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A chemical analysis to assess drinking water treatment facilities in Fallujah, Anbar Governorate, Iraq

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Abstract
Water consumption is an essential resource intricately connected to human health and ecological stability. Purification is an essential process to guarantee the absence of physical, chemical, and biological pollutants. This study seeks to assess the quality of drinking water at six prominent water purification facilities in Fallujah City, Anbar Governorate, Iraq.

The findings indicated that the turbidity of the raw water surpassed the allowable threshold (5 NTU), measuring between (7.7±0.103) and (9.9±0.251) NTU. Post-filtration, the turbidity diminished to a range of (1.3±0.112) to (2.7±0.113) NTU, demonstrating the efficacy of the treatment. The pH value was documented within the permissible range (6.5 - 8.5) both prior to and subsequent to filtration. The electrical conductivity exhibited a modest rise post-treatment, rising from (1325 - 1331) µS/cm to (1431 - 1440) µS/cm, however it remained beneath the acceptable threshold of 2000 µS/cm. Total hardness was noted to remain elevated before and after filtration (540-546 mg/L), surpassing the allowable maximum limit (200 mg/L). Calcium exhibited a marginal rise post-treatment, to a concentration of (153±8.322) mg/L, surpassing the allowed limit of (150 mg/L). The amounts of magnesium, chloride, sulphate, sodium, potassium, and total dissolved solids remained below acceptable levels.

The data demonstrate that the filtration plants in Fallujah are proficient in eliminating turbidity and regulating pH, yet they are inadequate in diminishing hardness and mineral concentrations, including calcium.

Keywords: Water, pollutants, water purification

Introduction

Water is a crucial natural resource indispensable for sustaining life, as it is intrinsically connected to public health, agriculture, industry, and sustainable development [1]. Due to escalating population growth, industrialisation, and the proliferation of pollution sources, water quality has emerged as a significant environmental concern for communities, particularly in regions dependent on surface water susceptible to contamination [2]. The critical significance of drinking water treatment plants arises, as they function as the primary safeguard in ensuring safe and potable water for human consumption by eliminating or diminishing physical, chemical, and biological contaminants to acceptable levels in accordance with established health standards [3].

This study aimed to assess the efficacy of six primary drinking water purification facilities in Fallujah, Iraq, which are essential for servicing extensive residential zones within the city. The assessment was conducted in the spring of 2025 by collecting water samples pre- and post-purification from each station, intending to analyse the chemical alterations occurring during treatment and to evaluate the efficacy of the various treatment units.

This study's chemical studies concentrated on essential variables that represent the overall properties of water, with pH being the most significant, serving as a crucial indicator of the balance between acidity and alkalinity. The fluctuation in its levels influences the efficacy of disinfection procedures and the toxicity of specific substances [4]. Turbidity was assessed, indicating water transparency and serving as a proxy for the concentration of suspended and organic components, which may influence disinfection efficacy and signify the existence of undetectable pollutants [5].

The study also encompassed the measurement of electrical conductivity and total dissolved solids (TDS), which serve as indicators of the overall concentration of dissolved ions in the water, including cations and anions, thereby reflecting the saltiness of the water and its geological or industrial origin [6]. Alkalinity was assessed as the water's capacity to withstand pH fluctuations, indicative of its bicarbonate and carbonate content, which contribute to the stabilisation of the water's chemical equilibrium [7]. The total hardness resulting from the concentration of calcium and magnesium ions was assessed, impacting the utilisation of water for home and industrial applications [8].

The emphasis was on quantifying the concentrations of specific ions with health and environmental implications, including chlorides and sulphates, which serve as potential indicators of pollution from wastewater or agricultural activities, alongside sodium and potassium, which are critical for evaluating water salinity and its appropriateness for consumption or irrigation [9]. Calcium and magnesium concentrations were recognised as essential elements of hardness and indications of mineral equilibrium in water [8].

This study seeks to deliver a precise scientific assessment of filtration stations' efficacy in enhancing water quality, juxtapose them with established standard criteria, and furnish an updated database regarding the state of drinking water in Fallujah during the spring season, thereby aiding in the refinement of technical and administrative decisions pertinent to water resource management and the enhancement of water services in the region.

Materials and Methods

The research was carried out in the spring of 2025 at six primary drinking water treatment facilities in Fallujah, Iraq (Figure 1). Two samples were obtained from each station: one from the untreated water prior to treatment and another from the treated water post-filtration, resulting in a cumulative total of 12 samples.

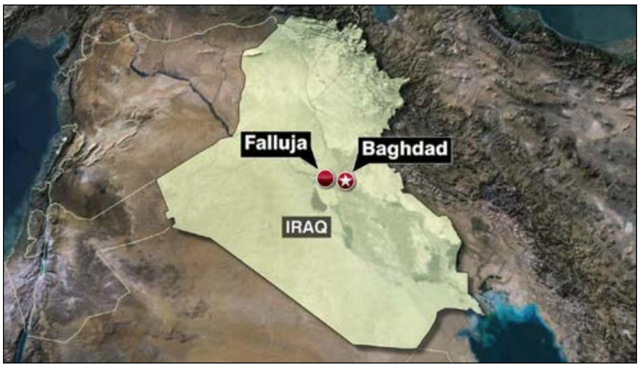

Fig 1: Site Study

Sampling

The samples were gathered in sterile plastic containers, promptly stored in chilling units, and transferred to the laboratory for analysis within six hours of collection. The collection and analysis processes conformed to the World Health Organisation (WHO) standard criteria and the Iraqi standards for drinking water quality.

Chemical and Physical Tests

- Chemical and physical analyses in the laboratories of the College of Chemical Engineering at Tikrit University were performed with diverse instruments and methodologies as detailed below:
  The pH function was assessed utilising a Biobass pH meter, which was calibrated with standard solutions to guarantee the precision of the measurements.
- The turbidity was quantified with a turbidimeter from MKLAB, and the results were documented in NTU (Nephelometric Turbidity Units).
- The electrical conductivity (EC) and total dissolved solids (TDS) were quantified using the integrated electrical conductivity apparatus from Hanna, produced in Singapore, which utilises an internal algorithm to translate conductivity into salt concentration.
- The determination of sulphate (SO_4^{2-}) was conducted via the turbidimetric method, wherein sulphate ions reacted with barium chloride to produce a turbid precipitate, thereafter quantified with a spectrophotometer at a suitable wavelength [10].
- Chloride (Cl^-) was quantified utilising the Mohr method, which entails titrating silver nitrate in a neutral environment with potassium chromate serving as an indicator. The concentration is determined by the volume of silver nitrate utilized [11].
- Alkalinity was assessed using titration with an acidic solution (HCl), employing phenolphthalein and methyl orange to identify the specific type of basicity (carbonate or bicarbonate) [12].
- Total hardness was assessed using titration with an EDTA solution, employing Eriochrome Black T indicator to ascertain the endpoint, followed by the calculation of total calcium and magnesium concentrations [13].
- Sodium (Na^+), potassium (K^+), and calcium (Ca^+) were quantified utilising a Biobass flame spectrometer, after the preparation of a set of standard solutions and the construction of calibration curves for each element. The observed values for the water sample were juxtaposed with these curves to ascertain the concentrations, as illustrated in Figure (2).
- Magnesium (Mg^+) was quantified utilising a Shimadzu atomic absorption spectrometer, model AA-6200, with absorbance measured at the designated wavelength (285.2 nm), and the findings were juxtaposed with the standard calibration curve for each element depicted in Figure (3).

The data were derived from three measurements per test utilising Graphpad Prism9 statistical software.

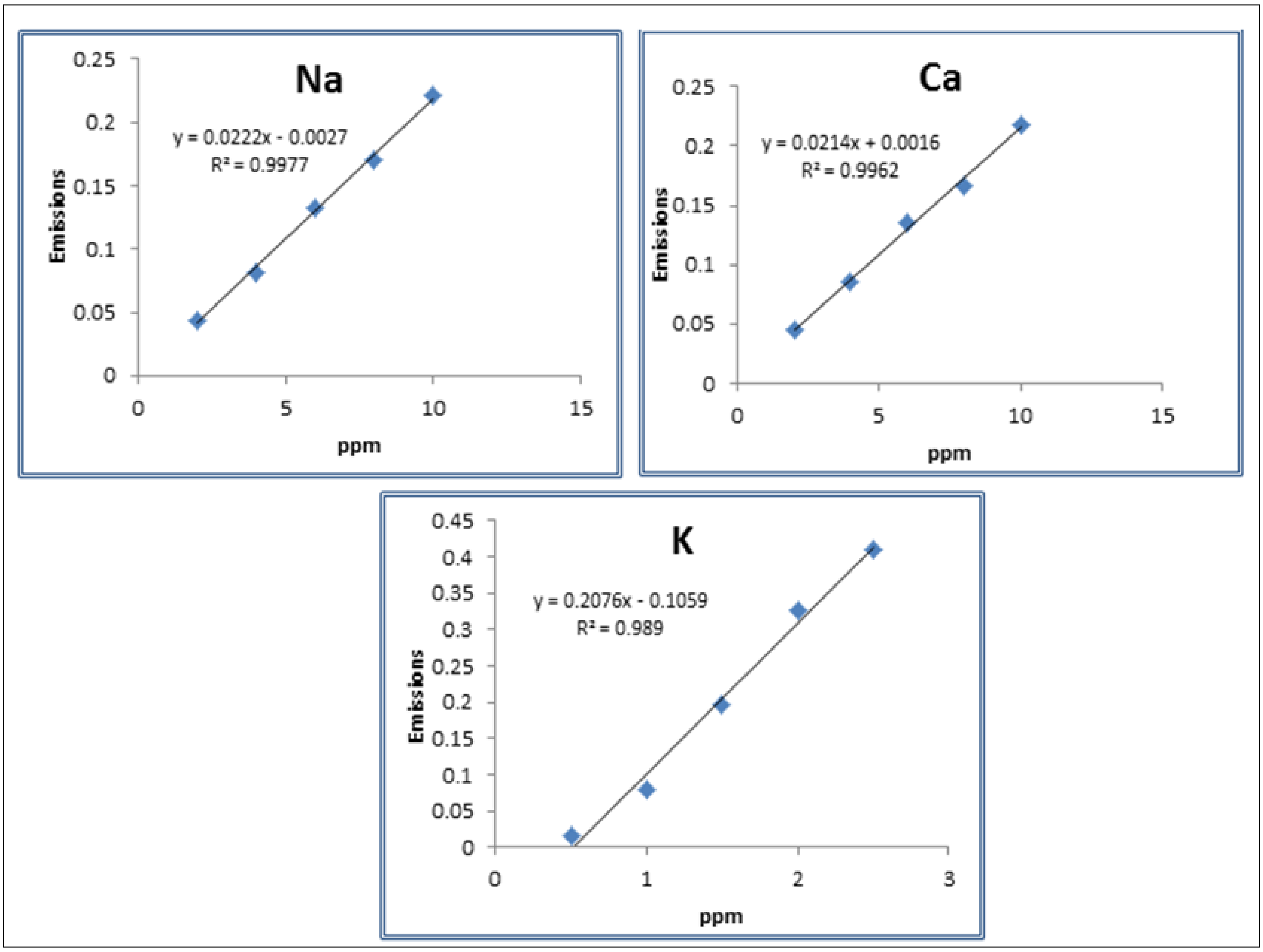

Fig 2: Titration curves for alkali metals

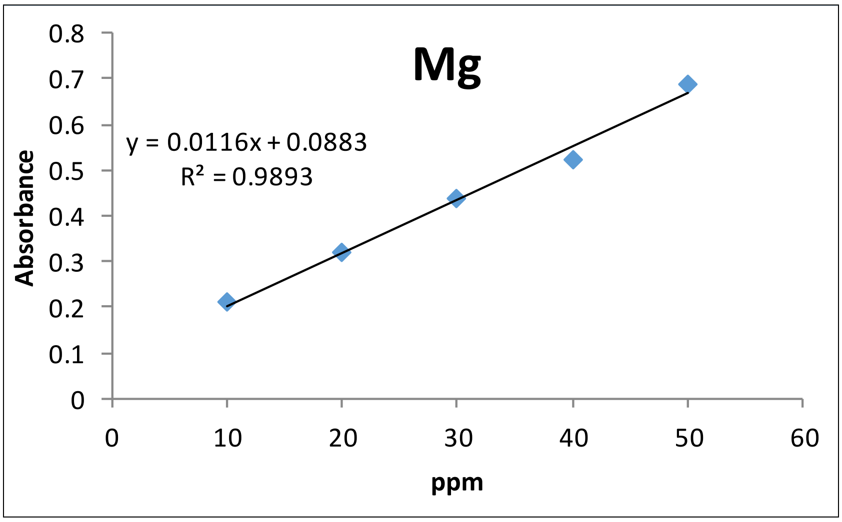

Fig 3: Calibration curve for magnesium

Results and Discussion

Table No. (1) presents the results of the chemical and physical characteristics of the water prior to treatment at the examined stations, whereas Table No. (2) displays the results obtained from the water samples subsequent to treatment at the same stations. Each variable will be addressed subsequent to the presentation of the results.

Table 1: Presents the results of the chemical and physical characteristics of the Raw water

Sample location	Al-Fallujah New Water Project	Al-Fallujah Old Water Project	Al-Risalah Water Complex 1	Al-Risalah Water Complex 2	Al-Tahaddi Water Complex 1	Al-Tahaddi Water Complex 2	MPL
Parameters in mg/L Unless otherwise Stated	Raw	Raw	Raw	Raw	Raw	Raw	
Turbidity, NTU	9.9±0.251	9.8±0.108	8.8±0.113	7.7±0.103	9.3±0.112	8.1± 0.111	5
pH	7.6±0.211	7.7±0.251	7.8±0.305	7.8±0.313	7.7±0.401	7.7±0.222	6.5-8.5
E.C. µS/CM 25 C°	1326±2.956	1325±4.892	1330±4.452	1330±5.112	1331±4.928	1326±4.312	2000
Alkalinity (as $CaCO_3$)	113±2.462	110±2.145	110±1.998	112±2.611	113±3.112	114±3.246	125-200
Hardness (as $CaCO_3$)	540±6.121	540±7.118	540±6.984	542±10.322	540±8.349	541±7.524	500
Calcium (as Ca)	146±5.241	147±4.338	149±5.213	148±7.341	146±5.951	145±8.331	150
Magnesium (as Mg)	43±0.763	42 ±0.837	41±0.833	42±0.764	43±0.911	44±0.853	100
Chloride (as Cl)	213±5.362	216±7.311	218±7.842	212±6.824	217±8.431	212±6.834	350
Sulphates (as SO_4)	369±8.642	368±7.936	369±6.583	365±5.473	369±4.935	370±6.322	400
Sodium (as Na)	108±1.065	108±0.873	109±0.931	108±1.121	106±0.889	107±0.931	200
Potassium (as K)	4.6±0.531	4.5±0.455	4.5±0.397	4.6±0.461	4.4±0.511	4.5±0.601	12
T.D. S	870±7.341	874±6.482	876±8.112	878±9.461	880±8.211	868±9.341	1000

Table 2: Presents the results of the chemical and physical characteristics of the clean water

Sample location	Al-Fallujah New Water Project	Al-Fallujah Old Water Project	Al-Risalah Water Complex 1	Al-Risalah Water Complex 2	Al-Tahaddi Water Complex 1	Al-Tahaddi Water Complex 2	MPL
Parameters in mg/L Unless otherwise Stated	Clean	Clean	Clean	Clean	Clean	Clean	
Turbidity, NTU	1.18±0.085	2.7±0.113	1.7±0.106	1.3±0.112	2.2±0.131	2.3±0.141	5
pH	7.6±0.241	7.6±0.321	7.7±0.262	7.7±0.421	7.7±0.382	7.7±0.228	6.5-8.5
E.C. µS/CM 25 C°	1413±4.734	1410±5.325	1440±6.114	1420±7.132	1388±4.961	1389±5.213	2000
Alkalinity (as $CaCO_3$)	113±3.243	113±4.112	113±2.879	114±3.214	112±4.311	114±3.422	125-200
Hardness (as $CaCO_3$)	548±7.332	544±6.324	548±4.985	547±6.523	546±5.821	548±6.431	500
Calcium (as Ca)	146±3.231	147±1.642	147±1.095	147±1.232	147±1.642	146±2.085	150
Magnesium (as Mg)	45±0.641	42±0.536	44±0.722	44±0.693	44±0.352	45±0.212	100
Chloride (as Cl)	214±6.743	221±5.932	216±4.983	218±6.372	214±4.823	216±5.212	350
Sulphates (as SO_4)	377±6.857	381±7.322	380±5.847	378±6.431	373±3.998	377±4.367	400
Sodium (as Na)	107±1.023	108±0.996	110±1.130	109±1.207	109±2.011	110±1.753	200
Potassium (as K)	4.6±0.673	4.6±0.942	4.6±0.747	4.6±0.521	4.6±0.483	4.6±0.482	12
T.D. S	920±8.164	916±7.846	908±9.324	910±6.845	904±5.734	900±7.392	1000

The turbidity test results for raw water at all six stations indicated values between 7.7±0.103 and 9.9±0.251 NTU, all surpassing the maximum allowable limit of 5 NTU as per drinking water standards, signifying a substantial presence of suspended particles prior to filtration. Nonetheless, these values diminished markedly post-filter to entirely safe levels, ranging from 1.3±0.112 to 2.7±0.113 NTU, indicating the efficacy of the filtration and sedimentation units across all stations. As shown in the figure (4).

The pH values remained within the acceptable range (6.5 - 8.5) both prior to and following treatment. The pre-filtration values were (7.6±0.211) and (7.8±0.305), which slightly increased post-treatment to (7.6±0.241) and (7.8±0.421). This demonstrates stability in the acidic and basic properties, indicating that the filtration processes did not significantly affect them, which is a favourable sign of the biochemical stability of the water system. As shown in the figure (5).

Regarding electrical conductivity (E.C), an indirect measure of total dissolved salts, all pre-filtration values were below the maximum threshold of 2000 µS/cm, ranging from (1325±4.892) to (1331±4.928) µS/cm. However, post-treatment values increased slightly at most stations, reaching (1440±6.114) µS/cm, suggesting that certain ion exchange processes or interactions with added chemicals contributed to the elevated concentration of dissolved ions. As shown in the figure (6).

Alkalinity values were documented within acceptable limits (<200 mg/L), fluctuating between (110±1.998) and (120±4.115) mg/L prior to filtration, and diminished in certain locations post-treatment to a minimum of (112±3.243) mg/L. This indicates the efficacy of the treatment units in reducing the alkaline compounds responsible for elevated alkalinity, thereby enhancing the taste and chemical stability of the water. As shown in the figure (7).

The total hardness values prior to filtration were elevated, surpassing the recommended maximum for potable water (500 mg/L), with measurements ranging from (540±6.984) to (546±7.324) mg/L. Post-filtration, these levels remained unchanged, suggesting that the filtration facilities do not implement technologies for the removal of calcium and magnesium, such as ion exchange or reverse osmosis, which could adversely impact water quality if hardness is not managed. As shown in the figure (8).

Calcium concentrations prior to filtration surpassed the maximum threshold of 150 mg/L at all stations, attaining a peak value of (149±8.334) mg/L. Post-filtration, levels increased marginally to (153±8.322) mg/L at the "Challenge 2" station, likely due to potential secondary sources of calcium emanating from pipe materials or chemicals employed in the filtration process. As shown in the figure (9).

The concentration of magnesium prior to treatment varied between (41±0.833) and (44±0.853) mg/L, remaining within the permissible limit of 100 mg/L. Post-treatment, no significant alterations were observed, indicating the stability of this element and its resistance to fluctuations due to filtration processes. As shown in the figure (10).

Chloride concentrations rose markedly before to filtration, fluctuating between (212±6.834) and (218±8.532) mg/L, remaining below the permitted threshold of (350 mg/L). Subsequently, there was a little increase in most stations post-treatment, attaining a concentration of (222±8.141) mg/L, suggesting that the addition of chlorine for sterilisation may lead to a marginal rise in the overall chloride content of the water. As shown in the figure (11).

Sulphate concentrations ranged from (365±6.832) to (370±6.834) mg/L prior to filtration, remaining below the permissible limit of (400 mg/L). Following treatment, levels slightly increased to between (380±5.847) and (385±9.014) mg/L, demonstrating effective management of this compound and its absence of accumulation post-filtration. As shown in the figure (12).

Concerning sodium, all pre-treatment measurements fell within the acceptable limit of 200 mg/L, varying from 106±0.986 to 110±1.125 mg/L, and demonstrated a minor increase post-treatment to 110±0.951 mg/L, a negligible elevation likely due to the incorporation of sodium-containing treatment materials. As shown in the figure (13).

The potassium concentrations were notably low across all stations, both pre- and post-filtration, varying from (4.5±0.455) to (4.8±0.521) mg/L, significantly below the maximum permissible limit of (12 mg/L). This suggests a lack of substantial organic pollution sources or excessive salinity that could elevate this element's levels. As shown in the figure (14).

The total dissolved solids (TDS) values prior to filtration were within the acceptable upper limit of 1000 mg/L, ranging from (868±9.341) to (880±8.211) mg/L. Following treatment, TDS values exhibited a slight increase, reaching (922±8.146) mg/L at certain stations, attributed to the dissolution of specific salts during the chemical treatment process. As shown in the figure (15).

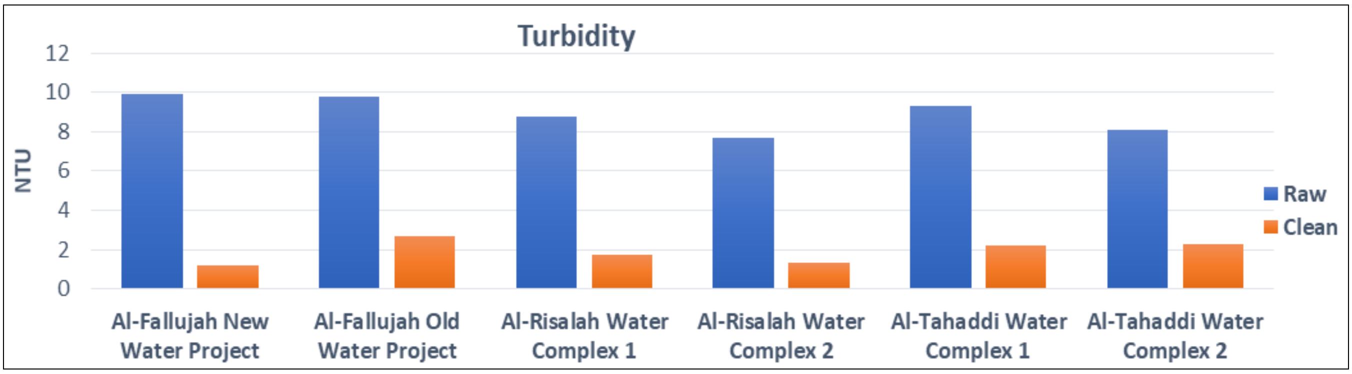

Fig 4: Turbidity levels

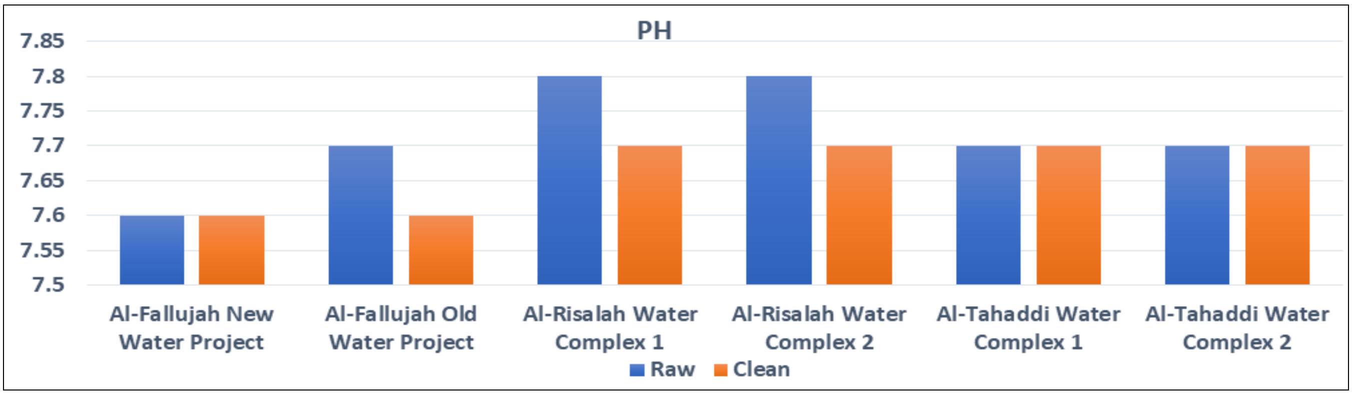

Fig 5: pH levels

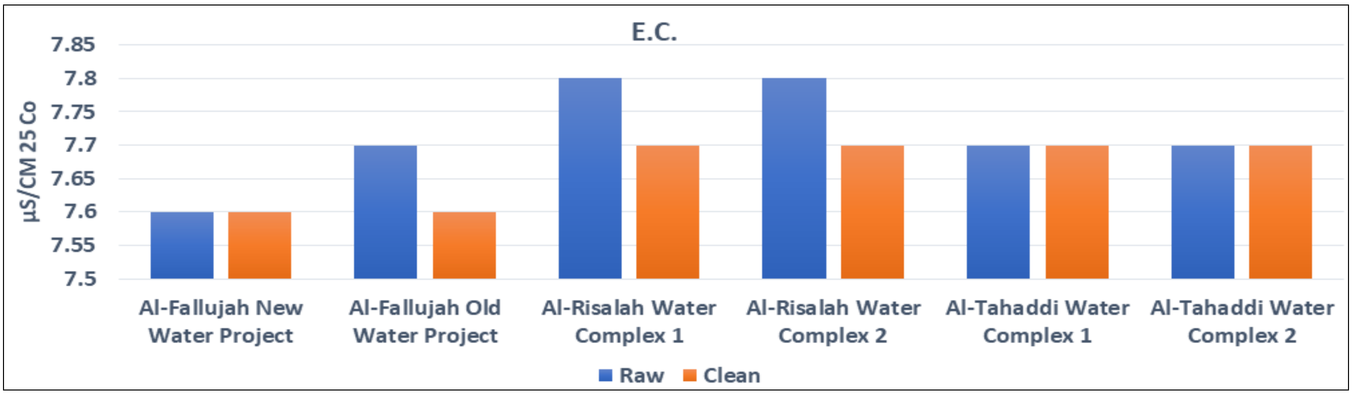

Fig 6: Electrical Conductivity levels

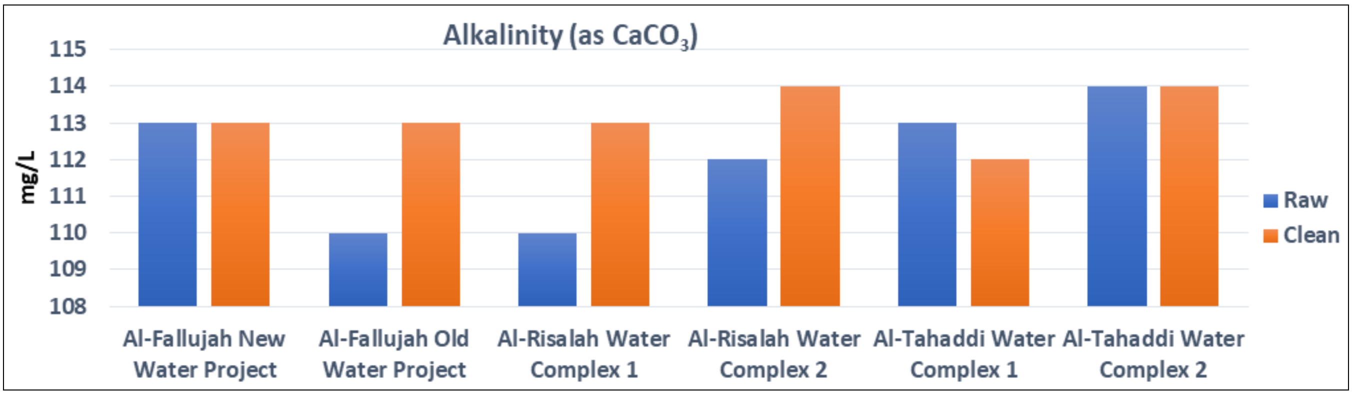

Fig 7: Alkalinity levels

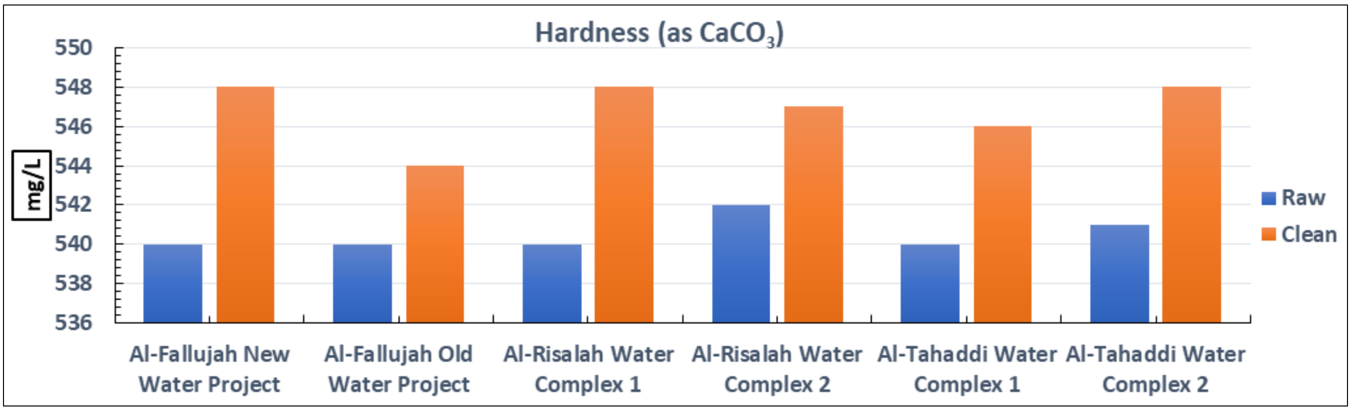

Fig 8: Total Hardness levels

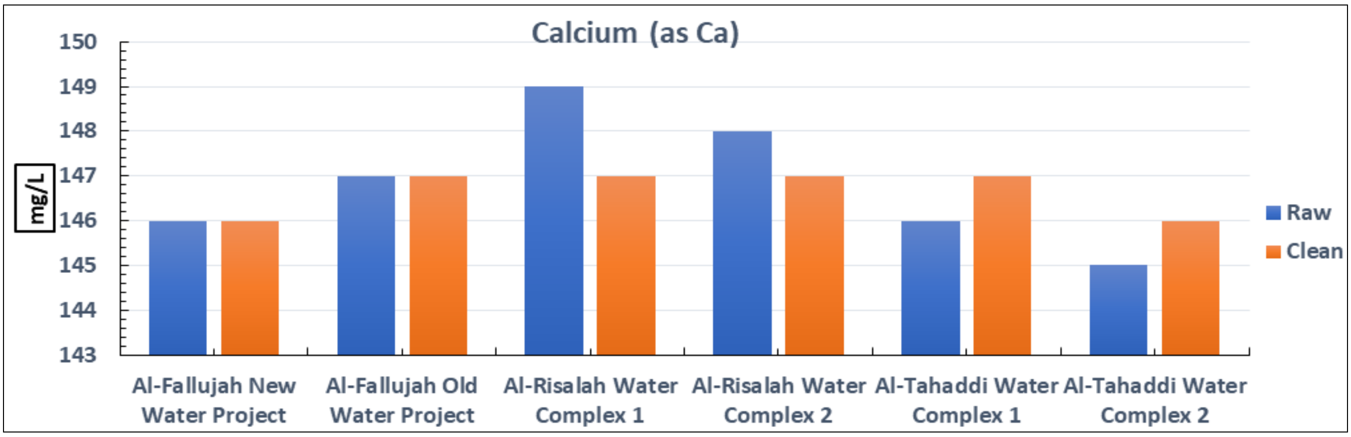

Fig 9: Calcium levels

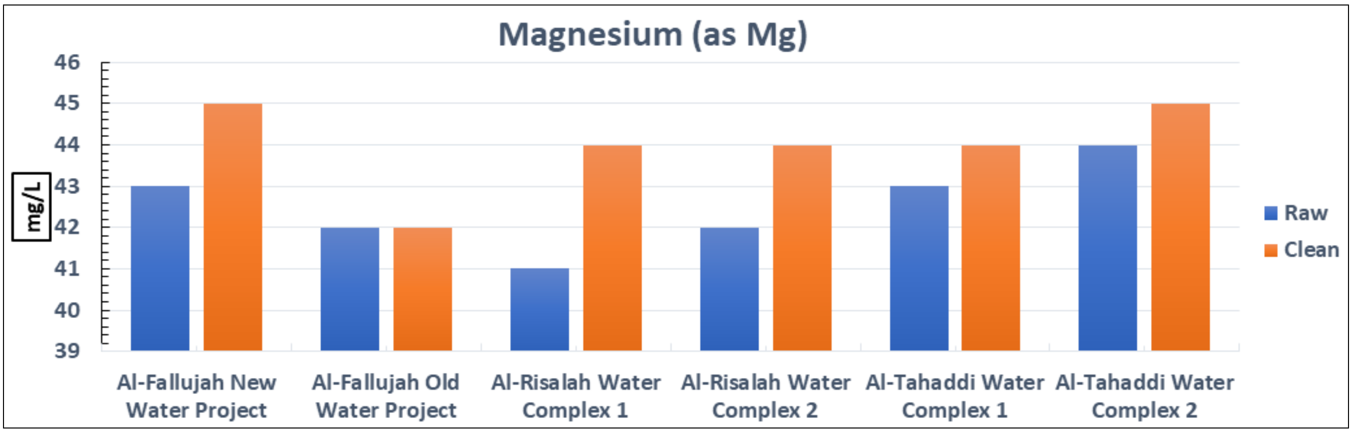

Fig 10: Magnesium levels

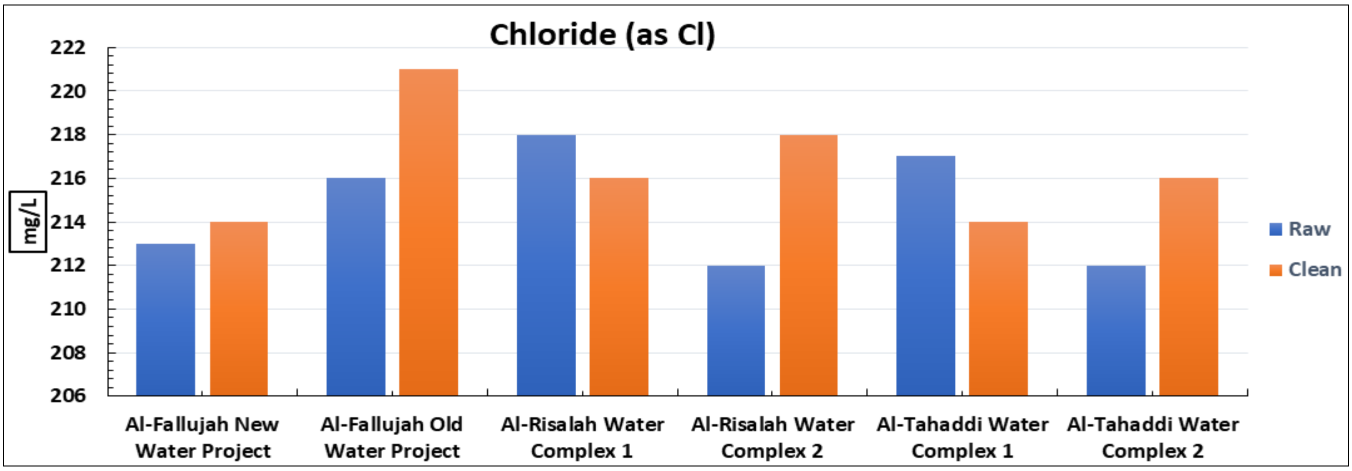

Fig 11: Chloride levels

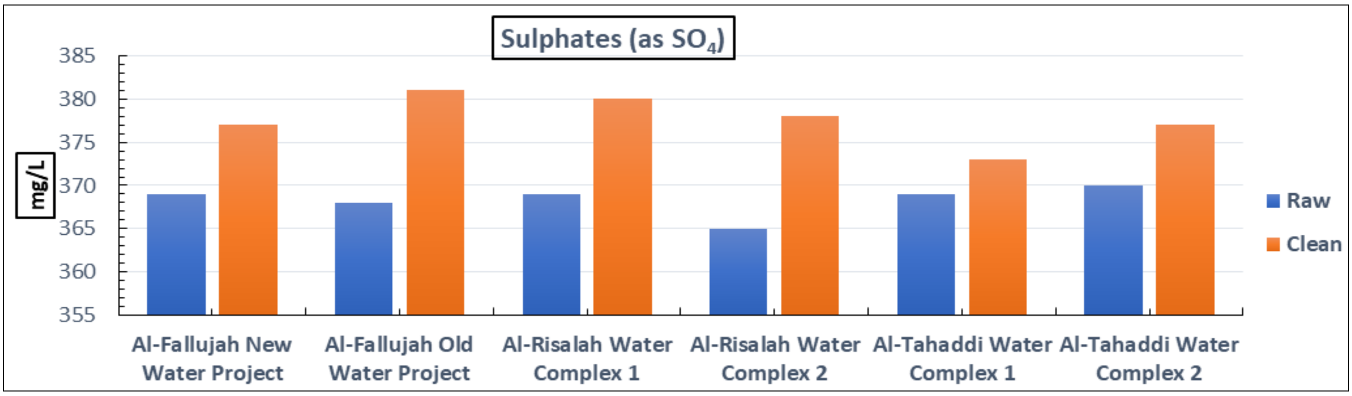

Fig 12: Sulphates levels

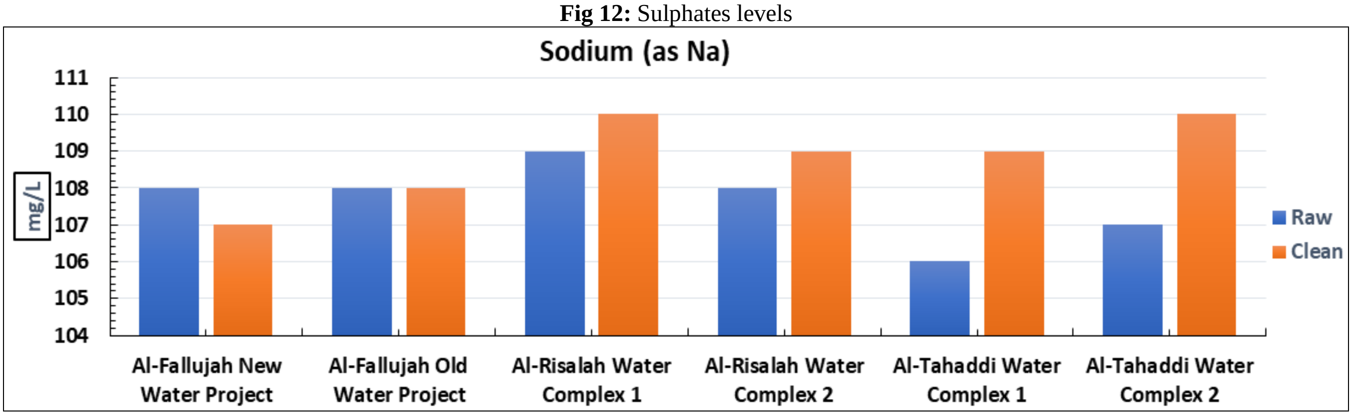

Fig 13: Sodium levels

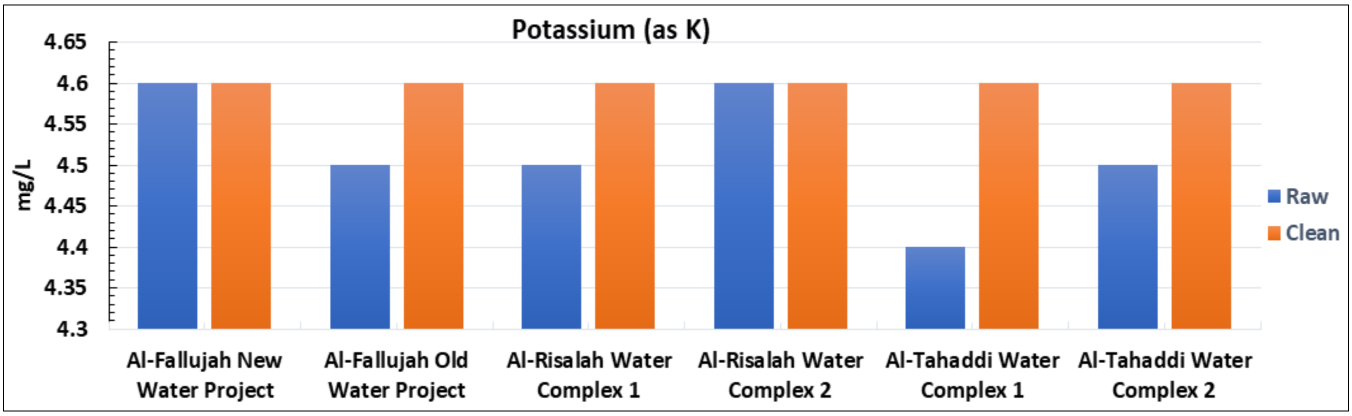

Fig 14: Potassium levels

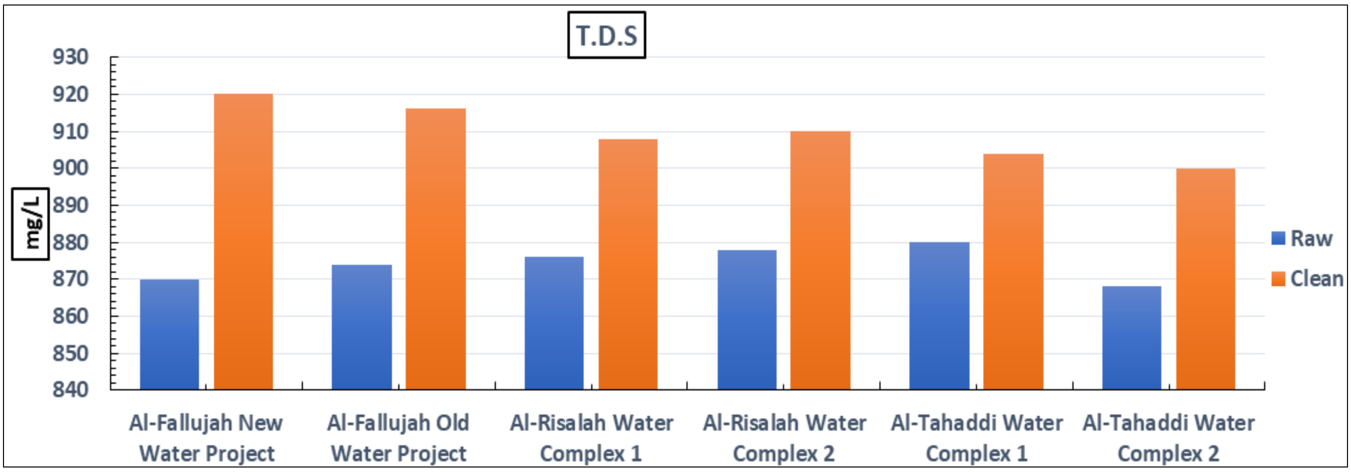

Fig 15: TDS levels

Conclusion

The filtration plants in Fallujah shown high efficiency in decreasing turbidity and regulating pH, hence showcasing the efficacy of the physical treatment processes. Nevertheless, the treatment failed to adequately diminish total hardness and calcium concentration, since both metrics remained elevated post-filtration. A little elevation in electrical conductivity and total dissolved solids was noted, indicating the possible impact of chemicals introduced during filtering. These findings underscore the necessity to enhance treatment technologies, specifically with the removal of salt and hardness, to guarantee consistent and safe drinking water quality.

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