(4), 438-447.

Azpurua, M., Ramos, K. (2010). A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude. *Prog. Electromagn. Res*., **14**, 135-145.

Childs, C. (2004). Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July-September, 32-35.

Cobbina, S. J, Nyame, F. K, Obiri, S. (2012). Groundwater quality in the Sahelian region of Northern Ghana, West Africa. *Res. J. Environ. Earth. Sci.,* **4**(4), 482–491.

Greenman, D. W., Swarzenski, W. V., Bennett, G. D. (1967). Groundwater hydrology of the Punjab, West Pakistan with emphasis on problems caused by canal irrigation. *US Geological Survey Water-Supply Paper*

Hadas, A. H., Frenkel, H. (1982). Infiltration as affected by long-term use of sodic-saline water for irrigation. *Soil Sci. Soc. Am. J.,* **46**(3), 524-530.

Hussain, Y., Ullah, S. F., Aslam, A. Q., Hussain, M.B. Akhter, G., Martinez-Carvajal, H.E., Satgé, F., Ashraf,A., Iqbal, B., Cárdenas-Soto, M. (2017c). Vulnerability assessment of an agro-stressed aquifer using a source-pathway-receptor model in GIS. *Model. Earth. Syst. Environ*., **3** (2), 595-604.

Hussain, Y. (2014). Hydrogeophysical investigations and GIS vulnerability mapping of Kot Adhu, M. Phil. Thesis, Quaid-i-Azam University, Islamabad, Pakistan.

Hussain, Y., Dilawar, A., Ullah, S. F., Akhter, G., Carvajal, H. M., Hussain, M. B., Aslam, A. Q. (2016b). Modelling the spatial distribution of arsenic in water and its correlation with public health, central Indus Basin, Pakistan. *J. Geosci. Environ. Protec.,* **4** (2), 18-25.

Hussain, Y., Satge, F., Hussain, M. B., Martinez-Carvajal, H., Bonnet, M. P., Cárdenas-Soto, M., Roig, H. L., Akhter, G. (2017d). Performance of CMORPH, TMPA and PERSIANN rainfall datasets over plain, mountainous and glacial regions of Pakistan. *Theor.. Appl. Climt*., (in press). doi:10.1007/s00704-016-2027-z..

Hussain, Y., Ullah, S. F., Akhter, G., Aslam, A. Q. (2017b). Groundwater quality evaluation by electrical resistivity method for optimized tubewell site selection in an ago-stressed Thal Doab Aquifer in Pakistan. *Model. Earth. Syst. Environ*., **3** (1), 15-23.

Hussain, Y., Ullah, S. F., Dilawar, A., Akhter, G., Martinez-Carvajal, H., Roig, H. L. (2016b). Assessment of the pollution potential of an aquifer from surface contaminants in a geographic information system: a case study of Pakistan. Geo Chicago 2016. Sustain. Resil. Geotech. Eng. doi:10.1061/9780784480120.063

Hussain, Y., Ullah, S. F., Hussain, M. B., Aslam, A. Q., Akhter, G., Martinez-Carvajal, H., Cárdenas-Soto, M. (2017a). Modelling the vulnerability of groundwater to contamination in an unconfined alluvial aquifer in Pakistan. *Environ. Earth. Sci*., **76** (2), 1-11.

Khan, A. D., Hagras, M. A., Naveed, I. (2014). Groundwater quality evaluation in Thal Doab of Indus Basin of Pakistan. Int. *J. Mod. Eng. Res*., **4** (1), 36-47.

MoPDR, (2015). Multidimensional Poverty in Pakistan. Ministry of Planning, Development and Reform. Government of Pakistan.

Nickson, R. T., McArthur, J. M., Shrestha, B., Kyaw-Myint, T. O, Lowry, D. (2005). Arsenic and other drinking water quality issues, Muzaffargarh district, *Pak. Appl. Geochem*., **20** (1), 55–68.

Punjab Irrigation and Power Department (PI&P), (1999). Database for groundwater management in Rangpur and Muzaffargarh canal Commands of Thal Doab (SCARP –III Rangpur Unit).

Samson, M., Swaminathan, G., Kumar, N. V. (2010). Assessing groundwater quality for potability using a fuzzy logic and GIS– A case study of Tiruchirappalli city–India. Comput. *Model. New Tech.*, **14** (2), 58-68.

Suleri, A. Q., Haq, S. (2009). In *Food insecurity in Pakistan.* A. Settle, A. Salman & L.d. Franchis (eds.): Swiss Agency for Development and Cooperation, Sustainable Development Policy Institute, World Food Programme Pakistan. 129 pages.

Shaheen, A., Baig, M. A. (2011). Drought severity assessment in arid area of Thal Doab using remote sensing and GIS. Int. *J. Water Resour. Arid Environ.*, **1** (2), 92-101.

Todd, D. K, Mays, L. W. (2005). *Groundwater hydrology*, 3rd Edition. Wiley, New York, 636 pages

Water and Power Development Authority (1981). Atlas – Soil salinity survey of irrigated areas of Indus basin 41 million acres. *Survey and Research Organization. Planning Division, WAPDA, Lahore.*