CASE STUDY

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GIS based Analysis of Ground Water Quality: A Case Study of Districts of Punjab- Pakistan

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ABSTRACT

Pakistan as a third world country, primarily depends on agriculture for its economic growth. This study is based on use of spatial analysis techniques for identification of threats to the agricultural fields irrigated by groundwater in different districts of Punjab province. 422 wells were extracted from the secondary data of Punjab Irrigation Department. Through Arc GIS mapping, the sampled wells were observed in the pre and post monsoon of 2006 and 2013. 63% of wells exhibited high salinity in the pre monsoon-2006. The Sodium Absorption Ratio (SAR) was in high concentration in 82 wells in the same year. While the Residual Sodium Carbonate (RSC) showed highest concentration of 34.4 me/L. Consuming water with high concentration of salinity, sodium and its carbonates results in decreased crop yield. Therefore, it is concluded as dire need for the strict implementation of laws and regulations to conserve natural resources and promote sustainable agricultural practices.

Reference Guide:

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INTRODUCTION

By the start of 21st century, population explosion resulted in mass trigger of the industrial revolution in order to meet the demand and supply mechanism. This uncontrolled change of events made the stress on environmental resources to increase. Pakistan is one of those countries of the world whose economy mainly depends upon the agricultural sector. Being

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an agronomic dominant country, Pakistan's sustainable economic growth along with other encountering socioeconomic issues depends on utilization of natural assets in the accurate proportion, which is also the most primary and major component of agrarian supporting system (Tahir, 2005). Groundwater in the world is second most water dependable resource that is used for drinking as well as in agriculture. It is stated that from the whole agricultural requirements about 35% is accomplished by ground water in Pakistan. As in other countries of the world, groundwater is also used for drinking and industrial purposes in Pakistan (Bhutta & Alam, 2006). According to the Sustainable Development Goals 2030 signed by Pakistan, it is an essential Objective for developing countries to maintain water security and availability to ensure sustainability (Saraswat et.al., 2018). Reports have indicated that due to unrestrained clearance of industrial and metropolitan wastewater without management and unprincipled application of fertilizers and pesticides have lead the value of water to diminish in chief cities of Pakistan (Javaid et.al., 2017).

Quality analysis and geochemical evaluation for water systems present an improved regulatory organization to save any resource troubling through environmental and especially anthropogenic stresses, and also helps in movement towards a better approach of action (Ramesh & Elango, 2012). Water buried underground, due to its mineral content and trace elements is found of more significance than water above ground. Electrical conductivity, Sodium Absorption Ratio and Residual Sodium Carbonate, are the three foremost groundwater quality parameters required to assess when water is required for irrigational activities (Hagras, 2013). With the increase in salinity and sodicity, the infiltration rate of soil becomes affected. This causes the soil to allow restricted access of water to flow resulting in severe exaggeration irrigation and cropping process, ensuing in decline of crop production, wilting and swelling of plants and soil, and change in geological properties and soil type of the region (Nishanthiny et.al., 2010). While the presence of Residual Sodium carbonates triggers and aids in water hardness, causes noxiousness in plants and their poor development, and if condition occurs in silt or clay soil structures then it results in diminution of soil permeability (Riaz et.al., 2018).

The present study is performed to reveal the monitoring process of groundwater used for irrigation purpose with fluctuations in electrical conductivity, SAR and RSC. Spatial dispersion is also analyzed through GIS by producing maps to promote an understanding based on accuracy and scientific approach. The spatial distribution pattern is an important tool that has helped to locate the precise amount of the prime parameters at their root locations. Study areas selected for the study were some districts of Punjab, which included Faisalabad, Toba Tek Singh and Jhang.

MATERIALS AND METHODS:

STUDY AREA:

The study has been conducted on the Districts of Punjab with longitude 73.06°E, latitude 31.26°N and elevation of 184.5m from mean sea level. The climate of central and southern Punjab possesses the dry semi-arid agro-climatic characteristics but well managed canal irrigation system has placed it among the highly productive agriculture zones. Mainly summer monsoon produces more rainfall and winter has a little contribution. Day time temperature reaches above 40˚C during summer from April to September except some occasional relief from monsoon rains and decreases the evaporation demand of the atmosphere. The winter season starts from November and continues till March. December, January and February are the coldest months. In winter, night time temperature drops below 0˚C. The highest amount of rainfall occurs during Rabi season in the months of March followed by April and February respectively. Day time mean maximum and night time mean minimum temperature gradually decrease from November to January and then start rising (Punjab Development Statistics).

DATA COLLECTION AND SORTING:

There was no primary data collected for this study. Secondary Data of Ground Water Quality of the target area was obtained from the website of Irrigation department of Punjab (Pakistan). A total of 2 Excel Worksheets were downloaded. Both of them contained groundwater quality data including EC and SAR and RSC values at pre and post monsoon times of year 2006 to 2013. Sorting and Refining was done in two steps. In the first step, partially filled cells were removed from the data while in the second step readings of two years were selected from the data for further Analysis. For water quality, the chosen years were 2006 and 2013. Further, the Lat/Long values of the sampling sites were also converted into Decimal Degree as they were given into Degree, minute and second's format.

DATA ANALYSIS:

IDW tool of interpolation was used to form contour maps showing Spatial and Temporal Variation of water's physiochemical quality. For this purpose, data of shape file of all selected Districts were exported from Pakistan map shape file downloaded from Diva GIS website. Sampled wells were classified according to the concentration and hazards. Tables and maps were organized in order to compare the variations found in selected years.

RESULT AND DISCUSSION:

The subsurface water of the study area is largely used for agricultural purposes. The feasibility of groundwater for watering of crops is based on the mineral content of the water. Good quality of groundwater is necessary to retain the soil crop productivity at a considerable amount. Dissolved Salts and their ions are a key threat to plant production which increases osmotic pressure in soil solution that in return, reduces the functionality of water absorption for osmosis (Eaton, 1950). To assess the suitability of irrigation groundwater its salinity, sodicity and toxicity are measured as the key factors to make its use fit for practices of agricultural activities (Aboukarima et.al., 2018), keeping in consideration that these ions play a major role in water's changing chemistry especially that of groundwater (Kelly, 1957).

PARAMETERS	WAPDA IRRIGATION WATER QUALITY CRITERIA (1981)	
Electrical Conductivity (dS/m)	Suitable	<1.5
	Unsuitable	>3
Sodium Absorption Ratio (SAR)	Suitable	<10
	Unsuitable	>18
Residual Sodium Carbonate (RSC) (me/L)	Suitable	<2.5
	Unsuitable	>5

I: WAPDA Standards for Irrigation Water Quality (1981)

Electrical Conductivity (EC) is the calculation of the extent of the mineralization of the water, which is based on water-rock correspondence, and hence the stay time of the water in the rock (Kelly, 1957). EC measurements are performed to detect two major physical specific parameters:

a) Total dissolved salts (T.D.S)

b) Salinity Hazard

EC value is converted into TDS by multiplying it with a constant factor that is mentioned in every table to represent in the standard in which it is studied in. While salinity hazard is simply a range of EC values on which there is likely some deformity to happen in the crops due to physiological drought. Physiological drought is a condition in which in spite of moisture in the soil, plant leaves wilt because of inability of plant's root to absorb water.

Sodium Absorption Ratio (SAR) is used to predict the danger of sodium accumulation in soil. Excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability and soil structure (Saleh et.al., 1999). The SAR is used to estimate the sodicity hazard of the water and it also determines the alkalinity of soil selected for agriculture. SAR is calculated by the following formula:

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

SAR value is an important indication of sodium hazard (Infiltration problem) that is the reduction of the permeability of the soil. This loss in permeability cause the soil to shrink and swelling in clayey soil when irrigation water flows through (Naseem et.al., 2010).

The Residual Sodium Carbonate (RSC) is another vital parameter besides EC and SAR and is used to determine the extent of aptness of groundwater consumed in irrigational terms (Punjab Irrigation Department). It is the evaluation of surplus CO_3 and HCO_3 ions which precipitates the Calcium and Magnesium ions present in disbursed asset. The RSC factor is computed through the following formula:

RSC= $(CO_3 + HCO_3) - (Ca + Mg)$

This estimates the level of toxicity to the flora as it aids the augmented accumulation of sodium and saline ions causing a threat to the irrigational lands and crop production and is expressed in me/L (milli equivalence per liter) (Thorne & Peterson, 1954).

PRE MONSOON AND POST MONSOON OF 2006:

Electrical Conductivity: Highest Value of EC in unit dS/m (deci siemens per meter) was 5.8 with corresponding highest value of T.D.S i.e. 4640 mg/L (milligram per Litre) was found to be at Chak Jhumra in the district of Faisalabad. The lowest value of EC and T.D.S were 0.30 dS/m and 192mg/L at a location present in Faisalabad.

Salinity Classification	No. of Wells/Sampling Sites	USDA Salinity Classification	
		TDS (mg/l)	EC (Ms/cm at 25°C)
Low	0	<150	<250
Medium	36	150-500	250-750
High	397	500-1500	750-2250
Very High	192	1500-3000	2250-5000

II: Tabulated Classes for Electrical Conductivity and TDS In Pre-Monsoon 2006

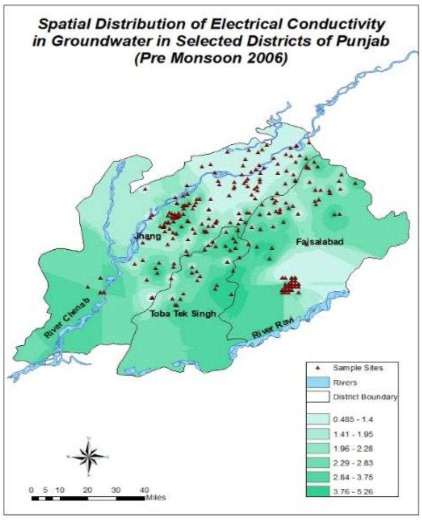

FIG.I: Variation in EC in Pre Monsoon 2006

Average value of EC was found to be 1.99 dS/m. If we discuss the distribution of T.D.S., most of the values were in the range of High Salinity i.e. about 63 % of the study area. Furthermore, there were no well from which a low salinity water was recorded (i.e. 0%). While in term of Salinity Hazards limitation in the field, we have found 36 wells in the "Medium" range, 192 as "very high" while major percentage in "high range". Moreover, Spatial distribution of EC values is also shown in figure.I.

According to the WAPDA criteria, the highest value found is about 3 times more than the standard recommended. While the average value estimated is also observed in breach of the standard criteria. This suggests that the quality of water underground in the span of pre-monsoon 2006 was witnessed to be declared as "Unfit" for agrarian process.

422 of the total wells were sampled and evaluated for quality. Importantly, the highest EC and TDS values were found at the same location as it was found in pre monsoon season of the same year i.e. at Chak Jhumra, Faisalabad, and the values were 6.20 dS/m and 4960mg/L. But the venue for the minimum value of EC and TDS got changed to Bhawana, Chiniot. And the EC and TDS values were found to be 0.4 dS/m and 193 mg/L respectively. The average EC value was 2.1 for this season. The classification of wells according to their TDS values is shown below. Another important outcome of the data is the determination of Salinity Hazard.

A recent study of irrigational groundwater quality of district Kasur showed that about thirty samples from their total collected 64 samples had exceeding values of EC, SAR and RSC which were >1250 µS/cm, 10 and 2.50 me/L respectively, and that it was acknowledged in the study as these extracted waters to be unfit for consumption and usage (Shakir et.al, 2002).

Salinity Classification	No. of Wells/Samples	USDA Salinity Classification	
		TDS (mg/l)	EC (Ms/cm at 25°C)
Low	0	<150	<250
Medium	24	150-500	250-750
High	408	500-1500	750-2250
Very High	193	1500-3000	2250-5000

III: Tabulated Classes for Electrical Conductivity and TDS in Post-Monsoon 2006

Faisalabad is situated in the lower Chenab canal circle and receives its surface water for agricultural fields from this canal (Riaz et.al., no date). An evaluation of Khurrianwala Industrial Estate groundwater quality, situated between Chenab and Ravi rivers in the vicinity of Faisalabad, provided the outcomes that TDS values in drinking water were found at an alarming rate with high salinity which varied from 987 to 2114 mg/L. While the EC concentrations of irrigation groundwater were shown to be in the range of 1590-3490 μS/cm (Aleem et.al., 2018).

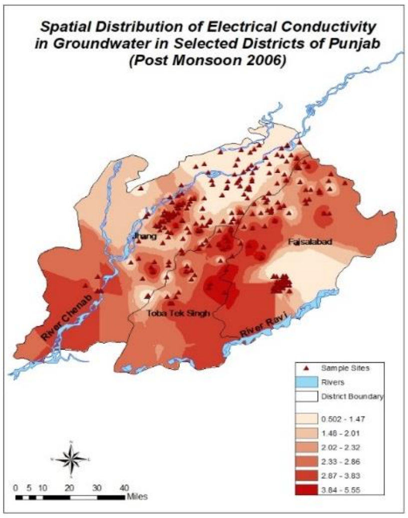

FIG.II: Variation in EC in Post Monsoon 2006

Sodium Absorption Ratio: Sodium ion increase cause the decline in crop yield. In Bahawalpur, GIS analysis revealed that 21% of the samples were explored to be unfit for irrigational purposes, while 65% were fit leaving 14% as marginally fit. This sodium absorption ratio helps and supplement the movement of sodium ions which reacts with Ca^{+}, Mg^{+}, CO_3^-, HCO_3^- and form such complexes that causes damage to the soil stability and its structure (Riaz et.al, 2018).

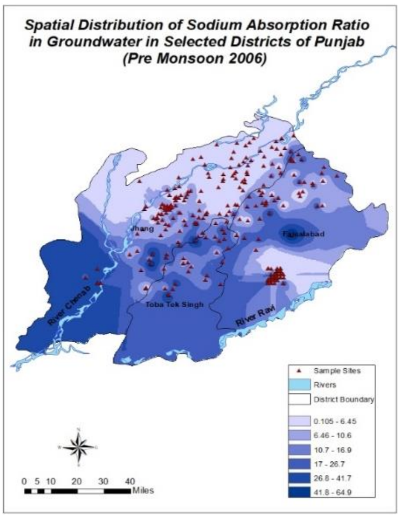

FIG.III: Sodium Concentration Variation in Pre Monsoon 2006

In this present study, the lowest value of SAR was found at Jhang that is 0.1. The highest value of SAR was found to be 91.0 in tehsil Samundri of Faisalabad in the pre monsoon span of 2006. In comparison with the standard recommended by WAPDA, the highest value is witnessed as significantly elevated, while the categories in which the sodium hazard is classified reveals the fact that most of the wells have been found to the safe limit.

High increase in TDS values results from the leaching of wastewater of industries and salts, which in terms lead to decrease in soil fertility and its ability in yielding crops

Sodium Hazard	No. of Wells	Standards for SAR
Low	395	1-10
Medium	101	10-18
High	82	18-26
Very High	47	>26

IV: Hazards Generated Regarding the SAR Concentrations in Pre Monsoon 2006

In Sargodha, the analysis of groundwater quality revealed that out of all 12 sampled areas, only 5 had sodium concentration under the WHO guidelines (200 mg/L) whereas all the samples had EC concentrations more than 1000 μS/cm and an alarming concern was reported (Riaz et.al., no date).

The lowest value of SAR in the post monsoon season of 2006 was found at Bhawana in district Chiniot which was 0.4. While the highest value of SAR was found to be 59.6 at Toba Tek Singh. In comparison with the standard value given for SAR, 28 wells fall in the category of very high concentration, while majority is assessed to be under safe and marginally safe limits.

Sodium Hazard	No. of Wells	Standards for SAR
Low	404	1-10
Moderate	139	10-18
High	53	18-26
Very High	28	>26

V: Hazards Generated Regarding the SAR Concentrations in Post Monsoon 2006

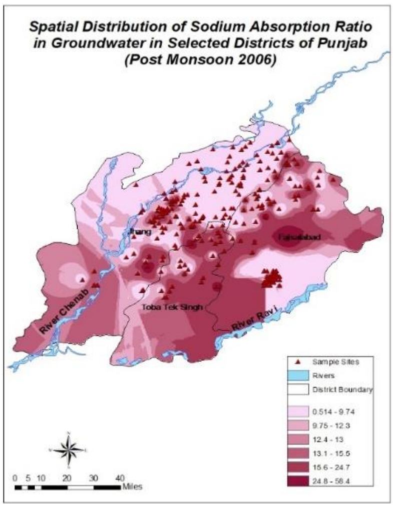

FIG.IV: Sodium Concentration Variation in Post Monsoon 2006

Residual Sodium Carbonate: Unceasing usage of irrigation water containing high levels of RSC causes the soil to lose its permeability by obstruction of pores leaving the crops to tolerate subsequent toxic effects and hindrances in appropriate growth pattern (Ashraf et.al., 2010). In this performed study the value for RSC is observed in the range of 0-34 in the pre monsoon season of 2006, revealing the highest value in Tehsil Samundri of District Faisalabad of 34.4, while majority of the wells were found to have shown no value for RSC and hence it can be stated that most of the samples were found to be under safe and fit limits.

In the Post Monsoon of 2006, the trends in RSC concentration found to be altered. At this time of the year the highest value was observed in Toba Tek Singh of about 23.6. While in most wells where no value was observed in pre monsoon showed slight increase in them, and those sites which showed some concentration were decreased to 0. For instance, the uppermost value observed in Faisalabad in pre monsoon was three times much high than the standard recommended (34.4). At the same area the concentration of RSC decreased to 8.7 in the post monsoon season of the same year. This indicates that due to recharge in the aquifer the concentration decreased to a marginal safe limit and hence an improvement is observed in quality of sampled water.

In GIS study conducted at Bahawalpur, it was reported that about 9 locations had increased concentration of RSC and the indication of vulnerability to the soil infrastructure and crop production was stated (Riaz et.al., 2018).

RSC PRE MONSOON 2006		
CARBONATE HAZARD	RANGE	NO. OF WELLS
Low	0-2.5	223
Moderate	2.5-5	86
High	5-8	65
Very high	>8	48

VI: Classification of Hazards of Sodium Carbonate Ions in Pre Monsoon 2006.

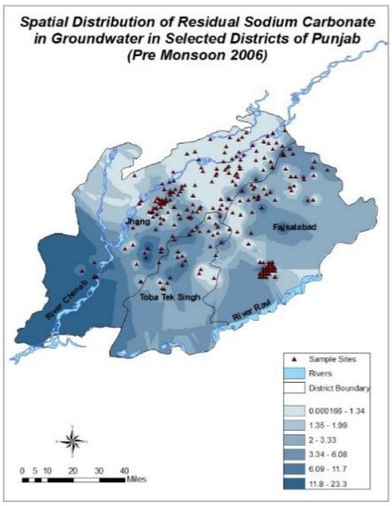

FIG.V: RSC Concentration Variation in Pre Monsoon 2006

RSC POST MONSOON 2006		
CARBONATE HAZARD	RANGE	NO. OF WELLS
Low	0-2.5	244
Moderate	2.5-5	74
High	5-8	56
Very high	>8	48

VII: Classification of Hazards of Sodium Carbonate Ions in Pre Monsoon 2006.

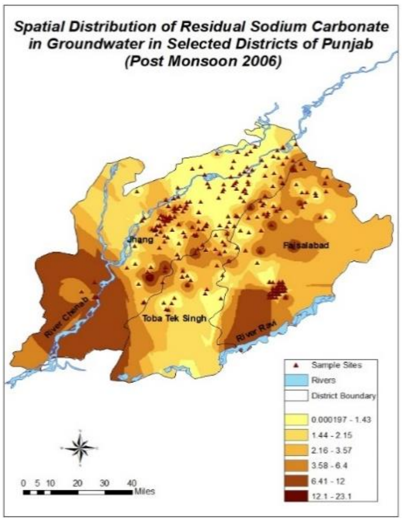

FIG.VI: RSC Concentration Variation in Post Monsoon 2006

PRE AND POST MONSOON OF 2013:

Electrical Conductivity: The previous year monitoring revealed the fluctuation of mineral content and various environmental factors that lead to another year of assessment in 2013. Highest Value of EC in pre monsoon season was 21.82 dS/m with corresponding highest value of T.D.S i.e. 17456 mg/L, which was established at Nankana Sahib in district Sheikhupura. The lowest value of EC and T.D.S was 0 dS/m in Jarranwala Faisalabad. Average value of EC was found to be 2.10 dS/m. Highest Value of EC in dS/m(deci siemens per meter) was 18.09 with corresponding highest value of T.D.S i.e. 14472 mg/L (milligram per Litre) was found to be at Nankana Sahab in district Sheikhupura. The lowest value of EC and T.D.S were 0.00 dS/m and 0 mg/L at a location of Jaranwala Faisalabad. Average value of EC was found to be 2.06 dS/m. On the basis of EC salinity classification and Hazard Classification of the sampling sites is performed whose summary is shown in the table. Furthermore spatial distribution of the EC values throughout the study area is also presented in figure.

Salinity Classification	No. of Wells/Sampling Sites	USDA Salinity Classification	
		TDS (mg/l)	EC (Ms/cm at 25°C)
Low	1	<150	<250
Medium	56	150-500	250-750
High	382	500-1500	750-2250
Very High	186	1500-3000	2250-5000

VIII: Tabulated Classes for Electrical Conductivity and TDS in Pre-Monsoon 2013

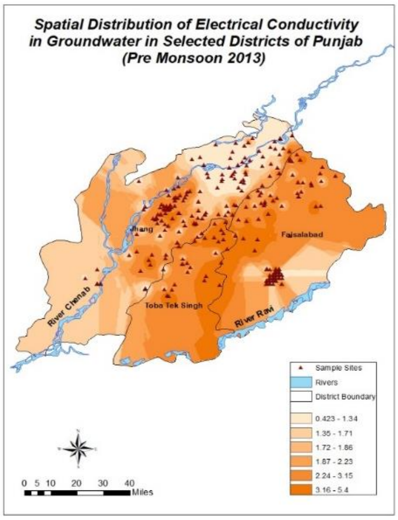

FIG.VII: Variation in EC in Pre Monsoon 2013

Salinity Classification	No. of Wells/Sampling Sites	USDA Salinity Classification	
		TDS (mg/l)	EC (Ms/cm at 25°C)
Low	5	<150	<250
Medium	52	150-500	250-750
High	404	500-1500	750-2250
Very High	164	1500-3000	2250-5000

IX: Tabulated Classes for Electrical Conductivity and TDS in Post-Monsoon 2013

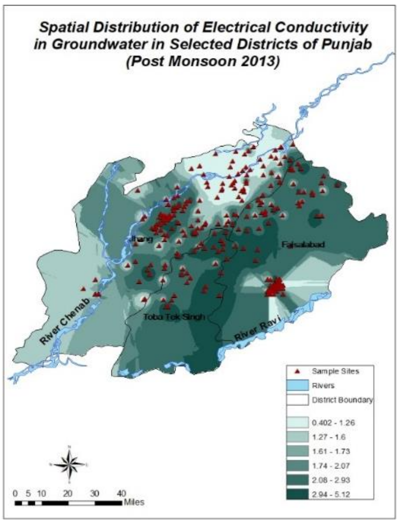

FIG.VIII: Variation in EC in Post Monsoon 2013

Sodium Hazard	No. of Wells	Standards for SAR
low	404	1-10
Moderate	100	10-18
High	71	18-26
Very High	50	>26

X: Hazards Generated Regarding the SAR Concentrations in Pre Monsoon 2013

A study conducted in Hafizabad District in the pre and post monsoon spell of 2013 of irrigation groundwater quality disclosed the statistic that the average value of Electrical Conductivity was 1.26 in pre monsoon while in post monsoon it decreased to 1.23, which was found to be under safe limits as suggested by WAPDA and USDA classification guidelines, as the soil type of the area is found to be slightly permeable and cannot hold extensive rain water and thus could promote erosion and surface flow (Maqsood et.al., 2016).

Sodium Absorption Ratio: In post monsoon 2013, the lowest value of SAR was found at Faisalabad, which was 0.5, and the highest value of SAR was found to be 54.1 at Shorkot, Jhang. While in about 190 of the sampled wells the value was found to exceed from 10 and hence indicated that SAR values were found exceeding the limit and marginally fit limitation. Whereas the research at Hafizabad showed the highest value to be within suitable and safe limits and this research concluded that most of the sampled areas had irrigation water under safe limits and that no potential hazard was found.

Sodium Hazard	No. of Wells	Standards for SAR
low	403	1-10
Moderate	103	10-18
High	71	18-26
Very High	48	>26

XI: Hazards Generated Regarding the SAR Concentrations in Post Monsoon 2013

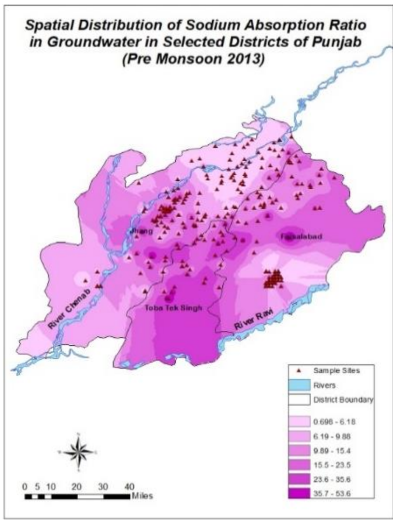

FIG. IX: Sodium Concentration Variation in Pre Monsoon 2013

When the same areas were sampled in pre monsoon 2013, the lowest value of SAR was 0.3, found at Sheikhupura. The highest value of SAR was found to be 46.8 at Faisalabad. In Comparison with the standard, the maximum value found at Faisalabad can pose serious threats to the agricultural fields and with the excess of Sodium Absorption Ratio, it can cause sodium ion to react with calcium, magnesium, carbonates and bicarbonates and can form complexes which can cause increase in alkalinity by the release of OH^- ions in the soil solution.

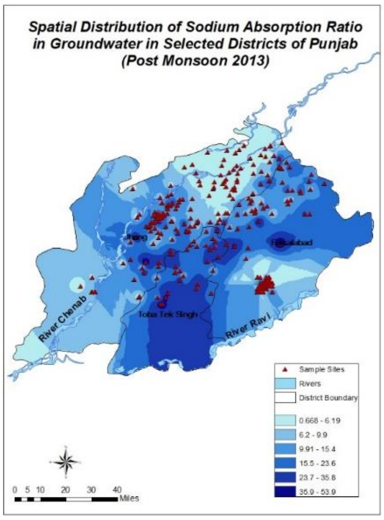

FIG. X: Sodium Concentration Variation in Post Monsoon 2013

Residual Sodium Carbonate: In 2013, Shorkot present in district Jhang showed the uppermost value of about 15.5 me/L in pre monsoon, which in comparison with the standard is found to be above the suitable levels and can initiate toxicity among crops, whereas depending on the soil structure, it can also affect its porousness and its capacity to hold nutrients essential for good production outcomes.

RSC PRE MONSOON 2013		
CARBONATE HAZARD	RANGE	NO. OF WELLS
Low	0-2.5	246
Moderate	2.5-5	74
High	5-8	52
Very high	>8	50

XII: Classification of Hazards of Sodium Carbonate Ions in Pre Monsoon 2013.

In post monsoon the estimates revealed that about 14 me/L of RSC was observed at the same location of Jhang and that it could be assumed that this decline must have been resulted when rain water had caused groundwater to recharge and dilution may have led to drop of concentration. Increased concentrations of RSC have been reported to show its physical appearance as alkaline blotches over the soil layer. While if RSC is found to be high in fine textured soils its continued use could turn soil into basic type and plants grown in such soil can die due to burning and toxicity [23].

RSC POST MONSOON 2013		
CARBONATE HAZARD	RANGE	NO. OF WELLS
Low	0-2.5	238
Moderate	2.5-5	59
High	5-8	75
Very high	>8	50

XIII: Classification of Hazards of Sodium Carbonate Ions in Post Monsoon 2013.

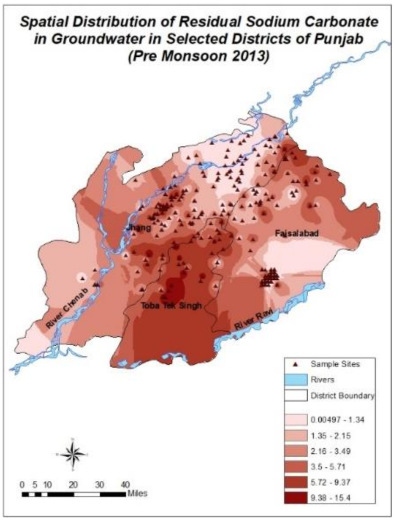

FIG.XI: RSC Concentration Variation in Pre Monsoon 2013.

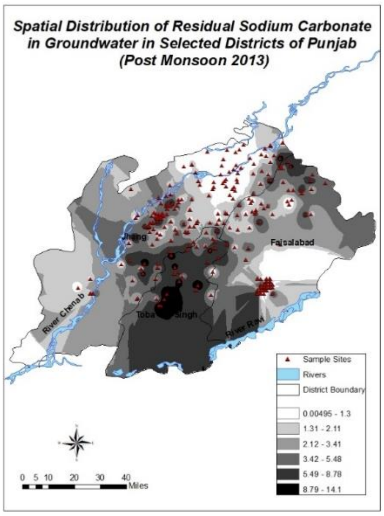

FIG.XII: RSC Concentration Variation in Post Monsoon 2013.

LAND UTILIZED (Thousand Hectares)	DIVISIONS	2007-2008	2011-2012	2014-2015
CULTIVATED AREA	Faisalabad	1470	1366	1426
	Gujranwala	1399	1420	1383
	Lahore	1048	1028	911
UNCULTIVATED AREA	Faisalabad	320	424	365
	Gujranwala	313	306	349
	Lahore	277	297	252
CROPPED AREA	Faisalabad	2040	2047	2017
	Gujranwala	2271	2260	2184
	Lahore	1525	1543	1478

XIV: Land Utilization Statistics (source: Punjab development statistics)

According to the land utilization statistics of Punjab, it can be seen that the cropped area of Gujranwala and Lahore have been seen to decrease, while the fluctuating trends in cultivated and uncultivated areas reveal that drought of 2006 and flood conditions of 2010 have made productions of crops to sustain the threat in 2006, but resulted in drop in 2011 and 2012. Whereas a major drop in cultivated area of Lahore division realizes the state of influence of various factors which also may include the irrigational activity and change of soil conditions (Punjab Development Statistics).

Taking note of the above observations, it can be concluded that the inconsistent trends of the major water quality parameters are needed to be assessed and monitored every year, so that it may assist in control and management of threats that make the agricultural production prone to vulnerabilities. In Punjab, Pakistan has provided the Irrigation Act 1873, Punjab Soil Reclamation Act 1952, Punjab Irrigation and Drainage Authority Act 1997 which have designated the administration of groundwater to the provincial government, authority to retrieve land areas affected by issues of water logging and salinity, and to conserve the aquifer. Although these laws are present but their strict implications are necessary as sustainability in the region is at the verge of numerous risks. Drip irrigation is been practiced around the world and is the need of time for Pakistani agricultural activities to conserve water and cope up with the water losses. Also the setup of intervals for recharge of aquifers is also recommended to establish the lost balance of exploitation and utilization.

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