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Risk Assessment of the Calcium in the Drinking Water Supplies in Babylon Governorate, Middle of Iraq

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Abstract

The study of the risk of high concentrations of drinking water parameters is an important part of the toxicity due to the direct effect to human health in a variety of ages. In this study, the adverse effects of high concentrations of calcium in drinking water the middle of Iraq was investigated. The study attempts to determine the risk to adults and children of the calcium in the drinking water. For this purpose, four main conventional water treatment plants were selected to determine the calcium risk in the water. Monte Carlo (MC) simulation were applied to determine this risk with different percentiles 10, 25, 50, 75 and 90. The results of Hazard Quotient (HQ) of adults and child were ranged (1-3) for both recent and future estimation, which is above the standard values. Therefore, suggested scenario was applied to decrease concentrations of calcium, includes the addition of a nanofiltration unit in each water treatment plant. The risk of the suggested recent scenario was determined which was within the acceptable range. To ensure the effectiveness of the scenario in the next time (MC) simulation were applied to determine the risk. The values of HQ were less than 1. The estimated values of the deterministic and probabilistic HQ have a value of about 10 %. These values were acceptable for diversity test using CV.

Keywords: drinking water, Monte Carlo simulation, calcium, risk assessment, hazard quotient, water treatment, calcium removal.

1. Introduction

Drinking water is essential for human life, yet it contains various constituents that can pose health risks. Changes in these constituents can render water harmful, and the degree of harm can be estimated through health risk assessment. Health risk assessment involves estimating the likelihood of toxic substances affecting human health and safety, based on toxicological, epidemiological, environmental, and exposure data. The assessment provides a health risk score, indicating the potential harm to human health [1].

In the past, water hardness was inaccurately and broadly defined chemically, where calcium and magnesium were collectively measured as hardness [2]. Recently, there has been increased interest in calcium due to its correlation with chronic heart disease risk from hard water consumption [3]. Over the last few decades, evidence has accumulated suggesting that water hardness, particularly high calcium and magnesium content, may be linked to increased cardiovascular mortality and other health issues such as growth delays and reproductive problems [4].

Studies have reported throat and kidney problems associated with long-term consumption of hard water. The World Health Organization recognizes the harmful effects of prolonged hard water consumption on the cardiovascular system, potentially causing kidney strain, stomach upset, nausea, abdominal pain, and interference with brain and heart function [5][6]. Excessive calcium intake has also been linked to health risks [7], prompting epidemiological studies to suggest a beneficial calcium concentration in drinking water of 20-30 mg/l for health benefits [8]. However, permissible limits vary; some sources recommend not exceeding 75 mg/l, while Iraqi standards set the guideline at 50 mg/l [9][10].

Research by [11] specifically investigated the relationship between calcium and cardiovascular diseases in Babylon Governorate, where the Shatt Al-Hilla river is the primary drinking water source. Cardiovascular diseases are a significant health concern in Iraq [12].

Different methods used for remove of decrease calcium concentration from water [13] ,[14], [15]. The percent of removal depends on the type of water being used [14]. Methods like Electromagnetic polarization , Ion flotation , Dialysis and nanofltration were used for calcium removal from water. [13] ,[14], [15] and [16].the selection of the perfect calcium removal method, depending on the water using type and cost factors.[13] and [16]. Your sentence is almost perfect. This study aims to assess the human health risks associated with calcium in drinking water sourced from surface water supplies in Babylon Governorate, Iraq. The calcium concentration levels are detailed in Table 1.

Table 1: Water quality depending calcium concentrations after [4].

Concentration (mg/L)	Type of water
0- 60	Soft
61- 120	Moderate
121- 180	Hard
>180	Very hard

2. Area of Study

The Shutt Al-Hilla River, a primary branch of the Euphrates River in Iraq, serves as the main source of drinking water for Babylon Governorate, located in the Middle Euphrates region between longitudes 44°16′11.9″E - 44°46′31.5″E and latitudes 32°03′14.5″N - 32°43′44.3″N [17]. This river is crucial for many residential areas in providing potable water [18]. Stretching approximately 104 km southeastward, it flows through agricultural, municipal, and industrial zones, ultimately marking the administrative boundary between Babylon and Al-Qadisiyah governorates [19]. The river has an average discharge of 200 m^3/sec [20].

The quality of Shutt Al-Hilla River water varies seasonally, with rain and ice thaw during the wet season and water from lakes during the dry season serving as its main sources [21]. Figure 1 illustrates the river's path, the main water treatment plants locations, and the study area.

Periodic tests of drinking water have consistently shown elevated calcium concentrations, exceeding the thresholds for soft water requirements. Numerous studies ([6], [7], [11], [12]) have documented the harmful effects on human health, particularly regarding cardiovascular diseases, in the Babylon Governorate where the Shutt Al-Hilla River is the primary water source.

The conventional water treatment plants that process river water employ conventional treatments for raw water. However, these methods do not effectively reduce calcium concentrations, as evidenced by negligible differences between raw and treated water calcium levels.

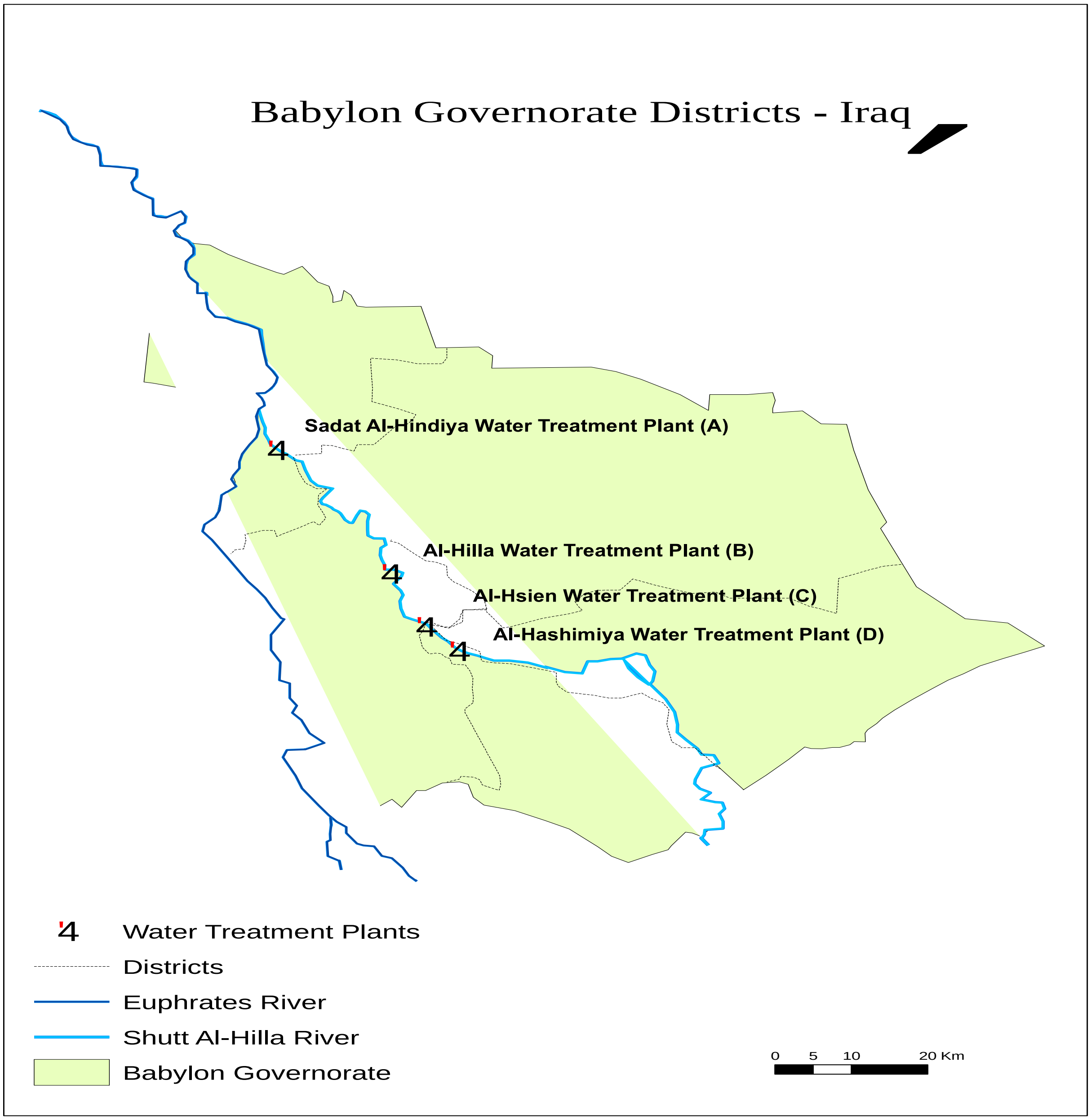

Figure 1: Shutt Al-Hilla River and the four conventional water treatment plants locations on it [20].

3. Water Treatment Plants

Conventional water treatment comprises various units and processes applied to raw water. The typical process includes rapid mixing, coagulation, flocculation, filtration, and disinfection [22]. This method is commonly used for treating surface water [23].

For the present study, four main water treatment plants designated as A, B, C, and D from upstream to downstream were selected as the primary sources of drinking water supply. These plants are strategically located along the Shutt Al-Hilla River and draw raw water directly from it. They employ conventional treatment processes as detailed in Table 2.

Table 2: Locations of water treatment plants used in the study ([17], 2023).

Water Treatment Plant	Longitude	Latitude	Symbol in the study
Sadat al Hindiya W.T. P.	44°16′19.9″E	32°43′31.8″N	A
Al-Hilla W. T. P.	44°16′19.9″E	32°43′31.8″N	B
Al-Hsien W. T. P.	44°39'87″ E	32°22'24″ N	C
Al-Hashimya W. T. P.	44°39′14.5″E	32°22′42.3″N	D

4. Data Collection

Data for raw and treated water samples of four water treatment plants along the river were collected between 2015 and 2019, from the Babylon Water Directorate.

5. Calcium concentration variations in raw water and treated water

The variations in calcium concentration in raw water and treated water during the study period (dry and wet seasons) is shown in Figures 2, 3, 4, and 5 for the four water treatment plants. Despite the considerable distance between the stations, the figures show convergent calcium concentrations ranging between 60-120 mg/L at all stations. This convergence suggests similarities in river flow characteristics and activities along it. Throughout the study period, calcium concentrations consistently exceeded the Iraqi standard limit of 50 mg/l. Furthermore, analysis of the collected data indicates no significant difference between calcium concentrations in raw and treated water supplied to the city, as shown in the previous mentioned figures, affirming that conventional treatment processes at the plants have minimal impact on calcium removal.

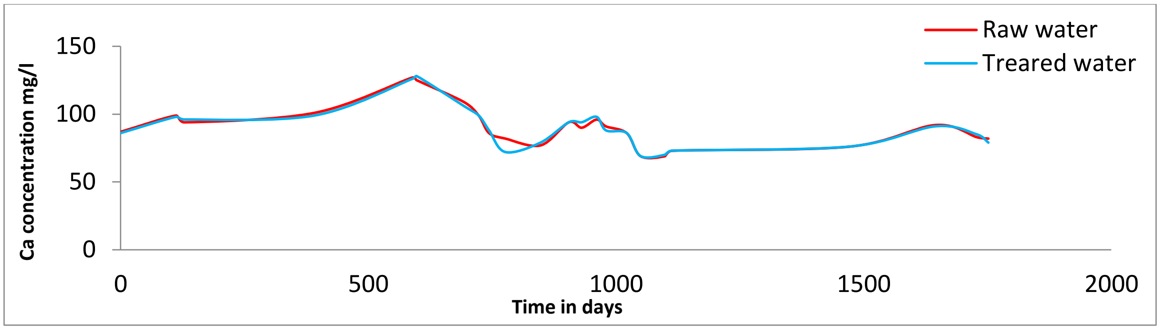

Figure 2: Variation of calcium concentration with time at station A

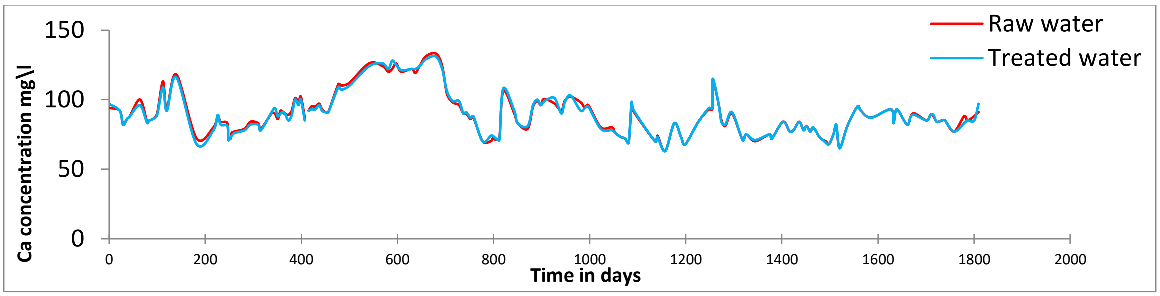

Figure 3: Variation of calcium concentration with time at station B

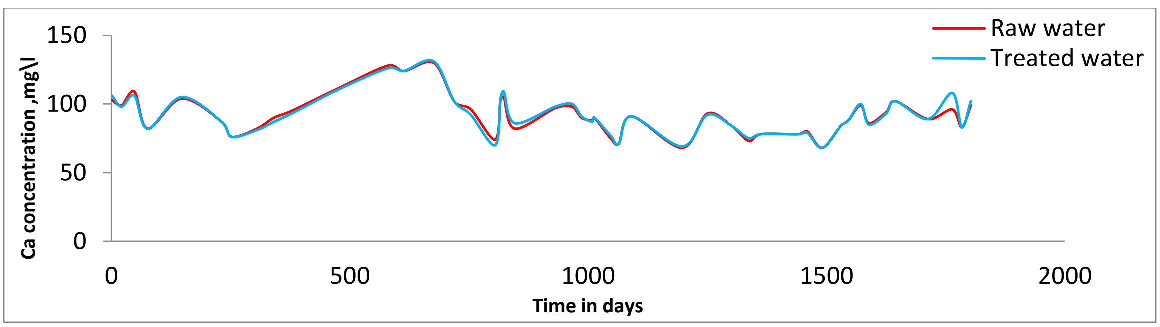

Figure 4: Variation of calcium concentration with time at station C

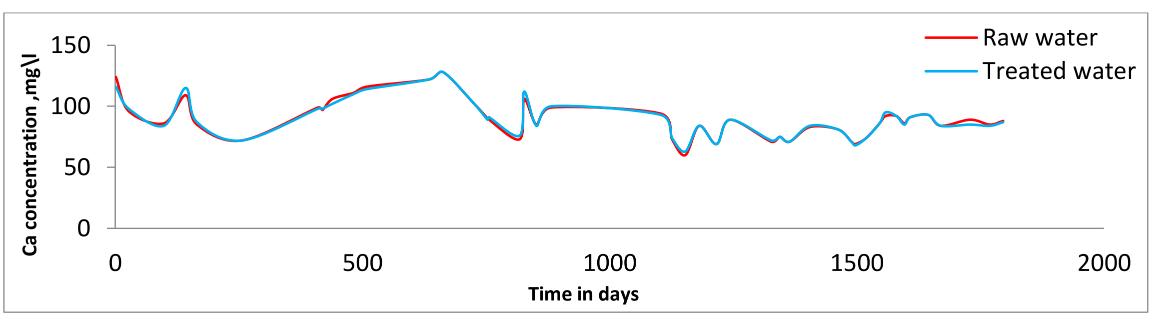

Figure 5: Variation of calcium concentration with time at station D

6. Calcium Intake and Risk Assessment

Health risk assessment involves both qualitative and quantitative evaluations of environmentally harmful factors that can affect organisms and human health [24]. Previous studies have examined the risk of hard water and its impact on human health [3][4]. Similarly, numerous researchers have conducted risk assessments focusing on calcium and other water quality parameters in specific regions [25][26][27][28].

In this study, risk assessment was conducted to quantify the potential health risks associated with calcium in drinking water, utilizing equations recommended by the EPA [29]. These equations are fundamental in estimating chemical intake through ingestion of water.

For specific details on the equations and methodologies used in the assessment, refer to references [1], [30].

$$\mathrm{CDI} = \frac{\mathrm{CW} * \mathrm{IR} * \mathrm{EF} * \mathrm{ED}}{\mathrm{BW} * \mathrm{AT}} \tag{1}$$

AT is the averaging time;

BW is the body weight,

CDI is the chronic daily intake,

CW is the concentration of chemical in water,

ED is the exposure duration,

EF is the exposure frequency

IR is the ingestion rate of water.

The risk assessment was initially conducted for adults. However, children, particularly neonates, can be biologically more sensitive to the same toxicant exposure on a body weight basis compared to adults [31]. Children may also be more vulnerable to environmental pollutants due to increased exposure or internal dose, or because of inherently more sensitive receptors [32]. They can exhibit greater biological sensitivity to toxicant exposure based on body weight than adults [33]. Therefore, separate risk assessments were conducted for both adults and children. The parameters used in Equation (1) are detailed in Table (3).

Table (3): Parameters values of risk assessment calculations.

Item	Definition	Value		Unit
		Adult	Child	
BW	Body weight	70	29	kg
AT	Average time	365	365	day
CW	Concentration	-	-	mg/L
IR	Ingestion rate	2.3	1.5	l
EF	Exposure frequency	1	1	-
ED	Exposure duration	5	5	year

The value of hazard quotient calculated according to the following equation: ([1] and [30]),

$$\text{Hazard quotient (HQ)} = \frac{\text{Average daily dose during exposure period (mg/kg.day)}}{\text{RfD}} \quad (2)$$

HQ is the hazard quotient (unit less)

RFD is the reference dose (mg/kg . day)

7. Reference Values for Calcium

The reference dose of calcium represents the required amount of this element for human health. Deviations below or above this value may cause health problems due to deficiency or excess, respectively, as shown previously. The average reference dose of calcium is 1.782 [28].

According to the equations above, the Hazard Quotient (HQ) index was plotted in Figures (6, 8, 10, and 12) for adults and (7, 9, 11, and 13) for children at the four stations. As depicted in the figures, the risk values exceeded acceptable levels for drinking water. The increase in HQ values for children was approximately 100% higher than those for adults. These findings were consistent across all water treatment plants.

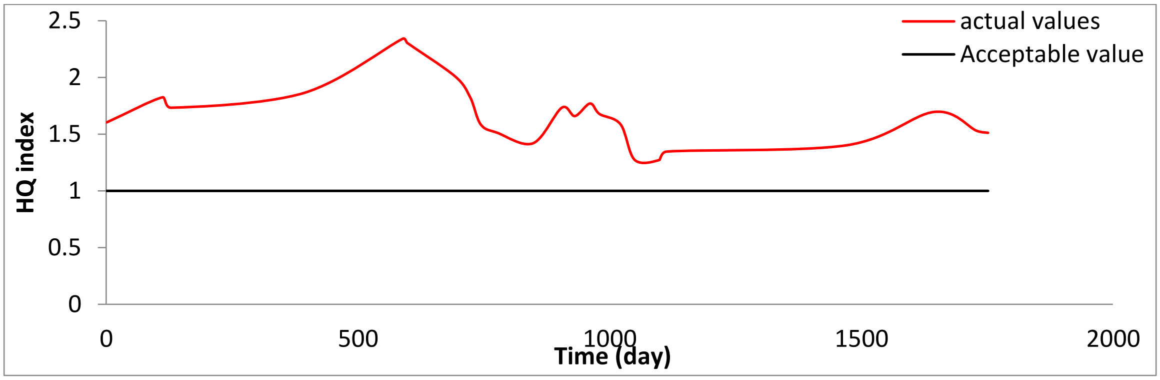

Figure 6: HQ values of adult at water treatment plant A.

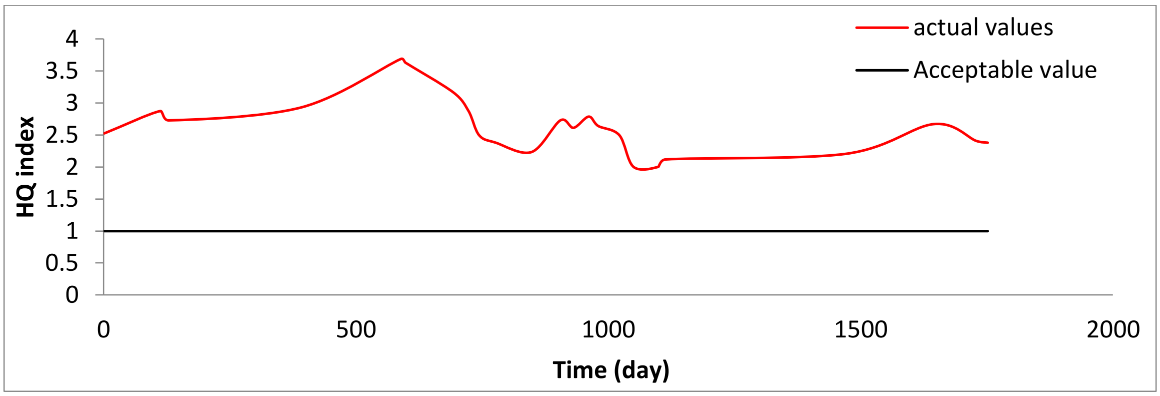

Figure 7: HQ values of child at water treatment plant A.

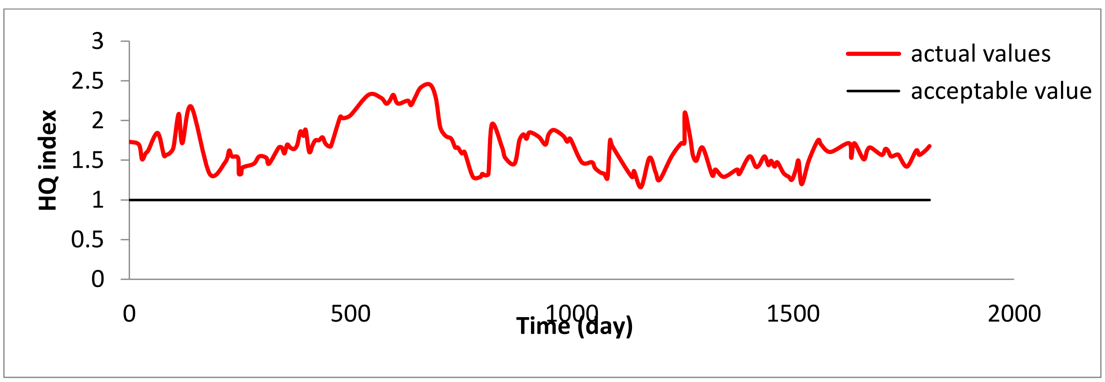

Figure 8: HQ values of adult at water treatment plant B.

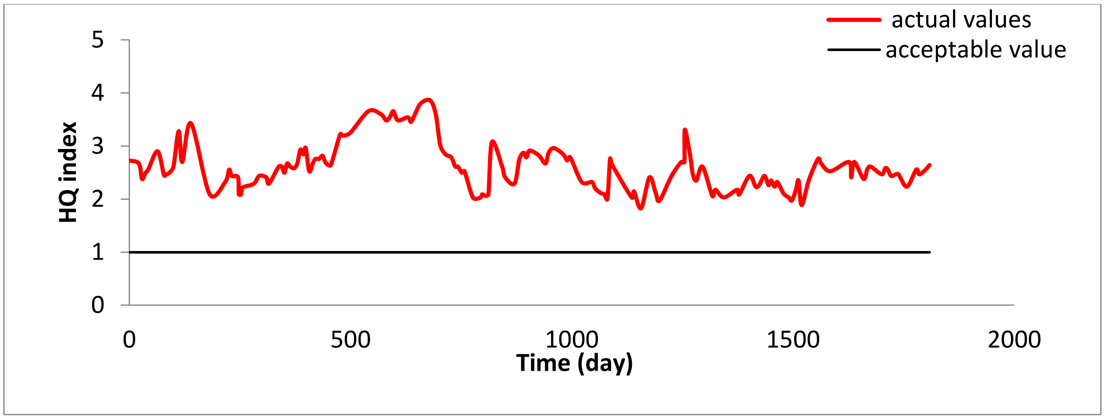

Figure 9: HQ values of child at water treatment plant B

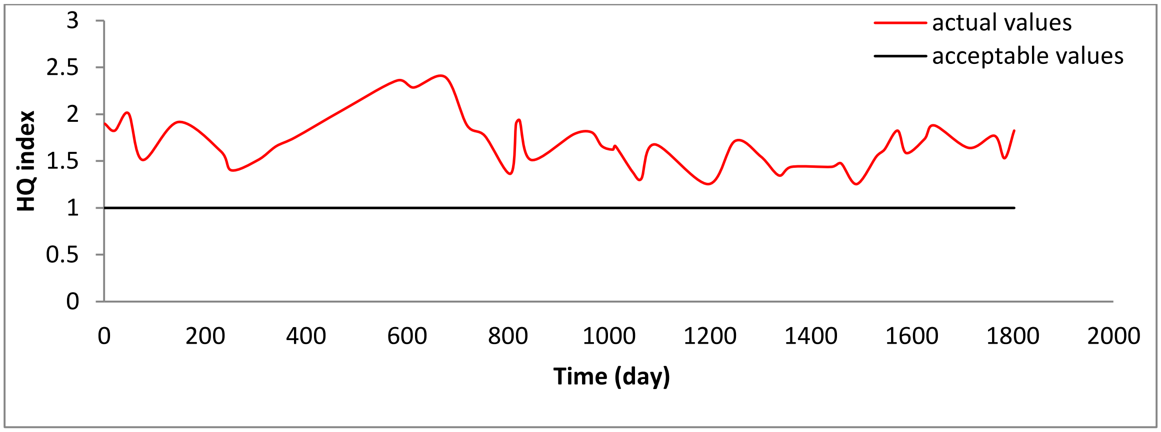

Figure 10: HQ values of adult at water treatment plant C.

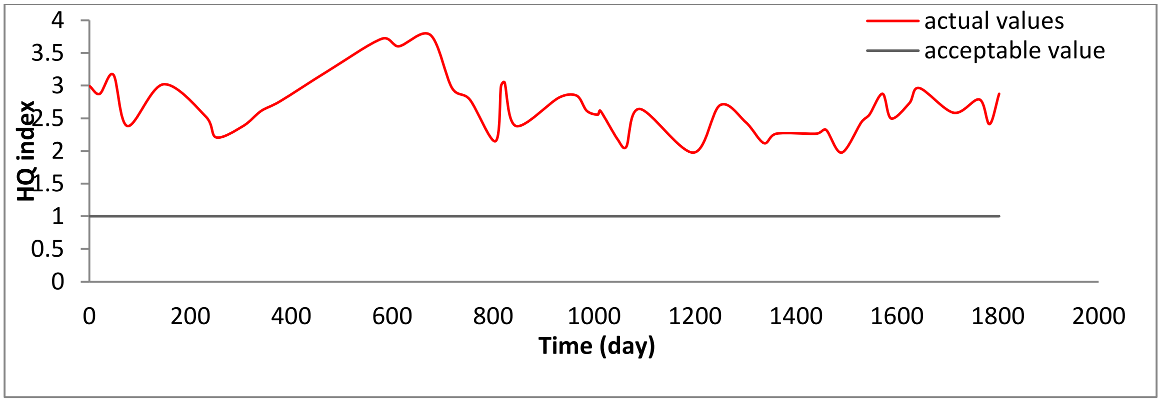

Figure 11: HQ values of child at water treatment plant C.

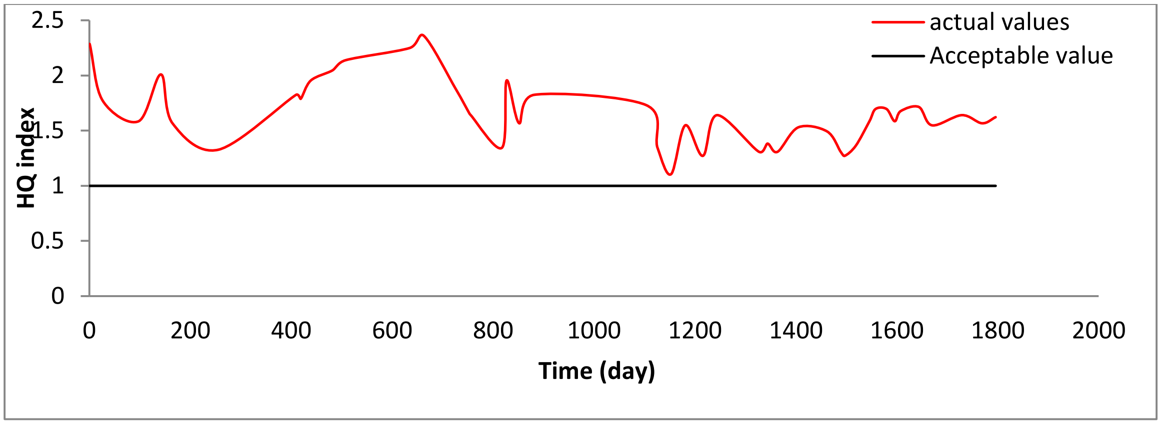

Figure 12: HQ values of adult at water treatment plant D.

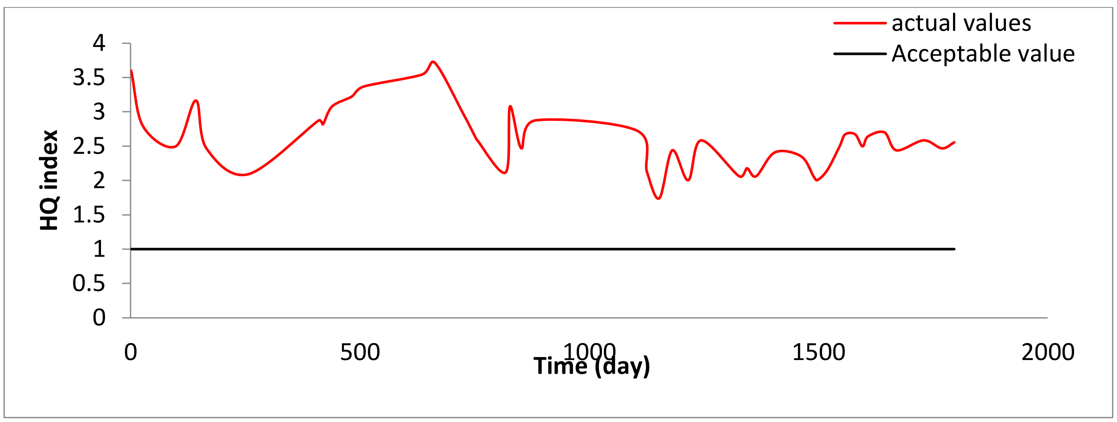

Figure 13: HQ values of child at water treatment plant D.

8. Probabilistic Risk Assessment

However, monitoring often suffers from deficiencies in developing areas due to high installation and maintenance costs. Therefore, it is often supported by water quality models, but the results are affected by the lack of detailed input data [34]. This section was study the probabilistic risk assessment of drinking water for both children and adults. This is important for understanding the effects of calcium in drinking water over time. Additionally, probabilistic risk assessment is crucial in cases where data availability is limited and monitoring costs are high [34].

In this study, estimation procedures were applied to assess the risk of calcium concentrations in drinking water. Future calcium values were determined using Monte Carlo (MC) methods with percentiles of 10, 25, 50, 75, and 90. This method relies on statistical estimation, as shown in Table (3). The selected percentiles were used to identify critical calcium concentration values where all HQ values exceeded the standard values for safe drinking water, ranging between 1 and 3. The calculated mean values for the four water treatment plants exceeded the acceptable limits. Additionally, the standard deviation of the estimated values was calculated.

The coefficient of variation can be calculated using the following equation [35, 36]:

$$CV = SD / \bar{X} \quad (3)$$

CV is the coefficient of variation

SD is the standard deviation

$\bar{X}$ is the mean

[37] , shows that he standard deviation may be using as a measure for diversity of the data.

9. Percentiles of the Hazard Quotient Values

To determine the probabilistic risk of calcium concentration in drinking water, Monte Carlo (MC) simulations were applied. Table (4) shows the results of the MC simulation, where all estimated HQ values exceeded the limit value. According to [38], the calculated standard deviation of the water treatment plants classifies as moderate, indicating an acceptable distribution of estimated values around the means when the coefficient of variation (CV) is approximately ten percent.

Table 4: Hazard Quotient Values for water treatment plants at different percentiles.

Statistics	A plant Adult	A plant Child	B plant Adult	B plant Child	C plant Adult	C plant Child	D plant Adult	D plant Child
$\bar{X}$	1.630	2.640	1.644	2.591	1.648	.8777	1.648	2.597
SD	.2783	.4358	.2709	.4265	.2860	.1630	.2860	.4502
CV	0.170	0.165	0.164	0.164	0.173	0.185	0.173	0.173
10	1.300	2.080	1.300	2.050	1.280	2.026	1.280	2.020
25	1.400	2.350	1.460	2.300	1.460	2.300	1.460	2.300
50	1.600	2.640	1.650	2.590	1.650	2.603	1.650	2.600
75	1.800	2.940	1.830	2.880	1.840	2.906	1.840	2.900
90	2.000	3.200	1.990	3.140	2.010	3.178	2.010	3.170

These procedures were applied for both adults and children. The risk values were plotted for different percentiles (10, 25, 50, 75, and 90), as shown in Figures (14, 15, 16, and 17). All HQ index values exceeded the standard values for adults and children. The percentile values for all stations were above the acceptable HQ limit. Consequently, all estimated concentration values exceeded the acceptable limit. This outcome necessitates practical solutions to reduce the calcium concentration in the supplied drinking water for all stations.

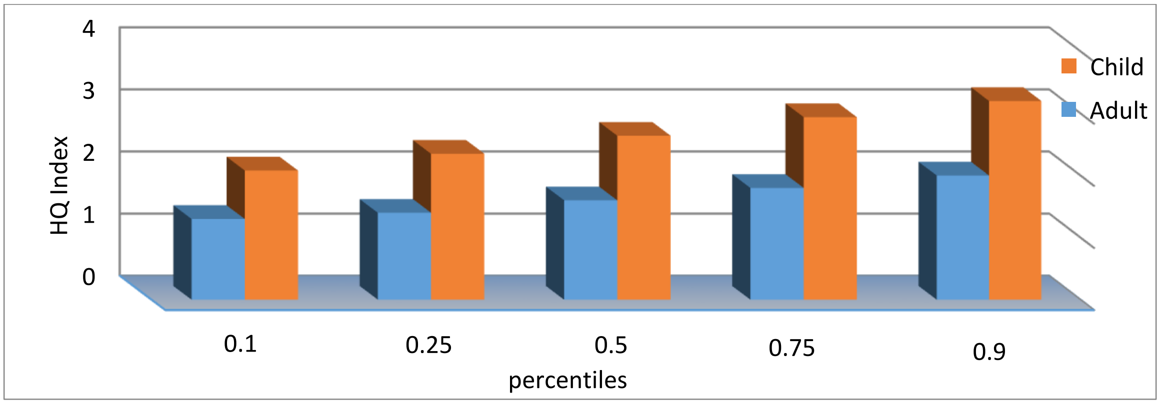

Figure 14: HQ values of water treatment plant A for related percentiles.

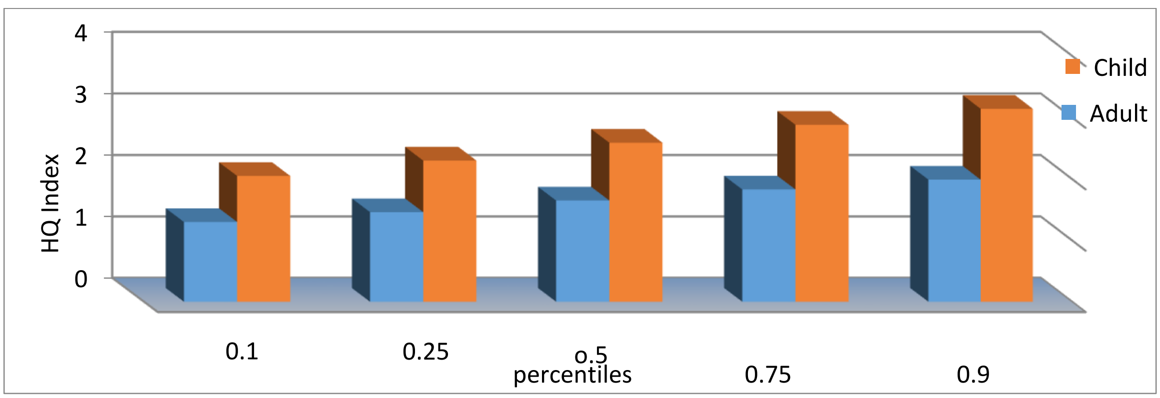

Figure 15: HQ values of water treatment plant B for related percentiles.

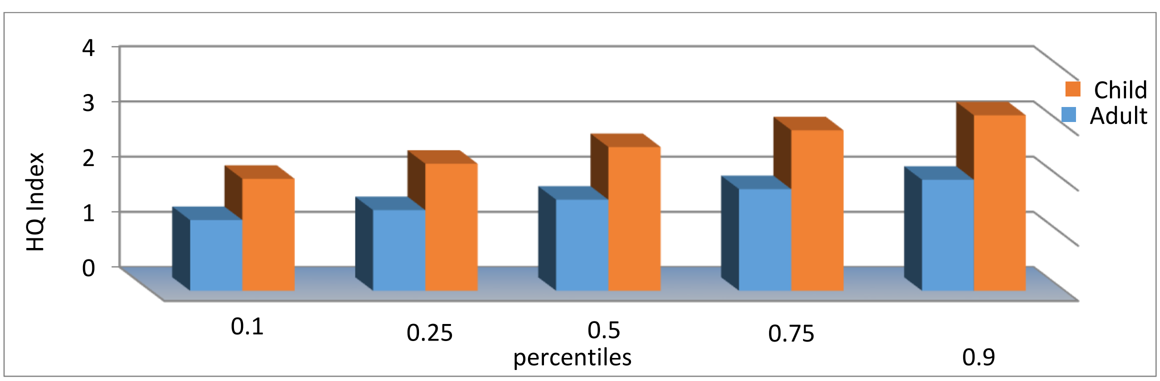

Figure 16: HQ values of water treatment plant C for related percentiles.

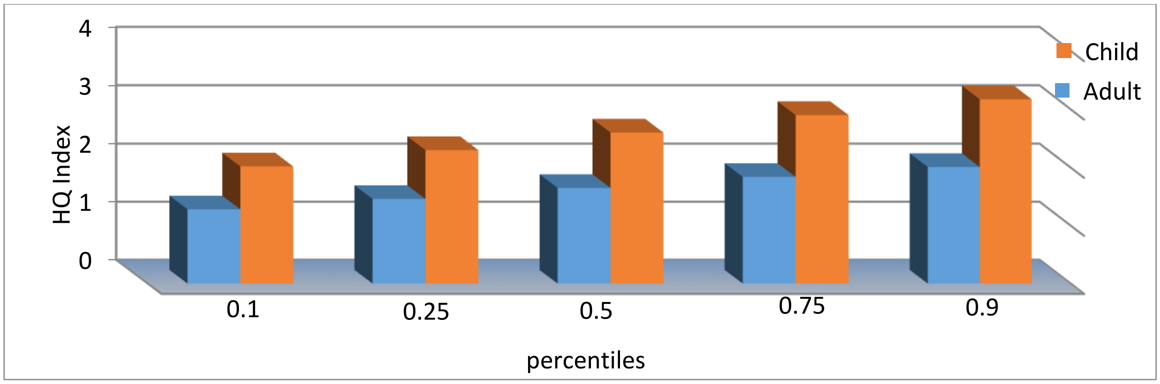

Figure 17: HQ values of water treatment plant D for related percentiles.

10. Calcium Removal Scenario

The second part of the paper explores procedures for softening raw water. Various methods of water softening exist depending on the intended use of the water [16]. For drinking water purposes, the chosen method must produce water of acceptable quality [39]. Therefore, nanofiltration is proposed as the method for softening raw water. According to [16], nanofiltration can reduce calcium levels by 44% to 99%. For this study, a moderate value of 71% calcium removal was selected. However, even with this moderate removal rate, the hazard quotient remains above acceptable values. Other softening methods can achieve higher calcium removal rates [16], but these are unnecessary as specific calcium concentrations are required in drinking water.

The variation of the calcium with time shown in the figures at the four stations after applied the nanofiltration unit in the each water treatment plant. As shown in the figures (18, 19, 20, and 21) there is a decreasing in the calcium concentrations according to the values of removal .The percent of removal of the nanofiltration unit depend on the initial concentrations of calcium in the treated water.

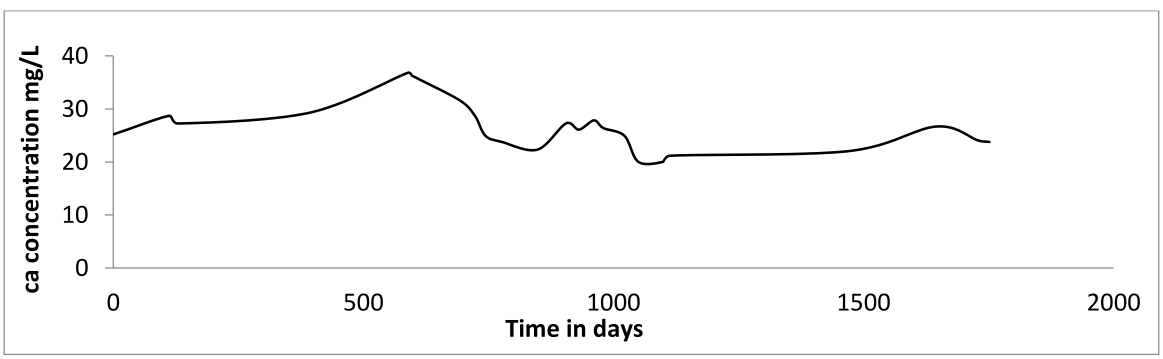

Figure 18: Variation of calcium concentration with time at station A (Nanofiltration Scenario).

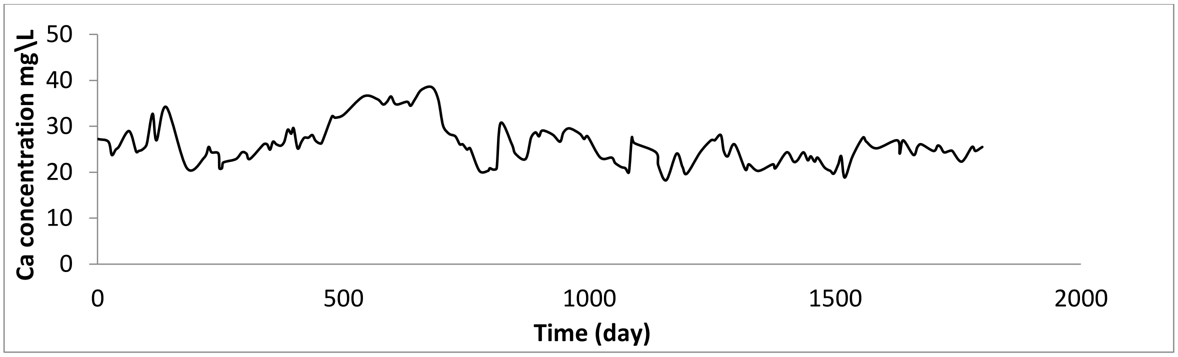

Figure 19: Variation of calcium concentration with time at station B (Nanofiltration Scenario).

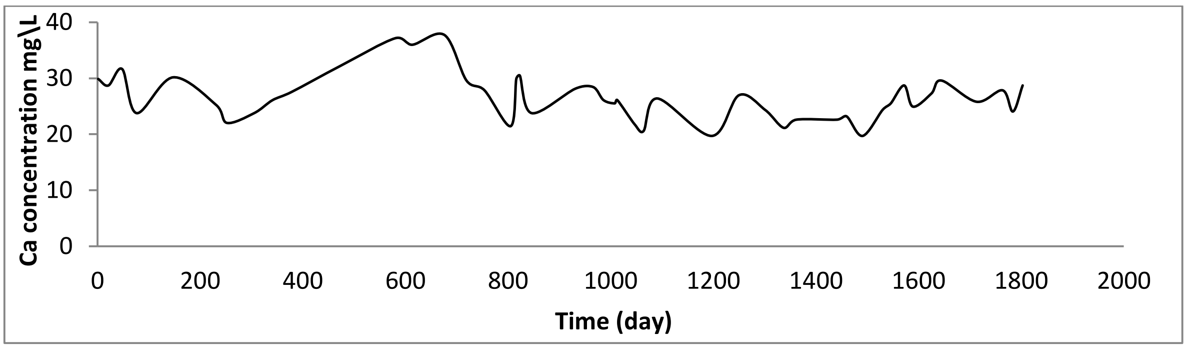

Figure 20: Variation of calcium concentration with time at station C (Nanofiltration Scenario).

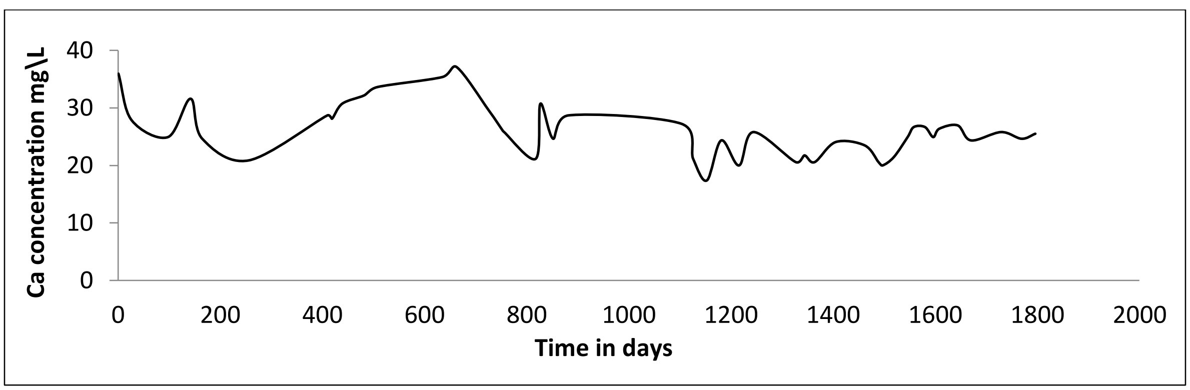

Figure 21: Variation of calcium concentration with time at station D (Nanofiltration Scenario).

11. Hazard Quotient Scenario

The accompanying HQ values for different calcium concentrations are depicted in Figures (22, 24, 26, 28) for adults and Figures (23, 25, 27, 29) for children. All HQ values are below the threshold of one, which is acceptable for calcium in drinking water. There is a slight exceedance of HQ values for children at stations B and D, approximately 10%. This exceedance could be mitigated by enhancing the efficiency of calcium removal in the nanofiltration units at both water treatment plants.

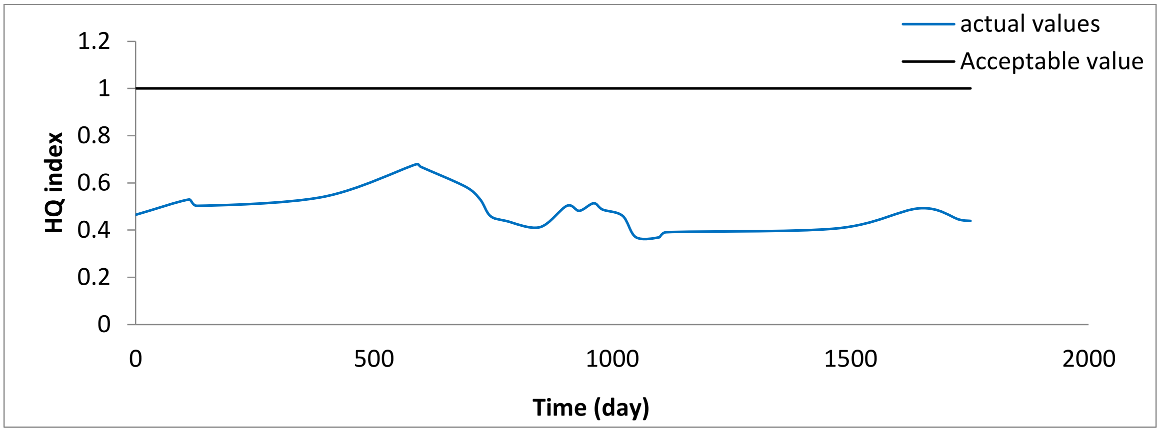

Figure 22: HQ values of adult at water treatment plant A (Nanofiltration Scenario).

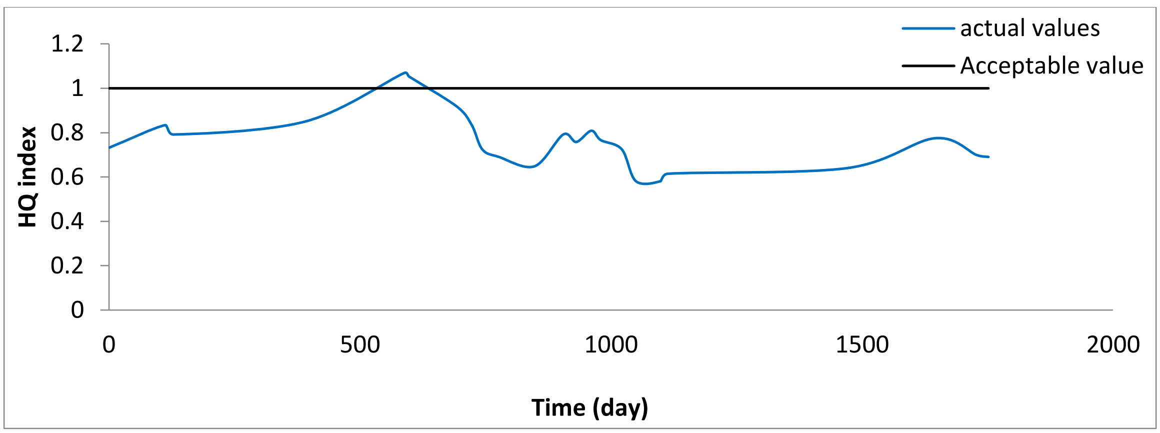

Figure 23: HQ values of child at water treatment plant A (Nanofiltration Scenario).

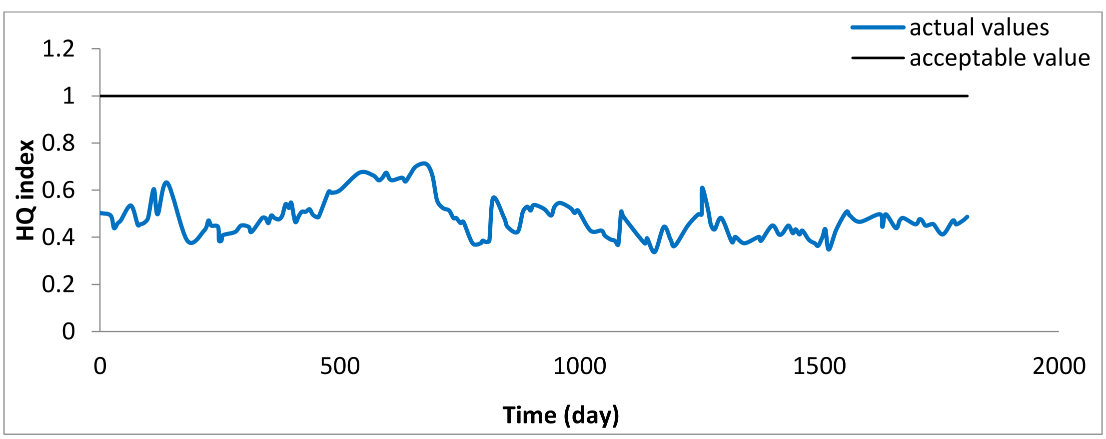

Figure 24: HQ values of adult at water treatment plant B (Nanofiltration Scenario).

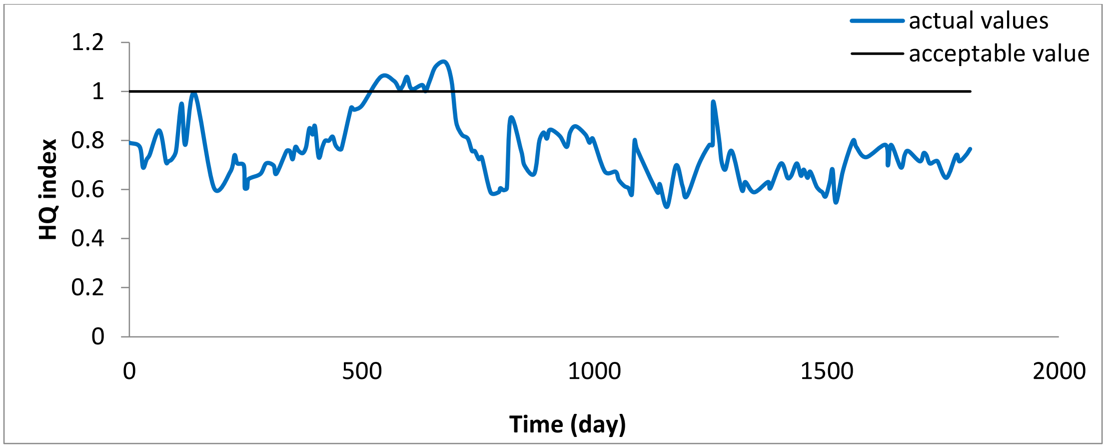

Figure 25: HQ values of child at water treatment plant B (Nanofiltration Scenario).

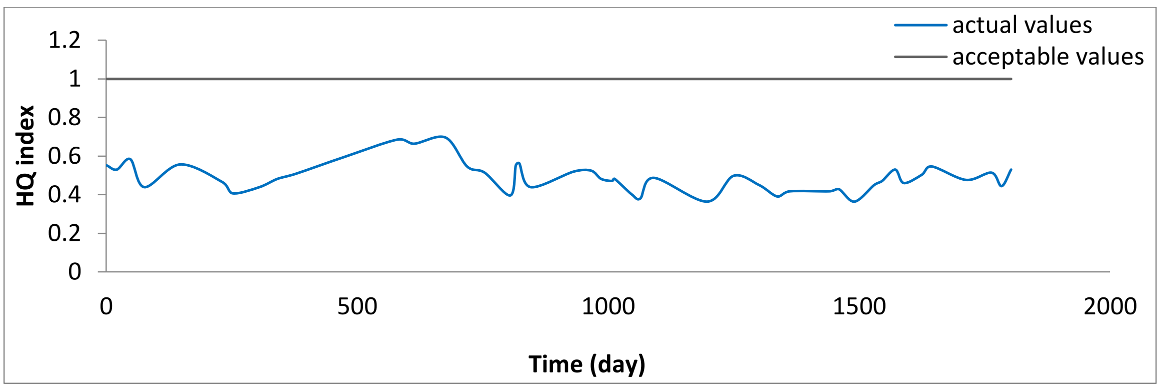

Figure 26: HQ values of adult at water treatment plant C (Nanofiltration Scenario).

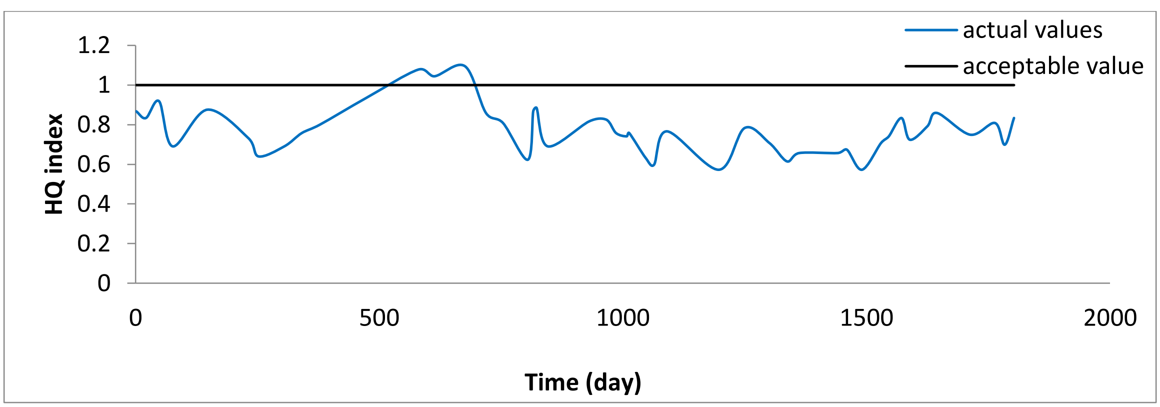

Figure 27: HQ values of child at water treatment plant C (Nanofiltration Scenario).

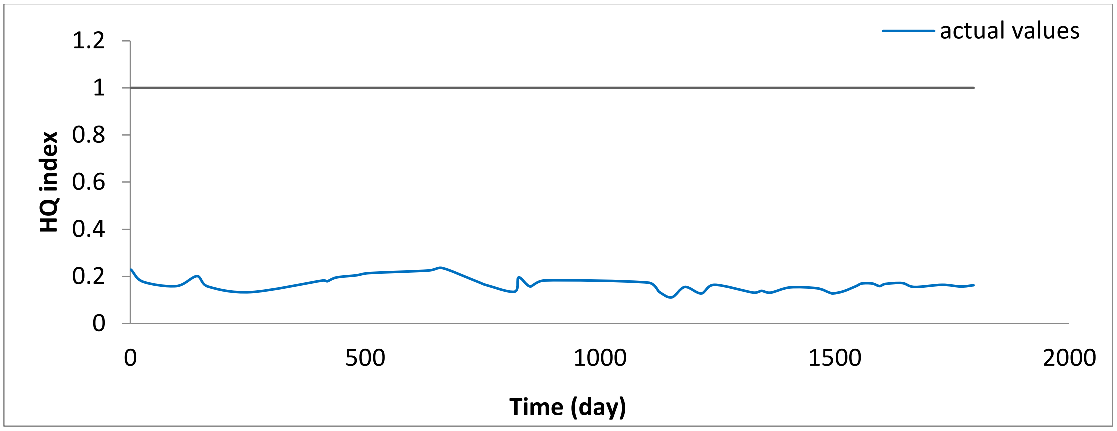

Figure 28: HQ values of adult at water treatment plant D (Nanofiltration Scenario).

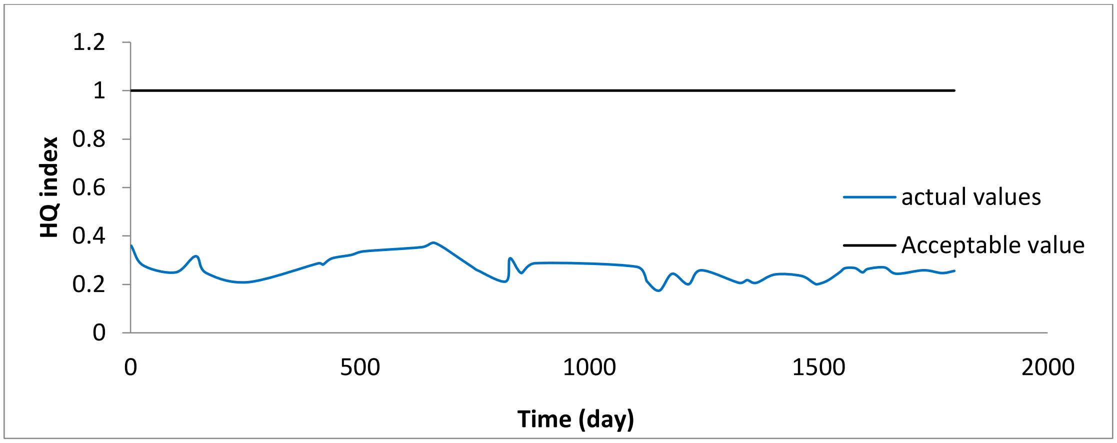

Figure 29: HQ values of child at water treatment plant D (Nanofiltration Scenario).

On the other hand, future water quality parameters were estimated using Monte Carlo (MC) simulation to calculate percentiles of HQ values for adults and children. All HQ values were acceptable, as shown in Figures (30, 31, 32, 33), ranging between 0.3 and 1.0.

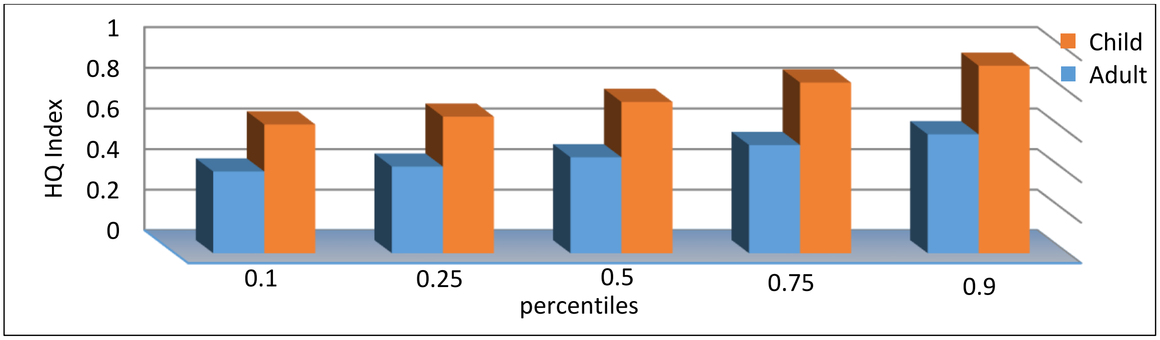

Figure 30: HQ values of water treatment plant A for related percentiles (Nanofiltration Scenario).

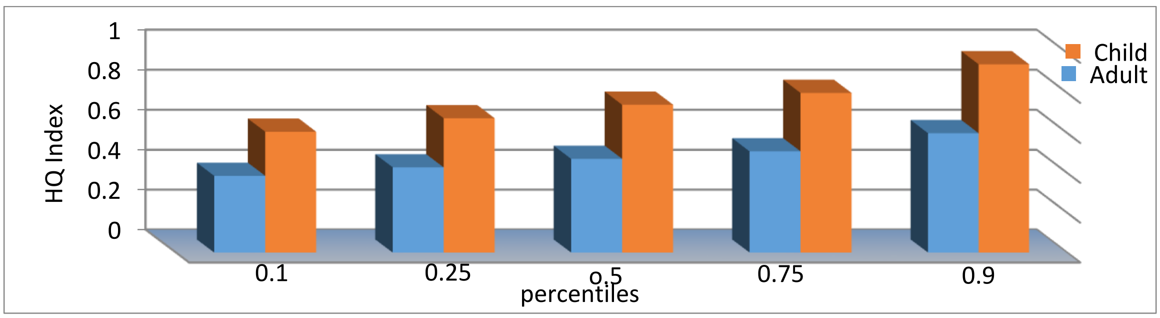

Figure 31: HQ values of water treatment plant B for related percentiles (Nanofiltration Scenario).

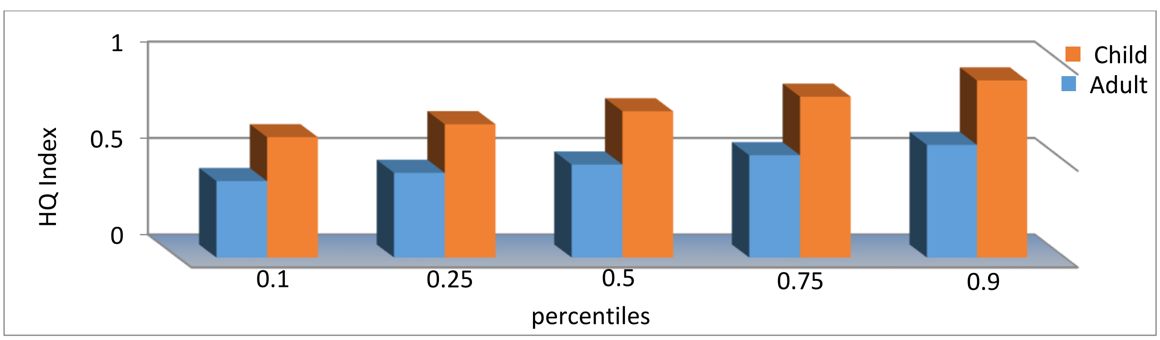

Figure 32: HQ values of water treatment plant C for related percentiles (Nanofiltration Scenario).

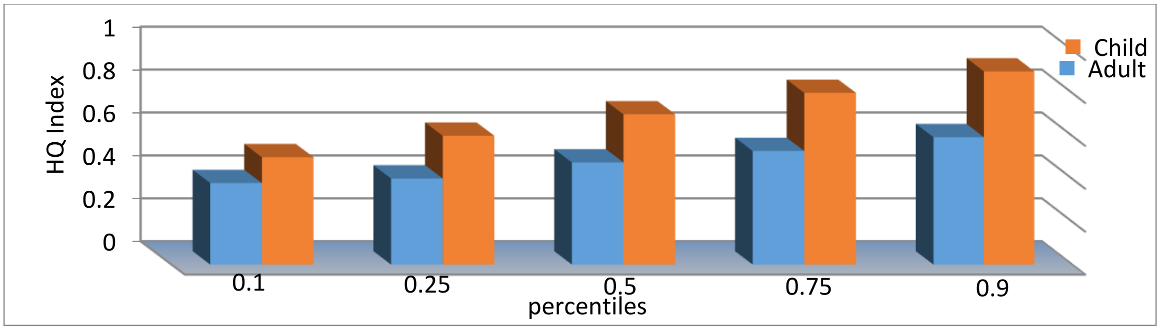

Figure 33: HQ values of water treatment plant D for related percentiles (Nanofiltration Scenario).

Table (5) summarizes the percentiles and statistical values. The mean value of estimated HQ values was less than one, with an acceptable standard deviation. Additionally, according to [38], the calculated standard deviation of the water treatment plants is classified as medium, indicating an acceptable distribution of estimated values around the means.

Table 5: Hazard Quotient Values for water treatment plants (Nano-filtration) at different percentiles.

Statistics	A plant Adult	A plant Child	B plant Adult	B plant Child	C plant Adult	C plant Child	D plant Adult	D plant Child
X⁻	.4851	.7637	.4785	.7533	.4910	.7730	.4793	.7066
SD	.0688	.1083	.0785	.1236	.0765	.1205	.0831	.1322
CV	0.141	0.141	0.164	0.164	0.155	0.155	0.173	0.187
10	.4036	.6353	.3849	.6060	.3956	.6228	.3796	.5000
25	.4279	.6736	.4277	.6734	.4384	.6902	.4010	.6000
50	.4738	.7459	.4705	.7407	.4812	.7575	.4758	.7000
75	.5343	.8411	.5079	.7996	.5293	.8333	.5293	.8000
90	.5868	.9238	.5988	.9427	.5828	.9175	.5935	.9000

12. Conclusions

This study aimed to assess the current risk associated with calcium in drinking water. The collected data indicated concentrations above the Iraqi standard, prompting the selection of four main water treatment plants (A, B, C, and D) along the Shutt Al-Hilla River, which applies conventional treatment to raw water. To evaluate future risks, Monte Carlo (MC) simulations were employed using different percentiles (10, 25, 50, 75, and 90). The study found significant calcium risks with Hazard Quotient

(HQ) values ranging between 2 and 3. Despite conventional treatments in surface water plants not affecting salt concentrations, including calcium, in raw water, a scenario for calcium removal was proposed to mitigate these risks. This scenario involves the installation of nanofiltration units at each selected water treatment plant along the river.

Risk assessment of the proposed scenario indicated HQ values well below the standard threshold, ensuring safety. MC simulations further supported this by showing HQ values ranging from 0.2 to 1.0, demonstrating a robust approach to variability testing with acceptable Coefficient of Variation (CV) results.

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تقييم المخاطر وطريقة إزالة الكالسيوم المقترحة في إمدادات مياه الشرب لمحافظة بابل وسط العراق

الخلاصة: تعد دراسة مخاطر التركيزات العالية لمعايير مياه الشرب جزءًا مهمًا من السمية بسبب تأثيرها المباشر على صحة الإنسان في مجموعة متنوعة من الأعمار. تم في هذه الدراسة دراسة التأثيرات الضارة للتراكيز العالية من الكالسيوم في مياه الشرب في وسط العراق. تحاول الدراسة تحديد مدى خطورة الكالسيوم الموجود في مياه الشرب على البالغين والأطفال. ولهذا الغرض، تم اختيار أربع محطات معالجة مياه تقليدية رئيسية لتحديد مخاطر الكالسيوم في المياه. تم تطبيق محاكاة مونت كارلو (MC) لتحديد هذا الخطر بنسب مئوية مختلفة 10 و25 و50 و75 و90. وتراوحت نتائج المقر الرئيسي (حاصل المخاطر) للبالغين والأطفال (1-3) لكل من التقديرات الأخيرة والمستقبلية. ، وهو أعلى من القيم القياسية. لذلك تم تطبيق السيناريو المقترح لتقليل تراكيز الكالسيوم، ويتضمن إضافة وحدة ترشيح نانوية في كل محطة معالجة مياه. وتم تحديد مخاطر السيناريو الأخير المقترح والتي كانت ضمن النطاق المقبول. للتأكد من فعالية السيناريو في المرة القادمة تم تطبيق محاكاة (MC) لتحديد المخاطر. كانت قيم المقر الرئيسي أقل من 1. وكانت القيم المقدرة للمقر الرئيسي الحتمي والاحتمالي تبلغ قيمتها حوالي 10٪. كانت هذه القيم مقبولة لاختبار التنوع باستخدام السيرة الذاتية.

الكلمات المفتاحية: مياه الشرب، محطة معالجة المياه، الكالسيوم، تقييم المخاطر، حاصل الخطر, تحلية المياه , ازالة الكالسيوم.