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Geospatial Modelling for Groundwater Quality with Contamination Potential Assessment of Three Urban Areas in Pakistan

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Abstract: Groundwater is the main source of drinking water for most the people in Pakistan. Keeping the importance of groundwater resources and devastating situation in Pakistan, so the aim of this study, make model mapping of geospatial variability and water quality through certain physico-chemical parameters in groundwater of some areas in Pakistan. Results of sixty six water quality parameters including pH, Taste, Turbidity, As, HCO_3Ca, Mg, K, TDS and coliform etc. were collected from three mega cities of Pakistan including Islamabad (27samples), Faisalabad (13 samples) and Bahawalpur (25 samples) during years 2001 and 2003. The collected water sample data was analyzed by using ArcGIS spatial analyst and Geostatistical analysis tools (inverse distance weighted interpolation). The water quality index (WQI) for the study area was computed using all the water quality parameters. According to Pakistan Standard for drinking water, the results revealed that most of the groundwater was not suitable for drinking and have risk of contamination with ratio 21%, 48% and 68% at Faisalabad,Islamabad and Bahawalpur respectively. Thus, this study can be valuable to develop a policy brief about the sustainable use and conservation of limited fresh water resources in future for Pakistan.

Key words: Model mapping of geospatial · Groundwater · Physico-chemical parameters · Water quality index (WQI) · Total dissolved salts · GIS

INTRODUCTION

Groundwater is one of earth's most commonly distributed resources as well as a significant source of water supply all over the world. Clean and safe drinking water is not available to everyone and everywhere in the world. Whereas, it is considered a basic requirement and a human right as it is vital for a healthy life [1]. The situation in Pakistan is the other way round [2]. The rapid urbanization and growth in population of Pakistan causes the water demand to rise which results in theover and above exploitation of available water resources. Per person water availability in Pakistan has significantly decreased to about 1,000 $m^3$from about 5,600 m^3which was once in the middle of 20th century. This condition has led Pakistan to the edge of water shortage country [3]. Groundwater can become polluted naturally or due to several human and agricultural activities [4-10]. Pollution of groundwater can result in poor drinking water quality, loss of water source, high clean-up costs, high costs for alternative water supplies and/or potential health problems. A number of materials have been recognized as pollutants found in groundwater. These consist of synthetic organic chemicals, hydrocarbons, inorganic cations, inorganic anions, pathogens and radionuclides [11]. The poor drinking water quality and unhygienic conditions are responsible of around 80% of all diseases and third of deaths in developing countries like Pakistan[12-13].Several reports states that the water quality of major cities of Pakistan such as Sialkot, Gujarat, Faisalabad, Karachi, Qasur, Peshawer, Lahore, Rawalpindi and Shekhupura is decliningdue to unchecked disposal of rawmetropolitan and industrial wastewater and unnecessary use of fertilizers and pesticides [14-15].There are different techniques to map, model the groundwater quality including laboratory tests, numerical modeling, statistical methods and geospatial techniques i.e. Remote Sensing and Geographic Information System (GIS) [15-20]. Geographic Information System (GIS) has emerged as a powerful tool for storing, analyzing and displaying spatial and non-spatial data and using these data for to take decisions in many areas containing engineering and environmental fields [21-25]. Groundwater can be ideally used and sustained only when the quantity and quality is appropriately assessed [26]. GIS has been used in the map classification of

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groundwater quality, based on relating total dissolved solids (TDS) values with some aquifer properties [27] or land use and land cover [17]. Many other studies have used GIS as a database system tomake maps of water quality along with concentration values of different chemical elements [28-29]. Rangzan et al. in 2008 applied GIS to prepare several layers of spatial maps to findlikely well sites based on water quality and accessibility [30]. Babiker et al. in 2007 proposed a GIS-based groundwater quality index method based on water quality data (for example, Cl, Na, Ca) using WHO standards [31].Keeping the importance of groundwater resources and devastating situation in Pakistan this research is designed. This study also aims to model the spatial variability of certain physico-chemical parameters of water quality through GIS. The specific objectives of the study are (1) to map groundwater physiochemical properties (pH, TDS, EC, Turbidity, Total, Ca and Mg Hardness, Alkalinity, Coliforms and others); (2) geospatial modeling & analysis of groundwater pollutant distribution and (3) to generate groundwater quality index map for the study areas.

MATERIAL AND METHODS

The present study was conducted in three mega cities of Pakistan including Islamabad, Faisalabad and Bahawalpur (Figure 1). The cities were selected as Islamabad lies in the North, Faisalabad in center and Bahawalpur in South of the Punjab, Pakistan.

Water quality data from (2001-2002) and (2002-2003) was obtained from Pakistan Council of Research and Water Resources (PCRWR) which is a government institute and deals with the water resources of the country. The data obtained had different physical, chemical and biological parameters. The obtained data was in raw, aspatial and analogue from. Thedata was consisted on several physiochemical properties of water like Color, E.C., Odour, pH, Taste, Turbidity, Alkali (mg/l), As (ppb), HCO3 (mg/l), Cl (mg/l), Hard (mg/l), Ca (mg/l), CO3 (mg/l), Cr (ppb), F (mg/l), Fe (mg/l), Mg (mg/l), N (mg/l), K (mg/l), PO4 (mg/l), Na (mg/l), SO4 (mg/l), TDS (mg/l), Coliform (MPN). To covert this non-spatial data into spatial information a field survey was conducted to collect the locations of the sampled points. GPS (Global Positioning System) technology was used and geospatial database was generated to analyze the data in GIS environment.

The detailed methodology of the research study is given in Figure 2.Total 27, 14 and 25 sample points were collected from Islamabad, Faisalabad and Bahawalpur cities respectively.The data was analyzed both by classical and spatial statistical techniques. After analyzing the data the Water Quality Index (WQI) was calculated. WQI is a unit less number ranging from 1 to 100; a higher number is indicative of better water quality. Scores are determined for several physiochemical properties of water e.g. temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended sediment, turbidity, total phosphorus and total nitrogen.

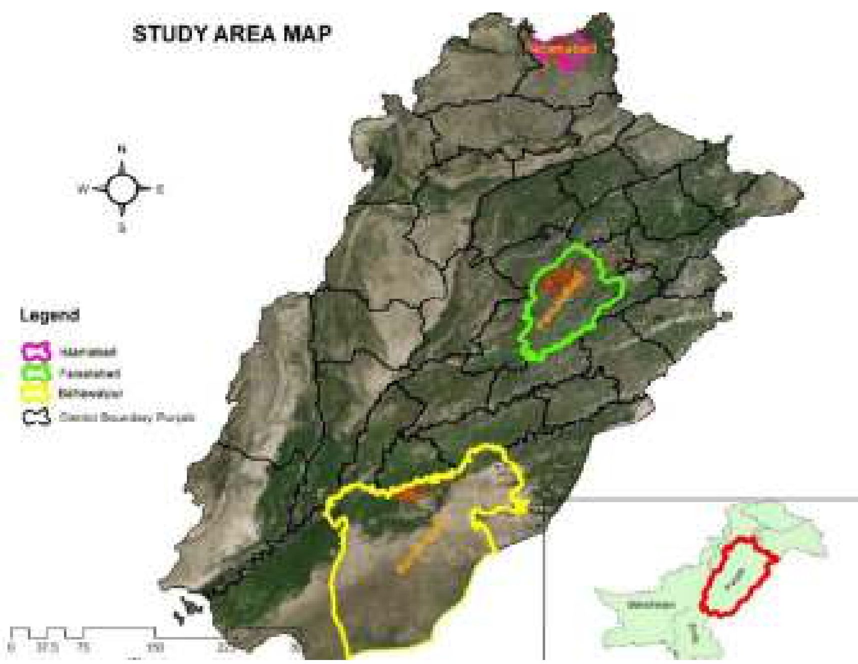


Fig. 1: Spatial location map.

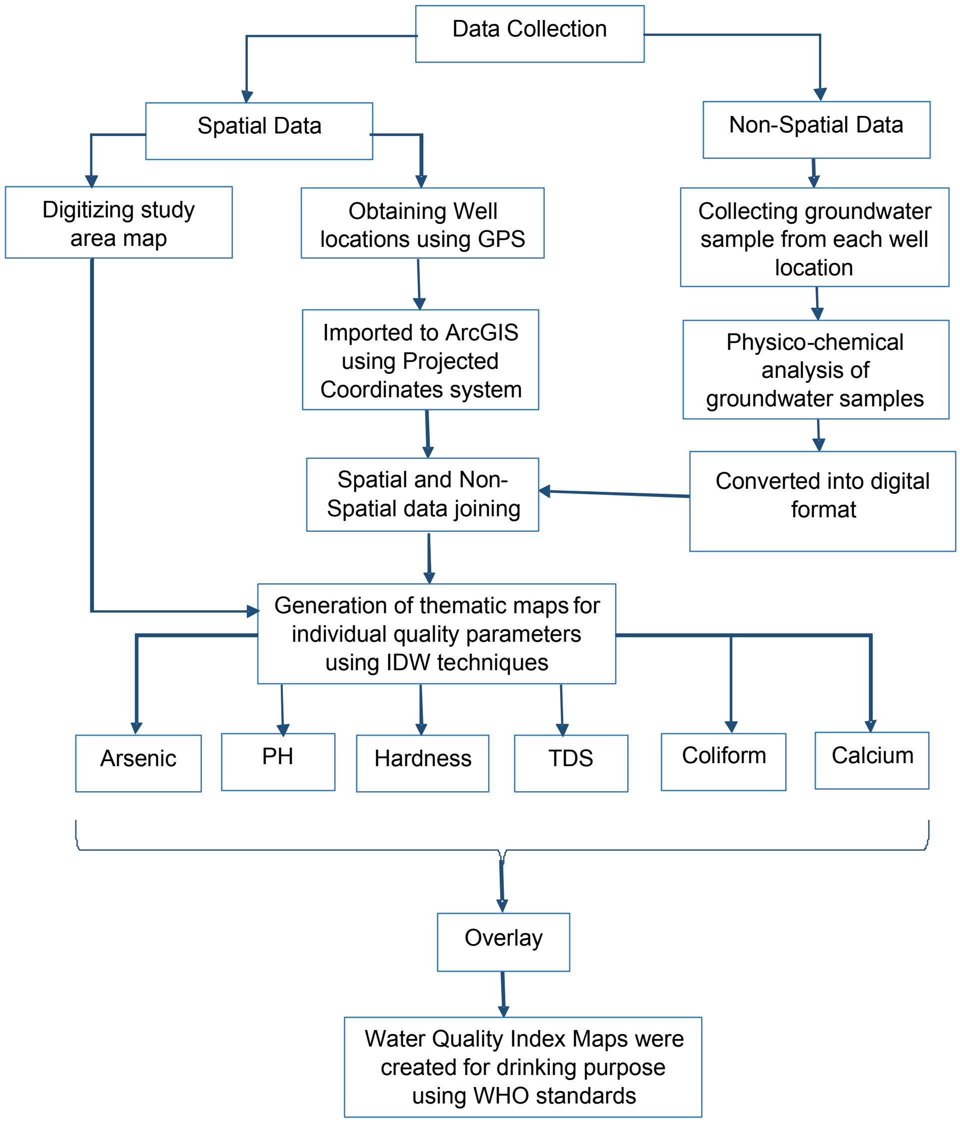


Fig. 2: Detailed methodology for the groundwater quality index mapping for drinking purposes.

The formula for WQI calculation[38] is as under:

Where n is the number of indicators at the site and I_i is the indicator value at the site.

The spatial distribution of each water quality indicator and the index was determined by using spatial interpolation techniques. In this research spatial interpolation Inverse Distance Weighted (IDW) technique was utilized to analyze the groundwater quality and directional distribution of groundwater pollutants present in the study area.

Inverse Distance Weighting (IDW): Spatial interpolation method IDW assigned weight to the point to be estimated. The value of weight reliant on the distance of the point to the other unknown point. These weights were measured on the bases of power of ten. Higher the power of ten, the effect of the points that are distant reduces. Smaller power allocates the weights more consistently between adjacent points. In this technique the distance between the points count, so the points of equal distance have the same weights [23-24].

The weight factor for IDW was measured with the help of this formula:

$$\lambda i = \frac{D_i^{-a}}{\sum_{i=1}^{n} D_i^{-a}}$$

λ_i= the weight of point,
D_i = the distance between point i and the unknown point,
a= the power ten of weight.

The advantage of IDW is that it is spontaneous and effective. This technique works best with uniformly dispersed spatial data but it is sensitive to outliers as well as randomly dispersed data gives invalid results.
The interpolated maps were then used to analyze the spatial distribution and the concentration of both physiochemical properties of water and water quality index.

RESULTS AND DISCUSSIONS

Groundwater quality maps are very useful for understanding their spatial relationship; but, an addition of temporal analysis adds value to the results. The study has resulted into spatio-temporal insight to the selected individual parameters and their overall impact in the form of WQI.

General Summary Statistics: The general statistics of Islamabad, Faisalabad and Bahawalpur is given in table 1 to 3. The classical statics shows that average pH of Bahawalpur,Islamabad and Faisalabad is 7.4,7.5and 8.5 respectively. The mean value of turbidity is higher for Bahawalpur which is 6.1. Same statistics for other physiochemical properties of water and water quality index are given there.

pH: pH is a common parameter for the analysis of water and soil. Very low levels of *pH* may cause irritation to skin and eyes. Spatio-temporal variation of pH is shown in Figure. 3 and range of pH values has been found above the neutral value, i.e., 7, making the water alkaline. The recommended range of *pH* for drinking water is 6.5–9.5 [32]change from 6.5 to 8.5 [39],and the measured values are within the prescribed limits for all three cities. In 2001there are few regions where value of pH is greater than 8 for all three cities. Several research studies conducted based on spatial measurement techniques also reveald the same results [40-43].

Total Dissolve Salts: Total Dissolve Salts (TDS) in water supplies can be present due to the sewage, industrial wastewater, urban and agricultural runoff. Its concentration may reach up to 6000 mg/L by natural sources alone [33]. The higher values of TDS is because of mixing of $CaCO_3$, HCO_3, *chlorides* and *sulfates* [34-36]. Meyers also determined a direct relation between the death from heart diseases and high concentration of TDS [37].

The spatial analysis of TDS concentration for the present study shows no remarkable change in Islamabad and Bahawalpur for year 2001 and 2003; however, the situation is totally opposite in Faisalabad. More than 80% of the area in Faisalabad has the value of TDS concentration greater than 1400mg/L as compare to the standard upper limit of 1000 mg/L. 13sample points out 14 shows TDS concentration more than the specified limit. The main reason for this higher concentration is dumping of industrial waste in very close vicinity of fresh water sources without any treatment [44].

Table 1: Descriptive statistical evaluation of water quality parameters for Islamabad.

	pH	Turbidity	Chlorine	Hardness	Calcium	TDS	Coliform	WQI
Mean	7.56	0.73	7.81	280.93	69.96	412.56	123.56	66.40
Median	7.40	0.40	6.00	320.00	76.00	470.00	96.00	65.66
Standard Deviation	0.40	1.18	4.76	94.70	24.39	135.00	115.92	8.49

Turbidity NTU; Chlorine ppm; Calcium ppm; TDS ppm; Coliform / 100 ml

Table 2: Descriptive statistical evaluation of water quality parameters for Faisalabad.

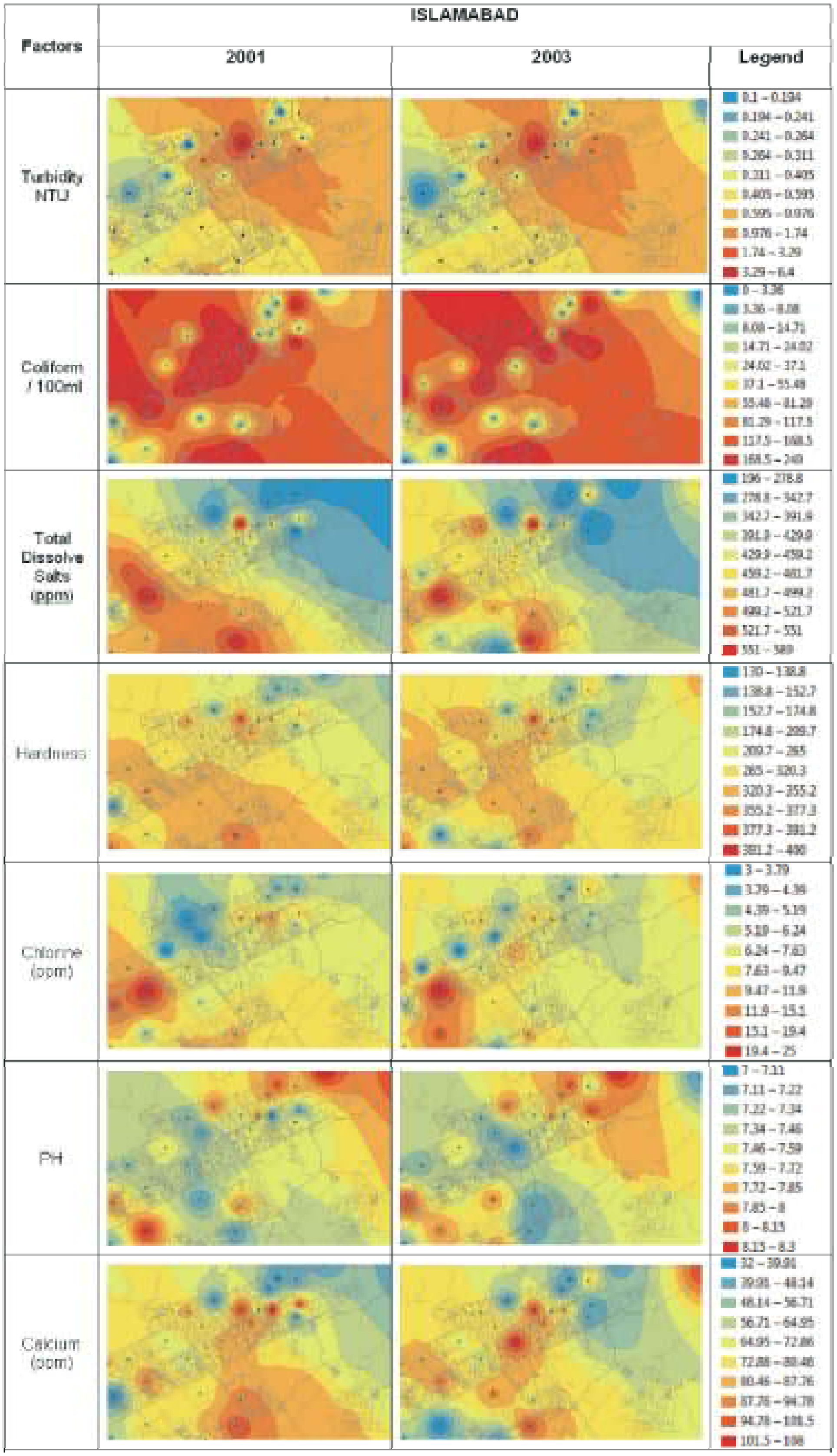
Parameters	pH	Turbidity	Chlorine	Hardness	Calcium	TDS	WQI
Mean	8.55	0.60	292.00	376.54	69.62	1408.85	74.48
Median	8.40	0.60	67.00	280.00	64.00	618.00	71.47
Standard Deviation	0.20	0.22	378.94	235.38	31.51	1210.03	10.34

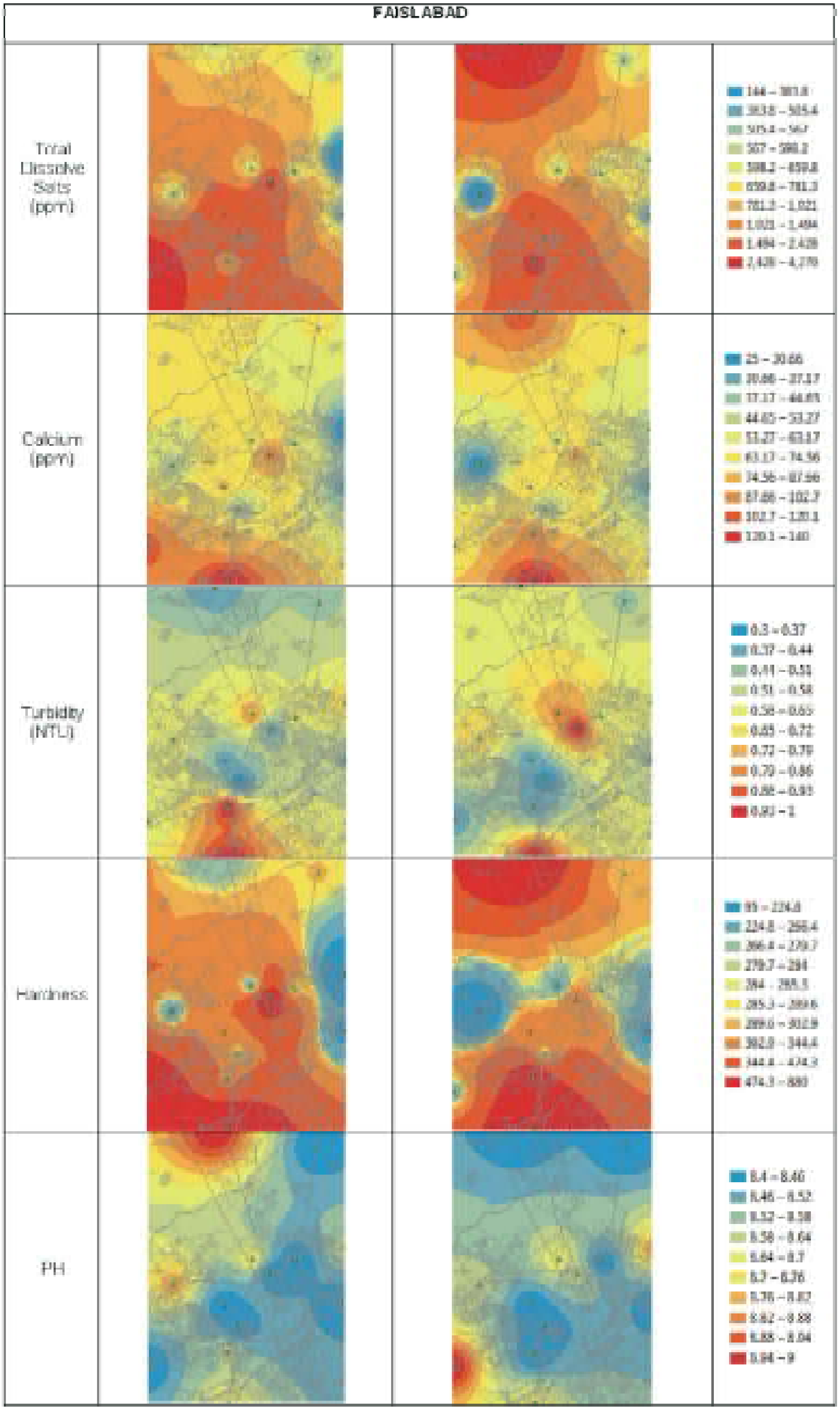
Turbidity NTU; Chlorine ppm; Calcium ppm; TDS ppm; Coliform / 100 ml

Table 3: Descriptive statistical evaluation of water quality parameters for Bahawalpur.

Parameters	pH	Turbidity	Arsenic	Chlorine	Hardness	Calcium	TDS	Coliform	WQI
Mean	7.4	6.1	25.4	66.9	366.3	82	760.7	29	55.3
Median	7.3	2	25	50	370	80	641	6	53.6
Standard Deviation	0.3	11.3	25.2	64.7	166.7	36.6	539.5	60.3	4.8

Turbidity NTU; Chlorine ppm; Calcium ppm; TDS ppm; Coliform / 100 ml


Factors
ISLAMABAD
2001
2003
Legend
Turbidity NTU
0.1 – 0.194
0.194 – 0.241
0.241 – 0.264
0.264 – 0.311
0.311 – 0.405
0.405 – 0.595
0.595 – 0.976
0.976 – 1.74
1.74 – 3.29
3.29 – 6.4
Coliform / 100ml
0 – 3.36
3.36 – 8.08
8.08 – 14.71
14.71 – 24.02
24.02 – 37.1
37.1 – 55.48
55.48 – 81.29
81.29 – 117.5
117.5 – 168.5
168.5 – 240
Total Dissolve Salts (ppm)
106 – 278.8
278.8 – 342.7
342.7 – 391.8
391.8 – 429.9
429.9 – 459.2
459.2 – 481.7
481.7 – 499.2
499.2 – 521.7
521.7 – 551
551 – 589
Hardness
130 – 138.8
138.8 – 152.7
152.7 – 174.8
174.8 – 209.7
209.7 – 265
265 – 320.3
320.3 – 355.2
355.2 – 377.3
377.3 – 391.2
391.2 – 400
Chlorine (ppm)
3 – 3.79
3.79 – 4.39
4.39 – 5.19
5.19 – 6.24
6.24 – 7.63
7.63 – 9.47
9.47 – 11.9
11.9 – 15.1
15.1 – 19.4
19.4 – 25
PH
7 – 7.11
7.11 – 7.22
7.22 – 7.34
7.34 – 7.46
7.46 – 7.59
7.59 – 7.72
7.72 – 7.85
7.85 – 8
8 – 8.15
8.15 – 8.3
Calcium (ppm)
32 – 39.91
39.93 – 48.14
48.14 – 56.71
56.71 – 64.95
64.95 – 72.86
72.86 – 80.46
80.46 – 87.76
87.76 – 94.78
94.78 – 101.5
101.5 – 108


FAISLABAD
Total Dissolve Salts (ppm)
144 – 303.8
303.8 – 505.4
505.4 – 567
567 – 598.2
598.2 – 659.8
659.8 – 781.3
781.3 – 1,021
1,021 – 1,494
1,494 – 2,428
2,428 – 4,270
Calcium (ppm)
25 – 30.66
30.66 – 37.17
37.17 – 44.65
44.65 – 53.27
53.27 – 63.17
63.17 – 74.56
74.56 – 87.66
87.66 – 102.7
102.7 – 120.1
120.1 – 140
Turbidity (NTU)
0.3 – 0.37
0.37 – 0.44
0.44 – 0.51
0.51 – 0.58
0.58 – 0.65
0.65 – 0.72
0.72 – 0.79
0.79 – 0.86
0.86 – 0.93
0.93 – 1
Hardness
95 – 224.8
224.8 – 266.4
266.4 – 279.7
279.7 – 284
284 – 285.3
285.3 – 289.6
289.6 – 302.9
302.9 – 344.4
344.4 – 474.3
474.3 – 880
PH
8.4 – 8.46
8.46 – 8.52
8.52 – 8.58
8.58 – 8.64
8.64 – 8.7
8.7 – 8.76
8.76 – 8.82
8.82 – 8.88
8.88 – 8.94
8.94 – 9

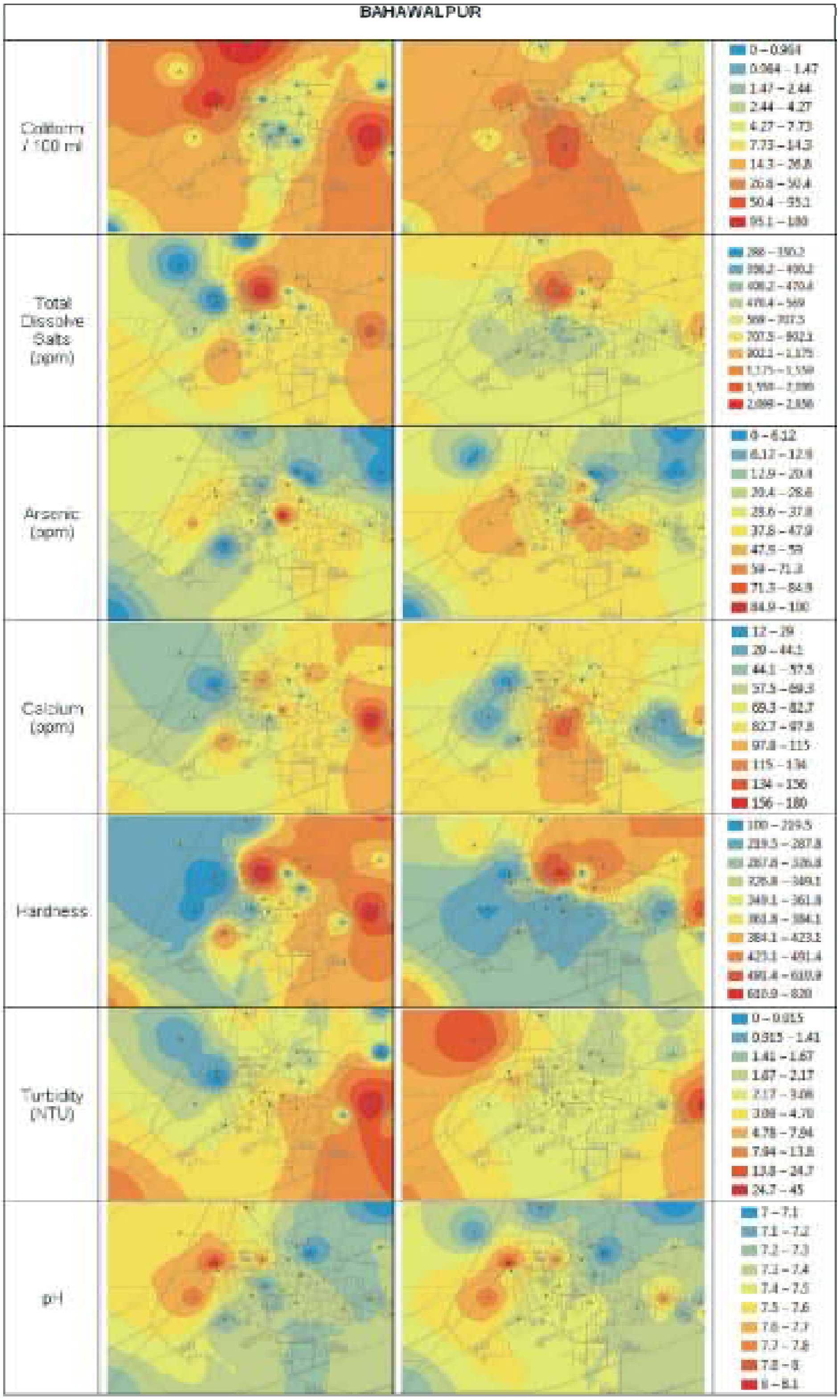


Fig. 3: Spatio-temporal distributions of physiochemical properties of water e.g. Color, E.C., Odour, pH, Taste, Turbidity, Alkali (mg/l), As (ppb), HCO3 (mg/l), Cl (mg/l), Hard (mg/l), Ca (mg/l), CO3 (mg/l), Cr (ppb), F (mg/l), Fe (mg/l), Mg (mg/l), N (mg/l), K (mg/l), PO4 (mg/l), Na (mg/l), SO4 (mg/l), TDS (mg/l), Coliform (MPN / 100 ml).

Calcium (Ca): Total 13%, 55% and 60% sample points were identified as having an excessive presence of *Ca* than the permissible limits allowed in Faisalabad, Islamabad and Bahawalpur respectively. But they can be considered safe, as a slightlyexcessive amount of calcium is not hazardous to health [45]. The main reason for excessive *Ca* in Bahawalpur water is due to the presence of calcareous mineral rocks in the district [46]. The spatial distribution of *Ca* for all three cities is shown in figure 3.

Coliforms: Coliforms are bacteria that are always present in the digestive tracts of animals, including humans and are found in their wastes. As well as they are also found in plant and soil material [47]. However they are harmless to some extend but excessive amount of coliform can be dangerous. All the sample points in Islamabad has the value of Coliforms in permit able limit. 70% of water in Faisalabad contains more coliforms than the permissible limit whereas in Bahawalpur 20% of water contains more coliform. The main reason for excessive coliform in both cities is the old sewerage system in some areas [41-42].

Water quality index (WQI): The summarized status of drinking water quality was expressed as the WQI. The spatial variability of WQI for the year 2001 to 2003 is shown in Figure. 4. Based on WQI score, the study area has been classified into four categorize; WQI>90 is ''Excellent'',70\WQI\89 is "Good", 69\WQI\50 is "Medium" and WQI<50 is Bad. The situation at Islamabad is critical as out of 27 points, only 13 points are found to be safe which meet the basic standards for safe drinking water. The situation in Faisalabad is not different than others but it is more worsen as only 3 points out of 14 had found safe for safe drinking. The main reason for poor quality of water at Faisalabad is leaky, rushed water pipes. The second reason is the improper sewerage and drainage system in the city [41]. To add on this the excessive industrial waste making water more pollutant. The situation in Bahawalpur is same like the other two cities that only 17 out of 25 the sample are found to be safe for drinking. The main reason for poor drinking water quality at Bahawalpur is the presence of excessive minerals e.g.arsenic and calcareous [42, 46].

CONCLUSIONS

In this work we have applied temporal Geospatial analysis and modeling techniques to find the areas of significant concerns regardingquality of groundwater. The quality of Islamabad, Faisalabad and Bahawalpur is deteriorating with the passage of time whereas the quality was very poor in 2001 as compare to 2003. From the city of Islamabad, 27 locations were selected for the sample collections. Out of these 27 locations, 13 water sources were found safe for drinking while the rest of water sources were found unfit for human consumptions, either due to chemical or microbiological contamination. The analysis revealed that 74% of samples were found to be contaminated with Coliforms and 41% were polluted with *E. coli*. Furthermore, 55% of the samples were identified as having an excessive presence of Ca than the permissible limits allowed but were considered safe as slightly excessive amount of calcium is not hazardous to health. In Faisalabad the parameter of TDS was found to be increased in most of the sources due to dumping of industrial waste in water sources without treatment. The major cause of the drinking water contamination were old and leaky, rusted water pipes. In Faisalabad, 13 locations were selected covering the major water sources of city. The overall supply of drinking water was found unsatisfactory as out of the 14 sources, only three sources were supplying safe drinking water. The Water Quality analysis revealed that 70% of water samples were found polluted with Coliforms &*E. Coli*. 13% water samples contain more calcium and hardness.Total 25 water samples were collected in Bahawalpur City. From analysis it was revealed that all the water samples were unfit for human consumption either chemically or microbiologically. Out of the 25 samples, 60% of the samples were found to be contaminated with coliforms, 88% possessing excess Arsenic than permissible limits. TDS were 16% where 60% of samples had higher concentration of calcium. This time series geospatial analysis proved very effective for differentiating temporaryand permanent spots of individual parameters as well as for Water Quality Index. Thisstudy concludes that the addition of time series to WQIproved productive not only to mark areas of main concernsbut also to differentiate them as permanent or short. The areas with low values of WQI have high risks of contamination as compare to the high values of WQI. Thisstudy can be valuable to develop a policy brief about the sustainable use and conservation of limited fresh water resources for coming generations.

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REFERENCES

1. Rosemann, N., 2005. Drinking water crisis in Pakistan and the issue of bottled water. The case of Nestlé's "Pure Life". Pakistan: Swiss Coalition of Development Organisations and Actionaid, available at: http://www.alliancesud.ch/en/policy/water/downloads/nestle-pakistan.pdf (last access: 20 August 2016).
2. Azizullah, A., M.N.K. Khattak, P. Richter and D.P. Häder, 2011. Water pollution in Pakistan and its impact on public health—a review. Environment International, 37(2): 479-497.
3. Hashmi, I., S. Farooq and S. Qaiser, 2009. Chlorination and water quality monitoring within a public drinking water supply in Rawalpindi Cantt (Westridge and Tench) area, Pakistan, Environ. 15 Monit. Assess., 158: 393-403.
4. U.S. EPA 1993. A review of methods for assessing aquifer sensitivity and ground water Vulnerability to pesticide contamination. U.S. EPS. EPA/813/R-93/002.
5. Jalali, M., 2005. Nitrates leaching from agricultural land in Hamadan, western Iran. Agric. Ecosyst. Environ., 110: 210-218.
6. Rivers, C.N., K.M. Hiscock, N.A. Feast, M.H. Barrett and P.F. Dennis, 1996. Use of nitrogen isotopes to identify nitrogen contamination of the Sherwood sandstone aquifer beneath the city of Nottingham, UK. Hydrogeol. J., 4(1): 90-102.
7. Kim, K.N., H.J. Rajmohan, G.S. Kim and M.J. Hwang, Cho, 2004. Assessment of groundwater chemistry in a coastal region (Kunsan, Korea) having complex contaminant sources: A stoichiometric approach. Environ. Geol., 46(6-7): 763-774.
8. Srinivasamoorthy, K., C. Nanthakumar, M. Vasanthavigar, K. Vijayaraghavan, R. Rajivgandhi, S. Chidambaram, P. Anandhan, R. Manivannan and S. Vasudevan, 2009. Groundwater quality assessment from a hard rock terrain, Salem district of Tamilnadu, India, Arabian J. Geosci., DOI=10.1007/s12517-0-09-0076-7.
9. Goulding, K., 2000. Nitrate leaching form arable and horticultural land. Soil Use Manage., 16: 145-151.
10. Pacheco, J. and S. Cabrera, 1997. Groundwater contamination by nitrates in the Yucatan Peninsula, Mexico. Hydrogeol. J., 5(2): 47-53.
11. Fetter, C.W., 1999. Contaminant Hydrogeology. Prentice-Hall, Englewood Cliffs, NJ.
12. Olajire, A.A. and F.E. Imeokparia, 2001. Water quality assessment of Osun River: Studies on inorganic nutrients. Environ. Monitor. Assess., 69(1): 17-28.
13. Prasad, N.B.N., 1984. Hydrogeological studies in the Bhadra River Basin, Karnataka, India: University of Mysore, Ph.D thesis, pp: 323.
14. Bhutta, M.N., M. Ramzan and C.A. Hafeez, 2002. GroundWater Quality and Availability in Pakistan, Proceedings of Seminar on Strategies to Address the Present and Future Water Quality Issues, March 6-7, 2002. Pakistan Council of Res. in Water Resources. Islamabad, Pakistan.
15. Shrestha, S. and F. Kazama, 2007. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling & Software, 22(4): 464-475.
15. Soomro, M., M. Khokhar, W. Hussain and M. Hussain, 2011. Drinking water Quality challenges in Pakistan. Pakistan Council of Research in Water Resources, Lahore, pp: 17-28.
16. Kazi, T.G., M.B. Arain, M.K. Jamali, N. Jalbani, H.I. Afridi, R.A. Sarfraz and A.Q. Shah, 2009. Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicology and Environmental Safety, 72(2): 301-309.
17. Asadi, S.S., P. Vuppala and M.A. Reddy, 2007. Remote sensing and GIS techniques for evaluation of groundwater quality in Municipal Corporation of Hyderabad (Zone-V), India. Int. J. Environ. Res. Public Health, 4(1): 45-52.
18. Singh, K.P., A. Malik and S. Sinha, 2005. Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques—a case study. AnalyticaChimicaActa, 538(1): 355-374.
19. Venkatramanan, S., S.Y. Chung, T. Ramkumar, R. Rajesh and G. Gnanachandrasamy, 2016. Assessment of groundwater quality using GIS and CCME WQI techniques: a case study of Thiruthuraipoondi city in Cauvery deltaic region, Tamil Nadu, India. Desalination and Water Treatment, 57(26): 12058-12073.
20. Matiatos, I., V. Paraskevopoulou, F. Botsou, M. Dassenakis, K. Lazogiannis, G. Ghionis and S. Poulos, 2016. Hydrogeochemical assessment of groundwater quality in a river delta using multivariate statistical techniques. In EGU General Assembly Conference Abstracts, 18: 14568.
21. Stafford, D.B., 1991. Civil engineering applications of remote sensing and geographic information systems. New York: ASCE.

22. Goodchild, M.F., 1993. The state of GIS for environmental problem-solving. In M. F. Goodchild, B. O. Parks, & L. T. Steyart (Eds.), Environ. Modeling GIS, New York: Oxford University Press, pp: 8-15.
23. Burrough, P.A. and R.A. McDonnell, 1998a. Creating continuous surfaces from point data. In: Burrough PA, Goodchild MF, McDonnell RA, Switzer P, Worboys M (Eds.). Principles of Geographic Information Systems. Oxford University Press, Oxford, UK.
24. Burrough, P.A. and R.A. McDonnell, 1998b. Principles of Geographical Information Systems Oxford: Oxford University Press, pp: 333.
25. Lo, C.P. and A.K.W. Yeung, 2003. Concepts and techniques of geographic information systems New Delhi: Prentice-Hall of India Pvt. Ltd, pp: 492.
26. Kharad, S.M., K.S. Rao and G.S. Rao, 1999. GIS based groundwater assessment model, GIS@ development, Nov–Dec 1999. http://www.gisdevelopment. net/application/nrm/ water/ground/watg0001.htm. Accessed 24 August 2016.
27. Butler, M., J. Wallace and M. Lowe, 2002. Ground-water quality classification using GIS contouring methods for Cedar Valley, Iron County, Utah. In: Digital mapping techniques, 2002, Workshop Proceedings, US Geological Survey Open-File Report 02-370.
28. Skubon, B.A. Jr. 2005. Groundwater quality and GIS investigation of a shallow sand aquifer, Oak opening region, North West Ohio. Geological Society of America. Abstracts Programs, 37(5): 94.
29. Yammani, S., 2007. Groundwater quality suitable zones identification: application of GIS, Chittoor area andhra Pradesh, India. Environ. Geol., 53(1): 201-210.
30. Rangzan, K., A. Charchi, E. Abshirini and J. Dinger, 2008. Remote sensing and GIS approach for water-well site selection, Southwest Iran. Environ. Eng. Geosci., 14(4): 315-326.
31. Babiker, I.S., A.M. Mohamed and T. Hiyama, 2007. Assessing groundwater quality using GIS. Water Resour. Manage., 21(4): 699-715.
32. WHO 2007. pH in drinking water: revised background document for development of WHO Guidelines for drinking water quality [Originally published in World Health Organization (1996) Guidelines for drinking-water quality. Health criteria and other supporting information, vol 2, 2nd edn. Geneva]
33. WHO 2003. Total dissolved solids in drinking water: revised background document for development of WHO Guidelines for drinking water quality [Originally published in World Health Organization (1996) Guidelines for drinking-water quality. Health criteria and other supporting information, vol 2, 2nd edn. Geneva]
34. Sohani, D., S. Pande and V. Srivastava, 2001. Groundwater quality at Tribal Town: Nandurbar (Maharashtra). Indian J Environ Ecoplan, 5(2): 4 75-479
35. Subba, R.N., 2002. Geochemistry of groundwater in parts of Guntur District andhra Pradesh, India. Environ Geol., 41(5): 552-562.
36. Akhtar, M.M., Z. Tang and B. Mohamadi, 2014. Contamination potential assessment of potable groundwater in Lahore, Pakistan. Pol J Environ Stud 23(6): 1905-1916.
37. Meyers, D., 1975. Mortality and water hardness. Lancet, 1: 398-399.
38. Yadav, K.K., N. Gupta, V. Kumar, S. Sharma and S. Arya, 2015. Water quality assessment of Pahuj River using water quality index at UnnaoBalaji, MP, India. Int J Sci Basic Appl Res., 19(1): 241-250.
39. WHO/UNICEF Joint Water Supply, Sanitation Monitoring Programme, & World Health Organization. (2014). Progress on drinking water and sanitation: 2014 update. World Health Organization.
40. Mussarat, M., A.U. Bhatti and F.U. Khan, 2007. Concentration of metals in sewage and canal water used for irrigation in Peshawar. Sarhad Journal of Agriculture, 23(2): 335.
41. Mahboob, S., S. Ashraf, F. Al-Misned, Z. Ahmed and S. Sultana, 2013. Determination of fluoride concentration in underground water from different urban areas of Faisalabad city. Life Sci. J., 10(10): 60-70.
42. Rasheed, H., F. Jaleel and M.F. Nisar, 2014. Analyzing the Status of Heavy Metals in Irrigation Water in Suburban Areas of Bahawalpur City, Pakistan.
43. Saeed, A. and I. Hashmi, 2014. Evaluation of anthropogenic effects on water quality and bacterial diversity in Rawal Lake, Islamabad. Environmental monitoring and assessment, 186(5): 2785-2793.
44. Jeyaraj, M., K. Ramakrishnan, A.J. Anandhi, S. Arunachalam and P.N. Magudeswaran, 2016. Investigation of Physico-Chemical and Biological Characteristics of Various Lake Water in Coimbatore District, Tamilnadu, India. Oriental Journal of Chemistry, 32(4): 2087-2094.

45. Mao, P.J., C. Zhang, L. Tang, Y.Q. Xian, Y.S. Li, W.D. Wang and Y.H. Zhou, 2013. Effect of calcium or vitamin D supplementation on vascular outcomes: a meta-analysis of randomized controlled trials. International journal of cardiology, 169(2): 106-111.
46. Mehmood, S., A. Ahmad, A. Ahmed, N. Khalid and T. Javed, 2013. Drinking water quality in capital city of Pakistan. Sci Rep, 2: 637.
47. Wiel-Shafran, A., Z. Ronen, N. Weisbrod, E. Adar and A. Gross, 2006. Potential changes in soil properties following irrigation with surfactant-rich greywater. Ecological Engineering, 26(4): 348-354.