

Article



Health Risk Assessment of Household Drinking Water in a District in the UAE

Mohammed T. Mahmoud ^{1,2}, Mohamed A. Hamouda ^{1,3}, Ruwaya R. Al Kendi ⁴ and Mohamed M. Mohamed ^{1,3,*}

- ¹ Department of Civil and Environmental Engineering, United Arab Emirates University, Al Ain P.O. Box 15551, UAE; mohtarig@uaeu.ac.ae or eng.mohammedtarig@outlook.com (M.T.M.); m.hamouda@uaeu.ac.ae (M.A.H.)
- ² Department of Civil Engineering, University of Khartoum, Khartoum P.O. Box 321, Sudan
- ³ National Water Center, United Arab Emirates University, Al Ain P.O. Box 15551, UAE
- ⁴ Department of Biology, United Arab Emirates University, Al Ain P.O. Box 15551, UAE; ruwayaa@uaeu.ac.ae
- * Correspondence: m.mohamed@uaeu.ac.ae; Tel.: +971-3-713-5155

Received: 17 October 2018; Accepted: 16 November 2018; Published: 26 November 2018



Abstract: The quality of household drinking water in a community of 30 houses in a district in Abu Dhabi, United Arab Emirates (UAE) was assessed over a period of one year (January to November 2015). Standard analytical techniques were used to screen for water quality parameters and contaminants of concern. Water quality was evaluated in the 30 households at four sampling points: kitchen faucet, bathroom faucet, household water tank, and main water pipe. The sampling points were chosen to help identify the source when an elevated level of a particular contaminant is observed. Water quality data was interpreted by utilizing two main techniques: spatial variation analysis and multivariate statistical techniques. Initial analysis showed that many households had As, Cd, and Pb concentrations that were higher than the maximum allowable level set by UAE drinking water standards. In addition, the water main samples had the highest concentration of the heavy metals compared to other sampling points. Health risk assessment results indicated that approximately 30%, 55%, and 15% of the houses studied had a high, moderate, and low risk from the prolonged exposure to heavy metals, respectively. The analysis can help with planning a spatially focused sampling plan to confirm the study findings and set an appropriate course of action.

Keywords: drinking water; heavy metals; multivariate statistics; risk assessment

1. Introduction

Access to safe and adequate drinking water is at the center of the development goals of any country. Concerns have been echoed on whether current practices in the water industry can successfully provide the intended water quality that is suitable for human consumption [1]. Standards and regulations for ensuring acceptable drinking water quality are issued by governments and special organizations [2]. Many local governments and municipalities maintain a drinking water distribution network by the continuous inspection of water mains, tanks, pipes, and junctions [3]. The United Arab Emirates is no exception; the Regulation and Supervision Bureau (RSB) in the Emirate of Abu Dhabi has issued the fourth edition of its water quality regulations [4]. Water quality in the distribution networks can be characterized by analyzing the representative parameters of the microbiological, physicochemical, and aesthetic aspects of water quality [5]. Regulations and standards help raise confidence in the quality of water supplied at the tap. However, the possibility of contamination incidents throughout the production and distribution processes remains the primary reason for consumer concerns regarding the safety of drinking water. The attribution of these incidents and factors influencing their frequency,

severity, and consequences has been the subject of many investigations [6–9]. Of these incidents, contamination in the distribution network, including household plumbing, proves to be the most challenging to detect and control [10–14].

In addition to setting contaminants' maximum concentration levels, regulations also stipulate the frequency of water quality monitoring at various points in the water supply network to ensure compliance with standards [4]. The frequency of sampling usually depends on the population that is supplied water, and the volume of distributed water. However, sampling done at "supply points to consumers" usually means that the samples are taken before they enter the household. Several studies have reported increased concentrations of contaminants in the household tap due to factors related to plumbing, water temperature, and stagnation [13,15,16].

The United Arab Emirates (UAE) suffers from water scarcity where the availability of renewable water resources is insufficient to meet the country's water demands [17]. Nevertheless, the country has successfully provided safe drinking water in compliance with international standards by tapping into unconventional water resources (mainly desalination) as well as maintaining water networks and periodically monitoring the produced water quality. However, many factors could affect water quality within a drinking water distribution network, including the dissolution of pipe materials, and possible cracks and breaks due to aging and stress. Some districts in the UAE's large cities have drinking water networks that were designed for continuous water supply decades ago. However, high population growth and drinking water subsidies lead to increased water demand and system overload. The country continuously upgrades the water supply networks to maintain acceptable service levels; however, water quality monitoring is needed at the point-of-use to prioritize system improvement efforts.

To assess the drinking water quality supplied to consumers, investigations of water quality at the tap need to be conducted. These investigations typically have one purpose, which is the identification of contaminant levels that are higher than set standards [18]. This approach is inadequate, as it lacks the necessary attribution that is required for planning appropriate contaminant control measures. The attribution and source identification of contaminants requires the careful selection of sampling points and frequency. The resulting data are usually too complex for traditional statistical techniques [19]. Attempting to make sense of complex data, several studies have implemented multivariate statistical analysis techniques to identify similarities and common trends that could help in the better interpretation of sampling results [19–23].

In this study, a range of water quality parameters was monitored at various locations in several households in Baniyas, Abu Dhabi. Baniyas is an old district, where residents have raised some concerns regarding their drinking water quality. Since most of the water quality monitoring conducted by the distribution company is confined to sampling water in the distribution network, it would be of importance to investigate the water quality at the household level. The objectives of this study were to identify contaminants that do not comply with the set standards and explore the use of multivariate statistical techniques to interpret water quality data. Spatial (qualitative) analysis was used in this study to explore the spatial variation of contaminant concentrations at different households. Principal component analysis (PCA) and cluster analysis (CA) were used to group households with significant water quality issues to effectively plan future water quality monitoring. Health risk assessment was used to evaluate the risk related to each contaminant of concern. Finally, the implications of the analysis on planning for future water quality monitoring and enhancement are discussed.

2. Materials and Methods

2.1. Study Area

The district of Baniyas is located 37 km from the capital of the UAE, Abu Dhabi (Figure 1). The population of Baniyas, according to a report published by the Urban Planning Council in 2011, is about 70,000 people who are a mixture of all segments of society in Abu Dhabi. The Abu Dhabi Water

and Electricity Company (ADWEC) is responsible for providing Baniyas inhabitants with a drinking water supply from the Taweelah desalination plant. The quality of the water entering the distribution system is continuously monitored by ADWEC according to UAE drinking water standards. ADWEC is a wholly owned subsidiary of the Abu Dhabi Water and Electricity Authority (ADWEA). The company operates five desalination plants with approximately 938 MGD (Million Gallons per Day) capacity. In addition, the Abu Dhabi Distribution Company (ADDC) is responsible for distributing water to the consumers.



Figure 1. Sampling locations and study area.

2.2. Sample Collection and Preparation

The sampling campaign aimed to be representative of the drinking water supplied to as large a proportion of the Baniyas population as possible. At the time of designing this campaign, there was no readily available data on the number of households and population in the supplied area. Thus, the district size and number of households was estimated based on satellite image analysis (around 3000 houses), which served as a proxy to the served population. Initially, 90 households were identified, which were mainly older houses that were suspected to have water quality issues. These households represented about 3% of the total houses in Baniyas, which provided good spatial coverage of the district. This coverage was considered acceptable for the purposes of our study, as this percentage is sufficient for identifying the main contaminants of concern. Consequently, 90 houses were contacted for voluntary participation in the study, of which only 30 households agreed to participate in the sampling campaign. The objectives of the research were explained to participating households. In addition, for participants who were interested, the outcomes of the study were shared.

Samples from four points in 30 households were collected on two phases (a total of 720 samples) (Figure 2). Phase-1 sampling (winter season) was conducted during the months of January through April 2015, while phase-2 (summer season) samples were collected from August to November 2015. Grab samples were taken from the four sampling points. Samples were collected from household water tanks (WT) using a sampling rod and 500-mL sterile glass bottles. In addition, samples were collected from three other locations: the kitchen faucet (KF), a bathroom faucet (BF), and from the water main (WM) before it enters the household. Prior to sampling, sampling containers were disinfected

with ethanol, rinsed once with ultra-high-quality water, and then rinsed twice with sampled water. Temperature, pH, and electric conductivity were measured onsite, and the sample was collected, stored, and transported to the laboratory according to standard methods for the Examination of Water and Wastewater [24].



Figure 2. Summary of the methodology used in the study.

2.3. Laboratory and Field Methods

In this study, water quality parameters were analyzed according to the Standard Methods for the Examination of Water and Wastewater by using field probes [25]. A multi-parameter probe (HANNA, HI2020, Hanna Instruments, Woonsocket, RI, USA) was used to measure the physicochemical properties of the samples: pH, temperature (Tem), and electric conductivity (EC). Other parameters were determined in the lab, such as: total dissolved solids (TDS), biochemical oxygen demand (BOD), and turbidity. In addition, the analysis included the determination of the heavy metals' concentration (As, Cd, Pb, Cr, Cu, Zn) and cationic composition of the samples (Mg²⁺, Ca²⁺, Ba²⁺, Na⁺, and K⁺) using inductively coupled phase-mass spectrometry (ICP-AES-715). Moreover, ion exchange chromatography (IEC-1100, LevelOne, Dortmund, Germany) was used to determine the concentration of anions in the samples (Cl⁻, SO₄²⁻). Standard reference materials and procedural blanks were tested after each set of water samples (15 samples) to ensure that the accuracy of the measurements was maintained. The precision of the method was controlled by collecting triplicated samples randomly and testing the agreement between the readings. The results showed a satisfactory agreement between the two readings for the same sample.

2.4. Data Analysis

Data were analyzed and interpreted using three major categories: qualitatively to study the spatial variation of each measurement, statistically to interpret the significance of each parameter, and finally by using a health risk analysis to assess the risk posed by each contaminant. The following sections will elaborate how these analyses carried out and the degree of their significance.

2.4.1. Spatial Analysis

Heavy metals and cations were analyzed qualitatively by producing maps using ArcGIS (ESRI, Redlands, CA, USA) to explore the spatial variation of each potential drinking water contaminant (Figure 3). The purpose of this step is to identify areas that show a high level of concentration of a certain drinking water contaminant. In addition, the generated maps were used to detect the possible source of the contamination by comparing the variation of the contaminant concentration at each sampling point.



Figure 3. Spatial variation of heavy metals; (**a**–**d**) Arsenic concentrations for the four sampling points: water main (WM), water tank (WT), bathroom faucet (BF) and kitchen faucet (KF), respectively. (**e**–**h**) Lead concentrations for the four sampling points WM, WT, BF, and KF respectively. (**i**–**l**) Cadmium concentrations for the four sampling points WM, WT, BF, and KF respectively.

2.4.2. Multivariate Statistical Analysis

After laboratory tests were carried out, the analyzed data was compiled into one database. Descriptive statistics were used to explore the nature of the data and make initial interpretations about the water quality of the network and identify the contaminants of concern. The mean, median, minimum, maximum, and standard deviation values were calculated for each water quality parameter. Moreover, the concentration of each water quality parameter in the samples were compared with the maximum acceptable values set by UAE's drinking water standards [4] (Table 1).

In addition, multivariate statistical analysis techniques were used to understand and evaluate the variations in the water quality parameters from the water main, through the household water tank, to tap. A detailed multivariate statistical analysis was carried out using Minitab software v18 (Minitab Inc., State College, PA, USA). To reduce dimensionality and avoid biases resulting from different units of measurement, data was standardized (z-scale) for each parameter prior to the statistical analysis [19,26]. Multivariate linear Pearson's correlation coefficients between parameters were determined to indicate statistical dependence (Tables A1 and A2).

Table 1. Descriptive statistics of physicochemical parameters and heavy metals for 30 households in Baniyas.

Devenuetar	T I	UAE	Phase-1					Phase-2						
1 afaiiletei	Unit	Standard	Min	Max	Median	Mean	SD	CV (%)	Min	Max	Median	Mean	SD	CV (%)
pН	pН	7.0–9.2	6.33	7.37	7.02	6.92	0.36	5.2	6.15	8.25	7.27	7.32	0.45	6.15
Tem	°C		20.61	29.79	25.66	25.27	2.55	10.09	22	55.15	38.38	39.23	8.28	21.11
EC	µS/cm	250	104.5	165.5	133.75	135.03	13.87	10.27	95.5	239	164.25	164.92	33.57	20.36
TDS	mg/L	100-1000	51.75	82	70	68.02	6.86	10.09	45	172	95	104.11	34.23	32.88
Turbidity	FNU	4	0.2	1.65	0.39	0.55	0.35	63.64	0.25	1.95	1	1.04	0.46	44.23
BOD	mg/l	0 to 4	0.05	2.93	1.6	1.43	0.79	55.24	0.5	4.35	2.53	2.48	1.06	42.74
Cl-	mg/L	250	7.99	17.26	12.86	12.9	2.43	18.84	7.45	16.91	10.14	10.8	2.65	24.54
SO_4^{2-}	mg/L	250	0.75	1.85	1.2	1.23	0.27	21.95	0.74	1.66	0.96	1.04	0.27	25.96
Ca ²⁺	mg/L	200	22.02	31.5	24.29	24.29	0.99	4.08	21.94	27.2	24.43	24.64	1.33	5.4
Na ⁺	mg/L	150	5.39	10.83	7.79	7.69	1.19	15.47	6.73	11.68	8.66	8.7	1.3	14.94
K ⁺	mg/L	12	0.02	0.52	0.23	0.24	0.08	33.33	0.11	0.31	0.19	0.2	0.05	25
Mg ²⁺	mg/L	30	0.77	1.9	1.07	1.09	0.19	17.43	0.63	1.95	0.84	0.93	0.24	25.81
Ba ²⁺	μg/L	700	1	40	4	4	4	100	1	16	2	3	3	100
As	μg/L	10	9	80	9	10.78	9.94	92.21	8.9	95.04	9	14.72	17.25	117.19
Cd	μg/L	3	1	11.54	1	2.16	1.75	81.02	1	15.4	1	1.73	2.04	117.92
Pb	μg/L	10	11	81.78	12	13.85	9.65	69.68	11	76.28	11	25.09	19.73	78.64
Cr	μg/L	50	2	6.41	5	4.99	0.3	6.01	1.5	12.22	5	4.93	0.9	18.26
Cu	μg/L	1000	10	210	20	20	20	100	0	90	20	20	10	50
Zn	μġ/L	5000	1	173.57	1	16.11	23.21	144.07	1	205.1	1	14.29	25.67	179.64

Bold: High values for the coefficient of variation (CV).

Principal component analysis (PCA) was conducted to interpret the correlation between water quality parameters by reducing the dispersion matrix to a few interpretable linear combinations of the data [19,27]. Each linear combination will correspond to a principal component. The PCA method has been adopted in many water quality studies [19,28]. The method has proven its efficiency in segregating the water quality parameters and correlating them together. Minitab software v18 was used to conduct this analysis.

Cluster analysis (CA) was used to complement the multivariate analysis by creating groupings of similar water quality characteristics that have the same concentration patterns. Agglomerative hierarchical clustering (AHC) is one of the most common clustering methods. AHC has been used in the literature to classify and examine spatial variation among the sampling stations [22,29]. In this study, AHC has been carried out on a normalized dataset using Ward's method and Euclidean distances as a measure of similarity. This method uses the analysis of variance approach to evaluate the distances between clusters, attempting to minimize the sum of squares of any two clusters that can be formed at each step [30]. In this study, a cut-off level based on similarity between the measured distance was set to 97% or more.

2.4.3. Health Risk Assessment

Health risk assessment is a process of quantifying the occurrence likelihood of any variable that affects the health over a specified timescale. Basically, the risk assessment process involves: hazard identification, exposure assessment, dose response, and risk characterization [31,32]. The calculated magnitude of the risk level is the base of any health risk assessment, and is usually expressed in terms of a carcinogenic or non-carcinogenic health risk [33]. In this study, the degree of toxicity of the heavy metals detected in the water samples was evaluated to determine the level of health risk posed by the contaminants. The health risk assessment was carried out using two main indicators: hazard index (HI) and hazard quotient (HQ) as proposed by the United States (US) Environmental Protection Agency (EPA) [19,32,34]. The non-carcinogenic hazard or HQ is defined as the ratio between the human exposure to each heavy metal, which is also reported as average daily dose (ADD) and the reference dose (RfD). On the other hand, the HI is used to estimate the total non-carcinogenic risk. The HI can be determined by combining the individual HQs. Equations (1)–(3) were used to calculate ADD, HQ, and HI, respectively.

$$ADD = \frac{C_{wt} \times IR \times EF \times ED}{BW \times AT}$$
(1)

$$HQ = ADD/RfD$$
(2)

$$HI = \sum HQ_i \tag{3}$$

where ADD is the average daily dose (μ g/kg/day), C_{wt} is the heavy metal concentration (μ g/L), IR is the water intake rate (2.0 L/day and 1.0 L/day for adults and children, respectively), EF is the exposure frequency (365 days/year), ED is the exposure duration (30 years and six years for adults and children, respectively), BW is the average body weight (76 kg and 30 kg for adults and children, respectively) [35], and AT is the average time (10,950 days/year and 2190 days/year for adults and children, respectively). RfD is the oral reference dose (μ g/kg/day).

In order to assess the risk associated with each heavy metal and their accumulative hazard in each house, this study relied on scales of chronic risk assessment set by previous studies [26,28], which commonly include the following categories:

- Risk category 1: Negligible risk, where the HI or HQ are <0.1
- Risk category 2: Low risk, where the HI or HQ are ≥ 0.1 but <1.0
- Risk category 3: Moderate risk, where the HI or HQ are ≥1.0 but <4.0
- Risk category 4: High risk, where the HI or HQ are ≥4.0

3. Results

3.1. Spatial Variation Analysis

The spatial variation of heavy metals and cations concentrations from the sampled locations was analyzed using ArcGIS interpolation tool and represented in Figures 3 and A1–A3. Based on the averaged concentrations, each individual parameter was evaluated and categorized into four groups based on meeting UAE standards. The most hazardous contaminants were presented in Figure 3, which includes As, Pb, and Cd. Other figures were developed for other parameters, but they did not show any risks due to their relatively low concentrations, which were below the limits set by UAE standards. In addition, the variation of each parameter concentration for the four sampling points was explored. Based on the results obtained, the WM samples had a high concentration of As, Pb and, Cd reaching up to $45 \mu g/L$, $40 \mu g/L$, and $7 \mu g/L$, respectively (Figure 3). Overall, the concentrations for other sampling points decreased as the water moves from the WM to WT and from the WT to the BF and KF. The sampling point KF had a relatively low concentration of heavy metals. While the spatial distribution of the sampling points was not sufficient for in-depth observations, it is clear from

Figure 3 that the western part of Baniyas suffers from higher concentrations of heavy metals, while the northern and southern parts had fairly low values. The middle part showed a high variation in most of the maps due to the intense sampling points and the high variation between the readings.

3.2. Descriptive Statistics

The physicochemical water quality parameters (pH, temperature, electric conductivity (EC), total dissolved solids (TDS), turbidity, and biochemical oxygen demand (BOD) are statistically described and summarized in Table 1. The statistical values of each parameter were compared with UAE standards to obtain a general overview of the quality of the household drinking water. The reported pH for all of the samples was within the standard ranges. However, some of the samples detected quite low pH values of 6.33 (in phase-1) and 6.15 (in phase-2). However, they are considered close to standard limits (Table 1). For the EC values, the ranges were within the standards, as no samples detected EC values over 250. The values of the coefficient of variation reflected that the pH, temperature, EC, and TDS exhibited a minor variation, and were all below the standard limits. However, turbidity and BOD showed a high variation, reaching 63% and 55% respectively for phase-1, and 44% and 42%, respectively, for phase-2, although the values were below the standard limits. In general, the ranges of physical water quality parameters indicate that the quality of drinking water was acceptable with respect to its color and taste, and that its physicochemical quality complied with limits set by the Regulation and Supervision Bureau (RSB).

Heavy metals concentrations were determined for the 30 houses to assess the quality of the drinking water. The statistical description of all of the individual parameters of the heavy metals revealed a wide variation (Table 1). Based on the average concentrations of Cr, Cu, and Zn, these parameters were below the standard limits recommended by the RSB [3]. However, the maximum concentrations of As, Cd, and Pb that were detected were considerably higher than the recommended limits. Although the maximum values for these heavy metals exceeded the standard limits, the median values indicated that most of the samples had concentrations lower than set limits. Almost all of the heavy metals' concentrations exhibited a very high variation in their datasets, as the coefficient of variation ranges from 70% to 145% for phase-1 and 50% to 180% for phase-2. On the other hand, concentrations of cations parameters (Ca, Na, K, Mg, Ba) were far below the standard limits, and their variation was very low.

3.3. Principal Component Analysis

To explore the association between water quality parameters and contaminants, a principal component analysis (PCA) was conducted to reduce the original dataset to certain influencing factors [19,36]. To sidestep the measuring unit differences and numerical ranges, the dataset was standardized using the z-scale transformation technique. Then, the influential factors were defined as those encompassing at least 70% of the total variance. The results of the PCA for the two phases are presented in Table 2. The PCA results show that for phase-1, four principal components were obtained, accounting for 71% of the total variance. The first principal component (PC1), which reveals about 34% of the total variance, correlates with five of the original variables. The first principal component increases with the increase of Cl⁻ (0.37), SO₄²⁻ (0.32), Mg²⁺ (0.35), Na⁺ (0.34), and EC (0.31), while it decreases with the increase of Ca^{2+} (-0.32). Overall, PC1 indicates the logical relation between EC and the concentration of anions and cations in the water matrix. The second principal component (PC2) reveals 16% of the variance and increases with the decrease of Cu (-0.48), Cd (-0.44), Ba (-0.45), and turbidity (-0.35). This component could be used as an indication of the general water quality. The third principal component (PC3) increases with the increase of turbidity (0.35), BOD (0.33), and Zn (0.34), and strongly increases with the decrease of pH (-0.51). The fourth principal component (PC4) significantly decreases with the increase of temperature (-0.62) and Zn (-0.45), while it fairly increases with the decrease of Pb (-0.31) and Cr (-0.31). PC4 could provide a link between water temperature and the concentration of heavy metals.

		Pha	se-1				Phase-2		
Eigenvalue	6.4361	3.0249	2.4226	1.5344	5.1403	2.801	2.1032	1.8423	1.4692
Proportion	0.339	0.159	0.128	0.081	0.271	0.147	0.111	0.097	0.077
Cumulative	34%	50%	63%	71%	27%	42%	53%	63%	70%
Variable	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4	PC5
pН	-0.15	-0.12	-0.51	0.03	-0.07	0.14	-0.02	-0.54	-0.12
Tem	-0.02	-0.14	-0.27	-0.62	0.09	0.45	-0.26	-0.06	-0.03
EC	0.31	-0.06	-0.08	-0.04	0.07	0.19	0.06	0.32	-0.48
TDS	0.29	0.01	0.06	0.22	-0.25	-0.21	-0.22	-0.10	-0.12
Turbidity	-0.03	-0.35	0.35	0.05	-0.02	-0.08	0.18	-0.44	-0.33
BOD	0.00	-0.11	0.33	0.09	-0.07	0.13	0.06	-0.21	-0.28
Cl-	0.37	-0.11	0.00	0.02	0.42	-0.08	0.01	-0.04	0.02
SO_4^{2-}	0.32	-0.16	0.00	0.03	0.38	-0.07	0.00	0.01	-0.09
Ca ²⁺	-0.32	0.01	-0.01	0.27	-0.36	0.21	-0.06	0.03	0.09
Na ⁺	0.34	-0.18	-0.18	0.07	0.41	-0.09	0.01	-0.12	0.08
K^+	0.28	-0.19	-0.24	0.09	0.41	0.05	-0.05	-0.14	0.14
Mg ²⁺	0.35	-0.16	-0.07	-0.04	0.32	0.35	-0.11	0.00	0.03
Ba ²⁺	-0.16	-0.45	0.19	0.03	0.00	0.39	0.34	0.00	0.05
As	0.15	-0.05	0.27	0.15	-0.03	0.26	-0.25	-0.20	0.29
Cd	-0.16	-0.44	-0.07	0.21	-0.08	0.11	0.57	-0.05	0.20
Pb	0.02	0.11	0.30	-0.31	-0.08	0.35	-0.14	0.25	0.29
Cr	-0.14	-0.24	-0.12	-0.31	0.00	0.30	0.34	-0.16	-0.12
Cu	-0.19	-0.48	-0.02	-0.01	0.03	-0.19	0.42	0.13	0.34
Zn	0.10	-0.09	0.34	-0.45	0.09	0.11	0.10	0.41	-0.41

Table 2. Eigenvalues and principal components for phase-1 and phase-2 datasets.

Bold: Influential factors (high correlation with the principal component).

Phase-2 PCA resulted in five principal components that encompassed 70% of the total variance. PC1 represents 27% of the total variance and correlates with six of the original variables. PC1 increases with the increase of Cl⁻ (0.42), SO₄²⁻ (0.38), Na⁺ (0.41), K⁺ (0.41), Mg²⁺ (0.32), and decreases with the increase of Ca²⁺ (-0.36). This component may represent the state of the ionic equilibrium of water. PC2 correlates the temperature (0.45) and cations Ba²⁺ (0.39) and Mg²⁺ (0.35), as well as the heavy metal Pb (0.35). This component may represent the increase of lead in the presence of positive ions (cations) and higher temperatures. PC3 correlates with three heavy metals: Cd, Cu, and Cr. The component strongly increases with the increase of Cd (0.57), Cu (0.42), and fairly with an increase of Cr (0.34). PC4 correlates the physicochemical parameters pH, TDS, and EC, and the heavy metal Zn. The component increases with the increase of EC (0.32) and Zn (0.41), while it decreases significantly with the increase of pH (-0.54) and turbidity (-0.44). Finally, PC5, which explains 8% of the total variance, correlates the water physicochemical characteristics EC, turbidity, and some heavy metals: Cu and Zn. This component increases with the decrease of EC (-0.48) and turbidity (-0.33), Zn (-0.41), and decreases with the increase of Cu (0.34).

3.4. Cluster Analysis

Cluster analysis was conducted for physicochemical parameters and heavy metal concentrations in the collected samples. The results show three clusters (C1, C2, and C3) that were formed from the analysis of both sampling phases. For samples taken in phase-1, the results of cluster analysis (Figure 4) show that for the first cluster C1, around 43% of the investigated houses (houses No. 6, 13, 14, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, and 30) had similarity in 98.9% of the water quality measurements. These houses are located in the northern and southern part of Baniyas, and their water distribution network could be forked from the same water main. The third cluster C3 only comprises houses No. 16 and 28, which represent the middle section of the study area; their water quality parameters had similarity in more than 99% of the measurements. The third cluster C3 encompasses 50% of the study locations

in Baniyas. The C3 cluster characterizes the western and the middle part of Baniyas, and shows a similarity in 98% of the water quality measurements.

Phase-2 results (Figure 4) show that the first cluster C1 includes around one-third of the studied houses (houses No. 1, 3, 6, 8, 17, 20, 21, 22, 23, 24, and 29). Their water quality parameters had a similarity of 95%. Also, the second cluster C2 includes 37% of the locations studied in Baniyas (houses No. 2, 7, 10, 11, 12, 16, 18, 19, 25, 28, and 30); however, its similarity was quite higher than C1 (97%). The third cluster C3 had the highest similarity between its water quality variables (98%). C3 includes 26% of the houses in Baniyas. Overall, phase-2 clusters had lower similarity between its clusters (87%).



Figure 4. Dendrogram showing phase-1 and phase-2 clusters for 30 houses in the Baniyas region.

3.5. Health Risk Assessment

Health risk assessment was carried out to investigate the effect of heavy metals on adults and children. The HQ ranges for each heavy metal for adults and children are presented in Table 3; while the hazard index (HI) for each house is shown in Table 4. To avoid exaggerating the risk assessment, the analysis did not rely on the maximum concentration, as it could have been observed only once during the study period; the other concentrations (the mean and the minimum) could be more representative, and were used alongside the maximum in the risk assessment. Based on the categories of risk assessment, each water quality parameter was evaluated. For both adults and children, the HQ values for Cd, Cr, and Cu range from negligible (<0.1) to low (<1) chronic risk. In addition, the HQ for Zn is shown to be of negligible risk (<0.1) with no effect on the health of the adults and children. In contrast, the HQs for As and Pb range from low (<1) to high (>4.0), indicating their adverse health effects on the human body and potential non-carcinogenic concern via daily oral intake.

The HI results revealed the overall risk of the heavy metals. The results show a significant hazard in approximately 30% of the houses studied in Baniyas (houses No. 5, 6, 15, 18, 20, 23, 25, 29, and 30), and categorized these houses at a very high risk (HI > 8). Moreover, about 55% of the houses experienced a moderate to high risk on human health for both adults and children. The remaining 15% of the houses had a low to moderate risk on human health. Overall, compared with adults, the higher HQ and HI values for children were observed, suggesting that children are more sensitive when exposed to heavy metals in water.

		$C \rightarrow (u \sigma)$	RfD (ug/kg/day)	HQ			
		C_{wt} (µg)	KID (µg/kg/uay) -	Adult	Children		
	Max.	95.04	$3.00 imes 10^{-1}$	8.34	10.6		
As	Avg.	12.75	$3.00 imes10^{-1}$	1.12	1.42		
	Min.	8.9	$3.00 imes 10^{-1}$	0.78	0.99		
	Max.	15.4	$5.00 imes 10^{-1}$	0.81	1.03		
Cd	Avg.	1.95	$5.00 imes10^{-1}$	0.102	0.13		
	Min.	1	$5.00 imes 10^{-1}$	0.052	0.066		
	Max.	81.78	$3.50 imes 10^{-1}$	6.15	7.79		
Pb	Avg.	19.47	$3.50 imes10^{-1}$	1.46	1.85		
	Min.	11	$3.50 imes 10^{-1}$	0.826	1.05		
Cr	Max.	12.22	3.00	0.107	0.136		
	Avg.	4.96	3.00	0.0437	0.055		
	Min.	1.5	3.00	0.013	0.0167		
	Max.	206	4.00 imes 10	0.136	0.172		
Cu	Avg.	23.21	4.00×10	0.0153	0.0194		
	Min.	2	4.00 imes 10	0.0013	0.0017		
	Max.	205.1	3.00×10^{2}	0.0180	0.0228		
Zn	Avg.	15.2	$3.00 imes 10^2$	0.0013	0.0017		
	Min.	1	3.00×10^2	0.0001	0.0001		

Table 3. Heavy metals concentration ranges, reference dose, and hazard quotient (HQ) for children and adults. RfD: reference dose.

Tandan		Adult			Children	
Location	Max	Mean	Min	Max	Mean	Min
House-1	5.1	2.23	1.71	6.46	2.83	2.17
House-2	7.14	2.66	1.68	9.05	3.37	2.13
House-3	7.21	2.46	1.69	9.13	3.11	2.14
House-4	3.78	2.11	1.68	4.79	2.67	2.13
House-5	9.92	3.42	1.68	12.57	4.32	2.14
House-6	8.35	3.05	1.71	10.58	3.86	2.17
House-7	3.69	2.15	1.71	4.68	2.72	2.17
House-8	5.56	2.2	1.7	7.04	2.79	2.16
House-9	4.94	2.36	1.71	6.25	2.99	2.18
House-10	3.51	1.95	1.71	4.45	2.47	2.16
House-11	2.79	1.86	1.71	3.54	2.35	2.17
House-12	4.43	2.08	1.71	5.62	2.63	2.17
House-13	6.15	2.28	1.71	7.79	2.89	2.16
House-14	4.8	2.15	1.7	6.08	2.72	2.16
House-15	9.28	2.68	1.71	11.76	3.4	2.16
House-16	7.27	3.51	1.71	9.2	4.44	2.18
House-17	5.7	2.72	1.71	7.22	3.44	2.17
House-18	11.08	3.48	1.71	14.03	4.4	2.18
House-19	9.89	3.35	1.7	12.52	4.24	2.16
House-20	10.08	3.34	1.71	12.77	4.23	2.17
House-21	5.99	2.58	1.7	7.59	3.28	2.16
House-22	7.77	3.03	1.72	9.84	3.84	2.18
House-23	9.3	3.45	1.71	11.78	4.37	2.17
House-24	6.25	2.92	1.71	7.92	3.7	2.17
House-25	13.65	4.5	1.73	17.29	5.7	2.19
House-26	5.77	2.55	1.72	7.31	3.23	2.19
House-27	3.04	2.06	1.72	3.85	2.61	2.18
House-28	6.57	3.24	1.72	8.32	4.1	2.18
House-29	8.1	2.58	1.72	10.26	3.27	2.18
House-30	11.74	3.41	1.72	14.87	4.33	2.18

Table 4. Hazard Indices for adult and children in the sampled houses.

Bold: High risk, even using the mean values of heavy metals concentrations.

4. Discussion

This study examined the presence of six potentially toxic contaminants (arsenic, cadmium, lead, chromium, copper, and zinc) in household drinking water. Only two contaminants, arsenic and lead, present a concern for public health due to their frequent occurrence and high concentrations (Tables 1 and 3). Thus, this discussion will focus on the presence of lead and arsenic in drinking water. Many studies have investigated the effects of Pb on human health; the reports show that Pb has a severe impact on the hemopoietic, nervous, endocrine, and cardiovascular systems in the human body. For arsenic, it was shown that long-term exposure from drinking water can cause cancer in the skin, lungs, bladder, and kidneys [32,37–39].

The spatial analysis of heavy metals (Figure 3) shows that the drinking water contamination is not regionally specific within the district of Baniyas; further analysis shows that the contamination is rather household-specific. While there were some differences in the principal components extracted from the two phases, there were some striking similarities, especially in the results for the heavy metals. Phase-1 PC4 and phase-2 PC2 both show the association between temperature and Pb concentration. The consistent patterns of some parameters (turbidity, cations, and heavy metals) in the PCA of the two phases suggest relatively strong associations between these parameters in Baniyas's drinking water. However, caution is warranted in the interpretation of the PCA for health consequences due to concerns of sampling adequacy for the collected data.

The results of clustering can help in planning for water quality monitoring in Baniyas. It may not be necessary to sample each house; sampling one house from each cluster can give the necessary information about the range of contamination in the cluster. This can reduce the cost and time of the study. It also helps and compliments the rapid assessment of the impact of any taken measures to enhance household water quality.

The presence of lead in drinking water is commonly attributed to plumbing components containing lead (mainly solders) that were previously used and are still available in the market [40]. These components, which are commonly known as 'end-of-line fittings', can particularly influence the water quality at the faucet. The presence of heavy metals (arsenic, cadmium, and lead) at high concentrations in the water samples may be a result of corrosion in the main pipes or household plumbing. However, the spatial and statistical analysis suggests that the source is from the water mains. This calls for a broader investigation of the water quality in the distribution mains.

4.1. Limitations of This Study

Some studies draw attention to the possibility of data skewness (bias) resulting from voluntary participation [40,41]. The premise of this claim is that volunteer participants will be willing to participate in the study when they are suspicious about the quality of their drinking water. This could result in most of the collected samples having high levels of contamination.

The multivariate statistical analysis would be more beneficial with a larger sample size [42] so that a detailed analysis of the contaminant in the drinking water samples could be carried out. In this study, the sample's size was limited due to several reasons. (a) There was no readily available data on the supplied area number of households and population at the time of designing the study. (b) Only 30% of the proposed number of households agreed to participate in this study. (c) Due to budget limitations, the choice had to be made between the number of contaminants that each sample was analyzed for, and the total number of households sampled.

The study did not examine the impact of the Baniyas distribution system's characteristics such as pipe materials, diameters, and network layout on drinking water contamination. It would be interesting to investigate the statistical relations between these characteristics and the presence of contaminants in drinking water.

4.2. Recommendations for Managing Contaminants in Drinking Water

Most environmental and health agencies advise consumers to flush the taps before consumption for two to three minutes [41,43,44]. This technique will help reduce the contaminant concentration (particularly lead); however, around 2000 L would be wasted annually per household, which is against the country's policy for reducing water consumption.

Other studies suggest using a tap made from a material that does not contain lead (lead-free taps), such as stainless steel taps. These taps could prevent lead dissolution in the plumbing system [41,45]. Yet, some studies reported the incidence of lead presence in water samples even when lead-free taps were used, which was attributed to in-line brass fittings within the household plumbing system.

5. Conclusions

In the present study, various water quality parameters (physicochemical parameters and heavy metals) were assessed for water samples collected at four sampling points from 30 houses in the Baniyas region over two seasons. The analyzed data was interpreted by utilizing two main techniques: spatial (qualitative) analysis and multivariate statistical techniques. The main findings are that for both phases, the arsenic, cadmium, and lead concentrations were higher than the maximum allowable levels set in UAE standards. In addition, the water main samples had the highest concentration of the heavy metals in comparison with the other sampling points. Overall, PCA revealed that some physical parameters could contribute to the elevated levels of heavy metals. Furthermore, a cluster analysis suggested that for the future rapid assessment of contamination status and evaluating the impact of

water quality interventions, only one house from each cluster needed to be sampled/monitored. This could help in reducing the time and cost associated with water quality enhancement measures.

Health risk assessment results revealed that for As and Pb, the HQs ranged from low (<1) to high (>4.0) chronic risk, indicating their adverse health effects on the human body and potential chronic concern via daily oral intake. In addition, approximately 30% of the houses studied in Baniyas were categorized as houses at a very high risk. Overall, the results of the health risk assessment concluded that the HQ and HI values for children were observed to be higher than the adults, suggesting that children are more sensitive when exposed to heavy metals in water.

To this end, it is recommended to conduct further investigations into the concentrations of heavy metals to warrant intervention by the government to improve the water quality from the distribution mains and reduce health risks.

Author Contributions: Conceptualization, R.R.A.K. and M.M.M.; Data curation, R.R.A.K. and M.M.M.; Formal analysis, M.T.M.; Funding acquisition, M.A.H. and M.M.M.; Methodology, M.A.H.; Resources, M.M.M.; Supervision, M.A.H., R.R.A.K. and M.M.M.; Writing—original draft, M.T.M.; Writing—review & editing, M.A.H.

Funding: This work was funded by the National Research Foundation of UAE under University Industry Research Collaboration (UIRC) Program and the National Water Center at UAE University under projects no 31R112 and 31R113.

Acknowledgments: The authors would like to thank Abu Dhabi Food Control Authority (ADFCA) for providing assistance in the microbial analysis done in this study. We also thank Mujahid Ali for helping with the water sampling and quality analysis. We are also grateful to the Departments of Geology and Chemistry at the United Arab Emirates University for their assistance in the physicochemical analysis of water samples.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Correlation Matrices have been produced in order to explore the relation between the physico-chemical parameters.

Appendix A.1 Physico-Chemical Parameters

Phase-1								
	pН	Tem	EC	TDS	Turbidity	BOD	Cl-	SO4 ²⁻
pН	1.00							
Tem	0.38	1.00						
EC	-0.12	0.09	1.00					
TDS	-0.29	-0.33	0.90	1.00				
Turbidity	-0.19	-0.09	-0.04	0.00	1.00			
BOD	-0.31	-0.14	-0.03	0.06	0.11	1.00		
Cl-	-0.30	-0.05	0.67	0.64	0.02	0.08	1.00	
SO_4^{2-}	-0.24	-0.04	0.51	0.49	0.16	-0.04	0.83	1.00
Phase-2								
	pН	Tem	EC	TDS	Turbidity	BOD	C1-	SO_4^{2-}
pН	1.00							
Ťem	0.10	1.00						
EC	-0.22	0.24	1.00					
TDS	0.13	-0.21	-0.09	1.00				
Turbidity	0.39	-0.10	-0.07	0.004	1.00			
BOD	0.24	0.04	-0.05	0.05	0.08	1.00		
Cl ⁻	-0.14	0.06	0.08	-0.45	0.02	-0.18	1.00	
SO_4^{2-}	-0.13	0.04	0.14	-0.35	0.04	-0.11	0.93	1.00

Table A1. Correlation matrix for physico-chemical parameters in the two phases.

Appendix A.2 Heavy Metals

Phase-1						
	Ar	Cd	Pb	Cr	Cu	Zn
Ar	1.00					
Cd	-0.16	1.00				
Pb	-0.05	-0.21	1.00			
Cr	0.03	0.38	0.09	1.00		
Cu	-0.19	0.78	-0.14	0.47	1.00	
Zn	0.04	-0.18	0.25	-0.11	-0.04	1.00
Phase-2						
	Ar	Cd	Pb	Cr	Cu	Zn
Ar	1.00					
Cd	-0.08	1.00				
Pb	0.15	0.04	1.00			
Cr	0.12	0.45	-0.02	1.00		
Cu	-0.20	0.38	-0.14	0.05	1.00	
Zn	-0.19	-0.14	0.08	0.06	0.07	1.00

Table A2. Correlation matrix for heavy metals parameters in the two phases.

Appendix B

Appendix B represents the spatial variation of the heavy metals and cations have been analyzed using ArcGIS interpolation tool.



Figure A1. Spatial variation of heavy metals; (**a**–**d**) Zinc concentrations for the four sampling points WM, WT, BF and KF respectively. (**e**–**h**) Chromium concentrations for the four sampling points WM, WT, BF and KF respectively. (**i**–**l**) Copper concentrations for the four sampling points WM, WT, BF and KF respectively.



Figure A2. Spatial variation of Cations; (**a**–**d**) Calcium concentrations for the four sampling points WM, WT, BF and KF respectively. (**e**–**h**) Magnesium concentrations for the four sampling points WM, WT, BF and KF respectively. (**i**–**l**) Sodium concentrations for the four sampling points WM, WT, BF and KF respectively.



Figure A3. Spatial variation of heavy metals; (**a**–**d**) Potassium concentrations for the four sampling points WM, WT, BF and KF respectively. (**e**–**h**) Barium concentrations for the four sampling points WM, WT, BF and KF respectively.

References

 Jalba, D.I.; Cromar, N.J.; Pollard, S.J.T.; Charrois, J.W.; Bradshaw, R.; Hrudey, S.E. Effective drinking water collaborations are not accidental: Interagency relationships in the international water utility sector. *Sci. Total Environ.* 2014, 470–471, 934–944. [CrossRef] [PubMed]

- 2. Gorchev, H.G.; Ozolins, G. WHO guidelines for drinking-water quality. *WHO Chron.* **2011**, *38*, 104–108. [CrossRef]
- Khanal, N.; Buchberger, S.G.; Mckenna, S.A.; Clark, R.M.; Grayman, W.M. Vulnerability assessment of water distribution system to chemical intrusions. In Proceedings of the World Water and Environmental Resources Congress, Anchorage, Alaska, 15–19 May 2005; Volume 56.
- 4. Regulation and Supervision Bureau (RSB). *The Water Quality Regulations*, 4th ed.; The Regulation and Supervision Bureau for the Water, Wastewater and Electricity Sector in the Emirate of Abu Dhabi; RSB: Abu Dhabi, UAE, 2014.
- 5. Deng, Y.; Jiang, W.; Sadiq, R. Modeling contaminant intrusion in water distribution networks: A new similarity-based DST method. *Expert Syst. Appl.* **2011**, *38*, 571–578. [CrossRef]
- Cartier, C.; Nour, S.; Richer, B.; Deshommes, E.; Prévost, M. Impact of water treatment on the contribution of faucets to dissolved and particulate lead release at the tap. *Water Res.* 2012, *46*, 5205–5216. [CrossRef] [PubMed]
- Deshommes, E.; Andrews, R.C.; Gagnon, G.; McCluskey, T.; McIlwain, B.; Doré, E.; Nour, S.; Prévost, M. Evaluation of exposure to lead from drinking water in large buildings. *Water Res.* 2016, 99, 46–55. [CrossRef] [PubMed]
- 8. Scheili, A.; Rodriguez, M.J.; Sadiq, R. Impact of human operational factors on drinking water quality in small systems: An exploratory analysis. *J. Clean. Prod.* **2016**, *133*, 681–690. [CrossRef]
- 9. Wongsasuluk, P.; Chotpantarat, S.; Siriwong, W.; Robson, M. Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agriculture area in Ubon Ratchathani province, Thailand. *Environ. Geochem. Health* **2013**, 2014, 169–182. [CrossRef]
- 10. Diao, K.; Sweetapple, C.; Farmani, R.; Fu, G.; Ward, S.; Butler, D. Global resilience analysis of water distribution systems. *Water Res.* **2016**, *106*, 383–393. [CrossRef] [PubMed]
- 11. Housh, M.; Ostfeld, A. An integrated logit model for contamination event detection in water distribution systems. *Water Res.* **2015**, *75*, 210–223. [CrossRef] [PubMed]
- 12. Liu, S.; Li, R.; Smith, K.; Che, H. Why conventional detection methods fail in identifying the existence of contamination events. *Water Res.* 2016, *93*, 222–229. [CrossRef] [PubMed]
- 13. Wu, J.; Man, Y.; Sun, G.; Shang, L. Occurrence and health-risk assessment of trace metals in raw and boiled drinkingwater from rural areas of China. *Water (Switzerland)* **2018**, *10*, 641. [CrossRef]
- 14. Dzulfakar, M.A.; Shaharuddin, M.S.; Muhaimin, A.A.; Syazwan, A.I. Risk assessment of aluminum in drinking water between two residential areas. *Water (Switzerland)* **2011**, *3*, 882–893. [CrossRef]
- 15. Deshommes, E.; Laroche, L.; Nour, S.; Cartier, C.; Prévost, M. Source and occurrence of particulate lead in tap water. *Water Res.* **2010**, *44*, 3734–3744. [CrossRef] [PubMed]
- 16. Liu, B.; Reckhow, D.A. Disparity in disinfection byproducts concentration between hot and cold tap water. *Water Res.* **2015**, *70*, 196–204. [CrossRef] [PubMed]
- 17. Murad, A.A.; Nuaimi, H.; Hammadi, M. Comprehensive assessment of water resources in the United Arab Emirates (UAE). *Water Resour. Manag.* **2007**, *21*, 1449–1463. [CrossRef]
- 18. Bi, H.; Burstein, G.T.; Rodriguez, B.B.; Kawaley, G. Some aspects of the role of inhibitors in the corrosion of copper in tap water as observed by cyclic voltammetry. *Corros. Sci.* **2016**, *102*, 510–516. [CrossRef]
- Wang, J.; Liu, G.; Liu, H.; Lam, P.K.S. Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China. *Sci. Total Environ.* 2017, *583*, 421–431. [CrossRef] [PubMed]
- 20. Facchinelli, A.; Sacchi, E.; Mallen, L. Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. *Environ. Pollut.* **2001**, *114*, 313–324. [CrossRef]
- 21. Mustonen, S.M.; Tissari, S.; Huikko, L.; Kolehmainen, M.; Lehtola, M.J.; Hirvonen, A. Evaluating online data of water quality changes in a pilot drinking water distribution system with multivariate data exploration methods. *Water Res.* **2008**, *42*, 2421–2430. [CrossRef] [PubMed]
- 22. Shrestha, S.; Kazama, F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environ. Model. Softw.* **2007**, *22*, 464–475. [CrossRef]
- 23. Vialle, C.; Sablayrolles, C.; Lovera, M.; Jacob, S.; Huau, M.C.; Montrejaud-Vignoles, M. Monitoring of water quality from roof runoff: Interpretation using multivariate analysis. *Water Res.* **2011**, *45*, 3765–3775. [CrossRef] [PubMed]

- 24. American Public Health Association (APHA). *Standard Methods for Examination of Water and Wastewater*, 21st ed.; APHA: Washington, DC, USA, 2005.
- 25. American Public Health Association (APHA). *Standard Methods for Examination of Water and Wastewater*, 20th ed.; APHA: Washington, DC, USA, 1998; pp. 5–16. ISBN 9780875532356.
- 26. Simeonov, V.; Stratis, J.; Samara, C.; Zachariadis, G.; Voutsa, D.; Anthemidis, A.; Sofoniou, M.; Kouimtzis, T. Assessment of the surface water quality in Northern Greece. *Water Res.* **2003**, *37*, 4119–4124. [CrossRef]
- 27. Muhammad, S.; Shah, M.T.; Khan, S. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. *Microchem. J.* **2011**, *98*, 334–343. [CrossRef]
- 28. Olsen, R.L.; Chappell, R.W.; Loftis, J.C. Water quality sample collection, data treatment and results presentation for principal components analysis—Literature review and Illinois River watershed case study. *Water Res.* **2012**, *46*, 3110–3122. [CrossRef] [PubMed]
- Brahman, K.D.; Kazi, T.G.; Afridi, H.I.; Naseem, S.; Arain, S.S.; Ullah, N. Evaluation of high levels of fluoride, arsenic species and other physicochemical parameters in underground water of two sub districts of Tharparkar, Pakistan: A multivariate study. *Water Res.* 2013, 47, 1005–1020. [CrossRef] [PubMed]
- Singh, K.P.; Malik, A.; Mohan, D.; Sinha, S. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—A case study. *Water Res.* 2004, 38, 3980–3992. [CrossRef] [PubMed]
- 31. Bortey-Sam, N.; Nakayama, S.M.M.; Ikenaka, Y.; Akoto, O.; Baidoo, E.; Mizukawa, H.; Ishizuka, M. Health risk assessment of heavy metals and metalloid in drinking water from communities near gold mines in Tarkwa, Ghana. *Environ. Monit. Assess.* **2015**, *187*, 1–12. [CrossRef] [PubMed]
- 32. Gul, N.; Shah, M.T.; Khan, S.; Khattak, N.U.; Muhammad, S. Arsenic and heavy metals contamination, risk assessment and their source in drinking water of the Mardan District, Khyber Pakhtunkhwa, Pakistan. *J. Water Health* **2015**, *13*, 1073–1084. [CrossRef] [PubMed]
- 33. United States Environmental Protection Agency (USEPA). *National Primary/Secondary and Drinking Water Regulations*; USEPA: Washington, DC, USA, 2009.
- Meng, Q.; Zhang, J.; Zhang, Z.; Wu, T. Geochemistry of dissolved trace elements and heavy metals in the Dan River Drainage (China): Distribution, sources, and water quality assessment. *Environ. Sci. Pollut. Res.* 2016, 23, 8091–8103. [CrossRef] [PubMed]
- 35. Kapur, V. UAE in World's Top 5 "Heaviest" Nations—Emirates 2417. Available online: http://www. emirates247.com/news/emirates/uae-in-world-s-top-5-heaviest-nations-2012-07-04-1.465700 (accessed on 1 February 2018).
- 36. Xiao, J.; Jin, Z.; Wang, J. Geochemistry of trace elements and water quality assessment of natural water within the Tarim River Basin in the extreme arid region, NW China. *J. Geochem. Explor.* **2014**, *136*, 118–126. [CrossRef]
- 37. Fewtrell, L.; Fuge, R.; Kay, D. An estimation of the global burden of disease due to skin lesions caused by arsenic in drinking water. *J. Water Health* **2005**, *3*, 101–107. [CrossRef] [PubMed]
- 38. Herath, H.M.A.S.; Kawakami, T.; Nagasawa, S.; Serikawa, Y.; Motoyama, A.; Chaminda, G.G.T.; Weragoda, S.K.; Yatigammana, S.K.; Amarasooriya, A.a.G.D. Arsenic, cadmium, lead, and chromium in well water, rice, and human urine in Sri Lanka in relation to chronic kidney disease of unknown etiology. *J. Water Health* 2018, wh2018070. [CrossRef] [PubMed]
- Patrick, L. Lead toxicity, a review of the literature. Part I: Exposure, evaluation, and treatment. *Altern. Med. Rev.* 2006, 11, 2–22. [PubMed]
- 40. Pieper, K.J.; Krometis, L.A.H.; Gallagher, D.L.; Benham, B.L.; Edwards, M. Incidence of waterborne lead in private drinking water systems in Virginia. *J. Water Health* **2015**, *13*, 897–908. [CrossRef] [PubMed]
- 41. Harvey, P.J.; Handley, H.K.; Taylor, M.P. Widespread copper and lead contamination of household drinking water, New South Wales, Australia. *Environ. Res.* **2016**, *151*, 275–285. [CrossRef] [PubMed]
- 42. Siddiqui, K. Heuristics for sample size determination in multivariate statistical techniques. *World Appl. Sci. J.* **2013**, *27*, 285–287. [CrossRef]
- 43. National Health. Health Guidance Statement Lead in Drinking Water from Some Plumbing Products. Available online: http://www.health.gov.au/internet/main/publishing.nsf/content/ A12B57E41EC9F326CA257BF0001F9E7D/\$File/Lead-plumbing-products-Guidance-Statement-July2018. pdf (accessed on 7 November 2018).

- 44. Minnesota Department of Health. Important Information on How to Protect Your Health: Let It Run ... and Get the Lead Out! Available online: http://www.health.state.mn.us/divs/eh/water/factsheet/com/letitrunenglish.pdf (accessed on 7 November 2018).
- 45. Ng, D.Q.; Lin, Y.P. Evaluation of lead release in a simulated lead-free premise plumbing system using a sequential sampling approach. *Int. J. Environ. Res. Public Health* **2016**, *13*. [CrossRef] [PubMed]



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).