A Geostatistical approach for mapping groundwater quality (Case Study: Tehsil Sheikhupura)

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Abstract: ***Groundwater is an important source of drinking water especially in rural areas of Pakistan. Therefore, it is very important to assess the quality of drinking water. The present study presents the geostatistical analysis of groundwater quality of tehsil sheikhupura where majority of people reside in rural areas. Groundwater is the only source of water for drinking purpose. The aim of the study is to present the data in GIS environment for better understanding the spatial distribution of each chemical parameter and mapping of the current situation of groundwater quality of tehsil sheikhupura. The most important chemical parameters of groundwater like Sulphate (SO_4), Nitrate (NO_3), Sodium (Na), Potassium (K), Calcium (Ca), Chloride (Cl), Magnesiurm (Mg), pH, Flouride (F), Total Dissolved Solids (TDS), Hardness, Iron (Fe), Arsenic (As) and Lead (Pb), are selected and compared to the guideline values presented by world health organization (WHO). The geostatistical analysis of these parameters was performed and spatial distribution maps are prepared for each groundwater parameter by ordinary kriging. The semivariogram values are tested and best fitted model for each parameter was selected on the basis of root mean square error (RMSE), average standard error (ASE), root mean square standard error (RMSSE) and mean square error (MSE). The water quality index was developed in order to present the overall water quality of the study area.***

Keywords: Geostatistics, GIS, Groundwater quality parameters, Ordinary Kriging, Groundwater quality index

1. Introduction

A clean drinking water is vital for a healthy life. In Pakistan, most of the people use groundwater for drinking purpose. In sheikhpura, groundwater is the major source of drinking water. The chemical contaminants pose serious health problems. The most important chemical contaminants which cause serious health problems are arsenic and fluoride which occur naturally and Nitrate from agricultural land as fertilizers. These three pollutants are often found in groundwater [1]. Sheikhupura is a part of the aquifer which is recharged by the River Ravi. The flow of River Ravi is dramatically decreased, which is the major source of aquifer recharge [2]. The major sources of groundwater recharge are seepage from rivers and irrigation canals, rainfall and return flow of pumped water. The major discharge source of groundwater is pumping through public and private tube wells. Generally the groundwater quality is fresh near the rivers and deteriorates to distant parts along the Doabs. The groundwater reservoirs are polluted through industrial, agricultural and different sewerage effluents [3].

Ahn and chon [4] studied the contamination of groundwater and its spatial distribution relationship among topography, land use, geology, topography and sources of pollution by the use of GIS in Seoul. The impact of urbanization on the quality of groundwater and the land use changes was studied by Barber [5] by using the techniques in GIS. In a research article by Ducci [6] produced the maps of groundwater quality and contamination by using GIS in Southern Italy. It was suggested that the use of GIS technique is vital in testing and improving the groundwater contamination risk assessment methods.

Subraman, Elago, and Damodarasamy [7] studied the hydrochemistry of groundwater and assessed the groundwater quality for determining its suitability for drinking purpose in Chittar Basin Tamil Nadu, India. Asadi and Reddy [8] conducted a study that monitors the ground water quality, related it to land use and land cover and mapped the groundwater quality for a part of Hyderabad metropolis by using gis techniques. Remesan and Panda [9] conducted a study to examine the pollution level of various contaminants in the watershed of Kapgari and projected it in GIS environment by various maps.

A detailed GIS based study on groundwater hydrochemistry in Vattamalaikarai Basin, Tamil Nadu, India, has been carried out to assess the quality of ground water for determining its suitability for drinking purposes in a research article by Vennilla, Subramanni, Elago [10]. Another work was done by Ahmed and Ali [11] to assess the groundwater contamination due to the growing population of Sohag, Egypt. The purpose of this study was to focus on the integrated role of various geochemical processes, agriculture and urbanization in evaluation of the composition of groundwater and its impact on the quality of groundwater.

Ishaku, Ahmed and Abubakar [12] studied the groundwater quality using chemical indices and GIS mapping in Jada area of Northern Nigeria. They had generated the surfaces of different parameters of water quality by using IDW interpolation technique and delineated the areas water quality. The significance of groundwater is increasing because of scarce presence of surface water. The unfavorable climatic conditions like high evaporation, low rainfall, frequent occurrence of dry spells and unsuitable geology has greatly affect the safe usage of these surface and subsurface water reservoirs. For sustainable management of groundwater resources, monitoring of groundwater quality is really important. The accuracy of interpolation for spatial prediction of groundwater is analyzed in various studies [13]. Geostatistical analysis is quite popular for the analysis of various hydrochemical parameters of groundwater chemistry. In geostatistical methods, kriging is the most important technique [14]. Marko performed the geostatistical analysis for mapping the groundwater quality of Wadi Usfan, western Saudi Arabia. They applied the kriging method to interpret the spatial distribution of groundwater quality and to predict the trend of anions and cations in the study area. Kumar and Remadevi [15] applied the spatial statistical technique for the analysis of groundwater in the area of Idira Gandhi Nahar Pariyojana in Rajasthan, India. Moasheri [16] studied the sodium absorption ratio of groundwater using geostatistical methods. In general he found it quite suitable for the estimation of SAR of groundwater quality. Sahebjalal [17] used the geostatistics to investigate the groundwater quality in the study area. By using the kringing method, the spatial prediction maps of each parameter were prepared. Shamsudduha [18] used different statistical methods to interpolate the spatial variability arsenic in groundwater of Bangladesh. The degree of spatial variability was predicted by variogram analysis. Various interpolation methods were applied and the most appropriate method was selected from cross validation. It was found that ordinary kriging produced better prediction models for arsenic concentration.

The objective of the research paper is to explore the groundwater data through exploratory spatial data analysis (ESDA) and mapping of the spatial variability of groundwater hydrochemistry. The study will also evaluate the geostatistical methods to interpolate the groundwater parameters. In this study the geostatistical analyst of ArcGIS is used for data investigation.

2. Study Area and Data Collection

District sheikhupura is an administrative subdivision of Lahore Division in the Punjab province of Pakistan. District sheikhupura consisted of five tehsils Sheikhupura, Safdarabad, Firozewala, Muridke and Sharaqpur. The study area is consisted of tehsil sheikhupura. The total area of tehsil sheikhupura is 1729.8 Km^2 and it lies between 73°37'45.60"E to 74° 7'39.52"E and 31°58'55.22"N & 31°29'44.07"N. Tehsil sheikhupura is further subdivided into 51 union councils. The data distribution shows that it was taken from all parts of the study area. The data is collected by Pakistan Council of Research and Water Resources (PCRWR) in 2006. The parameters selected for groundwater analysis are Sulphate (SO_4), Nitrate (NO_3), Sodium (Na), Potassium (K), Calcium (Ca), Chloride (Cl), Magnesiurm (Mg), pH, Flouride (F), Total Dissolved Solids (TDS), Hardness, Iron (Fe), Arsenic (As), Lead (Pb),.

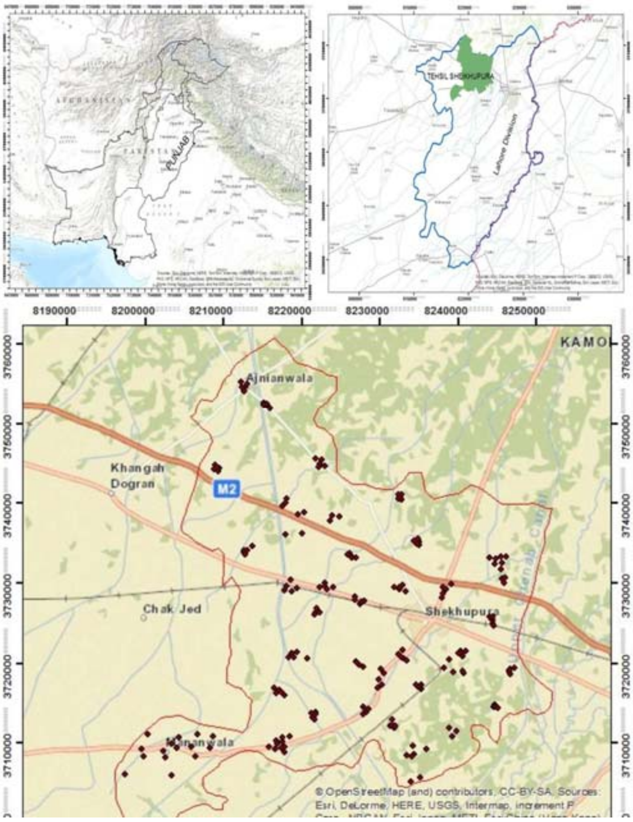


Figure 1: Location of Study Area

3. Statistical Analysis of Groundwater Samples

The chemical parameters of groundwater samples are examined by using exploratory spatial data analysis (ESDA) for normalization of data. The samples of nitrate, arsenic and magnesium are normally distributed whereas all the remaining samples are transformed by using logarithm.

The concentrations of SO_4 in groundwater vary from 7 mg/l to 580 mg/l with mean 159.4 and standard deviation 88.76. The log transformation is applied to make the data normalized. The desirable limit of SO_4 by WHO are 200 mg/l. 65 groundwater samples exceeded the concentration level of desirable limit of WHO standards for drinking water quality. The rest of groundwater samples are well within the desirable limit.

The concentration of nitrate (NO_3) in groundwater samples is observed to be well within the desirable limit (45 mg/l). The desirable limit for nitrate in drinking water is 45 mg/l. The range of nitrate concentration in groundwater samples is from 0 mg/l to 15.93 mg/l with a mean and standard deviation is 2.5077 to 3.0245 respectively. The nitrate data is normally distributed and there is no need of log transformation.

The concentration of iron (Fe) in groundwater samples are ranged from 0.05 mg/l to 0.91 mg/l with a mean and standard deviation 0.01815 to 0.08799 respectively. Only 10 groundwater samples of iron exceeded the desirable limit (0.3 mg/l) of WHO standards for drinking water quality. All the remaining 200 samples are well below the desirable limit.

Arsenic concentrations are groundwater poses serious health problems. Long term exposure to arsenic contaminated water produces health problems called arsenicosis. The symptoms are usually lassitude, muscular weakness and mild psychological effects. Arsenic also causes other diseases of cardio-vascular diseases, diseases of liver and kidney, neurological effects, diabetes and lung diseases [19]. The desirable limit for drinking water quality of WHO standards is 10ppb. The arsenic concentration in groundwater samples range from 0 ppb to 52 ppb with mean and standard deviation is 8.030 to 10.697. The concentrations of 58 groundwater samples are found to be more than the desirable limit.

Fluoride is found in groundwater naturally. High levels of fluoride in groundwater are found due to interaction of water with rocks and sediments. Most of the fluoride sources are geological while other sources are from industrial or impurities in phosphorus fertilizers (WHO). The WHO guidelines for fluoride is set at 1.5 mg/l. only one groundwater sample show the concentration of fluoride above the desirable limit. However all remaining groundwater samples have well below the concentration of fluoride. The mean and standard deviation of fluoride is 0.4488 and 0.2876 respectively. The values of fluoride in groundwater ranged from 0.02 mg/l to 2.5 mg/l.

Lead sources found in environment naturally and also due to various human activities. Lead put negative impacts on health. The harmful effects of lead on human health are high blood pressure, brain damage, nervous system damage, anemia, kidney damage and learning disruptions in children [20]. The levels of lead concentration in the groundwater samples ranged from 0.03 to 9.76. The WHO guideline values for lead are set at 10ppb. The mean and standard deviation values of lead are 3.045 and 2.277. All the groundwater samples have values which are well below the desirable limit.

The chloride values of groundwater samples of the study area vary greatly from 8 mg/l to 667 mg/l. out of 210 groundwater samples, 32 samples have values which are well above the desirable limit (200 mg/l). The mean and standard deviation values of chloride are 113.7 and 109.7. The chloride data is not normally distributed therefore log transformation is applied to make it normalized.

The values of Calcium in the area vary from 8 mg/l to 140 mg/l with mean 57.338 and standard deviation 23.23. The concentrations of 44 samples are above the desirable level (75 mg/l). All sample values are with the permissible limit (200 mg/l). The concentration of Mg in groundwater samples vary from 0 mg/l to 85 mg/l. the data of magnesium is normally distributed. The mean and standard deviation values are 31.85 and 14.49 respectively. Out to 210 groundwater samples, 104 samples have values above the desirable limit (30 mg/l).

The concentrations of sodium in the groundwater samples are ranged from 23 mg/l to 930 mg/l with a mean and standard deviation values of 231.12 and 147.02. The concentrations of 140 samples are within the desirable level (250 mg/l) while 70 samples have values above the desirable limit. The values of total dissolved solids in groundwater samples vary from 46 mg/l to 2207 mg/l with mean and standard deviation 890.46 and 379.37 respectively. According to WHO standards for drinking water quality, the desirable limit for total dissolved solids is 500 mg/l. the concentration of TDS in 194 samples is exceeded the desirable limit.

The concentration values of potassium in groundwater samples are ranged from 1 mg/l to 60 mg/l. the mean and standard deviation values are 10.88 and 8.091 respectively. The values of potassium in 95 samples exceeded the desirable limit (10 mg/l) while in 115 samples is below the desirable limit.

The values of pH in groundwater samples are ranged from 7 to 8 with mean and standard deviation 7.31 and 0.2085 respectively. All groundwater samples have pH values well with the desirable limit (6.5 to 8.5). The values of hardness in groundwater samples vary from 60 mg/l to 575 mg/l with mean and standard deviation values of 178.15 and 101.36. The values of hardness in 168 groundwater samples are above the desirable limit (200 mg/l).

4. Geostatistical method

Geostatistics assume that at least some of the spatial variation of natural phenomena can be modeled by random processes with spatial autocorrelation. The techniques of geostatistics are used to:

- To predict values at unsampled locations
- To assess the uncertainty associated with predicted values
- To model the spatial patterns

The values at unmeasured locations were calculated by using Ordinary Kriging method. Kriging method is used to produce surface maps of predicted values, maps of standard errors, maps of probability and maps of quintiles [21]. The data of groundwater quality was interpolated using geostatistical method. The geostatistical interpolation model consists of statistical models that are based on autocorrelation. The prediction surface of all groundwater parameters was prepared using Ordinary Kringing. The following steps are required for producing prediction surface by Ordinary Kriging.

5. Exploratory spatial data analysis

Before using the interpolation techniques, the data can be explored by following tools provided in Geostatistical wizard of ArcGIS.

- Histogram- used to explore the data to determine the spatial distribution of data.
- Normal QQPloat- it is used to check to normal distribution of dataset
- Vornoi map- to analyze the spatial variability and stationarity of dataset.
- Trend analysis- to determine the global trend in dataset
- Semivariogram- to examine the spatial autocorrelation in dataset

- General QQPlot- to determine whether datasets have same distributions
- Crosscovariance Cloud- to understand the crossvariance

Through the use of ESDA tool in ArcGIS, data was explored to check the data distribution and remove the outliers and trend in dataset before creating prediction surfaces. The histogram and normal QQ plot used to examine if the data is normally distributed. In this case, it is observed that data is more or less normally distributed for all the groundwater parameter. The QQplots and histograms show the normal distribution of data of various groundwater parameters ($SO4_,$ $NO_{3,}$ F, Fe, Cl, Mg, K, As, Pb, Hardness, Na, Ca, TDS, pH) in the figure. The statistical values for these parameters are shown in the table 1. The log transformation is applied to various groundwater parameters except magnesium, arsenic and nitrate to make the data normally distributed. The high skewness values indicate the presence of outliers. The outliers are the values which are very high or low as compared to the surrounding values in the dataset. These outliers put negative effect on the geostatisical analysis so therefore their presence is very necessary to know and remove it from the dataset.

6. Fitting a Model

Semivariograms are used to quantify the spatial autocorrelation between groundwater samples. Things that are close to each other are more alike than the things farther away is called the spatial autocorrelation.

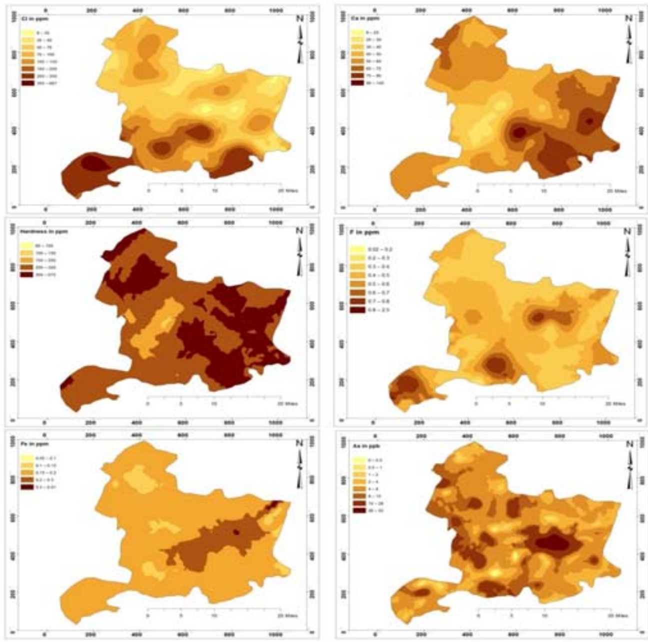
This relationship between samples is measured by semivariograms. The selection of a particular model has great impact on the prediction of unknown values (ESRI, 2003).

Four models (Circular, Gaussian, Exponential, Spherical) were tester for each groundwater parameter ($SO4_,$ $NO_{3,}$ F, Fe, Cl, Mg, K, As, Pb, Hardness, Na, Ca, TDS, pH) and best model selected for prediction by cross validation. The values of mean error (ME), root mean square error (RMSE), average standard error (ASE) and root mean square standard error (RMSSE) were assessed by applying the models of circular, Gaussian, exponential and spherical. The model is best fitted if the root mean square error (RMSE) values are closer to the average standard error (ASE). The mean error should be closer to zero for best performance of the fitting model.

The accuracy of a model usually depends on the values of mean square error (MSE) which should be close to zero. If the values of root mean square error (RMSE) and average standard error (ASE) are close to one another, the prediction error is much accurate. If root mean square error values are more than the average standard error, the prediction is overestimated. On the other hand if the values of root mean square error are smaller than average standard error values, the prediction is underestimated. The values of root mean square standard error should be closed to 1. If the values are over 1, the prediction is overestimated and if the root mean square standard error is less than 1, it is underestimated. So the best model was selected after assessing all these statistics.

7. Interpolation of groundwater quality parameters

The spatial distribution of groundwater quality parameters is shown by using Ordinary Kriging method in ArcGIS gesostatistical wizard. The surfaces created by using Ordinary Kriging method show the spatial distribution of groundwater quality parameters ($SO_{4,}$ $NO_{3,}$ F, Fe, Cl, Mg, K, As, Pb, Hardness, Na, Ca, TDS, pH) in the study area.



The maps generated by Ordinary Kriging method show the areas where the level of groundwater parameter is above the desirable standards of WHO for drinking water quality. The desirable limit for SO_4 in drinking water quality is 200 mg/l. the spatial distribution map of sulphate show that in most parts of the study area, the level of sulphate in groundwater is well below the desirable limit. However in some parts it is above the desirable limit like south west and central parts of tehsil sheikhupura. The spatial distribution map of nitrate shows that the level of nitrate concentration in groundwater is well below the desirable limit in all parts of tehsil sheikhupura. The spatial distribution map of total dissolved solids of tehsil sheikhupura shows that in south and south west of the study area, TDS values are well above the desirable limit (500 mg/l). The pH map of tehsil sheikhupura shows that pH of groundwater is well within the desirable limit (6.5 to 8.5). The concentration of potassium in groundwater is above the desirable limit in north and central parts of tehsil sheikhupura. More than 70 % of the study area shows that the concentration level of potassium in groundwater is quite high than the desirable limit of 10 mg/l.

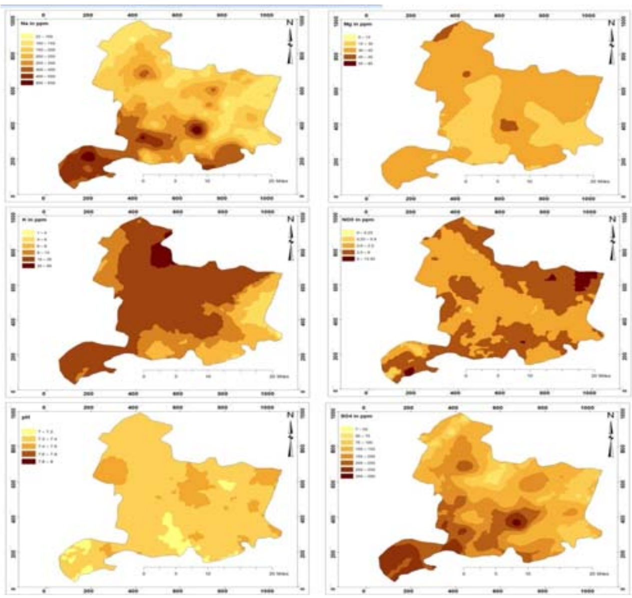


Figure 2: Spatial distribution maps of SO4, NO_3, F, Fe, Cl, Mg, K, As, Pb, Hardness, Na, Ca, TDS and pH.

The spatial distribution map of sodium shows that concentration of sodium is above the desirable limit (250 mg/l) in south and south west of the study area. The concentration level of magnesium is above the desirable limit in most parts of tehsil sheikhupura.

The map of magnesium shows that most of the northern and central parts have high values of magnesium in groundwater. Very small parts of tehsil sheikhupura have values of magnesium which are below the desirable limit (30 mg/l). The desirable limit of calcium in drinking water is 75 mg/l. the spatial distribution map of tehsil sheikhupura shows that groundwater of the south and south eastern parts have concentration level of calcium above the desirable limit. While most of other parts show the concentration level of calcium within the desirable limit. The spatial distribution map of chloride shows that some parts of the study area show concentration level of chloride in groundwater above the desirable limit (200 mg/l). The concentration levels of chloride found quite high in south and south western parts of tehsil sheikhupur, while all other parts have levels of chloride within the desirable limit. In most of the areas, the hardness values are above the desirable limit (200 mg/l). Very small part of tehsil sheikhupura has hardness values below the desirable limit. In all parts of tehsil sheikhupura, the concentration of fluoride in groundwater is well within the desirable limit (2.5 mg/l).

The spatial distribution map of arsenic shows that in some parts of the study area, the concentration of arsenic in groundwater is more than the desirable limit (10 ppb). The high values of arsenic are found in the center and some other parts of the study area. The distribution map of iron shows that the concentration level of iron in groundwater is quite high in the central parts of tehsil sheikhupura. All other parts of the study area have values well within the desirable limit (0.3 mg/l). The desirable limit for lead in drinking water is 10 ppb. In all parts of the study area, the concentration levels of lead are well below the desirable limit.

8. Calculation of Water Quality Index

The groundwater quality index developed and used by many authors, for example, Banoen-Yakubo [22], Banerjee and srivastava [23], Soltan, Ramakrishnaiah [24] and some others. The procedure adopted to calculate water quality index is described below.

Table 1: calculation of relative weight of each parameter

Parameters	*Desirable limit*	*Weight (wi)*	*Relative weight (Wi)*
SO4	200	5	0.08475
NO3	45	5	0.08475
Fe	0.3	5	0.08475
TDS	500	5	0.08475
F	1.5	5	0.08475
As	10	5	0.08475
Pb	10	5	0.08475
Cl	200	5	0.08475
Ph	7.5	3	0.05085
Ca	75	3	0.05085
Mg	30	3	0.05085
Na	250	4	0.0678
Hardness	200	4	0.0678
K	10	2	0.0339
		Σwi= 59	ΣWi = 1

To calculate water quality index, 14 parameters of groundwater quality are selected from the dataset of study area. Each parameter is assigned weight according to its relative importance for quality of water for drinking purposes (Table 1). Maximum weight of 5 is assigned to sulphate (SO_4), nitrate (NO_3), Flouride (F), Iron (Fe), Chloride (Cl), Arsenic (As), Lead (Pb), Total Dissolved Solids (TDS) and weight of 4 is assigned to Hardness, Sodium (Na) and weight of 3 is assigned to , pH, Magnesium (Mg), Calcium (Ca), and weight of 2 is assigned to Potassium (K). the relative weight of each parameter is calculated by following formula;

$$Wi = wi \sum_{i=1}^{n} wi \quad (1)$$

Where, Wi is the relative weight, wi is the weight of i*th* parameter and n is the number of parameters In the next step quality rating scale is calculated by following equation

$$qi = (Ci / Si) \times 100 \quad (2)$$

Wher qi is the quality rating, Ci is the concentration of water quality parameter and Si is the drinking water quality standard according to the guidelines of WHO in mg/l. For determination of water quality index, the Sli of each parameter is determined first by the following equation;

$$Sli = qi \times Wi \quad (3)$$

Finally the water quality index can be calculated by the following equation

$$WQI = \sum Sli \quad (4)$$

On the basis of water quality index values, the type of water is defined and given in the table 1.

Table 2: Classes of water quality

Range	*Type of water*
< 50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very Poor water
> 300	Water

The calculated values by water quality index are used to generate the final water quality map of the study area.

Table 3: Water quality in the study area

Water Quality Class	Water Quality Index	Area (sq km)	Percentage of total study area (%)
Excellent Water	<50	0.47	0.027
Good Water	50-100	1134.37	65.577
Poor Water	100-200	595.448	34.396

On the basis of water quality index values, the area is divided into three types of water, excellent water, good water and poor water. In most parts of the study area, water fall into good water category which is 65.577 % of the total area of tehsil sheikhupura. the poor water quality area is about 34.396% of the total area. The excellent water is found in a very small part which is about 0.027% of the total area of tehsil sheikhupura.

9. Conclusion

The groundwater quality of tehsil sheikhupura is studied by using the geostatistics. The analsis of chemical parameters is performed using geostatical tool in ArcGIS. The ordinary kriging method is adopted to generate the surfaces of each chemical parameter. Fourteen (14) chemical parameters were selected to examine the situation of drinking water quality in tehsil sheikhupura by geostatistics. The spatial distribution maps shows the pattern of each parameter in the groundwater of the study area. The contamination of chemical parameters is shown in different parts of tehsil sheikhpura.

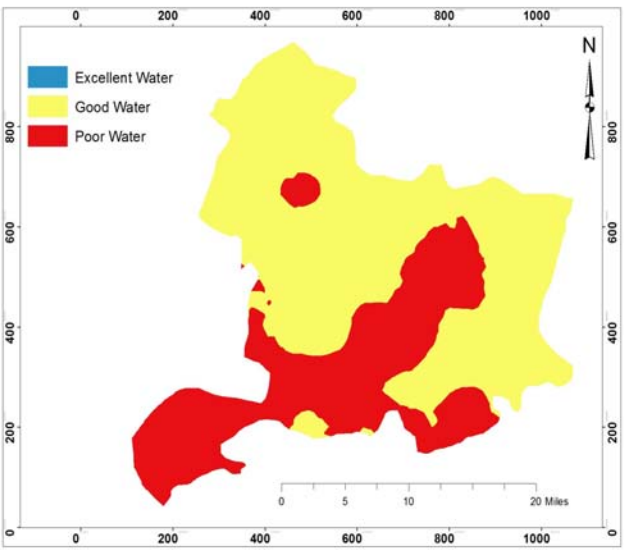


Figure 3: Groundwater quality map of study area

The spatial distribution maps of chemical parameter like sulphate (SO_4), nitrate (NO_3), Iron (Fe), Chloride (Cl), Arsenic (As), Total Dissolved Solids (TDS), Hardness, Sodium (Na), Magnesium (Mg), Calcium (Ca), and Potassium (K) show the contamination in different parts of tehsil sheikhupura. The spatial distribution maps of Flouride (F), Lead (Pb) and pH is well within the desirable limit standards for drinking water quality by WHO. In order to present the combine effect of all these chemical parameters for common people, water quality index method was developed to prepare the map of overall drinking water quality of tehsil sheikhupura. The WQI map presents the overall picture of the quality of drinking water in the study area. More than 595.44 square km of the study area has poor water quality, while 1134.37 square km area falls in the category of good water quality.

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