Groundwater Quality Assessment Using Water Quality Index Technique: A Case Study of Kirkuk Governorate, Iraq.

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Abstract. The quality of groundwater is a global concern that is usually assessed using quality indices. The Canadian Water Quality Index (CWQI) alongside with Geographical Information system (GIS) were adopted to evaluate the quality of Kirkuk’s groundwater in terms of its suitability for drinking, irrigation, aquatic, recreational purposes, and livestock uses, in 60 wells within the time period of 2017 to 2019. The groundwater quality was assessed depending on Iraq’s and world health organization (WHO) guidelines. The Iraqi standards were used for drinking purposes. The WHO standards were used for irrigation, aquatic, recreational, and livestock purposes. Both standards were incorporated in CWQI Excel Spreadsheet to evaluate the groundwater quality for studied wells. Samples were collected and analyzed for 15 major parameters. According to the CWQI, groundwater samples obtained were classified as marginal in 2017 and 2018; while poor water for drinking was observed in 2019.

Keywords: Canadian Water Quality Index (CWQI), GIS, Groundwater, Kirkuk, Iraq

1. Introduction
Water scarcity in the semiarid area is a critical issue for local citizens. In Iraq, water scarcity is expected and is a challenging issue. This is correlated to the construction of new dams on the wellsprings of the two main rivers of Iraq (Euphrates and Tigris), which in turn reduces the recharging process of the two main rivers [1]; [2]; [3]. Therefore, the use of ground water resources is increasing considerably and becoming the main source of water supply in arid parts of Iraq. The quality of groundwater should be assessed in order to protect public health and the environment [4]; [5]; [6]. Groundwater pollution has attracted considerable attention worldwide due to its influence on the environment, economy, and health. Reporting water quality data to concerned authorities and to the general public members is complex due to a large number of parameters that need to be summarized and analyzed.

Traditionally, water quality reports were made to investigate the compliance of each parameter with its objective. However, concerned authorities and the general public may not have the knowledge and basic training to interpret these reports. Therefore, all environmental monitoring programs require a simple and easy method to report results in order to make them legible. As a solution to this, mathematical methods that combine water quality parameters and provide a specific description of the water quality have been developed. Several water quality indices are also available to simplify the analysis of the water data and ease the reporting process. One prime example of such indices is the Canadian Water Quality Index (CWQI). The CWQI user’s manual 2017 showed that the minimum number of water quality parameters to be used for obtaining consistent and reliable result is eight. Al-Mussawi [7] investigated the groundwater quality of 30 wells located in Umm Er Radhuma unconfined aquifer (western desert of Iraq) during wet and dry seasons in 2010. Al-Mussawi [7] analyzed water samples for major ions, total dissolved solid, pH, and electrical conductivity. The
water quality was assessed using irrigation water quality (IWQ) and integrated with GIS to provide a tool for water resource management. Al-Mussawi [7] found that 80% of the study area could be classified as severe and highly restricted in dry seasons; however, this percentage declined to 60% during wet seasons.

Abbood et al. [8] investigated the quality of Main Drain River, Iraq, using CWQI during the time period from 2004 to 2011. It has been included that the water can be classified as poor quality according to the range of CWQI (26.6 to 35.5). Ismail et al. [9] used multivariate statistical techniques to assess the quality of groundwater in urban areas of Baghdad. Sixty six Samples were collected from 66 wells for analysis in 2010 and factor analysis revealed that three factors including mineralization of soil, irrigation, and agricultural activities were associated with variance in the groundwater quality. Al-Azawi and Al-Shamma'a [10] investigated the suitability of the groundwater in Al-Salhubia area, south of Iraq for irrigation purposes using Arc GIS 9.3 and GMS 6.5 programs. In this study it has been found that the groundwater in Al-Salhubia area was suitable for irrigation purposes. Al-Basrawi et al. [11] evaluated groundwater in Baghdad, Iraq and concluded that the groundwater salinity ranges from fresh to brine water and the direction of the groundwater was mainly from the west towards the east. Abbas and Hassan [12] implemented CWQI to determine water quality to protect the aquatic life of Diwanyiah River. Nine water quality parameters have been investigated in this study including TDS, Nitrogen Dioxide (NO\(_2\)), temperature, Turbidity, pH, Alkalinity, DO, NO\(_3\)), and PO\(_4\)). Results showed that poor water quality based on the CWQI.

Furthermore, Muftin et al. [13] have been used CWQI to assess the effect of the electric power plant at Al-Zafaraniya city, Baghdad, on the water quality of Tigris River. It has been found in this study the water quality parameters of turbidity, electrical conductivity, water temperature, and phosphate were significantly influenced by the power plant discharge. The result shows that the groundwater in this particular area needs to be treated before its consumption, and in addition, it is needed to be treated for avoiding the hazard of contamination. Hommadi et al. [3] investigated the water quality upstream of Alhindya Barrage, Euphrates River, using CWQI. The water quality indices in the years of 2008 and 2009 have been compared according to data availability. Awad and Al-Kalbi [14] investigated the quality of groundwater in Hawija, Kirkuk by analyzing 28 samples to determine the suitability of groundwater for irrigation. With regard to the sodium absorption ratio (SAR) and the remaining sodium carbonate (RSC), no hazard and no harmful effects were observed.

Groundwater is the major source of water in semi-arid areas like Kirkuk Governorate, Iraq. In Kirkuk, the population relies mainly on groundwater through several private and conservative wells. As a result of the growing population and industrialization in the Kirkuk region, the demand for water has increased mainly for drinking and irrigation. The objectives of this paper were to investigate the suitability of groundwater in Kirkuk Governorate for drinking, irrigation, aquatic, livestock, and recreational activities using CWQI combined with GIS techniques. Spatial distributions of physical, chemical, and biological parameters of groundwater were spatially mapped using the GIS tool in the study area. The water quality samples of 60 wells were collected and analyzed for 15 different water quality parameters.

2. Study Area
Kirkuk Governorate is located about 283 km to the north of Baghdad City, the capital of Iraq. The province is situated between (34° 41’ 42”- 35° 51’ 50”) N and (43° 16’ 37”- 44° 43’ 60”) E. In the last 50 years, the population of Kirkuk Governorate has increased about 50% and was recorded as 996,000 persons in 2019 [15]. According to figure 1, the province is mostly dependent on groundwater for irrigation, drinking, and industrial purposes, due to the low availability of surface water in Kirkuk. The climate of Kirkuk is semi-arid with cold rainy winter and hot dry summer. Floods caused by rain are considered as the main source of Kirkuk’s groundwater despite the availability of surface water. The study area of the studied wells is located to the east-northern strip of Kirkuk Governorate (figure 1). The study area covers about 1273.78 km\(^2\) of the Kirkuk total area of 9999.38 km\(^2\).
3. Materials and Methodology

In order to investigate the groundwater quality of wells, water samples from 60 private and governor wells were collected from January of 2017 to July of 2019. The samples corresponding to well numbers of 1 to 24, 25 to 46, and 47 to 60 were collected within 2017, 2018, and 2019, respectively. The groundwater is found in two hydrological basins within Kirkuk Governorate. The first one is within Mukdadiya formations and Bai Hassan extended from northwest to southeast of Kirkuk, while the second one is within Quaternary sediments and Bai Hassan formation located to the southwest of Baba dome. Most of the sampling points are located within the first hydrological basin (figure 1). The groundwater of these wells is used for drinking, irrigation, and industrial purposes.

3.1. Chemical, physical, and biological analysis of groundwater

The collected data were obtained from Iraqi Ministry of Environment. The 15 water quality parameters of collected data including pH, temperature (T), Electrical conductivity (EC), Total Dissolved Solids (TDS), Sulfate (SO\text{4}^{2-}), Nitrate (NO\text{3}^{-}), Phosphate (PO\text{4}^{3-}), Magnesium (Mg\text{2+}), Calcium (Ca\text{2+}), Total Hardness (TH), Total Plate Count (TPC), Chloride (Cl\text{1-}), Sodium (Na\text{1+}), Total Coliforms (T. Coliforms), and E-coli (E-coli) were analyzed based on the Iraqi standards for drinking purposes and world health organization (WHO) standards for irrigation, aquatic, recreational, and livestock purposes. The water quality parameters were classified according to three classifications: physical, chemical, and biological parameters. The Fecal Coliform was calculated using the Membrane Filter method (APHA, 9215-D). Total Coliform was determined using the Standard Total Coliform Multiple-Tube (MPN) technique (APHA, 9221-B). Total Plate Count (TPC) was conducted according to the standard methods for the examination of water and wastewater [16]. The pH, EC, and temperature were determined on-site using portable pH meter (HQ11d). Samples were preserved at 4 °C before analysis. TDS was determined according to the standard methods for the examination of water and wastewater (APHA, 2540). Concentrations of Ca\text{2+}, Na\text{1+}, Cl\text{1-}, SO\text{4}^{2-}, and NO\text{3}^{-} were determined using Atomic Absorption Spectrophotometry (AAS). The method proposed by Lind [17] was adopted to determine Calcium; consequently, while Magnesium was calculated using the following formula [16]:

\[
\begin{align*}
\text{Mg}^{2+} \text{ (mg/l)} &= 0.243 \times [\text{TH (as CaCO}_3\text{/l}) - \text{Ca}^{2+} \text{ (as CaCO}_3\text{/l})]
\end{align*}
\]  

(1)

Sodium adsorption ratio (SAR) was determined using the following equation:

\[
\text{SAR} = \frac{\text{Na}^{1+}}{\sqrt{\frac{\text{Ca}^{2+}}{2} + \text{Mg}^{2+}}}
\]  

(2)
Figure 1. The location of 60 studied wells in Kirkuk Governorate, Iraq.

3.2. Calculation of Canadian Water Quality Index (CWQI)
Assessing water quality involves dealing with several hydro-chemical parameters that are difficult to understand or interpret by locals or individuals with no basic training regarding the water quality. The main objective of the water quality indices is to provide simplicity and an easy way to understand the assessment of water quality. Several water quality indices are available. The CWQI classifies the water quality into five different groups depending on the number originated by the CWQI (table 1). This number ranges from 0 to 100, refers from poor to excellent category of the water quality.

| Rank      | CWQI values |
|-----------|-------------|
| Excellent | 95-100      |
| Good      | 80-94       |
| Fair      | 65-79       |
| Marginal  | 45-64       |
| Poor      | 0-44        |

The CWQI compromises of three elements, scope, frequency, and amplitude. The scope is referred to as $F_1$, which represents the number of parameters that fail to meet water regulations. The frequency referred to as $F_2$, denotes the number of time or percentage at which tests failed to meet regulation. According to CCME [18], both $F_1$ and $F_2$ are determined as follows:

$$F_1 = \left( \frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \quad (3)$$
Amplitude referred to as $F_3$, represents the amount at which water tests failed to meet water regulation. The $F_3$ is calculated using equation (5a) through (5d), as follows [18]:

$$F_3 = \left( \frac{NSE}{0.01 NSE + 0.01} \right) \times 100$$ (5a)

$$NSE = \left( \sum_{i=1}^{n} \frac{\text{excursion } i}{\text{Number of tests}} \right)$$ (5b)

$$\text{excursion } i = \left( \frac{\text{Objective } j}{\text{Faild test value } i} \right) - 1$$ (5c)

$$\text{excursion } i = \left( \frac{\text{Objective } j}{\text{Faild test value } i} \right) - 1$$ (5d)

where; $\text{excursion } i$ represents the number of times by which an individual test value failed to comply with the guideline; $NSE$ is the normalized sum of excursions; $n$ is total number of variables, $i$ and $j$ are iterations. Consequently, the CWQI is calculated as follows:

$$\text{CWQI} = 100 - \left( \frac{F_1^2 + F_2^2 + F_3^2}{1.732} \right)$$ (6)

**Figure 2.** The physical parameters of groundwater including well depths, temperatures, pH, TDS, TH, and EC for studied wells, Kirkuk Governorate, Iraq.

Due to the various uses of Kirkuk’s groundwater, the water quality was assessed for drinking, aquatic, recreation, irrigation, and livestock purposes using the CWQI calculator. The use of groundwater for
drinking and irrigation uses is critical in terms of public health. An excel spreadsheet of CWQI 1.0 calculator was utilized in this study to investigate the water quality index for wells from which samples were collected at different periods [18]. The standard of drinking water was based on Iraqi standards while others are depending on WHO standards. This was due to lack of information regarding with Iraqi standards for other usages. Both Iraqi and WHO standards were incorporated in CWQI Excel Spreadsheet.

In addition, the measured 15 water quality parameters were statistically inspected using the analysis of variance (ANOVA) technique within Sigma Plot 13.5 Software. The descriptive statistics for measured water quality parameters were reported as the mean, standard deviation, standard error, maximum, minimum, 25% percentile, and 75% percentile. The paired t-test method for pairwise comparisons was suggested by the Software. The paired t-test revealed a significant difference compared to ANOVA with a significance level of P-value less than 0.05 [19]; [20]; [21].

4. Results and Discussions
The physical water parameters as well as to the well water depth was mapped for each well in the study area, as shown in figure 2. Table 2 shows the details of the statistical description for measured physical parameters of 60 studied wells in Kirkuk city. Table 2 shows also the Iraqi standard for drinking as an example. The other standards were incorporated in the CWQI Excel Spreadsheet.

Table 2. Details of statistical description for measured physical, chemical, and biological parameters for studied wells (n = 60).

| Water quality parameters | Mean | Std. Dev. | Maximum | Minimum | Median | 25% | 75% | Iraqi Standard for drinking |
|-------------------------|------|-----------|---------|---------|--------|-----|-----|---------------------------|
| Physical parameters     |      |           |         |         |        |     |     |                           |
| Well depth, m           | 101.2| 38.4      | 200.0   | 5.0     | 100.0  | 70.0| 120.0|                           |
| Temperature, C°         | 19.1 | 3.7       | 28.0    | 12.0    | 20.0   | 18.0| 20.0|                           |
| pH                      | 7.5  | 0.3       | 8.2     | 6.8     | 7.5    | 7.2 | 7.7 | 6.5-8.5                   |
| TDS, ppm                | 826.2| 512.2     | 2510.0  | 209.0   | 829.0  | 371.3| 1097.5| 1000                     |
| TH, mg/l                | 665.9| 510.1     | 2400.0  | 120.0   | 540.0  | 313.0| 757.5| 500                      |
| EC, µS/cm               | 1220.8| 757.7    | 3700.0  | 310.0   | 1220.5 | 548.5| 1623.8| 1563                     |
| Chemical parameters     |      |           |         |         |        |     |     |                           |
| SO₄²⁻, mg/l            | 313.3| 302.2     | 1210.0  | 23.0    | 214.0  | 96.3 | 416.0| 400                      |
| NO₃⁻, mg/l             | 38.83| 33.2      | 155.0   | 3.3     | 29.0   | 20.8 | 43.8 | 50                       |
| PO₄³⁻, mg/l            | 0.7  | 3.7       | 28.7    | 0.02    | 0.09   | 0.07| 0.31| -                        |
| Cl⁻, mg/l              | 71.7 | 67.3      | 430.0   | 12.0    | 62.0   | 26.25| 83.5 | 350                      |
| Mg²⁺, mg/l             | 85.3 | 73.6      | 361.1   | 14.6    | 58.9   | 39.6 | 97.7 | 100                      |
| Ca²⁺, mg/l             | 128.0| 97.6      | 512.0   | 24.0    | 102.0  | 59.0 | 160.0| 150                      |
| Na⁺, mg/l              | 65.5 | 71.4      | 480.0   | 6.1     | 48.0   | 28.5 | 75.0 | 200                      |
| SAR, %                  | 2.3  | 1.9       | 11.6    | 0.36    | 1.8    | 1.36| 3.0 | -                        |
| Biological parameters   |      |           |         |         |        |     |     |                           |
| TPC, CFU/100 ml         | 43.5 | 29.0      | 120.0   | 0.0     | 40.0   | 20.0| 70.0|                           |
| T. Coliforms, CFU/100 ml| 30.0 | 81.2      | 540.0   | 5.3     | 5.3    | 0.0 | 32.0|                           |
| E-coli, CFU/100 ml      | 2.2  | 4.2       | 22.0    | 0.0     | 0.0    | 0.0 | 4.0 | -                        |

A maximum well depth of 200 m recorded in well # 1, while a minimum well depth of 5 m recorded in well # 40. The highest temperature (T), pH, Electrical conductivity (EC), Total Dissolved Solids (TDS), and Total Hardness (TH) were 28 C°, 8.2, 3700 µS/cm, 2510 ppm, and 2400 mg/l for well numbers # 13, 7, 28, 28, and 28, respectively. The measured EC, TDS, and TH for well # 28 exceeded
the Iraqi standard limits. In general, the mean of TH for studied wells exceeded the Iraqi standard limits. Seventy five percent of EC, TDS, and TH for studied wells exceeded the Iraqi standard limits for drinking (table 2 and figure 2). High EC, TDS, TH could be related to complex ionic exchange developed within the aquifer scheme. Therefore, the water quality index is needed to investigate the water quality for the studied wells.

Figure 3. The chemical parameters of groundwater including Sulfate (SO\textsubscript{4}\textsuperscript{2-}), Nitrate (NO\textsubscript{3}\textsuperscript{-1}), Phosphate (PO\textsubscript{4}\textsuperscript{3-}), Chloride (Cl\textsuperscript{-1}), and SAR for studied wells, Kirkuk Governorate, Iraq.

The chemical water parameters were plotted for each well in the study area as shown in figure 3. The highest SO\textsubscript{4}\textsuperscript{2-}, NO\textsubscript{3}\textsuperscript{-1}, PO\textsubscript{4}\textsuperscript{3-}, Cl\textsuperscript{-1}, and SAR were 1210 ppm, 155 ppm, 28.7 ppm, 430 ppm, and 11.6% for well numbers of 28, 60, 51, 49, and 49, respectively. The measured chemical parameters exceeded the Iraqi standard limits for these wells (table 2). The 75% of SO\textsubscript{4}\textsuperscript{2-} for studied wells exceeded the Iraqi standard limits (table 2 and figure 3). Chlorine is a conservative compound and represents the rule of urbanization in altering groundwater chemistry [22]. Elevated concentrations of chlorine could be related to organic waste from domestic sewage of seepage pits from surrounding residential areas. Similar finding was obtained by Yogendra and Puttaiah [23] and Singh and Khan [24]. Similarly, occurrence of nitrate revealed the contamination of groundwater in urbanized areas such as Kirkuk [25]. The high value of NO\textsubscript{3}\textsuperscript{-1} in ancient residential areas in studied area may be generated from oxidation of ammonium formed from sewage of seepage pits through an unsaturated zone, where sufficient Oxygen diffuses from atmosphere causing most oxidation of the reduced wastewater components [26].
Biological properties of water significantly influence water quality and human life. Presence of total coliforms and E-coli were detected in 30 out of the 60 wells under investigation (figure 4). The highest values of TPC, T. coliforms, and E-coli were 120, 540, and 22 CFU/100 ml for well numbers 21, 23, and 23, respectively (table 2 and figure 4). Presence of E-coli in water makes it incompatible for human consumption. Occurrence of E-coli is linked to fecal contamination by humans and other warm-blooded species. This may be related to the infiltration from seepage pits [27]. Proper water treatment must be conducted to eliminate bacterial growth through chlorination. Chlorination of water is defined as the addition of chlorine to water to form a weak hypochlorous acid that is efficient at killing bacteria including E-coli.

The results of 15 water quality parameter including pH, T, EC, TDS, SO₄²⁻, NO₃⁻, PO₄³⁻, Mg²⁺, Ca²⁺, TH, TPC, Cl⁻, Na⁺, TC, and E-coli for 60 studied wells were used to determine the CWQI. As mentioned above, the CWQI was determined for well numbers of 1 to 24 (for 2017), 25 to 46 (for 2018), and 47 to 60 (for 2019). Due to the various uses of the groundwater of Kirkuk, the groundwater quality was assessed for drinking, aquatic, recreation, irrigation, and livestock purposes. The Iraqi guidelines were used to determine the CWQI for drinking, while CWQI for irrigation, aquatic, livestock, and recreational uses were calculated depending on the WHO standards. Ten and eleven out of 15 parameters failed to meet the drinking guidelines in collected samples of 2017 and 2018, respectively. Amongst samples of 2019, twelve parameters failed to meet the drinking guidelines. For irrigation, only 2 parameters failed to comply with the irrigation standards in collected samples of 2017 and 2018, while three parameters failed for irrigation in 2019. Therefore, CWQI was implemented to obtain general understanding regarding the groundwater quality.
Figure 5. The Canadian water quality index (CWQI) for well numbers 1 to 24 that were sampled within 2017 of study area.

Figure 6. The Canadian water quality index (CWQI) for well numbers 25 to 46 that were sampled within 2018 of study area.

Figures 5 and 6 show the CWQI of the studied wells during 2017 and 2018, respectively. The CWQI values were 53, 98, and 98 for drinking, aquatic, and recreational, respectively, of wells numbered 1 to
that were sampled within 2017 (figure 5). The groundwater for wells collected in 2017 can be classified as excellent for both aquatic live and recreational activities. This was due to both aquatic live and recreational activities are meanly depended on pH values. The values of pH were within the limits of Iraqi and WHO standards (table 2). In contrast, the groundwater for wells collected in 2017 was classified as marginal for drinking usages depending on the CWQI (figure 5 and table 1). This is significant as most of the wells were used for drinking purposes. Hence, caution must be taken to protect human health and sufficient water treatment should be conducted to raise water quality to acceptable levels, prior to drinking. Similar observation was noticed in 2018 regarding the groundwater categories depending on CWQI for aquatic, recreational, and drinking as shown in figure 6. Figure 7 shows the CWQI for studied well # of 47 to 60 from which samples were collected within 2019. The case was even worst during 2019 as the CWQI was 40, indicating poor water quality for drinking (figure 7). Thus, caution must be taken when using water for drinking and sufficient water treatment must be conducted for these wells.

![Figure 7. The Canadian water quality index (CWQI) for well numbers 47 to 60 that were sampled within 2019 of study area.](image)

In case of irrigation usages, the CWQI were 70 and 69 within 2017 and 2018, respectively. This is referred to as fair water quality (figures 5 and 6). In the year of 2019, the CWQI was 56 and was categorized as marginal (figure 7). In general, drinking water quality declined from marginal to poor from 2017 to 2019 (figure 8). The CWQI also declined from fair to marginal for irrigation usages. According to a study conducted by Abdul Jalil and Al-Hamdani [27], hydro chemical data suggested that both leakages from agricultural area and infiltration from domestic seepage pits caused groundwater contamination in Kirkuk Governorate. The findings of this study showed low water quality in comparison with Saud [28] study in terms of good water quality for all purposes including drinking. Saud [28] reported that the CWQI were 48 and 66 in 2007 for drinking and irrigation purposes, respectively. This was due to global warming and low water surface recharges due to low flowrate quantities from neighboring countries and low rainfalls in recent years.
Figure 8. Comparison of CQWI for drinking and irrigation water usages for 60 studied wells that were sampled in 2017, 2018, and 2019.

5. Conclusions
Quality of groundwater in Kirkuk was assessed using CWQI combined with GIS tool. Samples from 60 wells within Kirkuk Governorate were used to assess groundwater quality for drinking, irrigation, aquatic, recreation and livestock based on the Iraqi and WHO guidelines. The results of 15 water quality parameters including pH, T, EC, TDS, SO\(_4^{2-}\), NO\(_3^{-}\), PO\(_4^{3-}\), Mg\(^{2+}\), Ca\(^{2+}\), TH, TPC, Cl\(^{-}\), Na\(^{+}\), TC, and E-coli for studied wells were used to determine the CWQI. According to data availability, CWQI was determined for samples taken in 2017 from well # 1 to 24, in 2018 from well # 25 to 46, and in 2019 from well # 47 to 60. Detected of Fecal coliforms and E-coli within 30 wells out of the 60 in the study area indicated that there is a fecal contamination of groundwater. The groundwater was categorized as excellent for aquatic and recreation purposes over the studied wells. The result showed marginal water quality for drinking in studied wells of the year of 2017 and 2018. However, poor water quality for drinking was suggested by the CWQI calculator in studied wells of 2019. This study also showed that the groundwater is unsuitable especially for drinking purposes in comparison to previous studies. Global warming and low water surface recharges due to low flowrate quantities from neighboring countries along with low rainfalls are the reason for poor water quality in recent years. Declining water quality with time requires further investigation to clearly identify contamination causes and sources. It is also beneficial to investigate the level of groundwater in Kirkuk’s hydrological basins to find whether sufficient recharging and water levels are available for diluting the contamination levels.
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