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GROUND WATER QUALITY ANALYSIS USING GIS: A CASE STUDY OF BARI DOAB, PUNJAB - PAKISTAN

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ABSTRACT

At present, Pakistan is striving hard to uplift its economy with sustainability. Agriculture, being the largest economic support system of the country, also faces numerous challenges due to changes in socio-environmental practices. This research has been performed to evaluate and map the quality of groundwater resource as per United Nations Sustainable Development Goals (UNSDG 6). Water samples of 125 wells were taken from the Punjab irrigation department, for pre and post monsoon 2010 and 2018, respectively. TDS, EC, SAR and RSC were selected as physiochemical parameters for groundwater of Lahore, Kasur and Okara. Data was processed in ArcGIS environment to produce interpolated maps. Regression analysis was performed to determine the degree of impacts by combination of two parameters. In 2010, TDS values were found dispersed after rainfall and slight hazard for salinity was observed. In 2018, TDS values were found high in Kasur. SAR values showed increase after rainfall and severity of RSC shifted from 14 to 17 wells in post-monsoon. Rise in concentration of residual sodium carbonates after rainfall indicates that deposition of minerals amplified with less retention time and undulating slope throughout the region of Bari Doab. It is recommended to restrict the exploitation of groundwater with incorporation of efficient water governance at district levels.

Keywords: Groundwater quality, United Nations Sustainable Development Goals (UNSDG 6), GIS, Salinity, Regression, Physiochemical characteristics.

INTRODUCTION

United Nations Sustainable Development Goals (SDGs) # 6, states that water resource in any region of the world should be contaminant free, sufficiently available for the locales and must not be over-exploited. This goal is aimed to safeguard natural resource and reduce its associated hazards and risks, both, on the environment and on human health (Howard, 2021). According to the monitoring report issued by the UN in 2021, population of 3 billion individuals around the world consume water from different sources (ground, lakes, rivers, tube-wells etc.) of unknown quality (UN-Water, 2020). Water scenario in Pakistan is showing degrading trends with time and population expansion. The country is supporting a population of more than 20 million individuals, residing in haphazard patterns of urbanization. In a report issued in 2018, renewable freshwater resource withdrawal in Pakistan is about 74.4%, whereas human induced depletion of groundwater resource has reached to 1.4 m^3/year/capita (Gul *et al.*, 2018). Accepting the fact that existing freshwater resource in the world is groundwater majorly, increase in its dependency and over-exploitation has greatly affected its quality (Blondes *et al*., 2016).

Agriculture in Pakistan is the most impactful sector of the country. Through agricultural practices, people belonging to lower and lower-middle class are provided with better employment opportunities (62% of the rural population and 44% labors), country generates valuable amount of GDP (21%) and foreign exchange, and food demands of citizens are met (Azam and Shafique, 2017). Irrigation system present in Pakistan is one of the largest systems existing in the world, whereas in terms of groundwater usage, Pakistan stands 2nd in the consumer list, as the annual exploitation rate has reached to 60 billion cubic meter (bm^3) (Qureshi *et al*., 2015). Land distribution patterns state that agriculture has occupied 22 million acres of land under cultivation, while 38 million acres have been remained un-cultivated. From the total area of 79.6 million hectares of cultivated land, only 21.2 million hectares is used and 23.8 million hectares comes under the cropped lands (GOP, 2016; GOP, 2012). Socio-economic and environmental consequences when combined, are imposing deleterious impacts on the agricultural industry. Population expansion has resulted in increasing food insecurity, on the other hand, extreme temperatures, seasonal shift, environmental disasters like floods, droughts, earthquakes and landslides, have become potential issues in diminishing the fruitful outputs of agriculture (GOP, 2015). Indus water irrigation system faces unreliable trends in its flow due to varying rainfall patterns and floods. This has caused farmers to shift towards groundwater. Where only surface water meets the demand of 16 million hectares of agriculture fields, more than 50% of the remaining water requirements are accomplished through groundwater (Qureshi, 2020; Kahlown *et al*., 2007).

The primary purpose of this research was to monitor the quality of groundwater consumed for irrigation. Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were taken as vital parameters. This paper is also aimed to determine the possible relationship between parameters in order to identify the hazards and negative impacts on the agricultural fields. Parameters taken under observation are reported to decrease soil efficiency, hinders crop growth, alter healthy growth of plant structures, which ultimately affects the agricultural outputs (Aboukarima *et al*., 2018). Geographic Information System (GIS) based analysis incorporated in this study, has vitally assisted in portraying accurate concentrations within the entire study area. Its integration has efficiently depicted the changing trends of parameters in the presence of different variables.

Study Area:

Study area of upper Punjab (Bari doab) consists of districts of Lahore, Kasur and Okara (Fig.1). It lies within the coordinates 31.15°—30.81° N and 74.01°—73.45° E on the North-Eastern side of the province. It shares southern boundary with Bahawalpur district, Wagah border to the east, Faisalabad and Sheikupura district to its west. Ravi River flows through North-western part and River Sutlej to the south. 85% of the total area contributes to agriculture with crops of high economic significance (Government of Punjab, 2018; Shirazi and Kazmi, 2020). Climate in this region is recorded to extremes in summers of May, June and July, and in the winter season from December till February. Mean minimum temperature drops to 26°C in summers and 2°C in winters. Due to the presence of medium to high percent of humidity, rainfall patterns vary accordingly. The highest rainfall of more than 160- 200 millimeter (mm) is recorded in the monsoon season of July. However, through the year, minimum 3-4 days of the month are counted as rainy days. The area possess sandy, loamy and clayey soil type (Climate-data, 2018; District profile- Government of Punjab, 2018; GOP, 2012).

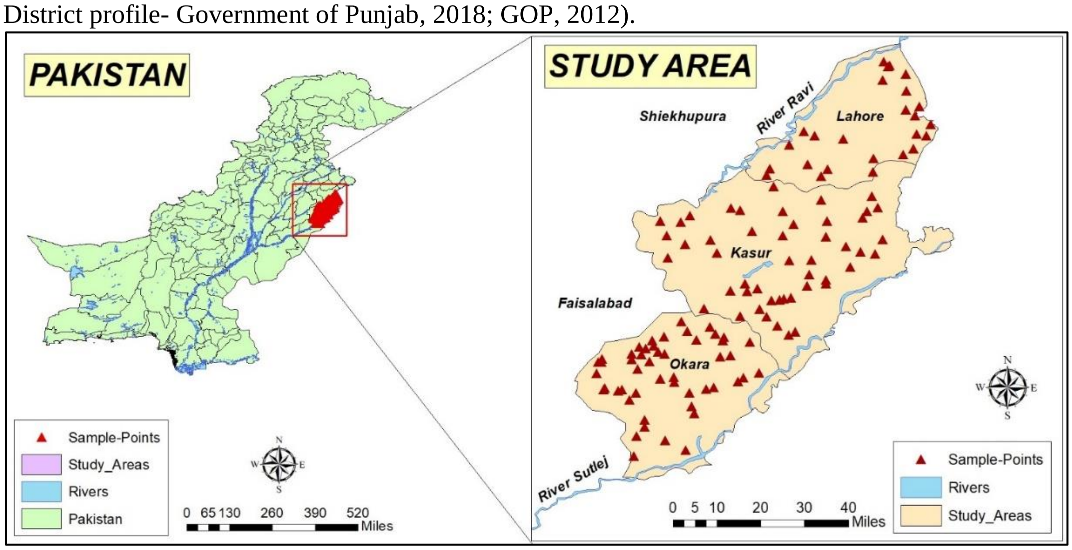


Fig.1. Selected Study Area.

METHODOLOGY

Data Collection and Sorting

Raw Data of irrigation water quality of the wells of study areas were downloaded from the website of Punjab irrigation department. EC, SAR and RSC (pre and post-monsoon) in 2010 and 2018 were selected as groundwater quality parameters. TDS values were derived from EC and added as 4th parameter. Huge data was sorted according to year and season then finally 125 sample sites were used for further processing in ArcGIS environment.

Data Analysis

After sorting, data was imported in ArcGIS environment to incorporate Inverse Distance Weightage (IDW) technique of interpolation. Hence, physiochemical characteristics of groundwater were displayed in the form of isopleth maps. In order to determine the detrimental hazards on the agricultural fields, 122 wells were categorized into different classes of salinity, sodicity and sodium hazards as recommended by the Food and Agriculture Organization (FAO). Furthermore, in accordance with the irrigation water quality index, EC and SAR were categorized together to plot infiltration hazards according to the standard guidelines to check the safety of their use. Statistically, regression analysis was performed for TDS and SAR to determine the possible interdependency relationship and their impacts.

RESULTS AND DISCUSSION

Groundwater available in different sample wells are majorly used for irrigation of various croplands. The selection of water resource for replenishment of agricultural fields depends on the good and standard concentration of its quality parameters. Water which possess optimum amount of minerals and salts is beneficial and necessary requirement for crop's healthy development and soil productivity (Throne and Peterson, 1954). Total dissolved salts and their ionic components are the critical elements on which agricultural output is dependent. These components alter the pore structure and osmotic force of soil which results in reduction of water absorption capacity of crops. Therefore, monitoring of quality by determining the concentration of various salts, sodium ions, carbonates and bicarbonates ions are vital components that are sensitive for water's chemistry (Raza *et al.*, 2017; Hagras, 2013).

Table 1. Hazard Classification of Quality Parameters According to Food and Agriculture Organization (FAO).

HAZARD CLASSIFICATION	**SALINITY**		**SODIUM**	**CARBONATES**
	TDS (ppm)	**EC (dS/m)**	**SAR**	**RSC (me/l)**
None	<500	<0.75	<10	>1.25
Slight	500-1000	0.75-1.5	10-18	1.25-2.5
Moderate/High	1000-2000	1.5-3	18-26	2.5-5
Severe	>2000	>3	>26	>5

EC and TDS are the key elements that help in determining salinity levels in a water body. Water reserves present near coastal regions and extracted from ground possess varying amount of salt concentrations either by saltwater intrusion or by insufficient water recharge from rainfall (El Moujabber *et al*., 2006; Stigter *et al*., 2006). TDS and EC possess direct relationship between each other and are correlated quality parameters. EC can be defined as the measurement of capacity of water body to carry electric charges (Patil *et al*., 2012; Marandi *et al*., 2013; Logeshkumaran *et al*., 2015). Ability of EC is dependent on ionic strength, temperature of various components and concentration of dissolved ions. TDS concentrations constitutes the dissolved ions in a water reserve (Hem, 1985). In groundwater quality analysis, TDS measurements play more crucial role than EC. It is calculated through the following formula (Siosemarde, 2010):

TDS (ppm or mg/L) = k x EC (µs/cm or dS/m)

Where "k" is constant and increase in its value is shown by the increase and decrease of ions in the water. When agricultural fields are irrigated by water with high values of EC and TDS, its possible impacts may brought physiological drought and deformation in crops. This evaluation of risk is measured in terms of "Salinity Hazards" and is very significant to ensure safety of different crops (Eaton, 1950).

SAR is the ratio of sodium with calcium and magnesium ions to predict the risks and hazards of ionic-exchange activity among the soil particles and water molecules. High values of sodium ions in irrigation water can cause soil structure to swell and disperse (Clark and Mason, 2006). Dispersion of soil causes its particles to form grainy structures, resulting in infiltration problems and reduction of soil porosity. In this study, SAR is measured in terms of "Sodium Hazard" to determine the detrimental impacts upon the agricultural fields. Sodium ions are also reported to increase and decrease soil's alkalinity and is evaluated by the following formula (Saleh *et al.*, 1999):

$$\mathbf{SAR= [Na^{+}/\sqrt{Ca^{2++}Mg^{2+}/2}]}$$

(Riaz *et al*., 2018; Raza *et al*., 2017) RSC determines the presence of bicarbonates (HCO_3) and carbonates (CO_3) ions which could react with calcium (Ca^{+}) and magnesium (Mg^{+}) ions and augment the sodium content of soil. When water with high levels of RSC is used for irrigation, it increases the alkalinity of soil and hence, crops face toxicity and wilt or burn. Unit for RSC and SAR is **me/L (milli equivalent per liter)** and estimation of RSC is performed by the following formula:

$$\mathbf{RSC= (CO_3 + HCO_3) – (Ca + Mg)}$$

Electrical Conductivity and Total Dissolved Solids

Maps in Fig.2 shows that EC and TDS levels have slight increase in their values all over the study area. However, the sample wells present at south of Kasur and Okara shows severely high EC and TDS values in 2010, while, in 2018 (Fig.4), only Kasur district is under high levels of salinity. In 2010, EC was recorded as 4.79 near River Sutlej in pre-monsoon which decreased to 4.38 in post-monsoon (Fig.2). Fig.3 shows the varying concentrations of TDS in the study area. The highest value of 3096 ppm is found at a sample well in Kasur district in pre-monsoon 2010. While in the post monsoon, rain has diluted the concentration at the same sample well to 2814 ppm as shown in the Fig.3. Other sample wells show lower and moderate levels of salt concentrations all over the study area. In fig.4, EC has augmented to hazardous level of 5.60 and after rainfall, it has decreased to 4.41 in Kasur district. However, these values are still above the standard limit. Annually, about 45 million ton (Mt) of salts is added to the basin by the river, from which 41.5 Mt salts are found in Punjab. These salts are also a prime reason to be deposited in layers of soil underground and result in severe levels of salinity in groundwater when excessively extracted (Qureshi and Perry, 2021).

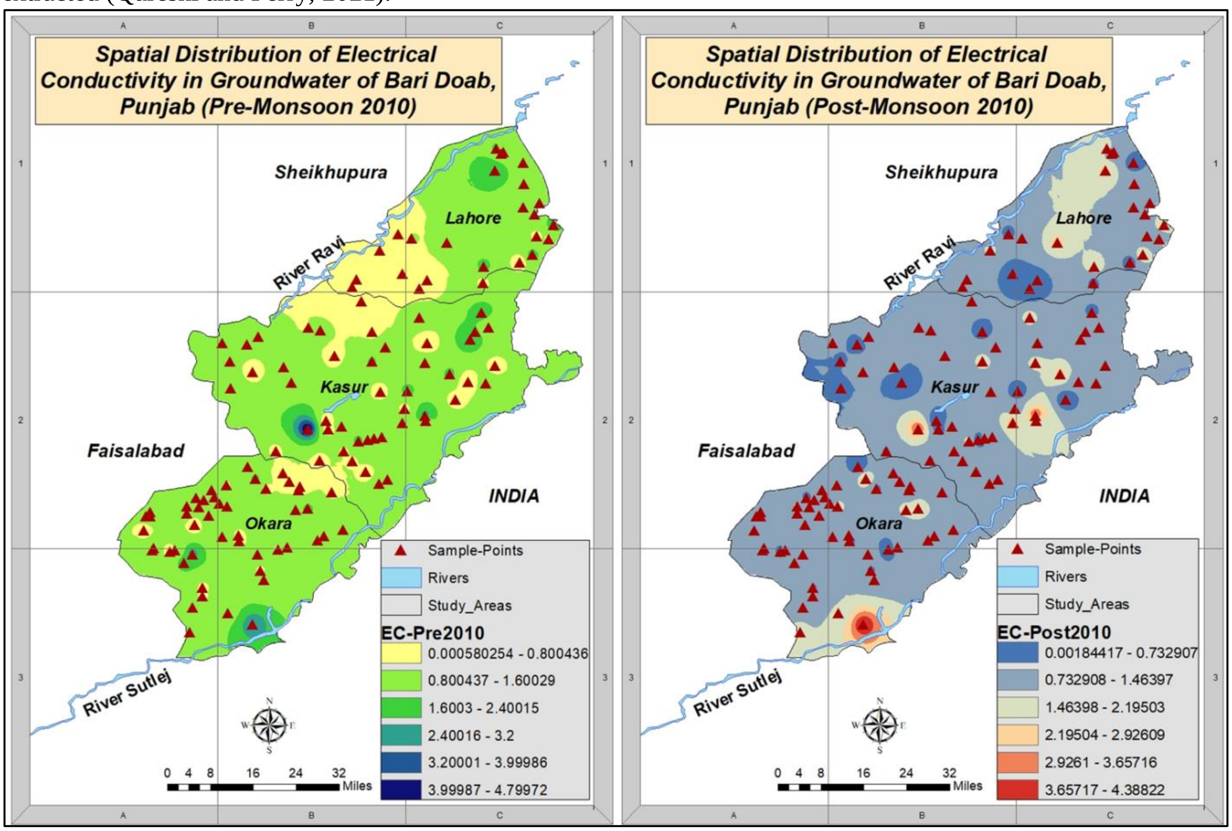


Fig.2. EC Variations in Pre and Post Monsoon 2010.

Salinity Control and Reclamation Project (SCARPs) promulgated in all provinces, is designed to report about soil salinity and percolation of salts due to excess extraction of groundwater for irrigational activities. In a study of Indus Basin management, Bari Doab irrigation zone, present between Ravi and Sutlej rivers, shows that its groundwater quality is fresh to marginal levels. Therefore, in order to maintain sustainable usage, its monitoring is beneficial under this project (Qureshi and Sarwar, 2009).

Fig.5 shows the spatial distribution of TDS in pre and post-monsoon of 2018. In comparison with 2010, Kasur district is visibly showing increase in salt deposition in groundwater. 3586 ppm has been recorded in pre-monsoon and 3230 ppm in post-monsoon at the same region. Graphical presentation in fig.6 is the illustration of 4 classes of salinity hazard. In total 125 sampled wells, 2 and 5 have shown severe concentration of salts in pre-monsoon of 2010 and 2018 (Fig.6 (a) and (b)), but in post-monsoon, in 2010, number of wells in severe hazard has increased to 3. However, majority of the wells in both years have shown slight or no salinity hazard and that the results are safe and under standard limitations.

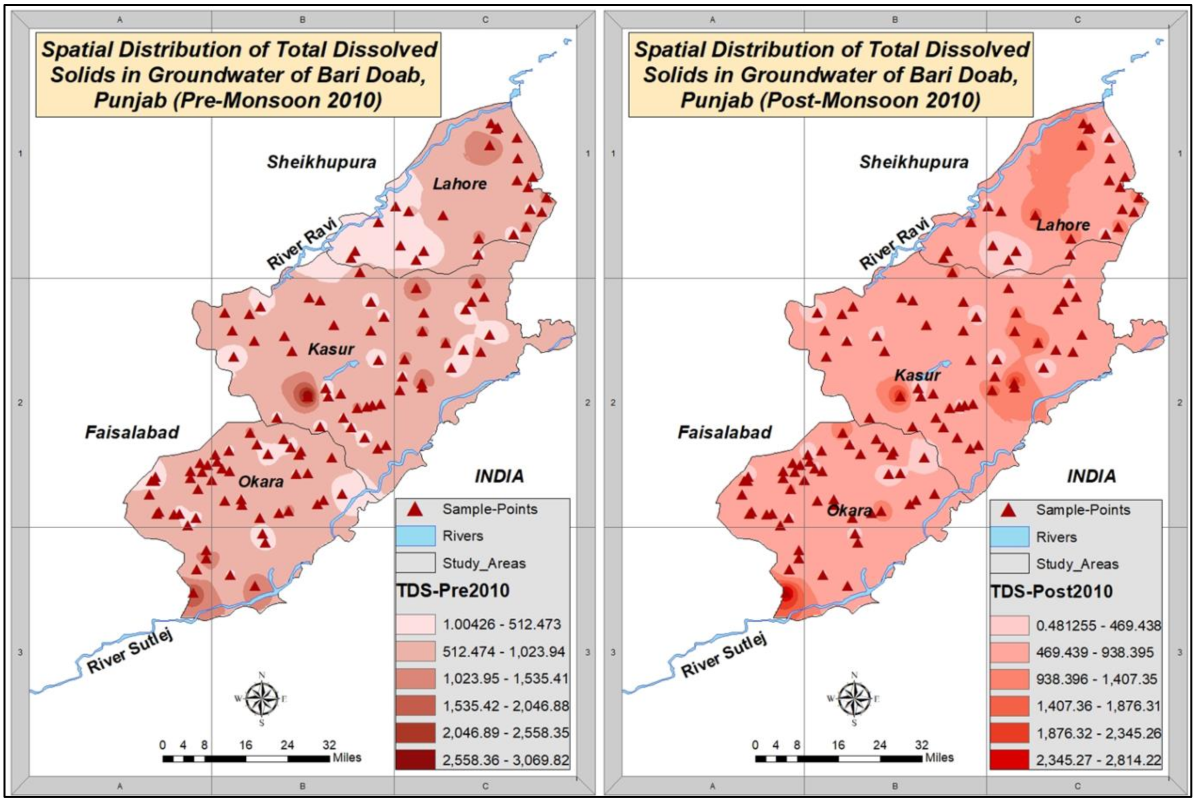


Fig.3. TDS Variations in Pre and Post Monsoon 2010.

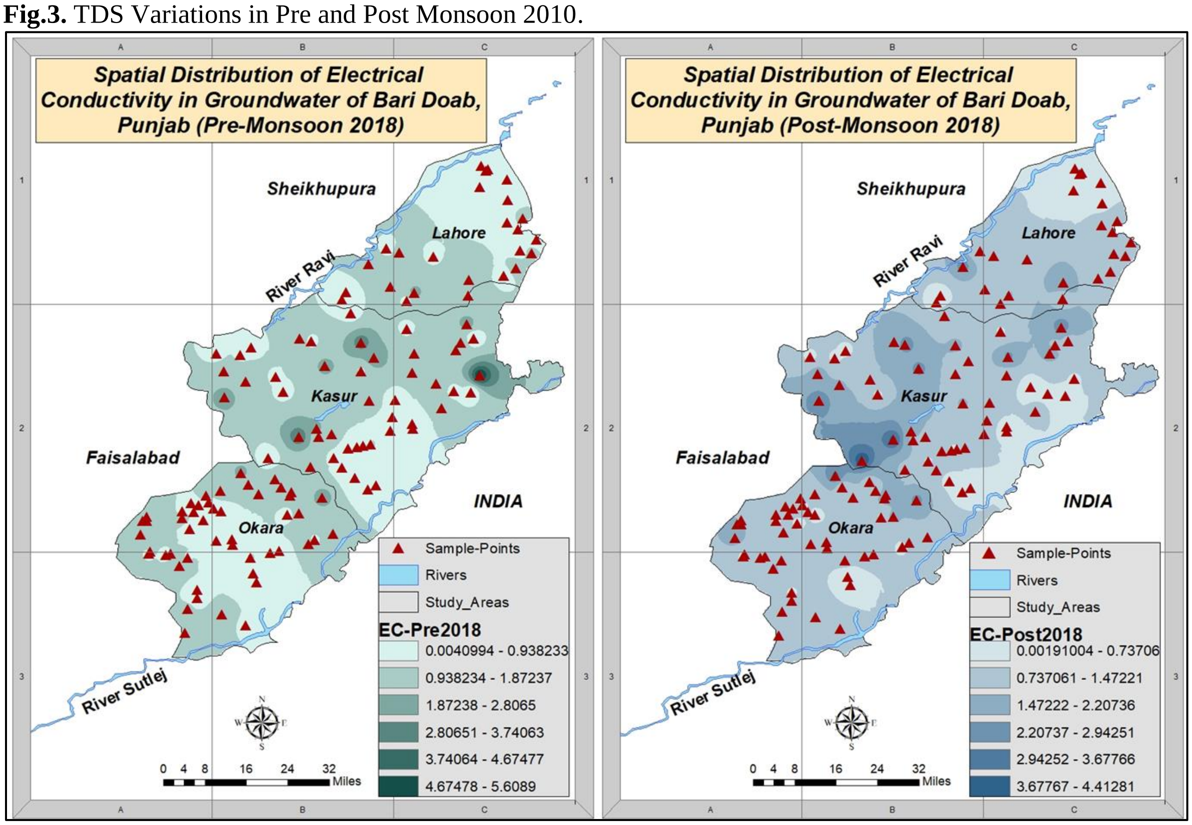


Fig.4. EC Variations in Pre and Post Monsoon 2018.

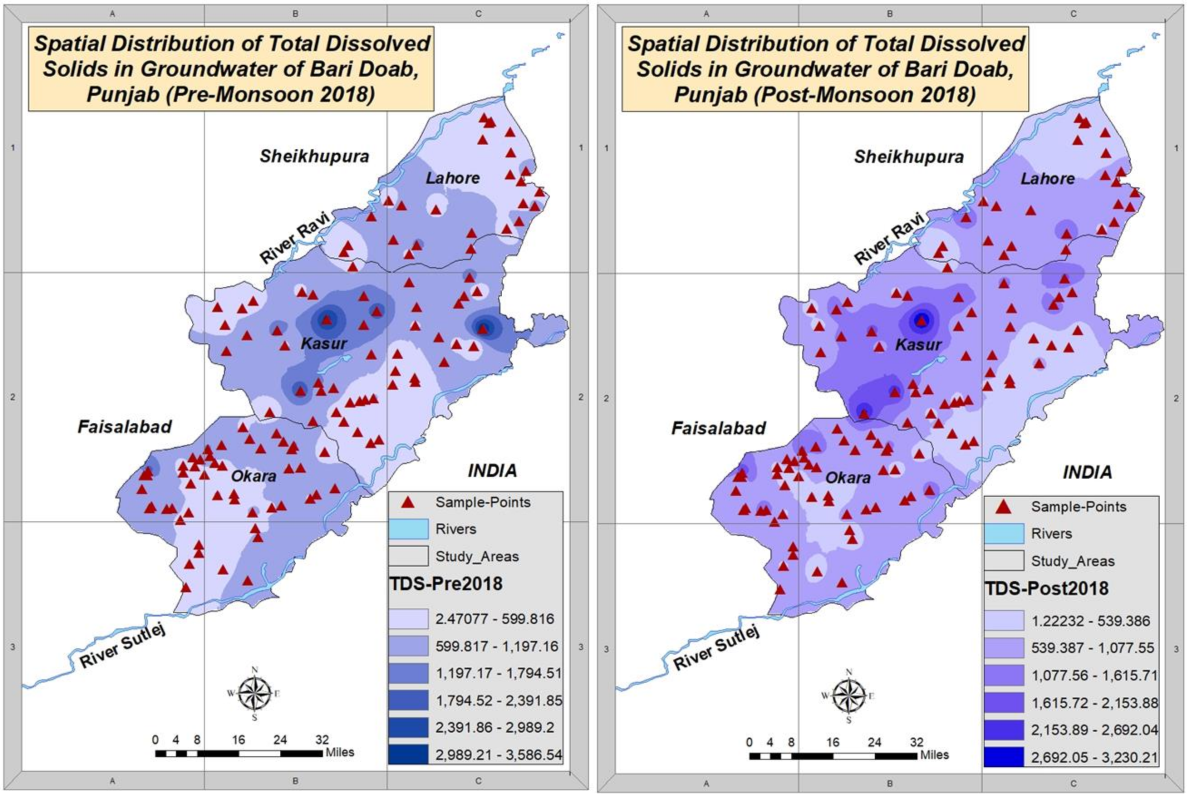


Fig.5. TDS Variations in Pre and Post Monsoon 2018.

(Shafiq *et al*., 2018) evaluated the quality of irrigation groundwater in Thal region of Punjab. 30 samples from total 174 samples were declared unfit for use. Whereas, 25 samples were affirmed to be of poor quality because of accumulative influence of EC, SAR and RSC, whose consumption would make the agricultural fields, infertile.

Sodium Absorption Ratio (SAR):

In pre and post-monsoon 2010, Fig.7 shows that the highest value recorded is above the standard limit recommended. In pre-monsoon, through spatial analysis, 45.89 SAR is observed at a sample well in Kasur district at shown in Fig.7. In post-monsoon of the same year, the concentration ranges is observed in decrease and the severe concentration of 32.97 is observed at the sample well present along River Ravi under the premises of Lahore district. In Fig.8, concentrations of SAR in pre and post-monsoon 2018 have moved under the standard recommended by FAO (Table 1). Moderate concentration of 23.77 and 25.57 in pre and post-monsoon respectively can be observed in Kasur district. In pre-monsoon, the upsurge in concentration was found towards the water body present in Kasur district and towards the northern end of River Sutlej, while in post-monsoon, the increase in concentration has been towards the wells present along the River Ravi at the western side of the study area. Darker shade is evident in the same pattern shown in Fig.8.

Hazard classification in Fig.9 shows that no hazard has been detected in more than 100 wells in the 2 years. In 2010 (Fig.9 (a)), dilution of nutrients after rainfall has increased the number of wells in "none" hazard. While in 2018 (Fig.9 (b)), increase in wells have shifted towards slight, moderate and severe hazard classes. 110 wells have decreased to 101 in none hazard, but 4 wells have shifted to slight hazard (11 to 15), 4 wells in moderate hazard (3 to 7) and 1 well (1 to 2) in severe hazard. Research study by (Riaz *et al*., 2016) reported that SAR in groundwater of Sargodha district of Punjab was in severe concentrations in 42% of the samples. The usage of water for any purpose was declared unfit.

Residual Sodium Carbonate:

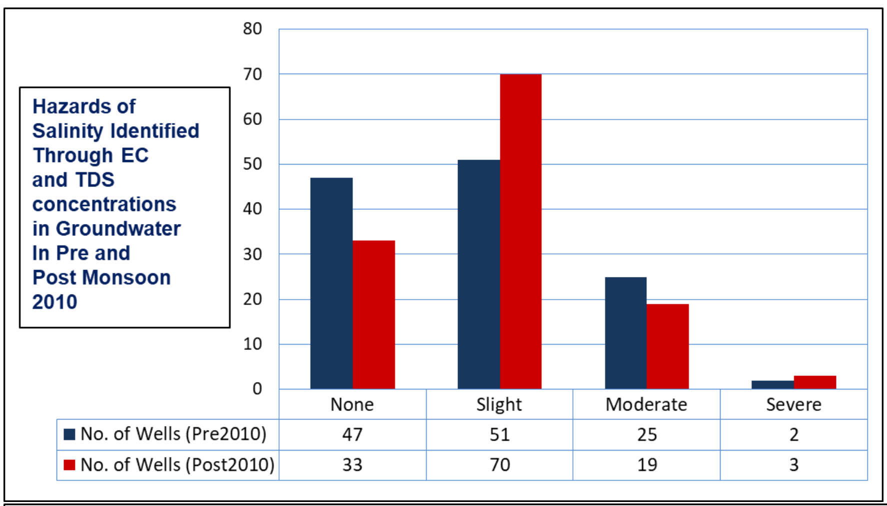
In this present analysis, high concentrations are witnessed more in the year 2018 than in 2010. In 2010, 17.09 me/L was the highest value recorded among 125 wells at Kasur and northern side of Lahore district as shown in Fig.10. Conversely, in 2010 post-monsoon, values in Kasur district has been reduced in concentration but still to severe levels at different wells in Lahore district. Spatial distribution of RSC in Fig.10 shows the concentrations of

RSC to be under severe levels and above the standard of 5 me/L. In 2018 (Fig.11), Values of RSC have shown increase in severity after rainfall, which may be due to the formation of carbonate compounds in the region. Severe concentration of 11.94 me/L at the sample well towards northern boundary of Kasur, has shown minor reduction to 11.15 me/L. Severity in concentration is visible on the southern side of Lahore in Fig.11. Undulating slope and existence of Lahore and Kasur in between two rivers and their basins would also have been one of the potential reasons for severity in values of RSC.

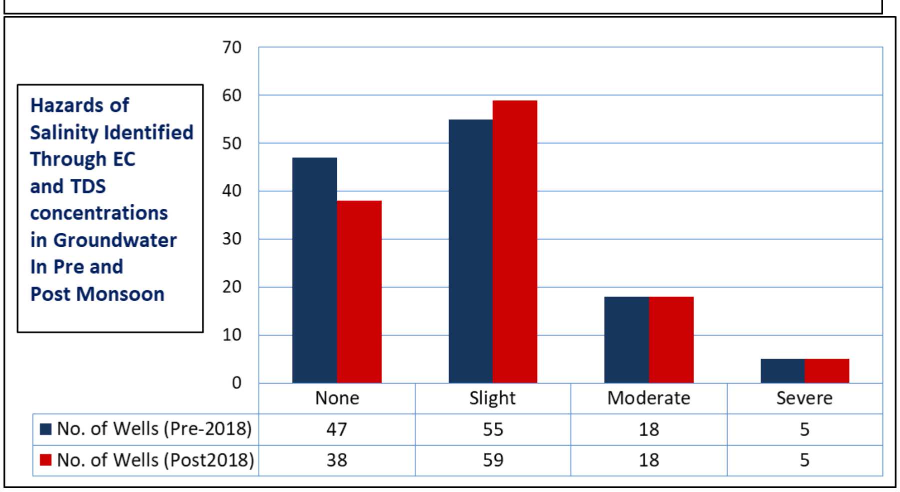
Classification of carbonate hazards is shown in Fig.12. During 2010 (Fig.12 (a)), number of wells showing no hazard had increased, which has decreased the severity of carbonate hazard (23 to 18 wells). In Fig.12 (b), the carbonate hazard has increased in moderate and severe levels after rainfall (14 to 18 wells in moderate and 14 to 17 wells in severe) which can be understood by the spatial distribution shown in Fig.11 and as discussed above.

Regression Modeling:

Regression analysis between TDS and SAR (Fig.13 and 14) was performed to evaluate their relationship that can cause infiltration hazards in the agricultural fields. According to irrigation water quality index, infiltration hazard is also a vital part of it. The regression analysis shows that with the increase in dissolved solids in water, sodium accumulation increases in soil. However, in 2010, the values show dispersion after rainfall, which predicts that flood situation and slope terrain of study areas has deposited more salts and provided less time for groundwater aquifer to recharge and dilute its parameter's concentrations. Regression model has shown 74% positive relationship in pre-monsoon of 2010 Fig.13 (a), whereas after rainfall, it has reduced to 62% as shown in Fig.13 (b). In Fig.13 (a), when TDS value has reached to 3070 ppm, absorption ratio has also reached to 45.9. Hence a positive relation is evident among these two parameters in pre-monsoon 2010. In Fig.13 (b), the concentration of SAR had shifted back from 45 to less than 35 with the corresponding decrease in TDS concentrations in post-monsoon 2010.



(a)



(b)

Fig.6 (a) and (b). Salinity Hazard Classification of Pre and Post-Monsoon 2010 and 2018.

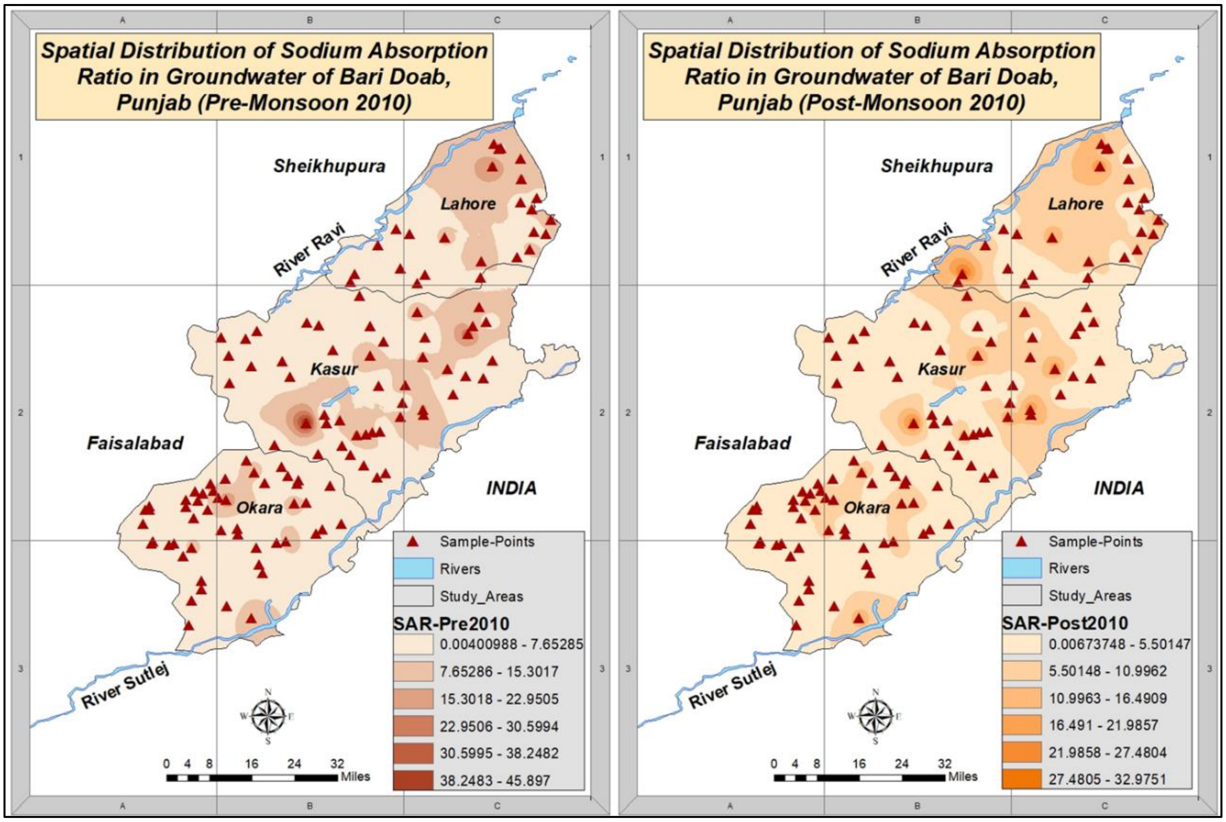


Fig.7. Spatio-temporal Variation of SAR in Pre and Post Monsoon 2010.

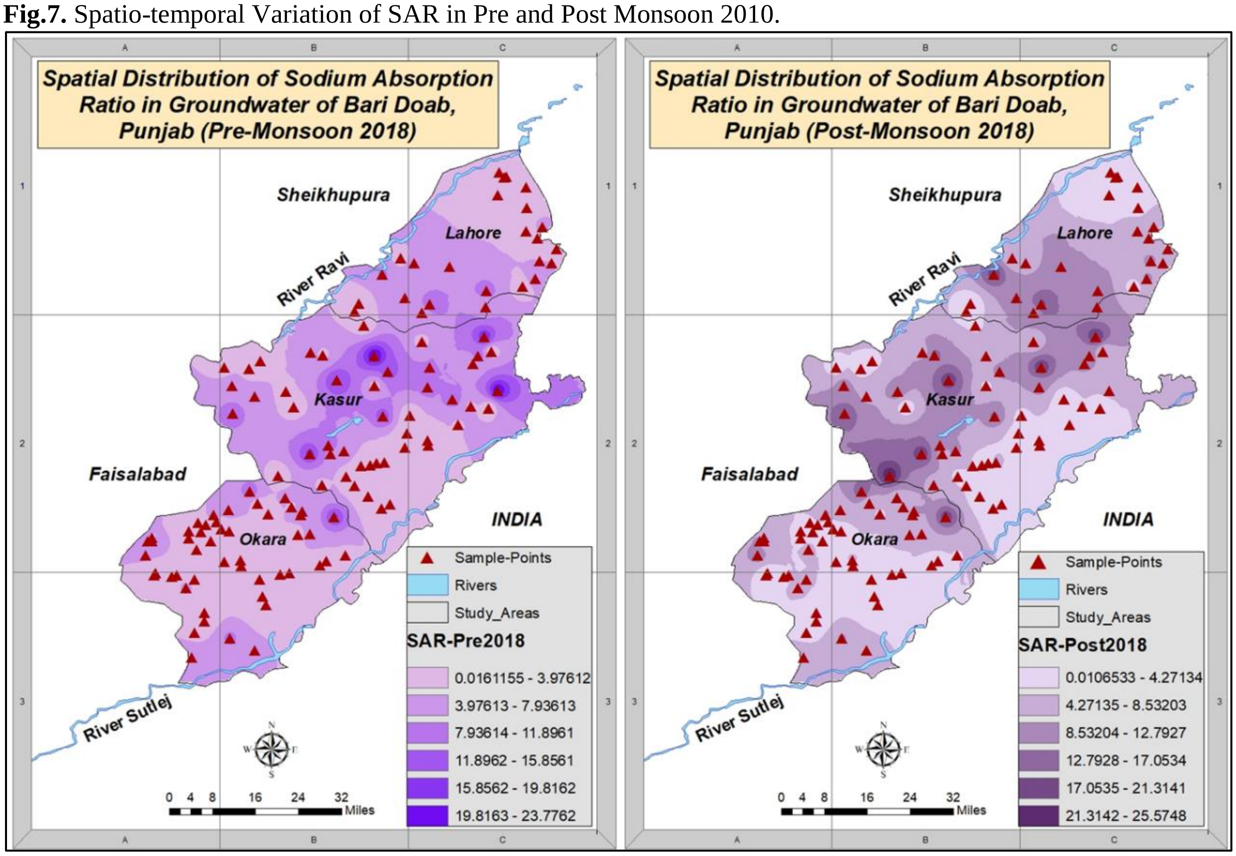
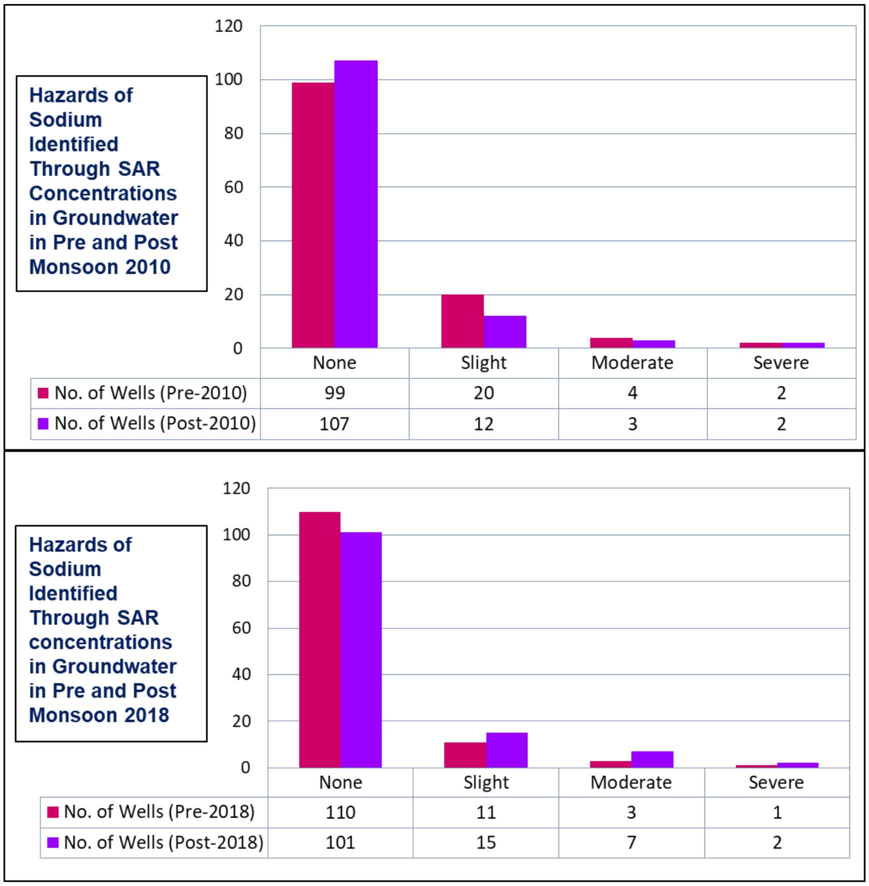


Fig.8. Spatio-temporal Variation of SAR in Pre and Post Monsoon 2018.

(a)



(b)

Fig.9 (a) and (b): Sodium Hazard Classification of Pre and Post-Monsoon 2010 and 2018.

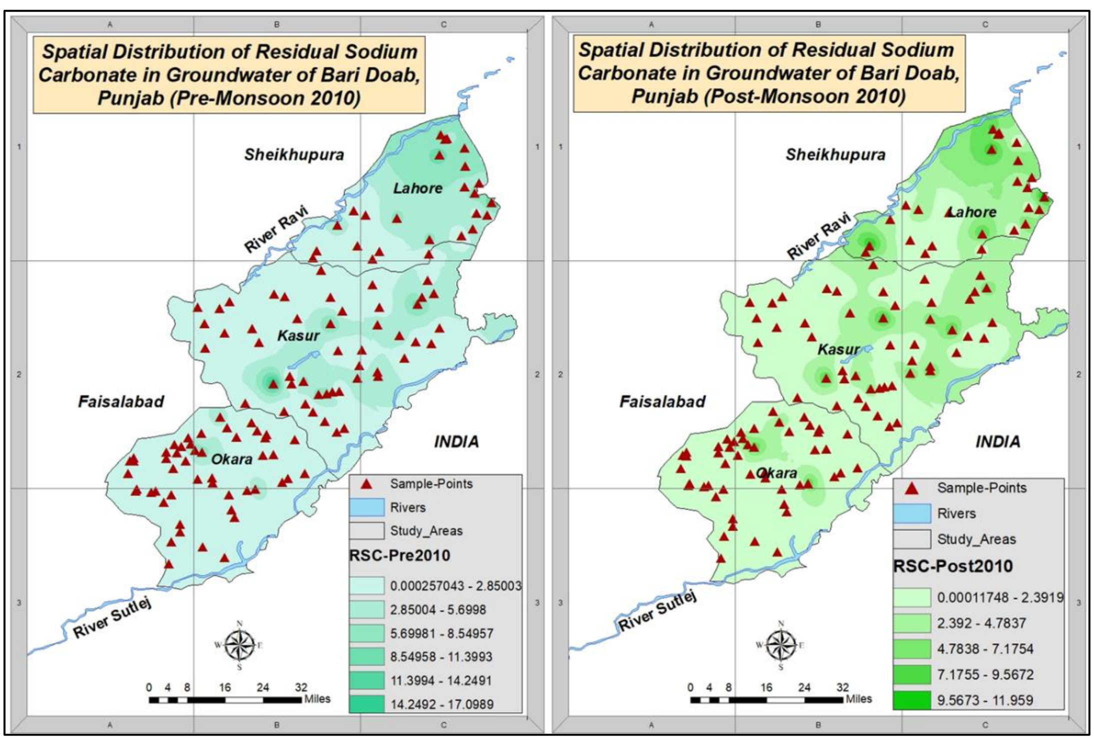


Fig.10. Spatio-temporal Variation of RSC in Pre and Post Monsoon 2010.

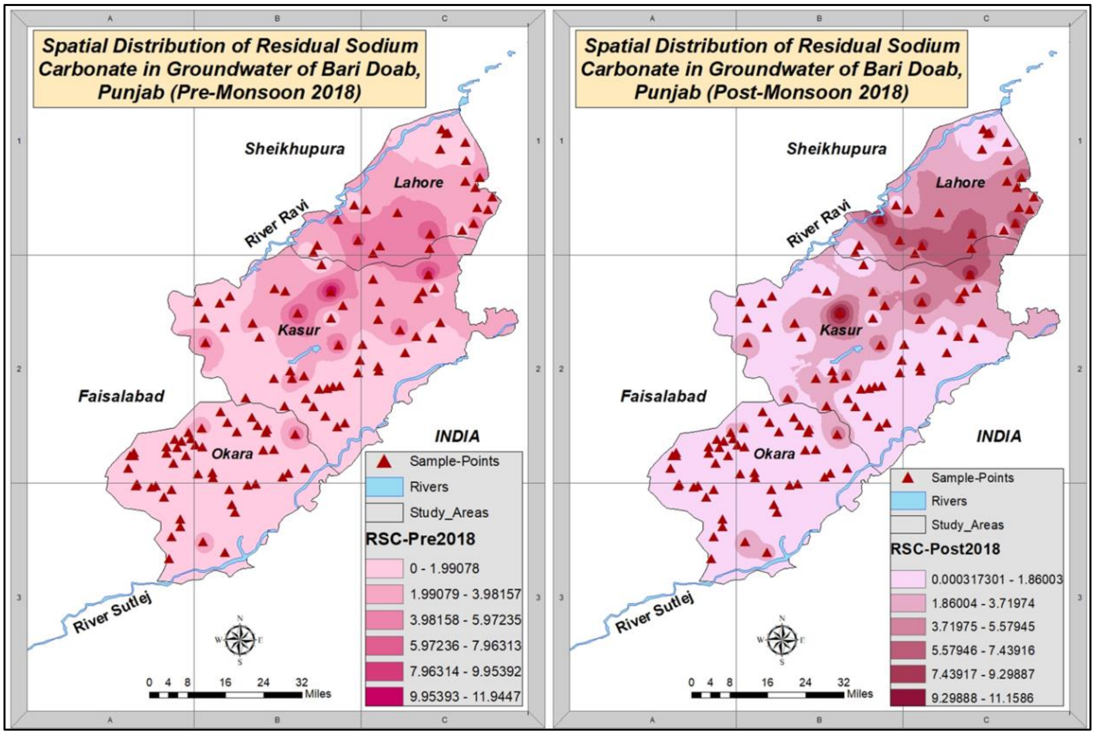
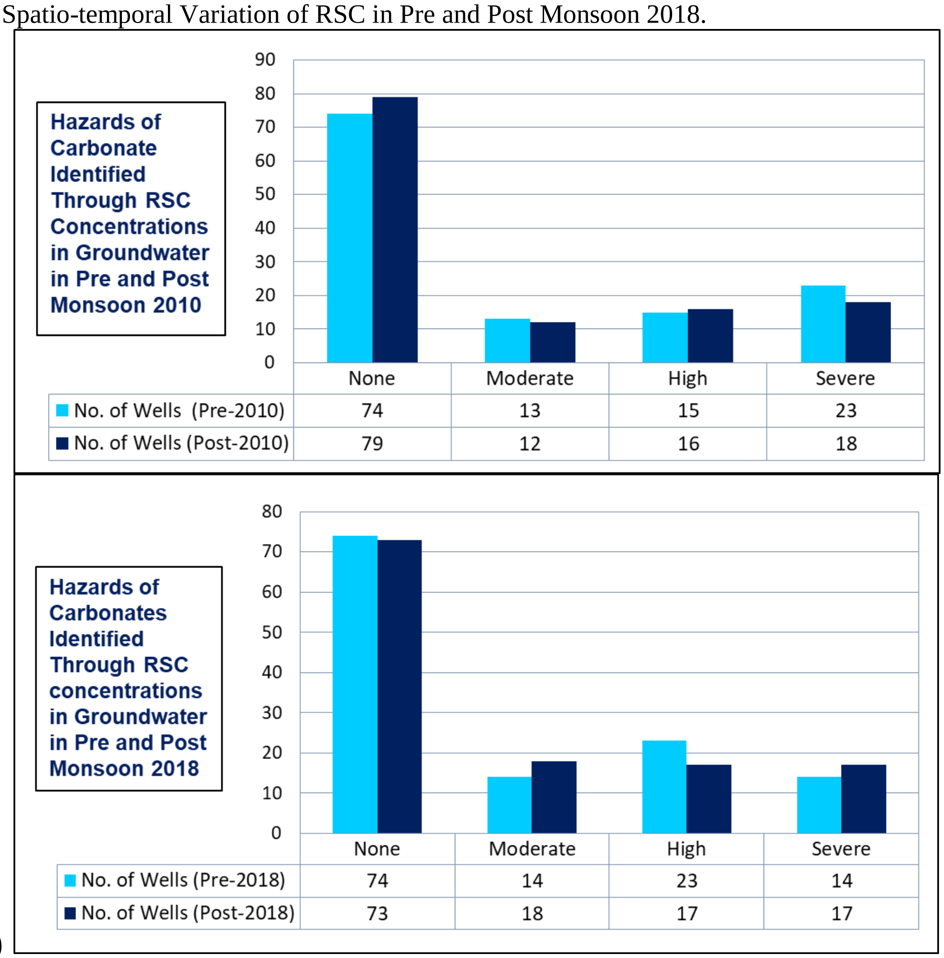


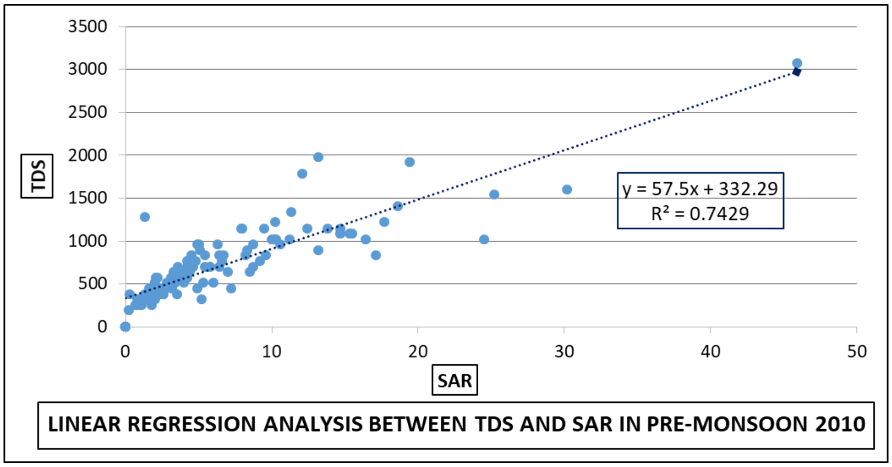
Fig.11. Spatio-temporal Variation of RSC in Pre and Post Monsoon 2018.



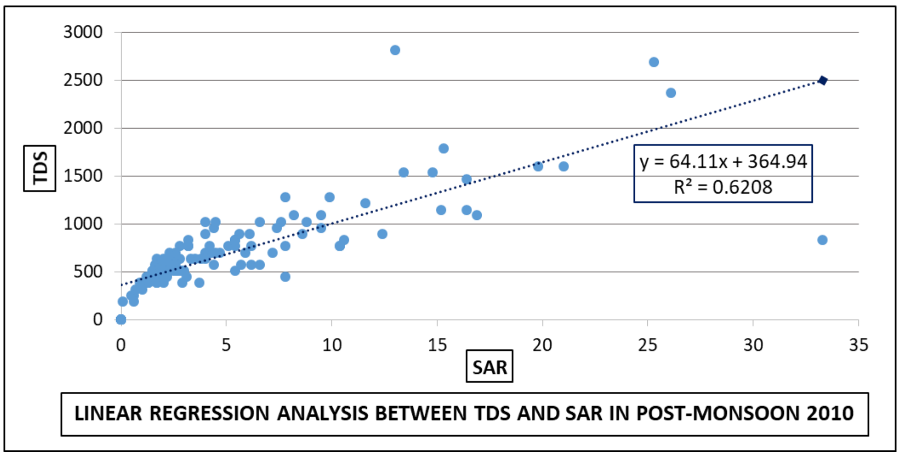
(a)

(b)

Fig.12. Carbonate Hazard Classification of Pre and Post-Monsoon 2010 and 2018.



(a)



(b)

Fig.13 (a) and (b). Regression Analysis between TDS and SAR in Pre and Post 2010.

In Fig.14 (a), at the SAR concentration of 36.23, value of 3140 ppm for TDS has been recorded, while for SAR concentration of 23.52, 3600 ppm TDS value is recorded. This shows that dissolved salts has other salts more in concentration than sodium. The model presents 81% effectiveness. In Fig.14 (b), the highest value of SAR (55.43) shows the corresponding TDS concentration of 3240 ppm, which is less than the value observed in pre-monsoon 2018 for TDS and more severe for SAR. Regression Model in Fig.14 (b) is 77% effective.

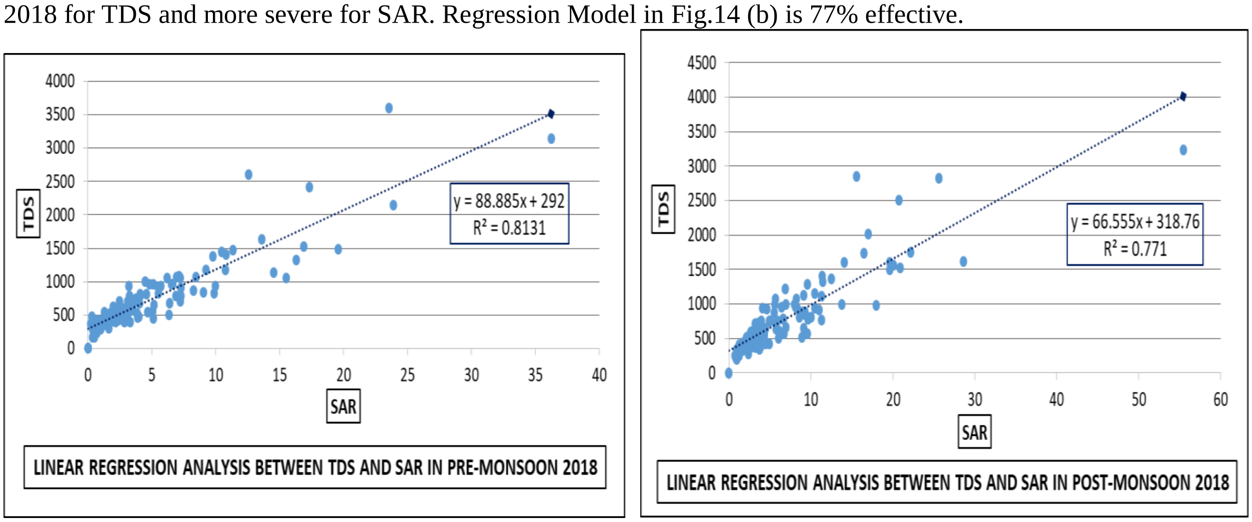


Fig.14 (a) and (b). Regression Analysis between TDS and SAR in Pre and Post 2018.

CONCLUSION

Primary objective for this study was to analyze the risks and hazards linked with the application of groundwater to the croplands. Evaluation of EC, SAR and RSC has shown that effects of single parameter is less than cumulative impacts of the parameters as each one, acts as a catalyst for the other as analyzed by the spatial distribution patterns, regression modeling and by the review of previous studies. These combined effects could make productive lands, infertile and barren, which could bring innumerable loss to the agriculture sector. However, severe levels of a single parameter would hinder healthy crop growth, produce deficient structures and disrupt sensitive environments for area specific species as specified by individual definitions and impacts of the selected parameters. It is recommended for a strong water governance in the province at district level to incorporate efficient laws and monitoring systems for the protection of natural treasures. It is essential to stop overexploitation of groundwater and to implement the national and international standards and limits for its extraction to minimize the hazards and risks of outbreak of toxic compounds and minerals. Drip irrigation should necessarily be implemented to save water and promote sustainability.

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REFERENCES

Aboukarima, A.M., M.A. Al-Sulaiman and M.S. El Marazky (2018). Effect of sodium adsorption ratio and electric conductivity of the applied water on infiltration in a sandy-loam soil. *Water SA*, 44(1): 105-110.

Aftab, I., M. Kamal and A. Irfan (2020). Mapping Sustainable Development Goal Indicators for Pakistan: Way Forward. *Journal of Strategic Innovation & Sustainability*, 15(1): 10-35.

Azam, A. and M. Shafique (2017). Agriculture in Pakistan and its Impact on Economy. A Review. *Inter. J.Adv. Sci. Technol.*, 103: 47-60.

Blondes, M. S., K.D. Gans, E. L. Rowan, J. J. Thordsen, M. E. Reidy, M. A. Engle and B. Thomas (2016). US Geological Survey National Produced Waters Geochemical Database v2. (Provisional) Documentation. USGS Energy Resources Program: Produced Waters, USGS, 16.

Clark, M. L. and J.P. Mason (2006). Water-quality characteristics, including sodium-adsorption ratios, for four sites in the Powder River drainage basin, Wyoming and Montana, *water years 2001-2004* (No.2006-5113).

Eaton, F. M. (1950). Significance of carbonates in irrigation waters. *Soil science,* 69(2): 123-134.

El Moujabber, M., B.B. Samra, T. Darwish and T. Atallah (2006). Comparison of different indicators for groundwater contamination by seawater intrusion on the Lebanese coast. *Water Resources Management*, 20(2): 161-180.

GOP (16). Government of Pakistan, Pakistan Federal Bureau of Statistics, Agriculture Statistics, 2015-16.

GOP (15). Government of Pakistan, Pakistan Bureau of Statistics, Labor Force Statistics, 2014-15.

GOP (12). Government of Pakistan, Pakistan Bureau of Statistics, Agriculture Statistics, 2011-12.

Hagras, M. (2013). Water Quality Assessment and Hydro chemical Characteristics of Groundwater in Punjab, Pakistan. *International Journal of Research and Review Applied Science (IJRRAS)*, 16(2): 254-262.

Hem, J. D. (1985). *Study and interpretation of the chemical characteristics of natural water* (Vol. 2254). Department of the Interior, US Geological Survey.

Howard, G. (2021). The future of water and sanitation: global challenges and the need for greater ambition. AQUA—*Water Infrastructure, Ecosystems and Society*, 70(4): 438-448.

https://en.climate-data.org/asia/pakistan/punjab/lahore-33/

https://kasur.punjab.gov.pk/district%20_profile

https://lahore.punjab.gov.pk/geographic_conditions#:~:text=Lying%20between%2031%C2%B015,km%C2%B2%20and%20is%20still%20growing.

https://punjab.gov.pk/okara

Kahlown, M. A., A. Raoof, M. Zubair and W.D. Kemper (2007). Water use efficiency and economic feasibility of growing rice and wheat with sprinkler irrigation in the Indus Basin of Pakistan. *Agricultural water management*, 87(3): 292-298.

Logeshkumaran, A., N.S. Magesh, P. S. Godson and N. Chandrasekar (2015). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Science*, 5(4): 335-343.

Marandi, A., M. Polikarpus and A. Jõeleht (2013). A new approach for describing the relationship between electrical conductivity and major anion concentration in natural waters. *Applied geochemistry,* 38: 103-109.

Patil, P. N., D.V. Sawant and R.N. Deshmukh (2012). Physico-chemical parameters for testing of water–A review. *International journal of environmental sciences*, 3(3): 1194-1207.

Qureshi, A. S. (2015). Improving food security and livelihood resilience through groundwater management in Pakistan. *Global Advanced Research Journal of Agricultural Science*, 4(10): 687-710.

Qureshi, A. S. (2020). Groundwater Governance in Pakistan: From Colossal Development to Neglected Management. *Water,* 12(11): 3017.

Qureshi, A. S. and C. Perry (2021). Managing Water and Salt for Sustainable Agriculture in the Indus Basin of Pakistan. *Sustainability*, 13(9): 5303.

Qureshi, A. S. and A. Sarwar (2009). Managing salinity in the Indus Basin of Pakistan. *International Journal of River Basin Management,* 7(2): 111-117.

Raza, M., F. Hussain, J.Y. Lee, M. B. Shakoor and K.D. Kwon (2017). Groundwater status in Pakistan: A review of contamination, health risks, and potential needs. *Critical Reviews in Environmental Science and Technology*, 47(18): 1713-1762.

Riaz, U., Z. Abbas, M. Mubashir, M. Jabeen, S.A. Zulqadar, Z. Javeed and M.J. Qamar (2018). Evaluation of Ground Water Quality for Irrigation Purposes and Effect On Crop Yields: A GIS Based Study of Bahawalpur. *Pakistan Journal of Agricultural Research,* 31(1): 00-00.

Riaz, O., T. Abbas, M. Nasar-u-Minallah, S. ur Rehman and F. Ullah (2016). *Assessment of ground water quality: a case study in Sargodha city, Pakistan*. *Sci. Int*. (Lahore), 28(5): 4715-4721.

Saleh, A., F. Al-Ruwaih and M. Shehata (1999). Hydrogeochemical processes operating within the main aquifers of Kuwait. *Journal of Arid Environments*, 42(3): 195-209.

Shafiq, M., A.G. Sagoo, M. Arif, M. Yousaf, M. Zafar, N. Akhtar, K. Nazir and A. Hannan (2018). Assessment of groundwater quality status for irrigation in thal area. *Curr. Investig. Agric. Curr. Res.*, 5: 753-758.

Shirazi, S. A. and S.J.H. Kazmi (2020). Analysis of population growth and urban development in Lahore-Pakistan using geospatial techniques: Suggesting some future options. *South Asian Studies*, 29(1): 269-280.

Siosemarde, M., F. Kave, E. Pazira, H. Sedghi and S. Ghaderi (2010). Determine of constant coefficients to relate total dissolved solids to electrical conductivity. *World Academy of Science, Engineering and Technology*, 46: 258-260.

Stigter, T. Y., L. Ribeiro and A. C. Dill (2006). Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies–Two Portuguese case studies. *Journal of Hydrology*, 327(3-4): 578-591.

Thorne, D. W. and H.B. Peterson (1954). *Irrigated Soils*. Constable and Company Limited, London, 113.

UN-Water (2020). *Summary Progress Update 2021 – SDG 6 – water and sanitation for all.* Version: 1 March 2021. Geneva, Switzerland.

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