*Proceedings of the Pakistan Academy of Sciences: B*
*Life and Environmental Sciences* 61(3): 283-294 (2024)

ISSN (Print): 2518-4261; ISSN (Online): 2518-427X
http://doi.org/10.53560/PPASB(61-3)955

Pakistan Academy of Sciences

Research Article

# Spatial Assessment of Drinking Water Quality in Mardan City, Khyber Pakhtunkhwa, Pakistan

**Muhammad Ibrahim[1], Ihsanullah[2], Ghani Rahman[3, 4,*], and Muhammad Hamza[5]**

[1]Department of Geography, Government Post Graduate College Mardan, Pakistan
[2]Department of Geography and Geomatics, University of Peshawar, Pakistan
[3]Department of Civil and Environmental Engineering, Sejong University, South Korea
[4]Department of Geography, University of Gujrat, Punjab, Pakistan
[5]Department of Geography, Government Post Graduate College Nowshera, Pakistan

**Abstract:** The quality water is needed for human health. However, most of the water supply agencies focus on only water supply aspect instead of water quality. Majority of the consumers are also not aware of the importance of water quality. In the present study, samples of drinking water were collected from households located in Mardan city. These water samples were evaluated for physical parameters (electrical conductivity (EC), pH, total hardness, total dissolved solids (TDS), and turbidity) and chemical parameters (sulphates, nitrates, sodium, chlorides and potassium ions). The physical parameters (pH, alkalinity, total hardness and TDS) and chemical parameters (sodium, chloride and nitrate) in all the water samples were found according to the guidelines prescribed by WHO for the quality of drinking water. However, this study has shown abnormal conditions regarding physical parameters (turbidity 0.82 NTU and EC 1480 µS/cm) and chemical parameters (potassium 13.7 mg/l and sulphates 512 mg/l) at selected sample areas. These water samples values are higher than the guidelines values recommended by WHO for the quality of drinking water. Therefore, it can be concluded that the groundwater quality at the majority places are safe drinking purposes in the study area.

**Keywords:** Water Samples, Stratified Sampling, Physio-chemical Analysis, Spatial Distribution, Water Quality.

## 1. INTRODUCTION

Water is essential for human needs and life processes on the globe [1]. The large part of living things is consist of water [2]. In human beings, three to fourth of its weight consists of water [3]. It is not possible to sustain life on earth without water [4]. The earth approximately consist of 1.4 trillion cubic meter of water [5]. Less than 1 percent of this water is available in the form of rivers and groundwater to meet our requirements [6]. According to a study conducted by United Nations, revealed that population is increasing and the availability of freshwater is declining [7]. It would results in severe shortage of water in South Asia, Africa, and Middle East in the next two decades [8]. Due to rapid population growth and urbanization, not only quantity of water is diminishing but its quality is also deteriorating particularly in the developing countries [9]. Water should not contain any substance which is injurious to human health [10]. Disease-causing microbes, chemical molecules and minerals are the examples of such substances [11]. Many people in developing countries experiencing health problems either due to lack of access to quality water and thus using contaminated water for drinking purposes [12]. About 5 million children mortality occurs each year due to the drinking of contaminated water in the developing countries[13]. Rapid population growth and inadequate water quality management further aggravating this issue [14]. Quality of water supply is considered a serious issue in the developing countries of the world [15]. The people of these

Received: June 2023; Revised: August 2024; Accepted: September 2024
* Corresponding Author: Ghani Rahman <ghani.rahman@uog.edu.pk>

countries are also unaware of quality drinking water and their impacts on health [16, 17]. These health issues are directly or indirectly related to high or low concentration of the contaminants in the drinking water [18]. Majority of the residents of developing countries are prone to water borne diseases due inadequate and unsafe public water supply [19]. Water borne diseases associated with inadequate and unsafe water supply is responsible approximately for 60% of the health issues in developing countries [20]. The contamination in drinking water changes its chemical properties which is disturbing the overall equilibrium of the system and is resulting its consumption impractical [21]. The improved water supply to the public depends on the analytical assessment of the drinking water. Therefore, analysis of water quality parameters is necessary for the evaluation of water pollution.

The major cause of waterborne diseases is the consumption of contaminated water [22]. The use of contaminated water results in morbidity and mortalities in underdeveloped and developing countries [23]. The infant mortality rate is particularly high in poorer countries [24]. The scientific studies carried out in different parts of Pakistan have reported the contamination of drinking water and its related health problems [25]. Almost 30% of the diseases and 40% of the deaths in Pakistan are caused by poor water quality [26]. Every fifth inhabitant in the country reports having a disease or illness brought on by contaminated water [27]. Diarrhea being the most common cause of mortality in newborns and young children in the country [28]. According to a report, ¼ infant mortality is due to waterborne diseases in dveloping countries [29]. Inspite of this crictical situation, the water supply agencies give less attention to water quality and their emphasis, in most cases, is only on the supply of water [30].

Water quality is an important aspect of drinking supply system. It has a direct effect on the health of its consumers. It not only affects the health of human beings but also aid the economic burden on its consumers. Therefore, the main aim of the current study is to evaluate the drinking water quality of different water samples collected from different union councils of Mardan city, Khyber Pakhtunkhwa, Pakistan and to compare it with WHO standards for drinking water [31].

This study analyze the current quality of drinking water supply to check either it is safe for drinking purpose or not. The results of analysis of drinking water samples will be helpful for the awareness for the people of the study area. Therefore this study evaluate the physio-chemical parameters of drinking water in Mardan City like pH, alkalinity, total dissolved solids, total hardness, electrical conductivity, turbidity, sodium, potassium, chlorides, nitrate and sulphates ions. The whole Mardan city is selected for the purpose of water quality assessment. Sixteen drinking water samples were collected from private bores within the houses located in different neighborhood Councils of Mardan city. These samples were analyzed for various physio-chemical parameters. The spatial distribution of these samples is shown in Figure 1.

## 2. MATERIALS AND METHODS

### 2.1. Drinking Water Quality Parameters Tested

Sixteen drinking water quality samples were collected from the study area. These samples were tested for six physical and five chemical parameters. Physical parameters tested were pH, conductivity, total hardness, total dissolved solids (TDS) and total alkalinity.

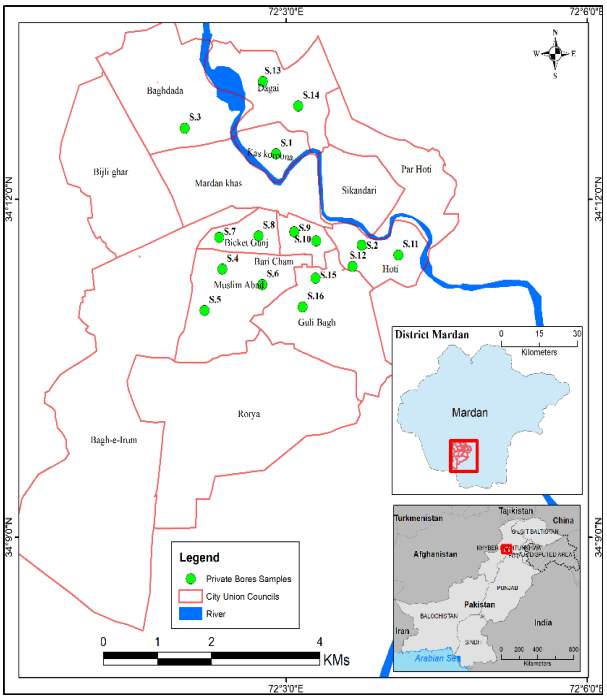


**Fig. 1.** The map shows the location of the study area and distribution of the locations of water samples.

The solubility and biological availability of chemical elements are determined by the pH of water. Both too high and low concentrations of pH can affect the quality of drinking water. High concentration of pH in drinking water produces bitter taste and deposits in water using equipment's and water pipes. WHO recommends the range of pH from 6.5 to 8.5 for drinking water [31].

Electrical Conductivity (EC) in drinking water is the measures of the capacity of water to conduct electricity. It indicates the presence of impurities in the drinking water in the form minerals, chemicals and dissolved substances. Its concentration is affected by temperature and salinity in the form of dissolved salts. High concentration of EC can affect its odor, taste and quality of drinking water. WHO recommends 400 μS/cm levels of EC for drinking water [31].

Total dissolved solids (TDS) are the presence of inorganic and some organic minerals or salts such as chlorides, potassium, sodium, bicarbonates, magnesium and sulfates etc. These minerals can cause change in taste and in color of water. The high values of TDS indicate that the water is highly mineralized and vice versa. High concentration of TDS may affect persons who are suffering from and heart and kidney diseases. WHO recommends 500 mg/l as a desirable limit and maximum limit of 1000 mg/l of TDS for drinking purpose [31].

The normal range of alkalinity is considered 5 to 125 mg/l for drinking purposes. However, WHO recommends maximum permissible limit of 200 mg/l of alkalinity in drinking water [31]. Total Suspended Solids or Turbidity is caused by sewage matter. The turbidity in water increases the risk pathogenic organisms as they are protected by turbidity particles and escaping them from the disinfectant effect. WHO recommends 5mg/l as a permissible limit in drinking water.

Niterate is one of the most significant diseases causing parameters of water quality. It is responsible for blue baby syndrome in infants. The main sources of nitrate in drinking water are erosion of natural deposits, nitrogen cycle, nitrogenous fertilizers and industrial waste. The WHO allows maximum permissible limit of 50 mg/l of nitrate in drinking water.

The dissolution of sulphuric acids is the main source of sulphates in water and is found in all sources of water. Other important sources of sulphates are mine drainage and oxidation of pyrite in water sources. There are no serious health effects of sulphates in water however, high concentration of sulphates can cause gastrointestinal diseases in human beings. WHO recommends 250 mg/l of sulphates for drinking water. The concentration of sulphates higher than 500 mg/l should be reported to the health authorities.

The dissolution of salts of hydrochloric acid is the main source of chlorides in water sources. Chloride is also added to water through industrial waste, sewage and sea water. Groundwater has more concentration of chlorides as compared to surface water bodies. Chloride is vital for appropriate functioning in the human body and is not injurious if ingested with suitable amounts of fresh water. WHO recommends maximum permissible limit of 250 mg/l in drinking water.

Potassium is present in both plant and animal cells and is also necessary for all living cells functions. Its deficiency can result in hypertension, irregular heartbeat asthma and kidney diseases. However, its higher intake can also cause irregular heartbeat, kidney diseases, an abnormal protein breakdown, severe infections and weakened immune system. WHO recommends 12 mg/l as a maximum possible of potassium in drinking water.

Sodium is present in natural water either in high or low concentration. It also necessary for the smooth functioning of plant and animal cells. Sodium deficiency in human body can result in low blood pressure, fatigue, dehydration, depression and mental apathy. However, it over dose can also result in hypertension, headaches, stroke, kidney damages, nausea and stomach problems. WHO maximum permissible limit of sodium is 200 mg/l [31].

### 2.2. Methodology

The Mardan city consists of fourteen Union Councils (UCs). We have selected eight UCs for our study through random sampling tecnique. We have taken sixteen samples of water from private boreholes located within the homes. These samples were collected, on 18$^{th}$ December 2022 using a stratified random sampling technique.

The Polyethylene sterilized bottles were used for the collection of water samples for physical and chemical analysis. After the collection water samples from the study area, we transported them to the Integrated Rural Support Program (IRSP) laboratory in Mardan city for physio-chemical analysis. All the instruments and equipment's were sterilized and calibrated before the analysis of each and every parameter. For the analysis of the physio-chemical parameters of drinking water quality, several instruments and specific procedures were used to measure physical parameters like pH, electrical conductivity, turbidity, alkalinity, total dissolved solids, total suspended solids and chemical parameters like concentrations of ions of potassium, chloride, sodium, nitrate and sulphates. A standardized pH meter was used to measure to pH of collected water samples. For this purpose, each water sample was poured into a clean container. Then the electrode of pH meter was inserted in the water sample until steady reading is recorded. Hardness and alkalinity of each water sample was determined through titration method using methyl orang and phenolphthalein as indicators to show end point of reactions which were related to the hardness and alkalinity levels. Electric conductivity meter, TDS meter and turbidity meter were used to measure electric conductivity, total dissolved solids and turbidity values in the collected water samples in the study area. For chemical analysis of ions (Sodium, potassium, chlorides, sulphates and nitrates) spectrometer was used. For spectrophotometric analysis, reagents specific to each ion type were added, resulted in a color change that were correlated to concentration of ions (Sodium, potassium, chlorides, sulphates and nitrates).

Each of this test was executed with strict quality control to guarantee precise results, permitting laboratory to evaluate whether these water samples meet safe drinking standards or not. Then the data was organized in tabulated form. The data was also plotted on maps using Inverse Distance Weighted interpolation techniques in ArcGIS and spatial distribution maps were prepared. The results obtained were compared with WHO standards and were shown in the form of figures for analysis and interpretation. WHO standard values for these parameters are shown in Table 1 [31].

## 3. RESULTS AND DISCUSSIONS

### 3.1. pH

The pH is among the key operational parameter of water quality. The values less than 6.5 pH increase corrosion in water pipes and household sanitation system and greater than 8 is not appropriate for active cleaning. Industrial pollution, Acid rain, and agricultural runoff can change pH level, with bad consequences for both biodiversity and freshwater systems globally. Therefore, the desirable range proposed by WHO is from 6.5 to 8.0. All the samples analyzed had pH values ranges from 6.9 to 7.5. The highest value of pH 7.5 was found in UCs Dagai, Kaskoroona, Muslim Abad and VC Gulibagh I, while lowest values of pH 6.9 were found in UCs Bughdada and Bari Cham respectively. However, all the pH values of sixteen water samples are within permissible limit proposed by WHO. The results of the present investigation are similar to a previous study by Gae *et al*. [32]. The spatial variation in the pH values of sixteen water samples in the study area are shown in Figure 2.

### 3.2. Total Alkalinity

The total alkalinity values for sixteen water samples are shown in Figure 3. This figure shows that the values of total alkalinity range from 4 to 7 ppm across all samples. The highest alkalinity values

**Table 1.** Water Quality Standards recommended by WHO [31].

| Chemical parameters | Standard (mg/l) | Physical parameters | Standard |
|---|---|---|---|
| Nitrates | 50 | pH | 6.5- 8.5 |
| Sodium | 200 | Conductivity (µS) | 400 µS/cm |
| Potassium | 12 | Total Hardness | 500 mg/l |
| Chlorides | 250 | Total Alkanality as$CaCO_3$ | 50-500 mg/l |
| Sulphates | 250 | Total Suspended Solids | 5 mg/l |
| Fluorides | 1.5 | Total Dissolved Solids (TDS) | 500-1000 mg/l |

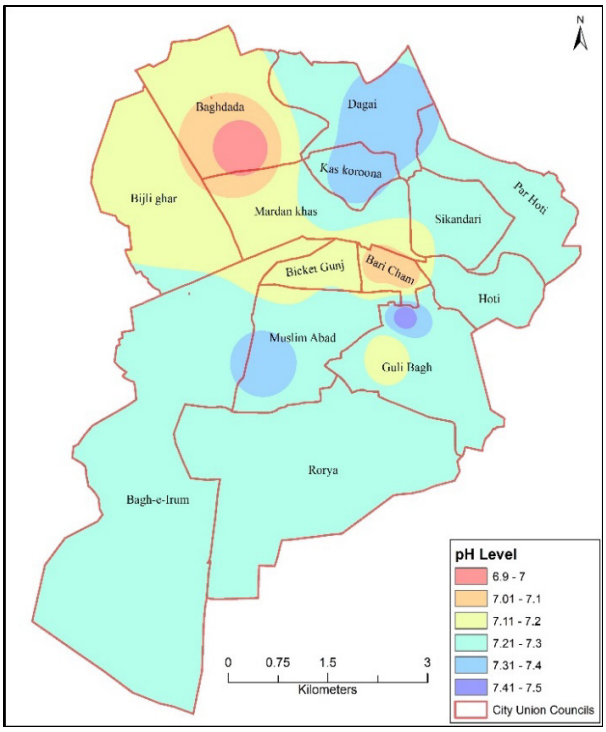


**Fig. 2.** Spatial distribution of pH.

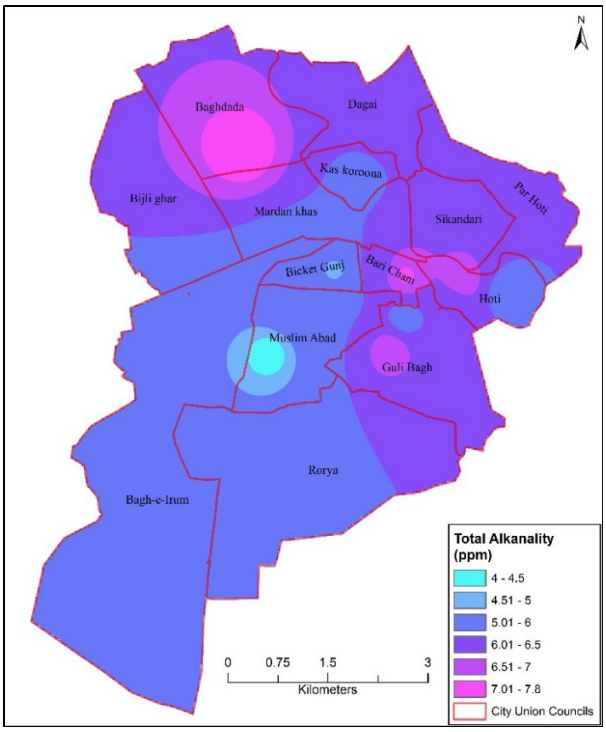


**Fig. 3.** Spatial distribution of total alkalinity (ppm) in the study area.

were found in the water samples collected from UCs Bughdada, Bari Cham and the lowest alkalinity values were found in UCs Muslim Abad and Bicket Gunj respectively. The maximum permissible level of total alkalinity determined by WHO ranges from 50-500 ppm. It shows that the total alkalinity values of sixteen samples lies within low range determined by WHO. These values of total alkalinity also show low concentration of alkaline salts in these water samples. The geology and the human activities like agriculture and mining can effect the alkalinity in specific geographical area. Alkalinity is important for maintaining stable pH levels in aquatic systems of the world [33]. Hussain *et al*. [5] conducted a research on wtaer quality in Mardan district and found similar results having low alkalinity.

### 3.3. Total Suspended Solids or Turbidity

The values of turbidity ranges from 0.24 to 0.82 NTU as shown in Figure 4. The highest turbidity values were found in VCs Muslim Abad I and II followed by UCs Bughdada, Dagai and VC Hoti III. While, the lowest turbidity values were found in the water samples collected from VCs Muslim Abad I and Hoti I, respectively. WHO recommended value for turbidity is 0.5 NTU (Table 1). It is evident from Figure 4 that five water samples collected from VCs Hoti I, Muslim Abad I and UCs Baricham, Kaskoroona and Sikandari have values below 0.5 NTU and the remaining eleven samples have values above 0.5 NTU. This shows that the majority of water samples have turbidity values above than the standards recommended by WHO. The higher turbidity values in drinking water increases the chances of gastro-intestinal diseases. The higher turbidity values are especially problematic for the people of weak immunity because the bacteria and viruses can be attached to these solid particles. This process can increase the intensity of gastro-intestinal diseases in those people [34]. Therefore, it is recommended to improve this aspect of water quality in the study area.

### 3.4. Electrical Conductivity (EC)

The natural water is not a good conductor of electricity. Its electrical conductivity increases with the increase of contamination in water. The recommended value for EC is 400 µS/cm for drinking water recommended by WHO (Table 1). However, its permissible limit is 800 µS/cm for human consumption. The electric conductivity values of all sixteen water samples ranges from 700 to 1480 µS/cm. The highest values of EC were found in the water samples collected from UCs

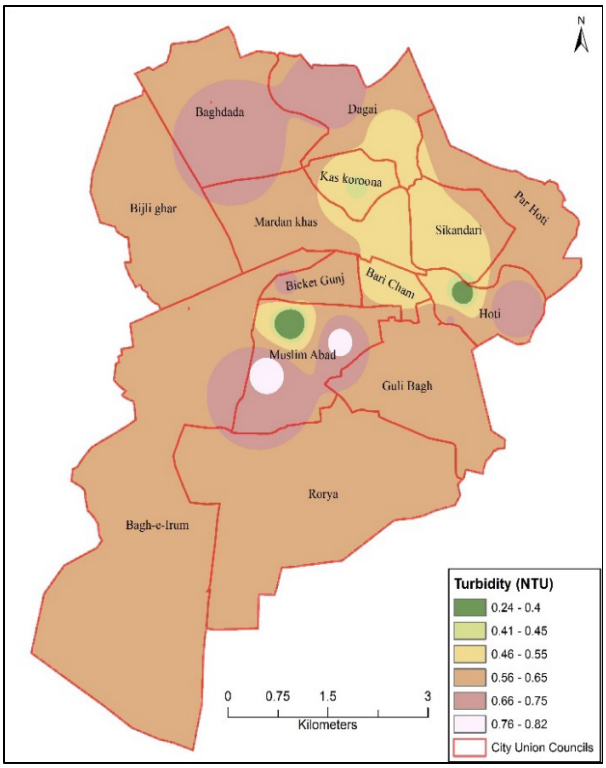


**Fig. 4.** Spatial distribution of turbidity (NTU).

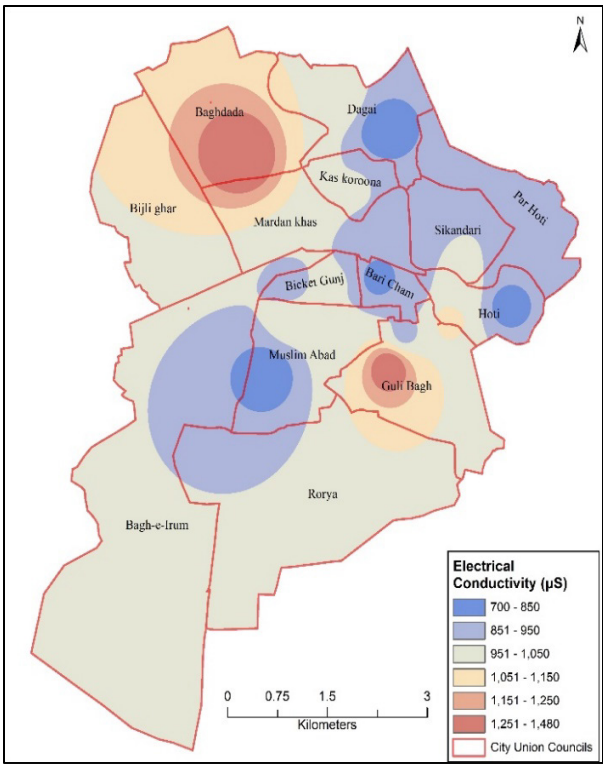


**Fig. 5.** Spatial distribution of electric conductivity.

Bughdada and Gulibagh. While the lowest values of EC were found in water samples collected from UCs Dagai, Baricham, Hoti and muslim as shown in Figure 5. It is evident from these results that the majority of water samples have higher values than permissible limit prescribed by WHO. High conductivity values in drinking water has no direct health impacts. However, indirectly it can increase alkalanity or hardness in drinking water that may effect consumer satisfiction [35].

### 3.5. Total Dissolved Solids

Total dissolved salts spatial distribution is shown in Figure 6. It is ranging from 406- 841 mg/l. The highest values of dissolved salts are found in UCs Bughdada and Gulibagh and the lowest values are found in UCs Dagai, Hoti and Muslim Abad (Figure 6). The WHO recommends 500 mg/l as a permissible limit of total dissolved solids and 1000 mg/l as a admissible limit for drinking water. This indicates that all the sixteen water samples are within the permissible and admissible limit proposed by WHO. Total dissolved solids excessive amounts are unpleasant in drinking water because of the potential physiological influence, unfriendly mineral taste and decay [36].

### 3.6. Total Hardness

The values of total hardness as a $CaCO_3$ of sixteen private bores samples are shown in figure 7. These values range from 30-400 mg/l which are within the permissible limit of 500 mg/l recommended by WHO [31]. The highest values of hardness were found in the UCs of Bugdada, Baricham and Hoti and the lowest values were found in UC Muslim Abad as shown in Figure 7. All these values of hardness are still higher than desirable value of 100 mg/l of WHO except a single sample whose value is less than 100 mg/l. However, this guideline value is not given on the health basis. Human beings can afford hardness greater than 500mg/l. However, higher values of hardness can create problems for kidney and heart patients. It is therefore, necessary to control factors contributing hardness in water. A research study by Mustafa *et al*. [37] on physio-chemical and biological analysis of drinking water quality from the residential areas of Islamabad, Pakistan have also reported similar results in which all selected water samples have less than 500 mg/l values of total hardness and were also within permissible limit of WHO.

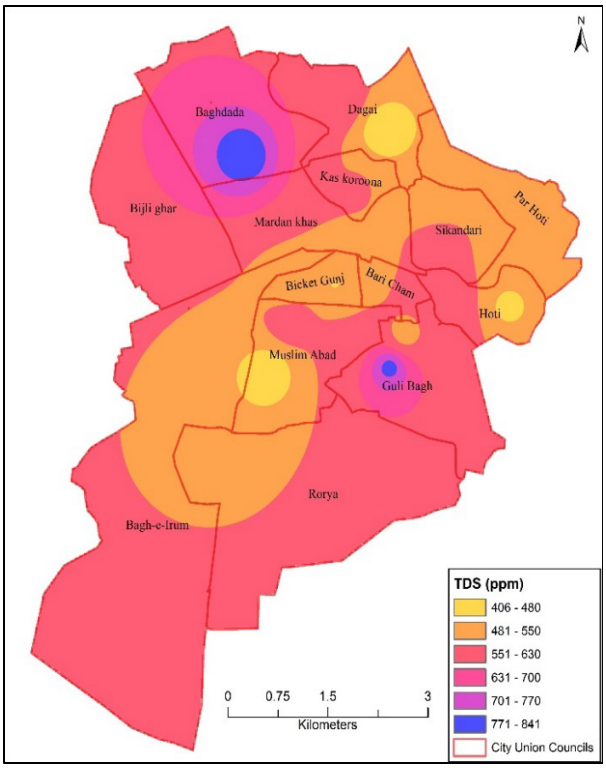


**Fig. 6.** Spatial distribution of total dissolved solids.

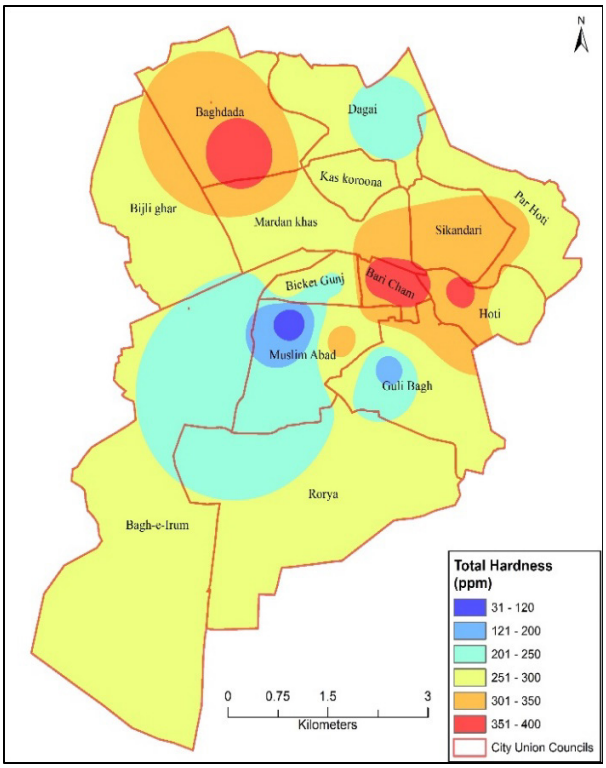


**Fig. 7.** Spatial distribution of total hardness (ppm).

### 3.7. Potassium ($K^+$)

The concentration of potassium in water samples varies from 3.7 to 14.3 ppm (Figure 8). The highest potassium concentration were found in the UCs Hoti, Bicket Gunj and Bughdada while the lowest values of potassium were found in UCs Dagai, Hoti, Bari Cham and Muslim Abad, respectively, as shown in Figure 8. WHO recommends 12 ppm as a maximum possible of potassium in drinking water. All the water samples except a single sample at UC Hoti has potassium concentration within the limit recommended by WHO. It shows that the majority of the water samples areas are safe for drinking purpose as far as potassium concentration in drinking water is concerned. Potassium is present in both plant and animal cells and is also necessary for all living cells functions. Its deficiency can result in hypertension, irregular heartbeat asthma and kidney diseases. However, its higher intake can also cause irregular heartbeat, kidney diseases, an abnormal protein breakdown, severe infections and weakened immune system [38].

### 3.8. Nitrates ($NO_3$)

The values of nitrate for sixteen water samples are in the rangeof 3.6 to 7.1 ppm. The highest concentrations of nitrate ions were found in the water samples collected from UCs Bughdada, Bicket Gunj and VC Muslim Abad II and lowest concentration of niterates in UCs Dagai, Kaskoroona, Hoti and VC Muslim Abad I as shown in Figure 9. The minimum value of nitrate is 40 ppm and the maximum value is 70 ppm which are within the permissible level as recommended by WHO. Similar low concentration of niterates were reported by another research study conducted on drinking water quality in district Mardan [25].

### 3.9. Sulphates

The concentration of sulphates in water samples is shown in Figure 10 indicating a range from 35-511ppm while the highest permissible limit of sulphates recommended by WHO is 250 ppm for drinking water. The highest concentration of sulphates was found in the water sample collected from VC Gulibagh I and the lowest concentration of sulphates ions were found in UCs Dagai, Hoti, Muslim Abad and Bicket Gunj respectively. The Figure 10 shows that all water samples have sulphates concentration within permissible limit except sample collected from VC Gulibagh I whose

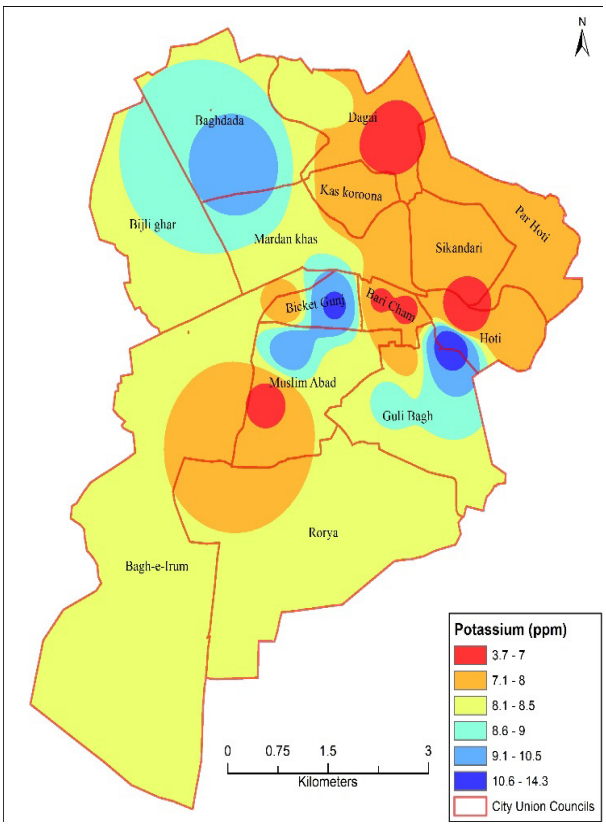


**Fig. 8.** Spatial distribution of potassium (ppm).

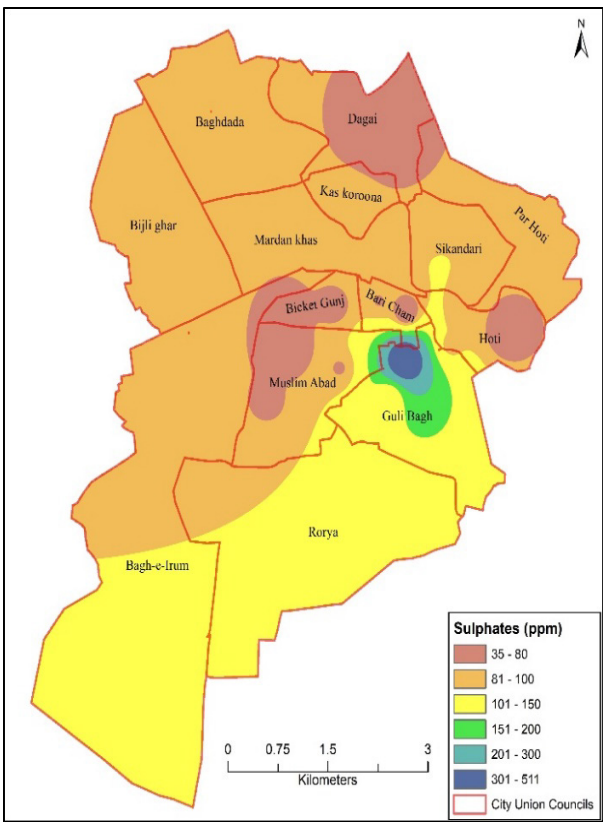


**Fig. 10.** Spatial distribution of sulphates (ppm).

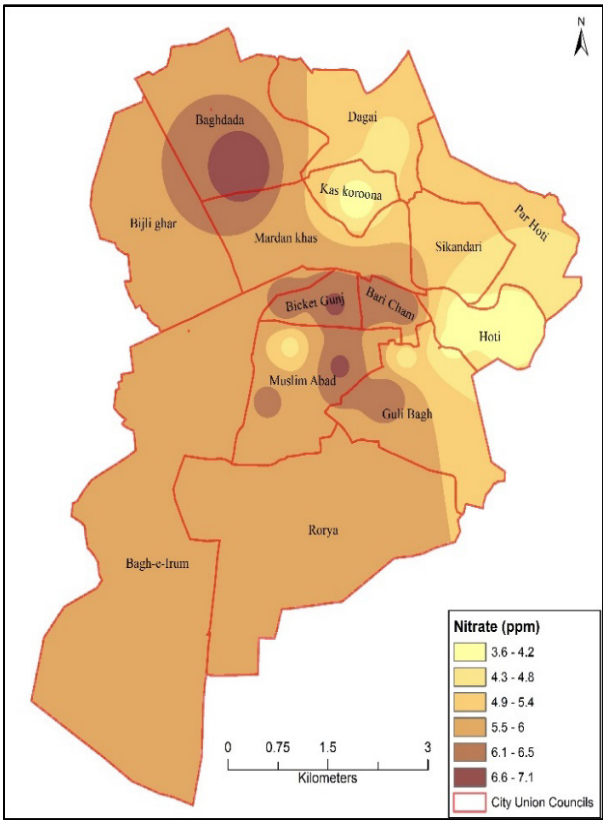


**Fig. 9.** Spatial distribution of nitrates (ppm).

concentration is far greater than recommended limit of WHO. High concentration of sulphates in drinking water can result in gastro-intestinal irritation and catharsis. Its higher concentration can also affect the taste of drinking water. Leaching of sulphate fertilizers to the water table is one of the major causes of high concentration sulphates in drinking water. Sulphates are present in almost all natural water due high solubility nature of water. A reseach on the physio-chemical analysis of drinking water was carried out in district Dir, Khyber Pakhtunkhwa, Pakistan by Shakirullah *et al*. [39]. The results of that study also revealed high concntration of sulphates in two drinking water samples and the remaining water samples have the sulphates ions concentration within the permissible limit of WHO.

### 3.10. Chlorides

The Figure 11 shows the concentration of chlorides in water samples which ranges from 25-170 mg/l and are found within the range of WHO limits as the maximum recommended chlorides limit is 250 ppm for portable drinking water (Table 1). The highest

value of chloride ions were found in the water samples collected from UC Bughdada, Gulibagh and VC Muslim Abad I and the lowest values of chloride were reported in UC Hoti, Baricham and VC Gulibagh I respectively. It is evident from the figure 11 shows that all sixteen samples of water has chlorides concentration within permissible limit of WHO. These results are compareable to a study conducted on physio-chemical analysis of drinking in district Dir, where it was found thatchlorides ions concentration were within permissible limits of WHO [39]. It can be concluded that these water samples are safe for human drinking purpose as far as chlorides concentration is concerned.

### 3.11. Sodium ($Na^+$)

Sodium is present in natural water either in high or low concentration. It also necessary for the smooth functioning of plant and animal cells. Sodium deficiency in human body can result in low blood pressure, fatigue, dehydration, depression and mental apathy. However, it over dose can also result in hypertension, headaches, stroke, kidney damages, nausea and stomach problems. The values sodium in sixteen water samples is shown in Figure 12. The figure 12 shows that the values of sodium in these water samples range 60-170 ppm. The highest values of sodium ions were found in the water samples collected from UCs Bughdada and Gulibagh and the lowest values of sodium were found in UCs Hoti, Bari Cham and Muslim Abad as evident from figure 12. WHO maximum permissible limit of sodium is 200 ppm. It shows that the sodium concentration in all the water samples is within the permissible limit of WHO and is safe for drinking purposes. A study conducted by Arega [40] on sodium and potassium analysis of drinking water quality assessment and its health effects in Ethiopia found that majority of water samples have less than 200 mg/l of sodium concentration.

## 4. CONCLUSIONS

The physical parameters (pH, alkalinity, total hardness, and total dissolved solids) and chemical parameters (sodium, chloride and nitrate) in all sampled areas fall within the WHO recommended limits for drinking water quality. However, this study identified abnormalities in some specific

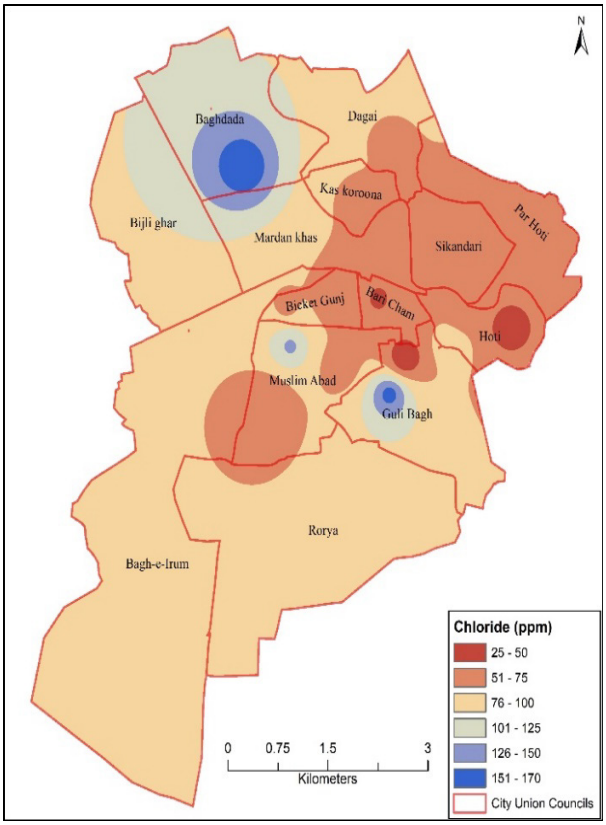


**Fig. 11.** Spatial distribution of chloride (ppm).

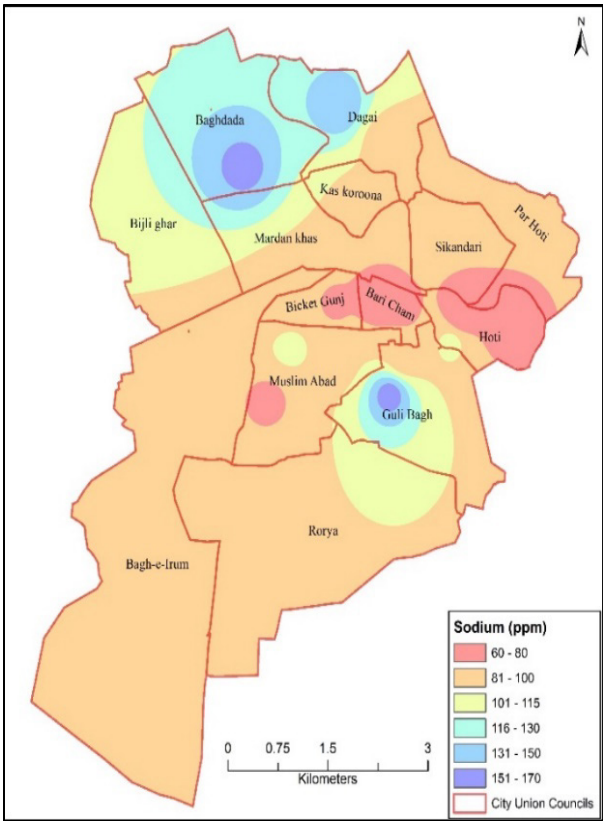


**Fig. 12.** Spatial distribution of sodium (ppm).

locations regarding physical parameters (turbidity 0.82 NTU and electrical conductivity 1480 µS/cm) and chemical parameters (potassium 13.7 mg/l and sulphates 512 mg/l). These values exceed the WHO guideline limits for drinking water. Therefore, it can be concluded that the quality of groundwater at majority places in the study are safe for drinking purpose. However, it is recommended that the concerned department should implement effective measures to ensure the provision of safe drinking water in accordance with WHO standards for all residents.

## 5. ACKNOWLEDGEMENTS

The authors acknowledge the support of the Water and Sanitation Services Company, Mardan and Public Health Engineering Department, Mardan throughout this research study.

## 6. CONFLICT OF INTEREST

The authors declared that they have no competing interests.

## 7. REFERENCES

1. A.A. Khan, K. Khan, S. Arshad, and W. Waqar. Drinking suitability assessment of treated and untreated ground water used in Bahawalpur City of Pakistan. *Journal of Geography and Social Sciences* 2(1): 63-77 (2020).
2. A.Y. Hoekstra and A.K. Chapagain. Water footprints of nations: Water use by people as a function of their consumption pattern. In: Integrated Assessment of Water Resources and Global Change. E. Craswell, M. Bonnell, D. Bossio, S. Demuth, and Van De Giesen (Eds.). *Springer, Dordrecht* pp. 35-48 (2007).
3. S.G. Gebremichael, E. Yismaw, and B.D. Tsegaw. Assessing the socio-demographic, economic and water source types that influences households drinking water supply in Debre Tabor Town, north-west Ethiopia. *MOJ Public Health* 9(3): 63-74 (2020).
4. W.J. Cosgrove and D.P. Loucks. Water management: current and future challenges and research directions. *Water Resources Research* 51(6): 4823-4839 (2015).
5. J. Hussain, S. Jehangir, W. Hussain, R. Ali, L.J. Sousa, W.A. Lopes, and I.A. Nascimento. Evaluation of the quality of drinking water of Mardan District, KPK, Pakistan. *American-Eurasian Journal of Agricultural & Environmental Sciences* 12(8): 1047-1051 (2012).
6. T.A. Bhat. An analysis of demand and supply of water in India. *Journal of Environment and Earth Science* 4(11): 67-72 (2014).
7. M. Mohsin, S. Safdar, F. Asghar, and F. Jamal. Assessment of drinking water quality and its impact on residents health in Bahawalpur City. *International Journal of Humanities and Social Science* 3(15): 114-128 (2013).
8. M. Nilsson, A. Sie, K. Muindi, A. Bunker, V. Ingole, and K.L. Ebi. Weather, climate, and climate change research to protect human health in Sub-Saharan Africa and South Asia. *Global Health Action* 14(1): 1984014 (2021).
9. W.J. Cosgrove and D.P. Loucks. Water management: current and future challenges and research directions. *Water Resources Research* 51(6): 4823-4839 (2015).
10. O. Bozorg-Haddad, M. Delpasand, and H.A. Loáiciga. Water quality, hygiene, and health. In: Economical, Political, and Social Issues in Water Resources. O. Bozorg-Haddad (Ed.). *Elsevier, Amsterdam, Netherlands* pp. 217-257 (2021).
11. M.O. Dinka. Safe Drinking Water: Concepts, Benefits, Principles and Standards. In: Water Challenges of an Urbanizing World. G. Matjaz (Ed.). *IntechOpen, Croatia* pp. 163-182 (2018).
12. F. Edition. Guidelines for Drinking-Water Quality. *WHO Chronicle* 38(4): 104-108 (2011).
13. S. Haydar, M. Arshad, and J.A. Aziz. Evaluation of drinking water quality in urban areas of Pakistan: A case study of southern Lahore. *Pakistan Journal of Engineering and Applied Sciences* 5: 16-23 (2009).
14. A. Jabeen, X. Huang, and M. Aamir. The challenges of water pollution, threat to public health, flaws of water laws and policies in Pakistan. *Journal of Water Resource and Protection* 7(17): 1516 (2015).
15. E.J. Lee and K.J. Schwab. Deficiencies in drinking water distribution systems in developing countries. *Journal of Water and Health* 3(2): 109-127 (2005).
16. M.T. Sohail, M. Ehsan, S. Riaz, E.B. Elkaeed, N.S. Awwad, and H.A. Ibrahium. Investigating the drinking water quality and associated health risks in metropolis area of Pakistan. *Frontiers in Materials* 9: 864254 (2022).
17. M. Saeed, F.A. Al-Saeed, M. Altaf, S.D. Alahmari, T.H. Bokhari, M.A. Bajaber, and A.E. Ahmed. Synthesis of a visible-light-driven $Ag_2O$–$Co_3O_4$ Z-Scheme photocatalyst for enhanced photodegradation of a reactive yellow dye. *New*

*Journal of Chemistry* 46: 23297-23304 (2022).
18. M.K. Daud, M. Nafees, S. Ali, M. Rizwan, R.A. Bajwa, M.B. Shakoor, and S.J. Zhu. Drinking water quality status and contamination in Pakistan. *BioMed Research International* 2017(1): 7908183 (2017).
19. S. Javed, A. Ali, and S. Ullah. Spatial assessment of water quality parameters in Jhelum City (Pakistan). *Environmental Monitoring and Assessment* 189: 119 (2017).
20. M. Pal, Y. Ayele, M. Hadush, S. Panigrahi, and V.J. Jadhav. Public health hazards due to unsafe drinking water. *Air Water Borne Dis*eases 7(1): 2 (2018).
21. D.P. Loucks and E. van Beek (Eds.). Urban Water Systems. Chapter 12. In: Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications. *Springer, Geneva, Switzerland* pp. 527 (2017).
22. M. Fazal-ur-Rehman. Polluted water borne diseases: Symptoms, causes, treatment and prevention. *Journal of Medicinal and Chemical Sciences* 2(1): 21-6 (2019).
23. M.A. Montgomery and M. Elimelech. Water and Sanitation in developing countries: Including health in the equation. *Environmental Science & Technology* 41(1): 17-24 (2007).
24. Z. Lu, J.S. Bandara, and S.R. Paramati. Impact of sanitation, safe drinking water and health expenditure on infant mortality rate in developing economies. *Australian Economic Papers* 59(1): 13-33 (2020).
25. W. Ali, M. Nafees, S.A. Turab, M.Y. Khan, and K. Rehman. drinking water quality assessment using water quality index and geostatistical techniques, Mardan District, Khyber Pakhtunkhwa, Pakistan. *Journal of Himalayan Earth Science* 52(1): 65-85 (2019).
26. M. Mohsin, S. Safdar, F. Asghar, and F. Jamal. Assessment of drinking water quality and its impact on residents health in Bahawalpur city. *International Journal of Humanities and Social Science* 3(15): 114-128 (2013).
27. S. Jabeen, U.R. Saha, C.F.A. van Wesenbeeck, and K. Mushtaq. An overview of diarrhea among infants and under-five in Punjab-Pakistan. *Journal of Pediatric Nursing* 71: 28-37 (2023).
28. M. Povitkina and K. Bolkvadze. Fresh pipes with dirty water: How quality of government shapes the provision of public goods in democracies. *European Journal of Political Research* 58(4): 1191-1212 (2019).
29. U. Zafar, M. Mobeen, G. Rahman, M. Ahmed, and M.J. Iqbal. Assessment and analysis of groundwater reservoir suitability for drinking purpose using GIS based multi criteria decision approach, a case study of Faisalabad city. *Journal of Biodiversity and Environmental Sciences* 11(5): 2222-3045 (2017).
30. Z. Iqbal, M. Imran, Natasha, G. Rahman, M. Miandad, M. Shahid, and B. Murtaza. Spatial distribution, health risk assessment, and public perception of groundwater in Bahawalnagar Punjab, Pakistan: a multivariate analysis. *Environmental Geochemistry and Health* 45(2): 381-391 (2023).
31. WHO. Guidelines for Drinking-Water Quality: Fourth ediction incorporating the first and second addenda. *World Health Organization*, Geneva, Switzerland (2022). https://www.who.int/publications/i/item/9789240045064.
32. J. Gao, F. Proulx, and M.J. Rodriguez. Synergistic effects of quenching agents and pH on the stability of regulated and unregulated disinfection by-products for drinking water quality monitoring. *Environmental Monitoring and Assessment* 192: 143 (2020).
33. S.T. Summerfelt, A. Zühlke, J. Kolarevic, B.K. M. Reiten, R. Selset, X. Gutierrez, and B.F. Terjesen. Effects of alkalinity on ammonia removal, carbon dioxide stripping, and system pH in semi-commercial scale water recirculating aquaculture systems operated with moving bed bioreactors. *Aquacultural Engineering* 65: 46-54 (2015).
34. V. Kothari, S. Vij, S.K. Sharma, and N. Gupta. Correlation of various water quality parameters and water quality index of Districts of Uttarakhand. *Environmental and Sustainability Indicators* 9: 100093 (2021).
35. P.K. Mbaka, J.K. Mwangi, and C.K. Kiptum. Assessment of water quality in selected shallow wells of Keiyo highlands, Kenya. *African Journal of Science, Technology, Innovation and Development* 9(3): 329-338 (2017).
36. M. Gopalkrushna. Assessment of physico-chemical status of ground water samples in Akot City. *Research Journal of Chemical Sciences* 1(4): 117-124 (2011).
37. M.F. Mustafa, A. Afreen, Y. Abbas, W. Athar, Z.U. Rehman, Q. Khan, S.W. Rehaman, and A. Ali. A study on physio-chemical and biological analysis of drinking water quality from the residential areas of Islamabad, Pakistan. *Journal of Biodiversity and Environmental Sciences* 8(4): 109-125 (2016).
38. T.W. Behailu, T.S. Badessa, and B.A. Tewodros. Analysis of physical and chemical parameters in ground water consumed within Konso area, south western Ethiopia. *African Journal of Environmental*

*Science and Technology* 12(3): 106-114 (2018).
39. M. Shakirullah, I. Ahmad, K. Mehmood, A. Khan, H. Rehman, S. Alam, and A. Shah. Physio-chemical study of drinking water from Dir Districts. *Journal-Chemical Society of Pakistan* 27(4): 374-387 (2005).
40. T. Arega. Sodium and Potassium analysis of drinking water quality assessment and its health effects in Ethiopia: A Retrospective Study. *Journal of Oral Health & Dentistry* 4(1): 261-266 (2020).