Delineation and Evaluation of Groundwater Quality by using GIS mapping system and Statistical Approaches in Southern Punjab, Pakistan

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Abstract
The groundwater is the second largest source of Irrigation water in Pakistan. This study deals with the delineation and evaluation of spatial variations in the water quality in Multan, Khanewal, Lodhran, Vehari, Pakpattan and Sahiwal district of Southern Punjab, Pakistan. The three major indicators such as EC, SAR and RSC parameters were used and appraisal for irrigation to check groundwater quality via GIS, GS+ software and statistical analysis. The groundwater samples were evaluated for its applicability in irrigation and for mapping consequence . The parameters analyzed were compared with Standards that were adopted by WAPDA, PID and PCRWR. Kriging interpolation maps were delineated with three zone layers such as good (weight = 3), marginal (weight = 2) and bad (weight = 1). It was concluded that the areas under marginal and hazardous groundwater quality with low weights were significantly increased from 2 to 10% and 7 to 40% in pre- and post-monsoon respectively due to analyzed parameters. Hazardous effects were observed more during post monsoon than pre-monsoon season. Most of the area (> 35%) contaminated was due to EC parameters. Most of the study area (tehsil Kabirwala) was observed with low quality against all discussed quality parameters in both season. The groundwater quality parameter weightage decreases from northeast to southwest of study region. Low weightage zones were observed in lower part of the area. It is recommended that in high vulnerability area artificial well recovery, auriferous storage and rain harvesting techniques should be adopted specially in lower part to reduce salinity of water. The policy maker should make policies about regulation of water resources with good quality for best utilization of water for agricultural and industrial use.

Keywords: Groundwater, GIS, mapping, Ordinary kriging, Geostatistical.

Introduction

Water is backbone role of hydrological cycle phenomenon and in economic growth of the country as a natural gift for plants, livestock and human beings (Rosa et al., 2020; Jia et al. 2019; Yoon et al., 2021; Wu et al., 2013; Saatsaz et al. 2011; Allen et al., 2012). The major irrigation water requirement sources in Pakistan are rainfall, river water and groundwater. Groundwater is the second large source used to provide 50% water for irrigation purpose in semi-arid to arid climate with hot summer (Jia et al. 2019; Sarwar et al., 2021; Chaudhary et al. 2002; Mongat et al., 2015; Javed et al., 2015). Water resources management, designing and operation depend upon the groundwater availability, rainfall and surface water bodies flow rate. Some natural reactions and anthropogenic activities like agricultural land preparation, industrialization and urbanization cause vulnerability and degrading of groundwater quality (Teshome 2020; Varol 2020; Jalali et al. 2017; Nema et al. 2017Sauer et al. 2010; Mangalekar and Samant 2012; Khatri and Tyagi 2015). In Pakistan, four season exist with all climate and weather conditions. During high rainfall intensities flood occurs but there is no resources of water to store this large amount of water through different resources like dams, barrages and rain harvesting techniques. Therefore, in under developed countries, lack of water resources exist during all era (Asif Ali 2021).

Groundwater quality is dependent upon the groundwater flow towards lower area from northern to southern region in Indus basin of Pakistan. More than 90% of pumped water from 1.2 million private tubewells is used for agriculture. To complete the integral demand of water supply for food and drinking purpose, 62 billion cubic meter of groundwater is extracted per year (Arshad et al., 2013).

It is difficult to collect large number of groundwater data due to less observation points and more distance of installed monitoring sites, interpolation method is useful significantly to save time and money. Geostatistics techniques are used at different spatiotemporal scales and focuses on numerical collection techniques temporal data and time series analysis (Liu et al. 2016; Sahebjalal 2012; Basharat 2012; Bohling 2005; Masoud et al. 2016). GIS techniques were used to determine how much weights of each layer groundwater quality varying spatially and temporally and investigate the groundwater flow and hydro-chemical facies to assess the groundwater quality influence with different weights (Daughney and Reeves 2006; Chen and Feng 2013).

Kriging interpolation was used to estimate the groundwater quality that lower weights and contain mixture of heavy metal concentration, rocks, minerals and different chemicals and fertilizers (Abedinzadeh, et al., 2019; Istok and Cooper, 1988). Most of the researcher used this crucial tool to evaluate the surface and groundwater quality. Water surface change were estimated by suitable mapping in Netherland (Finke et al., 2004) by simple kriging, different groundwater quality parameters were assessed in Iran (Zehtabian et al. 2013) by interpolation techniques and geostatistics application in modelling of groundwater flow in Belgium (Huysmans and Dassargues, 2009). Ordinary kriging of geostatistical method is used in this study to assess the quality of water from different types such as simple, cokriging, universal, ordinary (OK), block, and disjunctive kriging but its detailed explanation is given in previous studies (Yamamoto et al., 2000; Stein et al., 1999, Gringarten and Deutsch 2001; and Cressie et al., 1990). The ordinary kriging is the most used tool to estimate the quality parameter for irrigation, livestock, and drinking purpose (Mcgrath and Zhang., 2003; Zimmerman et al., 1999). The research was conducted to evaluate the groundwater quality impact in Pre & Post-monsoon season using statistical techniques, GS+ (Gamma Design) and GIS software.

Methodology

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Study Area

This study deals with the assessment of variations in the groundwater quality in Multan, Khanewal, Lodhran, Vehari, Pakpattan and Sahiwal districts of Southern Punjab province, Pakistan. The study area of about 14658 km² is selected as shown in Figure 1. Mostly cultivated crops of the area are wheat, sunflower, cotton, paddy and sugarcane. The weather of this region is hot and dry summer due to more temperature and desert sandy area along western part. The maximum temperature recorded in summer is 54 °C and lowest recorded temperature in cold winter is − 1 °C (F. Abbas 2013). Paddy, Sugarcane, Cotton and wheat are the major crops that are cultivated mostly in this area. Average annual rainfall recorded was measured about 100 to 300 mm . In this region of South Punjab, main reason of anthropogenic activities involved due to more installation of industries and population (Ali et al., 2020; Faisal et al. 2013). The average elevation of this region is about 130 m above mean sea level. This aquifer consists of alluvial deposition and plains that were transported with flowing rivers during usually flood period.

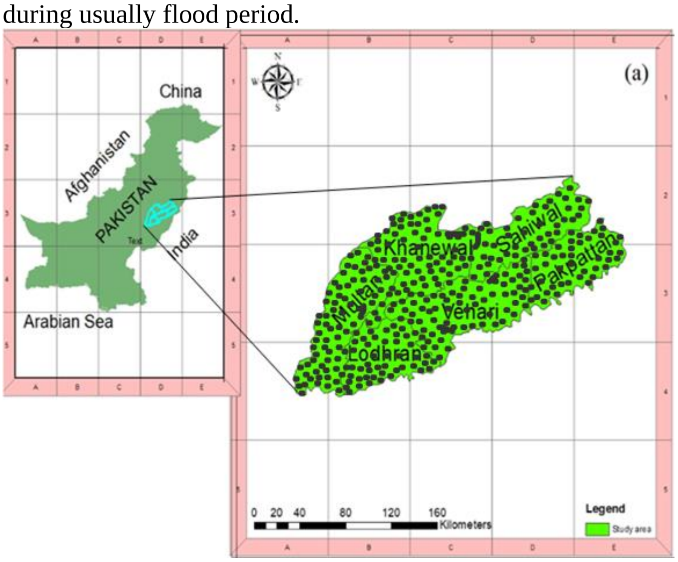
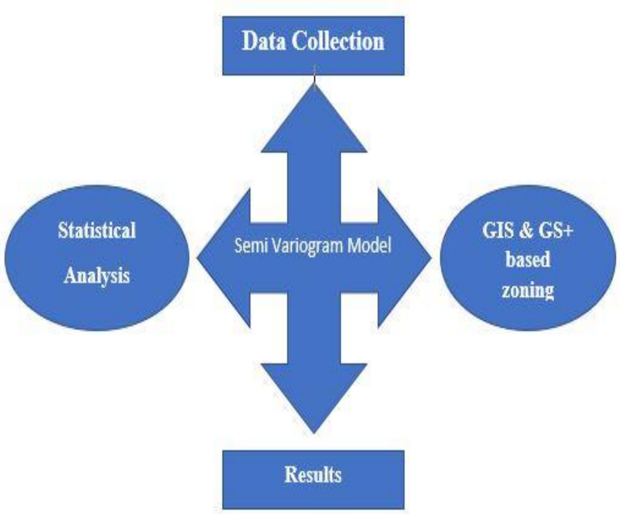


Figure 1. Study area location of six district of Southern Punjab

Data Collection and Methodology



Schematic View

Groundwater Data Collection

The 669 monitoring sites data of one year was collected from two Irrigation Zones of Irrigation Department, Pakistan. The water quality parameter for irrigation were examined, using standard protocols of PCRWR and Punjab Irrigation Department (PID). The samples are collected from each monitoring sites two times in the pre-monsoon and post-monsoon season. The three major indicator of irrigation are used to illuminate the water quality.

Geostatistics

The wide applications of geostatistics are mostly applicable in the field of hydrology, geology and water resources engineering and management. Especially used in different field for evaluation of contamination distribution and delineation with elevation, water level, soil and water EC. Multivariate geostatistical analysis assimilate the geostatistical and multivariate techniques and used for delineation of different variable sources at different spatiotemporal scales to assess the best variogram model to justify the spatial regression against different parameters. The standard best fit model resultant of theoretical variograms should extract the utilized parameters that used in the kriging equation for delineation (Geoffrey M. L., 1989). The variogram γ(h) is deliberated (Jalali et al, 2017) as Eq. (1):

$$\gamma(h) = \frac{1}{2} \mathrm{Var}\,[Z(x)-Z(x+h)] \tag{1}$$

where, h represents the lag distance, Z(x) is the value of the variable at location x, Z(x+h) is the value at location x+h, Var is the database variance , in the other word Var is defined as Eq. (2):

$$\mathrm{Var}\,(a) = S^2{}_{N-1} = \frac{1}{N-1}\sum_{i=1}^{N}(a_i - \bar{a})^2 \tag{2}$$

where N represent the number of data and a is the average of given data.

Commonly used semi variograms model is of four types are Linear, Spherical, Exponential

and Gaussian and their equation are (Robertson, G.P., 2008) Such as:

Exponential Model:

$\gamma(h) = C_0 + C\,[1 - \exp(-h / A)]$

Gaussian Model:

$\gamma(h) = C_0 + C\,[1 - \exp(-h^2 / A^2)]$

Spherical Model:

$\gamma(h) = C_0 + C\,[1.5(h / A) - 0.5(h / A)^3]$ for $h \leq A$

Linear Model:

$\gamma(h) = C0 + h\,(C / A)$

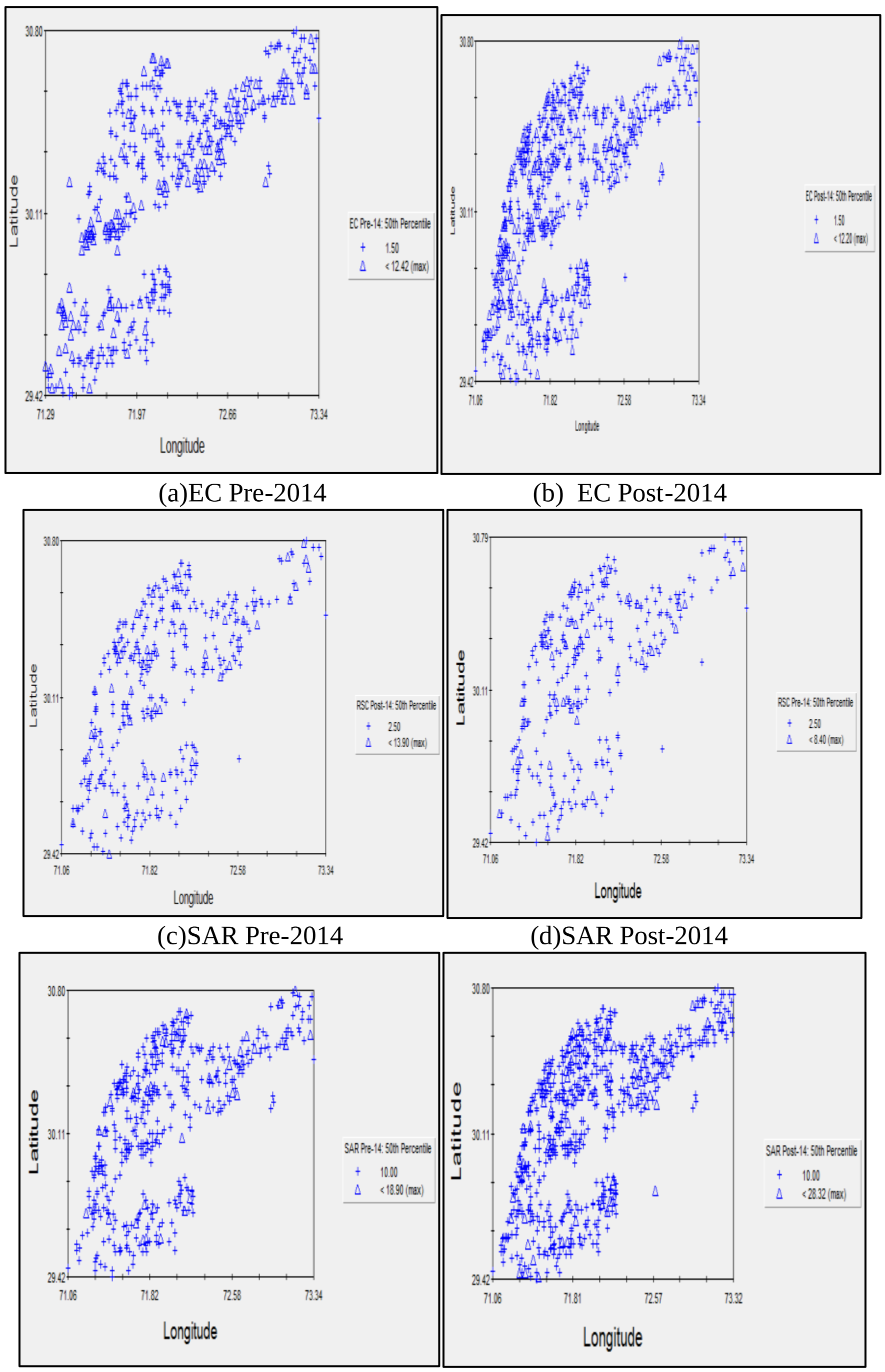
where γ(h) is the semi variogram value, h represents lag interval, a denote the range parameter a. Models having different parameter characteristics such as nugget effect (C0), sill (C0 + C), effective range (R^2) and RSS. All statistical parameters were investigated using Gamma Design software. Best fit semi variogram model was adopted and dependent of R^2 and RSS score for kriging interpolation (Karami, et al, 2018).

GIS and GS+ based zoning

GIS software is one of the most powerful tool than other GS+ and WinGslib software to capture, manipulate, manage, integrate, evaluate and store spatial data with reference to the earth. There are four types of interpolation, where kriging is a geostatistical approach to interpolate the unknown location with reference to known locations (Rossi et al. 1994). After justifying best fit model, GS+ software used to operate the mechanism to draw maps using kriging interpolation. Quantile Posting-Z indicate the water quality pattern with reference to good and hazardous contamination. In the first step, maps were prepared in 2D and 3D pattern to check accuracy with GIS and pattern trend with reference to GIS maps. In the second step study area was made using tutorial as shown in Figure 1. and then converted into shapefile using GIS software. Using shapefile different delineation were made according to semi variogram model.

Results and Discussions

In Figure 2. quantile posting-Z of SAR, RSC & RSC are shown to indicate the data variability to indicate good and bad groundwater quality symbols. Positive sign indicates the good range (≤1.50) of EC, SAR and RSC as well as small triangles indicates the results with adverse effect of z-posting having score (>1.50)



(a)EC Pre-2014 (b) EC Post-2014

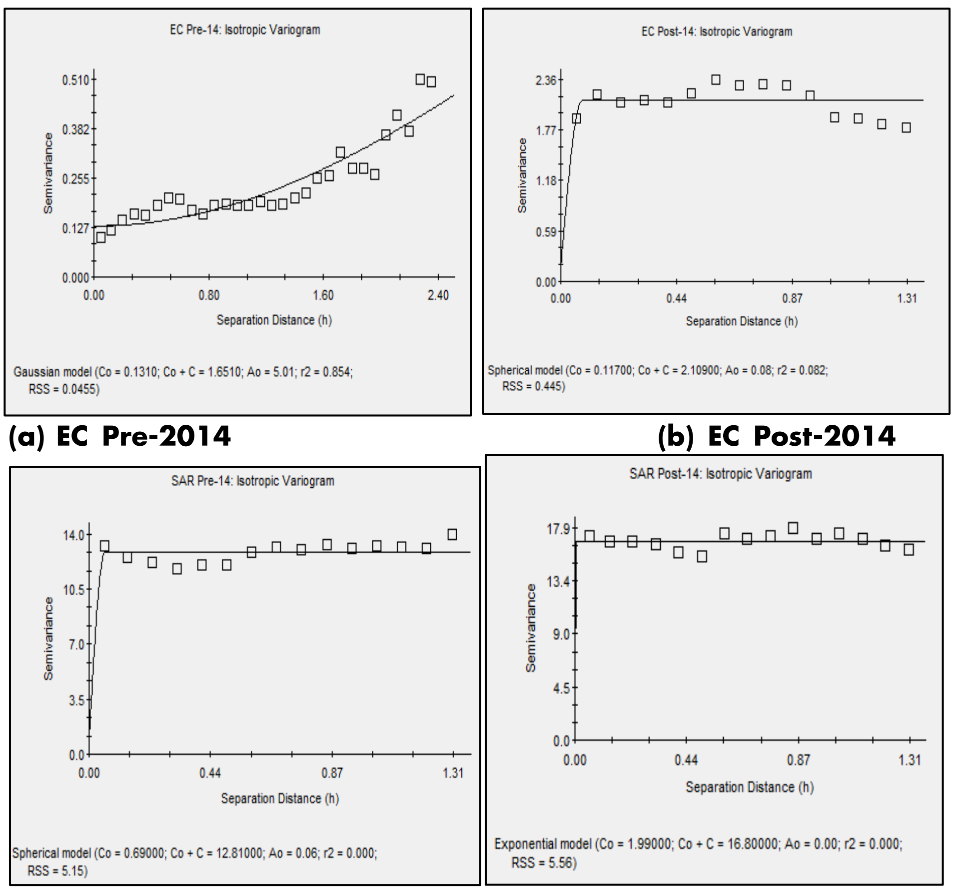
(c)SAR Pre-2014 (d)SAR Post-2014

(e)RSC Pre-2014 (f)RSC Post-2014

Figure 2. Quantile Posting-Z of SAR, RSC & RSC.

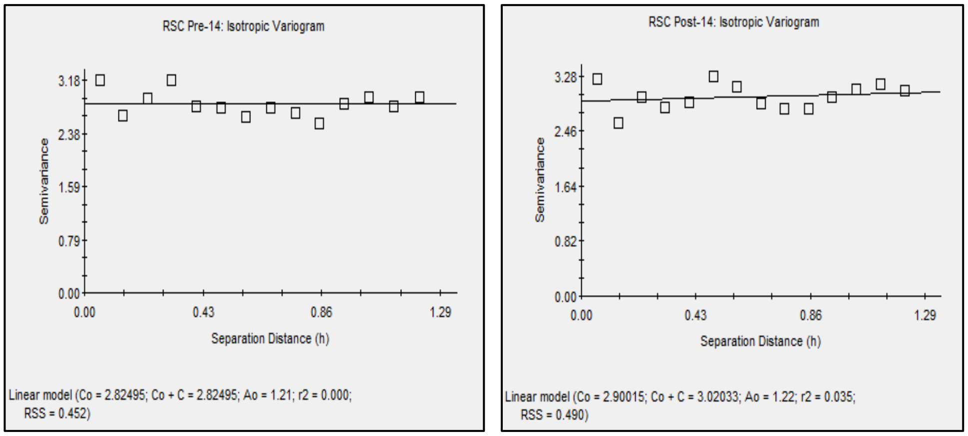
Analysis the data and selection of Best fit Model using gamma design software to perform Interpolation techniques via GIS and GS+ software. Delineation of groundwater quality will show the results, after the selection of best fit model from given five models such linear, spherical, exponential and gaussian. Best fit model selected using GS+ software, with reference to lower the value RSS but maximum value of r^2 to define how much accurate a model fits the variogram data of groundwater data. But according to data variability of Pre-2014 & Post-2014, best fit model adopted using gyma design software to select best fit model in kriging equation and GIS software are shown in Figure 3. And experimental variogram were fitted to different mentioned model as theoretical variogram according to spatial data. Table 1. Shows that valid variogram parameters sites data of both monsoon season.

The ratio of the nugget and sill is classified in three categories such as variable have ratio less than 0.25 have best agreement, ratio range 0.25 to 0.75 represent moderate agreement and ratio greater than 0.75 indicate week spatial dependence agreement (Mehrjardi et al. 2008). EC and SAR parameters having good spatial dependence but RSC parameter having week due to high score of ratio. One of the kriging interpolation advantage is that it evaluates MSIE (mean square interpolation error). The parameters of model defined in Table 1. used in kriging equation to assess and produce the actual data by evaluated parameters. Frequency histogram was made to normalize the data firstly, to assess the model and 2D and 3D delineation (Rossi et al., 2014). Default 2D and 3D Maps made using GS+ software, used to check the accuracy of software with best fit model against ArcGIS, are shown in Figures 4 and 5. Evaluated the 2D and 3D maps, prepared in GS+ software. Same trend was observed in GS+ software mapping to justify observed data with low accuracy than GIS mapping zones. GIS is a more precise and powerful tool than GS+ for accurate delineation of groundwater assessment. GS+ software (gyma design) was used to assess and justify the different parameters of groundwater quality, at different region of the world (Jalali, et al, 2017; Karami et al., 2018; Al-Omran et al., 2017; Mohammadyari et al., 2017)



(a) EC Pre-2014 **(b) EC Post-2014**

(c) SAR Pre-2014 (d) SAR Post-2014

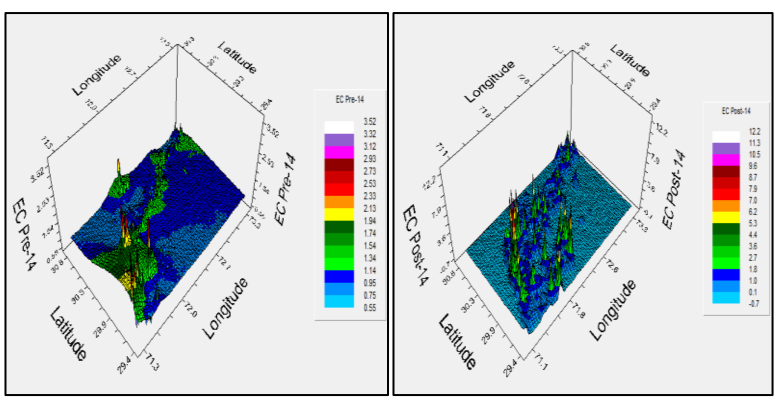


(e) RSC Pre-2014 (f) RSC Post-2014

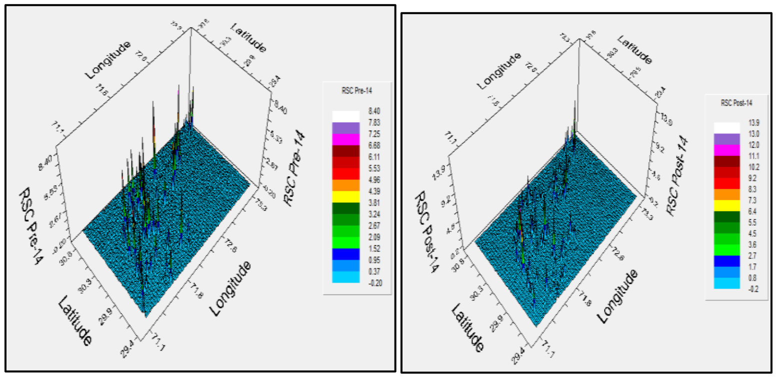
Figure 3. Best fit model selection for Kriging interpolation.

Table 1. Best fitted semi variogram models with its characteristics and groundwater quality parameters

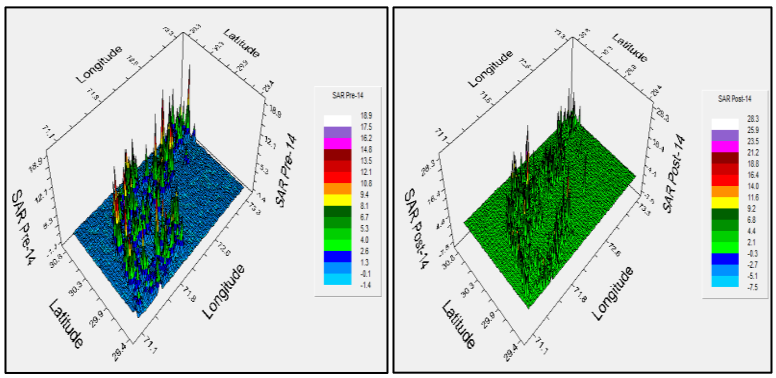
Groundwater quality	**Model**	**Nugget (C_0)**	**sill (C_0 + C)**	$\frac{C0}{(C0 + C)}$	R^2	**RSS**
EC Pre-2014	Gaussian model	0.13	1.65	0.07	0.85	0.04
EC Post-14	Spherical model	0.11	2.10	0.05	0.082	0.44
SAR Pre-14	Spherical model	0.69	12.81	0.05	0	5.15
SAR Post-14	Exponential model	1.99	16.80	0.11	0	5.56
RSC Pre-14	Linear model	2.82	2.82	1	0	0.45
RSC Pre-14	Linear model	2.90	3.02	0.96	0.035	0.49



(a)EC Pre-2014 (b) EC Post-2014

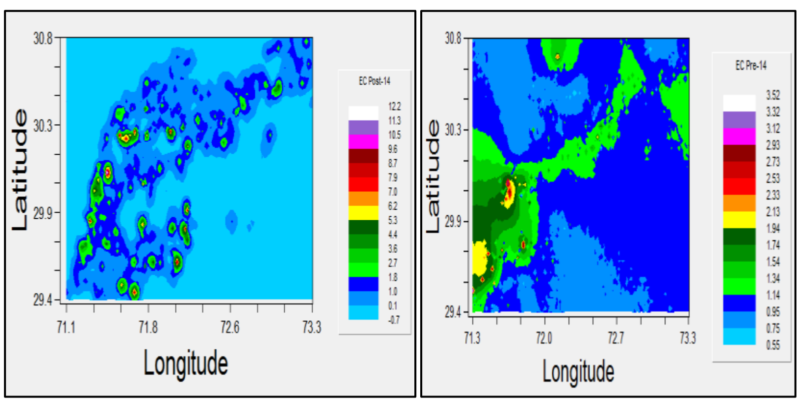


(c)SAR Pre-2014 (d)SAR Post-2014

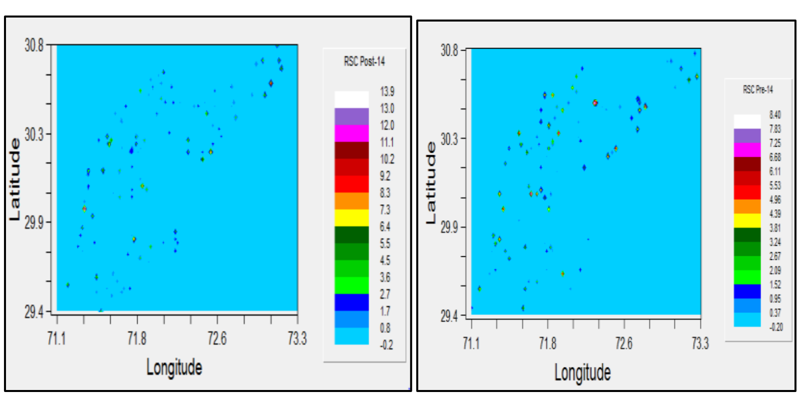


(e)RSC Pre-2014 (f)RSC Post-2014

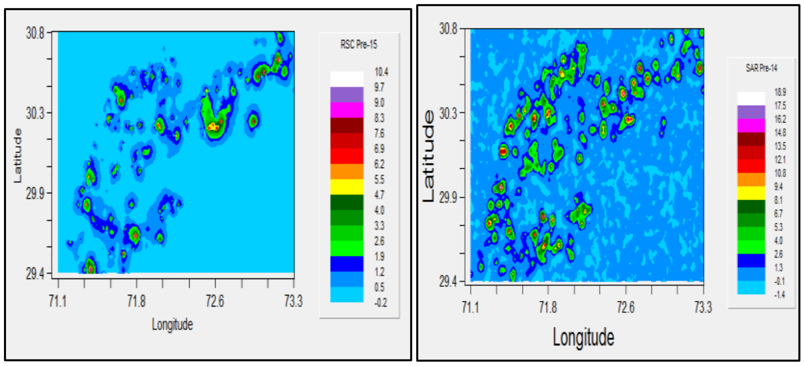
Figure 4. 3D Mapping of groundwater quality parameters



EC Pre-2014 (b) EC Post-2014



SAR Pre-2014 (d) SAR Post-2014



(e) RSC Pre-2014 (f) RSC Post-2014

Figure 5. 2D Mapping of groundwater quality parameters.

The weights of irrigation water criteria were classifying in three categories such good, marginal and bad (hazardous) according to allowable limits followed by WAPDA (1982) as shown in Table 2. Hight weightage quality was referred to good limit in Figure 6. All delineation pattern consists of three layers for each water quality parameter as described in table 2. Where marginal and bad categories referred to low weights (Bonham C.G. 1994 and Vijay et al., 2011). The most valid category was Groundwater quality data was assessed and delineated by using kriging interpolation method by several researcher in previous studies (Solangi et al., 2017; Nikroo et al., 2010; Rahmawati et al., 2013; Ebrahimi et al.,2011; Nwankwoala et al.,2012) Maps with kriging interpolation that are on the base of best fit model are to be compared with the 2D & 3D map prepared (with GS+ software having low accuracy) and also give excellent spatial variance in data for delineation and evaluation of wide data. These delineated maps distinctively show that quality of groundwater become hazardous from northeast to southwest and most of the area was affected by EC. In post monsoon more hazardous area was detected with EC, SAR and RSC.

It was summarized that marginal and bad category of groundwater for EC, SAR and RSC was more in post-monsoon season due to rainfall water recharge rate (17 to 22%). About 15% water is recharged from field that are irrigated by surface water bodies and tube wells. The huge amount contribution of chemicals and pesticides used during land reparation that flow during percolation and recharge rate of field and rainfall water from soil. In the previous studies, hazardous groundwater quality was observed in lower part of any region due to groundwater flow and percolation rate (Qureshi et al. 2004), same results occurred in Figure 6(a-f). During monsoon season more rainfall exist but after monsoon canal discharge becomes higher monsoon, same residual effect causes high sodium ratio in groundwater . Water chemistry involve in this process, when recharged water (field water, flooded, rainfall and surface waterbodies) leach down and dissolve the salts, rocks and reactive minerals and become a part of groundwater such as plagioclase feldspars (Fisher R. S. et al., 1997). The study area (2 to 10%) and (7 to 40%) was affected in pre-monsoon season and post monsoon respectively, due to EC, SAR and RSC. Maximum affected area was due to EC parameter. This shows groundwater quality is being affected due to climate change with more precipitation after monsoon (summer) season and increase of many tube wells. Similarly, SAR and RSC of both seasons justified the increasing no of contaminated monitoring sites

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Table 2. Weights of different layers with respected irrigation water quality parameters

Parameter	Quality	Criteria	Weight
EC (dS/m)	Good	<1.5	3
	Marginal	1.5 – 2.7	2
	Bad	>2.7	1
SAR	Good	<10	3
	Marginal	10 - 18	2
	Bad	>18	1
RSC (meq/L)	Good	<2.5	3
	Marginal	2.5 – 5	2
	Bad	>5	1

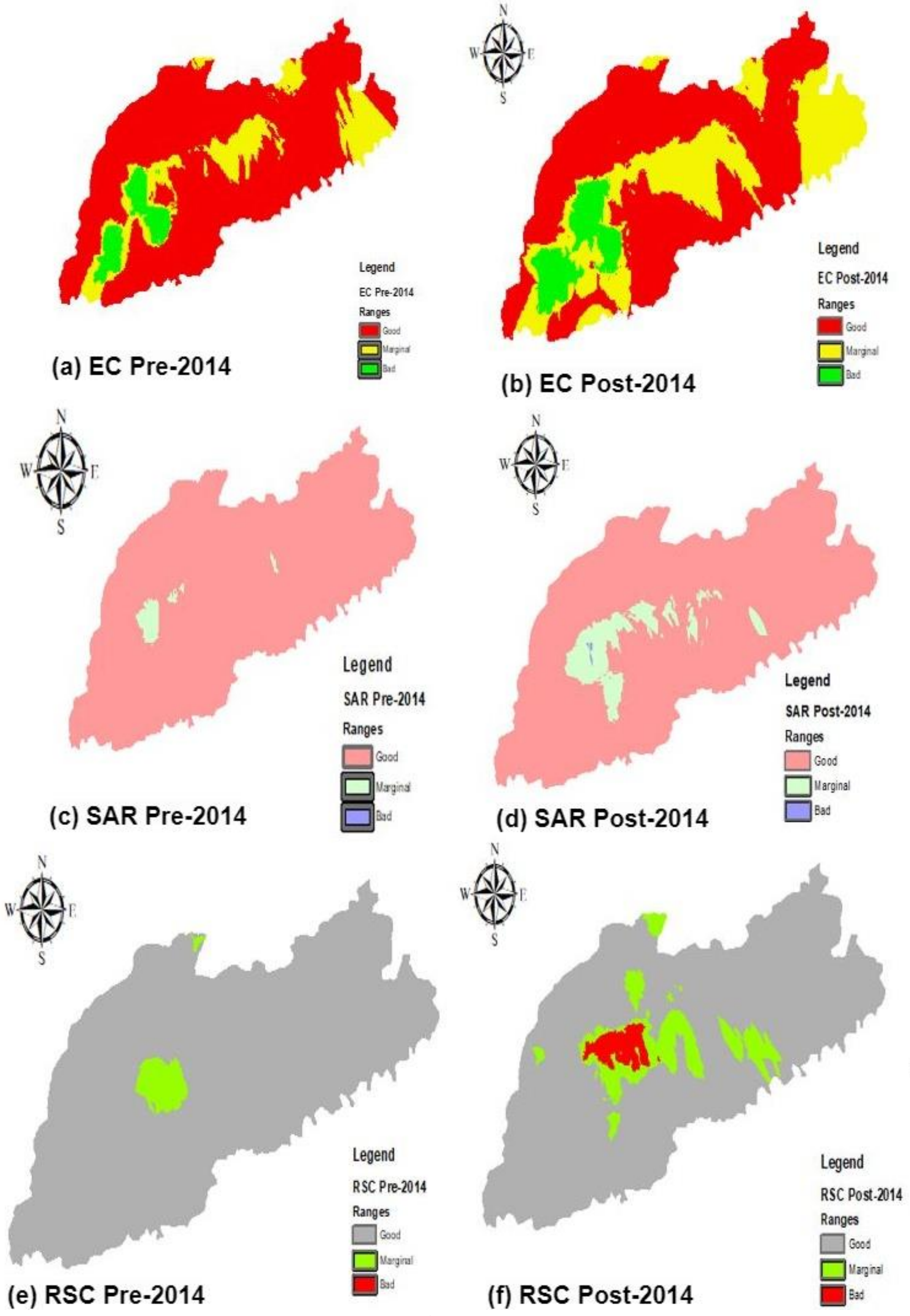

Figure 6. Groundwater quality of parameters., such as EC, SAR & RSC.

Conclusion

In statistical analysis approaches were used to estimate and manage long term data and understand the weightage of ground water quality analysis. In statistical analysis, semi variogram models were selected for using best fit model during kriging interpolation techniques. The study area adverse affected with poor quality in pre & post monsoon was about 2 to 10 % and 7 to 40 % respectively unfit for irrigation purpose due to change in temperature, rainfall and canal discharge in Multan irrigation zone. Rainwater harvesting, auriferous storages and artificially recharge techniques should be adopted to protect groundwater quality in zone-weightage 2 and 1. Kabir Wala (Khanewal) and its surrounding areas (Multan) were more affected by EC, SAR and RSC parameters in industrial zone area. The water quality is under stressed conditions due to increase of population, more agricultural practices (more fertilizers, pesticides and other agriculture wastes), industries and sewerage discharge which take part underground with different chemical reaction during infiltration and percolation at different temperature and level. Accordingly, following recommendations are summarized:

It is concluded that the Policy maker should make such standard rules that helps to maintain ground water quality as well as groundwater level. Because decreasing of groundwater level also effects groundwater quality. So, there should be defined standardized rule to install number of tube wells within limited range and at standard depth and distance. Water quality becomes poor after extracting more quantity of water specially at lower level. In tehsil Kabirwala, groundwater quality is decreasing continuously due to more effluent discharge of industries. The installation of new industries should be according to standard protocol of environmental act of Pakistan to control water quality.

Abbreviations:

EC = Electrical Conductivity
RSC = Residual Sodium Carbonate
SAR = Sodium Adsorption Ratio
WAPDA = Water and Power Development Authority
PID = Punjab Irrigation Department
PCRWR = Pakistan Council of Research in Water Resources
GIS = Geographic Information System
RSS = Residual Sums of Squares

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