GROUNDWATER VULNERABILITY MAPPING IN FAISALABAD DISTRICT USING GIS BASED DRASTIC MODEL

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ABSTRACT The demand of groundwater has significantly increased during the past two decades to meet the food and fiber requirements due to constrained surface irrigation water. The groundwater has a major share to grow agriculture in Punjab-Pakistan, which produces more than 90% gains of the country. Beside the importance of groundwater, a major concern in recent years is the contamination of groundwater. The consecutive monitoring and mapping of aquifer water quality in large areas is a hectic job and not even economically feasible. Thus groundwater vulnerability maps are becoming more in demands to represents regional aquifer contamination potential. The aim of this research work was to find out the groundwater vulnerability potential zones in Faisalabad and its nearby areas, which is the fastest growing city of Pakistan. For this purpose, GIS based DRASTIC model was used to measure vulnerability related to agriculture in Faisalabad district. The inputs of the model are based on seven different layers. The results of the model were compared with groundwater samples. It was found that the DRASTIC model accurately identified the vulnerability of Faisalabad District with prediction efficiency of about 73%. The results revealed that more than 30% of study area was under high vulnerability potential. The areas under high vulnerable pollution are located in middle and upper part of Faisalabad District. The high vulnerable pollution in surrounding of Salarwala, Chak Jhumra and Khurianwala cities was due to shallow groundwater table, high recharge, gradual slope, sandy aquifer media and soil media consist of medium sand. The high vulnerable pollution in surrounding of Dijkot city was due to shallow groundwater table, gradual slope, vadose zone consist of coarse sand and high hydraulic conductivity. It is therefore recommended that Rainwater harvesting and ASR (Aquifer Storage and Recovery Wells) should be adopted in medium and high vulnerability areas to reduce water salinity.

1 INTRODUCTION

Groundwater is one of the most important component of our life support system and has significant contribution in economic development (Saatsaz et al., 2011). In recent decades, the utilization of groundwater has remarkably increased. World widely, more than 2 billion people depends upon groundwater to meet drinking water requirements (Senthilkumar et al., 2014), while in Pakistan, 90% population utilized aquifer water for daily domestic need (Qureshi et al. 2010).

Irrigated agriculture exists worldwide on about 260 million hectares of land, out of which, four countries i.e. India, China, USA and Pakistan account for more than half of the world's irrigated land (Bhatti et al., 2017; Doll and Siebert, 1999). Globally, irrigated agriculture produces about 60% of grain production that utilizes two third of world's fresh water for irrigation with a significant contribution from groundwater resources. It was estimated that annually, about 750-800 billion cubic meters of global groundwater withdrawals were being used for irrigated agriculture (Shah, 2007).

Like many other countries of the world, Pakistan depends heavily on irrigated agriculture because of the arid climatic conditions (Javed *et al.*, 2015; Mongat *et al.*, 2015; Asghar et al., 2002). During the drought period, groundwater was the main cause for the survival of irrigated agriculture in Pakistan (Arshad et al., 2013). The use of groundwater is expected to increase further with rising pressure of population to produce more food. About 1.2 million small capacity private tubewells are working in Pakistan, out of which, more than 90% are used for agriculture (Shakoor et al., 2017; Qureshi, 2012). About 62 billion cubic meter (BCM) of groundwater is being pumped annually to supplement surface water supplies as food demand is increasing in Pakistan due to population growth (Arshad et al., 2013; Shakoor et al., 2012). The tubewells not only provide additional water but also add flexibility to water supplies to match the crop water requirements. Most of tubewell installation has taken place in Punjab due to intensive agricultural development (Arshad et al., 2013). In irrigated agriculture, the application of poor quality groundwater was considered as one of the major source of salinity in root zone and ultimately a reason of reduction in crops yield (Kijne,

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1996; Shakoor et al., 2015). In Punjab, about one fourth of the groundwater has poor quality groundwater, while it is about 3/4 in Sindh (Haider, 2000). In Punjab, the quality of groundwater varies between 0.3 to 4.6 dS/m (deci-Siemens per meter) in the Punjab province.

Currently, several methods have been popular for evaluating groundwater vulnerability (Zhonghua et al., 2015; Ersoy et al., 2013) and DRASTIC is the most widely used approach, which combine physical and hydrogeological characteristics of a specific area (Senthilkumar et al., 2014; Adjim and Bensaoula, 2013; Babiker et al., 2005). DRASTIC method was developed by the staff of the U.S. Agency for Environmental Protection USEPA (Aller et al., 1987). DRASTIC method, a standardized system for evaluating groundwater pollution potential has been frequently implemented (Al-Ansari et al., 2013; Saha and Alam, 2014). It allows the assessment of vulnerability of the vertical aquifer pollution caused by parametric systems (Madjid and Omar, 2013). DRASTIC model employs hydro-geological data in a Geographical Information System (GIS) environment to compute aquifer vulnerability index. DRASTIC is an shortening of seven physical parameters of hydro-geological which used to define groundwater system and its susceptibility towards pollution (Zhonghua et al., 2015; Pradhan et al., 2014; Rahman, 2008; Jamrah et al., 2007). It considers seven parameters, which taken together, provide the acronym such as Depth to groundwater (D), Recharge (R), Aquifer type (A), Soil type (S), Topography (T), Impact of the vadose zone (I), Hydraulic conductivity

(C) (Hanini et al., 2013). Each parameter, divided to an interval of significant values, is assigned by a numerical rating based on its growing importance in the vulnerability. These seven parameters are used to define the different hydrogeological units, variously influenced by transport processes and attenuation of contaminants in the soil (Madjid and Omar, 2013; Khan et al., 2010).

Groundwater vulnerability is sensitive to humans and natural impacts on the ground surface and within the aquifer system and consider and thus indispensable property of groundwater. The regional groundwater management and protection from contamination can be achieved by vulnerability zone maps. For this purpose, the area of Faisalabad district was selected, one of the largest growing cities of Pakistan, to delineate the groundwater vulnerability zones. The specific objectives of this study were to conceptualize a method to identify the groundwater vulnerability and to delineate the groundwater vulnerable zones in the Faisalabad District.

2 MATERIALS AND METHODS

Study Area: This research work was conducted at Faisalabad district, which covers the area of 5856 km². Geographically, Faisalabad district is situated in 30.68°N 72.85°E to 31.76°N 73.21°E with an elevation of 184.14m (604 feet) above sea level and is located in the Punjab province, as shown in Figure 1.

Figure 1: Location of study area and piezometers

in northeast side and comparative lower elevation (164m) was found in southwest side of the study area.

The climate of Faisalabad is arid climate in which summer is extremely hot with temperature variation of 21-51°C, while in winter season is 7-27°C. The surface elevation data were downloaded from ASTER GDEM Worldwide Elevation Data (1.5 arc-second Resolution) using Global Mapper software. Global Mapper is one of the most widely used software for reading large amounts of geospatial data in native format (Korzeniowska, 2012; Cliften and Weeden, 2009). The specific latitude/longitude bound of the area extracted using Global Mapper (version 13.2) in decimal degree. The file was saved in Raster file (BIL format). The data were processed and the model area was clipped using GIS software, as shown in Figure 2. The higher elevation (271m) was found

Figure 2: Elevation of District Faisalabad

2.1 Description of DRASTIC Model

The DRASTIC is GIS based model which required seven layers of different hydrogeological data of a particular

area. The acronym DRASTIC represents to the letters of the seven base maps (Figure 3).

Figure 3: Seven parameters and layers of DRASTIC model

The final vulnerability DRASTIC indexed (D_i) map is computed by weighted sum overlay technique of all seven layers in GIS using the Equation 1 (Shirazi et al., 2012):

$$2.2 \text{ DRASTIC index } (D_i) = DrDw + RrRw + ArAw + SrSw + TrTw + Irlw + CrCw \quad (\text{Eq. 1})$$

Where, D, R, A, S, T, I, and C are the seven different hydro-geological parameters, r is the user defined rating

values of each range, and w is the fixed weight assigned to each layer parameter (Table 1). The weight of each parameter in the model is fixed, higher weight indicates the relative higher influence of the parameter in transportation of pollution to the groundwater. The rating of each parameters are variable, depending on the features and variability of the study site (Dixon, 2005).

Table 1. The seven DRASTIC model parameters and their relative weights

Factors	Descriptions	Original Relative Weight	Modified Relative Weight*
Depth to Water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5	5
Net Recharge	Represents the amount of water which penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants.	4	4
Aquifer Media	Refers to the saturated zone material properties, which controls the pollutant attenuation processes.	3	3
Soil Media	Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2	5
Topography	Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1	3
Impact of Vadose Zone	Is defined as the unsaturated zone material, it controls the passage and attenuation of the 2contaminated material to the saturated zone.	5	4
Hydraulic Conductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3	2

*

Source Dixon (2005)

Groundwater Data: The data of groundwater level were acquired from the Department of Irrigation and Drainage Faisalabad for the years of 2014-2015. The

groundwater samples were collected from 40 tubewells across the study area for determining groundwater quality. In order to do so, the water analysis were performed in the Water Quality & Environmental Engineering Lab, Dept. of Agricultural Engineering, Bahauddin Zakariya University, Multan.

Rainfall Data: In this study a total of 55 rain gauge stations were used for temporal analysis of rainfall data, acquired from Pakistan Metrological Department (PMD), Islamabad for year 2016 TRMM Satellite rainfall data at monthly (TRMM 3B43 V6) and daily (TRMM 3B42 V6) time steps for the year 2016 were collect from (<http://neo.sci.gsfc.nasa.gov/Search.html?group=39>) NASA public domain. The cumulative annual rainfall was occurred in the range of 932-1091mm (Figure 4). The maximum rainfall was occurred on the upper side of the area.

Figure 4: Rainfall distribution in the study area

Table 2: DRASTIC parameters and percent area

1-Groundwater Depth				2-Net Recharge				3-Aquifer Media				4-Soil Media			
Ranges (ft)	Ratings Dr	Index DrDw	Area (%)	Ranges mm/year	Ratings Rr	Index RrRw	Area (%)	Ranges	Ratings Ar	Index ArAw	Area (%)	Ranges	Ratings Sr	Index SrSw	Area (%)
5-10	10	50	14.5	185-195	2	8	14.51	Fine to medium sand	5	15	36.86	Clay	3	15	28.87
10-15	9	45	22.15	195-200	4	16	20.21					Clay Loam	4	20	35.63
15-20	8	40	19.73	200-205	6	24	25.39					Fine Sand	5	25	22.85
20-25	7	35	13.13	205-210	8	32	23.32	Medium Sand	6	18	40.05	Medium Sand	7	35	9.21
25-30	6	30	7.07	210-218	10	40	16.58	Sand & Gravel	8	24	23.1	Mix Sand & Silt	8	40	3.44
30-35	5	25	6.21												
35-40	4	20	5.17												
40-45	3	15	5.45												
45-50	2	10	4.78												
50-60	1	5	1.79												
Weight:5				Weight:4				Weight:3				Weight:5			
5-Topography				6-Impact of Vadose Zone				7-Hydraulic Conductivity							
Ranges (%)	Ratings Tr	Index TrTw	Area (%)	Ranges	Ratings Ir	Index Irlw	Area (%)	Ranges (m/day)	Ratings Cr	Index CrCw	Area (%)				
0-6	8	24	11.77	Sand with Silt	3	12	4.91	70-80	1	2	11.79				
6-10	7	21	11.43	Medium Sand	4	16	20.39	80-90	2	4	27.64				
10-20	6	18	57.7	Sand	5	20	48.16	90-100	4	8	21.99				
20-60	5	15	17.35	Course sand with Gravel	6	24	23.34	100-110	6	12	25.68				
60-85	1	3	1.76					110-120	8	16	7.37				
				Gravel	7	28	3.19	120-126	9	18	5.53				
Weight:3				Weight:4				Weight:2							

2.3 Lithological Data

Water and Power Development Authority (WAPDA, 1978) conducted a study at Rechna Doab which contained the data of 487 boreholes to determine the sub-surface lithology and aquifer characteristics. The lithological data thus were collected from WAPDA. The boreholes depth were from 91 to 457m below the land surface. These are river transported deposits (alluvium), which are quite thick and fairly homogeneous in extent. The analysis showed that the soils had different classification according to different textural characteristics. The soil texture class includes: Fine (Sandy Clay, Silty Clay and Clay), Moderately Fine (Sandy Clay Loam, Clay Loam and Silty Clay Loam), Medium (Loam, Silt Loam and Silt), Moderately Coarse (Sandy Loam, Fine Sandy Loam) and Coarse (Sandy Loam, Sand). The soils consist of alluvial

deposits transported by the Indus River and its tributaries. The surface soils textures are predominantly fine and moderately medium, with favorable permeability characteristics and are similar throughout the area.

Model Validation: The model was validated by comparing the predicted values with the values of monitoring wells. The vulnerability index values of model were converted from raster to point values using the Raster to Point conversion tool and the point values were compared with the water samples. The prediction accuracy rate was determined by whether the model successfully identified a low vulnerability area for a low irrigation water quality observation and a high vulnerability area for a high water quality observations with respect to salinity.

3 RESULTS AND DISCUSSIONS

3.1 Depth to Groundwater

The depth of groundwater level from the ground surface is one of the significant factor in the model because it describes the downward traveling distance of the leaching contamination before mixing in the groundwater. This factor also depicts the potential of interaction between the deep percolated pollution and groundwater. The shallow groundwater depth generally has higher potential of

pollution from the ground surface. The maps of borehole data were contoured by interpolating and presented in Figure 5. The interval of groundwater water, rating, weight and resulted index for water table are given in Table 2. The water table depth is ranged from 5ft to 60ft and divided into ten categories with interval of 5ft. The comparative deep water level is present around Faisalabad, Mamunkajan and Jaranwala cities and has less potential of contamination and vice versa.

Figure 5: Spatial distribution of groundwater depth and DrDw index

3.2 Net Recharge

The total amount of rainfall is consider as net recharge to groundwater and work as vehicle to transport

contamination from ground surface to saturated aquifer. The estimation of recharge is complicated and involves a number of unknown factors, which made the estimation difficult. Sources of recharge to groundwater include infiltration from rainfall and losses from irrigated fields.

Figure 6: Spatial distribution of recharge and RrRw index

The rainfall recharge data were collected from the Satellite based (TRMM) data and spatial distribution is presented in Figure 6. The upper part of the study area has higher level of risk because higher recharge reached more quickly from ground surface to groundwater. An area receive low groundwater recharge is has less potential to carry pollution because of the minimum permeable pathway from the ground surface to the groundwater (Table 2). Ahmed and Chaudhry (1988) conducted a field study to determine the recharge contribution to groundwater from rainfall and water delivered in

irrigation fields in Upper Gogera Branch canal, Punjab, Pakistan. The contribution of recharge to groundwater was found from 17 to 22% of rainfall, while 20% was selected as used by Arshad *et al.* (2005), conducted a field and modeling study in Rechna Doab, Punjab, Pakistan.

3.3 Aquifer Media

The movement of salinity in groundwater is strongly depend upon the aquifer media and it describe the time for intrusion process such as diffusion, advection and

dispersion with or without sorption effects. Aquifer media provides the interconnected pore spaces to solute transport

from one place to other. Thus the movement of contaminates are highly depends on the aquifer media.

Figure 7: Spatial distribution of aquifer media and ArAw index

According to the geological data of District Faisalabad, the aquifer was classified as Fine to Medium Sand, Medium to sand and Sand to Gravel and rating of aquifer media is from 5 to 8 (Table 2). The higher rating was given to Sand and gravels and the spatial distribution of aquifer media is shown in Figure 7.

3.4 Soil Media

The type and grain size in the soil are the main factor for potential of pollution of soil media. The characteristics of

upper soil layer will define the amount of water infiltrating from the ground surface and purifying process of contaminants. The presence of clay and silt particles in the soil decreases infiltration rate and forbid contaminant migration via physico-chemical processes, i.e., ionic exchange and absorption. The weightage of 5 and ratings from 3-8 were assigned to prepared a soil media map (Table 2). The majority of the Soil varies from Clay to Fine Sand in the study area (Figure 8). In comparison to fine soil media, coarse soil media have high rates because it has high potential to infiltrate contamination from ground surface.

Figure 8: Spatial distribution of soil media and SrSw index

3.5 Topography

Topography generally describe the slope of an area. In less slope areas the potential of contamination is high because it allow water to stand for longer period of time and hence greater recharge occurred which can carry pollution. In steep slopes areas, larger amount of water has runoff due

to gravity and hence it allow less amount of water to infiltrate or recharge. To prepare the topographic map, the specific latitude/ longitude bound of the area extracted using Global Mapper (version 13.2) and file was saved in Raster file (BIL format). The data were processed using slope calculation tool in GIS software and clipped from the model, as shown in Figure 9.

Figure 9: Spatial distribution of slope and TrTw

3.6 Impact of Vadose Zone

The vadose zone's influencing and essential component for determining potential of aquifer pollution. The impact of vadose zone to groundwater vulnerability is the combination characteristics of topography and aquifer

media. Vadose zone layer is the in between the saturated and unsaturated aquifer and has great influence on solute transport. Impact of vadose zone map was delineated from the analysis of lithological data of the study area. The vadose zone has a high impact on water movement if it is composed of a permeable material. The weights and ratings for the vadose zone are shown in Table 2. Vadose zones have been mapped as shown in Figure 10.

Figure 10: Spatial distribution of vadose zone and Irlw

3.7 Hydraulic Conductivity

The ability of aquifer media to transmit water within its saturated profile is known to be hydraulic conductivity. It is largely influenced by the effective porosity of the aquifer, is the amount of actual interconnected pore spaces takes part to transmit water. Higher hydraulic conductivity allows water flux to carry solute from higher to lower contamination zone, hence more vulnerable. The

hydraulic conductivity of the study area was calculated from the soil data according to CSIRO (2003) and map to represent spatial distribution of hydraulic conductivity was prepared. The range of hydraulic conductivity is between 71 m/day to 126 m/day in the study area. The ratings for hydraulic conductivity are from 1-9, depending upon the hydraulic conductivity, shown in Table 2. The spatial delineation of hydraulic conductivity and its index is shown in Figures 11.

Figure 11: Spatial distribution of hydraulic conductivity and CrCw

3.8 Vulnerability Zones

All these seven hydro-geological data layers of DRASTIC model were sum up in ArcGIS environment using weighted sum overlay analysis to delineate vulnerability map. In this final index map, the value of each cell was computed as the sum of all the assigned indexes which ranged from 94 to 200. Finally, vulnerability layer was further reclassified into three classes i.e., low vulnerable (94-139), moderate vulnerable (139-167) and high vulnerable (167-200) zones (Table 3). The results revealed

that an area of about 1287.52 km² is in the low vulnerable zone, about 2787.86 km² are in the moderately vulnerable zone and about 1780.61 km² are in the high vulnerability zone with a DRASTIC index ranging between 167 and 200. This means that more than one third of the Faisalabad District's groundwater is at high risk in terms of agricultural pollution potential and about half of area in moderate pollution potential. The areas under high vulnerability zone is mainly in the North and Central parts of the study area, where different physical factors supporting the chances of getting aquifer water polluted.

Table 3: Area under vulnerability to groundwater pollution

Vulnerability	Vulnerability Index Range	Area (Ha)	Area (Percent)
Low	94-139	1287.52	22.00
Moderate	139-167	2787.86	47.60
High	167-200	1780.61	30.40

Figure 12: Groundwater vulnerability map

The spatial distribution of groundwater vulnerability based on agricultural point of view is shown in Figure 12. The areas, which are under the high vulnerable pollution, are in surrounding of Salarwala, Chak Jhumra, Khurianwala, Dijkot, Satiana, Tandlianwala cities which is mainly due to following 5 reasons particularly for that area, such as 1) shallow groundwater table, which imply higher chance for contamination to occur because contamination reached rapidly to it. 2) high recharge, which paly as the vehicle for transporting pollutants from the surface 3) lesser slope, which help water to infiltrates more than runoff 4) coarse sand aquifer media which has high potential of groundwater intrusion and movement 5) higher hydraulic conductivity, which transmit more contaminated water within the groundwater system. The areas having moderate vulnerability are in surrounding of Faisalabad, Painsra, Samundri, Jaranwala cities. The remaining areas such as Jaranwala and Mamunkanjan has low groundwater vulnerability. The major limitation of

DRASTIC approach is that it can be used to any pollutant which leached from ground surface to water level but it does not produce a clear picture of the pollution potential of individual chemical.

3.9 Model Validation

The model was validated by comparing the predicted values with the values of monitoring wells. The vulnerability index values of model were converted from raster to point values using the Raster to Point conversion tool and the point values were compared with the water samples. The prediction accuracy rate was determined by whether the model successfully identified a low vulnerability area for a low irrigation water quality observation and a high vulnerability area for a high water quality observations with respect to total dissolved solid (TDS). The results of predicted water TDS and model prediction vulnerability are depicted in Table 3.

Table 3: Model prediction results

Well #	TDS (mg/L) Observation	Model Predicted Vulnerability	Accuracy (True=1, False=0)	Well #	TDS (mg/L) Observation	Model Predicted Vulnerability	Accuracy (True=1, False=0)
W1	2560	High	1	W21	4416	Medium	0
W2	4480	Medium	1	W22	5888	Medium	0
W3	2624	High	1	W23	512	Low	1
W4	3264	High	1	W24	960	Low	1
W5	2176	Medium	0	W25	640	Low	1
W6	1664	Medium	1	W26	3776	Medium	0
W7	1856	Medium	0	W27	576	Low	1
W8	8320	High	1	W28	1984	Low	1
W9	1984	Medium	0	W29	2496	Medium	0
W10	1088	Low	0	W30	583	Low	1

W11	2240	High	1	W31	605	Low	1
W12	1600	Medium	1	W32	704	Low	1
W13	1336	Medium	1	W33	2944	Medium	0
W14	5568	High	1	W34	2432	High	1
W15	4992	High	1	W35	1664	Medium	1
W16	4480	High	1	W36	512	Low	1
W17	1496	Medium	1	W37	1024	Medium	1
W18	1216	Medium	1	W38	356	Low	1
W19	728	Low	1	W39	3648	Medium	0
W20	5120	Medium	0	W40	192	Low	1
				Count			
				29			
				Prediction Rate			
				72.50%			

The groundwater quality of fresh and saline water for total dissolved solid were formulated according to criteria (Good: < 1000mg/L, Marginal: 1000-1800mg/L and Hazardous: >1800mg/L) as described by WAPDA (1982) for irrigation water. The accuracy was calculated with True and False with values of 1 and 0, respectively. It was found that 29 samples out of 40 for TDS satisfied the model results with prediction efficiency of 72.5%.

4 CONCLUSIONS

In this research work, a GIS based DRASTIC model was employed to measure the agricultural groundwater vulnerability of Faisalabad district. Seven different hydrogeological layers according to model were used to represent the pollution potential. In final map, the DRASTIC index ranges from 94 to 200 and it was further reclassified into three sub-classes such as Low vulnerable (94-139), Moderate vulnerable (139 to 167) and High vulnerable (167 to 200). The final vulnerability map represents the areas which could be more disposed to groundwater contaminations relative to one another. The main conclusions drawn from the research were as follows:

- The DRASTIC model accurately identified the vulnerability of Faisalabad District with prediction efficiency of about 73%.
- The areas under high vulnerable pollution are located in middle and upper part of Faisalabad District.
- The high vulnerable pollution in surrounding of Salarwala, Chak Jhumra and Khurianwala cities was due to shallow groundwater table, high recharge, gradual slope, sandy aquifer media and soil media consist of medium sand.
- The high vulnerable pollution in surrounding of Dijkot city was due to shallow groundwater table, gradual slope, vadose zone consist of course sand and high hydraulic conductivity.

It is recommended that,

- Proper drainage system should be prepared in high vulnerable areas for avoiding water contamination.
- Rainwater harvesting and ASR (Aquifer Storage and Recovery Wells) should be adopted in medium and high vulnerability areas to reduce water salinity.
- This kind of study should be conducted in all major districts of Pakistan for future planning to protect groundwater resources.

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