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Assessment of Drinking Water Quality Index (WQI) in the Greater Amman Area, Jordan

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Abstract

Abstract: The Water Quality Index (WQI) is considered the most effective method of measuring water quality. Several water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of water for drinking purposes. This work aims to evaluate the quality of drinking water in Greater Amman using the water quality index method (WQI). For this purpose, twenty-six water sampling zones were used to calculate the WQI during the period 2012 to 2016. The water samples were analyzed for a various set of physicochemical parameters such as pH, turbidity, total dissolved solids, Sodium, Potassium, Calcium, Magnesium, Chloride, Sulfate, Bicarbonate, Total Hardness, Nitrate, and trace heavy metals such as(Ba, Cd, Cr, Cu, Fe, Mn, Ni and Zn). In addition, the biological parameters were also analyzed such as total coliform, Fecal coliform, Fungi and Pseudomonas.

The relative weight has assigned to each parameter and ranges from 1 to 5, based on the importance of the water quality parameters for domestic purposes. The computed WQI collected from twenty-six sampling zones in the Greater Amman area has a range from 29.17 to 62.32 The WQI analysis reveals that the water quality varies from excellent to good water quality. The water quality for potable drinking water was compared with the guidelines of the World Health Organization (WHO)and Jordan Drinking Water Standard (JS286) and the results indicate that water quality in the Greater Amman water is of high quality for drinking purpose.

The spatial distribution mapping of the water quality index (WQI) has been prepared using ArcGIS software. Comparing the WQI for the five years from 2012 to 2016) indicates that the water quality of potable drinking water has been deteriorated in 2016 due to the high population growth of Greater Amman in comparison to the precedent years.

Keywords: Water Quality, Index, Greater Amman, Drinking water, physio-chemical parameters

1. Introduction

One of the major challenges in the drinking water supply is the quality of the produced water. Water quality depends on water composition influenced by natural process and human activities. Eighty percent of drinking water in Jordan comes from groundwater and 20% from surface water sources. The average water demand in the distribution network is estimated to be 85 liters per capita per day (MWI, 2017). The main obstacles to potable water supply in Jordan are the shortage of water, and the water supply is intermittent, especially during the summer period; the deterioration of the water quality of different sources of water; the increasing of water demand; and the water leakage throughout the water distribution network is estimated to account for the loss of 45% of the total water distributed.

To assess the suitability of water quality for different uses, there is of utmost importance need to develop a quality index, which will classify the quality of water. World Health Organization (WHO) set guidelines for chemical contaminants in drinking water. Water Quality Index (WQI) is considered the most effective method of measuring water quality. Diverse water quality parameters are included in a mathematical equation to assess the water quality, determining the suitability for water for potable purposes (Ochuko et al., 2014). Water Quality Index (WQI) is used to assess the suitability of water for a variety of uses (Shala et al., 2020). WQI was introduced and demonstrated in the early 1970s but not widely used or accepted by water agencies that monitor the quality of water. (Cude, 2001). So WQI is used to relate a collective of variables to a common scale and combining them into a single numerical value according to a chosen model or method.

Clean potable water is an essential factor for human survival and the whole life. Due to many factors such as the population increase, the water demand is increasing steadily over time (Ramakrishnaiah et al., 2009). This challenge is leading to more demands for clean water and therefore the lack of water in many parts of the world is increasing consequently. Most of the diseases in human beings are water pollution according to WHO (World Health Organization). Because of these factors, it is necessary to monitor the water quality and to protect it from pollutants (Tiwari and Mishra, 1985). Water quality assessment can be evaluated

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for potable water purposes using physio-chemical and biological parameters. Hazards of drinking polluted water involve diseases like cholera, diarrhea, typhoid, parasitic worm. Consequently, there is an increasing attention to water quality aspects and guidelines, based on setting standards or guidelines of potable drinking water criteria (WHO, 2011).

Water quality is defined by pollutants, which can be grouped as physical, chemical and biological properties of the water. These variables can collectively be integrated into a systematically structured indexing scale, commonly known as the water quality index (WQI).

The WQI offers a single value that expresses water quality by integrating diverse variables of water quality (Stambuck-Giljanovic, 1999; Stigter et al. 2006; Saeedi et al. 2010). The traditional approaches for assessing water quality are mainly based on the comparison of analyzed parameters with the local or international standards. Various studies have suggested the use of a WQI (Cude, 2001; Saeedi et al., 2010; Lateef, 2011). There are various methods for calculating the WQI, considering a comparable physical and chemical parameter but varying in the way the parameters are valued (Abdulrasoul et al., 2015).

The WQI is capable of converting a large quantity of water pollution data into a single dimensionless index value, which represents the level of contamination of the water resources (Kalyani et al., 2016; Ponsadailakshmi et al., 2018 and Ewaid et al., 2018). Considering such ability to integrate a pool of water quality variables into a simple easily understood number, WQI is, therefore, regarded as a very effective and significant communication tool for water managers and policymakers (García-Ávila et al., 2018). Water quality indices are used to simplify and streamline what would otherwise be impractical assignments, thus justifying the efforts of developing such indices.

The main goal of this study is to assess the potable drinking water quality and introduce the use of the WQI as a potential monitoring tool for the drinking water quality of the Greater Amman area.

2. Materials and methods

2.1. Description of Study Area

Amman City is the capital of Jordan which is located between latitudes 220000 and 265000 E and longitudes 135000 and 165000 N and occupies an area of about 1680 km^2 (Figure 1). The population of Greater Amman is approximately 4,008,000 and is expected to increase in Amman at a rate of about 1.8 percent per year until 2030 (Jordan Department of Statistics, 2017). The climate in Jordan is of Mediterranean type. The summer season in Amman extending from May to September which is hot and dry with cool evenings, whilst the winter season starts from mid of October to the ends of April(Jordan Meteorological Department (JMD) (2019). The climate in Amman is overall mild and dry. Amman city is situated on the East Bank Plateau, an upland characterized by three major wadis which run through it. Originally, the city had been built on seven hills. Amman's terrain is typified by its mountains. The most important areas in the city are named after the hills or mountains they lie on. The area's elevation ranges from 700 to 1,100 m. The average elevation is around 800 meters above sea level and has an average temperature ranging from 8.5 °C in January to 26.5 °C in July and August. The mean annual temperature in Amman is 17 °C. The average minimum monthly temperature is 7.7 °C and the average maximum monthly temperature is 25.2°C. Rainfalls between November and March with an average annual of 250 mm/year. Spring is brief, mild and takes a little less than a month, from April to May. Sometimes snow is falling on the city during spring. Autumn is also mild and lasts from September to late November or December(Jordan Meteorological Department (JMD) (2019).

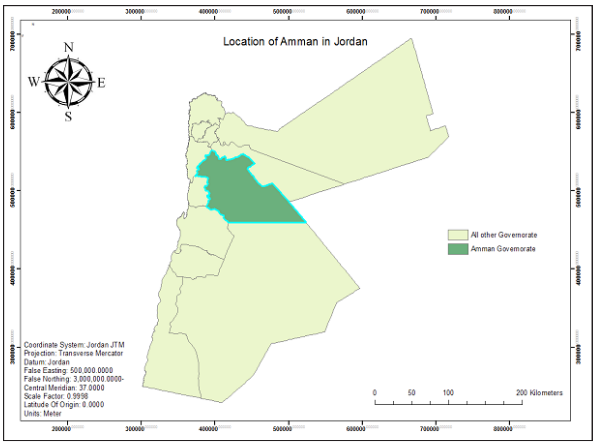

Figure 1. Location of Amman Governorate within Jordan map.

2.2. Water Sampling and Physicochemical Analyses

In this study, Greater Amman Municipality has divided into twenty-two (22) sampling zones according to the distribution of domestic water. The tap water samples were collected from the restaurants and service shops. The total number of water samples in this study was 180 samples. The hydrochemical data was collected during the period 2012-2016 from the Health and Business Inspection Department HBID laboratories of Greater Amman Municipality. The data included the routine analysis, in addition to turbidity, microbiological analysis such as E. coli, coliform, fungi and Pseudomonas.

A flowchart diagram representing the methodology layout to determine and evaluate the water quality index in Greater Amman (Figure 2). Data collection is an important stage in any research. The physicochemical analyses were taken from HBID laboratories-Greater Amman Municipality. Twenty-two (22) representative water samples from 22 sampling zones for five years period were collected from tanks (tap water) from restaurants, Bakery, beautification saloon, and all shops dealing with food. The samples were collected and analyzed in cooperation with HBID laboratories for their physiochemical constituents. The representative water samples were collected in polyethylene bottles of (500 ml volume) for chemical and physical analysis and (250 ml volume) for microbiological analysis- because chemical and physical tests need more quantities water than microbiological tests- after washing them twice by samples water to avoid contamination. The analysis of water samples waschecked, and the accuracy of the analysis should not exceed 5%.

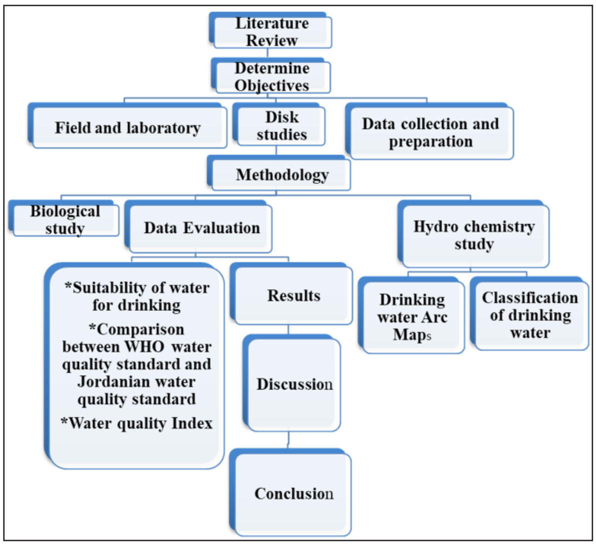

Figure 2. Flowchart illustrating the research stages.

The major, minor elements and trace elements analyses were conducted in the HBID Laboratories. These analyses aimed to determine the concentration of cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and the anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}), Nitrate (NO_3^{-}), pH, TDS , Turbidity in addition to Total hardness and trace elements (Iron, Zinc, Manganese, Cadmium, Chromium, Copper, and Nickel) in the four private wells.

The water samples included 4 private wells (drinking water). These drinking water sampling zones include (AL-Madeenah (Mid Town), Swuayleh, Abu Nusayr, Shafa Badran, AL-Jubayhah, Tareq, Marka, Tla'a Ali, Badr AL-Jadeedah, Wadi AL-Seer, Marj AL-Hamam, Badr, Zahran, AL-Muqabalin, Khraibet AL-Souq, Ohoud, AL-Nasr, Ras AL-Ain, AL-Yarmouk, AL-Abdali, AL-Qwaismeh, and Basman) whilst wells sampling zones include Marj AL-Hamam, Sahab, AL-Jubayhah, Dwar Al-Waha, (Figure 3 and Figure 4).

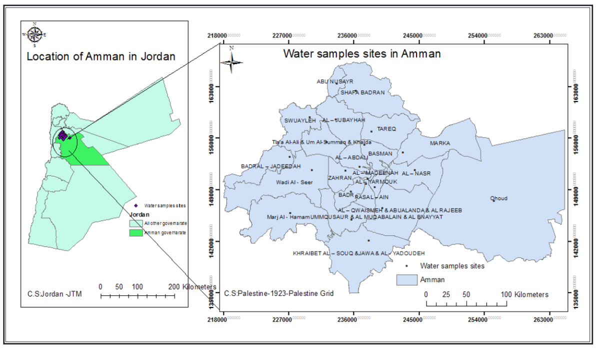

Figure 3. Drinking water sample sites in the Greater Amman area.

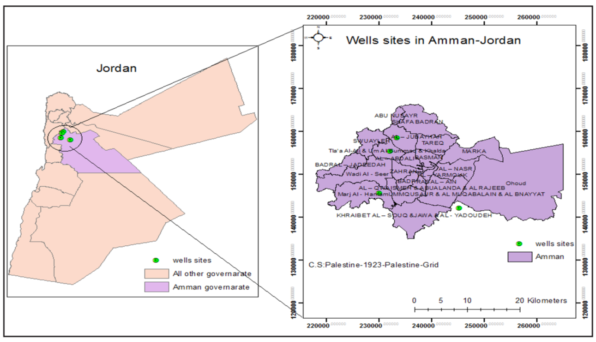

Figure 4. Groundwater sampling sites from 4 wells in the Greater Amman area.

2.3 Analytical Methods

Water chemical analyses were conducted to identify the quality of water according to standard methods for the standard methods for examination of water and wastewater22nd edition (Eugene, 2012). The pH of water samples was determined using a pH meter. The Total Dissolved Solids (TDS) was measured using the portable Electrical Conductivity (EC) meter. The concentrations of major cations and anions were determined using ICP-MS. Turbidity was determined by turbidity meter. The assessment of water quality in the greater Amman was considered the following analyzed parameters of drinking water including pH, Turbidity, Total Dissolved Solids, Total hardness, Calcium, Magnesium, Sulfate, Nitrate, Total alkalinity, Chloride, Iron, Cadmium, Chromium, Nickel, Zinc, Manganese, Sodium and Potassium.

Several microbiological analyses have been conducted including the total coliform, fecal coliform, fungi, and pseudomonas and Escherichia coli. The total number of colonies was determined by the nutrient agar method and the coliforms group and E. coli were determined by Colilert (defined substrate) method, as described by Maurice et al., 2008). The requisite data of various water quality parameters were analyzed monthly during the period from 2012 to 2016 which are available data at the laboratories of HBID.

2.4 Measurements of physiochemical Parameters

Physical parameters including turbidity, total dissolved solids (TDS) are measured directly in the field. The chemical analyses of Major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-} and CO_3^{2-}) and minor ions (NO_3^{-}) are carried out in the HBID laboratories. The chemical analyses of trace elements which are Cd, Cr, Ni, Mn, Cu, Fe, Zn, and B were carried out in HBID laboratory. Table (1) shows the physiochemical parameters for the sampling zones in Greater Amman area. The accuracy of the results of water samples analyses was estimated by calculating the absolute difference between total cations and the total anions as shown in Equation (1) (Hem, 1985):

$$Error\ (RD\%) = \frac{100 * \Sigma cations - \Sigma anions}{\Sigma cations + \Sigma anions} \quad \text{.... Eq. (1)}$$

Where:

RD %: Relative Difference

r ∑ Cations: Summation of positive ions concentrations in (meq/L).

r ∑ Anion: Summation of negative ions concentrations in (meq/L).

- If (RD ≤ 5%) the results could be accepted for interpretation.
- If (5% ≤ RD ≤ 10%) then the results are acceptable with risk.
- If the value (RD% > 10%) cannot depend on the results in hydrochemical interpretation (Hem, 1985).

2.5 Water quality assessment for drinking purposes.

The assessment of chemical characteristics for the potable water samples that were analyzed compared with World Health Organization (WHO, 2011) Guidelines and Jordanian water quality standards (JISM, 2015). Potable water quality was assessed by calculating the Water Quality Index (WQI) for each sample that indicates the impact of individual water quality parameters on the whole water quality. The Water Quality Index (WQI) was calculated for evaluating the influence of natural and anthropogenic activities based on several key parameters of drinking water chemistry (Krishna et al., 2014). The weight for the physio-chemical parameters has been assigned according to the relative significance of the parameter to the overall quality of water for domestic water purposes.

The spatial distribution for potable water quality parameters and water quality index maps for drinking purposes in the Greater Amman were done with the help of spatial analyst modules in ArcGIS software. Geographic Information System (GIS) is a powerful tool for creating solutions for assessing water quality and managing water resources. Inverse Distance Weight IDW interpolation technique was used for spatial modeling. The IDW referred to as the determinant interpolation techniques used because they assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface (Selvam et al., 2015). Because the IDW is a weighted average, the distance the average cannot be greater than the highest or lesser than the lowest input, it determines the cell values using a linearly weighted combination of a set of sample points and controls the significance of known points upon the interpolated values (Selvam et al., 2015).

2.6 Classification of drinking water samples

Classification of all analyzed drinking water samples collected from the Greater Amman area has been done by using the software Aquachem, 2014. These classifications were done to determine the water types and the variations of water quality, these displayed graphical plots depending on the main cations and anions concentrations measured as milligrams per liter (mg/l) or milliequivalents per liter (meq/l). The distribution of water types in the Greater Amman is shown in Figure (5).

Table 1. The physio-chemical parameters of the analyzed water samples during the period (2012-2016).

ID	Site	HCO3 (mg/l	TH (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Turbidity (NTU)	TDS (mg/l)	pH-Value	K (mg/l)	Na (mg/l)	Mg (mg/l)	Ca (mg/l)
1	AL-Madeenah	125.1	178.8	121.9	48.7	20.4	0.2	479.6	7.7	3.6	47.6	20.5	77.6
2	Swuayleh	16.0	135.8	80.7	45.4	10.7	0.3	341.9	7.7	5.0	20.0	15.0	30
3	Badr	200.2	132.6	74.4	41.0	12.8	0.3	338.2	7.6	2.4	30.9	15.4	58.2
4	AL-Muqabalin	110.1	155.1	81.8	37.0	13.7	0.1	351.0	7.5	3.5	65.0	22.0	25
5	Ras AL-Ain	110.0	124.4	78.6	32.9	12.6	0.1	283.7	7.7	2.5	60.0	18.0	22
6	Zahran	100.0	143.4	99.6	55.5	13.0	0.5	380.0	7.7	5.5	70.0	18.0	30
7	AL-Abdali	80.0	138.9	104.6	47.0	14.0	0.2	370.8	7.7	2.4	63.0	14.0	28
8	Marj Al-Hamam	110.0	104.6	74.7	37.1	11.5	0.2	320.4	7.5	1.3	55.5	10.4	38.7
9	AL-Yarmouk	105.0	114.2	78.5	41.1	12.1	0.2	342.8	7.7	3.0	60.0	15.0	22
10	Marka	130.0	190.6	150.1	39.3	25.2	0.2	516.5	7.6	5.0	100.0	25.0	35
11	Tareq	140.0	156.8	150.4	37.3	8.6	0.1	311.1	7.6	4.5	105.0	20.0	32
12	AL-Nasr	90.0	117.7	52.7	51.5	11.0	0.1	268.0	7.7	4.0	45.0	15.0	22
13	AL-Jubayhah	160.0	149.3	89.1	57.6	9.7	0.1	304.3	7.6	8.6	55.0	14.8	71.4
14	AL-Qwaismeh	70.0	97.9	44.9	36.8	13.7	0.1	256.7	7.7	3.0	32.0	12.0	20
15	Khraibet Al- Souq	70.0	105.4	60.1	25.8	11.2	0.3	272.4	7.6	2.5	35.0	12.0	22
16	Basman	120.0	174.9	95.6	39.5	12.8	0.1	347.7	7.6	5.6	65.0	21.0	36
17	Shafa Badran	115.0	137.7	96.7	41.0	11.4	0.1	320.0	7.7	6.5	70.0	16.0	30
18	Abu Nusayr	120.0	169.5	115.4	51.8	18.4	0.2	331.2	7.6	8.2	85.0	18.0	38
19	BadrAl-Jadeedah	200.2	162.6	156.2	39.9	2.7	0.1	216.4	7.2	3.5	70.0	18.0	100
20	Ohoud	53.0	62.9	50.1	10.2	4.2	0.1	188.9	7.8	1.5	30.0	7.0	14
21	Wadi AL- Seer	90.0	160.8	62.3	45.5	9.5	0.1	240.0	7.4	6.2	35.0	18.0	34
22	Tla´a AL-Ali	53.0	158.7	70.1	31.6	8.2	0.1	244.7	7.5	5.0	50.0	21.0	28
	Mean	99.1	138.6	91.2	40.0	12.3	0.2	322.2	7.6	4.3	57.3	16.6	36.99

2.7 Water Quality Index (WQI) for Drinking Purposes

Water Quality Index has been successfully applied to assess the quality of potable drinking water in recent years due to its importance in understanding the water quality issues by integrating complex data and generating a score that describes water quality status (Othman et al., 2020).

Horton (1965) was first used the concept of WQI then developed by Brown et al. (1970) and improved by Deininger (Scottish development department, 1975). The development of WQI for water quality is described in the various studies (Backman et al., 1998; Stigter et al., 2006; Saeedi et al., 2010; Ramakrishnaiah et al., 2009; Prasada and Siddaraju, 2012) and Krishna Kumar (2015).

The chemistry of drinking water is often used as a tool for discriminating the drinking water quality (Subba Rao, 2006). The water quality index (WQI) is an important parameter for identifying the water quality and its sustainability for drinking purposes (Magesh et al., 2013). WQI is defined as a method of rating that provides a composite influence of individual water quality parameters on the whole water quality (Mitra, 1998).

The water quality index (WQI) was calculated for evaluating the influence of natural and anthropogenic activities based on several key parameters of drinking water chemistry Idris and Aydın (2016). World Health Organization (2011) Guidelines for drinking water quality have been used to calculate the WQI. To calculate the WQI, the weight has been assigned for the physicochemical parameters according to the relative importance of certain parameter to the overall water quality for domestic water purposes. The greatest weight of five (5) was assigned to the parameter nitrate, potassium and total dissolved solids due to its importance in the assessment of water quality; the weight of four (4) has been assigned to the parameters pH,sulfate and total Hardness; the weight of three (3) has been assigned to parameters chloride and bicarbonate; while the weight of two (2) has been assigned to the parameters calcium, and sodium, based on their importance in the quality of water for drinking purposes. Magnesium is assigned the minimum weight of one because it plays a fewer role in the water quality assessment. The relative weight is computed from the equation (Eq.2):

$$Wi = wi \Big/ \sum_{i=1}^{n} wi \quad \text{.......... Eq. (2)}$$

Where:
Wi is the relative weight.
wi is the weight of each parameter.
n is the number of parameters.

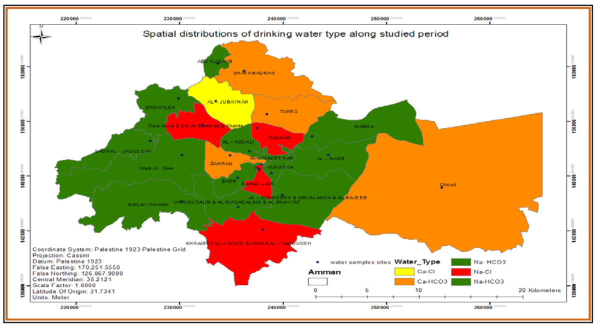

Figure 5. Spatial distributions of water type in the Greater Amman Area.

The quality rating scale for each parameter is calculated by dividing its concentration in each water sample by its respective standards of WHO (2011) and multiplied the results by 100 (Eq.3).

$$qi = \left(\frac{Ci}{Si}\right) * 100 \quad \text{.......... Eq. (3)}$$

Where:
qi is the quality rating.
Ci is the concentration of each chemical parameter in each sample in milligrams per liter.
Si is the World Health Organization Guidelines for each chemical parameter in milligrams per liter according to the guidelines of the WHO (2011).

For computing the final stage of WQI, the SI is first determined for each parameter (Eq.4). The sum of SI values gives the water quality index for each sample (Eq.5).

$$SIi = Wi * qi \quad \text{.......... Eq. (4)}$$

$$WQI = \sum SIi \quad \text{.......... Eq. (5)}$$

Where:
SIi is the sub-index of ith parameter.
qi is the rating based on the concentration of ith parameter.

The relative weight (w_i) was assigned for water quality parameters based on their relative importance on water quality for domestic purposes (Table 2). The computed WQI is shown in Table (3) where the WQI varies from “excellent water” to “good water for potable drinking purposes. The calculation of the WQI for potable water for the five periods from 2012 to 2016 are shown in Figures (6 to 10). The WQI for the whole period from 2012 to 2016 is shown in Figure (11). The WQI in the Greater Amman showed that the WQI for drinking water exceeding the value of 50 increases with time. The water quality of less than 50 is excellent in terms of chemical and physical characteristics and the greater than 50 can be classified as good water quality for drinking purposes. This means that 2012 was the lowest value of 50 and therefore the water quality was better than 2013, 2014 and 2015, but the year 2016 has the worst water quality index.

Table 2. Relative weight of chemical of physiochemical parameters.

Parameter	WHO Guidelines (2011)	Weight (wi)	Relative weight (Wi) $Wi = wi \Big/ \sum_{i=1}^{n} wi$
pH (on scale)	6.5 – 8.5	4	0.114
TH	300-600	4	0.114
TDS (mg/l)	500	5	0.143
HCO_3^- (mg/l)	500	3	0.086
Cl^-(mg/l)	250	3	0.086
SO_4^{2-}(mg/l)	250	4	0.114
NO_3^-(mg/l)	45	5	0.143
Ca^{2+}(mg/l)	75-200	2	0.057
Mg^{2+}(mg/l)	50-150	1	0.029
Na^+(mg/l)	200	2	0.057
K^+(mg/l)	10 – 50	2	0.057
		$\sum$ wi = 35	$\sum$ wi = 1

Table 3. WQI of water samples during the years 2012- 2016.

ID	Site	WQI/2012	WQI/2013	WQI/2014	WQI/2015	WQI/2016
1	AL-Madeenah	78.9	63.1	52.4	56.1	56.5
2	Swuayleh	59.2	40.4	39.1	50.2	42.3
3	Badr	43.6	47.6	43.8	43.1	41.2
4	AL-Muqabalin	43.6	47.6	44.9	44.8	48.6
5	Ras AL-Ain	59.7	45.7	35.7	45.9	31.9
6	Zahran	69.7	51.5	44.6	49.7	48.3
7	AL-Abdali	60.9	52.1	39.7	51.1	45.8
8	Marj Al-Hamam	52.3	0	40.2	43.9	34.4
9	AL-Yarmouk	43.9	38.2	42.9	46.9	32.5
10	Marka	72.9	54.8	60.5	71.5	62.3
11	Tareq	85.9	27.2	40.1	48.6	52.1
12	AL-Nasr	64.7	41.4	48.8	30.5	33.6
13	AL-Jubayhah	64.3	39.6	32.1	65.5	46.2
14	AL-Qwaismeh	30.3	40.2	30.9	41.9	36.7
15	Khraibet Al- Souq	43.3	33.9	42.5	27.8	43.8
16	Basman	61	43.8	42.3	51.8	42.7
17	Shafa Badran	75.2	25.6	43	35.3	48.1
18	Abu Nusayr	61.4	49.8	49.3	55	37.6
19	BadrAl-Jadeedah	47.6	0	17.6	47.7	17.3
20	Ohoud	0	0	0	26.8	26.9
21	Wadi AL- Seer	0	34.6	19.2	40.9	38.1
22	Tla'a AL-Ali	0	21.1	19	39.4	39

The WQIof twenty-two sampling zones shows lower values which classified as excellent water, and six sampling zones are classified as good water according to the classification of water quality based on WQI values (Table 4). The high value of WQI at these zones has been is attributed mainly to the higher values of TDS, Ca^{2+}, K^{+}, Cl^{-}, HCO_3^{-}, NO_3^{2-} and SO_4^{2-}.

Table 4. Classification of water quality based on WQI values.

Range	Type of water
< 50	Excellent water
50 – 100	Good water
100 – 200	Poor water
200 – 300	Very poor water
> 300	Water unsuitable for drinking purposes

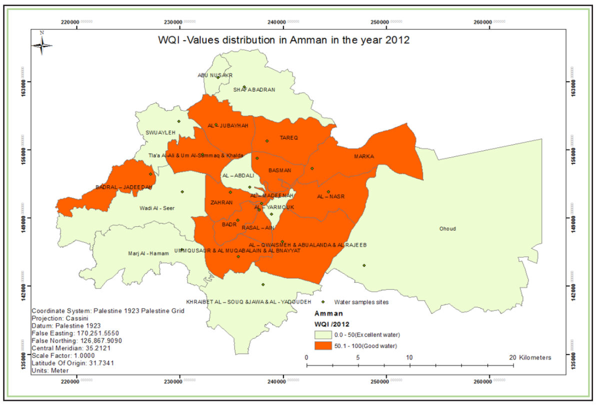

Figure 6. WQI-values in Greater Amman Area in the year 2012.

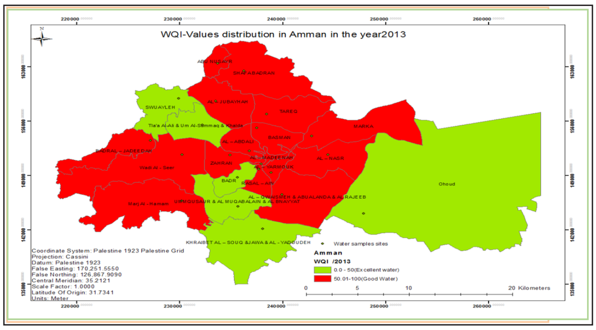

Figure 7. WQI-values in Greater Amman Area in the year 2013.

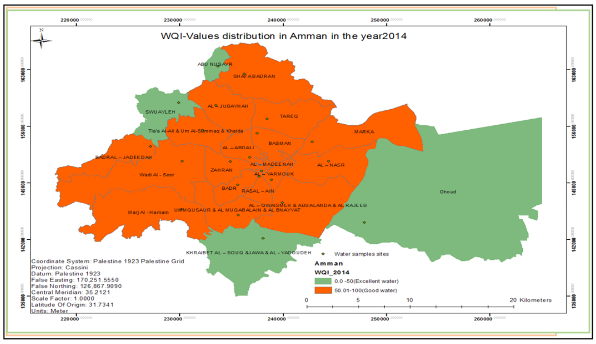

Figure 8. WQI-values in Greater Amman Area in the year 2014.

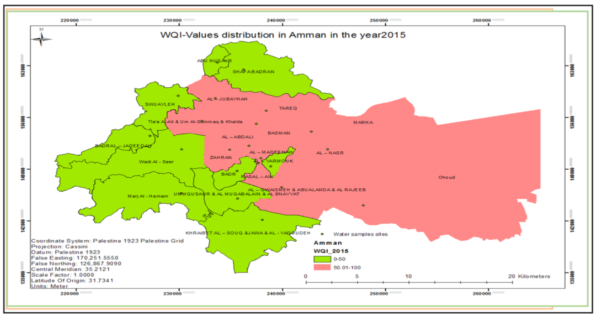

Figure 9. WQI-values in Greater Amman Area in the year 2015.

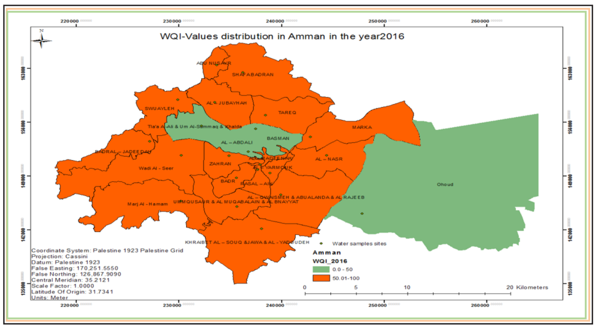

Figure 10. WQI-values in Greater Amman Area in the year 2016.

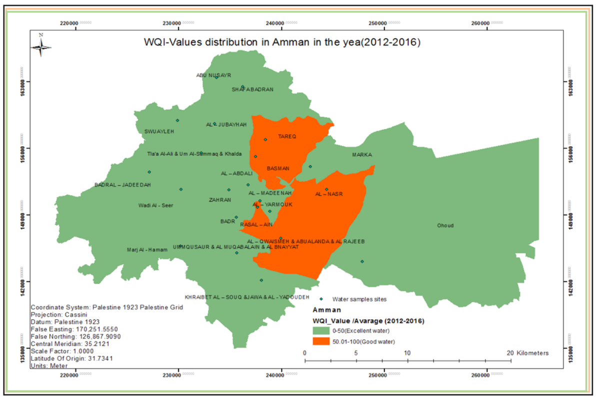

Figure 11. WQI-values in Greater Amman Area during the years 2012-2016.

3. Results and Discussion

Assessment of drinking water quality in a timely requirement where availability of safe water is at risk due to natural and man-made activities. This study conducted in the Greater Amman area to help in measuring drinking water quality using WQI which provide the composite effect of chemical parameters on water quality. The present study is contributing to designing and improving the monitoring programs in the city.

The study findings revealed that drinking water was slightly alkaline, although the ideal pH for human consumption is stated to be 7.6. The maximum permissible limit for pH in drinking water as given by the WHO is 8.5 (WHO, 2011). The values of pH in the drinking water samples in this study varied from 7.2 at Badr AL-Jadeedah to 7.8 at Ohoud with an average value of 7.6. It tends to be alkaline. A controlled pH of water is suggested in WHO guideline to reduce the corrosion and contamination of drinking water having health consequences. This explained higher alkalinity by the presence of two common ions calcium and magnesium, affecting the hardness of the water.

The maximum acceptable and potable limit of TDS value for drinking water of the Jordanian standard1000 mg/l, whereas lower TDS values of drinking water samples (<1000 mg/l) then the TDS values started to increase in the middle of Amman (Zahran, Basman, Bader, Tareq, Abdali, AL-Muqabalin Yarmouk).It is clear that Marka showed the highest TDS of 516.5 ppm value in comparison with other sites where the lowest value of TDS was measured in Ohoud with a value of 188.9 ppm. The average value of TDS was 319.4 ppm.

Turbidity is important because it affects both the acceptability of water to consumers, and the selection and efficiency of treatment processes. Turbidity is measured utilizing electronic meters. The turbidity of water samples in the Greater Amman varies from 0.1 to 0.5 and the maximum turbidity values were reported in Zahran area.

Nitrate is the most available indicator for pollution and it is well-dissolved in water. The concentration of NO_3^- is often an indicator of water deterioration due to agricultural impact. The consumption of water with high nitrate concentration causes several health disorders, such as gastric cancer, goiter, birth malformations and decreasing oxygen-bearing capacity of the blood. The acceptable limit of NO_3^- for drinking water is 50 ppm (WHO, 2011). In the study area, the minimum NO_3 concentration was observed of 2.7 at Badr AL-Jadeedah and a maximum of 25.2mg/l at Marka with an average of 12.3 mg/l. The middle parts of Amman have the highest values comparing to other parts.

The total hardness (TH) of the collected water samples ranges from 62.9 at Ohoud to 190.6 mg/l at Marka with an average value of 138.6 mg/l.According to WHO guidelines, the maximum allowable limit of TH for drinking purposes is 600 mg/l and the most desirable limit is 300 mg/l. The spatial distribution of total hardness concentration of water samples in the Greater Amman area indicated that the middle part of the Greater Amman have the highest values comparing with other parts.

The overall suitability of drinking water was assessed using a combined measure of water quality parameters: the WQI. The water quality index (WQI) was calculated for evaluating the influence of natural and anthropogenic activities based on several key parameters of drinking water chemistry. To calculate the WQI, the weight has been assigned for the physicochemical parameters according to the parameters relative importance in the overall quality of water for drinking water purposes. The assigned weight ranges from 1 to 5. The maximum weight of 5 has been assigned for NO3 and TDS; the weight 4 is assigned for pH, TH and SO_4; the weight 3 is assigned for HCO_3 and Cl; the weight 2 is assigned for Ca, Na and K and the weight 1 is assigned for Mg.

The chemical parameters of water samples were used to calculate the WQI value at each sampling site. The weighted arithmetic WQI method is applied to calculate WQI values. In this method, the permissible WQI value for drinking is considered to be 100, the water quality is considered poor if the value exceeded this acceptable limit. The water quality during the period 2012-2016 was found to good at these sites AL-Madeenah, Marka and Abu Nusayr areas due to low chemical parameter values contributing to lower composite effect on drinking water quality. The water quality was water was classified as excellent for drinking at most sample sites in the Greater Amman area.

The study had some limitations since it would have been better to collect samples throughout the year addressing seasonality. In addition, the testing of drinking water samples from all sites was not possible for this study due to limited resources.

4. Conclusions

The chemical and physical parameters were measured to determine the quality of drinking water of the collected samples in Greater Amman Municipality. The accuracy of the chemical analyses was checked using the charge balance error, which ranges between 0.05 to 5% for all analyzed water samples.

The quality of drinking water was assessed using the WQI which is a tool used for discriminating the water quality. The computed WQI values for twenty-six water sampling zones from different sites of the Greater Amman area were analyzed. The WQI was computed based on the eleven (11) chemical parameters such as nitrate, total dissolved solids, pH, turbidity, sulfate, bicarbonate, chloride, calcium, sodium and potassium and magnesium. The assigned weight for each parameter ranges from 1 to 5 based on their importance for analysis.

The WQI values calculated during the study period showed that the WQI value of more than 50 increases each year more than the preceding year in the different studied areas. Water quality of less than 50 is excellent in terms of chemical and physical characteristics. This means that 2012 was the lowest value of 50 and therefore the water quality was better than 2013, 2014 and 2015, but the year 2016 has the better water quality index which is below 50. It should be noted that these values in all years did not exceed 100 which means the water quality is good in general. The spatial distribution of WQI during the period 2012-2016 for Greater Amman area shows that most of the quality of drinking water in different zones are of excellent water quality which reflects the continuous monitoring by the governmental agencies responsible for the control on the quality of drinking water.

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