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Assessment of potable water quality in Balad city, Iraq

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Abstract. The assessment of the quality of tap water is very important to explore its fit for drinking, especially for developing countries. In the present paper, tap water quality evaluation has been carried out in the Balad city, Salah Al-Din Governorate, Iraq. A total of 17 tap water samples were collected from the city and analysed for various physicochemical and biological parameters, namely, pH, total dissolved solids (TDS), electrical conductivity (EC), turbidity, total hardness (TH), calcium magnesium, chloride and total coliform (TC). Suitability of water for drinking was evaluated based on the World Health Organization (WHO) and Iraqi standards. Spot maps were also generated using GIS to identify the spatial distribution of tap water quality parameters. The results revealed that the tap water is fit for drinking purpose regarding bacteriological pollution. Physicochemical parameters concentration of water samples were within standards except for turbidity. This parameter was highly exceeding the limits (5 NTU) in all tap water samples. Generally, tap water in the Balad city may pose risks to the health of people using it for drinking purposes. Moreover, cluster analysis revealed that the distribution system might affect the quality of tap water in the study area.

1. Introduction

Potable or drinking water has defined by the World Health Organization (WHO) as “water used for all usual domestic purposes including consumption, bathing and food preparation” [1]. In Iraq, the water potabilization services are the responsibility of the public sector where piped water supply is the norm for urban households. Many sources of water can be used for potable abstractions such as groundwater, freshwater from rivers, streams, lakes, and reservoirs [2]. The major source of drinking water in Iraq is the surface water (Tigris and Euphrates rivers) [3]. Despite the groundwater is less susceptible to occasional contamination inputs than the surface water [2], Iraq rely on surface water for water supply since a long time.

Surface water can be used as raw water for drinking water, which needs some kind of treatment before being introduced into the distribution system. A good surface water quality may require only a simple physical treatment and disinfection, whereas moderate quality needs normal full physical and chemical treatment with disinfection and intensive physical and chemical treatment with disinfection is required for poor quality water [4]. Recently, the surface water in Iraq has deteriorated due to a rapid growth of population, an increase for wastewater discharged into the rivers and stream without adequate treatment, drought problem due to the climate change and mismanagement of water resources because of Iraq's political instability [5]. This poses an external load on the water treatment process in the water treatment plants (WTPs). On the other hand, the water that enters the distributing system may subject to losses and microbial pollution. The main problems in the developing countries which cause pipelines contamination are the intermittent supply of water, the old age of the distributing system, low pressure in the distribution network, an inadequacy of wastewater collection systems, and leaking pipes [6], [7].

Numerous studies have been carried out to evaluate the potable water quality in different parts worldwide [8], [9], [10]. The present paper attempts to investigate the suitability of tap water in the Balad city used for domestic purpose. The main physico-chemical and bacteriological water quality parameters have been considered. Spot maps were also produced using GIS for each water quality parameter to illustrate the spatial distribution for each variable.

2. Materials and Methods

2.1. Study area

Balad city is one of the biggest cities located in Balad district in term of population. The major cities in the Balad district are Balad city (the capital of Balad district), Al-Dujail, Ishaqi, Nebaae and Yathreb. Balad city is located between Samarra city to the north and Dujail city to the south, at the southern end of the Selah ad Din Governorate and covers an area of about 363 km^2. The city lies between latitude 34◦1′30″ and 33◦59′30″ North and longitudes 44◦7′30″ and 44◦12′30″ East. The population of the city is about 80,000 [11]. Figure 1 a-d shows the map of the study area.

Before 2003, the water was supplied to the city through three main WTP; these are Yathreb, Balad old and new WTPs (Figure 1d). The latter two projects are being out of service after 2003. Consequently, two temporarily projects have been constructed in the city, namely AlHussain and Al-Furat projects (Figure 1d). Table 1 shows the design and production capacity of the water treatment plants available in the Balad city. The pipeline networks of water supply in Balad city has been renewed after 2003 with PVC pipes [11].

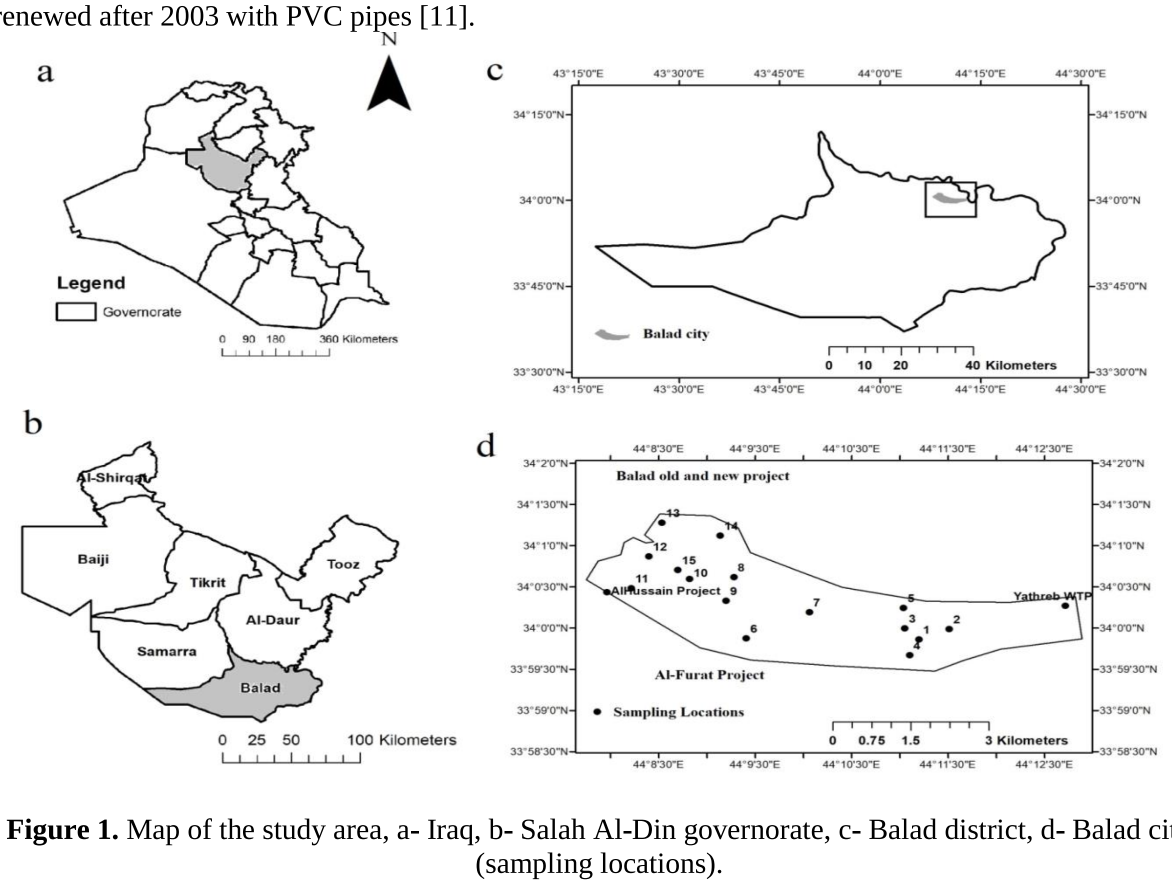

Figure 1. Map of the study area, a- Iraq, b- Salah Al-Din governorate, c- Balad district, d- Balad city (sampling locations).

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Table 1. Design and production capacity of the water treatment plants available in the Balad city

WTP/Project	Design Capacity m^3/day	Production Capacity m^3/day	Status
Yathreb	22000	18000	Operating
Balad old WTP	6000	2000	Out of service
Balad new WTP	10080	4000	Out of service
AlHussain project	200	200	Operating
Al-Furat project	200	200	Operating

2.2. Sampling and analysis

Seventeen tap water samples were collected from Yathreb WTP, AlHussain Project and other 15 different houses of the city during May 2018. Samples represent the present end-user tap water composition and thus, it represents the one we drink every day. Sampling locations are shown in Fig. 1d. Tap water samples were collected in 1 litre sterilized polypropylene bottles, transported to the laboratory of the Water Resources Techniques Department, Institute of Technology, and stored at 5°C for further laboratory analysis. The tap water samples were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), calcium, magnesium, chloride, turbidity, total hardness, and total coliform bacteria. The analyses were performed using standard methods recommended by the American Public health Association [12]. The analytical methods or the instrument used for each parameter and units used in this study are shown in Table 2.

Table 2. Instrument/analytical method used for water quality parameters.

Parameter	Units	Instruments / technique used
pH	-	Digital pH meter
Electrical conductivity (EC)	µs/cm	Measured by portable conductivity meter
Total dissolved solids (TDS)	mg/L	Temperature controlled oven
Calcium (Ca^{2+})	mg/L	EDTA titration
Magnesium (Mg^{2+})	mg/L	EDTA titration
Turbidity	NTU	Digital Turbidity Meter
Chloride (Cl^{-})	mg/L	Silver nitrate method
Total Hardness (TH)	mg/L	EDTA Titrimetric method
Total coliform (TC)	CFU/100 ml	Membrane filtration technique

2.3. Data treatment and multivariate analysis

Cluster analysis was used to provide a better explanation of the relationship between the similarities and dissimilarities among tap water samples. The water quality data was checked for normality distribution using Shapiro-Wilk test. Since, the cluster analysis (CA) requires water quality variables to fit to the normal distribution. It was observed that only pH, TH, $Ca^{2+}$and Cl^{-} were normally distributed. Consequently, the original data of non-normal distribution parameters were transformed in the form $x' = \log10(x)$ [13]. After log-transformation, it was noticed that all the parameters were normalized except TDS and EC and thus they were excluded. IBM-SPSS 25 software for Windows was used to explore the spatial variations among the sampling locations. CA was used to explore the spatial variations among the sampling locations. In this paper, hierarchical agglomerative clustering was executed using Ward's method. Squares Euclidean distance method was used for determining similarity distance.

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3. Results and Discussions

The results of the water quality parameters of the tap water in the study area are presented in Table 3. The pH values of the tap water in the Balad city vary between 7.7 and 8.5, with a mean of 8.12, which indicates alkaline water. EC and TDS in the tap water range from 431 to 554 µS/cm and 263 to 344 mg/L, with an average value of 466.19 µS/cm and 285 mg/L respectively (Table 3). The spatial distributions of TDS and EC in the study area are shown in Figure 2 and Figure 3, respectively. The maximum value of turbidity was recorded as 147 NTU, whereas minimum value was 9 NTU. The average value of water turbidity was 38.31 NTU (Figure 4). TH varied from 100 to 240 mg/L with a mean value of 171.88 mg/L (Figure 5). Ca^{2+} and Mg^{2+} in the tap water samples range from 12 to 76 mg/L and 2.4 to 64 mg/L, with an average value of 44.13 mg/L and 12.55 mg/L respectively. The spatial distributions of Ca^{2+} and Mg^{2+} in the study area are depicted in Figure 6 and Figure 7, respectively. The maximum Cl^{-} concentration in the tap water of Balad city was 29.9 mg/L, while the minimum concentration was 4.9 mg/L and the mean value was 14.96 mg/L. Figure 7 shows the spatial variation of Cl^{-} concentration in the potable water of Balad city. The water quality data shows that total coliform test was found negative. Even a single colony of any type in any sample was not detected.

Table 3. Results of the tap water quality analysis.

Location	pH	TDS	EC	Turbidity	TH	Ca^{2+}	Mg^{2+}	Cl^{-}
Yathreb WTP	8.1	304	498	29.4	240	76	12	29.9
AlHussain Project	7.9	269	485	11.7	130	22	4.8	9.99
1	8.5	320	526	24.2	150	52	4.8	14.9
2	8.3	344	554	9.2	190	12	64	9.9
3	7.7	310	503	16	170	52	33.6	19.9
4	8.3	314	509	48	230	44	28.8	24.9
5	8.2	290	476	24.5	200	52	16.8	24.9
6	8	279	441	63.4	110	40	2.4	4.9
7	7.9	269	436	57.4	150	52	4.8	14.9
8	7.9	270	431	46.4	100	36	2.4	19.9
9	8.1	267	441	25.3	130	48	2.4	9.9
10	8.2	263	436	39.3	100	36	2.4	14.9
11	8.2	271	433	147	180	52	12	14.9
12	8.1	281	459	21.8	230	44	4.9	8.4
13	8.2	263	436	40.7	220	40	4.5	8.2
14	8.2	271	435	24.2	240	50	5	19
15	8.3	265	436	9	180	50	12	14.9
Min	7.7	263	431	9	100	12	2.4	4.9
Max	8.5	344	554	147	240	76	64	29.9
Mean	8.12	285.00	466.19	38.31	171.88	44.13	12.55	14.96

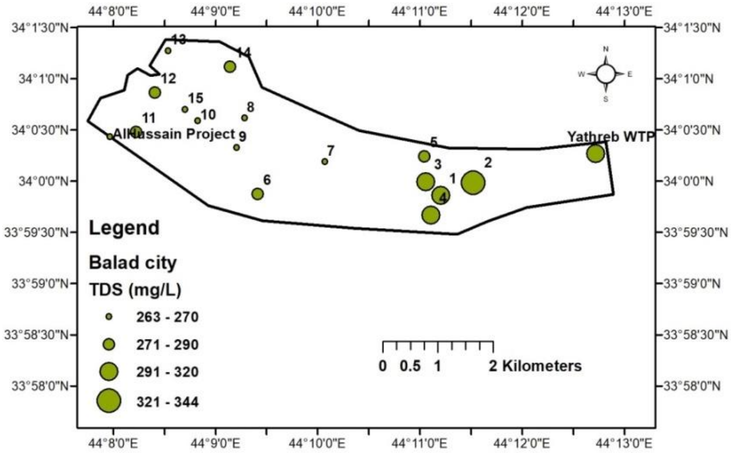

Figure 2. Spatial variation of TDS concentration in the tap water of Balad city.

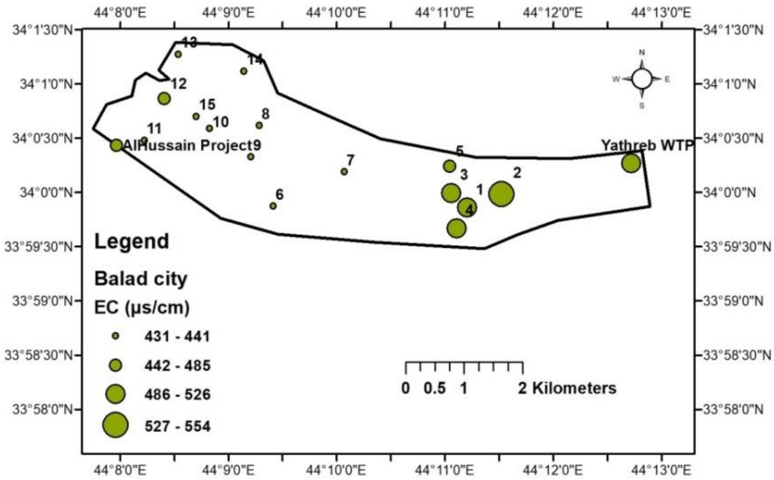

Figure 3. Spatial variation of EC in the tap water of Balad city.

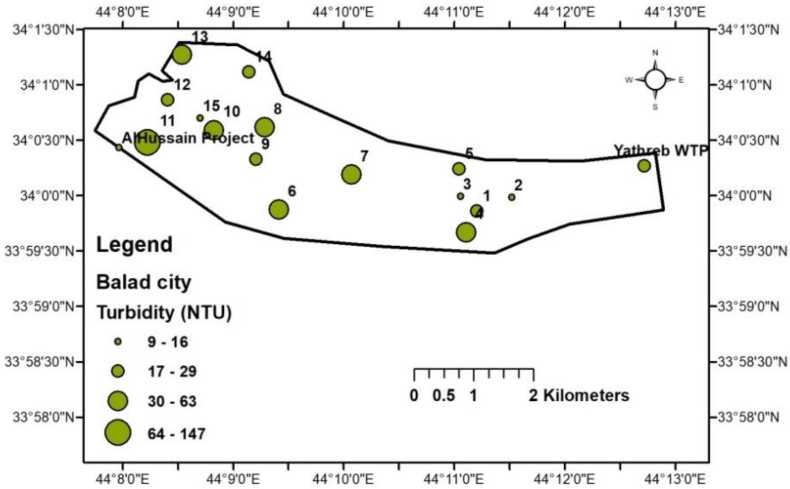

Figure 4. Spatial variation of Turbidity in the tap water of Balad city.

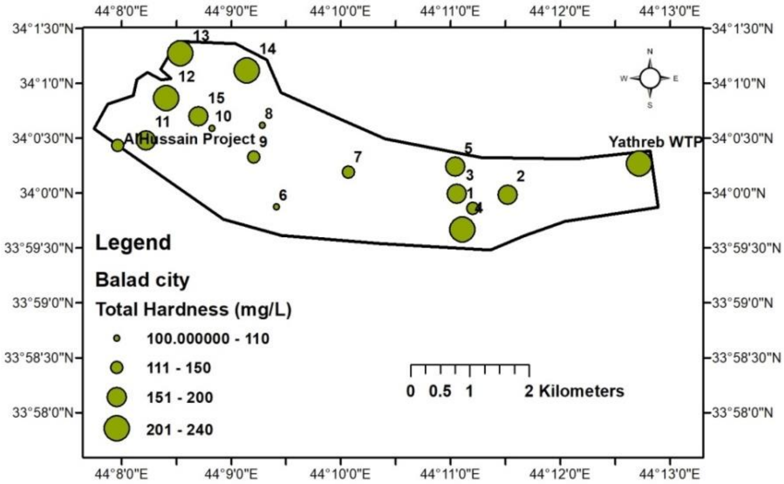

Figure 5. Spatial variation of TH in the tap water of Balad city.

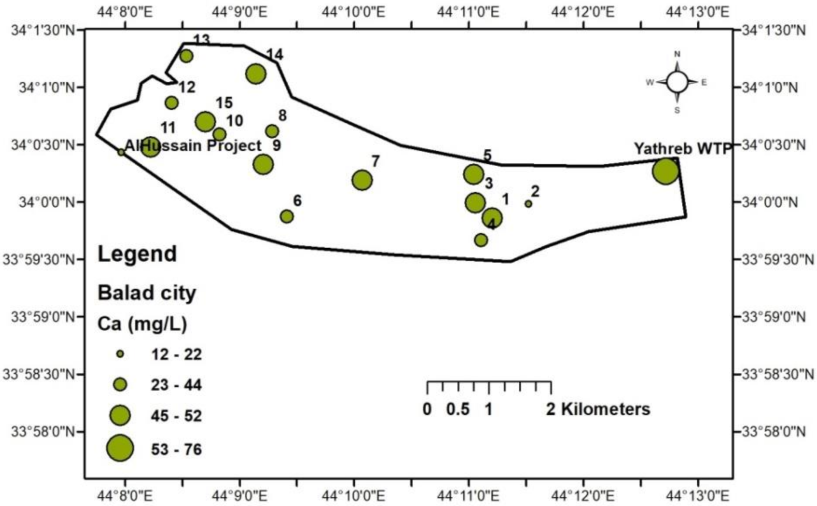

Figure 6. Spatial variation of Ca^{2+} in the tap water of Balad city.

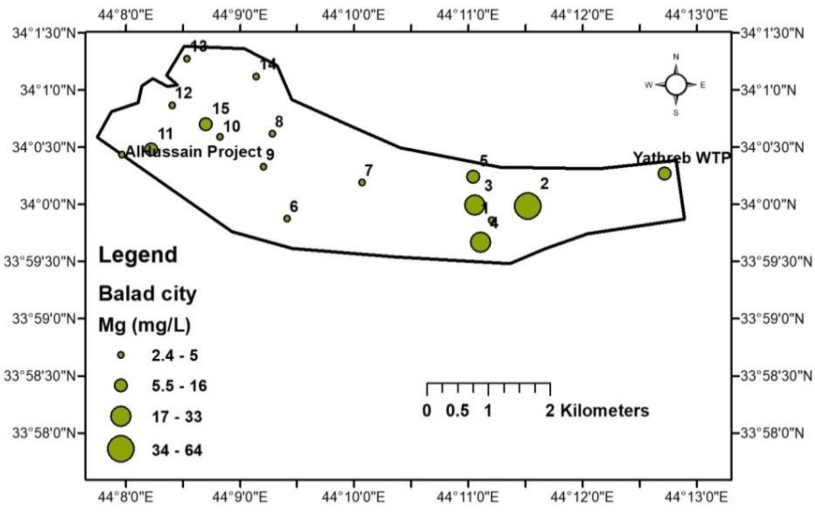

Figure 7. Spatial variation of Mg^{2+} in the tap water of Balad city.

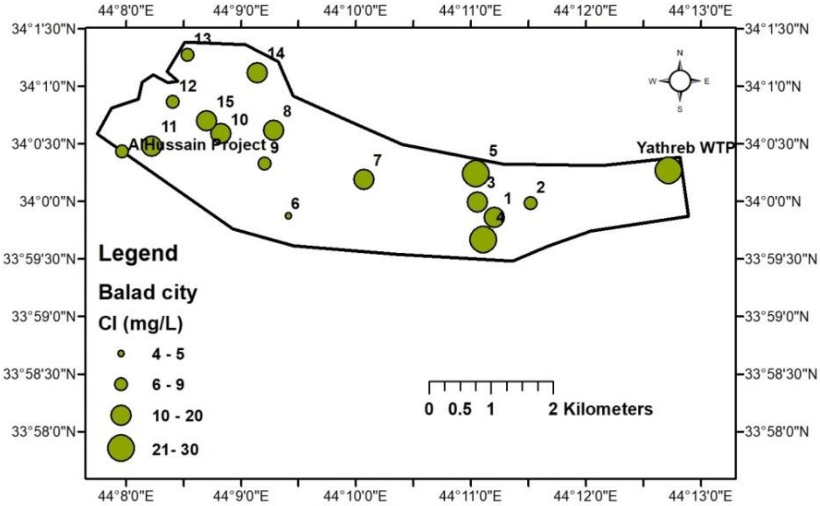

Figure 8. Spatial variation of Cl^- in the tap water of Balad city.

In order to evaluate the suitability of tap water in the Balad city for drinking purpose, the analytical results (Table 3) were compared with the drinking water standards of World Health Organization [14] and Iraqi standards [15] set by Central Organization for Standardization and Quality Control (COSQC) (Table 4). The prescribed limit of pH for drinking purpose given by WHO [14] and IQS [15] is 6.5–8.5. All the tap samples have pH within the prescribed limit indicating its suitability for drinking purpose. The prescribed limit of TDS for drinking water is 1000 mg/L. All the tap water samples were within the prescribed limit (Table 4). The prescribed limit of Ca and Mg for drinking water is 75 and 150, respectively. As for Cl and TH, the prescribed limit for drinking water is 250 and 500, respectively. All the tap samples have Ca, Mg, Cl, TH and EC within the prescribed limit indicating its suitability for drinking purpose. The prescribed limit of Turbidity for drinking water is 5 NTU. Turbidity was highly exceeding the permissible limit in all tap water samples (Table 4).

Table 4. Drinking water standard specifications given by WHO (2011) and IQS (2009) and water samples that exceeding the drinking water standards.

Parameters	IQS 2009	WHO 2011	Samples exceeding prescribed limits
pH	6.5-8.5	6.5-8.5	Nil
Electrical conductivity (EC)	2000*	-	Nil
Total dissolved solids (TDS)	500	1000	Nil
Calcium (Ca^{2+})	150	75	Nil
Magnesium (Mg^{2+})	100	100	Nil
Turbidity	5	5	All samples
Chloride (Cl^-)	350	250	Nil
Total Hardness	500	500	Nil
Total coliform (TC)	Negative	Negative	Nil

* Maximum allowable limit

The microbial quality of water samples was evaluated in terms of Total coliform bacteria (TC). TC is a collection of microorganisms that live in large numbers in the intestines of man and warm- and cold-blooded animals and aid in the digestion of food. TC is indicative of the presence of pathogens that may cause numerous water-borne diseases [16]. The presence of coliform bacteria in drinking water indicates that the water has been contaminated with the fecal material of man or other animals and thus the presence of pathogens that may cause numerous water-borne diseases. The results of the

analysis revealed that the microbiological quality in all tap water samples of Balad city have negative growth for total coliform. This confirms that the disinfection process in the Yathreb WTP, AlHussain and Al-Furat projects are guaranteed in which additional chlorination points were included in the distributing system to keep the concentration of free reactive Cl high enough up to the endpoint.
The total hardness is expressed as mg/L ($CaCO_3$) and classified as soft water (<17.1), slightly hard (17.1 - 60), moderately hard (60 - 120), hard (120 - 180) and very hard (>180) [2]. The classification of the total hardness of tap water in Balad city is shown in Figure 9. It is clear that no soft or slightly hard water exists in all tap water samples, only two samples were classified as moderately hard water and the other samples were ranged from hard to very hard water.

The water turbidity in all tap water samples was extremely higher than the prescribed limit (5 NTU). Turbidity indicates the presence of colloidal particles in the water. The removing of these particles occurs in the coagulation and flocculation process in which chemicals are added to the raw water to remove colloids and improve physical properties before complete removal of solid particles [2]. These chemicals are called "coagulants", many coagulants are available but the most popular is the Aluminium sulphate (Alum) [$Al_2(SO_4)_3$]. In all water treatment plants and projects in the Balad city, Alum is used for the coagulation process. However, water turbidity is very high in the treated water. Action should be made by continuous monitoring of Alum dose using Jar Test or find alternative coagulants such as sodium aluminate [$Na_2Al_2O_4$], activated silica and ferrous sulphate [$FeSO_4$ $9H_2O$]. Furthermore, it requires a continuous monitoring of the water quality of the surface water that is used as raw water for the treatment process.

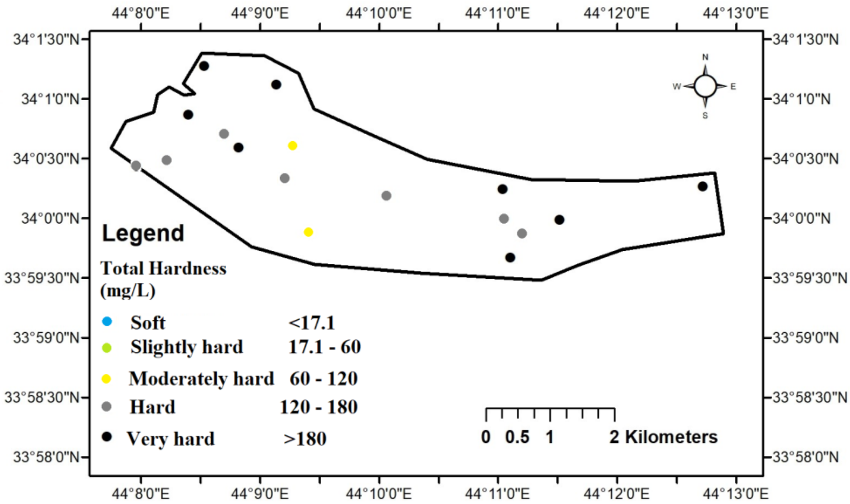

Figure 9. Map of total hardness of tap water in Balad city.

3.1. Cluster analysis(CA)

The spatial CA presented in a dendrogram and shown in Figure 10, where the distance between two samples corresponds to the similarity and dissimilarity between two samples, i.e. greater will be the distance, lesser will be the similarity. It was observed that the tap water samples in the Balad city were grouped into two significant clusters (Group 1 and Group 2). Group 1 is agglomerated two sub-groups and include samples 1, 7, 9, 8, 10, 6 and AlHussain project. Group 2 includes two sub-groups (samples 12, 13, 4, 14, Yathreb WTP, 11, 15, 3, 5 and 2). It should be noticed that tap water samples 1 to 5 belongs to Yathreb WTP, whereas, other tap water samples (i.e. samples 6 to 15) belongs to AlHussain and Al-Furat projects. Usually, the sampling sites are being agglomerated into a different level of pollution sites (i.e. less polluted sites, moderately polluted site, and highly polluted site). This is not the case with the present cluster analysis output; the logical explanation suggests that the distribution system may affect the quality of tap water in the study area.

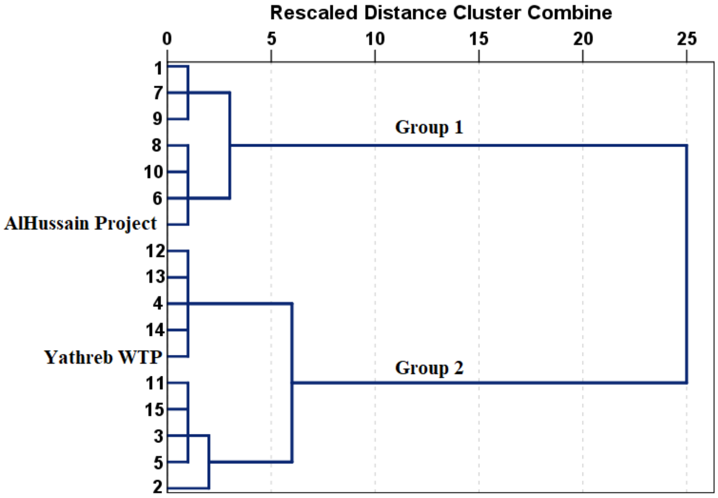

Figure 10. Spatial clustering of tap water samples in the Balad city

4. Conclusions and Recommendations

The weak confidence of consumer in the validity of drinking water supplied from water treatment plants makes people rely on bottled water instead of tap water. The study aimed at evaluating the tap water quality in Balad city to explore its suitability for domestic uses. The results demonstrated that the water is fit for drinking regarding the microbial quality. Moreover, the selected physico-chemical parameters of the water samples were within the prescribed limit set by WHO and IQS except for turbidity. Despite turbid water may be safe to drink and this parameter perhaps does not have a large health concern. Water with high turbidity means a presence of high quantity of suspended particles in the water, which leads to losing our zest for it. This study recommends people not to use the tap water in the Balad city for drinking purpose unless a proper solution is made to reduce the water turbidity.

This study considers only nine physico-chemical and bacteriological water quality parameters, it is recommended to evaluate other parameters that have a significant health concern such as sulphate, nitrate, in addition to the trace metals that may be found in the water due to pipes corrosion of the water distribution network.

Acknowledgments

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