Spatio-Temporal Assessment of Drinking Water Source in Gujranwala (Pakistan)

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Abstract

Improved living standards and unplanned urban growth are putting pressure on the environment and disturbing the sustainability of resources. This research has been conducted to study the effects of these irregularities in the natural ecosystem on groundwater resources. The residential area of Gujranwala, Pakistan, has been chosen as the case study. The study involves the spatio-temporal analysis of pH, Total Dissolved Solids (TDS), and Turbidity (TUR) in groundwater of the study area from 2014 to 2017. Geographical layers of all the available observations were prepared after optimizing the best interpolation method based on most minor the root mean square error. Although the measured concentration of the studied parameters was all well within the range of the safe limits for drinking water, due to anthropogenic activities, minute changes are occurring that need to be highlighted and addressed well in time. Spatio-temporal maps prepared over a standard scale have led the analysis to various details, i.e., for all three parameters in the beginning year of 2014 difference between pre- and post-moon soon patterns were very prominent that have faded away in coming years, showing decreasing recharge rates and any chemical changes caused by it. Both pH and TDS measurements show a continuous increase in their concentration with time, with maxima found in the year 2017. A different behavior has been found for turbidity, where the maximum value occurred in 2014, faded away in the next two years, and started increasing again in the final year of 2017. This assessment will help policy makers for better planning, leading to a sustainable and healthy society and achieving sustainable development goals of the United Nations.

Keywords: Groundwater Quality, Spatial Distribution, Temporal Changes, GIS Analysis.

Introduction

The climate change realization has enhanced the importance of water and its usage with each passing day (Chaplin, 2001; Tahir et al., 2010). The naturally stored water in the form of aquifers provides life to more than 50% of the world's population (Tahir et al., 2010; Akkaraboyina & Raju, 2012).

Ground water, one of the significant sources of freshwater in Pakistan, is under high pressure on account of population density, urbanization, and demographic migration. Excessive use of this precious resource has caused an imbalance between the extraction and recharge of the water table,

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causing a decline in its level. The situation is also impacting the quality of water sources as well (Ahmad, 1993). The absence of a legal framework for the extraction and utilization of water can be a severe issue for the future of water reserves as climate change and population displacement have already decreased the recharge process (Bhutta & Alam, 2006).

Usually, the water quality is assessed using various physical and chemical parameters which are affected by the pollutants from industrial waste and seasonal variations (Rao & Nageswararo, 2013).

In Pakistan, the salinity in drainage and the industrial waste pollute the drinking water. It is also harmful to the aquatic life. A few cities like Hyderabad, Karachi, Islamabad, Rawalpindi, and others have surface water sources. At the same time, others use groundwater, which is supplied mainly for domestic use. Unfortunately, water has not been tested regularly for domestic use and examination. Water quality is also directly linked with human health. Hence, contaminated drinking water causes a lot of waterborne diseases, impacting the health of vulnerable sections of society, especially females and children (Armah et al., 2012).

Gujranwala is the seventh most populous city in Pakistan. The water supply system in the city is provided by Water and Sanitation Agency (WASA). The latter has the responsibility of maintaining the water supply, its construction, design, and operation. As the water supply in Gujranwala city is purely based on the groundwater, WASA has installed seventy-four tube wells covering water supply and sewerage up to 37 and 65 percent, respectively. Moreover, WASA conducts tests for the bacteriological and chemical properties of water (Akram and Gabriel, 2007). The tube wells which WASA has installed are 68 in number (Annual performance report of WASA (GDA) Gujranwala for the year 2016-2017) (Requires reconsideration as it is contrary to what has been cited earlier). On a utility basis, the local population consumes about 28.52 cusecs or 15378650 gallons of water daily (Interim Report- Water Supply Gujranwala, 2011).

The Gujranwala Development Authority (GDA) is responsible for land planning and development. GDA is also administering the groundwater management of Gujranwala City through WASA. Monthly water samples are collected by the WASA itself or by the people hired by the agency to assess the quality of water in different parts of Gujranwala.

Geographical Information System (GIS) is an essential tool used in hydrology for groundwater assessment. It assists in interpolating the measured values of water quality of a specific location (Singh & Fiorentino, 2013). Moreover, GIS is software that is employed for testing and assessment of groundwater to map study areas to determine their potability (Singh & Khan, 2011). Spatial interpolation results in the creation of surfaces from known points on which further analysis is done. In GIS, the geographic coordinates are in the form of x, y, and z domains. The z coordinate measures elevation and is responsible for the creation of the surface in GIS. There are a lot of interpolation techniques and methods that discriminate from each other including deterministic' and 'stochastic' methods (Myers, 1994; Li & Heap, 2014). The deterministic method is divided into four techniques, which are (i) Inverse Distance Weighting (IDW), (ii) Radial Basis Function, (iii) Global Polynomial Function, and (iv) Local Polynomial Function. The Kriging is the geostatistical method that not only produces a predicted surface but also gives accuracy. Kriging has further been subdivided into Ordinary, Simple, and Universal techniques depending on data suitability.

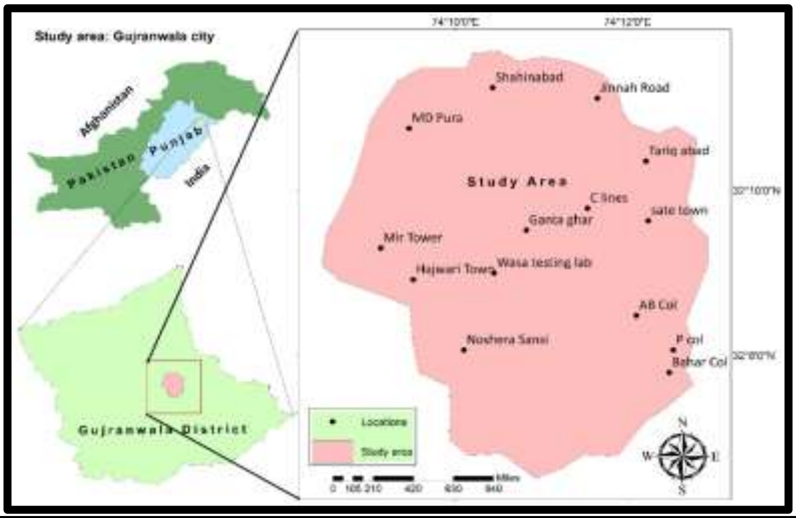
This study aims to examine the spatial distribution of physical, chemical, and biological parameters of drinking water in the rapidly growing city of Gujranwala. It is also focused on producing groundwater quality maps of study areas of 2014 -2017.

Materials and Methods

Study Area

Gujranwala is the seventh largest city of the Punjab. Geographical association of the area is shown in figure 1. It is in Rachna Doab. Gujranwala is situated on both sides of the Grand Trunk Road – one of the main tributaries in Punjab – which connects Multan, in the South, to Peshawar in the North. The district has an area of 3,622 square kilometers. It is listed among

Figure 1: Geographical Association of the study area



The fastest-growing cities in Pakistan, whose latitude and longitude are 32.1877° N and 74.1945° E, respectively (Minallah et al., 2016) and 226 meters (744 feet) above sea level.

Divided into upper and lower areas, the district exists on both sides of the road. The lower area exists near the Chenab River. The canal irrigation made this land the best for cultivation. The region exists between the Chenab River in the north and the Ravi River in the south. The study area soil includes a mixture of calcareous silty alluvium from the Himalayas, sediments of the river Chenab, and Pleistocene from the center of the Rachna Doab (Iqbal, 2011). On the north side of the Gujranwala district, the river Chenab connects it with Gujrat and Mandi Bahuddin. The climate of Gujranwala is semi-arid. The average annual temperature is 23.5 °C.

According to the Pakistan Bureau of Statistics, Gujranwala City contains a population of 259,556 with approximately 2.4% annual growth rate. The graph shows a population growth over a hundred years (1911-2011). The sharp increase in the rate of growth of the population between 1971 and 2011. This trend shows that it may continue in the future, thus increasing population density and internal migration.

Data Acquisition

WASA Gujranwala provides the data of 61 tube wells. The latitude and longitude information is deduced by the field survey with the help of the Global Positioning System (GPS) with the receiver of accuracy of 3m. The sample data provided by WASA consists of three physical parameters: PH (potential of hydrogen to determine acidity or basicity of a solution), turbidity, and Total Dissolved Solids (TDS). The data spans four years with varying months in each year, such as 2017 (five months), 2016 (four months), 2015 (four months), and 2014 (2 months) of each parameter, respectively. The ancillary data has been digitized using MS excel 2013 to assign GPS location to each point. Then, the data is exported to the GIS environment for further processing, to apply different techniques to analyze and create maps. This will provide spatial distribution for further analysis.

Methodology

The data has been collected from the Water and Sanitation Agency (WASA), Gujranwala. This data has been geo-referenced using GPS for location identification with an accuracy of 3m. After creating the point-based layer of the groundwater quality data, it has been put into interpolation for creating a continuous distribution of quality in the study area. Raster surfaces have been created using all the kriging methods by selecting Circular, Exponential, Spherical, and Gaussian models. The order of trend may be constant, first or second, depending on the particular root mean square value nearer to zero. The process results in the desired interpolated surface with continuous values for each parameter at an optimal best accuracy. To resolve the problem of diversity, the data has been classified into two classification schemes: (i) WHO standard and (ii) Equal interval classification with five classes for each of the parameters.

The selection of the interpolation method depends on the nature of the variable and the time scale on which the variable is represented. Each method works differently and relies on the concept of spatial auto-correlation. The exact process has been applied to the typical plain of Gujranwala.

While applying the kriging method, scattered variations are observed instead of the sharp ones. After creating surfaces by interpolation methods, the raster's of each technique were saved. Once the raster classification was done, a division of five classes at equal intervals was also made. We divided the raster of that month (whose range is generally high) into five classes at equal intervals. The classified raster of other months is accordingly, as shown in Table 1. The methodology adopted is as per international standards of research, considering data integrity as the primary focus while shifting from one step to the other.

Table 1: Equal Interval Classification

Years	**2017**		**2016**		**2015**		**2014**	
Parameter	**Class**	**Range**	**Class**	**Range**	**Class**	**Range**	**Class**	**Range**
PH	1	<7.25	1	<7.26	1	<7.18	1	<7.20
	2	7.25 - 7.41	2	7.25 - 7.26	2	7.1 - 7.34	2	7.20 - 7.34
	3	7.41 - 7.56	3	7.26 - 7.34	3	7.34 - 7.51	3	7.34 - 7.49
	4	7.56 - 7.71	4	7.34 - 7.42	4	7.51 - 7.68	4	7.49 - 7.64
	5	>7.71	5	>7.42	5	>7.68	5	>7.60
TDS	1	<243	1	<2.33	1	<239	1	<247
	2	243 - 257	2	233 - 243	2	239 - 253	2	247 - 251
	3	257 - 270	3	243 - 253	3	253 - 267	3	251 - 254
	4	270 - 284	4	253 -262	4	267 - 281	4	254 - 257
	5	>284	5	>262	5	>281	5	>257
TUR	1	<0.43	1	<0.60	1	<0.49	1	<0.60
	2	0.43 - 0.56	2	0.60 - 0.68	2	0.49 - 0.68	2	0.60 - 0.68
	3	0.56 - 0.69	3	0.68 - 0.77	3	0.68 - 0.87	3	0.68 - 0.77
	4	0.69 - 0.82	4	0.77 - 0.86	4	0.87 - 1.06	4	0.77 - 0.86
	5	>0.82	5	>0.8615	5	>1.06	5	>0.86

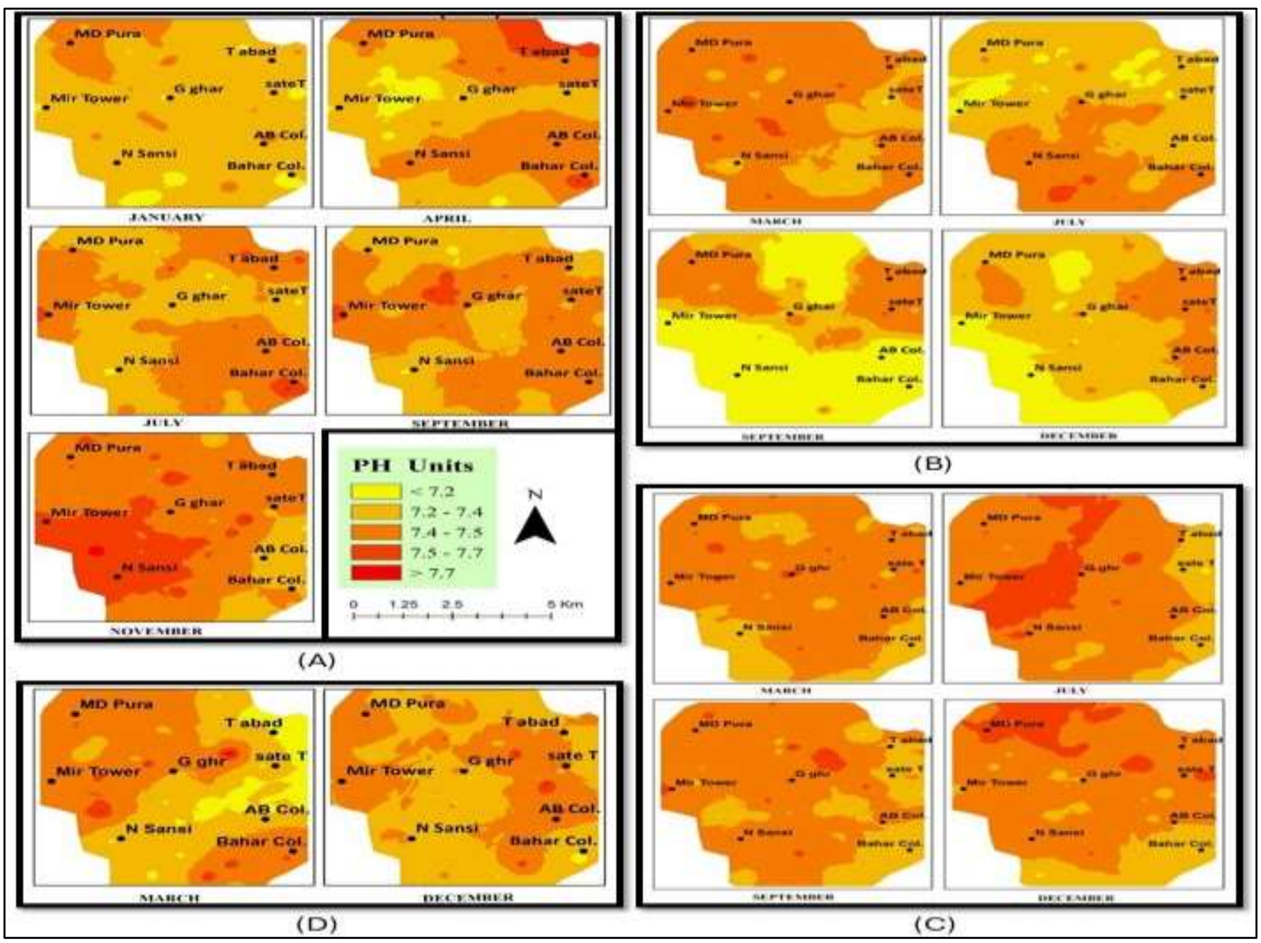
Results and Discussion

The outcome of the research has been divided into several sections, each dedicated to individual parameters so that an in-depth analysis of each of the parameters can be carried out.

PH

PH is defined as the negative log of hydrogen ion concentration. PH is not a physical parameter. PH value ranges from 0 to 14 along a logarithm scale (Bhardwaj and Verma, 2017). At zero units of PH the water quality is considered as poor. When the units increase the water quality increases until it reaches at 7 . At this value the water quality is excellent. Beyond 7 units the water quality again decreases; and it becomes very poor as it approaches the maximum limit (Gorde and Jadhav, 2013). A PH value greater than 11 units causes skin and eye irritations. A PH value below 2.5 units also induces skin damage and affects the living organs. As the PH value exceeds 6.5-9.5 range it damages and corrodes pipe due to increase in alkalinity. Here replacement of metallic pipelines is a very important element for health insurance of the community using the water for drinking purposes.

Figure 2: Spatial distribution of PH in 2017 (A), 2016 (B), 2015 (C) and 2014 (D)



The spatial temporal distribution for PH (2017) is shown in figure 2A. The maximum and the minimum values for PH (2017) are 7.7 and 7.2 units respectively. It clearly shows that values are above the neutral value of 7 and potable water is alkaline in nature. From the north on the right corner of the April map, the point which is noticeable is Jinnah road due to high concentration. Here the value of PH reaches 7.5 - 7.7 units. The summer rainy months are from June through September. The concentration of PH appears in April then it sheds due to rainy months and again it appears. The Jinnah Road is a congested area because it has high industrial concentration. There is no proper disposal of waste material which is an alarming situation. The second noticeable location is WASA testing lab which is situated near the Noshera Road. The value of PH reaches here is 7.5 - 7.7 units. Noshera Road is situated in an industrial and factory area. Due to which map shows us the high concentration in the month of November and then it disappears. The third point which is sharply concentrated is near Bihar Colony with small factory area near it. The high concentration appears in April and November. The value of PH reaches in the range of 7.5 - 7.7 units.

The spatial temporal distribution of PH (2016) is shown in the below figure 2B. The maximum and the minimum values for PH (2016) is 7.7 and 7.2 units respectively. That clearly shows that values are above the neutral value 7 units and drinking water is basic in nature. The first noticeable point is the March map having the large concentration of PH as compared to the others. The value reaches to 7.4 - 7.5 units. As, this large amount of alkalinity vanishes half as shown in the map of July. And further in September highest concentration of PH is almost disappears. But in December alkalinity reappears from the right side. And it again continues. But one point is notice that the concentration value is between 7.4 - 7.5 units and does not cross 7.5 units. The origin of spreading of concentration is satellite town. This highest concentration of PH is the result of the manmade activities especially the large dumpsites that remains there for months.

The spatial temporal distribution of PH (2015) is shown in figure 2C. The maximum and the minimum values for PH (2015) is 7.6 and 7.1 units respectively. That clearly shows that values are above the neutral value 7 units and drinkable water is alkaline in nature. All the months provide a blemish surface. The large concentrated area in all the months having values between 7.5 - 7.6 units.

The high concentration of PH appears in July and then disappears in September. Then again starts in December from Shahinabad which is a factory area and some industries exist there. The other noticeable point is civil lines which seems as a dark spot in July. Then in September it slightly increases. While in December it decreases slightly in size and finally vanishes in March. The civil lines area has a lot of dumping sites of waste materials and a has a high factory concentration. The value here reaches upto >7.6 units.

The spatial temporal distribution of PH (2014) is shown in figure 2D. The maximum and the minimum values for PH (2014) are 7.6 and 7.2 units respectively. It clearly shows that values are above the neutral value 7 units and the drinkable water is alkaline in nature. The noticeable thing is that in March from the north left corner the concentration of PH is spreading. In December, the above concentration is decreasing but spreading on the right side. The shifting of concentration of PH is directly related to the months of rainfall. The range of PH concentration is 7.5 - 7.6**.**

Another important thing is that civil lines is a dark spot which shows highly concentrated area. In March, it increases while in December it decreases slightly. This is due to the dumping sites and factory waste. The value of PH reaches here is >7.5 - 7.6.

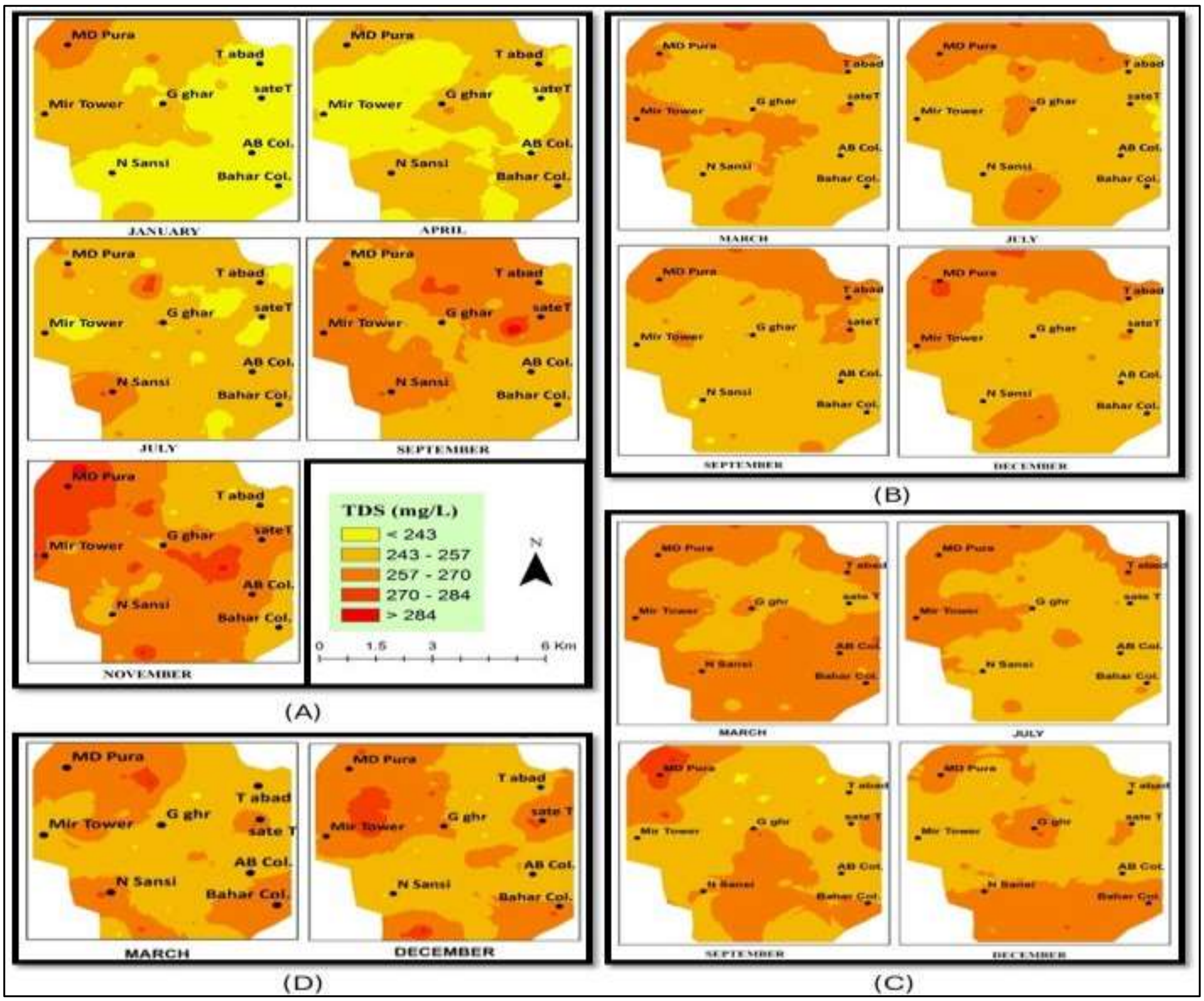
Total Dissolved Solids (TDS)

TDS stands for Total Dissolved Solids. It contains inorganic salts and other dissolved minerals (Appavu et al., 2016). The sources of these minerals are nature and human activity. The range of concentration of TDS for natural sources varies from less than 30 mg/liter to as much as 6000 mg/liter depending on the solubilities of minerals in different geological locations. The high level of ions in TDS can cause health risk (Kale, 2016). Some components of TDS cause aesthetic problem. Range wise category of TDS has been shown in table 2.

Table 2: TDS range wise category

Level of TDS (mg/l)	Less than 300	300 - 600	600 - 900	900 – 1,200	Above 1,200
Rating	Excellent	Good	Fair	Poor	Unacceptable

Figure 3: Spatial distribution of TDS in 2017 (A), 2016 (B), 2015 (C) and 2014 (D)



The spatial temporal distribution of TDS (2017) is shown in figure 3A. For surface map of TDS (2017), the maximum value and the minimum value is 284 mg/L and 243mg/L. In January, the most concentrated area is MD Pura. The concentration vanishes in the next few months. And then slightly increases in September, as the recharge increases due to monsoon rains showing involvement of surface pollutants as control of the groundwater quality. Finally, in November TDS has large concentration at Muhammad Pura. . The value of TDS is 270 mg/L to 284 mg/L. In September, near satellite town, the concentration increases until November due to waste. But in January it almost disappears. Another thing is also important that concentration increases in November. In January concentration decreases until it diminishes gradually.

The spatial temporal distribution of TDS (2016) is shown in figure 3B. For surface map of TDS (2016), the maximum and the minimum values are 262 mg/L and 233 mg/L respectively. In March the highly concentrated region of TDS in north region starting from Shahinabad. It decreases slightly in July, and a little bit further in September and then increases in December. Another noticeable point is that near Noshera Sansi the concentration decreases in March and then slightly increases in July. In September the spot vanishes. But again in December the concentration increases and persists for quite some time. This is because of the factory waste. The value of TDS from July to September diminishes because of the months of rainfall. The value ranges from 253–262mg/L.

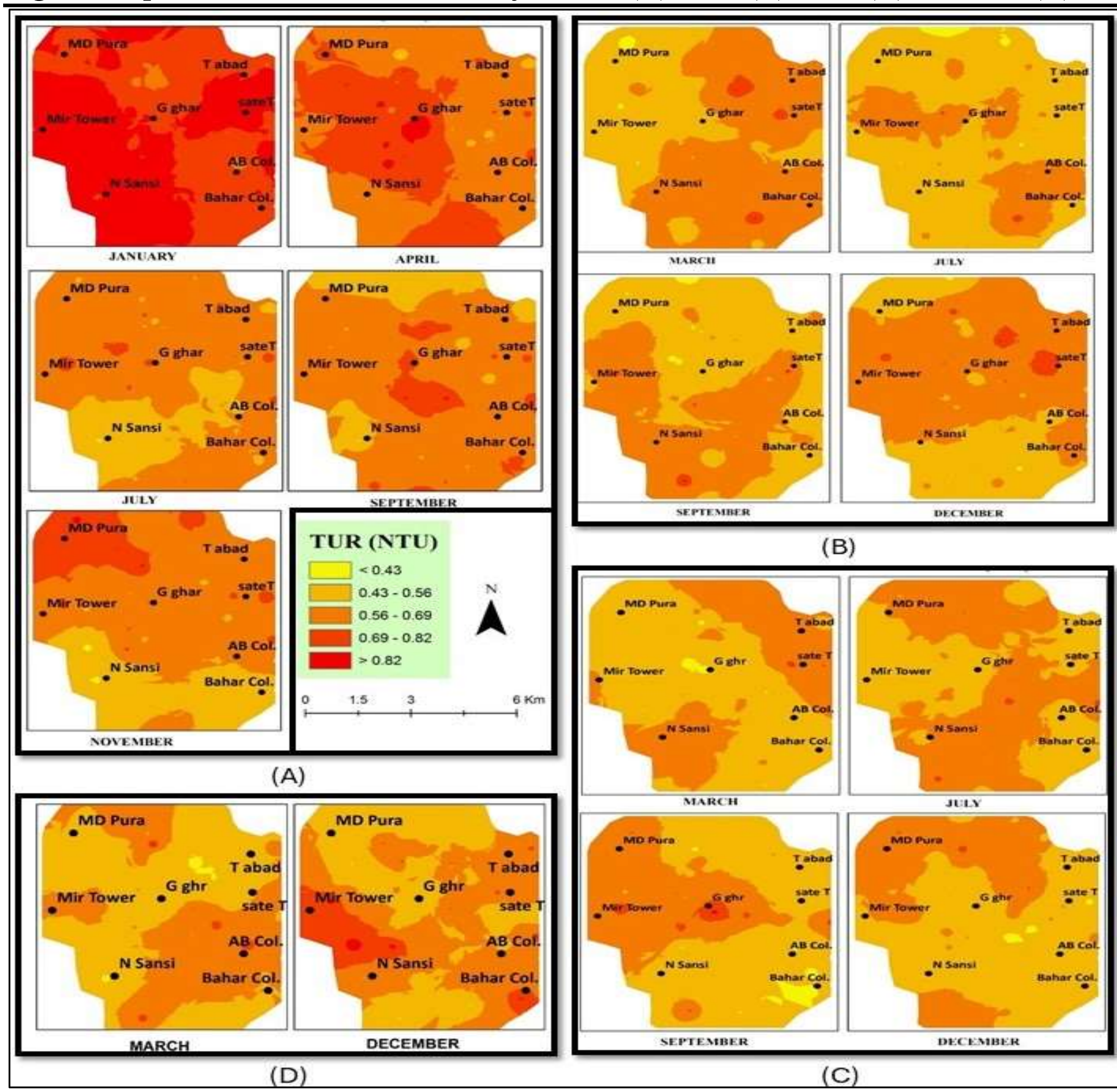
The spatial temporal distribution of TDS (2015) is shown in figure 3C. For surface map of TDS (2015), the maximum and the minimum values are 281 mg/L and 239mg/L respectively. As it is observed in the map that the highly concentrated is map of March. In July concentration remains to the north area only. But as it noticed that in September, the concentration is spreading from the south. Until in December large amount of concentration is spreading from the south. And the cycle again repeats. Another noticeable point is Muhammad Pura. The concentration very high as compared to other map. This is due to small factory area. The concentration range is from 261 mg/L to 281mg/L.

The spatial and temporal distribution of TDS (2014) is shown in figure 3D. The maximum and the minimum value of TDS (2014) is 276 mg/L and 240mg/L respectively. In both the maps the concentration of TDS is higher in December as compared to March. In March, the concentration of TDS spread from Shahinabad. But in December, the concentration of TDS is spreading towards south. Another noticeable spot is satellite town. In March, the intensity of TDS is covering small area in satellite town. But in December, the concentration of PH is spreading very fast. This is due to the large dumpsites that exist there.

Turbidity (TUR)

Turbidity is the measure of cloudiness caused by suspended particles in water (sediments and algae). The unit of Turbidity is Nephelometric Turbidity Unit (NTU). Turbidity cause water cloudy or opaque. Elevated value of turbidity in water cause health issues. Turbidity if not removed from the water then pathogens increases in number because turbidity feeds the pathogens. It further causes waterborne diseases (Tiwari et al., 2015).

Figure 4: Spatial distribution of Turbidity in 2017 (A), 2016 (B), 2015 (C) and 2014 (D)



As the concentration of Turbidity is very high in January as compared to other months the range here is >0.82. Here turbidity is caused by the scattering of light because of undissolved substances. The map in April indicates that the concentration is light as compared to January. Here the dark spot seems to be at Ghanta Ghar, and then in July, the concentration of Turbidity spreads towards Mir Tower in large quantity. In September, the concentration decreases rapidly. The process of increase in concentration again starts in December slightly, and it continues for some time. The concentration is high because of the construction of roads, bridges and buildings that increase the sediments in the water.

The spatial distribution of Turbidity is shown in figure 4. The spatial and temporal distribution of turbidity is shown in the figure. In March, the turbidity has the highest concentration. The value approaches here to >0.8615. But in July, the concentration decreases very rapidly. In September, some dark spots appear at Noshera Sansi, Satellite Town and near Mir Tower. The value reached

here is 0.7NTU – 0.8NTU. In December, the concentration again decreases and appears in March. This is because of the construction activities. The spatial and temporal distribution of Turbidity (2015) is shown in Figure 4C. In March, the concentration of turbidity is spreading from north from Shahinabad and Noshera Sansi. Ultimately in July, the concentration essentially increases from both sides. In September, the concentration is spreading towards the north. And finally, in December, the concentration remains only in the northern region of the map. The value reaches ranges from 0.6NTU to 0.8NTU. A dark spot seems at Ghanta ghar. The value here is 0.8 – 1.0.
The spatial and temporal distribution of Turbidity (2014) is shown in Figure 4D. In March, 3 points are noticeable. One is Shahinabad; the concentration is spreading towards the south. Secondly, from the satellite town concentration of turbidity is spreading towards Noshera Sansi. The range of concentration is 0.7NTU to 0.9NTU. In December, the intensity of turbidity is well distributed. The concentration is very high in Mir Tower and Hajweri Town. The values range from 0.9NTU to 1.1NTU. This is because of the construction and many artificial activities.

Conclusion

The study involves the spatial and temporal analysis of groundwater quality of Gujranwala city for the years 2017, 2016, 2015, and 2014. The analysis is done on the 3 parameters, namely PH, Total Dissolved Solids (TDS), and Turbidity (TUR). In PH 2017, the contaminated areas are Noshera Sansi, Jinnah Road, and Bahar Colony. The range is 7.5 units to 7.7 units, and the water is alkaline in nature. In PH 2016, the concentration is high in March. Although water is alkaline in nature, having ranges from 7.4 to 7.5 units.. In PH 2015, the contamination is spreading from south to north. The value here is 7.5 to 7.6 units. In PH 2014, the civil line is the highest contaminated area, ranging from 7.5 to 7.6 units. From the analysis of all the PH surfaces, it is concluded that the highest contaminated year is PH 2017. The water quality is alkaline in nature.
In TDS 2017, the prominent contaminated locations are Muhammad Pura and Ghanta Ghar. The range is here from 270mg/L to 284mg/L. In TDS 2016, the concentration in all the maps. The range here is 243 mg/l to 253mg/L. But the situation is better than in TDS 2017. In TDS 2015, the contamination is spreading from north to south. The value approaches here are 253 mg/L to 267mg/L. In TDS 2014, the dark spot occurred near Muhammad Pura, and then it spread towards Mir Tower. From the analysis of all the TDS surfaces, it is concluded that considerable contamination occurred in 2017. The TDS has been increasing in the water over the years due to artificial activities. In TUR 2017, the highest contamination is in January. The range here is >0.82NTU. In TUR 2016, the large contamination was in March. In TUR 2014, the highest contamination is in December. After the analysis of all the TUR surfaces, the highest contaminated year is 2014. It then decreases in 2015 and 2016, respectively. But it again increased in 2017 due to human activities, especially construction projects.
Hazardous effects of various point sources in the region on local groundwater have been identified, which are more prominent in the post-monsoon season and diluted by a decrease with the decrease in the recharge. Though quality parameters are well within the range of the drinking water standards, it is essential to keep in mind that these samples have been drawn from deep tube wells. Any influence from the surface that is not reaching down to this level may reach this depth with time and may turn out to be a big issue soon. Therefore, in the future, drinking water supply tube wells should be installed at locations with better-quality water. As shallow water is more prone to these risks, shallow bores in the area for drinking water need to be immediately banned; otherwise, it will cause many health issues, including stomach and kidneys. Any budget allocation for potential health issues can be avoided by planning, keeping in view the results of this research.

People awareness plans are necessary to stop unnecessary wastage of this precious freshwater resource for the sustainable development of the city.

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