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CRITICAL STUDY OF GROUNDWATER QUALITY OF METROPOLITAN LAHORE USING GEO-SPATIAL TECHNIQUES

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Lahore is famous for its rapid urban growth providing bread and butter to around 11 million population. Availability of clean drinking water to general public is the responsibility of the state. Pakistan ranks at 80 in terms of providing standard drinking water to people. This research is based on monitoring the temporal changes in water quality of various towns of Lahore for the years 2009-2019. Various water quality parameters e.g., pH, alkalinity, calcium, magnesium, hardness, turbidity, chloride, Total Dissolved Solid (TDS), Electric Conductivity (EC) and hardness were examined, and the spatial trend was mapped. Primary data about these parameters was collected from water and sanitation authority Lahore and the interpolation was applied to examine trend in variations of various levels of these parameters for a period from 2009 to 2019. The results show that pH, alkalinity, hardness and turbidity levels in most of towns were below the acceptable limit in comparison to World Health Organization permissible standards. We found that industrial boom, poor sanitation, seepage of sewerage water and its addition in ground water has declined the overall quality of drinking water. Local government must take blunt steps to improve the quality of drinking water otherwise the overall situation may lead to become drastic in near future.

Keywords: pH, Turbidity, Chloride, Water Quality, GIS

Introduction

Water is an essential component for all living organisms. Monitoring of water quality is essential to examine the variations in characteristics of water. Measuring water quality is expensive and time-consuming job. A variety of techniques have been used by many researchers to evaluate the concentration of impurities in drinking water. Remote sensing techniques are widely used throughout the world to obtain spectral responses of various land use features e.g., water, vegetation. soil and ice. These spectral responses provide very useful information not only to detect but also to discriminate between features. Water is categorized into many classes on the basis of concentration of impurities e.g., fresh water, alkaline water, turbidity water and deep water etc. These classes have different spectral responses and remote sensing is an important tool used in various water related applications e.g., soil moisture assessment [1], monitoring of water bodies [2], flood mapping [3], ground water management [4], modelling of water demand [3,4] and examining the water quality[5]. Dedicated sensors have been designed to monitor water bodies. The satellite offering monitoring of water bodies include sentinel-1[6], Landsat [7,8] and Sentinel-2 [9-12] offering open source datasets. Moderate Resolution Imaging Spectroradiometer (MODIS) provides coarse resolution [13] therefore, Unmanned Ariel Vehicle (UAV) is widely used for the detailed study of water quality, however Landsat sensors are capable enough to evaluate water transparency, suspended sediments, turbidity and the chlorophyll content in water [15]. Small lakes, rivers and dams cannot be evaluated in a good way by satellite images of coarse resolution.

There are multiple indicators to examine drinkable water quality which include pH level, concentration of Total Dissolved Solids (TDS), hardness, concentration of Sodium, Potassium, Magnesium, Sulphates and Bicarbonates. Turbidity of water determine the haziness or cloudiness of water due to high concentration of small particles which are invisible to naked eye.

In 1998, Eckner investigated the drinking water quality and obtained 338 water samples from diverse locations. About 261 out of the 338 samples were declared as potable water, while the rest 77 belonged to bathing water. The Colilert or Enterolert system for multiple tube fermentation and membrane filtration have been used to sample the water tested in this study. The results showed that the procedure Colilert was deeper than the Swedish standard method of Escherichia coli detection. The findings indicated that e.coli is higher in bathing water [16]. Sadeghioon, A. M et al., 2019 introduced smart wireless sensor to detect the leakage in water pipes. They identified that a small leakage resulted in wasted of 3281 million litter of water from 2009-2010 [17]. A review report by the Executive Committee emphasized the utility and durability of modern pipes instead of the old tubes. The efficiency of old tubes have been declined which cause to mixing of sewerage water with drinkable water which leads to a variety of number water borne diseases with high concentration of alkalinity, gross dissolved solids and high pH[18]

World Health Organization (WHO) has prescribed a permissible range for water quality indicators beyond which the quality of water gets poor. These formerly established standards are in line with the (Millennium Development Goals) MDGs of the United Nations (United Nations, 2000). Additionally, these standards are coherently in line with the World Summit on Sustainable Development agenda held in Johannesburg. Accordingly, in light of findings, some of these parameters are listed in Table 1 as below,

Table 1. WHO Drinking Water Quality Standards

S. No	Parameter	W.H.O Guidelines
1	pH	6.5-8.5
2	TDS	1000 mg/l
3	Hardness	500 mg/l

4	Alkilinity	500 mg/l
5	Turbudity	5 NTU
6	Cloride	250 mg/l
7	Electric Conductivity	400$\mu s/cm$
8	Calcium	75 mg/l
9	Megnisium	75mg/l

This research mainly focuses on examination of drinkable water quality in various towns of Lahore and to determine the trend using spatio-temporal analysis. It also aim at identifying the major reasons behind the temporal variations in water quality indicators.

Material and Methods

Investigation site

Lahore City is located at 31N latitude and 74E longitude. Lahore is bordered on the east by the Indian Wagah border. On the south side of Lahore is the Kasur district. It is located at about 210 meters high than sea level. Lahore is subdivided in to three density zones as per population: high, medium and low density. According to census 2017, the Lahore district had approximately 11 million population by incorporating 7,000 individuals per square kilometer. Lahore is ranked at 42nd in the world's most populous urban area. About 82% of the population live in the urban center, while the rest 18% live in rural areas. The rapid rise in Lahore's population is induced by the migration of people from rural areas in search for education and jobs [19]. The study site is mapped in Figure 1,

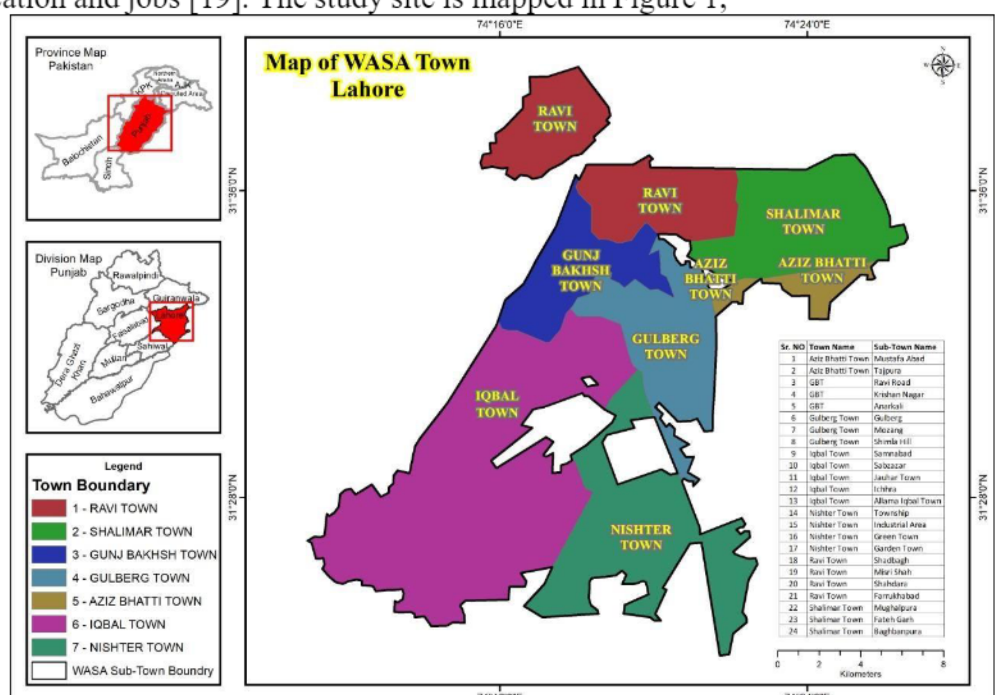

Figure 1. Study site.

Data Sources

Both the qualitative and quantitative methods of data collection are used in this study. The qualitative approach describes how a particular occurrence or event occurs; on the other hand, numerical knowledge is explained using quantitative methods to describe an event or occurrence. This cross-section illustrates the general state of beverage water quality in Lahore.

The data used in this research was collected from Water and Sanitation Agency Lahore which include town wise divisional boundaries.. We collected the record of water quality indicators e.g., pH, EC, TDS, hardness, Ca, Mg, Na and bicarbonates from WASA for the years 2009 to 2019 of various towns mapped in Figure 1. We obtained the coordinates of these towns using Global Positioning System (GPS) and extracted this spatial data in Arc GIS interface.

Spatial Interpolation

The interpolation technique is useful for prediction of unknown value on the basis of known value. There are many types of interpolation including Inverse Distance Weightage (IDW), Kriging and Spline. We used kriging technique in this research for data analysis.

Kriging

The interpolation technique weights the surrounding measured values to predict an unmeasured location (ESRI, 2011). Ordinary Kriging (OK) method was used and following steps were followed to generate the surface for different parameters:

- Selection of best fitted by using Semi-variogram
- Cross-validation of model

Semi-Variogram

The semi-variogram calculates the semi-variance or difference in the distance between the data. A semi-variogram may be used to determine the correlation or spatial dependency of results. The plot measures the laggard values. Various models e.g., square, gaussian and spherical were used for data evaluation.

Model validation

Various types of errors including put average error, root average square error, average square error, root average square error and average standard error were examined to evaluate the model's efficiency.

Water Quality Index (WQI)

WQI is considered as the most efficient tool for measuring water quality. A number of water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of water for drinking [20]. The index was first developed by Horton in 1965 to measure water quality by using 10 most regularly used water parameters. The method was subsequently modified by different experts. These indices used water quality parameters which vary by number and types. The weights in each parameter are based on its respective standards, and the assigned weight indicates the parameter’s significance and impacts on the index. A usual WQI method follows three steps which include (1) selection of parameters, (2) determination of quality function for each parameter, and (3) aggregation through mathematical equation [18]. The index provides a single number that represents overall water quality at a certain location and time based on some water parameters. The index enables comparison between different sampling sites. WQI simplifies a complex dataset into easily understandable and usable information. The water quality classification system used in the WQI denotes how suitable water is for drinking. The single-value output of this index, derived from several parameters, provides important information about water quality that is easily interpretable, even by lay people [21, 22].

National Sanitation Foundation Water Quality Index (NSFWQI)

National Sanitation Foundation (NSF) was developed in 1970 to compute water quality where water quality is subdivided in five categories as shown in Table 2 as below,

Table 2. National Sanitation Foundation Water Quality Index (NSFWQI)

WQI Range	Rating of Water Quality
91-100	Quality Water is Excellent
71-90	Quality Water is Good
51-70	Quality Water is Medium
26-50	Quality Water is Bad
0-25	Quality Water is Very Bad

RESULTS AND DISCUSSIONS

Alkalinity

Figure 2 is showing temporal variations of alkalinity in various towns of Lahore. According to WHO standards, the alkalinity must not exceed than 500 mg/l. The interpolation results describe different alkalinity levels recorded in the year 2009 e.g., the alkalinity level of Aziz Bhatti town was 164 to 300mg/l whereas it was 135 to 386 mg/l in Ganjbaksh and Shalimar towns. The alkalinity level of Gulbarg town was recorded as 116-420 mg/l, Iqbal town (98-380)mg/l, Ravi town (13.6-350) mg/l and in Nister town (144-740)mg/l. Water quality was observed within acceptable standards of WHO in most of towns. Similarly, the alkalinity levels within these towns were recorded in 2019 as Aziz Bhatti Town, 204-560 mg/l, Shalimar and Ganj Baksh town 110-536 mg/l, Gulberg Town 178-760mg/l, Iqbal Town 214-560 mg/l, and in Nishter Town, Ravi Town as 80-328 mg/l. Whereas, the alkalinity ranged from 110-538 mg/l in Itihad Colony. The highest level of alkalinity was recorded in Gulberg, as 740mg/l value, and the lowest value of alkalinity was recorded in Data Nagar and in Ravi Town as 80mg/l. The results indicate that alkalinity values were within the acceptable limits as per advised by WHO for the complete study period.

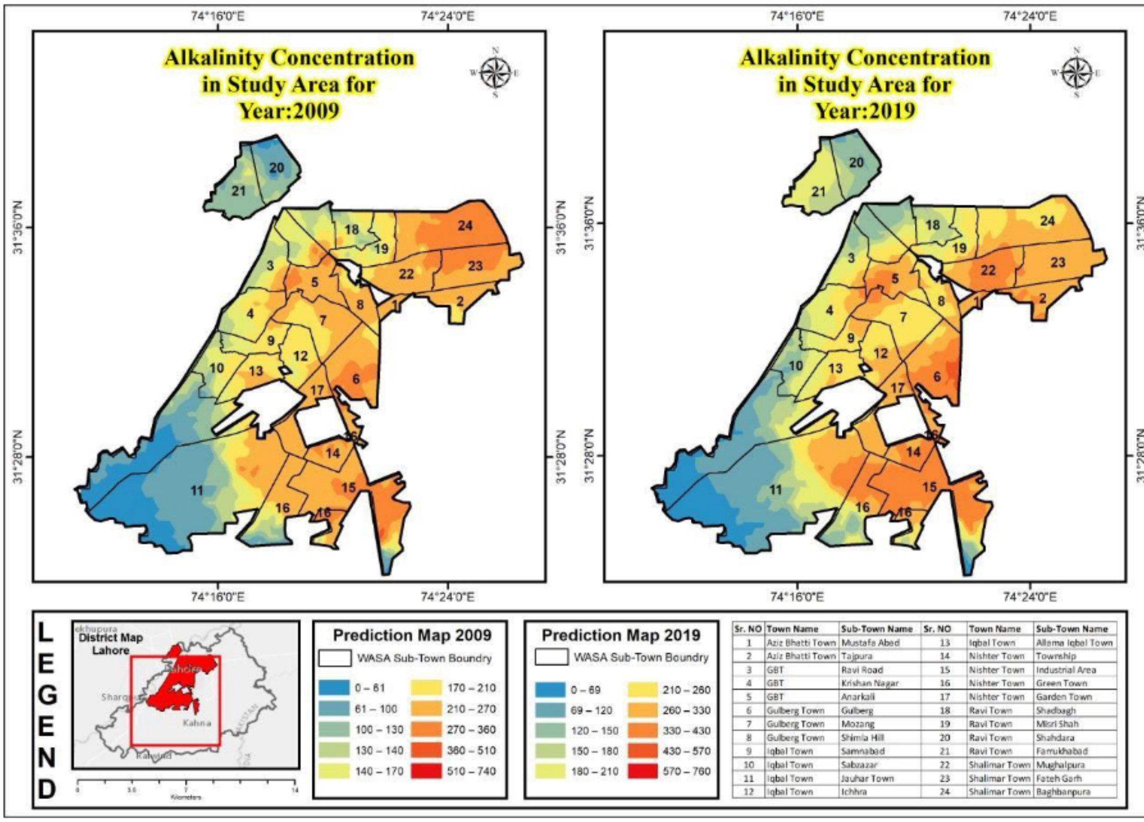

Figure 2. Spatial Distribution of Alkalinity in Study Area, in 2009-2019

pH

According to WHO standard, the acceptable limit of pH in water must be 6.5-8.5 which show the acidity level. The pH was recorded in various towns of Lahore for the year 2009, e.g., Aziz Bhatti town as (7.6-8.4), Shalimar Town (7.3-8.4), Ganj Baksh Town (7.3-8.9), in Gulberg Town (7.6-8.7), Iqbal Town (3.4-8.6), Nishter Town (7.1-8.9) and Ravi Town (7.3-8.6). The lowest value of pH was recorded in 2009 as 3.4 in Johar town and the highest value of 8.9 was observed in Liaqatabad (Ganj Baksh Town). The towns having value greater than 8.5 pH were beyond the permissible limit. On the other hand, the pH values recorded in the year 2019 show that pH ranged from 7.8-8.1 in Aziz Bhatti Town, 7.8-8.3 Shalimar Town, 7.8-8.3 in Ganj Baksh Town, 7.8-8.3 in Gulberg Town, 7-8.3 in Iqbal Town, 7.8-8.2 in Nishter Town, 7.8-8.3 in Ravi Town. The interpolation results are mapped in Figure 3 which show that the water of Ganj Baksh Town became more acidic and the trend of acidity is observed toward Shalmar town.

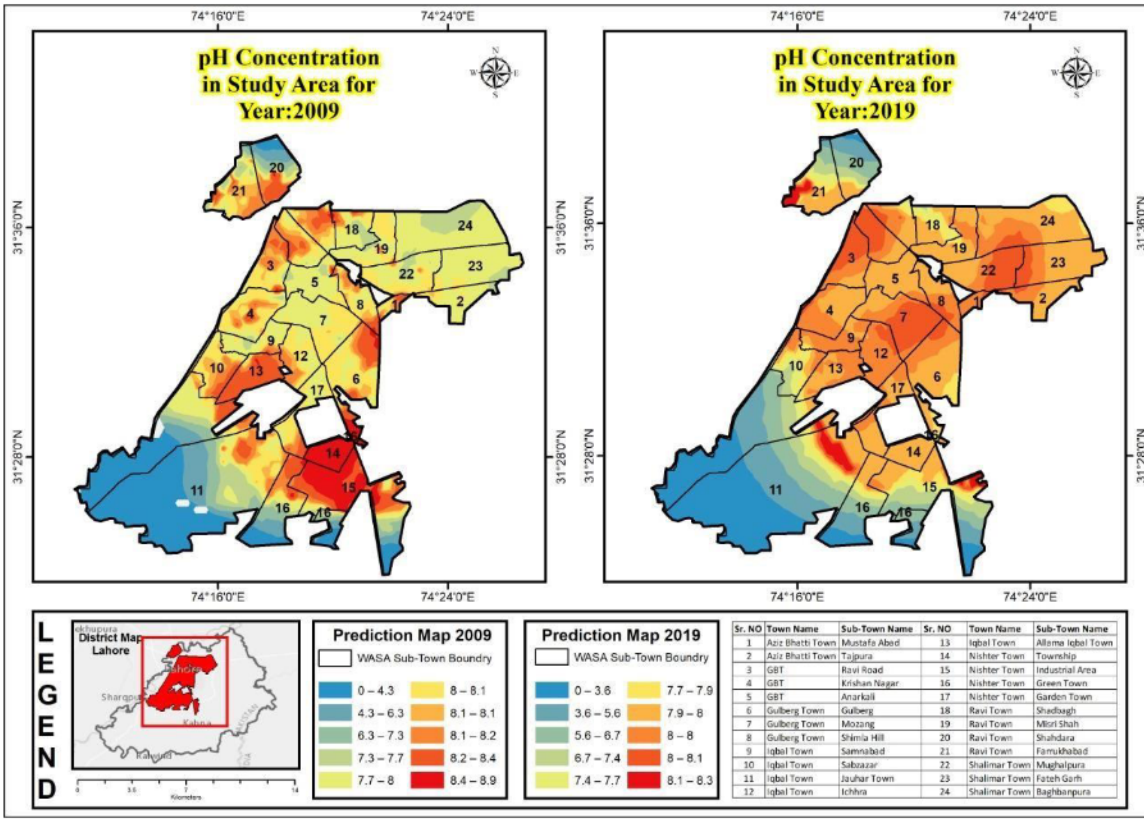

Figure 3. Spatial Distribution of pH in Study Area, in 2009-2019

Calcium

Calcium is found in the earth crust and it is the 5th abundant element. According to WHO, the permissible limit of calcium in drinkable water may be up to 75 mg/l. The results show that the calcium range in the year 2009, was recorded as 12-48 mg/l in Aziz Bhatti Town, 12-240 mg/l in Shalimar Town, 11-144.4 mg/l in Ganj Baksh Town, 18-97.6 mg/l in Gulberg Town, 16-80 mg/l in Iqbal Town, 16-65 mg/l in Nishter Town and 15.2-108 mg/l in Ravi town. The highest value of Calcium was observed as 240 mg/l in Mughalpura (Shalimar town) and the lowest value 11 was observed in Ganj Baksh town. The results show that the value of Calcium was within the permissible limit in most of towns in 2009. The concentration of Calcium in the year 2019 was observed different in different towns as 19.2-44 mg/l in Aziz Bhatti, 24-73.6 mg/l in Shalimar Town, 6.7-116 mg/l in Ganj Baksh Town, 11-90.4 mg/l in Gulberg Town, 12-111.2 mg/l in Iqbal Town, 17.6-56 mg/l in Nishter Town, 19.2-112.8 mg/l in Ravi town. The results show that the highest value of Calcium was 116 mg/l in Liaqatabad (Ganj Baksh town) and the lowest value 6.7 was observed in Data Ganj Baksh Town. Spatio-temporal distribution of Calcium was mapped in Figure 4 which show that the concentration of Calcium has increased in drinkable water in Iqbal Town in comparison to the year 2009.

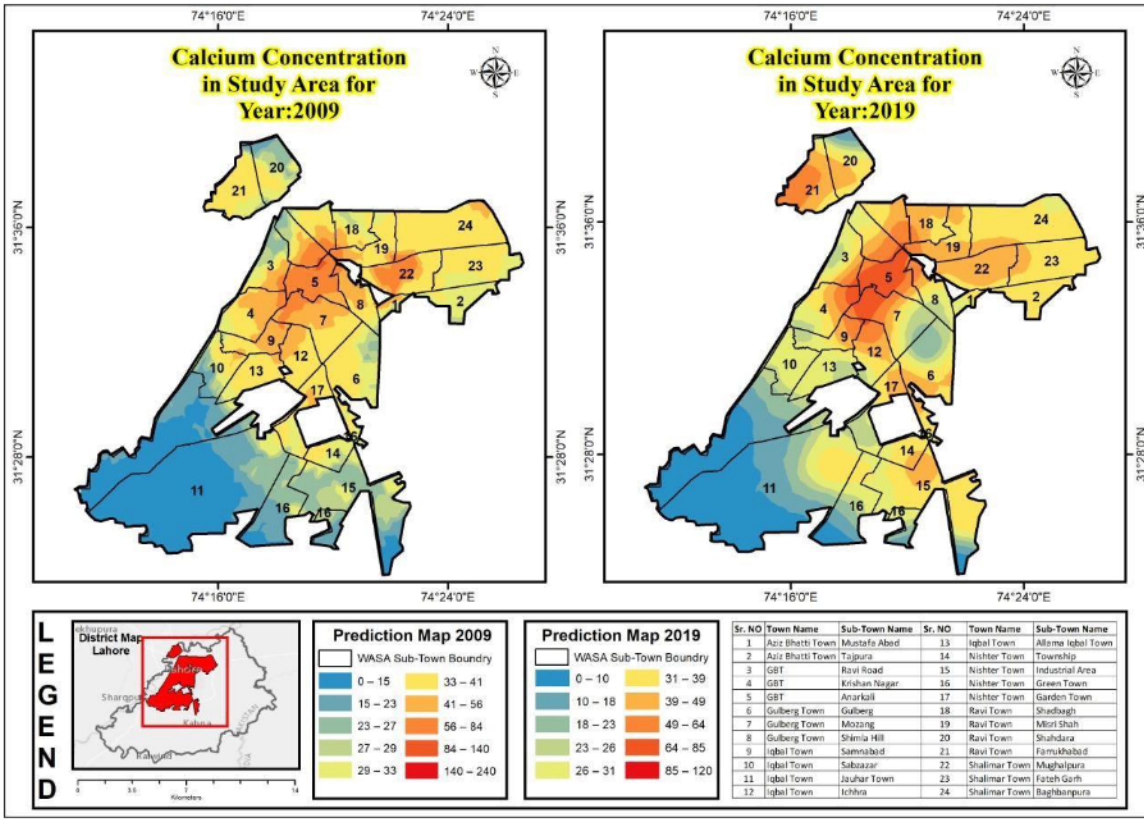

Figure 4. Spatial Distribution of Calcium in Study Area, in 2009-2019

Magnesium

According to WHO, the acceptable limit of magnesium concentration in drinking is 75 mg/l. The results of the year 2009 show that the concentration of magnesium ranged from 8-144 mg/l in Aziz Bhatti Town, 7-41.2 mg/l in Shalimar Town, 5-67.2 mg/l in Ganj Baksh town, 11.5-63.3 mg/l in Gulberg Town, 10-292 mg/l in Iqbal Town, 6-47.5 mg/l in Nishter Town and 10-192 mg/l in Ravi town. The lowest value of Magnesium was recorded as 5 mg/l on Ravi Town and the highest value 292 mg/L was observed in Ichra. The results of the year 2019 show that magnesium ranged from 7.7-32.6 mg/l in Aziz Bhatti Town, 6.7-59 mg/l in Shalimar Town, 6.7-117.6 mg/l in Ganj Baksh town, 7.7-57.1 mg/l in Gulberg Town, 3.8-61 mg/l in Iqbal Town, 3.8-46.6 mg/l in Nishter Town, 5.8-37.4 mg/l in Ravi town. In Napier Lane and Anarkali, the maximum magnesium concentration was 117,6 mg/l and the lowest concentration of magnesium was recorded in Samanabad as 3.8 mg/l as shown in Figure 5.

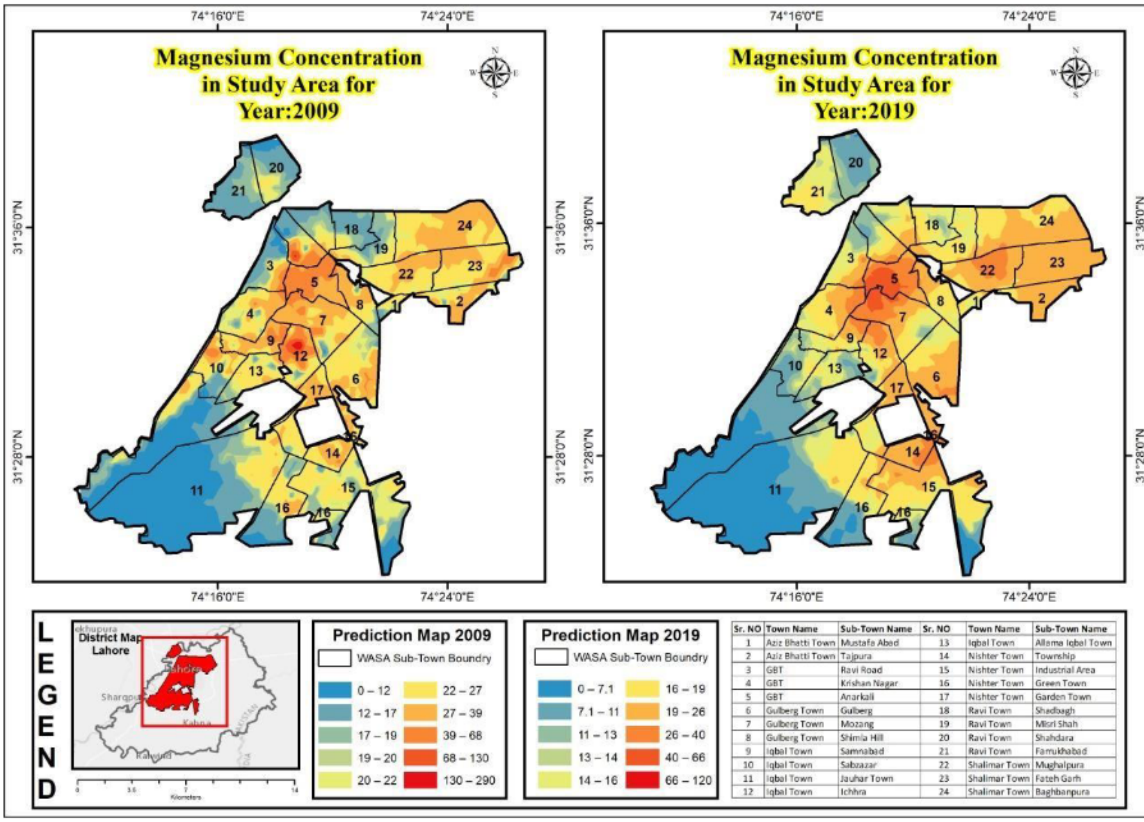

Figure 5 Spatial Distribution of Magnesium in Study Area, in 2009-2019

Hardness

The hardness of drinkable water must not exceed than 500 mg/l, according to WHO. The results of the year 2009 show that hardness ranged from 68-270 mg/l in Aziz Bhatti Town, 60-320 mg/l in Shalimar Town, 41.6-550 mg/l in Ganj Baksh Town, 100-508 mg/l in Gulberg Town, 84-400 mg/l in Iqbal Town, 76-340 mg/l in Nishter Town and 80-440 mg/l in Ravi town. The highest value of Magnesium was recorded as 550 mg/l near Farid courthouse (Ganj Baksh town) and the lowest value 41.6 mg/l was observed in Ravi Town (Bagh Munshi Ladha). The results of the year 2019 show that hardness of water ranged from 98-228 mg/l in Aziz Bhatti Town, 74-406 mg/l Shalimar Town, 84-510 mg/l in Ganj Baksh Town, 82-1256 mg/l in Gulberg Town, 44-532 mg/l in Iqbal Town, 68-334 mg/l in Nishter Town, 76-438 mg/l in Ravi Town. The highest value of hardness was recorded in Shimla hill and Johar city as 1256 mg/l and 720 mg/l respectively. The lowest value of hardness was 44 mg/l in Allama Iqbal town. Spatio-temporal variations in hardness were mapped in Figure 6 which show that the hardness in water was higher in 2009 in Nishter Town and in Shalimar town which reduced to admissible limit.

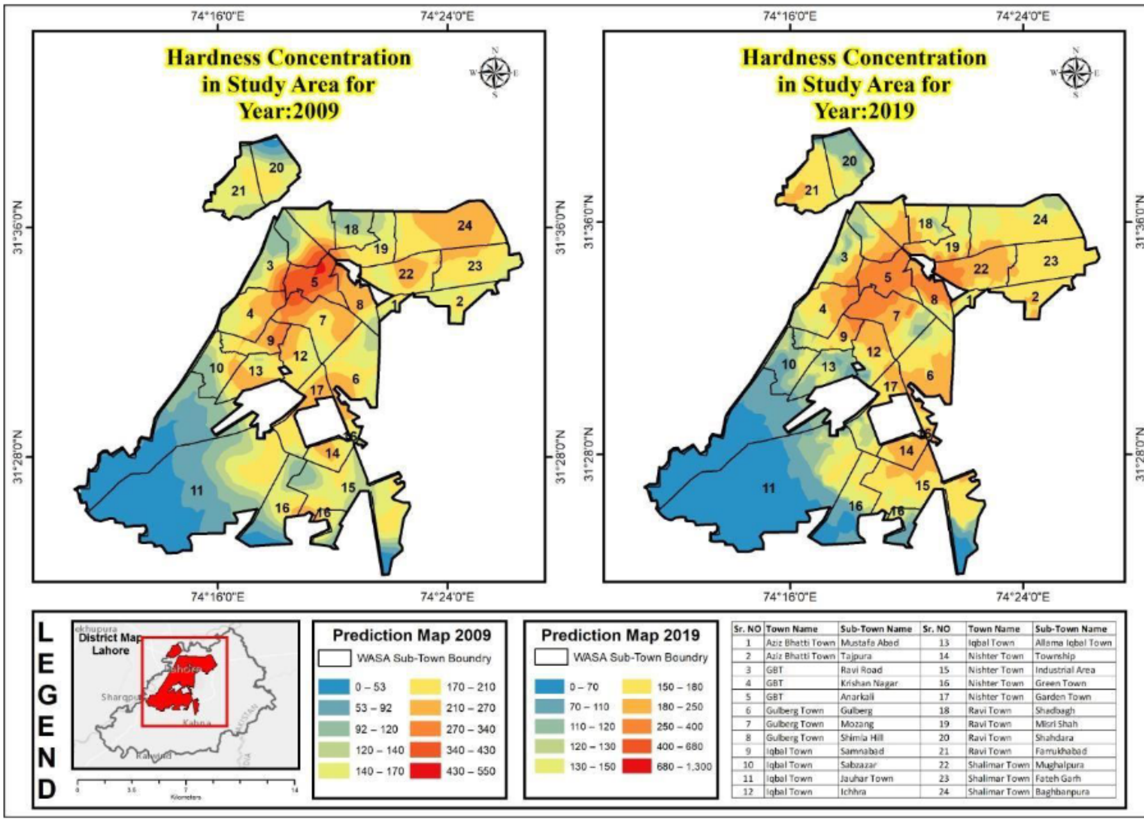

Figure 6 Spatial Distribution of Hardness in Study Area, in 2009-2019

Total Dissolved Solids (TDS)

According to WHO, TDS level in drinking water should not exceed the acceptable limit of 1000mg/l. The results of the year 2009 show that TDS ranged from 215.4-770 mg/l in Aziz Bhatti Town, 200-716.3 mg/l in Shalimar Town, 136.7-974.6 mg/l in Ganj Baksh Town, 5.52-987.8 mg/l in Gulberg Town, 139.2-778.6 mg/l in Iqbal Town, 214.8-1160.4 mg/l in Nishter Town and 28.1-602 mg/l in Ravi town. The highest value was recorded as 1160.4 mg/l in Nishter colony (Nishter town), and the lowest value 5.52 mg/l was observed in Gulberg. The results of 2019 show that TDS ranged from 207.2-606.8 mg/l in Aziz Bhatti Town, 80.6-949.4 mg/l in Shalimar Town, 185.2-1028.1 mg/l in Ganj Baksh town, 272.7-1266.3 mg/l in Gulberg Town, 195.9-1146.6 mg/l in Iqbal Town, 300.5-1667.8 mg/l in Nishter Town, 165.6-647 mg/l in Ravi town. The lowest value of TDS was recorded as 8.6 in Mughalpura and the highest value was 1667.8 in Nishter town. We mapped various TDS levels in Figure 7 using interpolation technique in Arc Map and found that Iqbal town and its outskirts were having high TDS in 2009 but GBT and Ravi Towns were observed with high TDS in 2019.

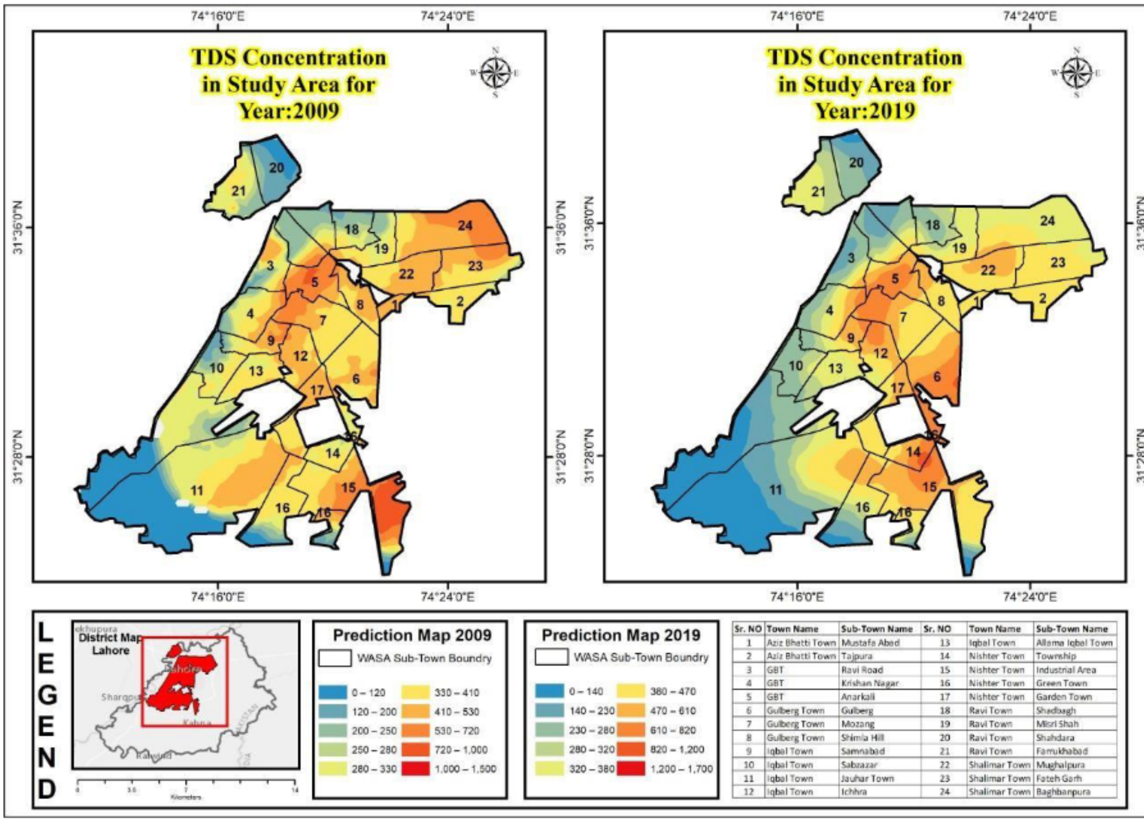

Figure 7 Spatial Distribution of TDS in Study Area, in 2009-2019

Turbidity

According to WHO, the water turbidity must not be greater than 5 NTU. The results of the year 2009 show that the turbidity ranged from 0.37-4.28 NTU in Aziz Bhatti Town, 0.67-4.26 NTU in Shalimar Town, 0.45-4.27 NTU in Ganj Baksh Town, 0.1-5.39 NTU in Gulberg Town, 0.67-19.08 NTU in Iqbal Town, 0.36-3.63 NTU in Nishter Town and 0.21-4.6 NTU in Ravi town. The highest value of TDS was recorded as 19.08 in Johar town and the lowest value 0.1 was observed in Gulberg. The results of the year 2019 show that turbidity ranged from 0.11-1.56 NTU in Aziz Bhatti Town, 0.03-2.51 NTU in Shalimar town, 0.01-10.97 NTU in Ganj Baksh Town, 0.01-3.81 NTU in Gulberg Town, 0.04-5.45 NTU in Iqbal Town, 0.08-2.3 NTU in Nishter Town, 0.04-3.41 NTU in Ravi town. The highest value of turbidity was recorded as 10.97 in Liaqatabad (Ganj Baksh town) and the lowest value was observed in Samanabad. The results show that most values were under the desirable limit; only some values were beyond the permissible limit. Interpolation results show that the water of Zone 11 was highly turbid in 2009. The water of Zones 4 and 21 became more turbid in 2019 as shown in Figure 8.

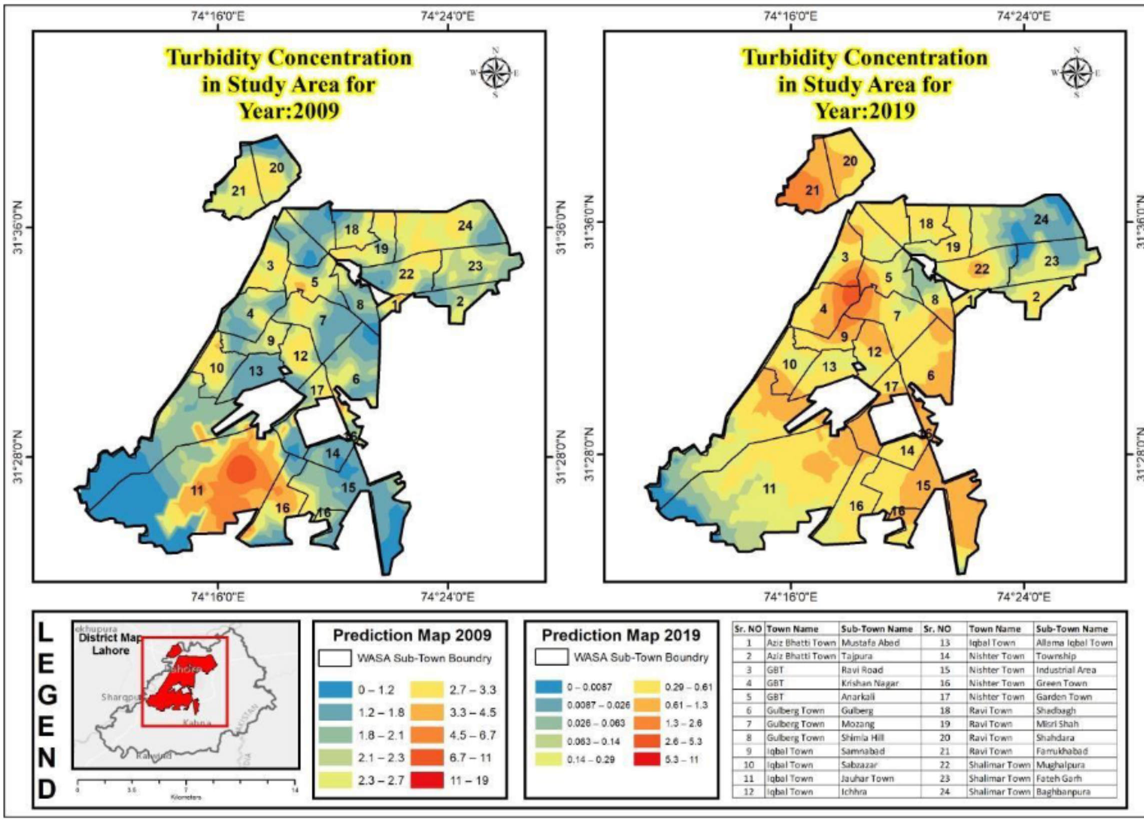

Figure 8. Spatial Distribution of Turbidity in Study Area, in 2009-2019

Electric Conductivity (EC)

Aesthetics (odor and color) are correlated with electric conductivity of water. The results of the year 2009 show that electric conductivity ranged from 342-1005 µS/cm in Aziz Bhatti Town, 286-1137 µS/cm in Shalimar Town, 217-1547 µS/cm in Ganj Baksh Town, 213.5-1568 µS/cm in Gulberg Town, 104-1236 µS/cm in Iqbal Town, 228.6-1842 µS/cm in Nishter Town and 183-956 µS/cm in Ravi town. The highest value of EC was recorded as 1842 µS/cm in the Nishter colony (Nishter Town) and the lowest value 104 µS/cm was observed in Samnabad. The results of the year 2019 show that EC ranged from 329-963 µS/cm in Aziz Bhatti Town, 15.7-1382 µS/cm in Shalimar Town, 294-1632 µS/cm in Ganj Baksh town, 433-2010 µS/cm in Gulberg Town, 311-1911 µS/cm in Iqbal Town, 477-1695 µS/cm in Nishter Town, 263-1027 µS/cm in Ravi town. Figure 9 is showing spatio-temporal distribution of EC in the study area which show that Zones 5, 15 and 24 were highly electric conductive in 2009 in comparison to zones 5,6 and 14 in 2019.

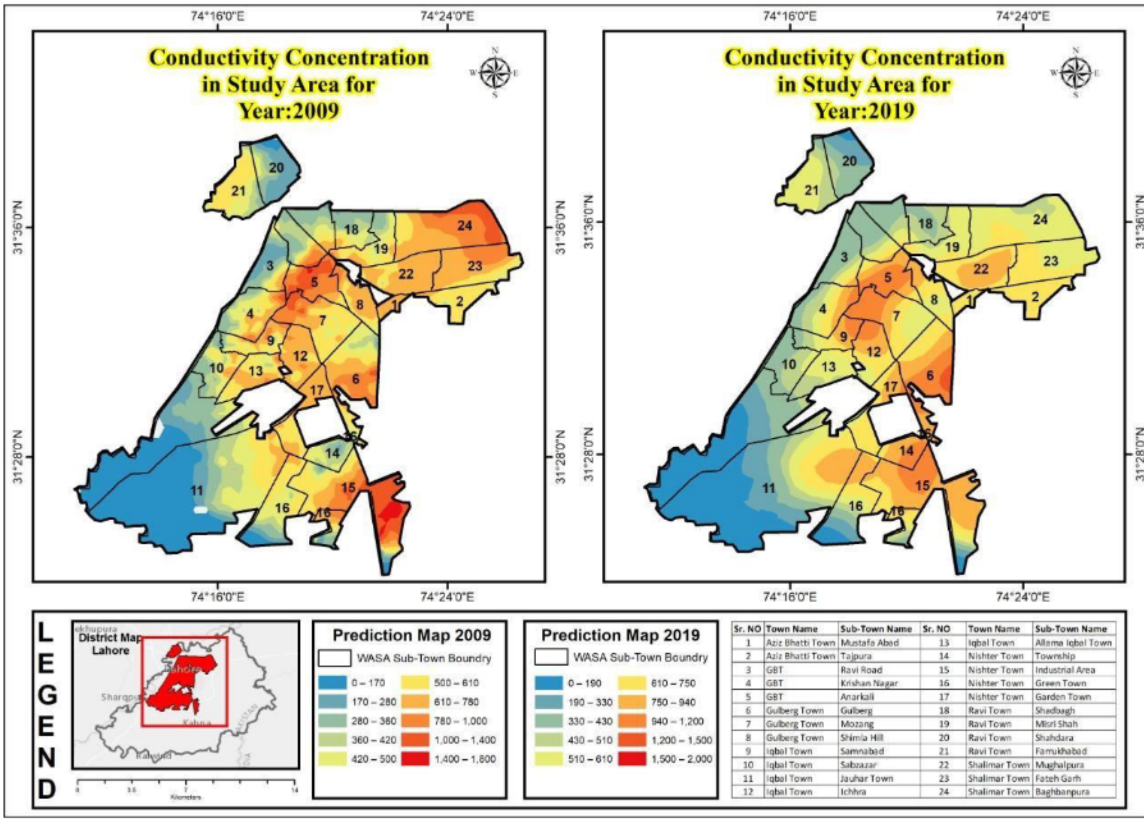

Figure 9. Spatial Distribution of Conductivity in Study Area, in 2009-2019

Chlorides

The admissible level of chloride in drinkable water must not exceed than 250 mg/l, according to WHO standards. Chloride content in water makes water salty. The results of 2009 show that chlorides ranged from 12-33 mg/l in Aziz Bhatti Town, 13-52 mg/l in Shalimar Town, 7-180 mg/l in Ganj Baksh town, 14-200 mg/l in Gulberg Town, 10-142 mg/l in Iqbal Town, 13-83 mg/l in Nishter Town and 5-118.4 mg/l in Ravi town. The lowest value of Chloride was recoded as 5 mg/l in Farrukabad (Ravi town) and the highest value 200 mg/l was observed in Mozang (Ganj Baksh town). The results of the year 2019 show that chloride ranged from 15-53 mg/l in Aziz Bhatti Town, 10-110 mg/l in Shalimar town, 10-120 mg/l in Ganj Baksh town, 8-70 mg/l in Gulberg Town, 10-160 mg/l in Iqbal Town, 12-73 mg/l in Nishter Town and 10-188 mg/l in Ravi town. The higher value of chloride was recoded as 180 mg/l was observed in Allama Iqbal town premises, while the lowest value was 10 mg/l at Data Nagar. Figure 10 is showing spatial distribution of chlorine mapped using interpolation techniques which describes that the level of Clorine declined in 2019 in comparison to 2009.

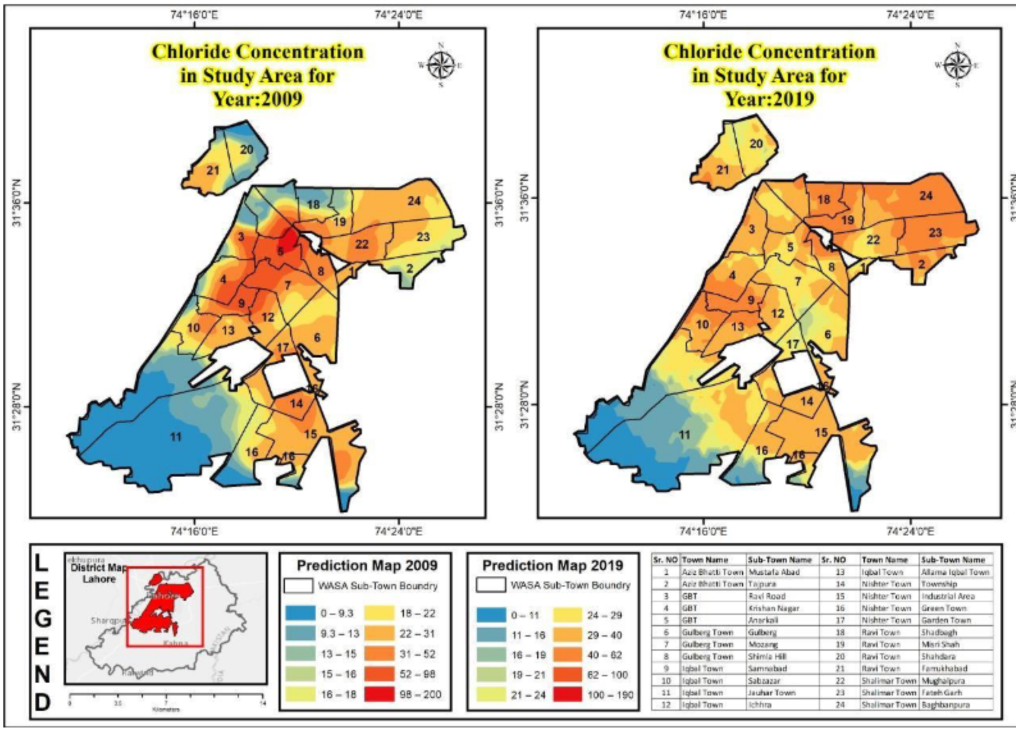

Figure 10. Spatial Distribution of Chloride in Study Area, in 2009-2019

Water Quality Index (WQI)

The WQI was used to merge all previously discussed parameters in at one place providing collaborative impact of all ingredients which show the overall quality of water. Water quality was categorized in five different levels as outstanding, good, fair, poor and very poor, as graded in the water quality index Table 2. Figure 11 is showing the overall situation of drinkable water which is devastating due to existence of many areas under poor quality water.

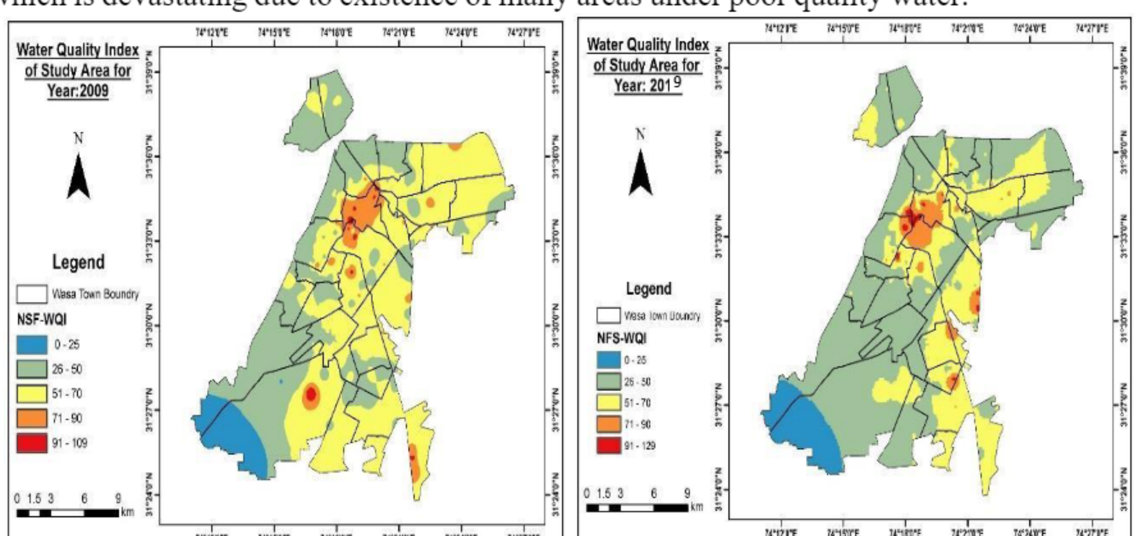

Figure 11. Water Quality Index Map of Study Area, 2009-2019

Average Water Quality Index (AWQI)

The average index map is drawn using AWQI in Figure 12 describing the overall water quality of study site from 2009 and 2019 Which show that water quality of most of areas in Lahore is not suitable for drinking. The central area of Lahore are show very drastic situation regarding quality of water while the outskirts are comparatively sound.

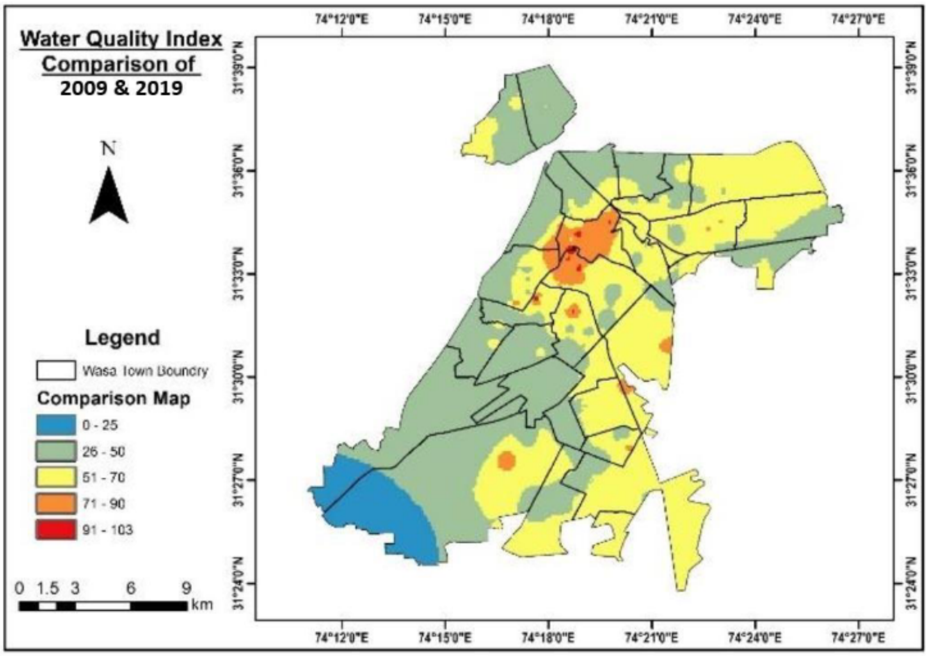

Figure 12 Average Water Quality Index Map of Study Area 2009-2019

There were a number of factors responsible for declining the water quality including cracked water sanitation pipes, urbanization, small industries and ill managed sewerage system. Current sewerage system is not capable enough to cater the flow of this metropolitan region.

CONCLUSION

The pH value of Lahore is within the appropriate limit proposed to be achieved by World Health Organization and is projected to be marginally higher than the recommended pH value in only a few areas, such as the city of Township, Ravi Town, Gulberg, Krishan Nagar or Allama Iqbal. The concentration of turbidity is within the World Health Organization permissible cap. The concentration of turbidity is higher than the prescribed limit in some areas like Johar City, Ravi Town and Samanabad.

The overall situation of drinking water is getting drastic day by day therefore, government must take appropriate actions to maintain the overall/improve the overall condition of water for a sustainable and green future.

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Author's Contribution. All authors have contributed equally.

Conflict of interest. The authors declare no conflict of interest in publishing this manuscript in IJASD.

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