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Research Article

Assessment of water quality in Kirkuk city: Using geographic information systems and multi-linear regression analysis

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Abstract

Climate change, pollution, and the degradation of water quality are making it harder to provide safe drinking water globally. For ensuring water safety, it is important to analyze its chemical and physical properties. Assessing the suitability of tap water for consumption according to World Health Organization (WHO) standards and Iraqi standards using GIS techniques and multi-linear regression analysis in Kirkuk City, Iraq, the study examines fourteen key water parameters across multiple city locations and conducted over 2020 and 2022, including pH, turbidity, conductivity, alkalinity, hardness, various ions, dissolved solids, temperature, and chlorine. GIS mapping was used to visualize the spatial distribution of these parameters, while multi-linear regression analysis was employed to identify statistical relationships between turbidity and other water quality indicators. The pH level of tap water in Kirkuk has been shown to be slightly to moderately alkaline, and turbidity exceeded acceptable limits in some locations and decreased slightly in 2022 from that in 2020. It was observed that total dissolved solids decreased during the period of this study and were under permissible standard limits. Electrical conductivity and total hardness remained stable and acceptable. The concentrations of most of the ions, including calcium, chloride, magnesium, sulfate, sodium, and chlorine, were lower than those of WHO and Iraqi standards. Potassium levels varied, meeting standards in some areas in 2020 but falling below WHO recommendations everywhere by 2022. The regression analysis revealed that turbidity was significantly influenced by total dissolved solids, electrical conductivity, and total hardness, with a strong correlation (R^2 = 0.939), indicating that changes in water quality parameters are interdependent. However, the R^2 value for single linear regression suggests potential variability, emphasizing the need for further data refinement and additional explanatory variables. The study highlights the need for ongoing monitoring and improvement of Kirkuk's water treatment processes, demonstrating the value of GIS-based spatial analysis combined with statistical modeling for identifying areas with compromised water quality and implementing targeted interventions to address these issues.

1. Introduction

Water is one of the most vital natural resources and a crucial national asset, playing a key role in the environment [1]. Water sources can include rivers, reservoirs, glaciers, precipitation, and groundwater, among others. Water services are often indispensable across various economic sectors such as irrigation, livestock development, forestry, agriculture, hydropower generation,

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fisheries, and other innovative activities, along with the essential need for drinking water [2]. Surface water is the primary source of water for human consumption, including drinking, agriculture, manufacturing, hydropower generation, and other economic sectors. One of the most pressing environmental issues globally is the decline in water quality due to climate change and rising pollution levels [3]. Water quality assessment involves examining physical, chemical, and biological parameters of specific environments [4]. Excessive levels of certain variables can harm human health [5]. Many underestimates water's importance in societal progress, and their actions often diminish water quality. Addressing this requires lifestyle changes and adherence to drainage regulations at various governmental levels [6]. Water quality evaluation has long involved analyzing physicochemical and biological parameters and examining spatial and temporal variations. Remote sensing, which collects data from a distance, has enabled various technical projects [7, 8]. Geographic Information Systems (GIS) have multiple applications in water management [9]. GIS incorporates mathematical, spatial, and monitoring components, allowing for geographical trend analysis through technological integration [10]. GIS has been used to study aquifer situations [11] and water harvesting criteria [12]. Studies using GIS have evaluated water quality in various locations. Research on the Tigris River showed certain pollutants exceeding permissible limits at specific stations [13,14].

Another study revealed high turbidity levels [15]. The Lower Zab River showed high concentrations of various minerals and chemicals due to factors like weathering, soil structure, runoff, and agricultural activities [16,17]. The Lesser Zab River's water was found to be moderately contaminated and moderately hard to hard, requiring treatment before consumption but suitable for agriculture and aquatic life [18]. A study of the Kirkuk irrigation project revealed several parameters exceeding WHO and Iraqi standards [19]. Research on the Tigris River showed seasonal variations in water quality parameters, with most within permissible limits for Iraqi drinking water regulations [20]. Water quality has decreased due to factors like population growth, industrialization, and urbanization. This study aims to assess tap water quality in the city by comparing samples from different settlements to Iraqi and WHO standards, in addition, the study has attempted to utilize linear regression analysis to predict the water turbidity value in terms of various key water parameters. GIS was used to visualize the spatial distribution of physicochemical parameters, highlighting high-risk areas. These spatial patterns informed the selection of variables used in the MLR model, which then quantified the influence of each parameter on turbidity.

2. Methodology

2.1. Study Area

This study was conducted in downtown Kirkuk, a province in northern Iraq. (Fig. 1) shows the sample locations and outlines the research methodology, including site selection, data collection, GIS analysis, regression modelling, and comparison with WHO and Iraqi water quality standards. As of 2021, Kirkuk was the tenth most densely populated governorate in Iraq, with a population of approximately 1.73 million [21,22].

The water quality parameters provided by the Directorate of Water in Kirkuk cover the years 2020 and 2022. Samples were collected from 15 sampling sites within Kirkuk city, as detailed in Tables 1 and 2, along with their corresponding coordinates. The evaluation of potable water quality relies on analyzing key physicochemical parameters that influence water safety and suitability for human consumption. pH determines acidity or alkalinity, affecting metal solubility and microbial growth, while turbidity indicates suspended particles that may harbor contaminants. Electrical conductivity (E.C.) and total dissolved solids (TDS) reflect the concentration of dissolved ions, impacting taste and potential contamination. Alkalinity and total hardness affect buffering capacity and scaling potential due to the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}). Chloride (Cl^{-}) and sodium (Na^{+}), frequently originating from industrial effluent or saline intrusion, impact palatability and corrosivity. Both sulphate (SO_4^{2-}) and potassium (K^{+}) are metabolically important, but their concentrations must be tightly regulated to prevent detrimental health effects. Chlorine (Cl^{-}) is a disinfectant used to ensure microbiological safety, while high levels can lead to undesired taste. Finally, water temperature influences solubility, reaction kinetics, and microbial activity.

Monitoring these parameters is critical for assessing water quality trends, identifying pollution sources, and ensuring compliance with WHO and Iraqi standards to safeguard public health and water resource sustainability.

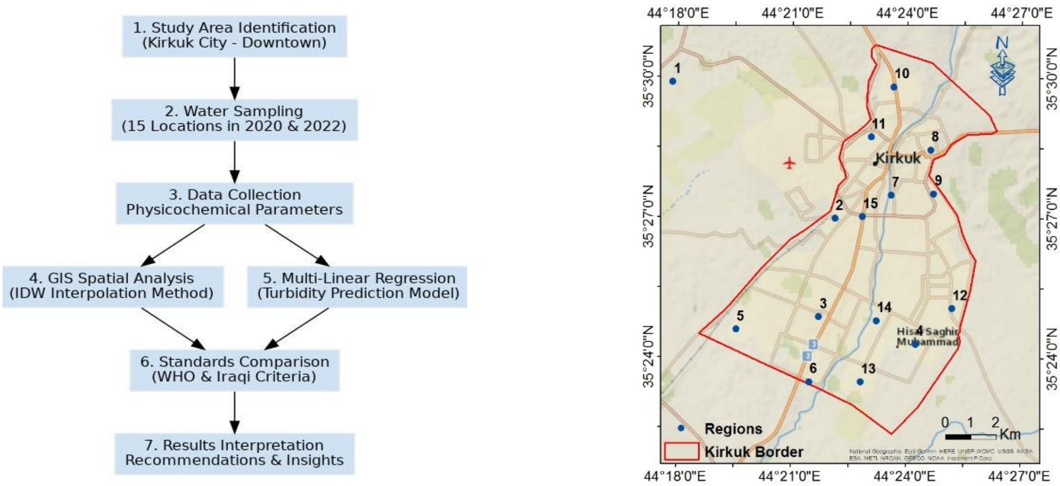


Fig. 1. Flowchart of the methodology and site locations of the water samples

2.2 Spatial Map Plotted by Using GIS

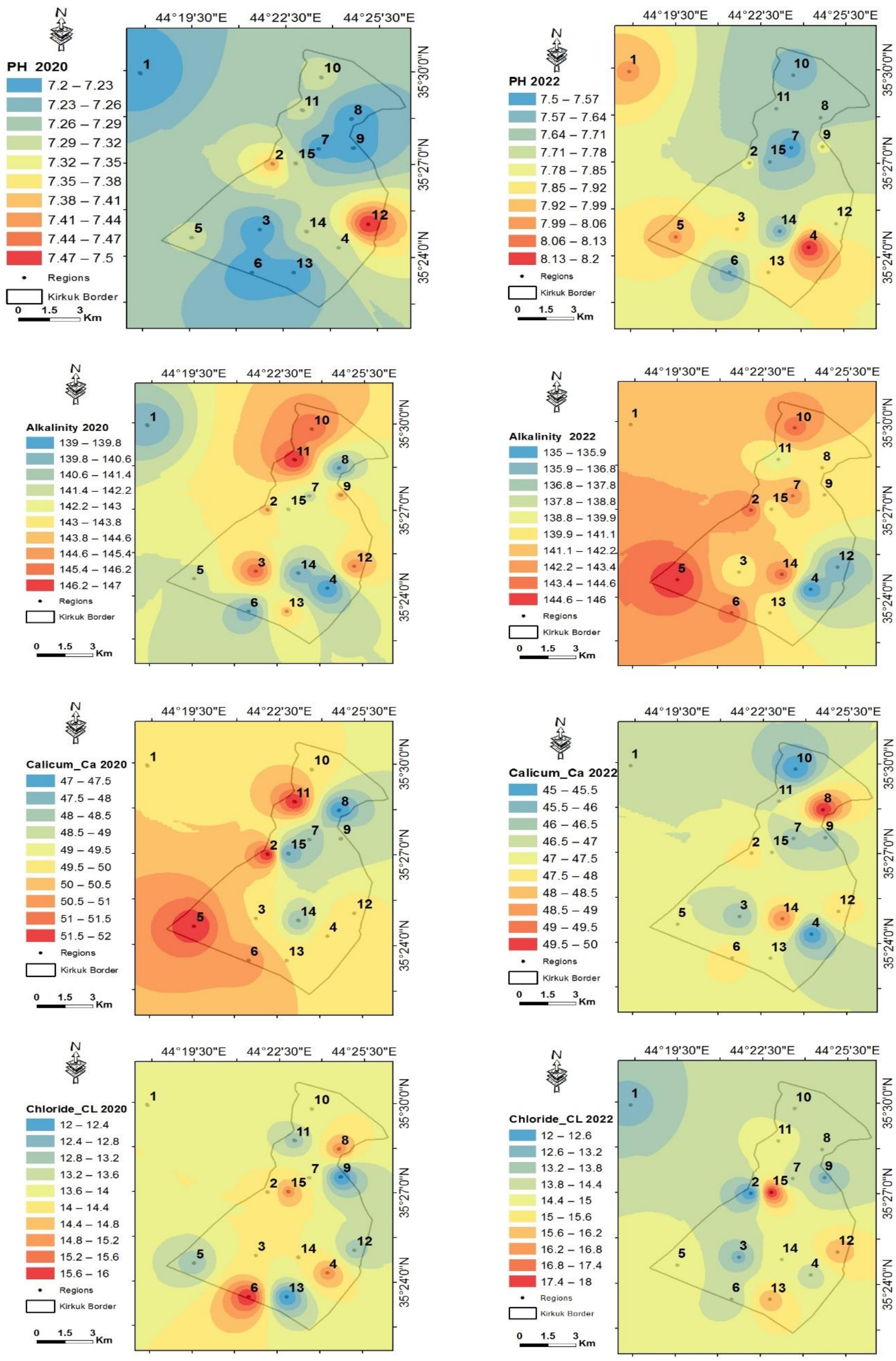
Water quality parameters were generated and evaluated in this study using GIS-based spatial analysis, and the outcomes were compared to WHO and Iraqi criteria. As indicated in Table 1, information was gathered from fifteen locations in Kirkuk City. Although locations 1 and 2 are representative of the same region, two distinct samples, one taken prior to and one following water treatment, were collected from this site. The spatial distribution maps were generated using the inverse distance weighting (IDW) technique. Eq (1) representing this technique is used in GIS [23]:

$$\hat{z}(s_0) = \frac{\sum_{i=1}^{n} z(s_i) d_{i0}^{-2}}{\sum_{i=1}^{n} d_{i0}^{-2}} \tag{1}$$

where $\hat{z}(s_0)$ is the predicted value, $z(s_i)$ is the measurements, d_{i0} is the distance that separate s_0 and s_i. IDW is a common interpolation method used for prediction, where GIS spatial interpolation efficiently estimates unknown areas from various points within calculated data [24, 25]. Principally, GIS provides spatial intelligence and data management capabilities, whereas multi-linear regression delivers the statistical structure for modelling, and the combination of both enables robust spatial analysis and well-informed decision-making in diverse areas such as environmental monitoring, urban planning, and public health.

3. Outcomes and Resultant

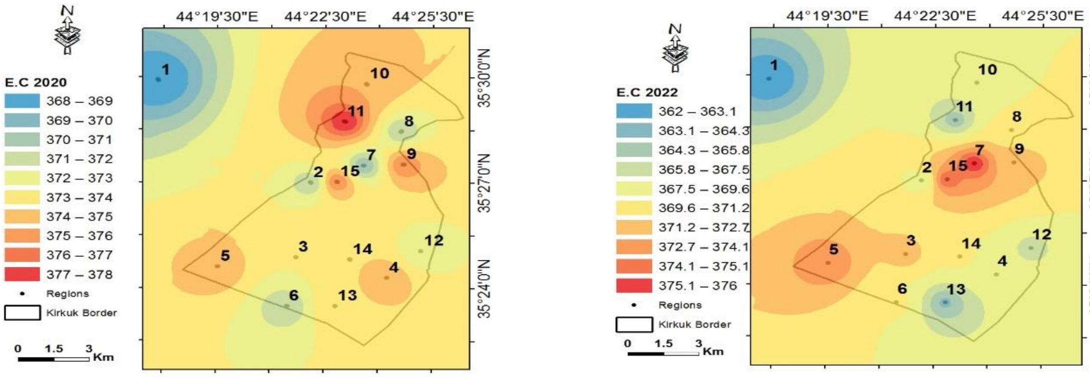
The pH levels observed in 2020 ranged from 7.2 to 7.499, while in 2022, they ranged from 7.5 to 8.199. These results indicate that the pH values of the water were largely neutral to slightly alkaline in nature. This consistency suggests that the water quality remained stable over the two-year period, with pH values falling within the acceptable limits set by both WHO and Iraqi standards. The findings confirm that the water in the study area maintained a pH level that is safe for consumption and meets international and national guidelines, as shown in (Fig. 2) (a, b), which illustrates the spatial distribution of pH levels across different areas within the Kirkuk settlement. (Fig. 2) (a) also presents the alkalinity concentration in Kirkuk settlements for 2020, with total alkalinity values ranging from 139.001 to 147 mg/l. Meanwhile, (Fig. 2) (b) depicts the 2022 alkalinity levels, which vary from 135.001 to 145.999 mg/l. This decrease in 2022 indicates that the alkalinity levels fell below Iraqi standards but remained above WHO standards. Calcium (Ca^{+2}) concentrations in 2020 ranged from 47.0008 to 52 mg/l, while in 2022, they varied between 45.0004 and 49.998 mg/l. As depicted in (Fig. 2), the calcium levels for both years were below the limits set by WHO and Iraqi standards.



(a) corresponds to the year 2020 (b) corresponds to the year 2022

Fig. 2. pH concentration and alkalinity concentrations maps

Chloride (Cl^{-1}) concentrations in 2020 ranged from 12.0001 to 15.9996.67 mg/l, while in 2022, they varied between 12.001 and 17.9955.18 mg/l. As shown in (Fig. 2), the chloride levels in both years were below the standards established by both WHO and Iraqi standards. Electrical conductivity (EC) measures the ability of water to conduct an electrical current, expressed in units of µS/cm or Mohs. In 2020, EC levels ranged from 369 to 378 µS/cm, while in 2022, they decreased to between 356 and 375.998 µS/cm. The data indicate a reduction in electrical conductivity in 2022 compared to 2020. Additionally, the EC values for both years were below the standards set by WHO and Iraq, as illustrated in (Fig. 3).



(a) corresponds to the year 2020 (b) corresponds to the year 2022

Fig. 3. Calcium and chloride concentrations and variation of E.C maps

The magnesium (Mg^{+2}) levels peaked at 13.0004 - 17.5994 mg/l in 2020, dropping to 12.0004 - 16.9999 mg/l by 2022. This decline is noticeable, yet the concentrations remain below the limits set by both WHO and Iraqi standards, as illustrated in (Fig. 4). Sulfate (SO_4^{-2}) levels in 2020 fell between 34.0005 and 39.9999 mg/l, while in 2022 they ranged from 30.0007 to 37.9995 mg/l. This indicates a reduction in sulphate concentrations over the two-year period. Notably, for both 2020 and 2022, the values remained under the limits prescribed by Iraqi and WHO standards, as depicted in (Fig. 4).

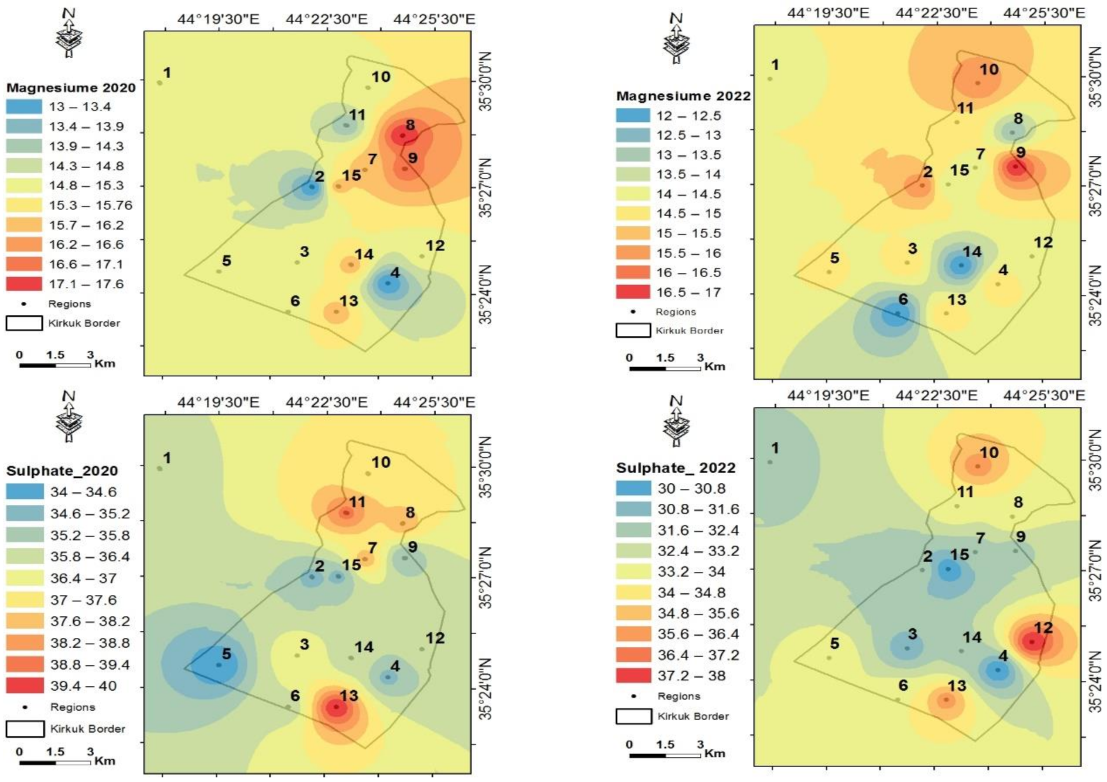
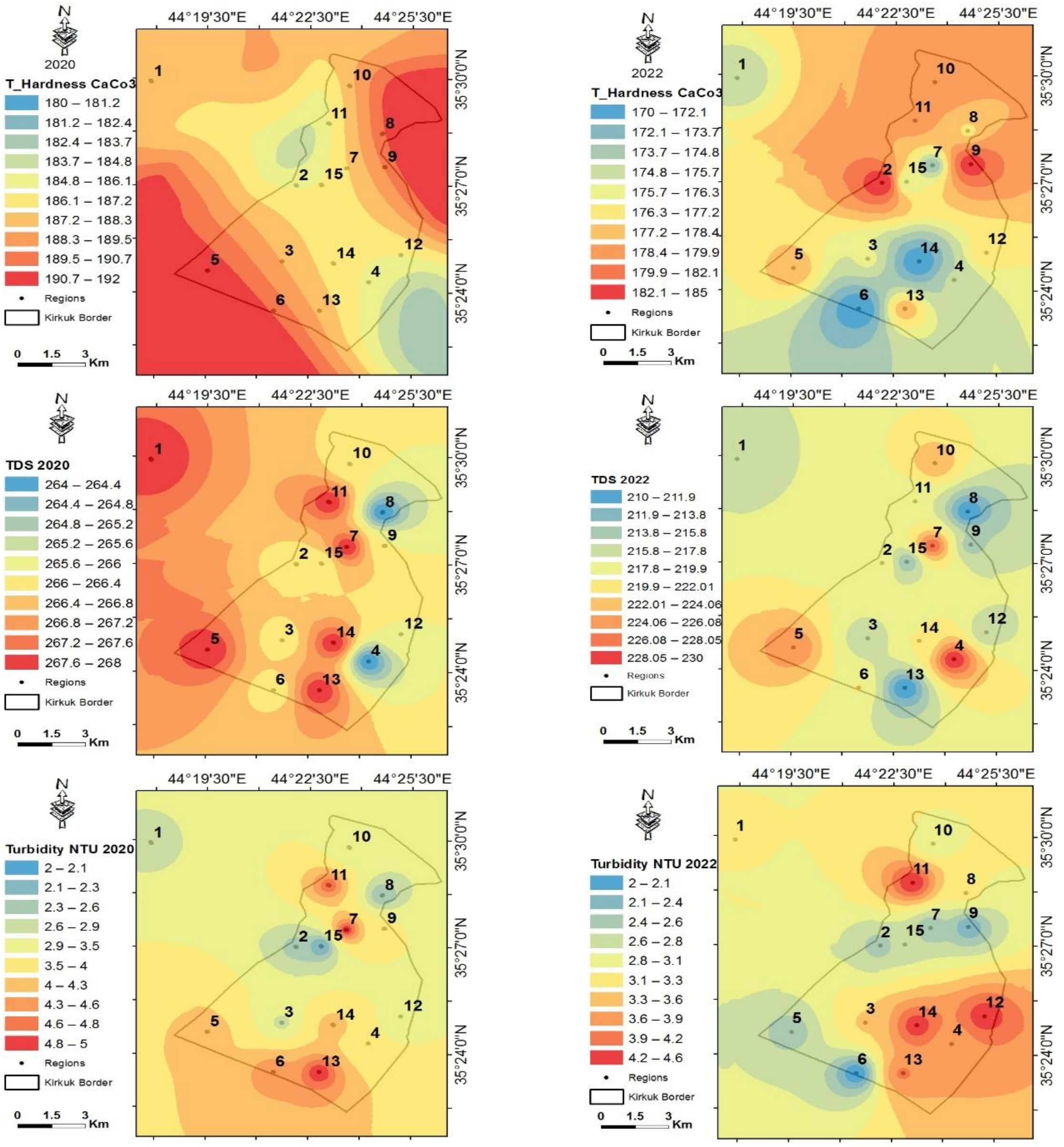


Fig. 4. Magnesium and sulphate concentrations maps

Total hardness (T.H.) measures the accumulation of calcium and magnesium in water, is typically expressed in milligrams per liter. In 2020, total hardness values ranged from 180.001 to 192 mg/l, while in 2022, they spanned from 170.001 to 184.998 mg/l. (Fig. 5) illustrates the distribution of total hardness across Kirkuk's settlement water supplies for both years. Notably, all recorded values were within the acceptable limits set by both Iraqi and WHO standards. Total dissolved solids (TDS) play a crucial role in determining tap water taste. The mineral content of the source water significantly impacts the mineral composition of drinking water. TDS levels ranged from 264 to 268 mg/l in 2020, decreasing to between 210 and 229.998 mg/l in 2022.

(Fig. 5) illustrates the TDS distribution in Kirkuk's water supply for both 2020 and 2022. Notably, all recorded values remained under the criteria by both WHO and Iraqi standards. Turbidity (Tur) levels in 2020 ranged from 2.00134 to 14.2 NTU, while in 2022 they spanned from 2.00023 to 21.0749 NTU. As shown in (Fig. 5), turbidity concentrations varied across different areas during both years. Some locations met the WHO and Iraqi standards, while others fell either below or above these guidelines. (Fig. 5) provides a visual representation of the turbidity concentrations observed in 2020 and 2022. Chlorine (Cl_2) concentrations remained consistent between 2020 and 2022, with values ranging from 1.50003 to 15.9911 mg/l in both years. These levels were below the standards set by both WHO and Iraqi guidelines. (Fig. 5) illustrates this consistency in chlorine concentrations across the two-year period.



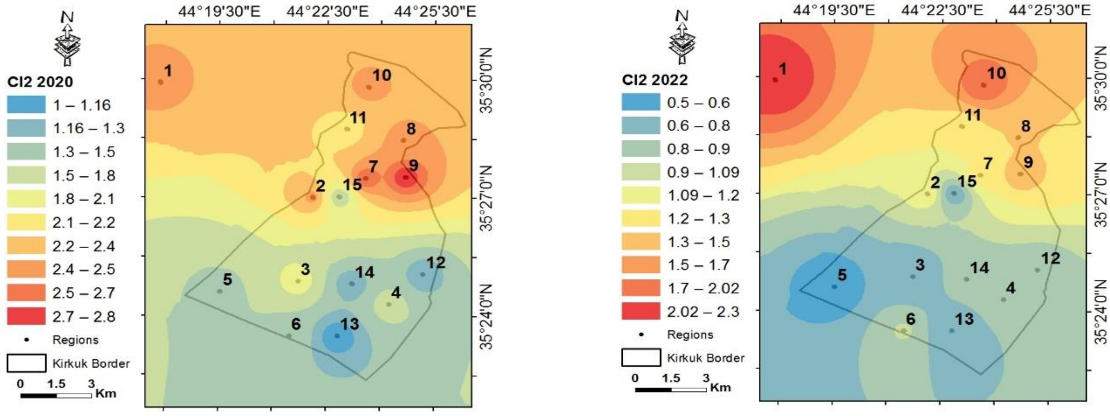
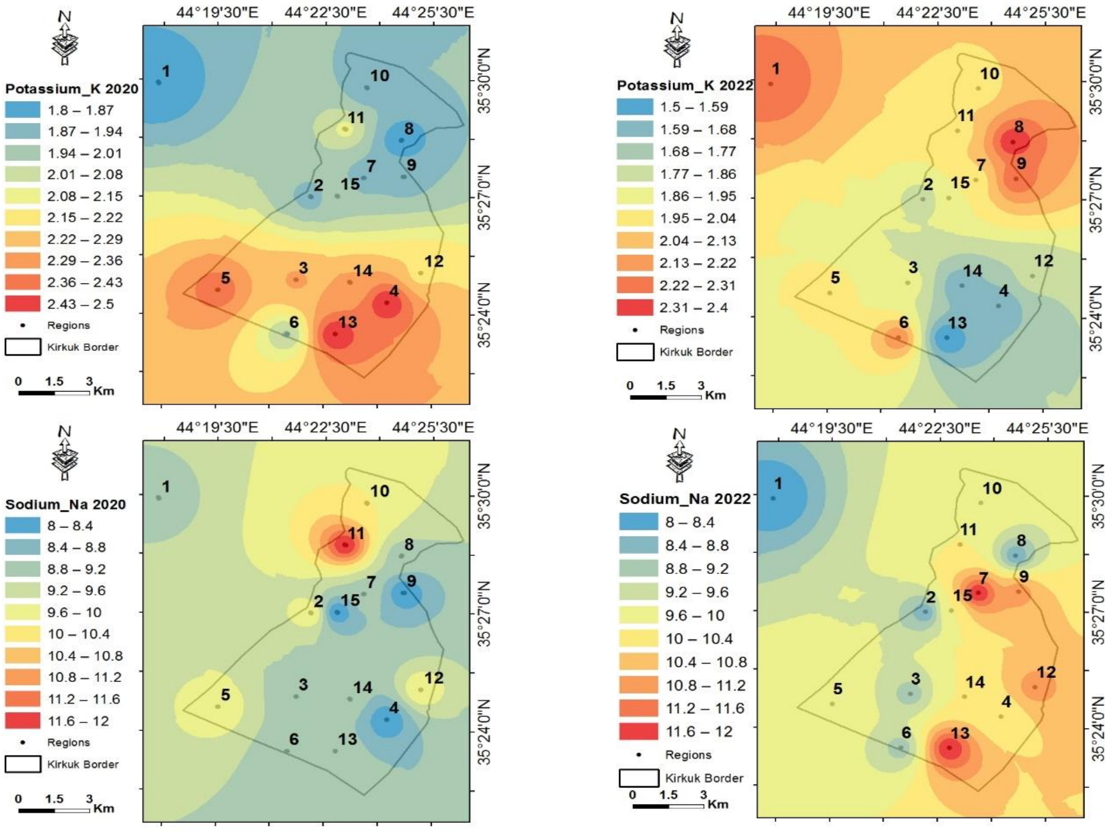
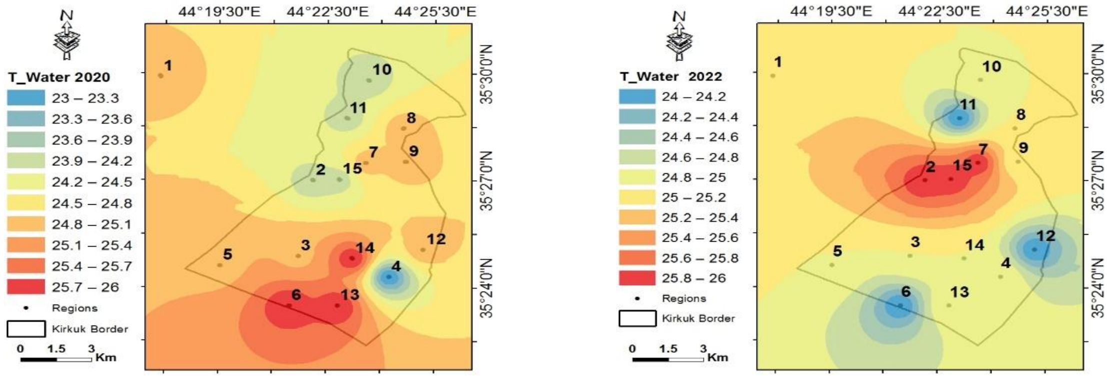


Fig. 5. T-hardness concentration, T.D.S., Turbidity, and Cl2 concentrations maps

Potassium (K) is vital for all living organisms, particularly in plant cells, and is present in all human and animal tissues. The human body contains between 110 and 140 g of potassium, which is crucial for various bodily functions, including heart health, blood pressure regulation, protein dissolution, muscle contraction, and nerve stimulation. While potassium deficiency is rare, it can lead to issues such as depression, muscle weakness, and heart rhythm disturbances. WHO standards set the maximum allowable potassium level at 20 mg/l, while Iraqi guidelines specify 10 mg/l. (Fig. 6) shows that potassium levels in the study area ranged from 1.50003 to 15.9911 mg/l in 2020, decreasing to 1.50001 - 2.39989 mg/l in 2022. These concentrations were within the limits established by both WHO and Iraqi standards. Sodium (Na+), a silvery-white metallic element, is found in small quantities in water. Maintaining an adequate salt level in the human body is crucial for preventing various serious conditions such as kidney damage, hypertension, and headaches. In most countries, water supplies typically contain less than 20 mg/l of sodium, though some areas report levels exceeding 250 mg/l (WHO, 1984). (Fig. 6) illustrates that the sodium content in the study area falls under both WHO and Iraqi standards. According to WHO standards, the acceptable limit for salt content in drinking water is 200 mg/L.





(a) corresponds to the year 2020 (b) corresponds to the year 2022

Fig. 6. Potassium and sodium concentrations and temperature of water distribution maps

In the study areas, the measured salt concentrations were well within this limit, ranging from 8.00003 to 12 mg/L in 2020 and from 8.50001 to 11.9999 mg/L in 2022. These values indicate that the salt levels in the water followed the WHO guidelines, ensuring that the water quality was safe for consumption. The temperature in 2020 exceeded the range in several areas; however, 2022 was limited by WHO and Iraqi standards, as illustrated in (Fig. 6). The water temperature in 2020 was between 23.0004°C and 26°C, while in 2022 it ranged from 24°C to 25.999°C. Based on (Figs 2-6), the key findings from the water quality analysis in Kirkuk City (2020 and 2022) reveal various trends, improvements, and concerns regarding the potable water supply. The evaluation of potable water quality in Kirkuk City revealed improvements in several physicochemical parameters between 2020 and 2022, alongside emerging concerns that warrant attention. The study found a decline in total dissolved solids and electrical conductivity, indicating enhanced water purity, possibly due to improved treatment processes, reduced industrial discharge, or changes in water sources. pH levels remained stable, with slightly alkaline nature, while alkalinity showed a slight decrease, indicating shifts in the chemical composition of the water. A notable reduction in water hardness and sulphate levels result to softer water, likely influenced by groundwater recharge variations. However, turbidity levels increased in certain locations, exceeding permissible limits, which may be attributed to sedimentation, urban runoff, or inefficiencies in the filtration system. Chlorine levels remained within acceptable ranges, ensuring effective disinfection, while potassium concentrations significantly declined, may affect the mineral balance of the water. Sodium levels remained unchanged and within safe limits, lowering potential health risks associated with high salinity. Water temperature exhibited minimal variations, likely influenced by seasonal changes or distribution pipeline conditions. Overall, the findings indicate improved water quality in several aspects, yet highlight the need for targeted interventions, particularly in enhancing filtration processes, regulating turbidity levels, and addressing potassium deficiencies. Periodic monitoring and optimized water treatment strategies are essential to ensuring sustained water quality and compliance with WHO and Iraqi standards.

4. Linear Multi-Regression Model

The Linear Multi-Regression Model presented in Tables 3 and 4 analyses the relationship between various water quality parameters and their impact on turbidity for the years 2020 and 2022. The regression analysis indicates that multiple parameters exhibit weak individual correlations with turbidity; however, when considered collectively, a strong overall correlation (R^2 = 0.939) is observed, suggesting that changes in these variables are significantly interdependent. The R^2 value of 0.147 indicates potential diversity in forecasts, suggesting that although turbidity is affected by various causes, incorporating new variables or improving data collection methods may increase predictability. The p-value was high in single linear regression analysis, suggesting that additional statistical refinement or the inclusion of more explanatory variables is necessary to enhance the model's predictive power. The results indicate that variations in pH, total dissolved solids (TDS), electrical conductivity (E.C.), and ion concentrations affect turbidity, highlighting the necessity for enhanced filtration methods and monitoring techniques to maintain water clarity. Comparisons between 2020 and 2022 reveal alterations in parameter interactions, indicative of potential factors such as seasonal fluctuations, urban expansion, or enhancements in water treatment efficacy. These regression analyses establish a foundation for enhancing water quality management in Kirkuk City, assuring adherence to WHO and Iraqi requirements while mitigating potential contamination sources. (Figs. 7 to 10) depict the relationship between different water quality metrics and turbidity by regression analysis, elucidating the primary factors affecting water clarity in Kirkuk City for the years 2020 and 2022.

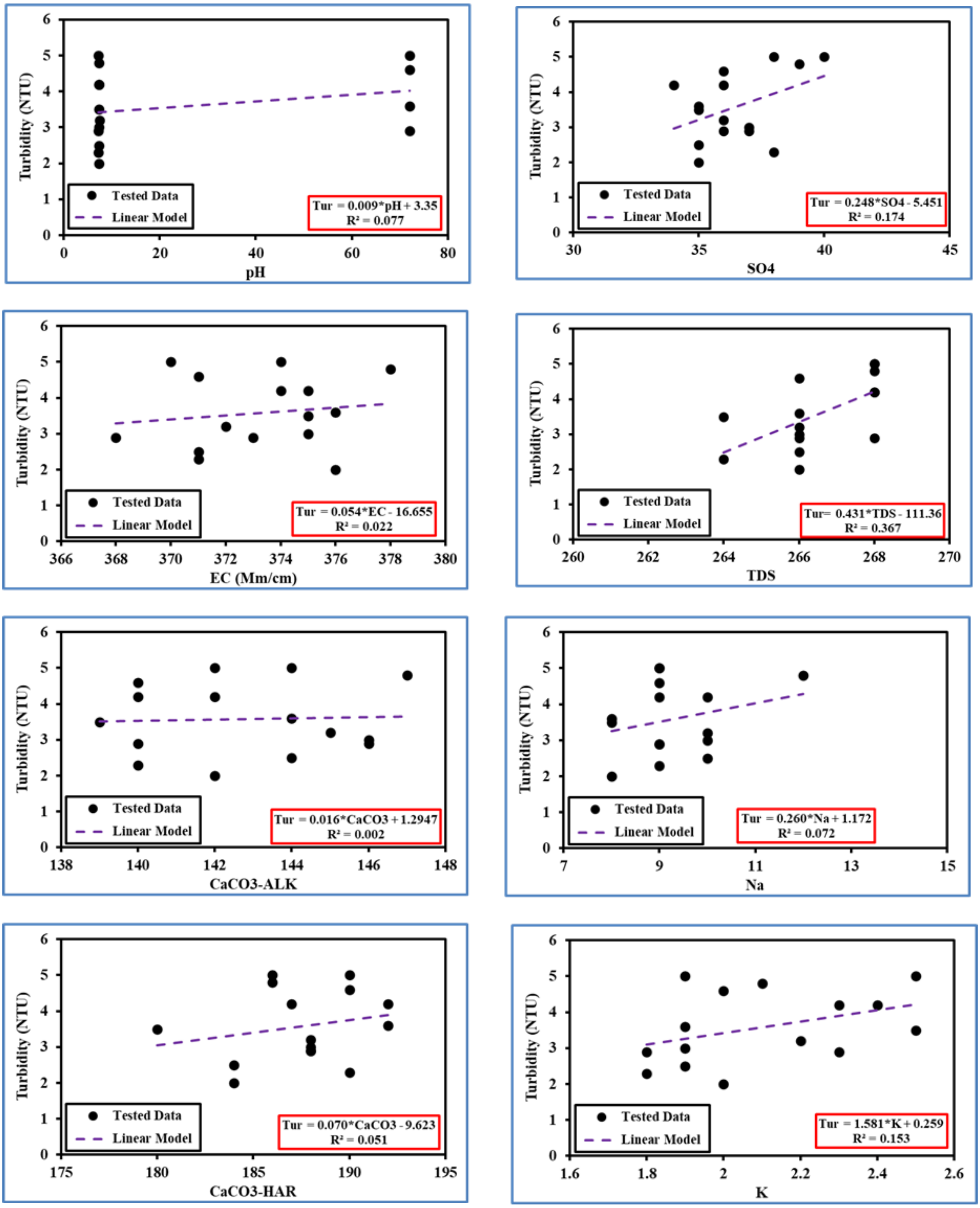


Fig. 7. Correlation of different water quality parameters with turbidity in 2020

Table 3. Regression analysis of water quality parameters in Kirkuk City (2020)

	Turbidity	pH	EC	CaCO3	CaCO3	Ca+	Mg+	Cl	SO4	TDS	Na+	K	T. Water	Cl2
Turbidity	1													
pH	0.277014	1												
EC	0.146761	-0.17631	1											
CaCO3	0.041628	0.064846	0.415434	1										
CaCO3	0.226789	0.283148	-0.07457	0.145664	1									
Ca+	0.300214	-0.08661	0.111629	0.377222	0.054873	1								
Mg+	-0.01718	0.247869	-0.06509	-0.14671	0.621145	-0.7315	1							
Cl	-0.33204	0.073733	-0.33861	-0.57356	-0.41178	-0.24864	-0.14491	1						
SO4	0.416555	0.011348	-0.01355	0.339755	0.121777	-0.10509	0.249322	-0.22855	1					
TDS	0.606017	-0.01513	-0.0025	0.197489	0.278939	0.247518	0.034922	-0.49301	0.24903	1				
Na+	0.267922	-0.31155	0.176842	0.586069	0.082886	0.624853	-0.3764	-0.27448	0.333897	0.386555	1			
K	0.391331	-0.18869	0.414512	0.011067	-0.12505	0.259228	-0.28846	-0.25607	0.017107	0.122857	-0.0279	1		
T. Water	0.43358	0.325332	-0.34231	-0.15276	0.708946	-0.13915	0.565093	-0.17673	0.265644	0.447503	-0.09629	0.066875	1	
Cl2	-0.29383	0.292194	-0.19905	0.139189	-0.01587	-0.10159	0.094269	0.035005	0.002339	-0.16235	0.026702	-0.7773	-0.3702	1

Table 4. Regression analysis of water quality parameters in Kirkuk City (2022)

	Turbidity	pH	EC	CaCO3	CaCO3	Ca+	Mg+	Cl	SO4	TDS	Na+	K	T. Water	Cl2
Turbidity	1													
pH	0.167064	1												
EC	-0.52692	-0.37525	1											
CaCO3	-0.51726	-0.38655	0.26973	1										
CaCO3	-0.17442	0.198358	-0.13198	-0.04763	1									
Ca+	0.187797	-0.28748	-0.0821	0.163186	-0.21873	1								
Mg+	-0.16942	0.335628	-0.07846	-0.15376	0.879547	-0.64109	1							
Cl	0.345845	-0.21626	0.14923	-0.24125	-0.33003	0.1234	-0.30464	1						
SO4	0.29653	-0.15444	-0.38612	0.00733	0.142555	0.221408	-0.0265	0.211312	1					
TDS	-0.20499	0.113809	0.294299	0.210111	-0.1499	-0.51094	0.074274	-0.22219	-0.23074	1				
Na+	0.406684	-0.12069	-0.05645	-0.01015	-0.44163	0.030472	-0.38669	0.492583	0.287097	0.241893	1			
K	-0.34078	0.018577	0.181747	-0.089	0.466298	-0.20182	0.493857	-0.26952	-0.13486	-0.18358	-0.86891	1		
T. Water	0.273404	-0.04053	-0.12858	0.130182	-0.44415	0.194644	-0.47605	0.248512	0.07463	0.191769	0.854968	-0.99393	1	
Cl2	-0.15889	-0.12817	-0.42316	0.132418	0.220424	-0.13904	0.195502	-0.48565	0.067891	-0.0211	-0.35456	0.213832	-0.19023	1

(Fig. 7) illustrates the correlation between turbidity and various physicochemical parameters in 2020, demonstrating a robust overall relationship (R^2 = 0.939), wherein factors such as total dissolved solids (TDS), electrical conductivity (EC), and total hardness significantly affected turbidity levels, presumably due to elevated dissolved solids and mineral content. (Fig. 8) expands this analysis to 2022, illustrating alterations in parameter interactions, possibly attributable to advancements in water treatment or modifications in environmental circumstances, with certain parameters demonstrating diminished correlations, indicating developing sources of turbidity. (Fig. 9) further refines the 2022 regression analysis, isolating parameters with the highest impact on turbidity, which may include chloride, sulphate, and potassium, emphasizing that fluctuations in their concentrations contribute to increased suspended particles. (Fig. 10) presents a refined model incorporating adjustments for outliers and variability, with the p-value and R^2 values for single linear regression indicating the need for further refinement and inclusion of additional parameters such as seasonal variations, microbial contamination, and treatment plant efficiency.

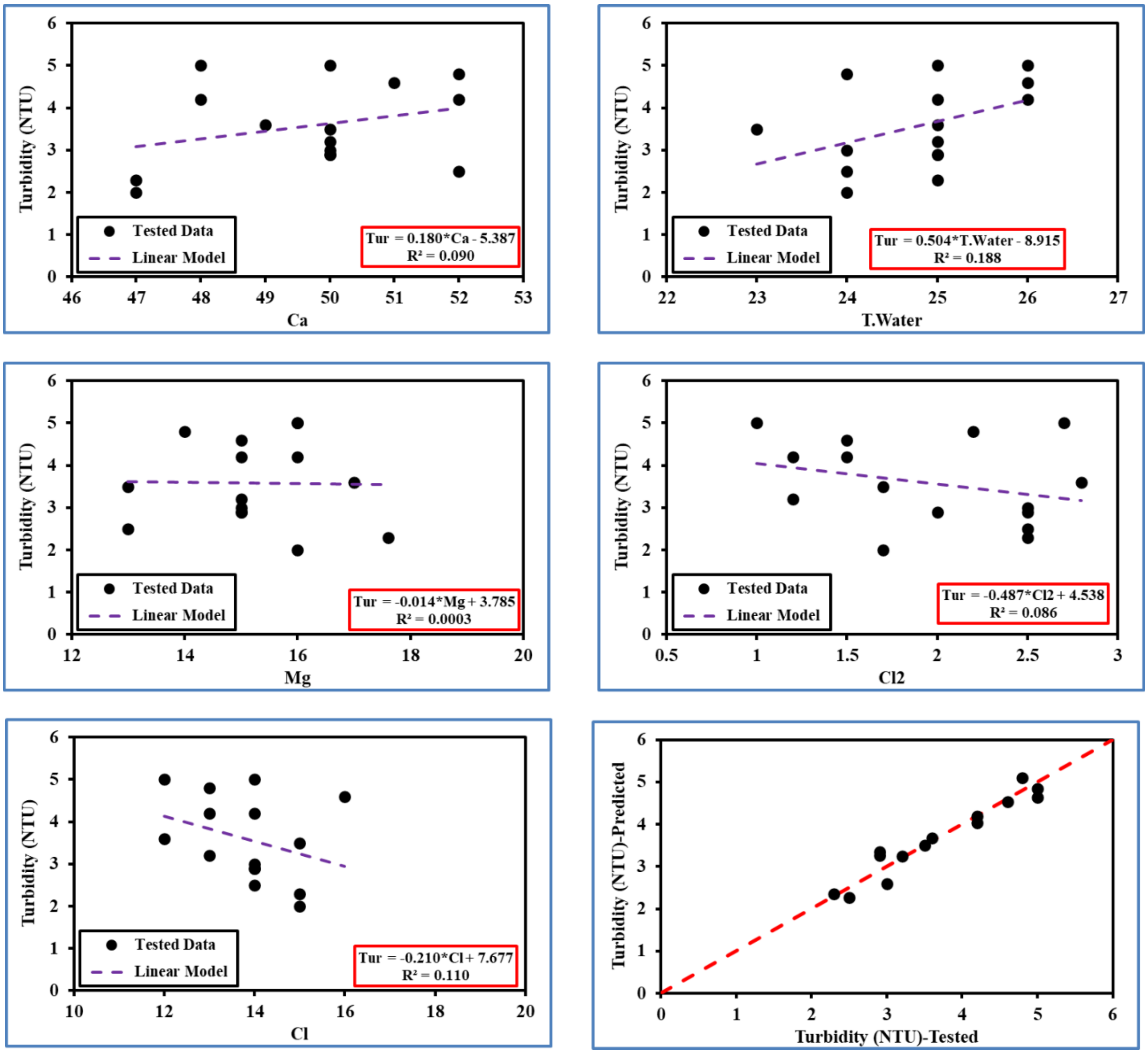


Fig. 8. Correlation of different water quality parameters with turbidity in 2020

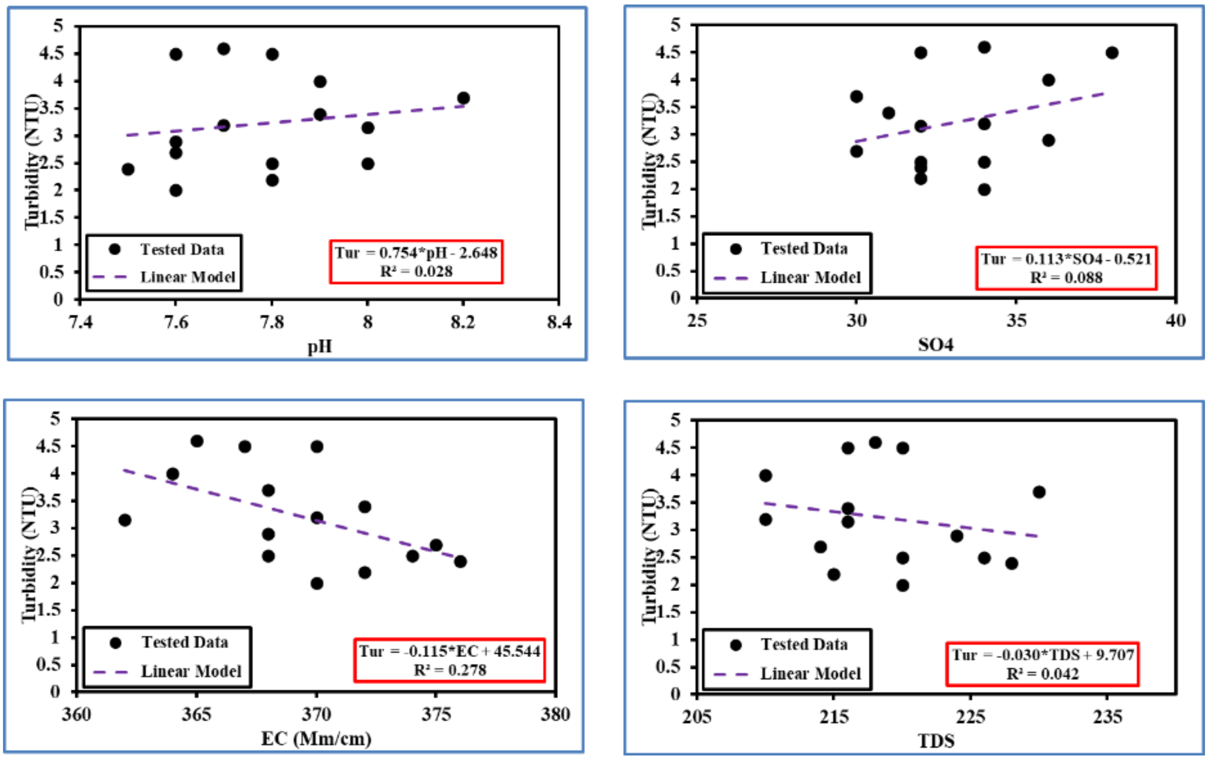
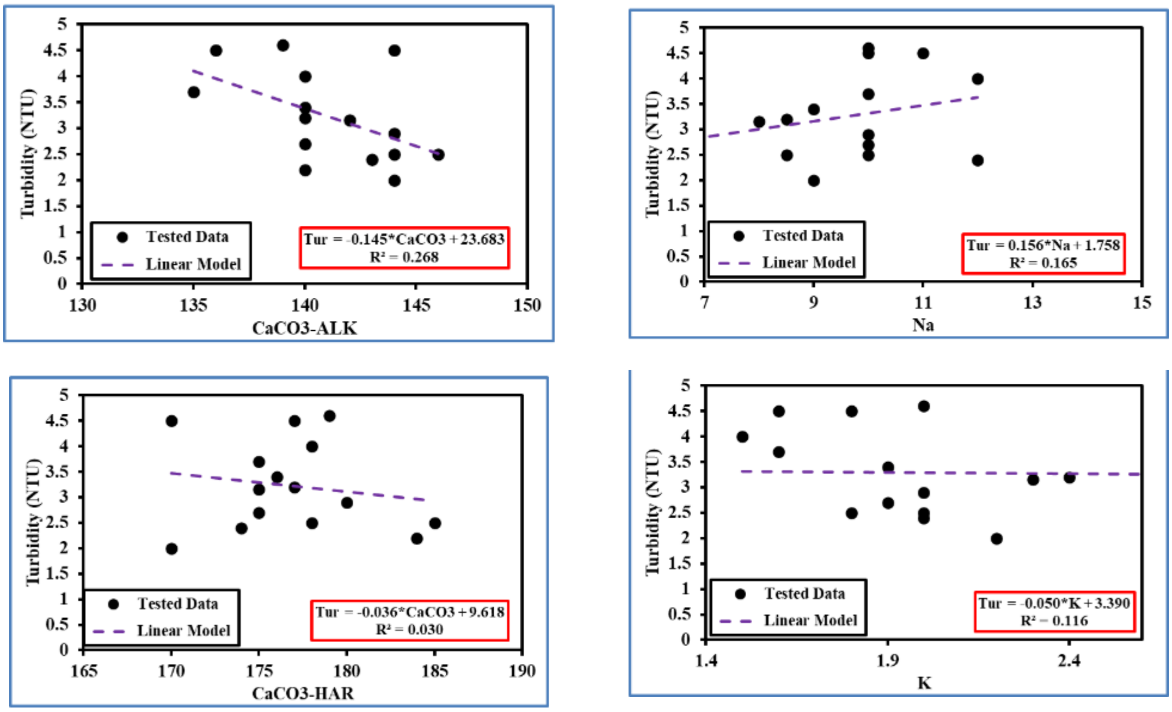


Fig. 9. Correlation of different water quality parameters with turbidity in 2022

The findings collectively suggest that while turbidity remains a significant concern, improvements in filtration processes and dissolved solids management can enhance water clarity and ensure compliance with WHO and Iraqi drinking water standards. The regression results indicate weak correlation between multiple parameters, but overall parameters indicate strong indication of turbidity with an R^2 value of 0.939, suggesting that changes in water quality variables are significantly interdependent. However, the R^2 of 0.147 for single regression analysis indicates potential variability in predictions. The significance (p-value) for single linear regression is relatively high, suggesting that further refinement in data collection or additional variables could enhance predictability.



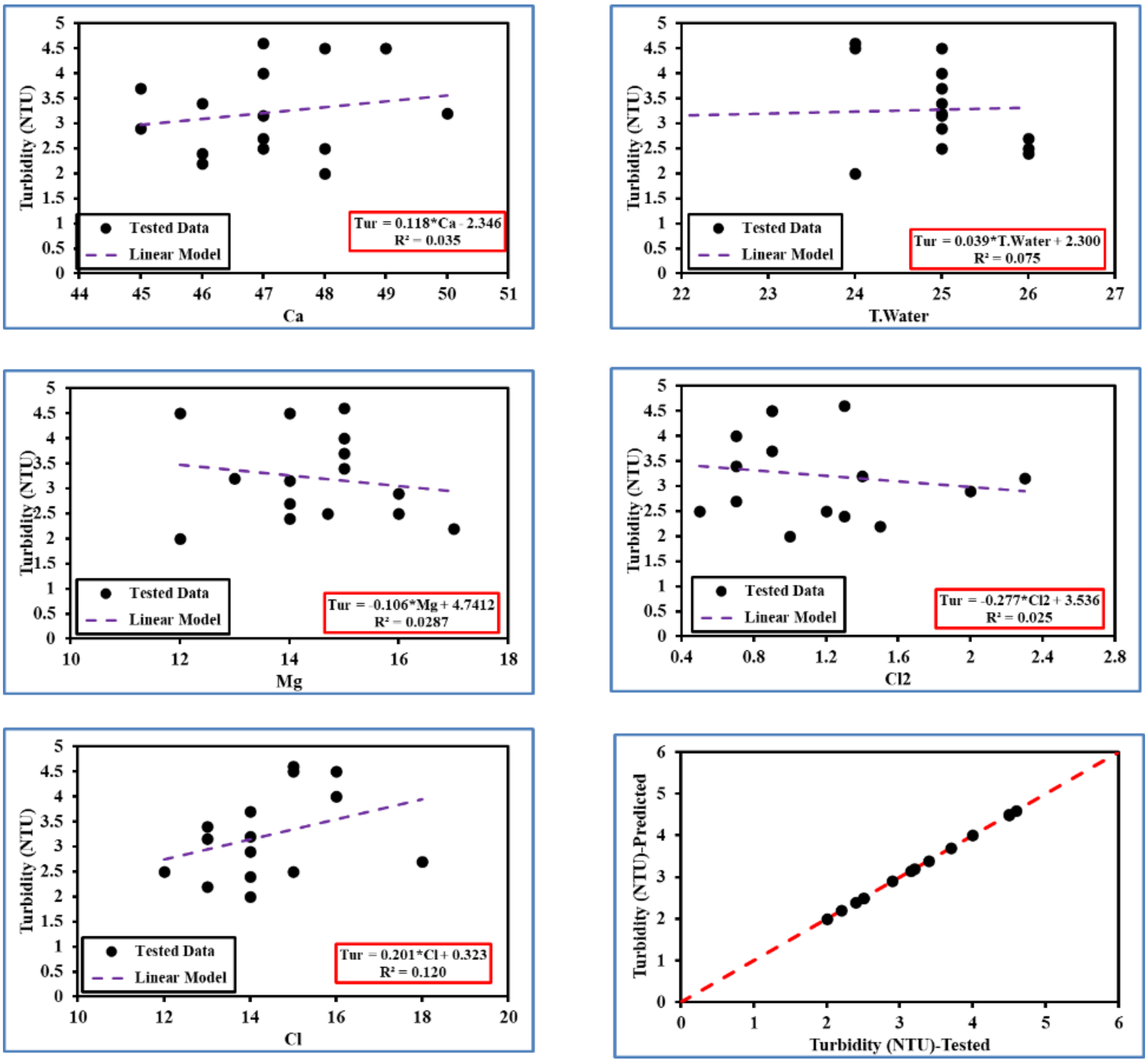


Fig. 10. Correlation of different water quality parameters with turbidity in 2022

5. Conclusion

This study analyzed key physicochemical parameters of potable water in Kirkuk City across fifteen locations using GIS spatial mapping and multi-linear regression analysis. Water quality was evaluated for 2020 and 2022, covering parameters such as pH, alkalinity, calcium, chloride, electrical conductivity, magnesium, sulphate, total hardness, total dissolved solids, turbidity, chlorine, potassium, sodium, and temperature, and compared against WHO and Iraqi drinking water standards. The results indicated that Kirkuk water remained slightly alkaline, with turbidity levels exceeding acceptable limits in some areas. Improvements were observed in water purity over time, as indicated by reductions in Total Dissolved Solids and Electrical Conductivity, possibly due to enhanced treatment processes or changes in pollution sources. However, the decline in potassium levels and persistent turbidity issues necessitate further intervention to maintain water quality. The regression analysis revealed a strong correlation (R^2 = 0.939) between turbidity and multiple physicochemical parameters, particularly Total Dissolved Solids, Electrical Conductivity, and Total Hardness. The resolved R^2 value revealed diversity in predictive accuracy, underscoring the intricate aspects affecting the purity of water. The regression model offers significant insights into parameter interdependencies; however, the high p-value for single linear regression indicates that the inclusion of additional variables, such as contamination from microbial sources, seasonal variations, and treatment plant efficiency, may improve the model's predictive accuracy. The research underscores the need of combining GIS and statistical modelling for thorough water quality evaluation, enabling data-informed decision-making in water resource management. The results indicate that Kirkuk's water quality is mainly satisfactory; nonetheless, localized turbidity problems and mineral deficits necessitate focused enhancements in filtration and treatment methods. The COVID-19 lockdown may have temporarily influenced water quality trends by reducing industrial discharge and altering domestic water consumption patterns. Future studies should focus on long-term data collection, incorporating seasonal effects, climate variability, and emerging pollutants to develop a more robust predictive framework. Periodic monitoring, optimized treatment strategies, and policy interventions are essential to ensuring sustained water quality and compliance with international and national standards.

The quality of Kirkuk water has been checked and the concentration of each element has been found. In this regard it is necessary to be periodically checked to avoid diseases and problems resulting from water quality, especially for turbidity concentrations as shown above the acceptable limits, E.C. and T. Hardness levels were also underneath the allowable ranges, and the concentrations of Ca^{+2}, Cl^{-1}, Mg^{+2}, SO_4^{-2}, and Na and Cl_2 were less than the allowable limits in all locations. Also, the concentration of K was less than the WHO standards. Depending on the results, the recommendation is to increase the filtration process and treatment of the water to reduce turbidity and increase the concentration rate of the elements that have low rates in Kirkuk water. Among the tested parameters, turbidity, total dissolved solids, and total hardness showed the strongest influence on water quality. Parameters like potassium, though below standard limits, also require attention due to their biological importance.

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