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Spatial Distribution Analysis and Mapping of Groundwater Quality of Malir and Landhi Town, Karachi

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Abstract. The scarce and fragile resource of groundwater in Karachi is at threat of deterioration in terms of quality (due to pollution) and quantity (due to overexploitation) because of rapid urbanization industrialization and it has become an important issue in health and environment sciences. The goal of our research is to assess the groundwater quality in the towns of Malir and Landhi, as well as to use GIS and geostatistical approaches to establish the spatial pattern of groundwater quality in these locations. Spatial distribution maps of all parameters in these towns are developed by the application of GIS (interpolation technique). It is found that temperature, TDS and EC were higher in comparison with SSDWQ and WHO guidelines, while pH was found to be basic. The study is the quality of groundwater is beyond the permissible limit of safe consumption and the population directly dependent on the groundwater sources in these towns which is prone to water borne diseases. The outcome of this study can be used as a preliminary study for further detailed groundwater quality analysis and to study spatial distribution pattern in these towns to assess the impact of groundwater quality on consumers, the determination of relationship between association of pollution sources. Thus, pollution hot spots and their contributing sources can be identified that will aid in developing effective mitigation and management programs by the government (policy maker) and non-government (polluters) entities.

Keywords: GIS application, pollution, groundwater quality, physical and biological parameters

Introduction

Increasing population, expanding areas of agriculture land, industrial and economic development are drivers for an ever increasing demand for water worldwide. Although globally such demand can be met by surface water availability (*i.e.*, water in lakes, rivers and reservoirs), regional variations are large, leading to water stress in several parts of the world. Some of the examples of regions facing re-current water stress include Sahel, south Africa, the central U.S., Australia, India, Pakistan and north east China (Hanasaki *et al*., 2008). It is estimated that over 2 billion peoples (35% of the world population) suffer from severe water stress (Alcamo *et al*., 2017). The groundwater is often used as an important water source, in large aquifer systems. If groundwater extraction exceeds into extensive areas for a longer time, so, over exploitation or persistent groundwater depletion can occur (Gleeson *et al*., 2010). Groundwater is used for consumption, agriculture, commercial and other purposes throughout the entire globe. The widespread use of groundwater in the domestic, commercial and farming sectors reported by (Hussain *et al*., 2020; Qureshi *et al*., 2010) as well as poor management reported by (KWSB and ILO, 2019) and unplanned over exploitation reported by (Shah *et al*., 2001) and these all resources under massive stress. The resultant can have devastating effects on natural stream flow, groundwater fed wetlands and related ecosystems and most importantly the survival of human living in water stressed areas will be jeopardized. In deltaic areas, groundwater depletion can result in land subsidence and saltwater intrusion. Groundwater is a life sustaining resource that supplies water to billions of people, which plays a central part in agriculture and influences the health of many ecosystems (Siebert *et al*., 2010; Giordano, 2009).

Formerly most assessments of water resources have focused on surface water (Oki and Kanae, 2006; Postel *et al*., 1996) but unsustainable depletion of groundwater has recently been documented on both regional by (Famiglietti *et al*., 2011; Rodell *et al*., 2009) and global scales (Konikow, 2011; Wada *et al*., 2010). According

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to these assessments, it remains unclear how the rate of groundwater depletion compares to the rate of natural renewal and the supply needed to support ecosystems. Humans are over exploiting groundwater in many large aquifers that are critical to agriculture, especially in Asia and north America. It is estimated that the size of the global groundwater footprint is currently about 3.5 times than the actual area of aquifers and that about 1.7 billion people live in areas where groundwater resources or groundwater dependent ecosystems are under threat. However, 80% of aquifers have a groundwater footprint that is less than their area, meaning that the net global value is driven by a few heavily over exploited aquifers (only 20% aquifers around the globe) (Gleeson *et al*., 2012). In Pakistan more than 60% urban population is consuming groundwater for drinking and domestic purpose without maintaining the standard of the World Health Organization (Khattak and Khattak, 2013). The scarce and fragile resource of groundwater is under the risk of degradation in both quality (pollution) and quantity (over exploitation) terms due to rapid urbanization and industrialization and has become a heated topic of high risk environment (Kazemi, 2011; Onodera *et al*., 2008). It is reported that 80% of all the diseases in human being are water borne (Munna *et al*., 2015). If the quality of groundwater is altered due to contamination of pollutants, it is not possible to easily restore the quality of groundwater simply by discontinuing the pollutants from entering it. Due to the said fact, it remains very critical to carryout spatial assessments of groundwater quality at set frequencies that can contribute in developing strategies to prevent it's contamination in first place (Al-hadithi, 2012).

As compared to other major cities of Pakistan, namely, Lahore, Multan, Rawalpindi, Quetta, Peshawar, Gawadar, Mardan, Faisalabad, the quality of groundwater of Karachi stands out to be comparatively more deteriorated and it is not fit for human consumption and consumers are prone to a diverse range of diseases (Khattak and Khattak, 2013). Karachi city comprises of more than two thousand industries of various nature and sizes discharging their almost untreated effluents of about 72 million gallons per day into the natural and man made drainage networks, which drain mainly through local rivers Malir and Lyari (Siddique *et al*., 2008). In Landhi area has more than four thousand wells, borings or hand pumps are being used to draw groundwater. In Landhi Industrial area (LIA) a large number of small and medium size industrial units are present which has concentrated groundwater. Thus, the scarcity of water in industrial units of LIA to dig wells or bore holes on their premises as a dependable source of water which reported by (Mahmood *et al*., 1998). Extensive studies are available on the tap water quality of Malir town (Aamir *et al*., 2015). The groundwater quality in Malir and Landhi towns almost has no study, except for one in which risk zone mapping is carried out for lead contamination in Karachi. This exceptional study has covered populated areas of Karachi city extensively. The quality of Malir and Landhi town groundwater specifically with respect to lead concentration is assessed to lie between no risk to moderate risk zones (Siddique *et al*., 2012). This type of groundwater is used for different purposes in growing of crops (Gide, 2018).

A Geographic Information System (GIS) is a comprehensive computer system to manage geospatial information. Geo-visualization has evolved as an efficient tool for assimilating, analyzing and exhibiting spatial data which can be utilized for numerous purposes such as environmental monitoring, assessment, mitigation, planning and resource management programs (Balla *et al*., 2022; Mester and Balla, 2020; Singha *et al*., 2015) specifically for large, multi-natured and intricated urban environmental setups. It is an efficient way for organizing large amounts of data and identifying and solving numerous spatial challenges in the field of environment. For example, interactive association of pollution data can be analyzed and visualized with respect to relevant demographic, meteorological and other information data set. Similarly, with the capacity to use spatial data according to desired needs and in various areas in an integrated environment, GIS has emerged as an important platform for resource management studies. Its accuracy in exploratory data analysis, its visualization, as well as model building capacity has enabled it to address multi dimensional resource management challenges including water (Peter *et al*., 2007). Therefore, GIS can be seen as the most appropriate multispectral spatial analysis tool, which can be applied in almost all areas (even real time data analysis) where spatial information has to be retrieved and analyzed (Rani *et al*., 2022). Besides it, geostatistical approach of GIS is very helpful to analyze the spatial variation of groundwater quality (Munna *et al*., 2015).

Considering the importance of geo-visualization, the objectives of our study are to determine the groundwater quality of Malir and Landhi towns and the application of GIS interpolation technique in determining spatial pattern of groundwater quality in these towns. The groundwater quality and spatial distribution maps for these towns can be helpful as a preliminary information for further detailed assessment for groundwater quality in these towns or to identify potential hotspots for planning and implementing strategies with respect to prevent groundwater contamination or water treatment options by the government and non-government entities.

Study area. The study area encompassing Malir and Landhi towns is shown in Fig. 1. The population of Malir town has increased from 398,289 (Census, 1998) to 604,766 (KMC, 2005). Malir town is one of the 18 towns of Karachi city which is located in the eastern part of Karachi, Sindh, Pakistan. It is bordered by the Malir cantonment to the west and north and Shah Faisal town to the south and Gadap town to the east. It has been regarded in history as the countryside of Karachi city due to its open atmosphere and lush green farms but now these are no more. Malir was once famous for its fruit and vegetable farms but now due to severe scarcity of groundwater, these farmlands are being converted into residential areas, thus increasing urbanization and environmental degradation.

Landhi town is a large industrial town in the eastern side of Karachi, Sindh, Pakistan. It is bordered by the Faisal cantonment and Shah Faisal town to the north across the Malir river, Bin Qasim town to the south and east and Korangi town to the west. The population of Landhi town was estimated to be 666,748 at the time of 1998 census, which has increased upto 10,12,393 in 2005 (KMC, 2005). The sampling sites in Malir and Landhi towns are presented in Fig. 2-3, respectively.

Materials and Methods

Water quality data acquisition and analysis. The nineteen (19) samples were taken from privately owned wells and borings of the residence of the Malir and Landhi town that is directly consumed for drinking and other domestic purposes in July, 2014. The location of all sample sites was marked and noted by using GARMIN (eTrex 10) hand held Global Positioning System (GPS) receiver. Samples were collected in 1.5 L of screw capped polyethylene bottles. Before sampling the bottles were pre cleaned by subsequent: rinsing with tap water, washing with distilled water, air dried at room temperature, properly capped and labelled.

Biological activity test kit (manufactured by PCRWR) was used to assess the biological status of drinking water. On site analysis of parameters was carried out for collecting samples. The pH, ORP and temperature of water samples were determined on site through Adwa

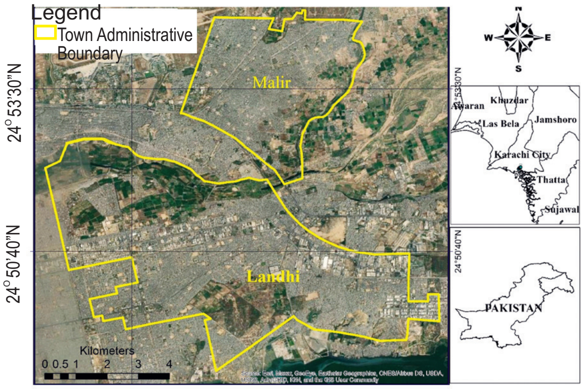

Fig. 1. Location of study area.

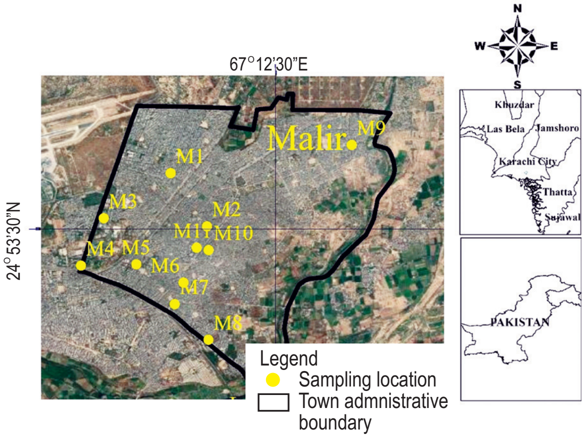

Fig. 2. Location of sampling sites in Malir town.

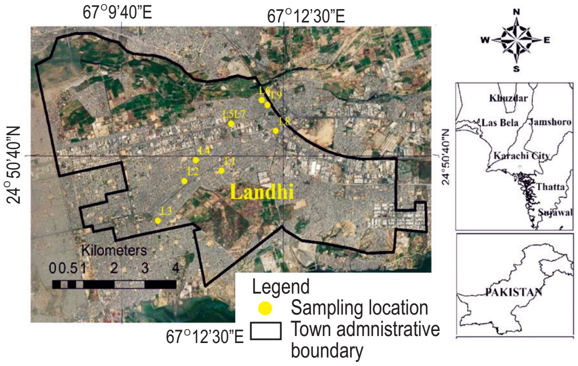

Fig. 3. Location of sampling sites in Landhi town.

pH/ORP/Temp portable meter (AD111), while the parameters of electrical conductivity and Total Dissolved Solids (TDS) were analyzed by Eutech conductivity/ TDS meter (Cyberscan CON1103k).

Spatial interpolation technique. Geographical information system (GIS) has been widely used in water and environment applications and many efforts have been made for applying it to resource and environmental management. A GIS software package with ESRI Arc GIS (version) 10.4 and Arc GIS geostatistical analyst extension was used to map the assessed parameters of groundwater. It is used for envisaging, managing, generating and analyzing data. The capability of spatial analysis makes Arc GIS different from other mapping system. Attribute information of samples was entered into a digital map using the Arc GIS 104 software. The sampling sites were marked in Arc Map with the help of their coordinates and the Inverse Distance Weighted (IDW) interpolation technique was used for developing maps presenting spatial distribution of groundwater quality parameters over the study. IDW uses the measured values surrounding the non sampled locations to predict a value for these areas, it is based on the assumption that things that are close to one another are more alike than those that are farther apart (Berktay, 2010). With the help of inbuilt statistical standard method values of minimum, maximum, mean and standard deviation for the selected parameters was also determined. The core of geo-statistical analysis is to select the appropriate spatial interpolation method to create the surface through the analysis of the sample data and the awareness of the geographical features of the sampling area. Before the interior data analysis, relevant maps and data material of the study area was collected at first. Then, relevant maps and data material was digitized by using Arc GIS and a unified coordinate system (World Geographic Coordinate System, 1984) was set to integrate this data through editing and registration. The structure of thematic layer and the data in the storage area of GIS system were applied to establish the basal spatial database of the studied area, meanwhile the pertinent attribute or sample analysis data was digitized and stored. It is necessary to note down the geodetic coordinates by using the (Global Positioning System, GPS) so, that the sampling point layers will automatically generate by means of Arc GIS and according to the coordinate of monitoring points and at the same time to match the unified coordinate.

Results and Discussion

The result of groundwater samples of Mailr and Landhi town which shown is in Table 1 and 3, respectively. The values of each parameter are compared with the SSDWQ and WHO guidelines. The basic descriptive statistical analysis of Malir and Landhi town samples is presented in Table 2 and 4, respectively. The maps of the spatial distribution of each parameter are developed and presented as Fig. 4-5. Each parameter is discussed individually in forthcoming sections.

Temperature. Temperature is an important biologically significant factor, which plays an important role in the metabolic activities of the organism. There are various biochemical processes going on under the ground due to the presence of biological agents. The sampling sites

Table 1. Groundwater analysis of Malir town

Sample site	Temp (°C)	pH	Eh (MV)	TDS (ppm)	EC (μS)	Biological activity test
M1	29.2	7.29	-14	2510	4820	Negative
M2	29	7.52	-28	1870	3780	Positive
M3	31	7.39	-24	4090	8190	Positive
M4	29	7.64	-35	726	1453	Positive
M5	31	7.33	-21	668	1300	Positive
M6	29	7.21	-21	996	2060	Negative
M7	28.9	7.48	-26	800	1605	Positive
M8	29	7.41	-11	945	1890	Positive
M9	30	7.25	-16	1440	2970	Positive
M10	30	7.13	-11	2060	4120	Positive
M11	29	7.47	-29	1890	3790	Positive
SSDWQ	N/A	6.5-8.5	N/A	<1000	N/A	0 MPN/100 mL
WHO guidelines	N/A	6.5-8.5	N/A	<1000	650-1200	0 MPN/100 mL

M3, M5 and L1, L3, L5 show the highest temperature values for Malir and Landhi town, respectively. The minimum and maximum values of temperature for Malir town samples is 28.9 and 30.98 °C respectively, while the mean value is 29.53 °C with a standard deviation of ± 0.311. The minimum and maximum values of temperature for Landhi town samples is 28 and 29.9 °C respectively, while the mean value is 29.42 °C with a standard deviation of ± 0.32.

pH. pH is used universally to express the intensity of the acidic or alkaline condition of water *i.e.*, indicator of relative acidity/alkalinity. An acidic water is vulnerable to any significant change in pH if effluent from industries and domestic activities is mixed. On the other hand, water with slight alkalinity is resistant to changes in pH and has a pleasant taste. Alkalinity of water is its capacity to neutralize a strong acid. Water is usually alkaline due to the presence of bicarbonate, carbonate ~~and hydroxide compounds of potassium, sodium and~~ calcium. It is an important operational water quality parameter, with the optimum pH in the range of 6.5-8.5 both by Sindh Standards for Drinking Water Quality (SSDWQ) and World Health Organization (WHO). All the samples showed the pH values within the prescribed range except for one sample (L3) in Landhi town. The minimum and maximum value of pH for Malir town samples is 7.13 and 7.63 respectively, while the mean value is 7.34 with a standard deviation of ± 0.04. The minimum and maximum value of pH for Landhi town samples is 7.43 and 9.08 respectively, while the mean value is 7.78 with a standard deviation of ± 0.26.

Table 2. Basic descriptive statistics of Malir groundwater

Parameter	Minimum	Maximum	Mean	Standard deviation
Temp	28.9	30.988	29.532	0.311
pH	7.13	7.639	7.344	0.046
Eh	-34.998	-11.001	-19.857	2.622
TDS	668.978	4087.954	1679.335	370.374
EC	1301.998	8185.896	3354.563	713.247

Total dissolved solids. TDS is comprised of constituent ions of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) which determines the saline behaviour of the water. Concentrations of TDS in water vary considerably in different geological regions due to differences in the solubilities of minerals (Nas and Berktay, 2010). It signifies the amount of total dissolved salts (Murhekar, 2011). TDS also helps in determining to some extent the amount of organic matter (particularly as suspended solids) that are dissolved in water (Mehdi and Bidgoli, ~~2012). The WHO guidelines say that TDS higher than~~ 500 mg/L makes the water somewhat undesirable for drinking, although under certain conditions, water up to 1500 mg/L can be used. However, under normal conditions TDS of water should not exceed 1000 mg/L. Except for samples M4, M5, M6, M7, M8 of Malir town and L3, L8 of Landhi town all other samples showed exceeded the values of TDS as compared with SSDWQ and WHO guideline value. A higher TDS causes adverse changes in the taste of water and is also not good for metallic pipelines used for transportation of water inside homes (Ramesh and Seetha, 2013). The minimum and maximum value of TDS for Malir town samples is 668.97 ppm and 4087.954 ppm, respectively, while the mean value is 1679.335 ppm with a standard deviation of ± 370.374. The minimum and maximum value of TDS for Landhi town samples is 583.745 ppm

Table 3. Groundwater analysis of Landhi town

Sample site	Temp (°C)	pH	Eh (mV)	TDS (ppm)	EC (µS)	Biological activity test
L1	30	7.78	-44	1970	3950	Positive
L2	29.9	7.76	-45	5350	10710	Positive
L3	30	9.09	-50	661	1366	Negative
L4	29.5	7.49	-28	1300	2600	Negative
L5	30	7.73	-41	2020	4030	Positive
L6	29	7.38	-31	1720	3430	Positive
L7	28	7.46	-33	1500	3000	Positive
L8	29	7.43	-23	583	1162	Positive
SSDWQ	N/A	6.5-8.5	N/A	<1000	650-1200	0 MPN/100 mL
WHO guidelines	N/A	6.5-8.5	N/A	<1000	N/A	0 MPN/100 mL

Table 4. Basic descriptive statistics of Landhi groundwater

Parameter	Minimum	Maximum	Mean	Standard deviation
Temp.	28	29.999	29.421	0.32088
pH	7.43	9.089	7.7823	0.26093
Eh	-49.996	-23.008	-36.778	3.85346
TDS	583.745	5347.575	1906.368	484.27463
EC	1163.496	10705.149	3819.611	969.63279

and 5347.575 ppm, respectively, while the mean value is 1906.368 ppm with a standard deviation of ± 484.274.

Electrical conductivity. The capacity of water to conduct electric current is referred to as electrical conductivity (EC). It is also used as an indirect means to determine the TDS in water (Saeed, 2014). The importance of EC and TDS lies in their effect on the corrosive nature of a water sample and in their effect

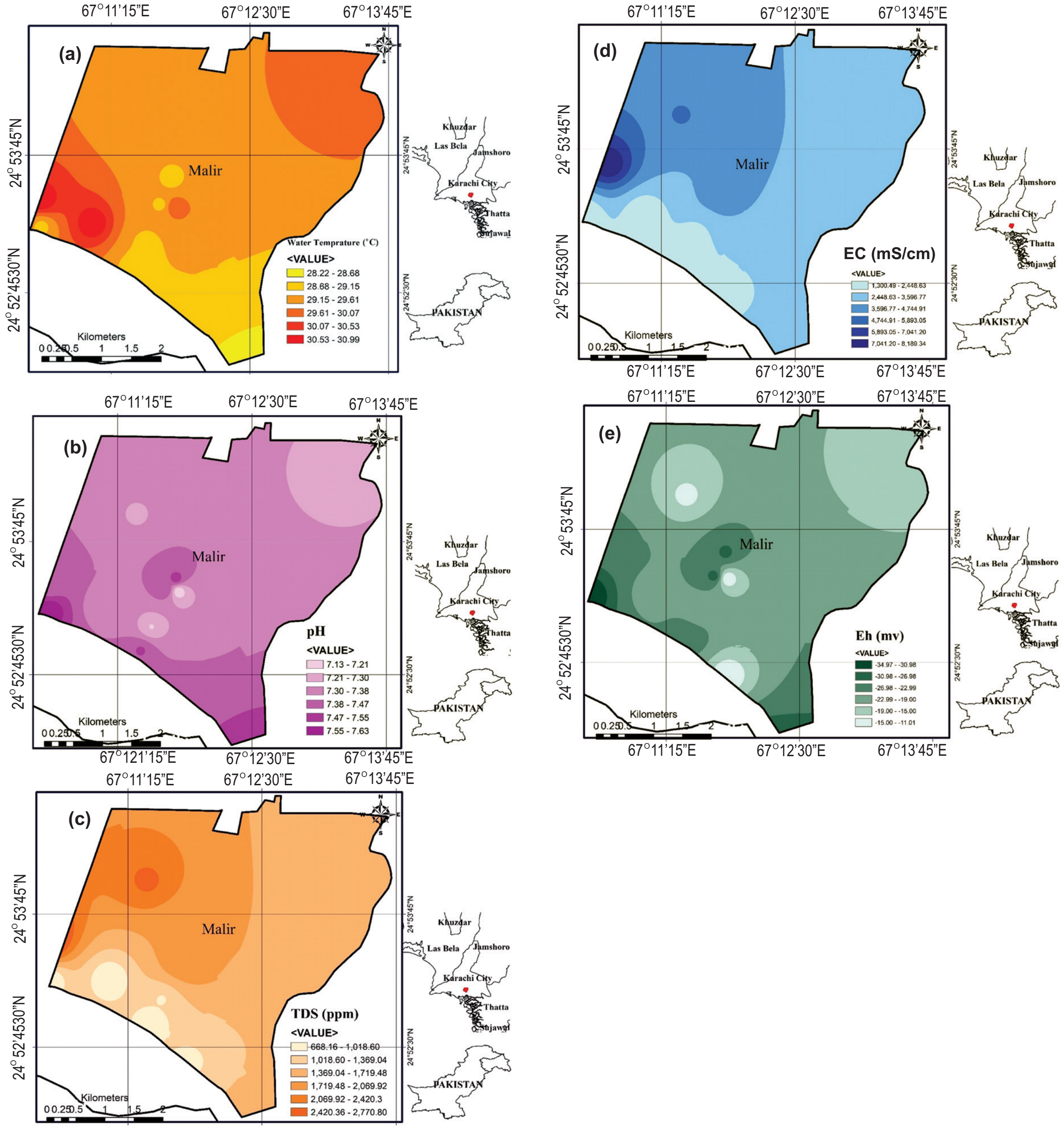

Fig. 4. Spatial distribution Maps of Malir town **(a)** Temperature, **(b)** pH, **(c)** TDS, **(d)** EC and **(e)** Eh.

on the solubility of slightly soluble compounds such as $CaCO_3$. The conductance of a water sample is directly proportional to the inorganic dissolved solids capable of dissociation into ions. The value of electrical conductivity is often used as an index of total dissolved materials in a water sample and is related to the TDS of water sample by a mathematical factor that depends upon the concentration and type of ions present in the water sample (Saeed, 2014). The acceptable limits for EC as given by WHO is 650 to 1200 µS/cm, all of the samples have shown high electrical conductivity values. A high value of EC in underground water may be contributed by discharge from polluting industries and untreated wastes (Ullah *et al*., 2009). The minimum and maximum

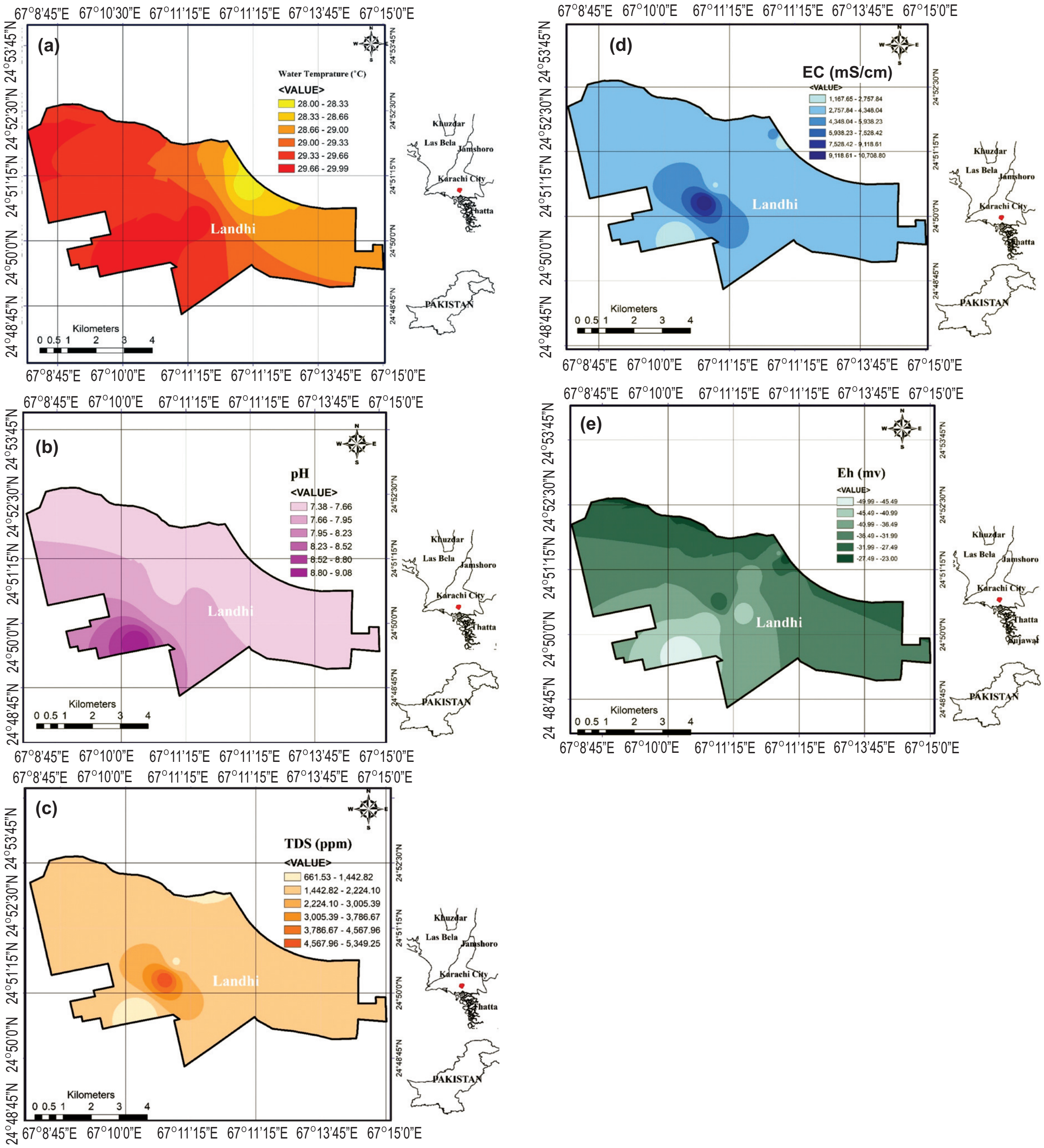

Fig. 5. Spatial distribution map of Landhi town **(a)** Temperature, **(b)** pH, **(c)** T DS, **(d)** EC and **(e)** Eh.

value of the EC of Malir town samples is 1301.998 µS/cm and 8185.896 µS/cm respectively, while the mean value is 3354.563 µS/cm with standard deviation of ± 713.247. The minimum and maximum value of the EC of Landhi town samples is 1163.496 µS/cm and 10705.149 µS/cm respectively, while the mean value is 3819.611 µS/cm with standard deviation of ± 969.63279.

Oxidation reduction potential. The analysis result of Eh is presented in Table 1-2 for Malir and Landhi town, respectively. These negative ORP values indicate reducing environment of the groundwater samples. Alkaline ionized water is an anti-oxidizing agent, and it is able to donate extra electrons. The minimum and maximum value of Eh of Malir town samples is -34.998 MV and -11.001 MV respectively, while the mean value is -19.857 MV with a standard deviation of ± 2.622. The minimum and maximum value of Eh of Landhi town samples is -49.996 MV and -23.008 MV respectively, while the mean value is -36.778 MV with a standard deviation of ± 3.85346 11. Various metals and heavy metals accumulated in the soils, sediments and even bedrock could be dissolved into the groundwater when pH and oxidation and reduction potential (Eh) conditions become appropriate. Thus, the conditions of Eh and pH in water affect the dissolved concentration of metals. If carefully monitored these parameters can help in determining and controlling the concentration (through mobilization or immobilization) of heavy metals and contaminants in groundwater. Almost all redox reactions in groundwater are biochemically mediated. The type of soil and bedrock also affect the quality of groundwater. As limestone prevails in Karachi's geological lithology therefore, greater chances of groundwater and limestone interaction are present that may be affected by the redox potential of groundwater. Slight alkaline pH and negative redox potential support limestone and groundwater interaction. Thus, also indicated that Ca and Mg ions would be in greater concentration in the water referring towards another property of groundwater *i.e*. hardness.

Biological activity test. The biological activity test showed positive results for all samples except for sites M1, M6 and L3, L4 of Malir town and Landhi town respectively. The presence of biological activity validates the occurrence of bio-geochemical processes in the groundwater.

Spatial analysis. The spatial distribution of the assessed parameters gives a clearer understanding and picture of groundwater condition and has also predicted values for areas in between tested sampling sites on a statistical basis. The spatial groundwater quality profile developed for Malir town is discussed as follows, according to Fig. 4a the spatial variation of temperature indicates that eastern and western side of Malir town has comparatively higher temperature zones. Fig. 4b the spatial variation of pH indicates that western and southern regions of Malir have a slightly basic pH. Figure 4c indicates that northern and western corner of the town contains groundwater with higher TDS values. The EC map shown in Fig. 4d indicates northern and western regions of the town having higher values. Figure 4e shows the spatial distribution of redox potential, the western side of the town has highly reduced condition of groundwater other regions of the town. As per the analysis of spatial distribution of groundwater quality, the western side of the town specifically contains groundwater with higher values of all parameters compared to other regions of the town.

The spatial groundwater quality profile developed for Landhi town is discussed as follows. The spatial variation of temperature shown in Fig. 5a has divided Landhi town in two large sections, one with higher temperature of groundwater on the left-hand side (with almost uniform distribution) and another with lower temperature on the right-hand side (with varied distribution). Figure 5b the spatial variation of pH indicates that southwestern side of the town is having a comparatively more basic pH. Figure 5c presents the distribution pattern of TDS in which a region near to center contains highest values. The EC spatial distribution map in Fig. 5d shows that it is following a similar distribution pattern as that of TDS. Figure 5e shows the spatial distribution of redox potential, the central, western and south western sides of the town have a highly reduced condition of groundwater. As per the analysis of spatial distribution of groundwater quality, variation exists in the spatial distribution of the assessed parameters except for TDS and EC.

Groundwater temperature is one of the most important parameters which can cause many changes to the water. In one of the studies conducted on Malir and Landhi town near areas, the temperature found to be high which indicates the maximum concentration of presence of pollutant in that specific site which is similar to this research study. One study also reported a slightly alkaline pH, a high TDS and higher CE values in the town of Malir and Landhi (Syed, 2020).

Conclusion

Application of GIS in the assessment of water quality and determination of spatial distribution has been very effective. These maps not only predict the water quality of un-sampled areas of the town, but also provide preliminary information regarding variations in water quality under the ground. Based on the study it is concluded that the quality of groundwater in Malir and Landhi towns stands to be unfit for human consumption. High TDS and EC of the water sample indicates that besides the underground geological interactions, the seepage of domestic and industrial waste water and sea water intrusion (as a result of over exploitation of groundwater resources) are key factors in deteriorating the groundwater quality. Wells or boring with acceptable quality standards for groundwater are very scarce in Malir and Landhi towns and are used by the inhabitant directly without any treatment or filtration. High TDS, EC and negative redox potential indicate presence of high concentration of unwanted metal or trace metals that might exceed human consumption limits. Form this study directions and areas of further research are also identified these include, there is need for further detailed groundwater quality assessment (of metals and heavy metals) in these town to analyzed the impact of groundwater quality on human health, the spatial distribution and interaction of metals and heavy metals in groundwater of these towns and determination of relationship between association of pollution data with relevant demographic and industrial information through the application of GIS. In this manner pollution hot spots and their contributing sources can be identified and thus effective mitigation and management programs could be developed and implemented to avoid deterioration of groundwater quality by the government (policy maker) and non-government (polluters) entities.

Conflict of Interest. The authors declare they have no conflict of interest.

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