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Pesticides, Heavy Metals and Plasticizers: Contamination and Risk Assessment of Drinking-Water Quality

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Abstract: This study highlights the impact of formal agricultural practices and their adverse effect on the deterioration of underground water quality, with special emphasis on toxic elements, including pesticides, herbicides, fungicides, plasticizer accumulation and heavy-metal contamination. A comprehensive study was conducted at various recently developed societies of Sadiqabad that were formerly used for agricultural purposes. Ten various societies were selected, and three samples from each society were collected from different regions of these areas. Data regarding the physicochemical properties, metal contamination and accumulation of pesticide residues were determined using standard protocols. The results revealed that almost all the physicochemical properties of water samples selected from these sites were close to the WHO's recommended limits. The range for physicochemical properties was pH (6.4–7.7), electrical conductivity (168–766 μ S cm^{-1}), turbidity (6–17 NTU), total hardness (218–1030 mg L^{-1}), chloride contents (130–870 mg L^{-1}) and phosphate contents (2.55–5.11 mg L^{-1}). Among heavy metals, lead and arsenic concentrations in all sampling sites were found to be above the recommended limits. The decreasing pattern in terms of water-quality deterioration with respect to physicochemical properties was FFT > USM > CRH > UCS > CHS > MAH > FFC > CGA > GIH > AGS. Overall, 95 different kinds of toxic elements, including pesticides, herbicides, plasticizer, etc., were detected in the groundwater samples. The toxic compounds in the groundwater were categorized into pesticides, herbicides, plasticizer, plant growth regulators, fungicides, acaricides and insecticides. Most of these parameters showed peak values at the Fatima Fertilizer Company area and Chief Residencia Housing Society. Pesticide contamination showed that water-filtration plants have a big positive impact on the drinking quality of water. Proper monitoring of the pesticides must be performed, as the majority of the pesticides showed low priority. The monitoring method of the pesticides needs to be updated so that the occurrence of recently authorized pesticides is demonstrated.

Keywords: pesticides; water pollution; heavy metals; plasticizers; physicochemical; monitoring

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1. Introduction

The recent decades have seen an increase in the generation and discharge of toxic pollutants into water bodies as a result of rapid urbanization, industrialization and economic growth. In Pakistan, lakes, rivers and manmade reservoirs are frequently used as sources of drinking water. Water supplies or watershed ecosystems have recently been affected by unlawful discharges or unintentional leaks of wastewater carrying heavy metals or other organic compounds [1]. Because it is so directly tied to the health of the local populations, attention should be paid to the quality of drinking-water sources. Pesticides have been employed more and more in recent years to increase agricultural yields, and special care should be taken to prevent them from entering drinking-water sources [2]. Water resources in Lebanon, including drinking water, included 28 pesticides, with individual pesticide concentrations in surface water reaching 220 ng L^{-1} [3]. Pesticides and heavy metals have both been found in water sources, thus threatening the quality and safety of the water [4]. Even though the over-standard concentration did not indicate an ecological or health risk, there is still a possibility that these pesticides could eventually harm the environment's ecology and endanger people's health. There have been publications on the noncarcinogenic and carcinogenic dangers of ingesting, inhaling, and touching heavy metals and pesticides. According to the research of Singh and Kumar [5] and Kumar et al. [6], the Ajay River Basin's high concentrations of Fe, Pb and Cd, which were beyond the allowable limit for the quality of drinking water, could pose possible health hazards through oral consumption and cutaneous absorption.

Water contamination poses a significant concern due to the presence of a multitude of pollutants, encompassing heavy metals and organic and inorganic compounds, among others. Within this complex landscape of harmful and persistent waterborne contaminants, heavy metals hold a particular spot [7]. The rapid pace of global economic growth and industrialization has led to pronounced levels of heavy metal pollution, initially in soil and subsequently in surface and groundwater systems on a global scale and specifically within Iran [8]. The introduction of heavy metals into water sources occurs through natural processes or as a consequence of human activities. Many heavy metals are inherent constituents of the Earth's crust, and their release into groundwater has occurred naturally throughout human history due to the weathering and disintegration of metal-bearing rocks and ores. However, the concentrations of these metals vary significantly from one region's soil to another's [9]. Anthropogenic interventions significantly alter the prevalence of heavy metals in ecosystems. Anthropogenic sources such as vehicle emissions; improper waste disposal; fossil fuel combustion; agricultural activities, including fertilizer and pesticide usage; unprocessed wastewater irrigation; and atmospheric deposition resulting from various human endeavors, such as mining, smelting operations and agriculture, can introduce heavy metals into water bodies in substantial quantities. This influx can impact human health by affecting vegetation, the food chain and overall water quality. Once heavy metals enter the drinking water, they can find their way into the human body through various routes, including ingestion, skin contact, inhalation, and exposure through the mouth and nose [10].

The presence of heavy metals in water ecosystems can exert extensive damage on the environment and subsequently pose risks to human health. This is attributable to the unique characteristics of heavy metals, which include toxicity, poor biodegradability and a tendency to accumulate in living organisms. While some heavy metals play crucial roles as structural and catalytic components of proteins and enzymes in the human body, if their concentration exceeds international guidelines, this can lead to adverse effects [11]. Prolonged exposure to heavy metals can result in their accumulation within specific tissues, such as the brain, liver, bones and kidneys, leading to severe health hazards, the nature of which depends on the specific element and its chemical form [11].

Water, energy security, economic development, human health and food security are the major issues that depend on strategic and effective resource management in sustainable societies [8,12]. Due to increased industrialization, agricultural practices, and population growth, both surface and groundwater are becoming contaminated with time; hence, demanding specific actions due to toxins that could bioaccumulate, persist, and pose a significant health risk [13]. Around the world, synthetic pesticides predominate in groundwater and drinking water in arable land. According to an estimate, the high-potential organic substances that could be harmful and have negative effects on the environment and human health amounted to 6 billion pounds from 2018 to 2019. The composition of the soil mainly controls the fate of pesticides after their application. Traditionally, the pesticides used in agriculture are applied directly or indirectly to the soil [14–16]. Pesticides are exposed to a variety of biological and physiochemical processes after they enter the soil environment. These processes are interconnected and ultimately control the fate of pesticides. Pesticide buildup in drinking water can be extremely dangerous, but it can be eliminated using techniques like adsorption and absorption [17]. Various procedures are developed to examine a wide range of chemicals found in drinking water as part of agricultural management scenarios. Multiple factors contribute to the presence of pesticides in drinking water, which can have an impact on both the human and natural environment. Many processes involving biological and chemical methodologies have been devised, which are safer and sustainable for our environment including water when used in the treatment of potentially toxic pesticides. The law imposes stringent penalties on those responsible for water pollution that result in harming the health of residents [18] and promote better management practices [19–21]. Since heavy metals can enter into human food chains, there is always a potential risk to human health [22–26]. The purity and safety of water are dangerously threatened by both pesticides and heavy metals. Numerous studies have indicated that the dermal contact, ingestion, and inhalation of pesticides and heavy metals can result in both carcinogenic and noncarcinogenic risks to human health. These studies also indicated that certain health risks should be highlighted due to the contaminated sediments and heavy-metal ions [27]. Natural contaminants found in groundwater are categorized as inorganic, organic, and biological contaminations. Anthropogenic activities are to blame for the organic material contamination of groundwater [28]. However, geological materials (e.g., minerals and ores) are the primary cause of the inorganic contaminations. Elevated levels of cations and anions including fluorides, magnesium, calcium, nitrate, sulfate, potassium, sodium, and phosphate are found as part of inorganic pollution. Pathogens such as bacteria, viruses, and protozoa are part of biological substances that may cause pollution [29]. Pesticides and oils are examples of organic contaminations. All these types of contaminations may put the ecosystem's health at risk when they surpass the acceptable thresholds. Lead, cadmium, nickel, arsenic, and other heavy metals as well as bacterial agents and other chemical substances such as fluorides, and nitrates, are the greatest threats to the groundwater's standard quality [30]. Organic contaminants known as persistent organic pollutants (POPs) have a negative impact on the environment and are hazardous to human health. Pesticides have been used in Pakistan at an amount of about 250 metric tonnes since 1954 [31,32]. The amount of insecticides consumed in Pakistan reached 7000 tonnes in 1960. But as of 2003, this has steadily risen to 78,132 tonnes. The use of certain prohibited chemicals has decreased in Pakistan during the last few decades, while biphenylenes, polychlorinated, polyaromatic hydrocarbons (PAHs), and organochlorine pesticides (OCPs) are persistent organic pollutants (POPs) found in Pakistani water sources [33,34]. Currently, OCPs, which induce immunological problems, reproductive disorders, and carcinogenesis, are the most serious concern to the health of the natural environment. Potential organochlorine pesticide pollutants in soil and water include hexachlorobenzene, DDD Di-chloro-diphenyl-chloro-ethane, DDP, and di-chloro-di-phenyl tri-chloro-ethane [35]. The main sources of OCPs are air and water exchange activities, but other sources include the use of pesticides for agricultural runoff, pond irrigation, material control of crops, and equipment cleaning. The research work carried out under the Punjab Groundwater Development project revealed the presence of endosulfan at a concentration of 0.02 mg/L in groundwater samples. However, the reported endosulfan levels in the Khyber-Pakhtunkhwa Province ranged from 0 to 0.13 mg/L [36]. Long-term pesticide exposure can have a negative impact on searing pain and urinary tract infections. Because they are carcinogens, pesticides also have the potential to damage human endocrine glands and disturb the body's hormonal balance. Pesticide use in agricultural areas cannot be modified but a prudent pesticide usage and management could aid in preventing major environmental issues [37,38]. Pakistan is one of the nations in the world that uses pesticides in significant amounts, and the pesticide sector is a major part of the agricultural commodities to control weeds and insects [39,40]. Chemical products that make water toxic and can result in dangerous levels of contamination are among the pollutants found in groundwater that are utilized for drinking purposes. Due to pesticide contamination and other substances including phenol, helomethanes, and volatile aromatics, the chemical oxygen demand (COD) level in drinking water derived from grounds is at its maximum level [41–43]. However, pesticides are chemically stable and are difficult to mineralize, and biodegrade slowly by microorganisms, especially fungi and bacteria, but the pesticides' toxicity also prevents microbial growth [44].

Plasticizers are widely utilized compounds employed to impart flexibility to polyvinyl chloride (PVC) products, and are also extensively integrated into various applications such as building materials, household furnishings, food packaging, and insect repellents. Moreover, they have also found applications in maintaining color and fragrance in an array of consumer and personal care items, including children's toys, cosmetics, blood bags, organic solvents, packaging materials, paper coatings, insecticides, as well as decorative and construction-care products. The pervasive and expansive utilization of phthalates has rendered them omnipresent environmental contaminants. Due to their physical, rather than chemical, incorporation within the polymer matrix, phthalates exhibit a propensity to migrate into consumables, beverages, and potable water through packaging, bottling materials, or manufacturing procedures [45]. Consequently, these compounds are ingested and may be absorbed into the human body. As the hazards of conventional plasticizers have become evident and are subject to regulations, the burgeoning demand for plasticizers has spurred the rapid emergence, production, and widespread use of alternative compounds, such as analogs of bisphenol A (BPA) and OPEs like t-butylphenyl diphenyl phosphate (BPDP) and bisphenol A bis(diphenyl phosphate) (BDP). However, these novel plasticizers also exhibit detrimental health implications. For instance, BPA substitutes like bisphenol AP (BPAP), bisphenol F (BPF), bisphenol B (BPB), and bisphenol S (BPS), have been found to pose harm comparable to BPA [46]. At low concentrations, these substances induce oxidative stress linked to endocrine disruptions in humans, and they also disrupt regular sperm production. It is worth noting that children, relative to adults, face challenges in metabolizing and eliminating plasticizers, hence rendering them more susceptible to the detrimental effects. Certain plasticizers can disrupt brain development, impact pituitary, and thyroid functionality, and perturb other aspects of the human endocrine system, particularly during pivotal developmental stages [47].

Vegetables are primarily grown in Southern Pakistan during the dry season (January–June). Traditional water supply systems include manually dug wells that are typically situated in the middle of fields. Although gardeners sometimes use them for drinking water, their main purpose is to reduce the distance to the nearest water source for irrigation. Water from boreholes is used in households, but water from wells and the surface water are typically used when working in the fields. While they are close to cultivated areas, they are submerged in water by seasonal lakes during the rainy season. These wells, generally, lack safety precautions with water-quality issues, are non-dependable in terms of predictable water availability and can be regarded as an unreliable water source.

The concentration of toxic pesticide residues and heavy-metal contents in both soil and underground water reserves of housing societies is at risk due to pollution resulting from agricultural practices. While various investigations on water pollution have been carried out by researchers, very little is known about the impact of pesticide residues in groundwater reserves, particularly in the study area. In this study, we will evaluate the levels of metal contamination and pesticide accumulation in water samples of Sadiqabad's newly developed societies.

2. Materials and Methods

2.1. Site Description and Sample Collection

Sadiqabad is a tehsil of district Rahim Yar Khan, located in the province of Punjab, and is the 32nd largest city of Pakistan. It is located on the border between Sindh and Punjab, on the eastern bank of the Indus River. Sadiqabad consists of fertile land and is rich in agriculture, producing a large quantity of cotton, wheat, sugar cane, oranges, and mangoes. The annual temperature in the district is 32.63 °C (90.73 °F), indicating an 11.74% increase compared to the average temperature of Pakistan. Sadiqabad usually reaches approximately 23.34 mm (0.92 inches) of rainfall distributed over 49.93 rainy days, accounting for around 13.68% of the year. Ten different locations in Sadiqabad City were chosen for groundwater sampling, including Gulshan E Ghafar Avenue (GGA), Chattha Housing Society (CHS), Ahmed Garden Housing Society (AGS), Fatima Fertilizer Colony (FFC), Fatima Fertilizer Town Ship (FFT), Model Avenue Housing (MAH), Chief Residencia Housing (CRH), Gulshan Iqbal Housing (GIH), Unique City Society (UCS) and USM Colony. Due to rapid urbanization, this agricultural land was converted into housing societies to cater to the needs of the rapidly increasing population. The water samples were collected from the underground water sources via the grab sampling technique and stored in plastic bottles, properly sealed, tagged, and stored until the analytical analysis. Each site's groundwater samples were taken in triplicate, for a total of 30 samples. These samples were transported to the lab for physical and chemical analysis in pre-sterilized plastic bottles following standard sampling procedures.

2.2. Physicochemical and Metal Properties of Water Samples

The pH of water samples was determined with the help of a pH meter (EUTECH, pH 700 Meter, Thermo Fisher Scientific, Shanghai, China) and EC was measured by an electrical conductivity meter (EUTECH, CON 700, Thermo Fisher Scientific, Shanghai, China). Total hardness was determined by titrating the water sample with 0.01 M EDTA [48] and the calculation was carried out using the following Equation (1):

$$Total\ hardness\ as\ CaCO3\left(\frac{mg}{L}\right) = \frac{vol.EDTA \times Molarity \times 1000}{Vol.of\ sample} \tag{1}$$

Calcium content was determined by the EDTA Titrimetric Method (0.01 M EDTA) [48]. The calcium content was determined by the following Equation (2):

$$Ca\ (mg/L) = \frac{A \times B \times 400.8}{mL\ of\ sample} \tag{2}$$

where A = mL of EDTA titrant used, and

$$B = \frac{mL\ of\ standard\ calcium\ solution}{mL\ of\ EDTA\ titrant} \tag{3}$$

Magnesium hardness was calculated from the difference between the total hardness and calcium hardness which is expressed in mg/L. The extent of magnesium contamination can be calculated by multiplying magnesium hardness by 0.243. Mohr methodology (Agrentometric 4500 B-Chloride) was used to measure the contents of chloride in the drinking/groundwater samples. The value was calculated using Equation (4):

$$Cl^{-}\left(\frac{\text{mg}}{\text{L}}\right) = \frac{(A - B) \times M \times 35.450}{mL\ of\ Sample\ Used} \tag{4}$$

where A = mL of titration of a sample; B = ml of titration of blank; and M = molarity of $AgNO_3$.

2.3. Heavy-Metal Determination in Water Samples

Digestion of water samples was made with perchloric acid and an Atomic Absorption Spectrophotometer (Perkin-Elmer, Model 3300, Waltham, MA, USA) was used to detect the heavy-metal concentrations. The heavy metals in the water samples were analyzed by atomic absorption following the method described by the Assubaie [49].

2.4. Determination of Pesticide Residues in Water Samples

Detection of pesticides in samples was conducted with GC/MS (Agilent Technologies GC 6890, MSD 5977A, Santa Clara, CA, USA) furnished with an HP-5MS fused-silica capillary column (15 m $\times$ 0.25 mm i.d., film thickness 0.25 µ m, J&W Scientific, Folsom, CA, USA). As a carrier, He (Helium) gas at a purity level of 99.99% was utilized at a flow rate of about 2.1 mL/min. For sample injection, 7890 A GC multimode inlet was used carefully and for its operation, the splitless injection mode was utilized which was equipped with an inlet liner stuffed with a glass wool frit (Inner liner (Ultra) from Agilent). Using the splitless injection mode, a small quantity ranging from 1 µ L to 3 µ L of samples under study was introduced. The temperature settings of the GC injection port and the MS interface were fixed to 280 °C. The oven temperature fluctuation was employed, where it was at first maintained at 70 °C for 1 min, then enhanced to 150 °C at 50 °C/min, maintained again at 150 °C for about 1 min, and increased from 200 to 225 °C at 6 °C/min, and maintained for about 0 min after that temperature increased to 295 °C at the speed of 16 °C/min and finally maintained at this temperature for 10 min. Up to this point, the total run time was 29.475 min. For running the mass spectrometer, the electron ionization mode was selected by the electron multiplier voltage value at 1058 V. MS quad and ion source temperatures were 200 °C and 300 °C, respectively. The results from the mass spectrometer were found in the atomic mass range from 45 to 550 amu. Various toxic chemicals (pesticides, herbicides, fungicides, plasticizers, etc.) were characterized by comparing mass spectra and the reference ions abundance ratio of the recognized analysis from the sample with one of the standards (RTL library and NIST-MS). Pesticides and other pollutants (plasticizers) were identified based on their respective peak areas (%).

2.5. Human Health Risk Assessment

The risk to human health posed by a particular chemical was divided into two categories: the risk that could cause cancer and the risk that would not. The most frequent routes for contaminants in water were thought to be the direct ingestion of drinking water [50]. The Integrated Risk Information System [51] and other databases were used to extract the slope factors for carcinogenic pollutants and reference doses for noncarcinogenic compounds. Here, 10^{-6} was used as the acceptable critical threshold, which was in accordance with the recommended acceptable risks supplied by the USEPA (2000).

$$ADD_{ingestion} = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{5}$$

$$R_i^n = \frac{ADD}{(RfD \times 70)} \times 10^{-6} \tag{6}$$

$$R = \sum_{i=1}^{n} R_i^n \tag{7}$$

where ADD is the average daily dose (mg kg^{-1} d^{-1}), C is the concentration of the target pollutants, and R is the noncarcinogenic health risk; IR stands for intake rate (kg or L per day); EF stands for exposure frequency (365 days per year); ED for exposure duration (years), which for an adult according to the USEPA (2011) is 30 years; BW stands for body weight in kilograms; AT for average exposure duration in days; and the reference dose for each pollutant is RfD. In this study, an adult's average lifespan of 65 years is used. Here, the term "carcinogenic risk" refers to the lifetime likelihood that a person may contract cancer as a result of exposure to pesticide and heavy-metal contamination. Equation (6)

(USEPA, 1991) was used to compute the carcinogenic risk. Using Equation (8), the overall risk was determined.

$$R_i^c = \frac{ADD \times SF}{65} \quad (8)$$

where R_i^c stands for the carcinogenic health risk; ADD is for average daily dosage (mg kg^{-1} d^{-1}); and SF stands for slope factor. In this study, an adult's lifetime of 65 years was taken to be the typical lifetime of an individual. The reference values for the exposure parameters that were used to calculate the intake values and risks of the heavy metals and pesticides that were the targets. RAIS and IRIS databases served as the primary sources for the RfD and SF values [51,52].

3. Results

3.1. Physicochemical Properties of Drinking-Water Samples

Table 1 summarizes the pH, EC, Total Hardness, and chloride values in the drinking water of the study area. The pH values of drinking water were in the following order: AGS > GIH > GGA > FFC = MAH > CHS > CRH = UCS > FFT = USM. In the USM area, the highest pH was found to be due to the high chloride contents. The low pH of drinking water was measured in the USM area. The results showed that the drinking water collected from the study area is slightly acidic to slightly alkaline. However, the pH value of drinking water was within the permissible limits as suggested by the WHO. Similarly, the EC of the drinking water was in the following order: FFT > USM > CRH > UCS > CHS > MAH > FFC > GGA > AGS = GIH. The highest observed EC value was 766 µ S cm^{-1} at the FFT society sampling location. Some of the samples values exceeded the guideline value set by the WHO. The lowest value was found at AGS and GIH society locations (168 µ S cm^{-1}). Significant variation in total hardness (218–1030 mg/L) was observed in water samples. Maximum total hardness (1030 mg L^{-1}) was observed in water samples collected from the FFT, followed by the USM colony, JDW Unit-II (840 mg L^{-1}), and chief residencia housing (716 mg L^{-1}), while the minimum total hardness (218 mg L^{-1}) was measured in water samples collected from the Ahmed Garden Housing Society.

Table 1. Physicochemical properties of drinking water.

Societies	EC (µS/cm)	pH	Cl Contents (mg L^{-1})	TH (mg L^{-1})
GGA	169	6.7	136	228
CHS	368	7.1	540	486
AGS	168	6.4	130	218
FFC	235	7	188	310
FFT	766	7.7	870	1030
MAH	313	7	190	390
CRH	540	7.3	820	716
GIH	168	6.6	136	218
UCS	424	7.3	680	704
USM	755	7.7	830	840
WHO Permissible limits	400 µS/cm	6.5–8.5	250 mg/L	500 mg/L

EC = Electrical conductivity; TH = Total hardness; Cl = Chloride contents.

The range of chloride contents was observed to be 130–870 mg L^{-1} in water samples. Maximum chloride contents (870 mg L^{-1}) were observed when the water samples were collected from the FFT, followed by the USM colony, JDW Unit-II (830 mg L^{-1}), and chief residencia housing (820 mg L^{-1}), while the minimum chloride contents (130 mg L^{-1}) were noticed when the water samples were collected from the Ahmed Garden Housing Society. A large variation in electrical conductivity (EC) was observed in water samples (168 µ S cm^{-1}–766 µS cm^{-1}). Maximum electrical conductivity (766 µS cm^{-1}) was observed when the water samples were collected from the FFT, followed by the USM colony, JDW Unit-II (755 µS cm^{-1}), and CRH (540 µS cm^{-1}), while the minimum conductivity (168 µ S cm^{-1}) was noticed when the water samples were collected from the AGHS.

3.2. Heavy Metals in Drinking Water

The concentrations of heavy metals in each sampling region are shown in Figure 1. The maximum concentrations of each heavy metal detected in the drinking water were 0.20 mg L^{-1} for Cd, 0.62 mg L^{-1} for Pb, 0.621 mg L^{-1} for Hg, and 0.88 mg L^{-1} for Zn. Among all the heavy metals detected in the drinking-water samples, the maximum concentrations were in the order of FFT > USM > JDW Unit-II > CRH > AGHS. It is worth noticing that Fe concentrations were higher than other elements in drinking-water samples compared with the second-grade state standard. No metals in the water samples exceeded the domestic standard level, with the exception of the highest concentration of Fe (610 mg L^{-1}), which was three times greater than the standard level.

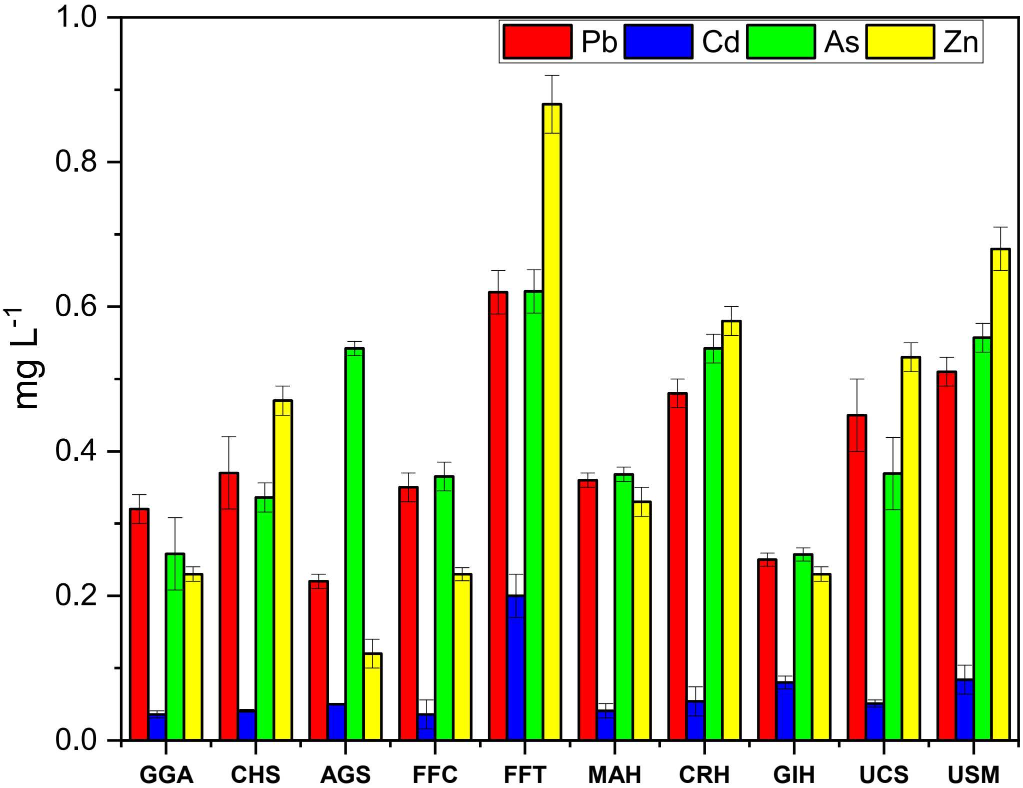

Figure 1. Heavy-metal concentration in drinking water collected from societies. WHO permissible limits of Pb (50 μg/L), Cd (5 μg/L), Zn (5000 μg/L), As = 10 μg/L.

3.3. Accumulation of Pesticide Residues in Drinking-Water Samples

3.3.1. Herbicide Contamination in Water Samples

Herbicide contamination in the drinking-water samples was detected from the study area. Sixteen (16) herbicides of different types were detected, as shown in Table 2. The results from different sites were compared and it was observed that eleven types of herbicides were found in the Fatima fertilizer township area which ranged from 0.31–5.71%, six from Gulshan E Ghaffar Avenue (0.15–1.16%), six from Chatham Housing Society (0.33–1.73%), six from Ahmed Garden Housing Society with peak area (0.76–1.21%), seven from the Fatima Fertilizer Colony with peak area (0.83–2.03%), five from Model Avenue Housing (0.45–2.15%), ten from chief residencia housing (0.51–4.49%), seven from Gulshan Iqbal Housing (0.21–0.98%), six from unique city society (0.72–2.60%) and ten from the USM colony, JDW UNIT-II (0.44–1.66%).

Table 2. Herbicide concentration in the drinking-water samples of recent developed societies of Sadiqabad.

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
1	Isocarbamide	Amide	-	0.50	-	-	-	-	0.50	0.34	-	-
2	Monalide	Anilide	-	2.10	0.55	1.20	1.18	0.68	1.58	0.51	-	-
3	Tebutam	Benzamide	0.84	1.09	1.46	0.84	0.95	0.44	0.74	-	1.01	0.31
4	Desbromo-bromobutide	Amide	-	1.12	-	-	0.95	-	-	-	1.11	0.45
5	Dimepiperate	Thiocarbamate	-	0.45	0.45	-	0.57	0.44	5.17	0.15	-	-
6	Bromobutide	Amide	-	1.26	1.26	-	2.49	1.18	2.17	1.16	1.12	0.98
7	Beflubutamid	Amide	1.52	-	-	-	3.00	1.66	2.17	0.89	-	0.81
8	Chloranocryl	Anilide	2.03	2.15	-	2.60	0.66	-	1.03	-	1.21	-
9	4-Isopropylaniline	Dinitroaniline		-	0.33		0.51	0.81	0.31	0.33	-	0.21
10	Propachlor	Chloroacetamide	1.02	-	-	1.12	0.51	0.84	0.43	-	-	0.56
11	Carbetamide	Carbamate	-	-	0.33	-	4.49	1.18	3.92	-	-	-
12	Dinoseb acetate	Dinitrophenol	-	-	1.73	0.72	-	-	-	-	0.76	-
13	Methoprotryne	Triazine	1.54	-	-	1.57	-	-	-	0.98	-	-
14	Cycloate	Thiocarbamate	1.61	-	-	1.60	1.33	0.97	-	-	-	0.89
15	MCPB methyl ester	Aryloxyalkanoic acid	-	-	-	-	-	1.52	5.74	-	-	-
16	2,4-DB methyl ester	Chlorophenoxy acid	0.89	-	-	-	-	1.52	2.74	0.89	1.11	-

GGA = Gulshan E Ghafar Avenue; CHS = Chattha Housing Society; AGS = Ahmed Garden Housing Society; FFC = Fatima Fertilizer Colony; FFT = Fatima Fertilizer Town Ship; MAH = Model Avenue Housing; CRH = Chief Residencia Housing; GIH = Gulshan Iqbal Housing; UCS = Unique City Society and USM = USM Colony, JDW Unit-II.

3.3.2. Fungicides and Acaricides Contamination in Water Samples

Fifteen (15) fungicides and acaricides in the drinking-water samples of the study area were detected (Table 3). Ten different types of fungicides and acaricides were found in the Fatima fertilizer township area with peak areas ranging from (0.22–0.94%), six from Gulshan E Ghaffar Avenue with peak area (0.19–1.65%), seven from Chattha housing society with peak area (0.21–1.97%), four from Ahmed Garden Housing Society with peak area (1.53–2.73%), seven from the Fatima Fertilizer Colony with peak area (0.33–2.13%), five from Model Avenue Housing with peak area (1.08–3.01%), eight from chief residencia housing with peak area (0.53–2.02%), six from Gulshan Iqbal Housing with peak area (0.21–1.45%), seven from unique city society with peak area (0.69–1.60%) and ten from the USM colony, JDW UNIT-II with peak area (0.16–3.01%).

Table 3. Fungicides and acaricides detected in the drinking-water samples of recently developed societies of Sadiqabad on the basis of peak area (%) using GC-MS.

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
1	Dinocap I	Dinitrophenol	1.63	1.92	0.32	1.46	0.53	0.86	0.53	1.13	1.53	1.03
2	Dinocap II	Dinitrophenol	2.02	1.08	0.52	0.98	0.53	0.47	0.53	-	2.42	-
3	Dinocap III	Dinitrophenol	1.98	1.30	-	1.06	0.97	1.03	0.57	1.65	2.34	1.45
4	Dinocap IV	Dinitrophenol	2.13	1.50	0.72	0.98	0.53	1.47	0.77	1.61	2.73	-
5	Binapacryl	Dinitrophenol	-	-	0.52	1.60	0.60	0.47	0.94	-	-	-
6	Oxamyl	Phenylamide	0.55	-	0.31	-	-	0.65	-	0.65	-	0.51
7	Iprobenfos	Organophosphate	-	3.01	1.97	-	2.02	3.01	-	-	-	-
8	Cyprofuram	Anilide	-	-	0.21	-	0.68	-	0.43	-	-	0.39
9	Cymoxanil	Cyanoacetamide oxime	0.55	-	-	0.69	-	0.43	-	0.41	-	-
10	Triadimefon	Triazole	-	-	-	1.18	-	-	-	-	-	-
11	1,2-Dibromo-3-chloropropane	Halogenated alkane	-	-	-	-	1.21	1.36	-	-	-	-
12	Bitertanol I	Triazole	-	-	-	-	-	-	0.25	-	-	0.21
13	Bitertanol II	Triazole	-	-	-	-	-	-	0.25	-	-	-
14	Phthalide	Unclassified	-	-	-	-	-	0.16	0.22	-	-	0.22
15	o-Phenylphenol	Phenol	0.33	-	-	-	-	-	0.25	0.19	-	-

3.3.3. Insecticide Contamination in Water Samples

Variation in the contamination of insecticides in the drinking-water samples of the study area was noticed. Fourteen insecticides of different types were detected which provided a substantial variation in the peak area (Table 4). The results from different sites were compared and nine various insecticides were found in the Fatima fertilizer township area with peak areas ranging from (0.22–2.74%), four from Gulshan E Ghaffar Avenue with peak areas (0.54–1.45%), five from Chattha housing society with peak area (0.28–0.66%), three from Ahmed Garden Housing Society with peak area (0.33–0.65%), six from the Fatima Fertilizer Colony with peak area (0.32–1.61%), seven from Model Avenue Housing with peak area (0.21–0.98%), seven from chief residencia housing with peak area (0.61–1.98%), seven from Gulshan Iqbal Housing with peak area (0.54–1.45%), six from unique city society with peak area (0.44–2.01%) and eight from the USM colony, JDW UNIT-II with peak area (1.34–2.15%).

Table 4. Comparative analysis of detected insecticides in the drinking-water samples of recently developed societies of Sadiqabad based on peak area (%) using GC-MS.

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
1	Methomyl	Carbamate	1.61	0.39	0.33	1.04	1.84	1.44	0.48	0.99	0.56	1.23
2	Cyanofenphos	phosphonothioate	1.31	-	0.66	-	1.36	1.41	0.36	1.45	0.65	-
3	N.N-Diethyl-m-toluamide	Unclassified	-	-	-	-	-	-	-	-	-	1.01
4	Propoxur	Carbamate	0.32	0.21	0.28	-	-	-	-	0.54	-	0.54
5	Trifenmorph	Morpholine derivative	-	-	-	-	-	1.95	0.22	-	-	-
6	Demeton-S	Organophosphate	-	0.39	0.33	1.16	1.71	1.95	-	-	0.33	1.45
7	Thiometon	Organophosphate	-	0.98	-	-	-	1.95	-	-	-	-
8	Demeton-S-methyl	Organophosphate	-	0.31	0.33	-	1.71	-	1.29	-	-	-
9	Vamidothion	Organophosphate	-	-	-	-	-	2.15	0.57	-	-	0.56
10	Demephion	Organophosphate	-	-	-	2.01	1.98	2.15	0.57	-	-	-
11	N,N-Diethyl-m-toluamide	Unclassified	0.69	0.34	-	0.44	0.61	-	0.67	-	-	-
12	Disulfoton	Organophosphate	1.19	-	-	1.52	1.69	1.34	2.74	-	-	-
13	Trichlorfon	Organophosphate	-	-	-	1.11	-	-	-	-	-	1.01
14	Chlordene	Organochlorine	0.45	0.54	-	-	-	-	0.98	0.71	-	0.71

3.3.4. Plant Growth Regulators Contamination in Water Samples

Variation in the contamination of plant growth regulators in the drinking-water samples of the study area was noticed. Eleven plant growth regulators of different types were detected which provided a significant variation in the peak area (Table 5). The results from different sites were compared and observed that seven various plant growth regulators were found in the Fatima fertilizer township area with peak areas ranging from (0.13–1.01%), six from Gulshan E Ghaffar Avenue with peak areas (0.29–1.01%), four from Chattha housing society with peak area (0.29–2.10%), three from Ahmed Garden Housing Society with peak area (0.14–1.41%), six from the Fatima Fertilizer Colony with peak area (0.21–1.24%), four from Model Avenue Housing with peak area (0.38–1.23%), six from chief residencia housing with peak area (0.23–2.32%), seven from Gulshan Iqbal Housing with peak area (0.34–1.91%), four from unique city society with peak area (0.20–1.45%) and six from the USM colony, JDW UNIT-II with peak area (0.45–1.23%).

3.3.5. Plasticizer and Chemicals Contamination in Water Samples

Variation in the contamination of plasticizers and various chemical contaminants in the drinking-water samples of the study area was noticed. Thirty-nine various plasticizers and various chemical contaminants of different types were detected which provided a substantial variation in the peak area (Table 6). The results from different sites were compared and observed that eight various plasticizers and various chemical contaminants were found in the Fatima fertilizer township area with peak area ranging from (0.39–6.57%), seventeen from Gulshan E Ghaffar Avenue with peak area (0.05–3.64%), seventeen from Chattha housing society with peak area (0.63–2.54%), six from Ahmed Garden Housing Society with peak area (0.08–2.01%), six from the Fatima Fertilizer Colony with peak area (0.38–0.73%), twelve from Model Avenue Housing with peak area (0.29–9.57%), seven from chief residencia housing with peak area (0.51–3.31%), fourteen from Gulshan Iqbal Housing with peak area (0.16–2.87%), nine from unique city society with peak area (0.47–4.14%) and nine from the USM colony, JDW UNIT-II with peak area (1.29–19.71%).

Table 5. Comparative analysis of detected plant growth regulators in the drinking-water samples of recently developed societies of Sadiqabad on the basis of peak area (%) using GC-MS.

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
1	2-(1-naphthyl) acetamide	Auxin	-	-	0.78	0.91	0.50	0.49	0.23	0.11	0.67	-
2	Ancymidol	Pyrimidinyl carbinol	-	0.89	-	0.98	-	-	-	-	-	0.91
3	Diisobutyl phthalate	Unclassified	1.24	-	0.29	-	2.32	-	0.91	-	-	1.12
4	Di-n-nonyl phthalate	Unclassified	1.11	1.23	-	1.30	-	1.23	-	1.01	1.41	1.91
5	Di-n-butylphthalate	Unclassified	0.21	-	-	-	-	-	0.45	0.29	-	0.45
6	Bis(2-butoxyethyl) phthalate	Unclassified	1.01	0.67	0.71	0.20	-	0.45	0.14	-	0.14	0.34
7	Endosulfan ether	Unclassified	0.89	-	-	-	0.61	0.56	-	0.79	-	-
8	Di-n-propyl phthalate	Unclassified	-	0.40	1.78	1.45	1.10	1.21	1.01	0.78	-	1.78
9	Dicyclopentadiene	Hydrocarbon		0.38	2.10	-	0.45	0.71	0.50			
10	Prohydrojasmon II {CAS # 158474…	Synthetic jasmonate	0.81	-	-	0.46	0.55	0.65	0.80	0.51	-	0.59
11	2-(1-naphthyl) acetamide	Unclassified	-	-	-	-	0.23	-	0.13	0.54	0.69	0.64

Table 6. Comparative analysis of detected plasticizers and various other compounds in the drinking-water samples of recent developed societies of Sadiqabad on the basis of peak area (%) using GC-MS.

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
1	4-Chloro-2-methylaniline	Unclassified	0.50	0.39	-	-	0.54	-	4.62	0.45	0.45	0.70
2	2-(2-Butoxyethoxy) ethyl thiocyclic	Cyclic aromatic	-	1.22	0.84	0.6	0.51	2.59	0.42	0.67	-	-
3	Cashmeran	alicyclic ketone	0.51	9.57	2.14	4.14	0.51	9.71	6.57	3.64	1.34	0.41
4	Chrysene	aromatic hydrocarbon in coal tar	0.56	-	2.29	0.47	-	-	-	1.47	2.01	0.16
5	2-ethyl-6-methylaniline		-	0.63	0.88	-	-	-	-	0.56	1.23	-
6	Naphthalene	Aromatic hydrocarbon	0.38	-	-	-	-	-	-	0.51	-	0.18
7	2-Chlorophenol		-	-	-	-	-	-	-	-	-	-
8	2-Ethyl-1,3-hexanediol		0.47	-	-	0.81	-	-	-	-	-	0.57
9	Ethylenethioure	Thiourea	-	-	2.29	-	1.02	1.63	-	-	-	-
10	Tonalide	Tetralin	-	0.48	-	-	-	-	-	0.55	-	-
11	Di-n-butylphthalat	Unclassified	-	0.44	2.5	2.28	-	3.74	2.22	2.28	-	-
12	Diamyl phthalate	Unclassified	-	-	2.54	2.28	-	3.74	2.22	2.28	-	2.12
13	Di-n-propyl phthalate	Unclassified	-	-	2.50	2.28	-	-	2.22	2.28	-	-
14	PCB 31		-	0.34	-	-	-	-	-	-	-	-
15	PCB 30		-	-	-	-	-	-	-	-	-	-
16	Cyclopentadecanone	saturated alicyclic ketone	-	0.29	-	0.60	-	-	-	0.60	-	-
17	Trifloxystrobin		-	0.50	-	-	-	-	-	-	0.08	-
18	Exaltolide [15-Pentadecanolide]	a natural macrolide lactone and a synthetic musk		-	-	-	0.65	-	0.39	-		0.89
19	Spiroxamine metabolite		-	2.59	-	-	-	-	-	0.59	-	-
20	Fenpropidin		-	-	-	-	-	-	-	-	-	1.34
21	Bis (2-ethylhexyl) Phthalate	Unclassified	-	0.67	-	-	-	-	-	-	0.67	-
22	Di-n-hexyl phthalate	Unclassified	-	-	1.25	-	-	-	-	-	-	-

Table 6. *Cont.*

Sr. No.	Chemical Name	Substance Group	FFC	MAH	CHS	UCS	CRH	USM	FFT	GGA	AGS	GIH
23	Cyclopentadecanone	saturated alicyclic ketone	0.73	-	-	-	-	-	-	0.75	-	0.63
24	Pyrazon		-	5.40	-	-	-	-	-	-	-	-
25	Pyrazophos	-	-	-	-	-	-	-		-	-	-
26	2-(2-Butoxyethoxy) ethyl thiocya	Cyclic aromatic	-	-	1.71	0.74	-	-	-	0.74	-	1.45
27	Aminocarb		-	-	0.63	-	-	-	-	-	-	-
28	Cyromazine		-	-	0.63	-	-	-	-	-	-	-
29	Bendiocarb		-	-	0.63	-	-	-	-	0.65	-	-
30	Benzo(a)anthracene		-	-	2.29	-	1.28	-	-	-	-	1.78
31	Phenanthrene		-	-	0.71	-	-	-	-	-	-	-
32	Anthracene		-	-	0.71	-	-	-	-	-	-	-
33	Carbofuran-3-keto		-	-	0.71	-	-	-	-	-	-	-
34	Beflubutamid	Amide	-	-	-	-	3.31	-	-	0.05	-	2.87
35	Chloroneb		-	-	-	-	-	19.71	-	-	-	-
36	N-Methyl-N-1-naphthyl acetamide	Unclassified	-	-	-	-	-	1.36	-	-	-	1.21
37	Tebutam	Benzamide	-	-	-	-	-	1.87	-	-	-	-
38	Crufomate		-	-	-	-	-	1.29	-	-	-	-
39	Benzophenone	Aromatic Ketone	-	-	-	-	-	-	2.69	1.55	-	1.23

3.3.6. Health Risk Assessment

Both for carcinogenic and noncarcinogenic assessment, only RIAS and IRIS data were used. Only those compound data for which Rfd and SF values were available was used in the calculation of Carcinogenic and noncarcinogenic health impacts.

Carcinogenic Risk Assessment

Carcinogenic risks have been calculated for pesticides and heavy metals, and their carcinogenic slope factors are provided. The carcinogenic risk calculation used the values for adults and the highest concentration in each sampling region (obtained from Tables 2–6) to reflect the typical scenario for exposure. A total of 26 cancer-causing chemicals were used for the calculation of the health risk index. The value of each carcinogenic chemical. A risk rating greater than 10^{-4} typically indicates an unacceptable risk to one's health from carcinogens, with 10^{-6} being the maximum amount allowed. Health hazards are regarded to be manageable or tolerable when they fall between 10^{-6} and 10^{-4}, and minor when they fall between 10^{-8} and 10^{-7}, according to the US EPA (2001) guidlelines [53]. In light of this, we determined that 10^{-6} was an appropriate critical threshold for adults. The results indicated that, except for the AGS society, the drinking-water samples collected showed a high risk of carcinogenicity. The highest concentration of carcinogenic content (that has the potential to cause cancer) was found in groundwater samples collected from the CRH housing society followed by FFC and GIH (Figure 2).

Noncarcinogenic Risk Assessment

The noncarcinogenic risk with the highest recorded concentrations of noncarcinogenic heavy metals, pesticides, herbicides, and insecticides was computed. Because their dose–response factors have been determined, considering the worst scenario of noncarcinogenic health risk was found to be the most appropriate approach. It was observed that there were no detectable noncarcinogenic health concerns in our research area because the total noncarcinogenic risk related to both heavy metals and pesticides varied from 0.001 to 0.004. It can be observed that the water samples collected from the GGA society contained the least risk factor when compared with the other sampled housing societies (Figure 3).

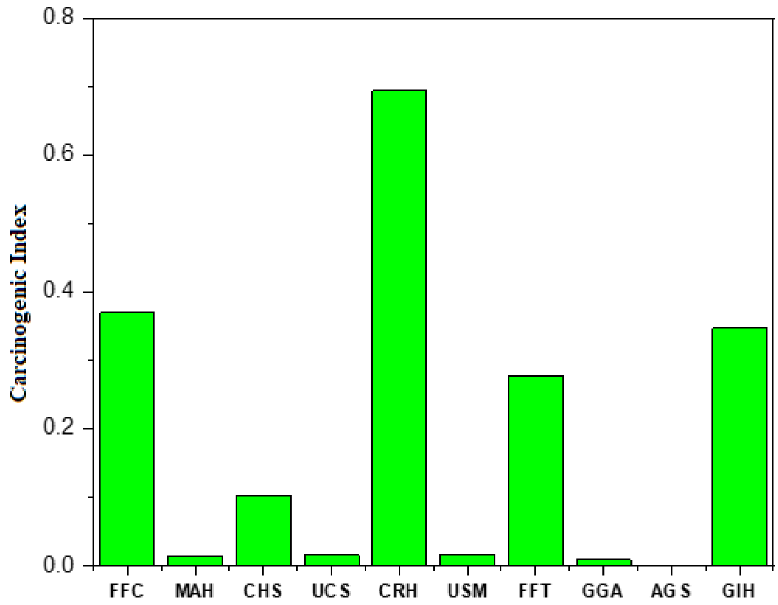

Figure 2. Carcinogenic index values calculated for the groundwater samples from various sampling sites of the study areas.

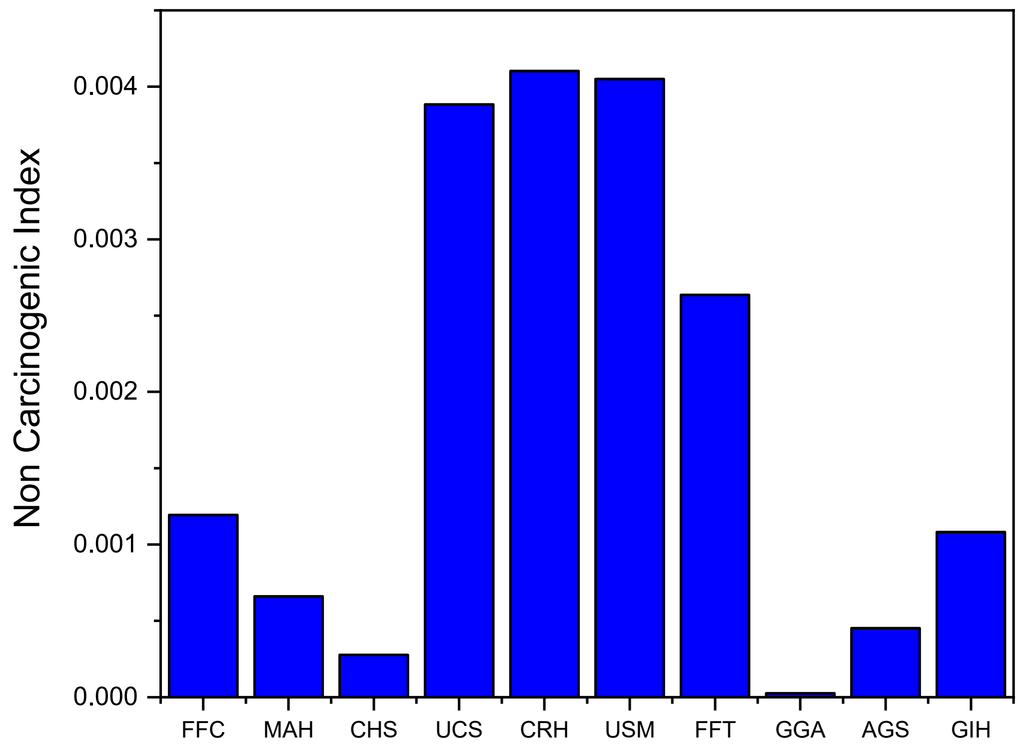

Figure 3. Noncarcinogenic index values for the groundwater samples from various study sampling sites.

4. Discussion

The pH in drinking water has a permitted level set by the WHO between 6.5 and 8.5. All samples' pH levels were within the acceptable range as specified by the WHO, making them suitable for drinking. A better water supply system or even a better purification facility being accessible to citizens was to be blamed for any significant change in tested sampling locations [54]. Drinking water's slight pH change is influenced by the composition of its ionic constituents, particularly the hydrogen and hydroxyl ions that are present in water [55]. These findings support earlier research by Farooq et al. (2008), in which pH values ranged from 7.02 to 7.30, and by Hashmi et al. [56], in which pH values varied from 7.03 to 7.73 in a residential neighborhood of Rawalpindi.

The EC range for all of the water samples was between 168 and 766 µ S cm^{-1}. The electrical conductivity standards for drinking water were not reached by most of the water sampled in the study area. There were no companies releasing wastewater without sufficient treatment close to the sampled areas as indicated by the variation in electrical conductivity in the tested samples [57]. The electrical conductivity of drinking water was found to be marginally altered by various human activities (agricultural runoff), and processes used in water treatment and chemicals used in the dry cleaning industry [58]. Statistically, the highest hardness value (1030 mg L^{-1}) was found in water samples collected from the Fatima Fertilizer Township while the minimum total hardness (218 mg L^{-1}) was observed when the water samples were collected from the Ahmed Garden Housing Society. Four samples showed total hardness values above the permissible limits as described by the WHO safe drinking water limits. High amounts of limestone and magnesium carbonate may also be attributed to a higher level of hardness in these areas [59]. The problem of hardness becomes more serious due to the presence of rocky materials and industrial operations in these areas [60]. Another possible source of increased hardness is the presence of inorganic materials (geogenic source) in the water [59]. Similarly, the chloride level detected in most of the samples was below the guidelines provided by the WHO; therefore, most samples are considered to be safe to drink concerning chloride levels. These results are in agreement with the findings reported in other studies [61], which also found an acceptable levels of chloride in drinking-water samples taken from the Rawalpindi and Islamabad regions.

The presence of heavy metals in drinking water higher than the WHO permissible limits can cause detrimental impacts on human health [62,63]. According to [64], Cd occurs naturally in rocks and soils and enters water when there is contact with soft groundwater or surface water. Moreover, it may be introduced by paints, pigments, plastic stabilizers, mining and smelting operations [65] and other industrial operations such as electroplating and fossil fuel, fertilizer (Diammonium Phosphate), and sewage sludge disposal [60]. This might be due to corrosion of galvanized steel pipe that is used for piping of water distribution over the areas and mainly the agricultural activities (intensive fertilizer application) [62]. Similarly, the higher concentrations of As in all the sampling points may be due to the chemical fertilizers and surface runoff in that area [66]. Meharg et al. [67] reported the presence of As in the rice grain and the soil due to chemical fertilizers.

The water samples contained a variety of toxic elements, including plasticizers, insecticides, fungicides, acaricides, pesticides, and herbicides. Similar conclusions were reached by Konstantinou [68], who evaluated pesticides in surface waters in Greek rivers and lakes. They found that atrazine, simazine, alachlor, metolachlor, and trifluralin were the types of herbicides most frequently found, while diazinon and parathion methyl were the types of insecticides. Profenofos, malathion, and diazinon were recently found to be pesticide residues in drinking-groundwater resources in Iran [69]. These insecticides, with the higher values of 0.542, 0.456, and 0.614 g/L, were the most frequently found substances. After being used in agriculture, a lot of pesticides are eventually discharged into the environment [39]. Heavy metals and pesticides in drinking water contained both carcinogenic risk and noncarcinogenic risk in the groundwater, which helped to clarify the role of heavy metals and pesticides in human health concerns in each sampling region. In our research location, the carcinogenic hazards were typically more serious than the noncarcinogenic risks. These findings may be influenced by the input river's watershed area, the local gross population, and the size of the livestock and poultry farm industry in the study area. Pesticides were often utilized by locals to cultivate farmland in our study region. As a result, a sizable volume of pesticide-containing agricultural runoff from farmland flowed directly into the aquatic environment and rivers. The permissible limits of certain commonly used toxic elements including pesticides, herbicides, plasticizers, etc., by various organizations are represented in Table 7.

Table 7. Permissible limits of toxic elements in drinking water.

Toxic Compounds	WHO (mg L^{-1})	US-EPA (mg L^{-1})	ISI * (μg L^{-1})
DDT	...	...	42
Aldrin	0.0003	...	17
Dieldren	0.0003	...	17
Endrin	...	0.002	1
Chlordane	...	...	3
Lindane	...	...	56
Heptachlor	...	...	18
Methoxychlor	0.02	0.04	35
Heptachlor-epoxide	...	...	18
Organic-phosphate	...	...	100
Toxaphene	...	...	5
Carbamate	...	...	100
Methoxychlor	0.02	...	...
Bentazon	0.3	...	...
Chlorotoluron	0.03	...	...
Pyradite	0.1	...	...
1,2-dicholoropropane	0.04	...	...
Polyaromatic hydrocarbons	0.01	...	...
Polyaromatic hydrocarbons	...	0.003	...
Toluene	...	1000	...
Xylenes (total)	...	10	...
Ethyl-benzene	...	0.7	...
Styrene	...	0.1	...
Chlorobenzene	...	0.1	...
Benzene	...	Zero	...
Oxamyl	...	0.2	...
1,2 dichloropropane	...	Zero	...
o-Dichlorobenzene	...	0.6	...
p-Dichlorobenzene	...	0.075	...
Ethylbenzene	...	0.7	...
Vinyl chloride	...	0.002	...
Chloride	...	250	...
Glyphosate	...	0.7	...

* ISI Indian standard institution.

Although most of these agrochemicals breakdown gradually in soil, water, and sediments, a few are persistent and bioaccumulative, which has a significant negative impact on water quality and have adverse environmental consequences [70]. A more thorough understanding of the impacts of pesticides in drinking water on human health and the ecosystem will be possible due to the work being carried out with effective pesticide pollution monitoring in real-time [71]. Many inquiries were made for people to comprehend and properly establish the health hazards based on scientific evidence [72]. In research for appropriate pesticide use and cutting-edge pest control techniques, the analytical confirmation of low amounts of pesticides is crucial [27]. These innovations will benefit both agricultural and aquatic ecosystems by reducing the toxicity of pesticide discharge [73].

5. Conclusions

Housing societies developed on agricultural land are at risk due to water contamination. Hence, the use of agricultural land for housing purposes has to be regulated. Our study provides comprehensive data on the presence and potential risks to human health posed by heavy-metal and pesticide contamination in underground drinking water. In this investigation, it was found that the mean levels of the target heavy metals (Cu, Zn, Cd, and As) in water from our study region were all below the domestic standard. Hexachlorobenzene and As in water were found to be the main contributors to carcinogenic hazards for humans, according to the risk assessment, but there were no obvious noncarcinogenic health problems connected to heavy metals and pesticides in the study area. It is worth mentioning here that there are more pesticides and other pollutants (plasticizers) identified in this study than the typically published problematic pesticides by the WHO and USEPA. This is probably due to the lack of enforcement of environmental and water-quality laws. At present, both corrective and preventive measures should be taken in the area to control groundwater contamination. The absence of proper legislation will certainly accelerate groundwater quality degradation, which would put the lives of our future generations at risk. This study highlights the importance of further detailed research work to investigate groundwater abstraction and the recharge rate, trace-heavy-metal levels, the quantification of pesticide and plasticizer concentrations, biological aspects concerning the boring depth, and daily water extraction.

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References

1. Ali, U.; Syed, J.H.; Malik, R.N.; Katsoyiannis, A.; Li, J.; Zhang, G.; Jones, K.C. Organochlorine pesticides (OCPs) in South Asian region: A review. *Sci. Total. Environ.* **2014**, *476*, 705–717. [CrossRef] [PubMed]
2. Li, H.; Zeng, E.Y.; You, J. Mitigating pesticide pollution in China requires law enforcement, farmer training, and technological innovation. *Environ. Toxicol. Chem.* **2014**, *33*, 963–971. [CrossRef] [PubMed]
3. Kouzayha, A.; Al Ashi, A.; Al Akoum, R.; Al Iskandarani, M.; Budzinski, H.; Jaber, F. Occurrence of Pesticide Residues in Lebanon's Water Resources. *Bull. Environ. Contam. Toxicol.* **2013**, *91*, 503–509. [CrossRef]
4. Taiwo, A.M. A review of environmental and health effects of organochlorine pesticide residues in Africa. *Chemosphere* **2019**, *220*, 1126–1140. [CrossRef]
5. Singh, U.K.; Kumar, B. Pathways of heavy metals contamination and associated human health risk in Ajay River basin, India. *Chemosphere* **2017**, *174*, 183–199. [CrossRef] [PubMed]
6. Kumar, S.S.D.; Rajendran, N.K.; Houreld, N.N.; Abrahamse, H. Recent advances on silver nanoparticle and biopolymer-based biomaterials for wound healing applications. *Int. J. Biol. Macromol.* **2018**, *115*, 165–175. [CrossRef]
7. Kamani, H.; Mirzaei, N.; Ghaderpoori, M.; Bazrafshan, E.; Rezaei, S.; Mahvi, A.H. Concentration and ecological risk of heavy metal in street dusts of Eslamshahr, Iran. *Hum. Ecol. Risk Assess. Int. J.* **2017**, *24*, 961–970. [CrossRef]
8. Chowdhury, S.; Mazumder, M.J.; Al-Attas, O.; Husain, T. Heavy metals in drinking water: Occurrences, implications, and future needs in developing countries. *Sci. Total. Environ.* **2016**, *569*, 476–488. [CrossRef]
9. Vetrimurugan, E.; Brindha, K.; Elango, L.; Ndwandwe, O.M. Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta. *Appl. Water Sci.* **2016**, *7*, 3267–3280. [CrossRef]

10. Sardar, K.; Ali, S.; Hameed, S.; Afzal, S.; Fatima, S.; Shakoor, M.B.; Bharwana, S.A.; Tauqeer, H.M. Heavy metals contamination and what are the impacts on living organisms. *Greener J. Environ. Manag. Public Saf.* **2013**, *2*, 172–179.
11. Kamunda, C.; Mathuthu, M.; Madhuku, M. Health Risk Assessment of Heavy Metals in Soils from Witwatersrand Gold Mining Basin, South Africa. *Int. J. Environ. Res. Public Health* **2016**, *13*, 663. [CrossRef] [PubMed]
12. Sevillano, M.; Dai, Z.; Calus, S.; Santos, Q.M.B.-D.L.; Eren, A.M.; van der Wielen, P.W.; Ijaz, U.Z.; Pinto, A.J. Differential prevalence and host-association of antimicrobial resistance traits in disinfected and non-disinfected drinking water systems. *Sci. Total. Environ.* **2020**, *749*, 141451. [CrossRef] [PubMed]
13. Stoler, J.; Pearson, A.L.; Staddon, C.; Wutich, A.; Mack, E.; Brewis, A.; Rosinger, A.Y.; Adams, E.; Ahmed, J.F.; Alexander, M. Cash water expenditures are associated with household water insecurity, food insecurity, and perceived stress in study sites across 20 low-and middle-income countries. *Sci. Total Environ.* **2020**, *716*, 135881. [CrossRef] [PubMed]
14. Covert, S.A.; Shoda, M.E.; Stackpoole, S.M.; Stone, W.W. Pesticide mixtures show potential toxicity to aquatic life in US streams, water years 2013–2017. *Sci. Total Environ.* **2020**, *745*, 141285. [CrossRef]
15. Sharma, A.; Shukla, A.; Attri, K.; Kumar, M.; Kumar, P.; Suttee, A.; Singh, G.; Barnwal, R.P.; Singla, N. Global trends in pesticides: A looming threat and viable alternatives. *Ecotoxicol. Environ. Saf.* **2020**, *201*, 110812. [CrossRef]
16. Petrovskaya, N.B.; Ellis, J.R.; Forbes, E.; Walters, K.F. Modelling a targeted use of pesticide procedure for pest populations with heterogeneous spatial distributions. *Ecol. Model.* **2020**, *427*, 109059. [CrossRef]
17. Chu, Y.; Tong, Z.; Dong, X.; Sun, M.; Gao, T.; Duan, J.; Wang, M. Simultaneous determination of 98 pesticide residues in strawberries using UPLC-MS/MS and GC-MS/MS. *Microchem. J.* **2020**, *156*, 104975. [CrossRef]
18. Aloizou, A.-M.; Siokas, V.; Vogiatzi, C.; Peristeri, E.; Docea, A.O.; Petrakis, D.; Provatas, A.; Folia, V.; Chalkia, C.; Vinceti, M.; et al. Pesticides, cognitive functions and dementia: A review. *Toxicol. Lett.* **2020**, *326*, 31–51. [CrossRef]
19. Luca, S.V.; Roehrer, S.; Kleigrewe, K.; Minceva, M. Approach for simultaneous cannabidiol isolation and pesticide removal from hemp extracts with liquid-liquid chromatography. *Ind. Crops Prod.* **2020**, *155*, 112726. [CrossRef]
20. Mojiri, A.; Zhou, J.L.; Robinson, B.; Ohashi, A.; Ozaki, N.; Kindaichi, T.; Farraji, H.; Vakili, M. Pesticides in aquatic environments and their removal by adsorption methods. *Chemosphere* **2020**, *253*, 126646. [CrossRef]
21. He, W. Analysis of Regional Differences in Digital Inclusive Finance in China. *Heliyon* **2020**, *3*, 17–22.
22. Esfahani, A.R.; Zhang, Z.; Sip, Y.Y.L.; Zhai, L.; Sadmani, A.A. Removal of heavy metals from water using electrospun polyelectrolyte complex fiber mats. *J. Water Process Eng.* **2020**, *37*, 101438. [CrossRef]
23. Mokarram, M.; Saber, A.; Sheykhi, V. Effects of heavy metal contamination on river water quality due to release of industrial effluents. *J. Clean. Prod.* **2020**, *277*, 123380. [CrossRef]
24. Eom, H.; Kang, W.; Kim, S.; Chon, K.; Lee, Y.-G.; Oh, S.-E. Improved toxicity analysis of heavy metal-contaminated water via a novel fermentative bacteria-based test kit. *Chemosphere* **2020**, *258*, 127412. [CrossRef]
25. Azmi, S.N.H.; Al-Balushi, M.; Al-Siyabi, F.; Al-Hinai, N.; Khurshid, S. Adsorptive removal of Pb(II) ions from groundwater samples in Oman using carbonized *Phoenix dactylifera* seed (Date stone). *J. King Saud Univ. Sci.* **2020**, *32*, 2931–2938. [CrossRef]
26. Lutfullah; Sharma, S.; Rahman, N.; Azmi, S.N.H.; Iqbal, B.; Amburk, M.I.B.B.; Al Barwani, Z.M.H. UV spectrophotometric determination of Cu (II) in synthetic mixture and water samples. *J. Chin. Chem. Soc.* **2010**, *57*, 622–631. [CrossRef]
27. Tyagi, R.; Jacob, J. Design and synthesis of water-soluble chelating polymeric materials for heavy metal ion sequestration from aqueous waste. *React. Funct. Polym.* **2020**, *154*, 104687. [CrossRef]
28. Peters, D. Sonolytic degradation of volatile pollutants in natural ground water: Conclusions from a model study. *Ultrason. Sonochemistry* **2001**, *8*, 221–226. [CrossRef]
29. Lu, F.; Astruc, D. Nanocatalysts and other nanomaterials for water remediation from organic pollutants. *Coord. Chem. Rev.* **2020**, *408*, 213180. [CrossRef]
30. Gopinath, K.P.; Madhav, N.V.; Krishnan, A.; Malolan, R.; Rangarajan, G. Present applications of titanium dioxide for the photocatalytic removal of pollutants from water: A review. *J. Environ. Manag.* **2020**, *270*, 110906. [CrossRef]
31. Ayodele, B.V.; Alsaffar, M.A.; Mustapa, S.I.; Cheng, C.K.; Witoon, T. Modeling the effect of process parameters on the photocatalytic degradation of organic pollutants using artificial neural networks. *Process Saf. Environ. Prot.* **2021**, *145*, 120–132. [CrossRef]
32. Anandan, S.; Ponnusamy, V.K.; Ashokkumar, M. A review on hybrid techniques for the degradation of organic pollutants in aqueous environment. *Ultrason. Sonochemistry* **2020**, *67*, 105130. [CrossRef]
33. Wu, Y.; Guan, C.-Y.; Griswold, N.; Hou, L.-Y.; Fang, X.; Hu, A.; Hu, Z.-Q.; Yu, C.-P. Zero-valent iron-based technologies for removal of heavy metal(loid)s and organic pollutants from the aquatic environment: Recent advances and perspectives. *J. Clean. Prod.* **2020**, *277*, 123478. [CrossRef]
34. Du, X.; Zhou, M. Strategies to enhance catalytic performance of metal–organic frameworks in sulfate radical-based advanced oxidation processes for organic pollutants removal. *Chem. Eng. J.* **2020**, *403*, 126346. [CrossRef]
35. Liu, Q.; Shao, W.; Zhang, C.; Xu, C.; Wang, Q.; Liu, H.; Sun, H.; Jiang, Z.; Gu, A. Organochloride pesticides modulated gut microbiota and influenced bile acid metabolism in mice. *Environ. Pollut.* **2017**, *226*, 268–276. [CrossRef]
36. Geller, A.M.; Stedile, F.C.; Peralba, M.D.C.R.; Pizzolato, T.M.; dos Santos, J.H.Z. Evaluation of zirconocene-based silica phases in organochloride pesticides preconcentration. *J. Colloid Interface Sci.* **2006**, *299*, 163–171. [CrossRef]
37. Luft, S.; Milki, E.A.; Glustrom, E.; Ampiah-Bonney, R.; O'Hara, P.B. Binding of Organochloride and Pyrethroid Pesticides to Estrogen Receptors α and β: A Fluorescence Polarization Assay. *Biophys. J.* **2009**, *96*, 444a. [CrossRef]
38. Goetz, C.G. *Organophosphates, Organochlorides, and Pesticides*; US EPA: New York, NY, USA, 2003.

39. Sultana, T.; Murray, C.; Kleywegt, S.; Metcalfe, C.D. Neonicotinoid pesticides in drinking water in agricultural regions of southern Ontario, Canada. *Chemosphere* **2018**, *202*, 506–513. [CrossRef]
40. Waheed, S.; Halsall, C.; Sweetman, A.J.; Jones, K.C.; Malik, R.N. Pesticides contaminated dust exposure, risk diagnosis and exposure markers in occupational and residential settings of Lahore, Pakistan. *Environ. Toxicol. Pharmacol.* **2017**, *56*, 375–382. [CrossRef]
41. Tariq, M.I.; Afzal, S.; Hussain, I.; Sultana, N. Pesticides exposure in Pakistan: A review. *Environ. Int.* **2007**, *33*, 1107–1122. [CrossRef]
42. Syed, J.H.; Malik, R.N.; Liu, D.; Xu, Y.; Wang, Y.; Li, J.; Zhang, G.; Jones, K.C. Organochlorine pesticides in air and soil and estimated air–soil exchange in Punjab, Pakistan. *Sci. Total Environ.* **2013**, *444*, 491–497. [CrossRef] [PubMed]
43. Tariq, M.I.; Afzal, S.; Hussain, I. Pesticides in shallow groundwater of Bahawalnagar, Muzafargarh, D.G. Khan and Rajan Pur districts of Punjab, Pakistan. *Environ. Int.* **2004**, *30*, 471–479. [CrossRef] [PubMed]
44. Shabbier, M.; Singh, M.; Maiti, S.; Kumar, S.; Saha, S.K. Removal enactment of organo-phosphorous pesticide using bacteria isolated from domestic sewage. *Bioresour. Technol.* **2018**, *263*, 280–288. [CrossRef]
45. De la Torre, A.; Navarro, I.; Sanz, P.; de los Ángeles Martínez, M. Organophosphate compounds, polybrominated diphenyl ethers and novel brominated flame retardants in European indoor house dust: Use, evidence for replacements and assessment of human exposure. *J. Hazard. Mater.* **2020**, *382*, 121009. [CrossRef]
46. Salthammer, T. Emerging indoor pollutants. *Int. J. Hyg. Environ. Health* **2020**, *224*, 113423. [CrossRef] [PubMed]
47. Ullah, A.; Pirzada, M.; Jahan, S.; Ullah, H.; Shaheen, G.; Rehman, H.; Siddiqui, M.F.; Butt, M.A. Bisphenol A and its analogs bisphenol B, bisphenol F, and bisphenol S: Comparative in vitro and in vivo studies on the sperms and testicular tissues of rats. *Chemosphere* **2018**, *209*, 508–516. [CrossRef]
48. Bawa, B.; Ribah, M. Assessment of physicochemical characteristics and heavy metals concentration in freshwater from Jega River, Kebbi State, Nigeria. *Int. J. Chem. Mol. Eng.* **2018**, *12*, 78–81.
49. Assubaie, F.N. Assessment of the levels of some heavy metals in water in Alahsa Oasis farms, Saudi Arabia, with analysis by atomic absorption spectrophotometry. *Arab. J. Chem.* **2015**, *8*, 240–245. [CrossRef]
50. Wu, B.; Zhao, D.Y.; Jia, H.Y.; Zhang, Y.; Zhang, X.X.; Cheng, S.P. Preliminary Risk Assessment of Trace Metal Pollution in Surface Water from Yangtze River in Nanjing Section, China. *Bull. Environ. Contam. Toxicol.* **2009**, *82*, 405–409. [CrossRef]
51. Jia, H.; Gao, S.; Duan, Y.; Fu, Q.; Che, X.; Xu, H.; Wang, Z.; Cheng, J. Investigation of health risk assessment and odor pollution of volatile organic compounds from industrial activities in the Yangtze River Delta region, China. *Ecotoxicol. Environ. Saf.* **2020**, *208*, 111474. [CrossRef]
52. Lin, B.-G.; Pan, P.; Wei, C.-X.; Chen, X.-C.; Zhang, Z.-Y.; Fan, Q.-F.; Liu, F.; Liu, B.-B.; Wu, L. Health risk assessment of trace metal(loid)s in agricultural soil using an integrated model combining soil-related and plants-accumulation exposures: A case study on Hainan Island, South China. *Sci. Total. Environ.* **2023**, *896*, 165242. [CrossRef] [PubMed]
53. Wang, H.; Wei, S.; Tang, B.-S.; Chen, J.; Li, W. A comparative study on registration system of real estate between Hong Kong and Mainland China. *Prop. Manag.* **2018**, *36*, 5–19. [CrossRef]
54. Mkwate, R.C.; Chidya, R.C.G.; Wanda, E.M.M. Assessment of drinking water quality and rural household water treatment in Balaka District, Malawi. *Phys. Chem. Earth. Parts A/B/C* **2017**, *100*, 353–362. [CrossRef]
55. Lukubye, B.; Andama, M. Physico-Chemical Quality of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *J. Water Resour. Prot.* **2017**, *9*, 707–722. [CrossRef]
56. Hashmi, I.; Farooq, S.; Qaiser, S. Chlorination and water quality monitoring within a public drinking water supply in Rawalpindi Cantt (Westridge and Tench) area, Pakistan. *Environ. Monit. Assess.* **2009**, *158*, 393–403. [CrossRef]
57. Mehmood, S.; Ahmad, A.; Ahmed, A.; Khalid, N.; Javed, T. Drinking water quality in capital city of Pakistan. *Sci. Rep.* **2013**, *2*, 637.
58. Leusch, F.D.; Neale, P.A.; Arnal, C.; Aneck-Hahn, N.H.; Balaguer, P.; Bruchet, A.; Escher, B.I.; Esperanza, M.; Grimaldi, M.; Leroy, G.; et al. Analysis of endocrine activity in drinking water, surface water and treated wastewater from six countries. *Water Res.* **2018**, *139*, 10–18. [CrossRef]
59. Kozisek, F. Regulations for calcium, magnesium or hardness in drinking water in the European Union member states. *Regul. Toxicol. Pharmacol.* **2020**, *112*, 104589. [CrossRef]
60. Rahmanian, N.; Ali, S.H.B.; Homayoonfard, M.; Ali, N.J.; Rehan, M.; Sadef, Y.; Nizami, A.S. Analysis of Physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia. *J. Chem.* **2015**, *2015*, 716125. [CrossRef]
61. Jehangir, M. *Bacteriological Contamination and Upward Trend in Nitrate Contents, Observed in Drinking Water of Rawalpindi and Islamabad*; The Network Consumer Protection in Pakistan: Islamabad, Pakistan, 2002.
62. Bamuwamye, M.; Ogwok, P.; Tumuhairwe, V.; Eragu, R.; Nakisozi, H.; Ogwang, P.E. Human Health Risk Assessment of Heavy Metals in Kampala (Uganda) Drinking Water. *J. Food Res.* **2017**, *6*, 6. [CrossRef]
63. Chika, O.C.; Prince, E.A. Comparative Assessment of Trace and Heavy Metals in Available Drinking Water from Different Sources in the Centre of Lagos and off Town (Ikorodu LGA) of Lagos State, Nigeria. *Adv. J. Chem. A* **2020**, *3*, 94–104. [CrossRef]
64. Salem, H.M.; Eweida, E.A.; Farag, A. Heavy metals in drinking water and their environmental impact on human health. In Proceedings of the International Conference on the Environ Hazards Mitigation, Cairo University, Giza, Egypt, 9–12 September 2000; pp. 542–556.

65. Rehman, K.; Fatima, F.; Waheed, I.; Akash, M.S.H. Prevalence of exposure of heavy metals and their impact on health consequences. *J. Cells Biochem.* **2018**, *119*, 157–184. [CrossRef] [PubMed]
66. Khan, S.; Shahnaz, M.; Jehan, N.; Rehman, S.; Shah, M.T.; Din, I. Drinking water quality and human health risk in Charsadda district, Pakistan. *J. Clean. Prod.* **2013**, *60*, 93–101. [CrossRef]
67. Meharg, A.A.; Williams, P.N.; Adomako, E.; Lawgali, Y.Y.; Deacon, C.; Villada, A.; Cambell, R.C.J.; Sun, G.; Zhu, Y.-G.; Feldmann, J.; et al. Geographical Variation in Total and Inorganic Arsenic Content of Polished (White) Rice. *Environ. Sci. Technol.* **2009**, *43*, 1612–1617. [CrossRef]
68. Konstantinou, I.K.; Hela, D.G.; Albanis, T.A. The status of pesticide pollution in surface waters (rivers and lakes) of Greece. Part I. Review on occurrence and levels. *Environ. Pollut.* **2006**, *141*, 555–570. [CrossRef]
69. Shakerkhatibi, M.; Mosaferi, M.; Jafarabadi, M.A.; Lotfi, E.; Belvasi, M. Pesticides Residue in Drinking Groundwater Resources of Rural Areas in the Northwest of Iran. *Health Promot. Perspect.* **2014**, *4*, 195–205. [CrossRef]
70. Stavra, E.; Petrou, P.S.; Koukouvinos, G.; Economou, A.; Goustouridis, D.; Misiakos, K.; Raptis, I.; Kakabakos, S.E. Fast, sensitive and selective determination of herbicide glyphosate in water samples with a White Light Reflectance Spectroscopy immunosensor. *Talanta* **2020**, *214*, 120854. [CrossRef]
71. Wang, D.-D.; Zhao, Y.; Yang, M.-N.O.; Guo, H.-M.; Yang, Z.-H. Magnetic polydopamine modified with deep eutectic solvent for the magnetic solid-phase extraction of sulfonylurea herbicides in water samples. *J. Chromatogr. A* **2019**, *1601*, 53–59. [CrossRef]
72. Dolan, T.; Howsam, P.; Parsons, D.J.; Whelan, M.J. Is the EU drinking water directive standard for pesticides in drinking water consistent with the precautionary principle? *Environ. Sci. Technol.* **2013**, *47*, 4999–5006. [CrossRef]
73. Sun, Y.; Cao, M.; Wan, Y.; Wang, H.; Liu, J.; Pan, F.; He, W.; Huang, H.; He, Z. Spatial variation of 2,4-D and MCPA in tap water and groundwater from China and their fate in source, treated, and tap water from Wuhan, Central China. *Sci. Total. Environ.* **2020**, *727*, 138691. [CrossRef]