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Full Length Research Paper

Application of geographical information system (GIS) to groundwater quality investigation: A case study of Mardan district, Pakistan

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A study was conducted to determine the groundwater quality of Mardan salinity control and reclamation project (SCARP) area and its suitability for irrigation purposes. A total of 18 villages were selected and water samples were taken from each one. Spatial data of the locations were taken by Magellan GPS Receiver. These samples were analyzed in the laboratory and then compared with the irrigation water quality guidelines suggested by WAPDA (Water and Power Development Authority Pakistan) and FAO (Food and Agriculture Organization) to determine the groundwater quality for irrigation. Analysis and mapping of ground water quality data were performed by using Arc GIS 9.2 software. Various statistical measures such as mean, standard deviation, coefficient of variation and confidence interval of groundwater quality data were calculated. The results indicated that majority of the ground water samples were in the range of marginal fit category of irrigation water quality. It is concluded that the ground water at certain locations get polluted due to seepage and percolation losses from surface.

Key words: Mardan salinity control and reclamation project (SCARP), groundwater, water and power development authority Pakistan (WAPDA), geographical information system (GIS).

INTRODUCTION

Majority of the Pakistani population depends on agriculture and it's the mainstay of Pakistan's economy. Agriculture contributes nearly 25% to the GDP and is responsible for nearly 75% of Pakistan's exports. Also 70% of the work force earns its livelihood through this sector (Malik, 2001). Out of total area of Pakistan, 287670.6 km^2 is cultivable, but only 54.4% of this cultivable land is cultivated and the remaining land is still kept uncultivated. Out of total cultivable area, 44.5% land is provided with water by irrigation and the remaining by rainfall. Every year 130.755 km^3 and 59.21 km^3 water is provided by canal irrigation and tube well irrigation, respectively (Rana, 2007).

Pakistan has been blessed with sufficient surface and groundwater resources. However rapid population growth rate, urbanization and the continued industrial development have placed huge stress on water resources of the country. From 1976 to 1997, the ground water contribution to irrigated agriculture has doubled, increasing from 31.6 to 62.2 billion cubic meters (GOP, 1998).

For efficient food production, fertile lands and good quality water are the basic resources. Successful agriculture depends on sufficient water supply of good quality. Due to abundant and ready availability of good quality water in the past, water quality concerns were neglected. But now that situation is completely changed, and good quality water is no more readily available. Water shortages and increasing competition for multiple uses of ground water harmfully affects the quality of

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ground water.

Review of groundwater studies

Studies related to ground water quality conducted by investigators independently and by various organizations in relation to this research are reviewed and summarized below:

Ahmad (1993) concluded that additional recharge from Tarbela Dam significantly maintained the groundwater quality. This water created portable and clean top water layer for the use of concerned population. But it also created serious problems, when recharged to brackish groundwater zone, for the disposal of saline effluents.

Chandio (1999) reported that nitrogenous fertilizers are the main pollutants of ground water in irrigated areas. Almost 477 samples were collected from four sets of experimental fields. The NO3-N concentration between 5 and 10 mg/l was found in three samples and concentration above 10 mg/l was found in 5 samples of the area. Chandio recommends public awareness and guidance, and proper monitoring system for good management of the area.

Chauhan et al. (1990) studied groundwater used for irrigation in the Mathura district which is very saline. RSC was associated with low salinity (ECw< 3dS/m). Multiple correlations between water quality parameters and soil characteristics show that salinity increased in soil positively correlated with salinity of water; while pH was influenced by ECw and RSC and SAR below and above 18 SAR of water respectively. ESP of the soil was a function of ECw, SAR and RSC of water. Degree of dispersion in both groups of water had significant positive relation with ECw whereas hydraulic conductivity had an opposite relationship with corresponding water quality parameter.

Haider et al. (1975) stated that groundwater having TDS of 2600 ppm could be used successfully for growing wheat crop providing that SAR value of water is less than 4.0 and RSC equal to zero. Water with SAR value of 16.5 and TDS of 1850 ppm caused serious deterioration of soil and reduced the crop yield.

Latif and Hussain (1992) compared pre- and post-project soil salinity and useable groundwater for East Khairpur Tile Drainage Project during the period 1982-1988. Comparison indicated that electrical conductivity of the soil had decreased in the top layer (0-0.25 m) and increased in the bottom layer (0.25-0.5 m). Data for the above period also indicated that useable groundwater was increased from 8 to 45%; marginal water quality was reduced from 39 to 32%, while hazard water reduced from 53 to 23%. He concludes that water quality would improve with the passage of time.

Latif et al. (1999) concluded that there is no risk of groundwater pollution in area where tile drainage system is working properly. He finds out that nitrate concentration in tile drainage area ranges from 0.03 to 3.25 mg/l. He investigated groundwater pollution from nitrate leaching in many area of Pakistan. The nitrate concentration increases in the area outside the tile drainage area. Muhammad et al. (1975) noted that low salinity water (mixture of tubewell and canal water) when amended by passing through gypsum stone or by addition of Calcium chloride gave maize crop yield comparable to those obtained with canal water and had no adverse effect on soil properties.

Qureshi and Barrett-Lennard (1998) concluded that about 70 % of the tube wells in the Indus Basin are discharging sodic water. This water when used for irrigation creates serious quality concerns for soil and hence crops.

Rhoads (1972) stated the effects of irrigation water on the level of solutes in the soil water. High soil water salinities occurring in deeper region of the root zone could be largely offset if sufficient low salinity water is added to the upper profile depth fast enough to satisfy the crops evapotranspiration requirements.

Shainberg and Oster (1986) reported that in the root zone salinity values including (SAR, Cl- and pH) increased with the use of saline irrigation water before the arrival of the monsoon. They also found out that irrigation with saline water did not significantly affect tree growth.

Syed and Swaify (1969) observed that the increasing salinity in irrigation water caused a decrease in fresh and dry matter yield of sugarcane. The loss in dry matter yield was 10% at low salinity (2 dS/m) but increased to 36% at high salinity level (8 dS/m).

Water and Soil Navigation Division of WAPDA (1974) found that SAR of all soils either decreased or remained unchanged when irrigated with tubewell water having ECw of 1.5 dS/m and SAR less than 10 and RSC more than 5 meq/l. After mixing water with ECw value less than 1.5 and RSC greater than 5 meq/l, it was found that SAR was increased; however the increase was not prominent.

Yasin at al. (1988) studied that most of the groundwater used for irrigation in Pakistan is saline, sodic and contains variable amount of bicarbonates. To make the best use of such water, an experiment in Lysimeter was performed on two crops namely sorghum and Berseem. Water having three EC levels (2, 3 and 4 dS/m), two SAR levels (10 and 15 $(meq/l)^{0.5}$) and two RSC levels (2.5 and 5 meq/l), maintaining low and high leaching fraction for each other were used for irrigation. Yield of Sorghum generally decreased with increasing ECw, SAR and RSC of irrigation water. Higher yields were obtained at higher leaching fraction because it is not controlled by ECw but also maintained exchangeable Sodium in the soil. There was a very small increase in soil pH with increasing ECw and SAR, while there was a small decrease with increasing leaching fraction and RSC of irrigation water. Soil EC and ESP increased with the increasing ECw, SAR and RSC of irrigation water at all the depths of soil column.

Problem statement

Groundwater is a very precious resource and its protection is very much important for the present and future generations. On a large scale, water cycle shows that ground water is a renewable source, but on a small scale from the viewpoint of ground water resources, the ground water is not a renewable source. Once it is polluted, it is not possible to clean the ground water resources/aquifers of an area. Water quality varies from place to place and with depth. Utilization of ground water depends on its quality. With increase in population rate, pollution of groundwater also increases due to increasing activities such as farming activities, industrialization, and urbanization. In such type of situation it is difficult to detect changes until the continuous revision of maps and plans for the management of ground water resources of an area.

When ground water moves from surface to underground sources, it passes through a large number of filtering media and hence becomes filtered. Also the earth cover protects the water from surface pollutants. But since ground water moves through rocks and subsurface soil, it is polluted by the dissolved substances and underground geologic strata. Different types of rocks affect ground water in different ways, depending on many factors such as weathering, temperature and the properties of the strata through which ground water passes. Some rocks material dissolve very easily in ground water while some do not. Ground water can get polluted from industrial, domestic, and agricultural chemicals when they percolate down into the ground water sources. These chemicals may be pesticides and herbicides. Almost all the ground water contains salts but its nature depends on many factors such as movement and source of ground water. Soluble salts found in groundwater originate primarily from solution of rock materials (Foster, 1942). Sedimentary rocks are more soluble than the igneous rocks. The use of such polluted ground water for irrigated agriculture may adversely affect the production potential of irrigated lands due to increasing problem of salinity, sodicity, and specific ion effects on crops and plants.

Pakistan has now exhausted its available water resources and is on the edge of becoming a water shortage country. There is no proper monitoring and evaluation system to manage and secure these precious sources of ground water. The quality of ground water and surface water is low and is further deteriorating day by day due to use of untreated municipal and industrial waste water for irrigation and extensive use of fertilizers and insecticides. “Pakistan’s population, for instance, will double on current trends” (Raja, 2009) and the growth rate in agriculture sector remains somehow lower than the demand for such rapid population growth rate due to shortages of irrigation water. For increasing rate of population we must bring more land under cultivation. For additional land to irrigate, additional water will be required. Since no additional water is available, it is better to improve the planning and management of the existing water resources to make it more efficient.

In Pakistan “There is a water shortage, there is an electricity shortage, there is a food shortage. All these require planning for the future as the population explosion is taking place in this part of the world” (Raja, 2009). The Government of Pakistan is continuously trying to reclaim the lost lands and secure future farming activities. For this purpose, a series of drainage schemes were completed in the past. On the other hand, water logging and salinity is still creating problems in many parts of the country. In order to handle this problem, salinity control and reclamation project (SCARP) was launched in many parts of the country. Before execution of Mardan SCARP, water table was very high and hence created a lot of problems of salinity and water logging for agriculture production in the area. Due to successful completion of Mardan SCARP and its maintenance after the completion produced very good results. Most of the area was reclaimed and was made suitable for quality crops. Currently almost all the area is suitable for agricultural practices, but in some areas ground water table is still very high although salinity and sodicity of the area at present are unknown. As salinity and sodicity are directly related to the rise of ground water table, so there is a danger to repeat problems of salinity and sodicity, and hence causing serious threats for future agricultural practices.

Groundwater quality is a continuously changing phenomenon, variation occurs with time and space, so there is a need to check and revise the water quality parameters and maps, regularly with time and space. Also there is a need of spatial data system for these types of changes and variations, and requires advanced type of mapping for better planning and management. Linking spatial data to the maps of respective location produces better results as compared to other techniques and methods. Variation in water quality at a specific point needs an advanced system which combines the spatial data (map) of a point to the non spatial data (attributes of a map) of that point and then to find out variation in water quality at that specific point. Geographical Information System is the only system which handles spatial data as well as non-spatial data, analyses and manipulates the data and performs the most advanced type of planning, management, and mapping. As ground water quality varies from place to place and with time, so there is a need of the most advanced management tool for such type of complicated changes and variations. For efficient and advanced planning and management of ground water quality in areas like Mardan SCARP (Salinity Control and Reclamation Project) area, the application of

Geographical Information System is very much important.

Objectives

Keeping in view the problems of salinity/sodicity and contamination of groundwater in Mardan SCARP area, the following objectives are likely to be achieved from this work:

1. To analyze ground water quality parameters and determine their variations at various locations for irrigation purposes in the area.
2. To prepare spatial maps of the selected ground water quality parameters using Geographical Information System.
3. To determine the area of polluted ground water.
4. To make suitable suggestions and recommendations from this research study for future planning and management of ground water quality of Mardan SCARP area.

DESCRIPTION

Study area

According to the 1999 population census, the population of District Mardan is 1.542 million (Government of NWFP, 2000), making it the second most populated district of Khyber Pakhtunkhwa province, Pakistan. Table 1 shows population, density, and area of District Mardan in detail. District Mardan shares its boundaries with the districts of Swabi, Nowshera, Charsadda, Swat, and Malakand Agency. Yousafzai is the major tribe of district Mardan. Location map of Mardan division is given in Figure 1.

District Mardan lies at elevation of 1200 feet above mean sea level having a cool, dry climate from November to the end of February, with day time temperature of about 19°C. During December and January, the temperature drops as low as 0°C at night. From May to September, the climate is warmer and more humid with day time temperature averaging about 35°C. The temperature reaches its maximum in the month of June. Dust storms are common in the months of May and June. The area is rather humid due to intensive cultivation (WAPDA, 1993).

The rainfall in District Mardan varies from about 15 inches on the western perimeter to about 32 inches East, during winter (December through March) and summer (Mid July to September). The winter rains are influenced by the cold fronts in the form of Hindu Kush Range, with warm fronts moving in from the Indian Ocean (WAPDA, 1993).

Most of the land is irrigated by canal irrigation while tube well and lift irrigation are also used. Lower swat canal and its distributaries were the main source of irrigation during the British Rule and are used until now. Table 1 shows useful information about District Mardan; different sources of irrigation and the percentage irrigated area by them are given in Table 1. Mardan SCARP project was launched during 1980s to reclaim the lost land which was water logged from the same source.

Normally stream flows from north to the south direction and finally drains into River Kabul. Streams like Baghiari Khawar, Maqam Khawar and Naranji Khawar combine with Kalapani and finally drain into River Kabul on the southern side.

District Mardan is very much fertile and is suitable for cultivation any time except for certain crops during cold nights of winter season. Also, frost during February-March cannot be ignored. Irrigation is necessary for good quality crop cultivation year round. Population and land use pattern are given in Table 1.

Mardan district is largely an agricultural area. The major crops of the district are wheat, sugarcane, maize, tobacco, rice, rapeseed, mustard and various vegetable crops. The famous fruits of the district are orange, plum, peach, apricot, pear, mango and apple. Table 1 shows major crops of Mardan district and its total quantity.

Most of the soil in the area are alluvially deposited and derived from shale’s, slates, sandstone and limestone. Most of the soils are quite deep, low in organic matter and coarse to moderately fine textured. The subsoil is commonly coarser than the top soils. Soil cultivation is not difficult and good seed beds can be prepared (WAPDA, 1993).

Location of project area

The research was conducted on the portion of Mardan SCARP area. The research area lies between longitudes 71°48`16 - 72°01`15 East and latitudes 34°06`22 - 34°09`37 North. The project covers major portion of Mardan and some small area of Nissata (District Charsadda). From Mohabbatabad to Nissata chowk, along with Motorway and Dosehra road, most of the area was covered during the groundwater sampling. Figure 2 gives the distribution of sample points. Figure 2 shows latitudes and longitudes on vertical and horizontal sides respectively. It shows that Nissata lies on the left side (west) while Muhabbat Mohabbatabad lies on the right (East) side of the research area.

METHODOLOGY

Procedures used for groundwater sampling and laboratory methods used for determination of various physical and chemical parameters are discussed. The analysis and management of water quality data by GIS are discussed here.

Water sampling

Eighteen water samples were collected randomly from different hand Pumps of the project area using clean mineral water

Table 1. Population and land use pattern of District Mardan (Government of NWFP, 2000).

Item	Unit	1999-2000
Area and population		
Area	Km^2	1632
Population	1000 persons	1542
Density	Persons/ Km^2	945
Annual growth rate	%	3.01
Agriculture		
Study area	Hectare	162085
Cultivated area	Hectare	112790
Culturable area	Hectare	116007
Irrigated area	Hectare	79505
Canal commanded area	Hectare	72720
Irrigation through tube well	Hectare	3622
Irrigation by other sources	Hectare	3163
CCA as % of total irrigated area	%	91.47
T. Well irrigated area as % of total irrigated area	%	4.98
Irrigated by other sources as % of total irrigated area	%	3.98
Forest area	Hectares	7938
Land use intensity	%	97.4
Cropping intensity	%	122.1
Population per hectare		
Cultivated hectare	Persons	14
Irrigated hectare	Persons	19
Yield per hectare		
Maize	Kg	1827
Rice	Kg	1633
Wheat	Kg	2023
Sugar cane	Kg	42521

PET(polyethylene terephtalat) bottles, of one liter capacity. The ground water through these hand pumps (also provided with electric motors to lift water from the underground aquifers for irrigation) is drawn from an average depth of 125 feet. Each PET bottle was rinsed with the pumped water for three times. The bottles were filled completely, sealed with stoppers, labeled, and brought to the laboratory. GPS readings were taken at these sample locations.

Table 2 provides information about the equipments, chemicals and methods of analysis used for the determination of water quality parameters. Analyses of ground water samples were performed in the laboratory.

Determination of parameters

Tests were performed in the laboratory to determine the electrical conductivity, total dissolved solids, total hardness, pH, Calcium and magnesium, Sodium, potassium, bicarbonate and carbonate, sulfate, chloride and nitrate.

Management and mapping by GIS

Arc Map module of Arc GIS 9.2 software was used for management, analysis and mapping of ground water quality data. Global positioning system (GPS) data as well as water quality data was combined into Microsoft Excel and then transformed into Arc Map. Interpolation methods of spatial and geostatistical analyses were used for calculation of statistical parameters such as mean, maximum etc. Natural Neighbors (Raster Interpolation) method was used for creating Maps.

RESULTS AND DISCUSSION

The results of experimental work and groundwater quality analysis which was carried out during the research study are given in the form of graphs and GIS's maps. Various statistical descriptive measure such as range, mean, standard deviation and coefficient of variation are determined and provided here.

Electrical conductivity concentration in groundwater

The ECw values measured at different locations and their statistical parameters calculated from the data are given

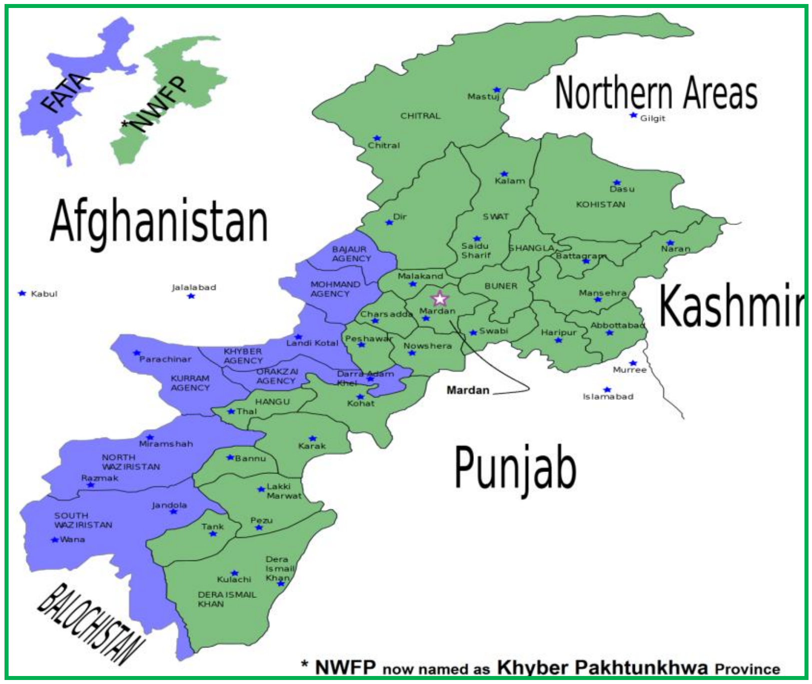

Figure 1. Location map of Mardan division in Pakistan (source: Wikipedia).

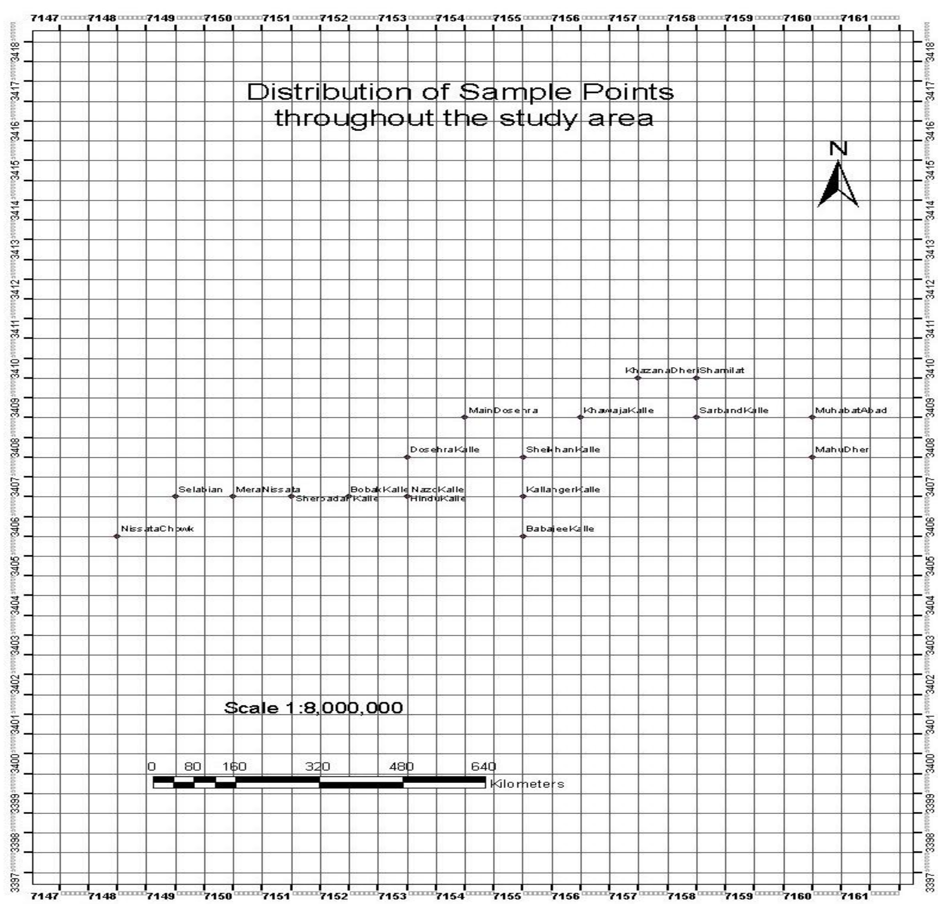

Figure 2. Distribution of sample points throughout the study area.

Table 2. Types of methods, equipment, and chemicals used during analysis.

S#	Parameter/Unit	Method	Reagent/ Apparatus
1	Conductivity (µmhos/cm)	Conductivity/TDS meter	HCL Solution, Phenolphthalein Indicator Solution, 1 g/l, NaCl Solution, Conductivity Meter
2	Total dissolved solids (mg/l)	Gravimetric	China dish, Water bath, Oven, Balance and Dissector
3	Total hardness (mg/l)	Titration	TitraVer Hardness Titrant, 0.02 N Buffer Sol. Hardness 1 ml calib. dropper, Eriochrome Blue Black-T (Murexide) Burette, automatic (50 ml) Flask, Erlenmeyer Cylinder, Graduated, 300 ml
4	pH	Electrometric	Buffer solution of pH 4.0 and pH 7.0 Distilled water
5	Calcium and magnesium hardness (mg/l)	Titration method	TitraVer Hardness Titrant, 0.02 N Potassium Hydroxide Standard Solution, 8 N Eriochrome Blue Black-T (Murexide) Burette, automatic, (50 ml) Flask, Erlenmeyer Cylinder, Graduated 300 ml
6	Sodium (mg/l)	Flame emission photometric	Standard solution of NaCl (Sodium Chloride)
7	Potassium (mg/l)	Flame emission photometric	KCl (Potassium Chloride) Solution, Distilled water
8	Bicarbonate and carbonate (mg/l)	Titration	Phenolphthalein Indicator Solution, 5 g/l Sulfuric acid Standard Solution 0.02 N (Tit.) Methyl Orange Indicator Burette, automatic, 50 ml Flask, Erlenmeyer Cylinder, Graduated, 50 ml
9	Sulfate (mg/l)	Ultraviolet spectrophotometric screening	SulfaVer4Sulfate Reagent Powder Pillows or $BaCl_2$ and Condition Reagent Clipper for Opening Pillows
10	Chloride (mg/l)	Argentometric	Silver Nitrate Standard Solution 0.0141 N, Digesdahl Digestion Apparatus (115 VAC) Graduated Cylinder, 10 ml (2 required) Potassium Chromate Indicator, Pipette Filter, Pipette Volumetric, 5.0 ml
11	Nitrate (mg/l)	Ultraviolet spectrophotometric screening	½ mL Phenol Disulfanic Acid,1.4 KOH Solution

in Table 3. The minimum value of ECw is 0.41 dS/m and the maximum value is 1.13 dS/m. The mean, standard deviation and coefficient of variation of ECw are 0.673 dS/m, 0.1712 dS/m and 34.37%, respectively.

According to the classification of FAO (Food and Agriculture Organization) given in Table 4, water having concentration below 0.7 dS/m is fit for irrigation. Figure 3 shows different locations exceeding the safe limits of irrigation water quality, in Mardan SCARP Area. Figure 5 (GIS's Map) shows the concentration levels of ECw at different locations geographically. GIS map shows that ECw concentration level in the range of 0.556 dS/m to 0.69 dS/m (medium olivenite color) covers greater portion of the Project area as compared to the other levels of ECw.

Total dissolved solids (TDS) concentration in groundwater

Total Dissolved Solids values and their statistical parameters calculated from the data are given in

Table 3. Groundwater quality parameters of the study area (Mardan SCARP).

Location	Lat	Long	Ele	Ca	Mg	Na	K	HCO_3	SO_4^{-2}	Cl	NO_3	CO_3	pH	TDS	T.H.	ECw	SAR	RSC
Shamilat	3409.583	7158.229	355.00	51.00	97.00	25.60	2.60	381.00	46.00	69.00	1.20	6.00	6.94	406.00	148.00	0.82	11.13	-4.16
Khazana Dheri	3409.624	7156.908	329.00	80.00	134.00	19.60	2.70	396.00	38.00	45.00	0.90	13.50	7.16	342.00	214.00	0.70	7.12	-8.22
Khawaja Kalle	3408.775	7156.242	305.00	69.00	125.00	13.70	2.10	279.00	26.00	14.00	2.20	12.00	7.36	245.00	194.00	0.49	5.21	-8.89
Sarband Kalle	3408.965	7157.718	286.00	67.00	213.00	16.60	2.30	387.00	48.00	34.00	2.30	8.00	7.12	322.00	280.00	0.64	5.31	-14.49
Mahu Dheri	3408.494	7159.771	293.00	71.00	129.00	28.50	3.40	592.50	69.00	98.00	1.60	12.00	6.97	562.00	200.00	1.13	10.67	-4.19
Muhabat Abad	3408.854	7159.999	290.00	90.00	130.00	21.30	2.40	384.00	51.00	62.00	1.00	6.00	7.02	372.00	220.00	0.75	7.70	-8.84
Nissata Chowk	3406.425	7148.265	297.00	152.00	194.00	6.10	0.30	239.00	34.00	31.00	1.00	0.00	7.09	275.00	346.00	0.55	1.77	-19.85
Mera Nissata	3407.029	7149.996	300.00	162.00	186.00	1.60	0.20	232.00	22.00	18.00	1.00	0.00	7.26	220.00	248.00	0.44	0.47	-23.22
Nazo Kalle	3407.224	7152.669	300.00	64.00	126.00	16.40	0.60	299.60	39.00	17.00	0.80	0.00	7.31	315.00	190.00	0.63	6.27	-2.39
Dosehra Kalle	3407.837	7153.462	292.00	128.00	262.00	18.50	0.30	374.00	83.00	62.00	1.30	0.00	7.92	440.00	390.00	0.88	4.92	-22.10
Main Dosehra	3408.517	7154.394	296.00	90.00	236.00	6.90	8.00	316.00	36.00	48.00	1.10	0.00	7.67	355.00	326.00	0.71	1.89	-18.98
Sheikhan Kalle	3407.764	7154.661	294.00	80.00	178.00	3.50	0.10	203.00	18.00	22.00	1.40	1.40	7.04	205.00	258.00	0.41	1.14	-15.46
Kallanger Kalle	3406.828	7155.419	293.00	44.00	54.00	10.20	0.06	314.00	52.00	34.00	0.20	26.60	7.21	390.00	98.00	0.78	5.57	-0.67
Babajee Kalle	3406.367	7154.912	297.00	172.00	206.00	1.20	0.13	371.00	62.00	27.00	1.20	26.60	7.19	285.00	378.00	0.57	0.33	-18.80
Hindu Kalle	3406.685	7153.049	299.00	60.00	76.00	14.50	0.20	238.00	53.00	61.00	0.00	19.60	6.94	344.00	264.00	0.60	6.71	-8.30
Bobak Kalle	3406.661	7151.892	294.00	37.00	75.00	30.30	0.12	284.00	24.00	28.00	0.00	25.00	7.11	376.00	112.00	0.75	13.62	-2.61
Sherbadar Kalle	3406.906	7150.967	296.00	102.00	162.00	15.40	0.15	312.00	58.00	51.00	0.40	16.80	7.04	300.00	136.00	0.69	5.05	-12.93
Selabian	3406.828	7149.196	292.00	121.00	130.00	11.90	0.35	263.00	38.00	35.00	0.10	5.60	7.32	293.00	251.00	0.59	4.10	-12.38
Statistical parameter																		
Min	3406.367	7148.265	286.00	37.00	54.00	1.20	0.06	203.00	18.00	14.00	0.00	0.00	6.94	205.00	98.00	0.41	0.33	-23.22
Max	3409.624	7159.999	355.00	172.00	262.00	30.30	8.00	592.50	83.00	98.00	2.30	26.60	7.92	562.00	390.00	1.13	13.62	-0.67
Mean	3407.74256	7154.319389	300.44	91.11	150.72	14.54	1.45	325.84	44.28	42.00	0.98	9.95	7.20	335.94	236.28	0.67	5.50	-11.47
Std. Dev.	0	0	16.33	40.46	57.91	8.69	2.00	90.33	17.19	22.04	0.67	9.59	0.25	84.74	86.00	0.17	3.71	7.18
CV(%)	0	0	5.43	44.41	38.42	55.91	138.70	27.72	38.82	52.46	0.68	96.38	3.52	25.22	35.37	34.37	65.63	60.85

Table 3. The minimum value for TDS is 205 mg/l and the maximum value is 562 mg/l. The mean, standard deviation and coefficient of variance are 335.94 mg/l, 84.737 and 25.22%, respectively.

According to FAO (Table 4), irrigation water having TDS below 450 mg/l is safe while water having TDS between 450 and 2000 mg/l is moderately unfit for irrigation.

According to this classification, except Mahu Dheri all the remaining water samples are safe with respect to TDS. Figure 4 shows that about all the sample of Mardan SCARP area are under normal range and can be used successfully for irrigation. Figure 6 shows that concentration level of TDS in the range of 277.35 to 348.143 mg/l (medium olivenite color) exist in majority of Mardan SCARP area.

Total hardness concentration in groundwater

Total Hardness values and their statistical measures are given in Table 3. The minimum value of Total Hardness is 98 mg/l while the maximum is 390 mg/l. The mean, standard deviation and coefficient of variance are 236.28 mg/l, 86 mg/l and 35.37%, respectively.

Total hardness concentrations at different locations are given in Figure 7. Figure 9 (GIS's map) shows the levels of total hardness concentration throughout the study area. This map shows that concentration exists uniformly in different ranges within the study area.

pH of ground water

The pH value and their statistical measures are tabulated in Table 3. The pH values show uniform trend about the mean value. The minimum value for pH is 6.94 and the maximum value is 7.92. The mean, standard deviation and coefficient of

Table 4. Irrigation water quality guidelines.

Parameters	Units	FAO – Food and Agriculture Organization (Irrigation water quality guidelines)				Water and Power Development Authority - WAPDA (Irrigation water quality guide lines)		
		Guidance for FAO	No risk	Slight to Moderate risk	Severe risk	Useable	Marginal	Hazardous
EC_w	dS/m	-	<0.7	0-3	>3	0-1.5	1.5-2.7	>2.7
TDS	mg/l	-	<450	450-2000	>2000	-	-	-
RSC	meq/l	-	-	-	-	0-2.5	2.5-5	>5
SAR	meq/l	0-3	>0.7 EC_w	0.7-0.2 EC_w	<0.2 EC_w	0-10	10-18	>18
SAR	meq/l	3-6	>1.2 EC_w	1.2-0.3 EC_w	<0.3 EC_w	-	-	-
SAR	meq/l	6-12	>1.9 EC_w	1.0-0.5 EC_w	<0.5 EC_w	-	-	-
SAR	meq/l	12-20	>2.9 EC_w	2.9-1.3 EC_w	<1.3 EC_w	-	-	-
SAR	meq/l	20-40	>5.0 EC_w	5.0-2.9EC_w	<2.9 EC_w	-	-	-
Na^+	meq/l	Sprinkler irrigation	<3	>3	>9	-	-	-
Na^+	meq/l	Surface irrigation	<3	3-9	-	-	-	-
Cl^-	meq/l	Sprinkler irrigation	<3	>3	-	-	-	-
Cl^-	meq/l	Surface irrigation	<4	4-10	>10	-	-	-
HCO_3^-	mg/l	-	<90	90-500	>500	-	-	-
pH	-	-	Normal range 6.5-8	-	-	-	-	-

The dash (-) shows unknown value for the cell in the table.

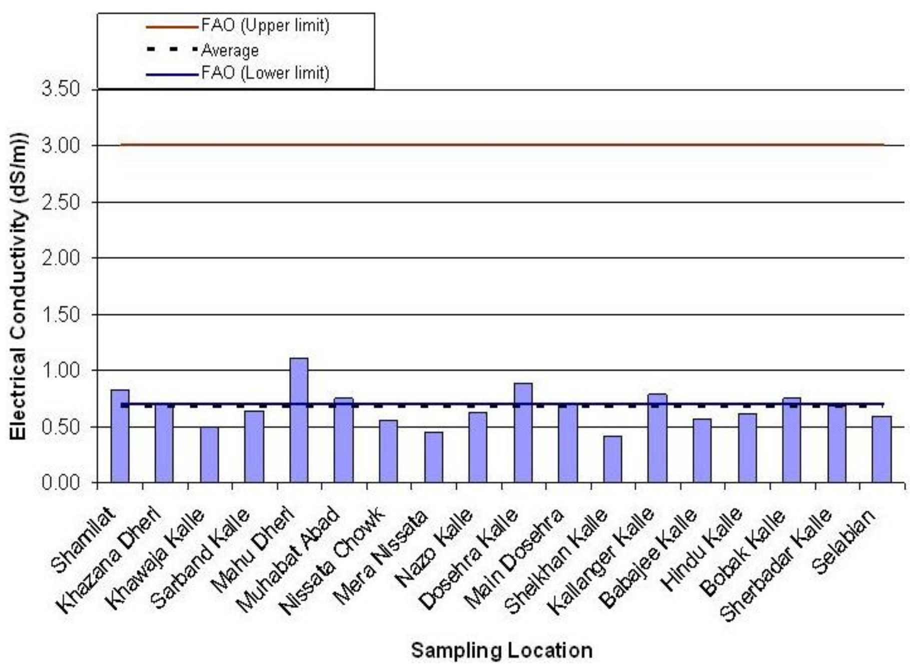

Figure 3. Electrical conductivity values in groundwater.

variance for pH are 7.2, 0.25 and 3.52%, respectively.

According to FAO (Table 4), the FAO upper limit for pH is 8; which shows that all water samples of groundwater quality in Mardan SCARP area lies below this limit and is completely safe. Figure 8 provides information about the concentration of pH at different locations of the study area. Figure 10 shows the concentration levels of pH throughout the project area. Medium olivenite color in Figure 10 shows that pH level in the range of 7.137 to 7.331 covers more area as compared to other levels of pH.

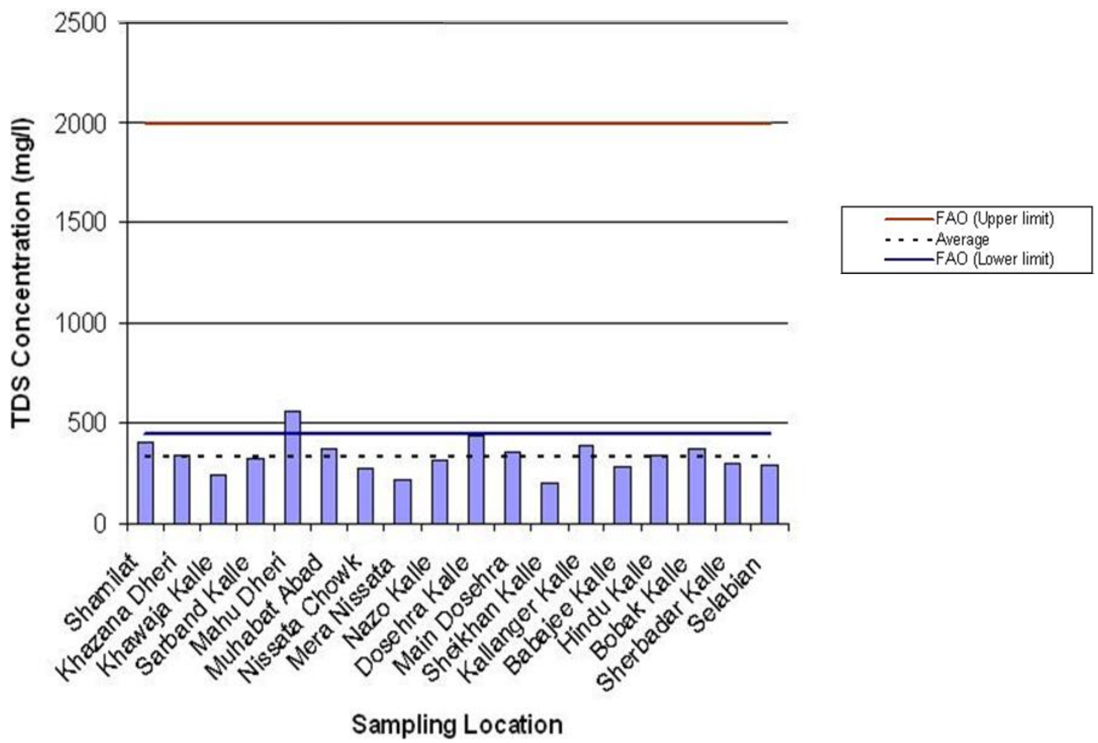

Figure 4. Total dissolved solids (TDS) concentration in Groundwater.

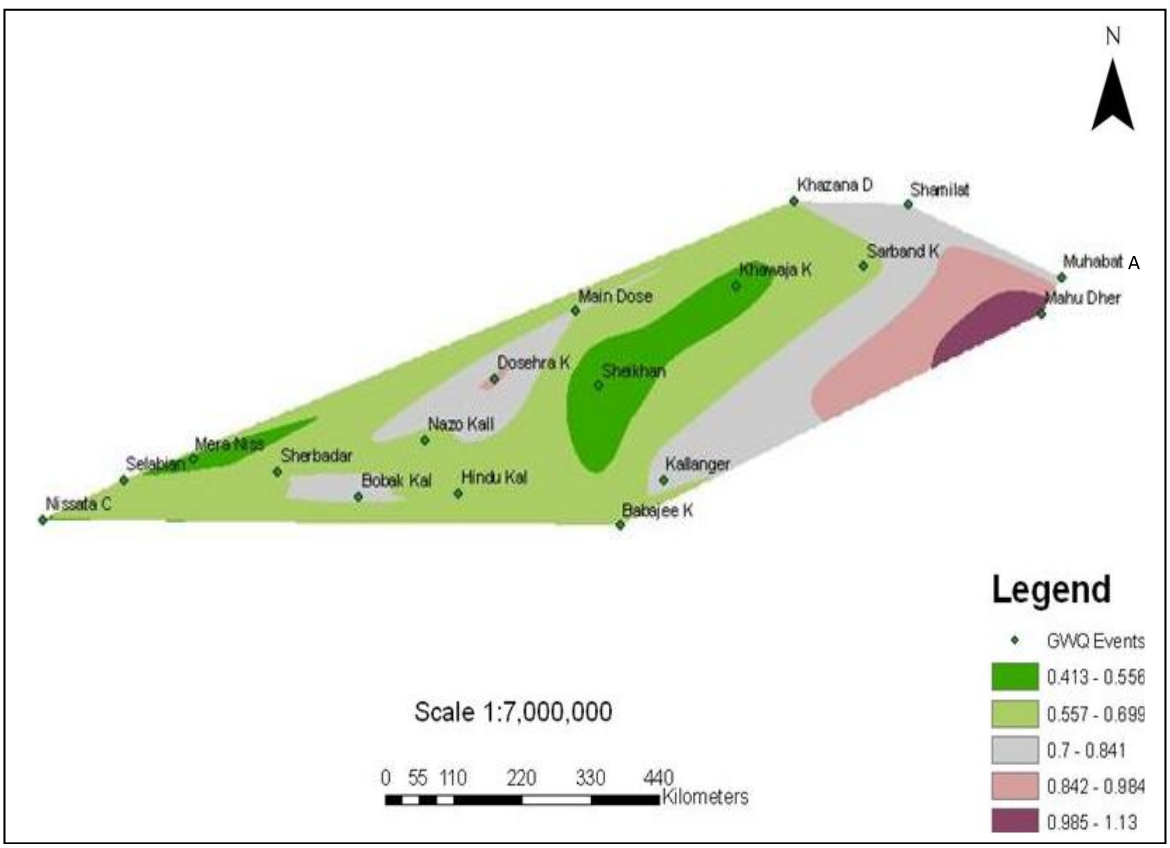

Figure 5. GIS's map showing electrical conductivity concentration levels in groundwater.

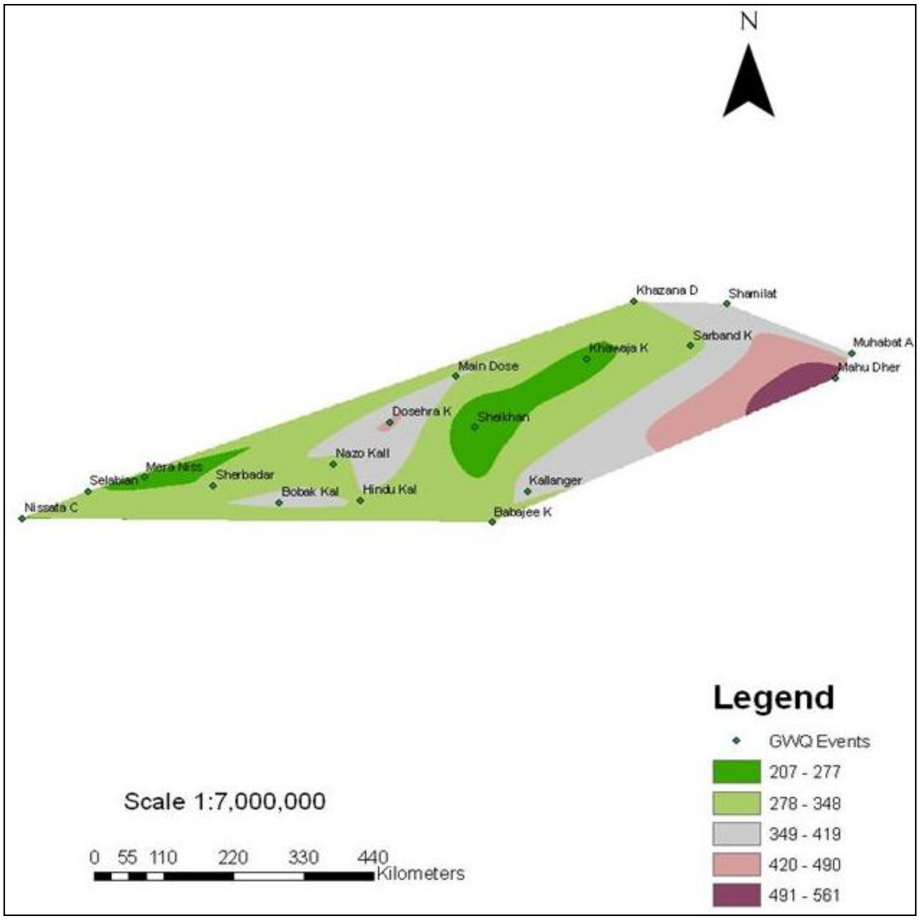

Figure 6. GIS's map showing TDS concentration levels in groundwater.

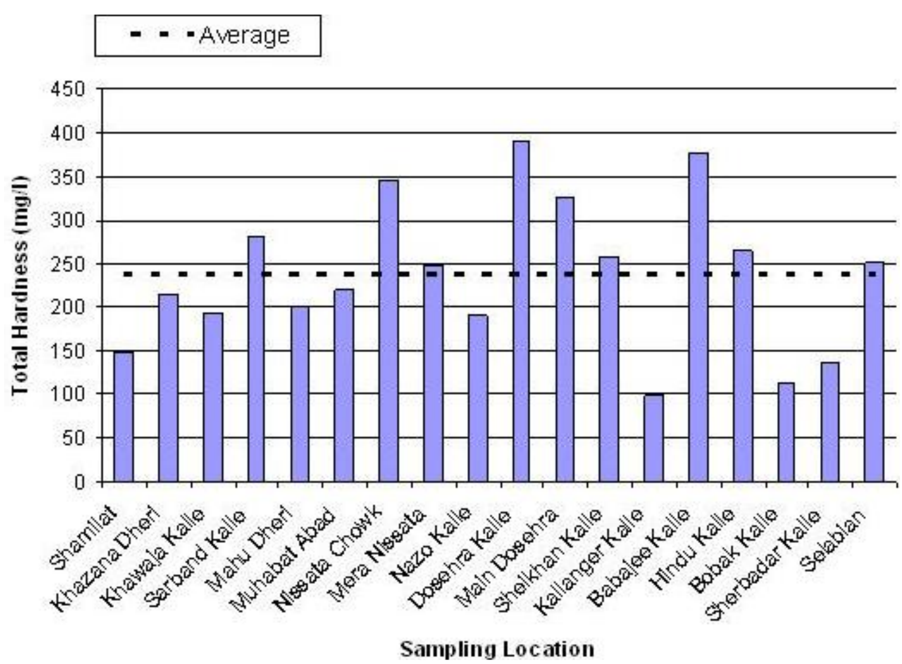

Figure 7. Total hardness concentration in groundwater.

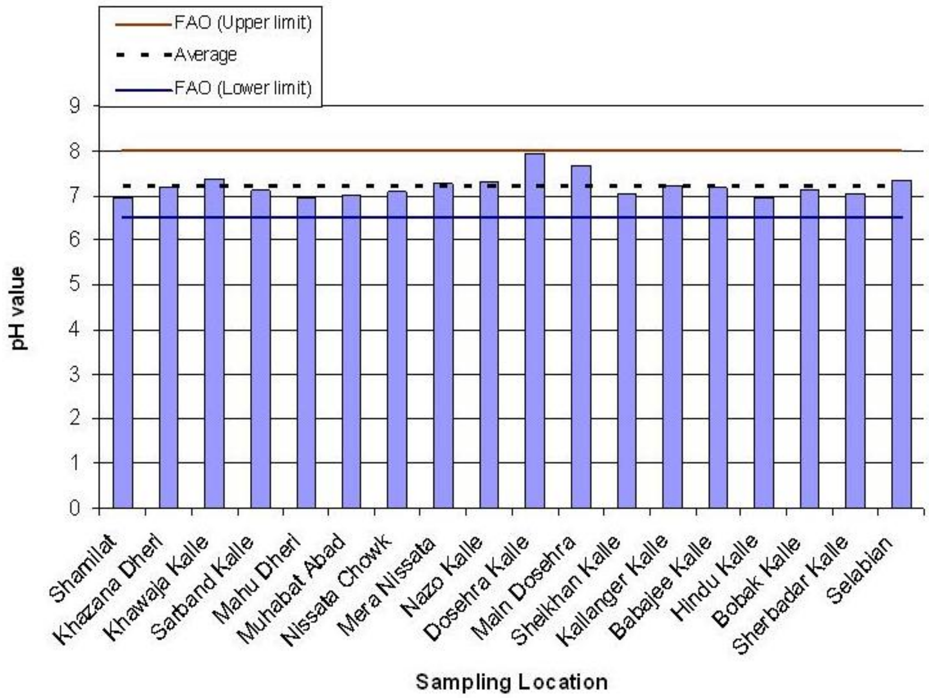

Figure 8. pH values of groundwater.

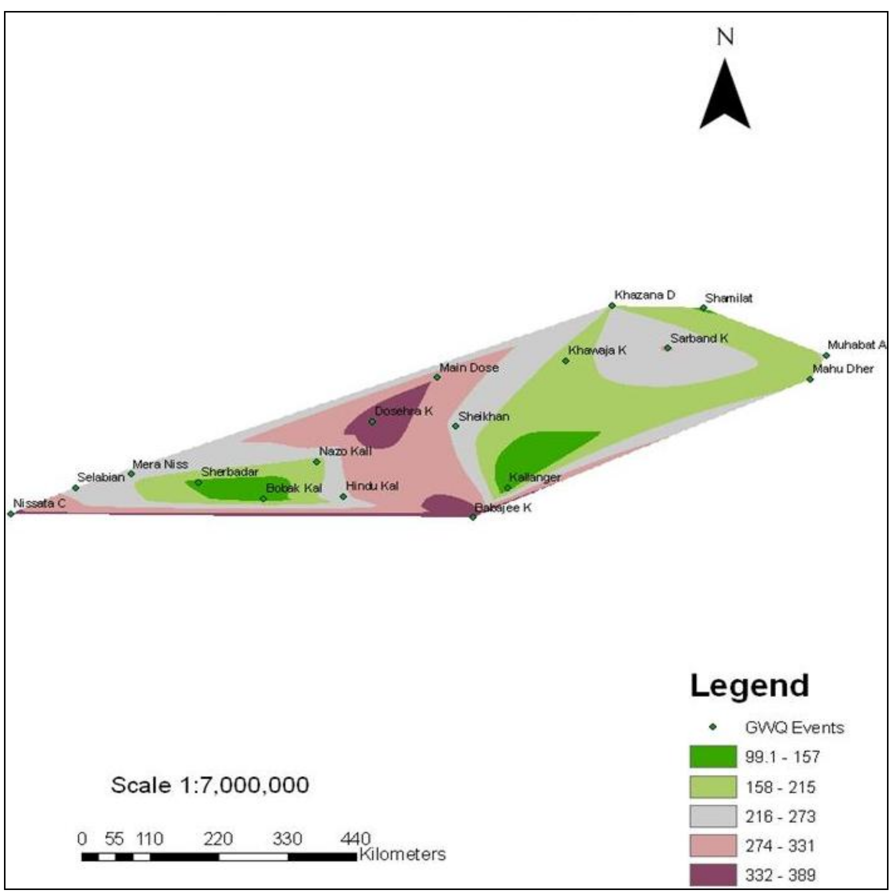

Figure 9. GIS's map showing total hardness levels in groundwater.

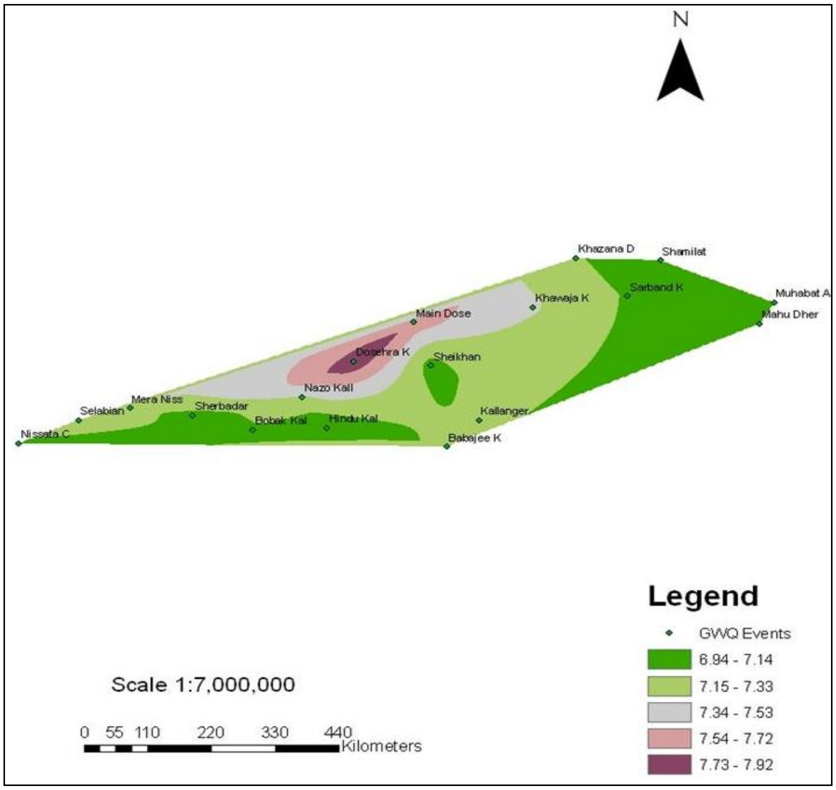

Figure 10. GIS's map showing pH levels in groundwater.

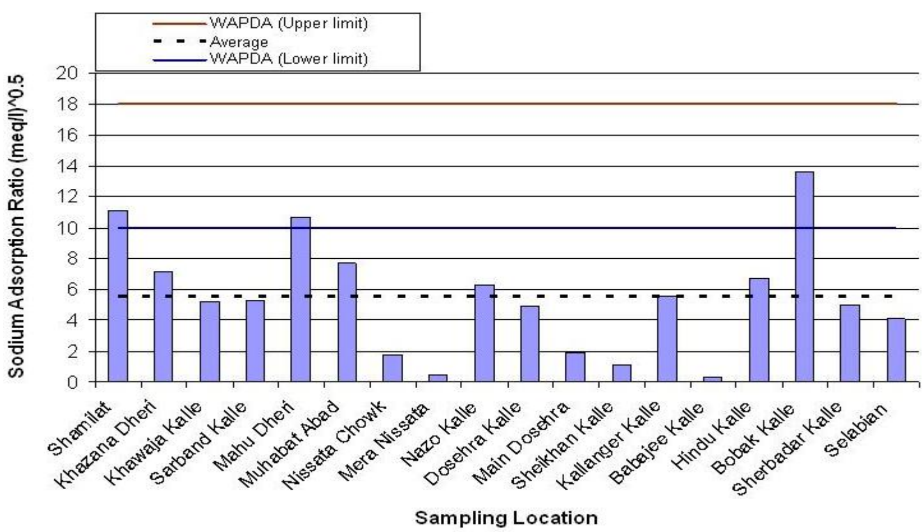

Figure 11. Sodium adsorption ratios (SAR) in groundwater.

Sodium adsorption ratio (SAR) concentration in groundwater

Sodium adsorption ratio (SAR) values along with statistical parameters are given in Table 3, and are graphically shown in Figure 11. The minimum value of SAR is 0.33 $(meq/l)^{0.5}$ and the maximum value is 13.62 $(meq/l)^{0.5}$. The mean, standard deviation and coefficient of variance are 5.5 $(meq/l)^{0.5}$, 3.71 $(meq/l)^{0.5}$ and 65.63%, respectively.

According to WAPDA (Table 4), irrigation water having Sodium adsorption ratio (SAR) below 10 $(meq/l)^{0.5}$ are

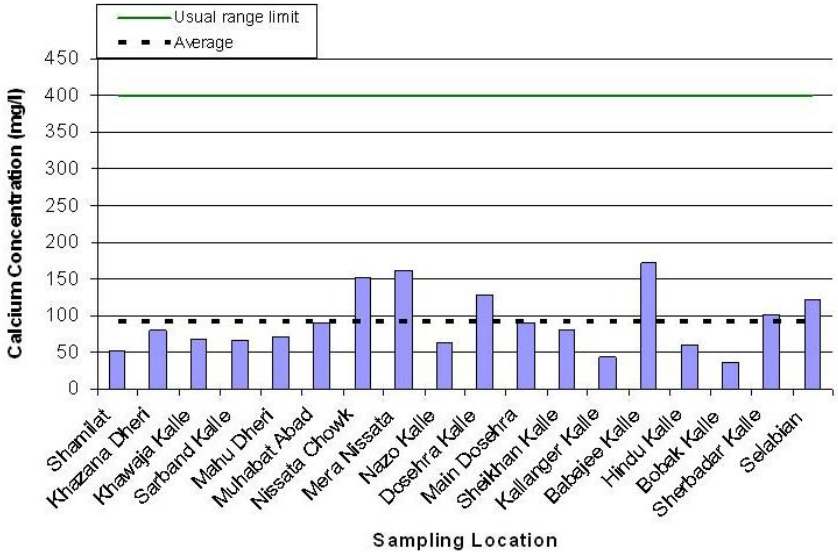

Figure 12. Calcium's concentrations in groundwater.

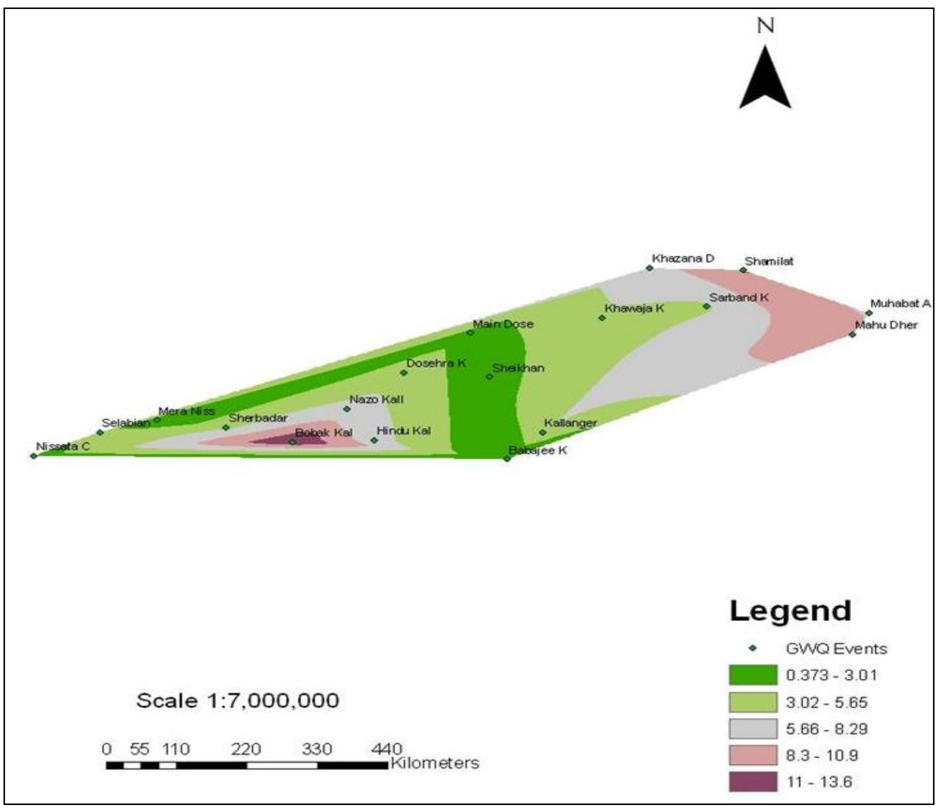

Figure 13. GIS's map showing Sodium adsorption ratio (SAR) (meq/l) ^0.5 levels in groundwater.

useable for irrigation while the hazardous limit is 18 meq/l$^{0.5}$. Figure 11 identifies three places in the study area exceeding the limit of 10 (meq/l)$^{0.5}$. These places are Shamilat, Mahu Dheri and Bobak Kalle. Figure 13 shows the concentration levels of SAR throughout the study area, separated by different colors. Medium olivenite color occupies more area and hence the concentration in this range is more common.

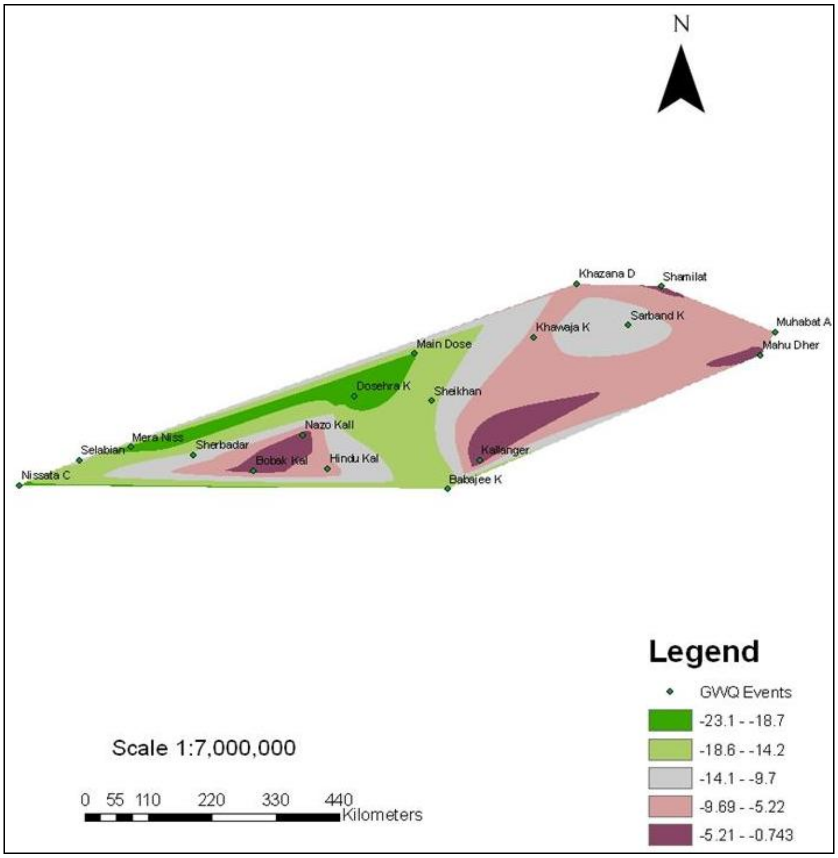

Figure 14. GIS's map showing residual Sodium carbonate (RSC) (meq/l) levels in groundwater.

Residual Sodium carbonates (RSC) concentration in groundwater

The values of Residual Sodium Carbonate and their statistical measures are given in Table 3. The minimum and maximum values are -23.22 meq/l and -0.67 meq/l, respectively. The mean Residual Sodium Carbonates value is -11.47 meq/l, standard deviation value of 7.18 meq/l and coefficient of variance value of 60.85%.

According to WAPDA (Table 4), irrigation water having RSC value below 2.5 is suitable for irrigation. So all ground water samples of the study area lie below this range and are suitable for irrigation, with respect to RSC. Figure 14 presents concentration levels of Residual Sodium Carbonate throughout the study area. The map shows uniform concentration levels of different ranges of RSC at different area of the project.

Calcium's Concentration in Groundwater

Calcium's concentrations values and their statistical measures are given in Table 3. The minimum and maximum values for Calcium are 37 mg/l and 172 mg/l, respectively.

The mean, standard deviation and coefficient of variance values for Calcium are 91.11 mg/l, 40.46 mg/l and 44.41%, respectively. Figure 12 graphically presents Calcium's values while Figure 15 presents the concentration levels of Calcium in the whole project area. Figure 12 shows the average value of Calcium and the usual limit of Calcium's concentration in irrigation water. Figure 15 (GIS's map) differentiates concentration levels of Calcium by different colors. GIS map shows that medium olivenite color (range 64.163-90.662 mg/l) exists in majority of the project area.

Magnesium's concentration in groundwater

Magnesium values and the statistical parameters are shown in Table 3. The minimum value for Magnesium is 54 mg/l and the maximum value for Magnesium is 262 mg/l. The mean, standard deviation and coefficient of variance are 150.72 mg/l, 57.91 and 38.42 % respectively.

Figure 16 graphically shows Magnesium's concentration at different locations of the study area, and the usual range of Magnesium in irrigation water. Figure 18 (GIS map) presents the concentration levels of Magnesium in

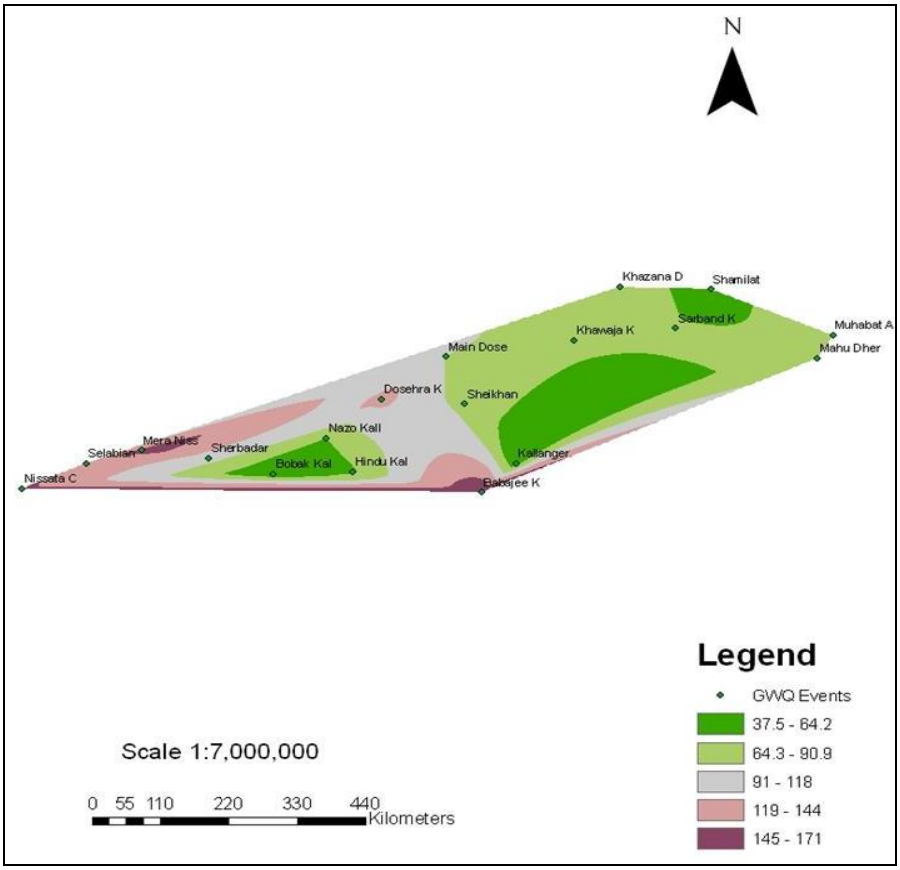

Figure 15. GIS map showing Calcium's concentration (mg/l) levels groundwater.

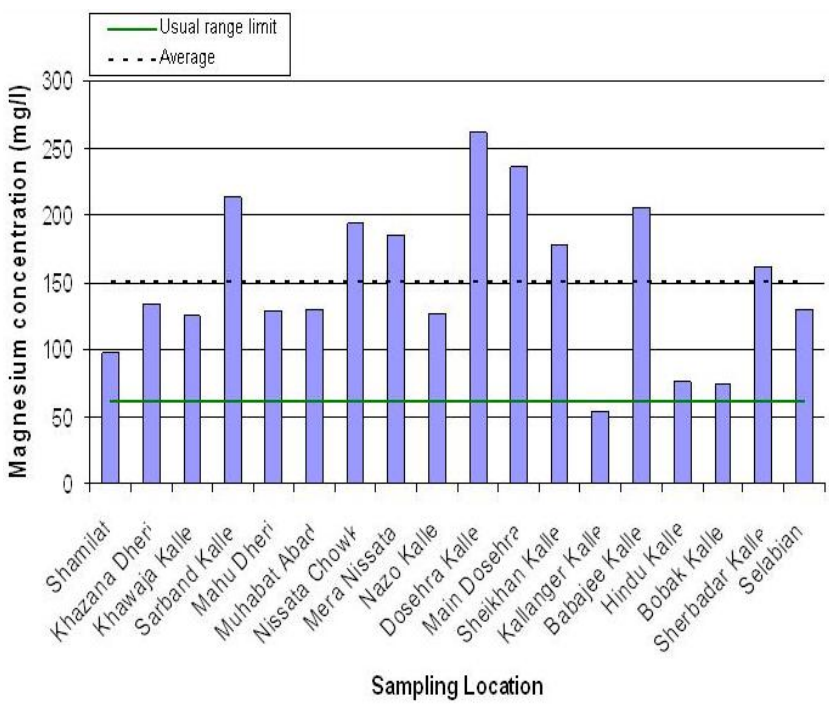

Figure 16. Magnesium's concentration in ground water.

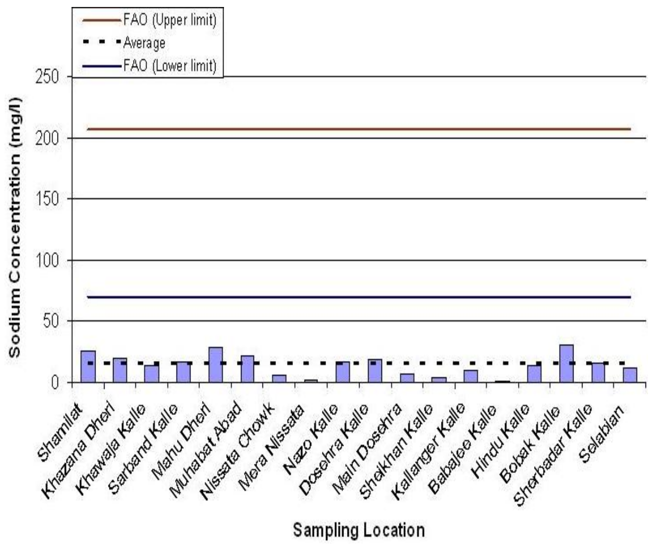

Figure 17. Sodium's concentration in groundwater.

the project area. A different color in the respected map shows different concentration levels of Magnesium at the respected locations. The map shows that about all the levels of concentrations of Magnesium cover the same amount of the project area.

Sodium's concentration in groundwater

Concentrations of Sodium and their statistical measuresare given in Table 3. The minimum value for Sodium concentration is 1.2mg/l and the maximum value is 30.30 mg/l. The mean, standard deviation and coefficient of variance for Sodium are 14.54 mg/l, 8.69 and 55.91 % respectively.

According to FAO (Table 4), all the samples of the project area lies below the FAO limits and is safe for irrigation. Figure 17 shows Sodium's concentration at different points of the study area. Figure 19 shows the concentration levels of Sodium throughout the study area. Different levels of Sodium's concentration covers about equal area of the project, as shown by different colors.

Potassium's concentration in groundwater

Potassium's values and their statistical measures aregiven in Table 3; having minimum and maximum values of 0.06 and 8 mg/l respectively. The mean, standard deviation and coefficient of variation values for Potassium are 1.45 mg/l, 2 mg/l and 138.8%, respectively.

Figure 20 shows that Potassium has the highest value of coefficient of variation for the current study area. According to Table 5, the usual range of Potassium in irrigation water is up to 0.06 mg/l while our irrigation water sample ranges only up to 8 mg/l. Figure 20 shows Potassium values at different locations while Figure 22 shows the levels of concentrations of Potassium in the project area. The map shows that medium olivenite color and dark green color (concentration range from 0.06 to 3.224 mg/l) covers about the same amount of the project area.

Bicarbonate's concentration in groundwater

Bicarbonate concentration and their statistical values are given in Table 3. The minimum value for Bicarbonate is 203 mg/l and maximum value is 592.5 mg/l. Statistical values for Bicarbonate are; mean 325.84 mg/l, standard deviation 90.33 mg/l and coefficient of variation 27.72%.

According to FAO (Table 4), the upper limit for Bicarbonate is 500 mg/l. Figure 21 shows the concentrations of Bicarbonate at different location of the project. Figure 21 shows that Bicarbonate concentration at Mahu Dheri is exceeding the FAO limit and is unsuitable with respect to Bicarbonate content. Figure 23 shows the concentration levels of Bicarbonate throughout the study area. This map shows that medium olivenite color (concentration range 281.523 to 358.89 mg/l) occupies more of the project area as compared to other colors or ranges.

Carbonate's concentration in groundwater

Carbonate and their statistical measures are given in Table 3. The minimum and maximum values for carbonate are 0 and 26.6 mg/l, respectively. The mean, standard deviation and coefficient of variance are 9.95 mg/l, 9.59 mg/l and 96.38%, respectively.

According to Table 5, the usual range of Carbonate in irrigation water is up to 30 mg/l while our irrigation water samples lie below this range. Figure 24 presents concentration of Carbonate graphically at different locations, while Figure 26 presents it geographically. Figure 26 (GIS's map) shows concentration levels of Carbonate throughout the study area. This map differentiates the concentrations of Carbonate by different colors.

Sulfate's concentration in groundwater

Sulfate values and their statistical parameters are given in Table 3. The minimum and maximum values of Sulfate concentrations are 18 and 83 mg/l. The mean, standard deviation and coefficient of variance for Sulfate are 44.28 mg/l, 17.19 mg/l and 38.82%, respectively.

Table 5 shows the usual range of Sulfate in irrigation

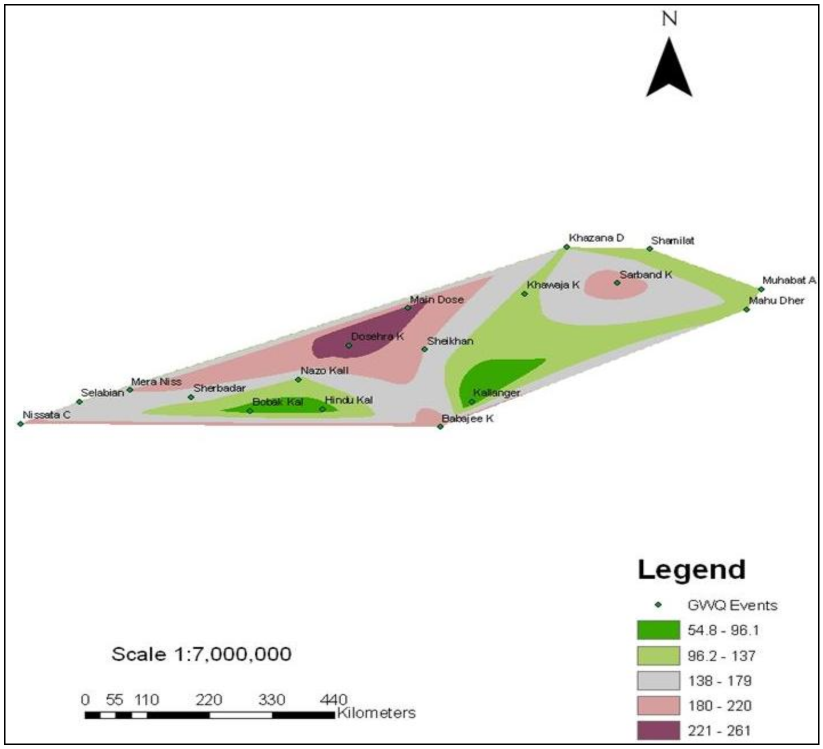

Figure 18. GIS's map showing magnesium's concentration (mg/l) levels in groundwater.

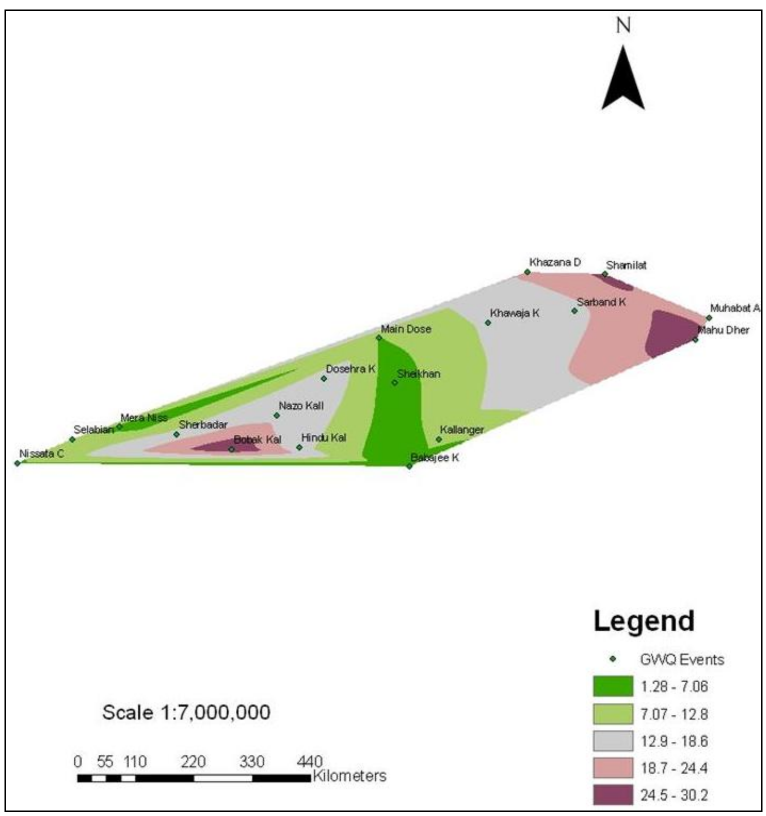

Figure 19. GIS's map showing Sodium concentration (mg/l) levels in groundwater.

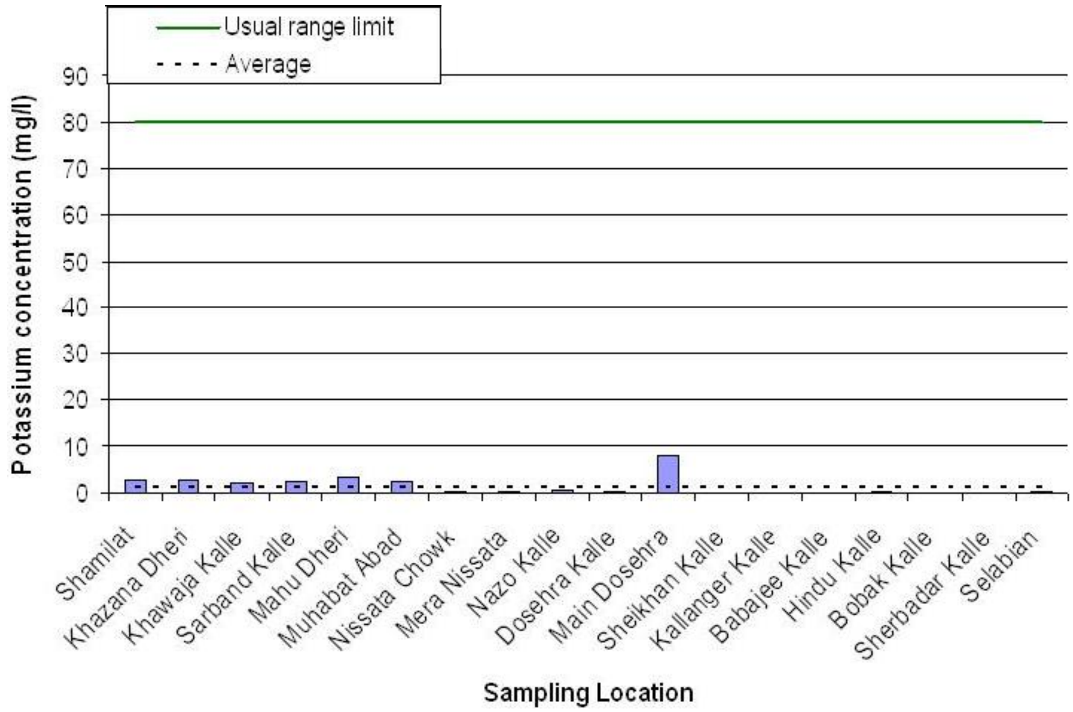

Figure 20. Potassium's concentration in ground water.

Table 5. Common irrigation water quality parameters and its usual range.

Water quality parameter	Symbol	Molecular or atomic weight	Unit	Usual ranges in irrigation water
Electrical conductivity	EC_w	-	dS/m	0 - 3
Total dissolved solids	TDS	-	mg/l	0 - 2000
Calcium	Ca^{++}	40.1	mg/l	0 - 400
Magnesium	Mg^{++}	24.3	me/l	0 - 60
Sodium	Na^{+}	23	me/l	0 - 920
Carbonate	CO^{-}_3	60	me/l	0 - 30
Bicarbonate	HCO_3^-	61	me/l	0 - 610
Chloride	Cl^-	35.5	me/l	0 - 1065
Sulphate	SO_4^{--}	96.1	me/l	0 - 961
Nitrate-Nitrogen	NO_3-N	62	mg/l	0 - 10
Potassium	K^+	39.1	mg/l	0 - 0.05
Acid/Basicity	pH	-	1 - 14	6 - 8.5
Sodium Adsorption Ratio	SAR	-	(meq/l)	0 – 15

The dash (-) shows no value for the cell.

water. The usual range is up to 960 mg/l while water samples contain lesser values as compared to this standard range. Figure 25 shows the concentrations of Sulfate at respected locations while Figure 27 shows the concentration levels of Calcium throughout the study area. Figure 27 indicates that different concentration ranges covers about equal amount of the project area.

Chloride's concentration in groundwater

Chloride values and their statistical parameters are

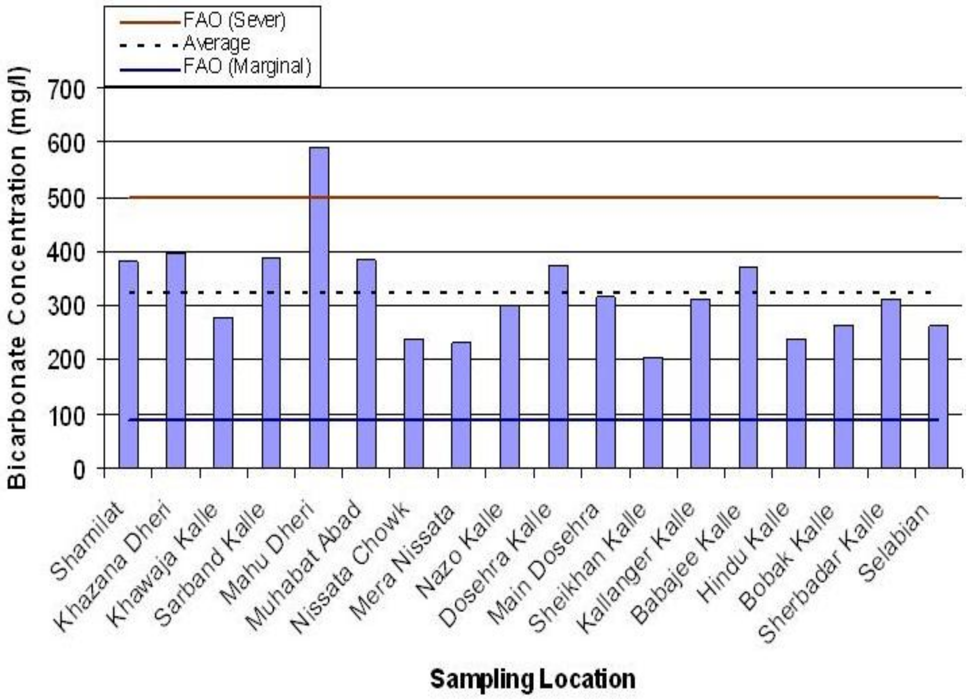

Figure 21. Bicarbonate's concentration in groundwater.

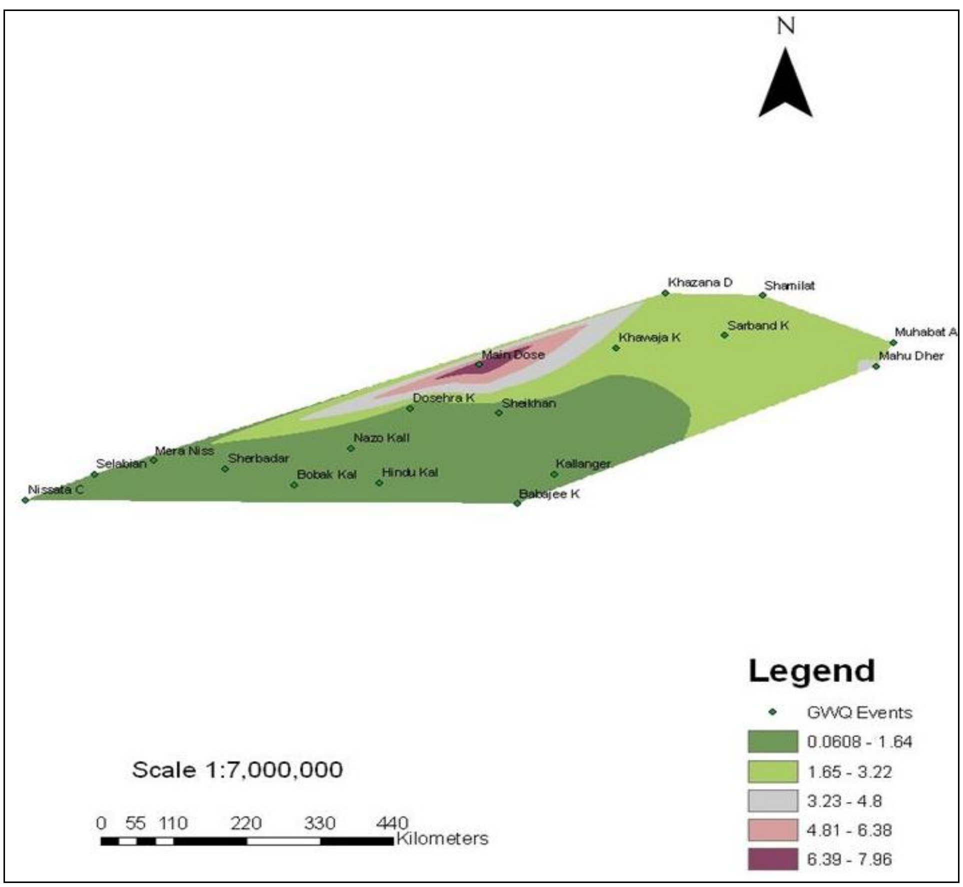

Figure 22. GIS's map showing potassium's concentration 9 mg/l) levels in groundwater.

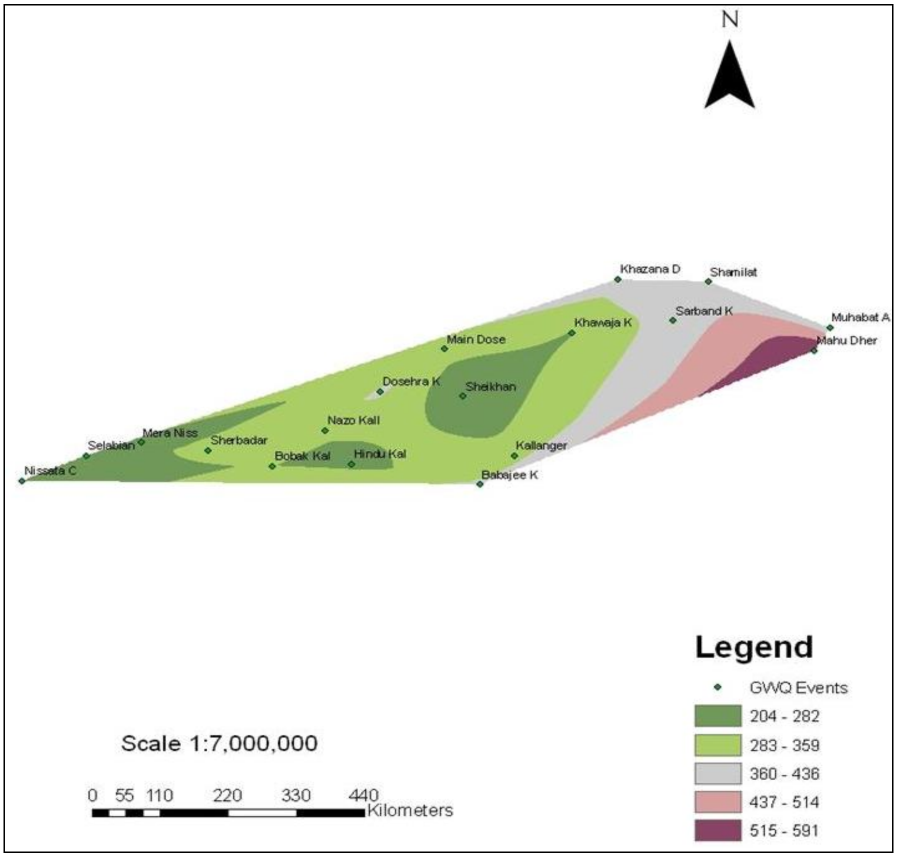

Figure 23. GIS's map showing bicarbonate's concentration levels of groundwater.

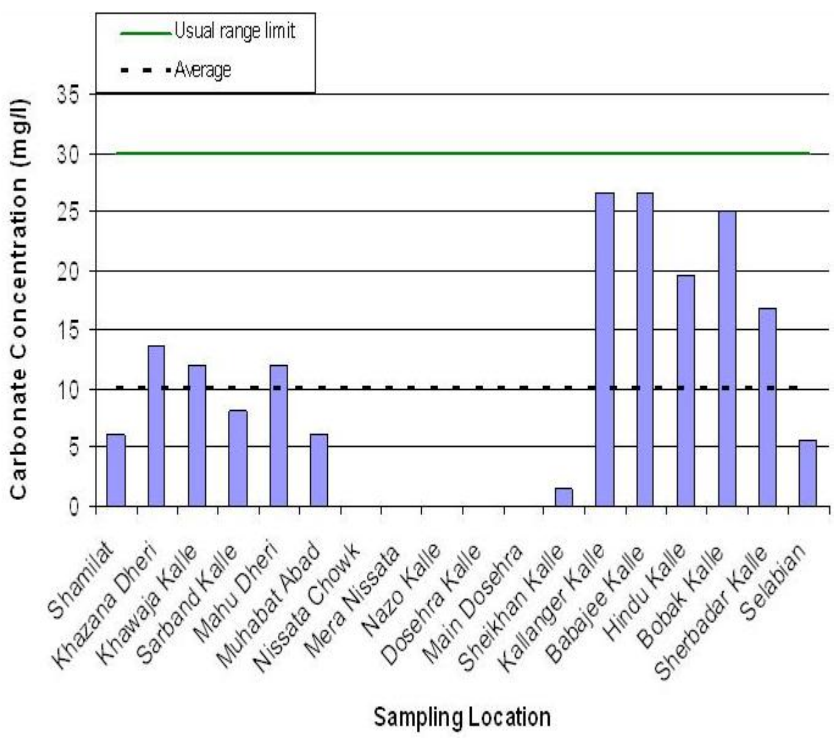

Figure 24. Carbonate's concentration in groundwater.

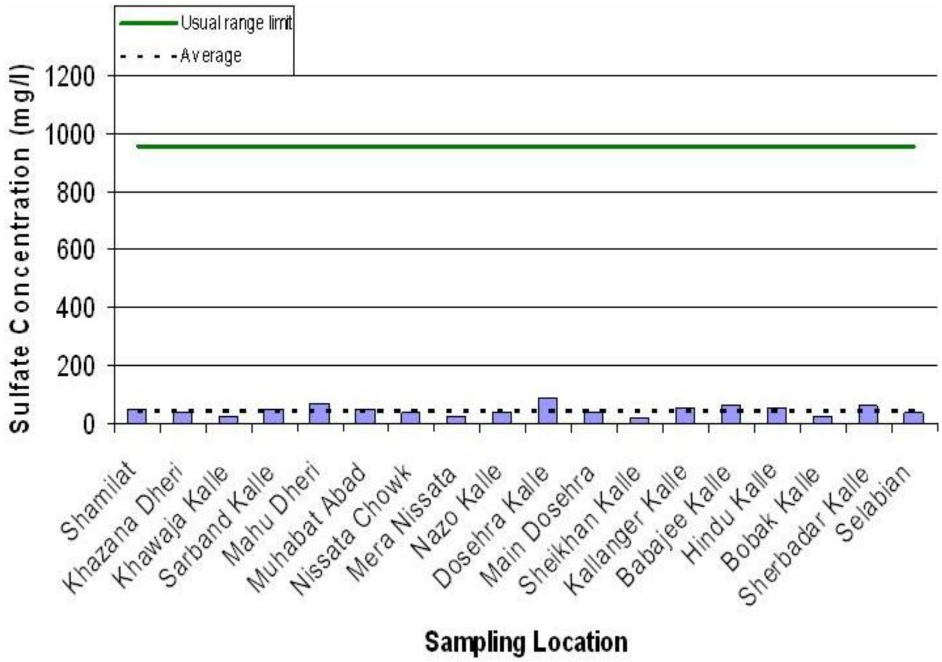

Figure 25. Sulfate's concentrations in groundwater.

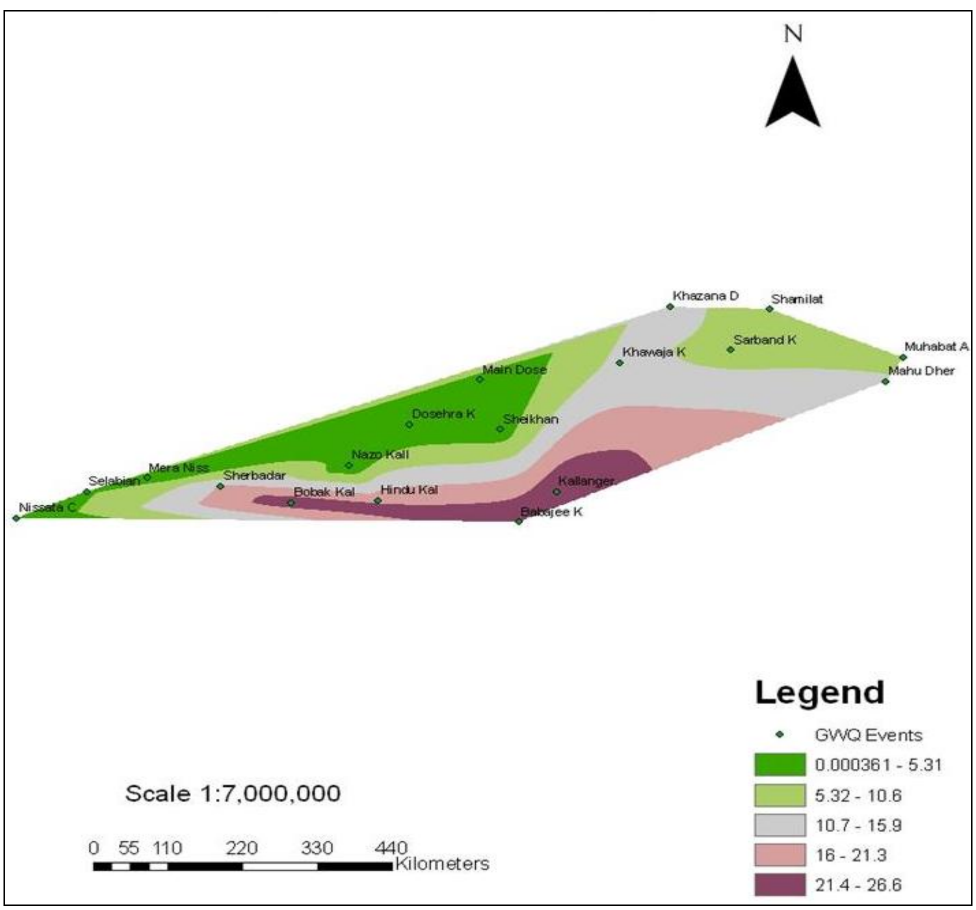

Figure 26. GIS's map showing carbonate's concentration(mg/l) levels in groundwater.

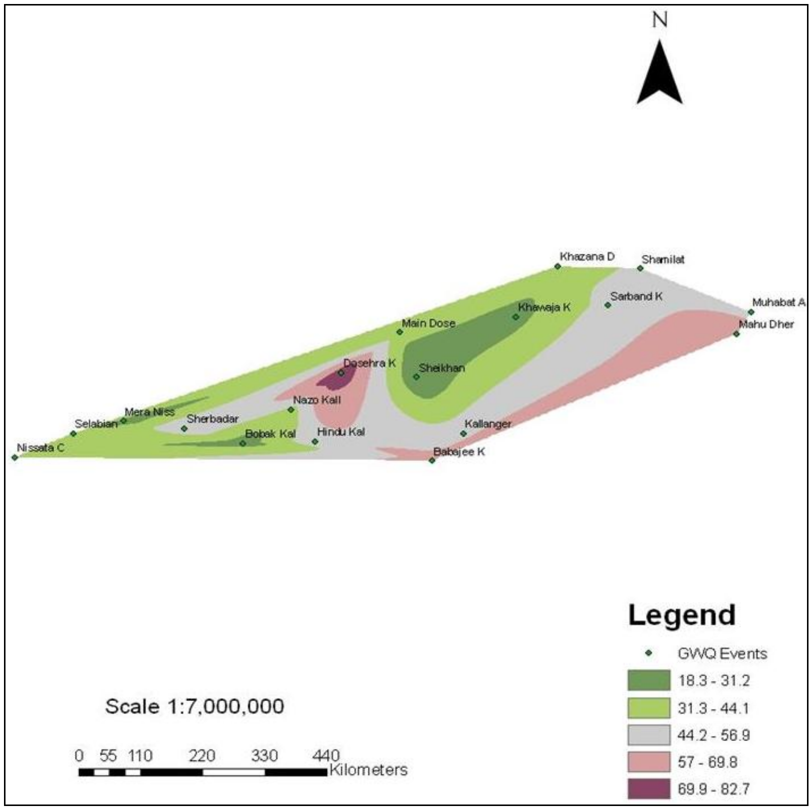

Figure 27. GIS's map showing sulfate's concentration levels in groundwater.

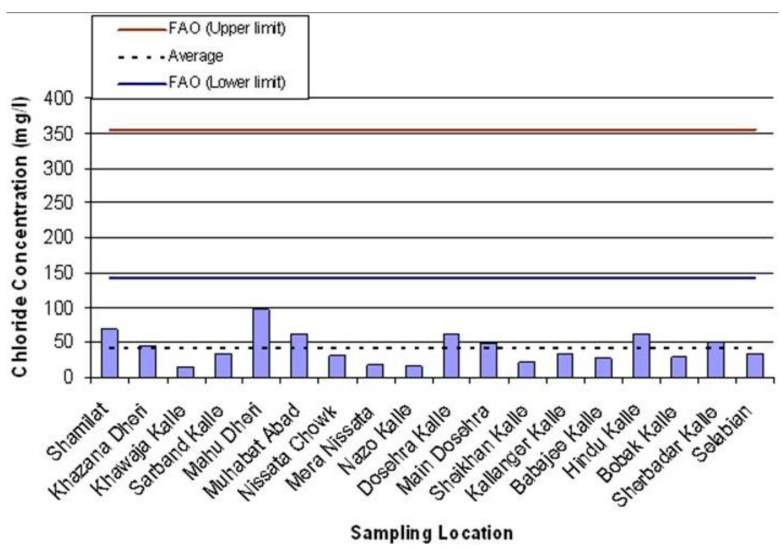

Figure 28. Chloride's concentration in groundwater.

presented in Table 3. The minimum and maximum concentrations of Chloride are 14 and 98 mg/l, respectively. The mean, standard deviation and coefficient of variance for Chloride calculated are 42 mg/l, 22.04 mg/l and 52.46%, respectively.

According FAO (Table 4), the upper limit for Chloride concentration is 355 mg/l while our samples ranges below this limit. Figure 28 graphically presents Chloride concentrations at their respective locations in the project area. Figure 30 shows that medium olivenite color occupies most of the project area and hence the respective concentration level of 30. 47.553 mg/l exist in major portion on the study area.

Nitrate's concentration in groundwater

Nitrate values and their statistical measures are given in Table 3. The minimum and maximum values for Nitrate are 0 and 2.3 mg/l, respectively. The mean, standard deviation and coefficient of variance are 0.98 mg/l, 0.67 mg/l and 0.68%, respectively.

Figure 32 shows minimum value of coefficient of variation for Nitrate. According to Table 5, the usual range of Nitrate in irrigation water is 10 mg/l but the water samples from project area contain lesser values. Nitrate concentrations at respected locations are shown graphically in Figure 29. Figure 31 (GIS's map) shows the levels of Nitrate concentration throughout the study area. This map distinguishes different ranges of Nitrate's concentration at their respective locations. Yellow color range (concentration range 0.921 to 1.379 mg/l) covers more of the project area as compared to other colors.

Statistical analysis of groundwater quality data

Coefficient of variation is a relative measure of dispersion that expresses variation in a set of data when the observations are expressed in different measurements units. It relates standard deviation and the mean by the following equation.

$$CV = \frac{Std.Dev.}{\overline{X}} \times 100$$

Where;

CV = Coefficient of variation
Std. Dev. = Standard Deviation
$\overline{X}$ = Mean value

For more comprehensive evaluation of groundwater quality, statistical analyses are performed. Coefficient of variation and confidence interval are calculated for this purpose. Figure 32 shows coefficient of variations for different parameters of ground water of Mardan SCARP area.

According to Figure 32, variation for Nitrate is the minimum while that for Potassium is the maximum. To estimate the probable interval of a parameter, then the confidence is called confidence interval. Interval estimate gives an indication of accuracy of an estimate. The t-distribution confidence interval is computed using the formula:

$$CI = \overline{X} \pm t(\alpha/2, DF)\frac{s}{\sqrt{n}}$$

Where;
S = Standard deviation,
n = Sample size = 18
D.F (degree of freedom) = n-1 = 18-1 = 17
For 95% Confidence Level: α = 0.05
From Table 6: t-distribution values table.
Confidence interval was calculated by the above equation for irrigation water quality of the project area. Table 6 shows confidence Intervals for different parameters.

Conclusions

This research study was conducted to determine the groundwater quality of Mardan SCARP area, for irrigation purposes. For the best planning and management of the data, Microsoft Excel and GIS techniques are used in this Research study. Various conclusions and recommendations drawn from this research work are presented.

The conclusions drawn from this research work are given below:

1. All physical parameters were within the range of guidelines set by FAO and WAPDA, except EC which shows higher concentrations at certain locations. These locations were Shamilat, Mahu Dheri, Bobak Kalle, Kallanger Kalle, Dosehra Kalle, Main Dosehra and Muhabbat Abad.
2. All chemical parameters are within the range of FAO and WAPDA except SAR and Bicarbonate, which shows higher concentrations at some locations of the study area. These locations are Shamilat, Mahu Dheri and Bobak Kalle.
3. Four locations of Khazan Dheri, Sarband Kalle, Nissata Chowk and Mera Nissata were found completely safe against groundwater pollution. The most polluted location was Mahu Dheri followed by Mohabbatabad while the remaining locations had marginal fit groundwater quality.
4. GPS provides help during groundwater sampling and GIS advances the planning and management of irrigation water quality data. GIS facilitates the statistical calculations of groundwater quality data during analysis.
5. GIS presented the results in the most efficient and advanced form of mapping. The maps prepared from the GPS data and water quality analysis data provide very basic type of information about ground water quality of Mardan SCARP. These maps show the concentration levels for each parameter throughout the project area, which is not possible through other means.
6. Irrigation is generally performed by canal water but during shortages of canal water tube well water is also used in Mardan SCARP area.
7. According to farmers of Nazo Village, Tube well irrigation needed frequent intervals for irrigation as compared to canal irrigation. It can be concluded that it is due to difference in water quality.

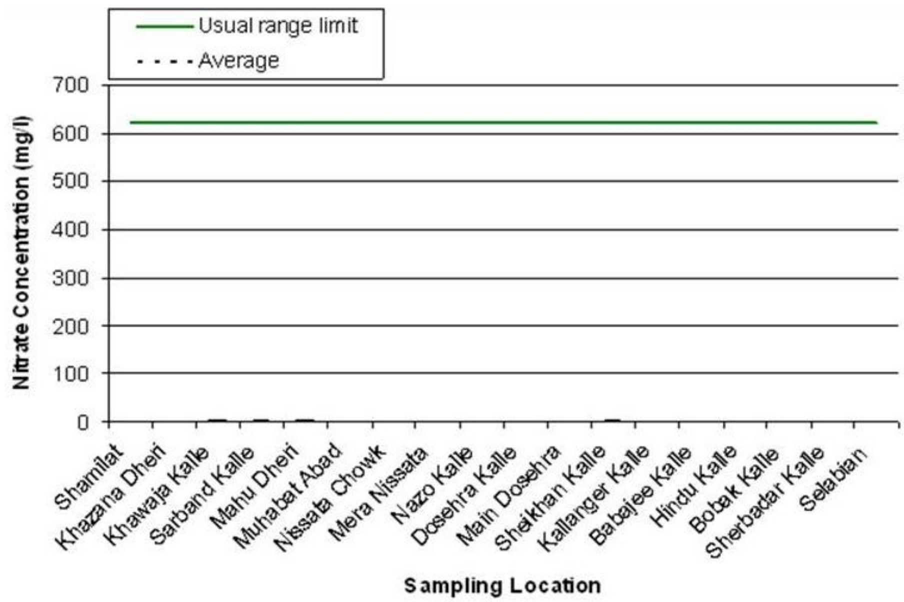

Figure 29. Nitrate concentration in groundwater.

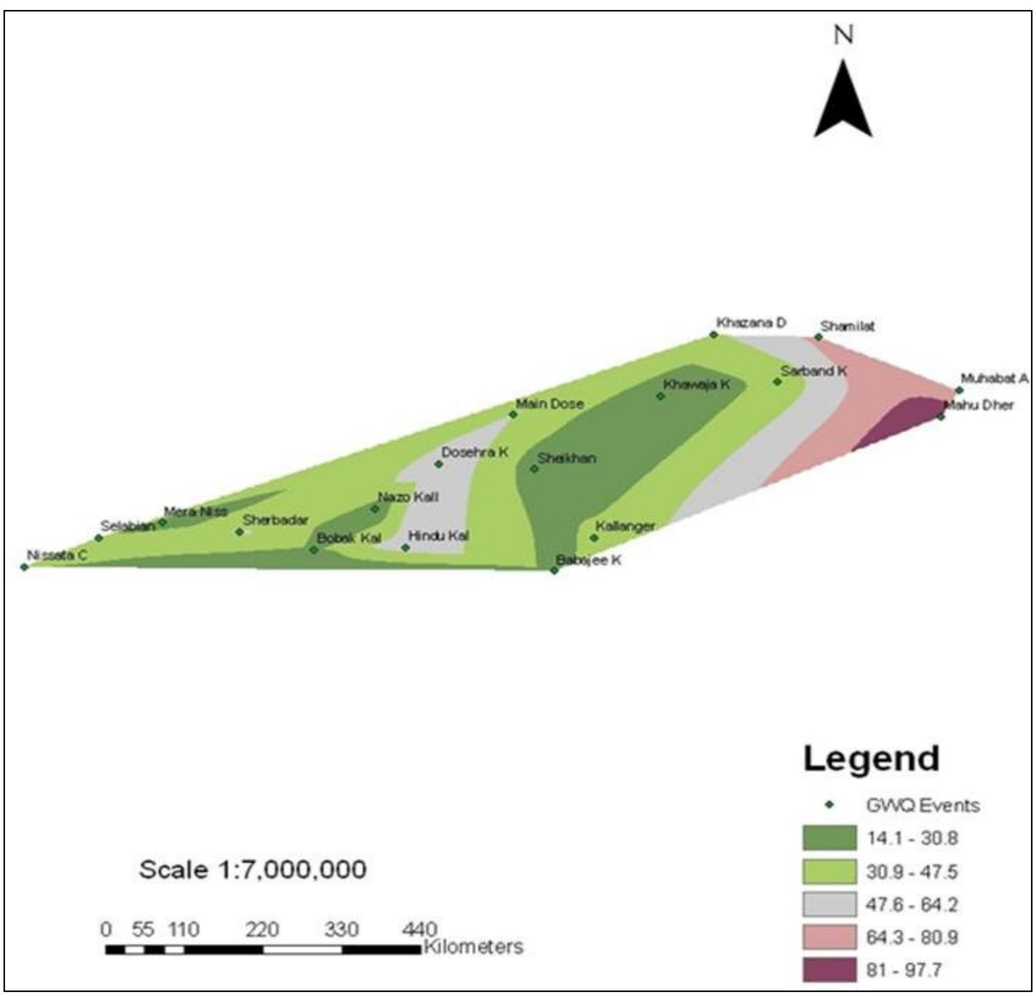

Figure 30. GIS's map showing chloride's concentration (mg/l) levels in groundwater.

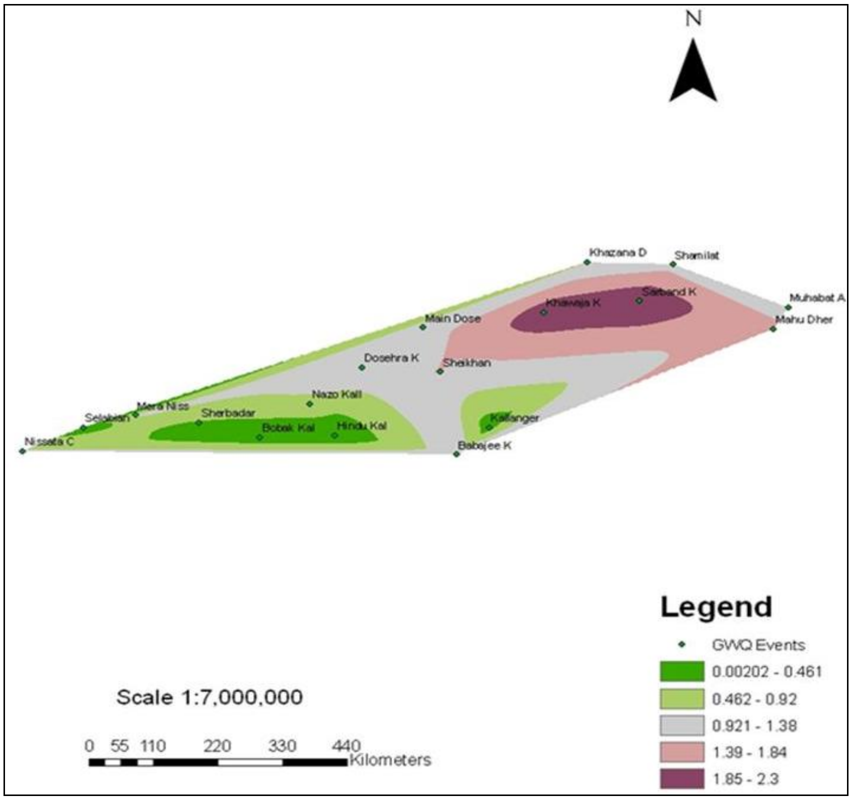

Figure 31. GIS's map showing nitrate's concentration (mg/l) levels in groundwater.

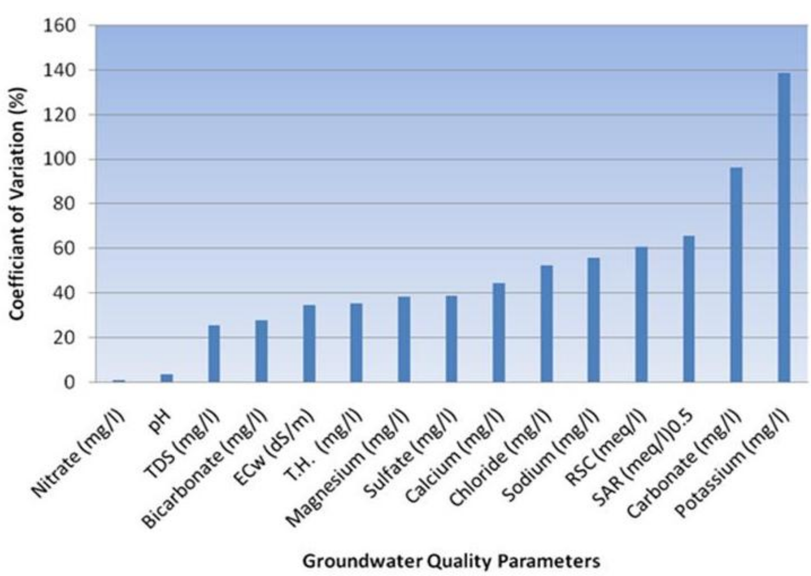

Figure 32. Coefficient of variation for various parameters of groundwater.

RECOMMENDATIONS

For future planning and management of ground water quality, various recommendations are drawn from this study.

1. Necessary precautions should be adopted before using groundwater of Mahu Dheri and Muhabbat Abad Kalle, for irrigation. Suitable arrangement should be made for reducing the risk of salinity and sodicity. Use of Gypsum and salt tolerant crops are recommended

Table 6. Statistical measures of various parameters.

S/N	Parameter	Min.	Max.	Mean	Std. Dev.	C.V.	$t(\alpha/2,DF)\frac{s}{\sqrt{n}}$	C.I
1	Electrical conductivity (dS/m)	0.41	1.13	0.67	0.17	34.37	0.085	(0.585, 0.755)
2	Total dissolved solids (mg/l)	205	562	335.94	84.74	25.22	42.14	(293.80, 378.08)
3	Total hardness (mg/l)	98	390	236.28	86	35.37	42.77	(193.51, 279.05)
4	pH	6.94	7.92	7.2	0.25	3.52	0.124	(7.08, 7.32)
5	Sodium adsorption ratio (meq/l)^0.5	0.33	13.62	5.5	3.71	65.63	1.845	(3.65, 7.35)
6	Residual Sodium carbonate (meq/l)	-23.62	-0.67	-11.47	7.18	60.85	3.571	(-15.04, -7.90)
7	Calcium (mg/l)	37	172	91.11	40.46	44.41	20.12	(70.99, 111.23)
8	Magnesium (mg/l)	54	262	150.72	57.91	38.42	28.8	(121.92, 179.52)
9	Sodium (mg/l)	1.2	30.30	14.54	8.69	55.91	4.322	(10.22, 18.86)
10	Potassium (mg/l)	0.06	8	1.45	2	138.7	0.995	(0.46, 2.44)
11	Bicarbonate (mg/l)	203	592.5	325.84	90.37	27.72	44.94	(280.90, 370.78)
12	Carbonate (mg/l)	0	26.6	9.95	9.59	96.38	4.77	(5.18, 14.72)
13	Sulfate (mg/l)	18	83	44.28	17.19	38.82	8.55	(35.730, 52.83)
14	Chloride (mg/l)	14	98	42	22	52.46	10.94	(31.06, 52.94)
15	Nitrate (mg/l)	0	2.3	0.98	0.67	0.68	0.34	(0.65, 1.31)

for this purpose.

2. Due to high water table of certain areas of Mardan SCARP, regular monitoring of groundwater quality may be recommended.
3. Adjoining areas with the current study area should be examined in the same way for complete management and planning of groundwater quality in Mardan SCARP.
4. Complete study of groundwater, surface water and soil salinity and sodicity, of Mardan SCARP is necessary for future farming in the area. Application of GPS/RS and GIS are recommended for basic and advanced planning of Mardan SCARP.
5. For advanced planning and management, complete GIS mapping of Mardan SCARP as well as other such means may be suggested.
6. Comparison of groundwater as well as surface water inside Mardan SCARP is recommended for complete investigation of water quality.
7. Conjunctive use of tube well and canal water will be the best practice to apply.
8. Vegetative bioremediation techniques are recommended for the best planning and management of the salt affected areas.
9. Due to the higher water table level; pesticides, herbicides and fertilizers must be used very carefully.
10. To reduce seepage and percolation losses, Sprinkler and Trickle irrigation should be used in the study area.

Abbreviations/Symbols: #, Number; **%,** percent; **amu,** atomic mass unit; **B,** Boron; **C^-,** clay; **Ca^{++},** Calcium; **$CaCO_3$,** Calcium Carbonate, **CCA,** cultivable command area; **CI,** confidence interval; **CIDA,** Canadian international development agency; **Cl^-,** Chloride; **CO_3^{--},** Carbonate; **CV,** Coefficient of Variation; **dS/m,** Deci Siemens per meter, **EC_w,** Electrical Conductivity of water; **Ele,** Elevation; **FAO,** food and agriculture organization; **F.R.,** final reading; **GDP,** gross domestic product; **GIS,** geographical information system; **GoP,** government of Pakistan; **GoNWFP,** government of NWFP; **GPS,** global positioning system; **GWQ,** ground water quality; **Ha,** hectare; **Ha-m,** hectare meter; **HCO_3^{--},** Bicarbonate; **H^+,** Hydrogen; **I.R.,** initial reading; **K^+,** Potassium; **Kgs,** kilograms; **Lat,** latitude; **Long,** longitude; **m,** meter; **M,** million; **Max,** maximum; **meq/l,** milli equivalent per liter; **Mg^{++},** Magnesium; **mg,** milligram; **Min,** minimum; **N,** normality; **Na^+,** Sodium; **NaCl,** Sodium Chloride; **$NaHCO_3$,** Sodium Bicarbonates; **NO_2^-,** Nitrite; **NO_3^-,** Nitrate; **NWFP,** North West Frontier Province; **P,** Phosphorous; **pH,** Power of Hydrogen ion concentration; **ppm,** parts per million; **RSC,** residual Sodium Carbonate; **SAR,** Sodium adsorption ratio; **SCARP,** salinity control and reclamation project; **Std. Dev,** standard deviation; **SO_4^{--},** Sulfate; **Sq. Km,** square kilometer; **TDS,** total dissolved solids; **TH,** total hardness; **TSS,** total soluble solids; **USDA,** United State Department of Agriculture; **WAPDA,** water and power development authority.

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