Hindawi
Journal of Food Quality
Volume 2024, Article ID 5516159, 15 pages
https://doi.org/10.1155/2024/5516159

Research Article

Pesticide Residues and Associated Public Health Risks in Vegetables from Irrigated Farms Adjacent to Rift Valley Lake Ziway, Ethiopia

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Received 10 August 2023; Revised 27 December 2023; Accepted 6 January 2024; Published 22 January 2024

Academic Editor: Latiful Bari

The overuse of pesticides has resulted in the accumulation of harmful residues in vegetables, which requires monitoring to assess the risks to human health. This article presents the levels of 35 pesticide residues in 15 composite vegetable samples from irrigated farmlands adjacent to Lake Ziway, Ethiopia, using the QuEChERS extraction method (Quick, Easy, Cheap, Effective, Rugged, and Safe) and then analyzes them using GC-MS. The study also estimated the health risks associated with the consumption of contaminated vegetables in children and adults, including carcinogenic and noncarcinogenic risks. The predominant pesticide residues found in tomatoes were α-endosulfan (0.58 mg/kg), β-BHC (0.04 mg/kg), heptachlor (0.02 mg/kg), and malathion (0.03 mg/kg), all of which were above the safety limits. Similarly, the mean concentration of heptachlor epoxide (0.04 mg/kg) and propargite (0.11 mg/kg) was higher than the allowed levels of the safety limits for onions. The concentration of pesticide residues detected in 10.6% and 7.9% of tomato and onion samples was above the maximum residual limits of the European Commission (EU-MRLs), respectively. Noncarcinogenic health risk estimates show that onion heptachlor epoxide had THQ > 1, indicating the possibility of systemic health risk in both adult and child consumers. The carcinogenic health risk (CHR) showed that heptachlor epoxide in adults and children and only heptachlor in children had CHR > acceptable limit (10^{-4}) for tomato and onion. Therefore, it is critical to raise awareness among stakeholders while simultaneously implementing sound monitoring policy actions to protect the ecosystem and the health of the population in the study area and beyond.

1. Introduction

Pesticides are natural or synthetic substances that are often used to control plant pests, weeds, and diseases [1, 2]. They are critical in modern agriculture; without them, up to 50% of crops in tropical warm-climate zones could be destroyed [3]. The agroclimatic conditions of the Ethiopian Rift Valley, particularly around Lake Ziway, are suitable for the production of fruits and vegetables; however, the area is highly affected by the infestation of pests and diseases during vegetable production and storage, which significantly reduces the yield and quality of agricultural products (Pesticide Action Nexus Ethiopia [4]). Therefore, the application of pesticides is mandatory in modern agriculture because it significantly reduces yield losses and maintains the quality of fruit and vegetables by controlling the infestation of pests and diseases [5].

Pesticide application is more severe in the Ethiopian Rift Valley than in other Ethiopian areas. Several studies have found that farmers overuse pesticides in their vegetable fields every other day, or even every day, due to a lack of knowledge and the lack of available sustainable alternatives [6–9]. Furthermore, reports revealed widespread use of pesticides in Ethiopia's Central Rift Valley and also poor pesticide management during storage, application, and empty container handling [8–10]. Furthermore, after

pesticide application, farmers and farm workers in the region reported symptoms of acute poisoning: headache, nausea, and vomiting, in addition to using empty containers for food and beverage storage [4].

Pesticide residues in fresh fruits and vegetables pose serious health risks to consumers [11]. As a result, the identification and quantification of pesticides in the food matrix is becoming a public concern [12]. Although a previous study [13] found metalaxyl, λ-cyhalothrin, p,p'-DDT, p,p'-DDE, and α and β-endosulfan pesticides in vegetables grown on irrigated farmland surrounding Lake Ziway, only profenofos residues exceeded EU MRL in tomato and onion, with widespread cultivation and sale in nearby cities, including the capital, Addis Ababa. However, no research has been conducted on the health risks associated with the consumption of pesticide-contaminated vegetables on the irrigated farmlands of the Ethiopian Rift Valley, particularly in the Ziway district. Thus, more research is needed to determine the actual scenario of pesticide residues present in vegetables grown by irrigation in Ethiopia's Rift Valley's Ziway district, as well as the risks to consumer health. The current study aims to determine the concentration of 35 pesticide residues in tomatoes and onions grown on irrigated farmlands adjacent to Lake Ziway. The pesticides chosen for this study are commonly applied to manage pests at various stages of vegetable production in irrigated farmlands near Lake Ziway, in particular, those pesticides formulated by Adami Tulu Pesticide Processing Share Company located in the Central Rift Valley of Ethiopia [5]. This study raises public awareness and assists policymakers in taking the necessary steps to reduce human health risks.

2. Materials and Methods

2.1. Description of the Study Area. The study was carried out on three irrigated farmlands located between Meki and Ziway in three villages: Abenea-Girmama, Wellibulla, and Girrissa, all of which are located near the western side of Lake Ziway in Ethiopia's Central Rift Valley (CRV) basin. The location is between latitudes 07°57′N and 08°07′N and longitudes 038°43′E and 038°48′E, with an elevation of 1643–1655 meters above sea level. It is a notable vegetable-growing zone located 135 kilometers south of Addis Ababa in the Oromia regional state of the East Shewa Zone.

2.2. Study Design and Period. In a cross-sectional laboratory-based study, the concentration and type of pesticide residues in tomato (*Lycopersicon esculentum* L.) and onion (*Allium cepa* var. *aggregatum*) from three irrigated farmlands adjacent to Lake Ziway were examined. The samples were collected during the rainy season in late August 2021. It is worth mentioning that pesticide contamination is considerably higher during the wet season compared to the dry season [14]. As described by the authors, this is due to the fact that pesticides from various sources can be washed into existing ones, leading to increased contamination levels.

2.3. Sampling Site Selection and Sample Collection. Three sample sites (*S*1–*S*3) were chosen from three villages: Abenea-Girmama, Wellibulla, and Girrissa, based on intensive and extensive irrigation activities, proximity to pesticide stores, and proximity to a water source (Lake Ziway). Additionally, each site is approximately 1 hectare in size and has been in cultivation for more than 20 years. Tomato (*Lycopersicon esculentum* L) ($n = 9$) and onion (*Allium cepa* var. *aggregatum*) ($n = 6$, because the onion was fully harvested at the third site) samples were collected with the permission of the farmers of the three irrigated farms. From each site, seven subsamples were collected in triplicate. The sample (roughly 1 kg for each type) was taken using the zigzag method with 1 m apart and homogenized to represent the bulk sample. Fifteen composite vegetable samples (tomatoes and onions) were collected in triplicate from three and two sampling sites, respectively. The sample was individually packed in ziplock polyethylene bags, labelled and brought to the laboratory in an insulated icebox, and then stored in the dark at 4°C until further analysis.

2.4. Chemicals and Reagents Used. All standards (99% purity) and chemicals and solvents (HPLC grade 99.9%) were obtained from Sigma-Aldrich (St. Louis, USA), including ethyl acetate (EtOAc), acetonitrile (MeCN), and glacial acetic acid. BDH (British Drug Houses) also offered sodium acetate (NaAc) (purity 99%), magnesium sulfate, and primary secondary amine (PSA).

2.5. Sample Preparation, Extraction, and Clean-Up of Samples

2.5.1. Sample Preparation. Each tomato and onion sample was chopped using a stainless steel knife and then blended to obtain a homogenous composite. After each sample was chopped, the chopping board and blender were washed to avoid cross-contamination. The homogenous composite samples were stored in labelled bags and kept refrigerated at 4°C until further analysis.

2.5.2. Extraction and Clean-Up of Samples. The Quick, Easy, Cheap, Effective, Rugged, and Safe extraction method (QuEChERS) was used for the extraction of pesticides in vegetable samples as indicated in the Association of Official Analytical Chemists (AOAC) Method 2007.01 with slight modifications [15]. Method optimization with its basic steps of the experimental procedure was done as described in Romniou et al. [16]. 15 g of homogenized sample matrices weighed in a 50 ml Teflon tube and 15 ml of acetonitrile (MeCN) containing 1% acetic acid, 6 g of anhydrous $MgSO_4$, and 1.5 g of NaAc were added and the sample was shaken for 1 minute with Vortex (IKA® Vortex Geniw3) to facilitate contact between the solvent and the sample before being centrifuged at 4000 rpm for 5 minutes (Eppendorf 5804 R, Hamburg, Germany). To clean the extract, the upper organic layer 4 ml was taken into a dispersive solid phase extraction tube (d-SPE) containing 150 mg $MgSO_4$ and 50 mg PSA. The

extracted sample was agitated for 30 seconds before being centrifuged for 5 minutes at 4000 rpm. A 4 ml supernatant was filtered through a 0.45 μm PTFE filter (polytetrafluoroethylene polymer) and transferred to clean GC vials for further analysis.

2.6. Quality Control and Pesticide Instrumental Analysis Method

2.6.1. Pesticide Standard Solution Preparation Methods. Standard pesticide stock solutions of the 35 target pesticides were prepared separately in acetonitrile (MeCN) using a method of Nisha et al. [17] at a concentration of 1000 mg/L. Then, working solutions of 0.1, 0.2, 0.5, 1, 2, 3, and 5 mg/L in MeCN were prepared. The matrix-matched standard for the preparation of the calibration curve was made by adding multiple standard working solutions to the blank extracts of both matrices separately [17] and kept in the dark at −20°C.

2.6.2. Method Validation. To create calibration curves for peak area versus pesticide concentrations, standard working solutions were made by dissolving required volumes of stock solution in acetone (9 : 1, v/v). The analytical performance of these solutions was tested for linearity (expressed as a correlation coefficient), accuracy (represented as the relative standard deviation of repeatability), and mean recovery/reliability (as a measure of trueness). Table 1 summarizes the results of these tests. Before conducting the real analysis, we validated the method as described in [18]. The validation results met the SANTE/12682/2019 guidelines with LOQ set at 0.010 mg/kg for all analytes.

2.6.3. Limits of Detection (LOD) and Determining the Quantity. The LOD and LOQ were calculated using the International Conference on Harmonization [19] suggested guidelines (LOD = $3.3 \times \delta$/m and LOQ = $10 \times \delta$/m), based on the standard deviation of the response and the slope of the calibration curves, where m is the slope of the calibration curve and δ is the standard deviation. The standard deviation of the result was used as the standard deviation of the y-intercepts of the regression lines (Table 1).

2.6.4. Instrumental Pesticide Analysis. Gas chromatography-mass spectrometry (GC-MS) (Agilent 7890B Turbo MSD 5977A, Agilent, Santa Clara, USA) was used to determine levels of pesticide residue. The GC-MS system was equipped with triple quadruple MS operated in electron impact (EI) mode, Triple-Axis HED EM employed as detector, and an HP-5 MS 30 m × 0.32 mm × 0.25 μm column (Agilent, Santa Clara, USA). The injection volume was 2 μL in splitless mode at 180°C, with helium used as a carrier gas at a flow rate of 1.2 ml/min. The oven temperature started at 60°C and remained at this temperature for 1 min, increasing to 120°C at 40°C min^{-1} for a ramp rate of 2.5 min and then to 310°C at a ramp rate of 5°C min^{-1}, holding at 300°C for 40.5 minutes. All instrumental analyses were performed at the Bless Agri-Food Laboratory, which is an approved laboratory of the Ethiopian National Accreditation Office (ENAO) (FA: T0030).

2.7. Potential Risk Assessment Method.

A previously described model proposed by Fakhri et al. [20] and USEPA [21] was used to assess the carcinogenic and noncarcinogenic risks of identifying pesticides to adults and children in the monitored region.

2.7.1. Noncarcinogenic Risk (NCR)/Hazard Quotient. The target hazard quotient (THQ) and the hazard index (HI) were used to evaluate noncarcinogenic health risks based on the results of the pesticide analysis and the exposure assumptions, according to the US Environmental Protection Agency [22]. THQ is calculated by comparing the chronic daily intake (CDI) with the reference dose (RFD) [23] using the following equation:

$$\mathbf{THQ} = \frac{\mathbf{CDI}}{\mathrm{RFD}}, \tag{1}$$

where THQ is the target hazard quotient, CDI is the chronic daily intake, and RFD is the oral reference dose obtained from the integrated risk information system, and equation (2) was used to calculate the CDI of pesticide-contaminated vegetables [20, 24].

$$\mathrm{CDI} = \frac{\mathbf{C_{veg} x IR_i x EF_i x ED_i}}{\mathbf{BW_i x}\ \mathrm{AT}}, \tag{2}$$

where C_{veg} is the concentration of pesticides (mg/kg) in vegetables (mean and 95% confidence interval detected concentrations); IR is the ingestion rate of vegetable food for adults and children, which is 240 g/person/day and 160 g/person/day, respectively, according to Ethiopian Food Based Dietary Guidelines [25]; EF_i is the frequency of exposure (from 365 days/year when consuming vegetables seven times a week to 52 days/year for people who eat vegetables once a week) according to the Food and Agriculture Organization (FAO, 2011); ED_i, the duration of exposure (for children and adults is 6 and 65 years, respectively) (FAO, 2011) [26]; BW_i, the default average body weight used by FAO/WHO (for children and adults is between 15 kg and 60 kg, respectively); AT is the average exposure time for noncarcinogens (365 days/year × ED) (for children and adults are 2190 and 23,725 days, respectively) (Kumar et al., 2013) [27].

The HI of a pesticide mixture was calculated by the sum of THQ for each component (equation (3)). According to the USEPA [28], HI < 1 indicates no appreciable risk of adverse health effects, while HI > 1 indicates a chance of noncancer effects.

$$\mathrm{HI} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{THQ_i}. \tag{3}$$

2.7.2. Target Carcinogenic Risk (TCR). The possible target cancer risk to the population due to the intake of specific potentially cancer-causing pesticides was assessed using

Table 1: Method validation parameter results in vegetable residue analysis.

Pesticides	%Recovery	%RSD	Linearity (r^2)	LOD (μg/kg)	LOQ (μg/kg)
Aldrin	101.2	11.6	0.9952	0.008	0.025
Alpha-BHC	89.0	1.53	0.9986	0.005	0.014
Alpha-endosulfan	100.5	2.7	0.9978	0.006	0.019
Bendiocarb	98.2	6.73	0.9945	0.018	0.053
Beta-BHC	**112.8**	1.63	0.999	0.004	0.011
Beta-endosulfan	104.4	11.2	0.9972	0.006	0.017
Bromophos-ethyl	89.4	5.31	0.9981	0.002	0.006
Chlordane	106.3	1.92	0.9977	0.006	0.017
Chlorpyrifos-methyl	85.3	5.59	0.9987	0.002	0.005
Cyfluthrin	80.6	3.14	0.9982	0.005	0.015
Cypermethrin (zeta)	96.4	4.13	0.9927	0.018	0.0562
p,p′-DDD	106.3	11.2	0.9954	0.008	0.245
p,p′-DDE	**75.8**	10.23	0.9961	0.008	0.025
p,p′-DDT	97.6	6.73	0.9937	0.009	0.029
Dieldrin	92.0	6.65	0.9977	0.009	0.02812
Diazinon	94.3	4.49	0.998	0.003	0.009
Dichlobenil	91.2	4.13	0.9972	0.004	0.011
Endrin	100.4	3.41	0.9995	0.006	0.01945
Ethion	94.7	5.96	0.9962	0.003	0.008
Famphur	101.1	2.11	0.9989	0.002	0.006
Fenitrothion	110.9	5.76	0.9982	0.003	0.009
Fenthion	104.2	5.12	0.9987	0.002	0.006
Heptachlor	80.6	10.26	0.9978	0.006	0.017
Heptachlor epoxide	108.9	6.97	0.9983	0.005	0.015
Hexachlorobenzene	80.2	10.62	0.9906	0.006	0.018
Indoxacarb	94.7	14.64	0.9969	0.004	0.012
Lindane	106.2	9.45	0.9966	0.014	0.04159
Malathion	104.8	4.48	0.9974	0.013	0.03799
Methoxychlor	103.2	8.26	0.9969	0.005	0.016
Parathion	97.7	10.3	0.996	0.004	0.013
Piperonyl butoxide	95.9	8.24	0.9963	0.007	0.02203
Profenofos	91.7	8.44	0.9991	0.002	0.006
Propargite	83.7	6.38	0.9963	0.007	0.02203
Propoxur	93.1	8.42	0.9987	0.002	0.007
Thionazin	76.9	13.83	0.9957	0.004	0.013

Values in bold indicate the lower and the upper recovery.

equation (4), and the TCR was estimated for adults and children based on their lifetime exposure to pesticides in this study [29].

$$\mathbf{TCR = CDI \times CSF \times ADAF}. \quad (4)$$

In equation (4), CSF is the cancer slope factor for carcinogenic pesticides in vegetables (mg/kg/day), the probability that a single substance increases the risk of cancer through an oral exposure pathway, and ADAF is an age-dependent adjustment factor (for children, it is 1, and for adults, it is 3) [22]. CSF (mg/kg/d) for targeted pesticides: heptachlor epoxide = 9.1; heptachlor = 4.5; hexachlorobenzene = 1.6; and not available for α-endosulfan, malathion, and propargite. If $TCR < 10^{-6}$, cancer risks are considered negligible; however, if $CR > 10^{-4}$, cancer risks are considered unacceptable by most international regulatory agencies [29, 30]. Acceptable risk limits for carcinogens range from 10^{-4} (where a person's lifetime risk of developing cancer is 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000) [30].

2.8. Data Analysis. Data were analyzed using SPSS software version 26.0. One-way analysis of variance (ANOVA) was used to compare site-wise differences in mean values of pesticide residues at $\alpha = 0.05$ level of significance. When significant differences were obtained, means were tested using Tukey's multiple comparison test at $\alpha = 0.05$. The result was statistically significant when the probability was less than 0.05 ($P < 0.05$). A one-sample *t*-test was used to assess the statistical significance of the sample pesticide residues with respect to the trading standards established by international agencies (e.g., Codex Alimentarius and the EU) to ensure that residues are regulated in the global food trade.

3. Results and Discussion

3.1. Method Validation Result. Ensuring the safety of pesticide use requires analyzing residues in food particularly vegetables, which pose a significant challenge to public health [17]. Table 1 shows that the validation results satisfied the SANTE/12682/2019 guidelines. The calibration curves

for a collection of 35 pesticide standards, including isomers and degradation products, have a correlation coefficient (r^2) greater than 0.9906. The average recovery for both vegetables was between 75 and 113%, which was within the analytical range permitted [31]. The LOD and LOQ for the pesticides tested ranged from 0.002 to 0.018 μg/kg and 0.005 to 0.245 μg/kg, respectively. The average relative standard deviation (% RSD) is less than 10%. These results indicate that the technique is accurate since most of the collected pesticides were within the allowed analytical range (70–120%) and precise, as the percentage RSD < 20 [31].

3.2. Pesticide Residue Concentration in Vegetables. Following validation of the QuEChERS method, the concentrations of pesticide residues in fifteen composite samples of tomatoes and onions were determined. The results show that 22 (62.9%) pesticide residues were detected in both vegetables, with 21 (60%) and 20 (57.1%) pesticide residues detected in tomato and onion, respectively (Tables 2 and 3), while the concentrations of the remaining 14 pesticides in tomato and 15 in onion were found to be below the detection limit. Tomatoes contain 8 different types of pesticides, which are organochlorines (α-endosulfan, chlordane,4-4(DDT, DDD, and DDE), dieldrin, lindane, and methoxychlor), 2 types of carbamates (bendiocarb and indoxacarb), 1 type of benzodioxole (pipronyl butoxide), and 3 types of pyrethroids (cyfluthrin, cypermethrin, and deltamethrin). Similarly, onions contain 10 different types of pesticides, which are aldrin, β-endosulfan, chlordane,4-4(DDT, DDD, and DDE), dieldrin, lindane, hexachlorobenzene, and methoxychlor; 1 type of carbamates (bendiocarb); 1 type of benzodioxole (pipronyl butoxide); and 3 types of pyrethroids (cyfluthrin, cypermethrin, and deltamethrin).

3.2.1. Pesticide Residue Concentrations in Tomato. As shown in Table 2, five pesticide residues in tomatoes exceeded the default EU-MRL 0.01 mg/kg standards. Only food items with pesticide residues exceeding the default EU-MRL of 0.01 mg/kg were considered for substantial pollution and food safety concerns. The mean residue of β-BHC in tomatoes was 0.024 mg/kg, which was twice that of EU-MRL (0.01 mg/kg) and Codex Alimentarius (FAO/WHO) (0.01 mg/kg). A sample t-test revealed statistically significant differences ($P < 0.05$) between the mean β-BHC content of tomatoes and the Codex Alimentarius and EU-MRL standards (see Table 2). As a result, eating tomatoes in the current study area may be unsafe due to β-BHC contamination.

The mean concentration of heptachlor was found to be higher than EU-MRL (0.01 mg/kg), while the difference was not statistically significant ($P > 0.05$) (Table 2). This indicates that the average heptachlor concentration was close to the acceptable standard of EU-MRL. According to the Agency for Toxic Substances and Disease Registry [32], heptachlor can accumulate in the soil and be passed on to vegetables. The mean residue concentrations of α-endosulfan (0.331 mg/kg) were six times higher than the EU-MRL limit of 0.05 mg/kg but less than the FAO/WHO standard of 0.5 mg/kg. The difference in mean concentrations of α-endosulfan and EU-MRL was statistically significant ($P < 0.05$). Therefore, the tomato in the current study may be unsafe to consume because of α-endosulfan contamination. In this particular study, the highest concentration of α-endosulfan recorded was similar to the findings of Sheikh et al. [37] in tomato samples from the Pakistani Sindh market, where the values ranged from null to 0.68 mg/kg. The average concentration of this study is also consistent with the results of Essumang et al. [38] from Ghana (0.3 mg/kg) and Mahugija et al. [39] from Tanzania (0.3 mg/kg). However, the current finding was higher than the results of López-Dávila et al. [40] (0.01 mg/kg) from Cuba, Oyeyiola et al. [41] (0.0016 mg/kg) from Nigeria, and Loha et al. [13] (0.006 mg/kg) from Ethiopia. The difference in results may be due to the difference in research settings. Nonetheless, the high concentration of endosulfan in tomatoes in this study could be attributed to the hyper-accumulating nature of tomatoes as stated by Kumar et al. [27].

Malathion residues were in concentrations ranging from less than the detection limit to 0.048 mg/kg (Table 2). The average recorded malathion concentration was 0.02 mg/kg, comparable to EU-MRL but less than FAO/WHO Codex Alimentarius (0.5 mg/kg). Consuming tomatoes according to the FAO/WHO standard could be safe with regard to malathion residues. This finding was lower than the 0.33 mg/kg reported by Fakhri et al. [20] from Bangladesh and comparable to the data obtained by Akoto et al. [42] from Ghana (0.027 ± 0.021 mg/kg). The residual concentrations of propargite were determined to be 0.154 mg/kg, higher than the EU-MRL limit of 0.01 mg/kg, but less than the Codex Alimentarius standard [26] of 2 mg/kg. According to FAO/WHO standards, the tomatoes at the current study site were safe in terms of contamination by propargite residues. This result was comparable to the 0.06 mg/kg reported by Marrez et al. [43] from Egypt. Generally, the order of pesticide residues in tomatoes was as follows: α-endosulfan > propargite > β-BHC > malathion > heptachlor (Table 2).

3.2.2. Pesticide Residue Concentration in Onion. As shown in Table 3, the present results indicated that the levels of heptachlor epoxide (0.023 ± 0.014 mg/kg) and propargite (0.042 ± 0.025 mg/kg) in onions were higher than the maximum residue limit (MRL) of (0.01 mg/kg) suggested by the European Union, while the remaining were detected below the EU-MRL standards. The concentration of identified heptachlor epoxide and propargite residues in onion exceeded the EU-MRL twice and five times, respectively. But the difference was not statistically significant ($P > 0.05$). As a result, onion in the present study area was safe for human consumption with respect to heptachlor epoxide and propargite residue contamination.

3.2.3. Pesticide Residual Concentrations in Vegetables Compared by Sites. The pesticide residue concentrations in both vegetables across sites are summarized in Table 4. In tomatoes, the pesticide residue loads of β-BHC, α-endosulfan, and heptachlor decreased in the following order: Site 1 (Abenea-Girmama) > Site 3 (Girrissa) > Site 2 (Wellibulla). Similarly, the average concentration of

Table 2: Concentration (mg/kg) of pesticide residues in tomato samples collected from irrigated farmlands in the vicinity of Lake Ziway ($n = 9$).

Category	Pesticides detected	Lowest value	Highest value	Mean ± SD	EU-MRL	Mean-difference (mean-EU-MRL)	P = value. sig. (2-tailed)
OC	α-BHC	0.002	0.005	0.003 ± 0.001	0.01	−0.0066	≤0.001
	β-BHC	0.0001	**0.04**	**0.024 ± 0.005**	0.01	0.0139	**0.034**
	Heptachlor epoxide	0.0001	0.01	0.005 ± 0.003	0.01	−0.0063	0.024
	Heptachlor	0.01	**0.02**	**0.012 ± 0.005**	0.01	0.0017	0.468
	α-Endosulfan	0.003	**0.63**	**0.331 ± 0.220**	0.05	0.3225	**0.003**
	Aldrin	0.0004	0.01	0.003 ± 0.003	0.01	−0.0069	0.015
	Hexachlorobenzene	0.000	**0.152**	0.001 ± 0.0005	0.01	−0.009	0.025
OP	Bromophos-ethyl	0.000	0.003	0.001 ± 0.001	0.01	−0.0086	≤0.001
	Chlorpyrifos-methyl	0.0002	0.003	0.001 ± 0.0007	0.01	−0.0089	≤0.001
	Diazinon	0.0000	0.001	0.0004 ± 0.0004	0.01	−0.0095	≤0.001
	Ethion	0.0001	0.001	0.001 ± 0.0004	0.01	−0.0092	≤0.001
	Famphur	0.0006	0.003	0.001 ± 0.001	0.01	−0.0085	≤0.001
	Fenitrothion	0.000	0.003	0.001 ± 0.001	0.01	−0.0090	≤0.001
	Fenthion	0.001	0.003	0.002 ± 0.001	0.01	−0.0081	≤0.001
	Malathion	0.008	**0.048**	**0.02 ± 0.02**	0.02	0.0112	0.304
	Parathion	0.0005	0.004	0.001 ± 0.0001	0.05	−0.0087	≤0.001
	Profenofos	0.0004	0.002	0.001 ± 0.0006	10	−9.9996	≤0.001
	Thionazin	0.0002	0.0005	0.0002 ± 0.0001	0.01	−0.0099	0.014
C	Propoxur	0.01	0.038	0.023 ± 0.00001	0.05	−0.0275	≤0.001
OS	Propargite	0.001	**0.792**	**0.032 ± 0.012**	0.01	0.0221	0.162
NA	Dichlobenil	0.0002	0.002	0.001 ± 0.0003	0.01	−0.0089	≤0.001

Note. OC = organochlorine; OP = organophosphate; *C* = carbamate; OS = organosulfite; NA = not assigned. Values in bold indicate the conc. above acceptable EU-MRL.

Table 3: Concentration (mg/kg) of pesticide residues in onion samples collected from irrigated farmlands in the vicinity of Lake Ziway ($n = 6$).

Category	Pesticides detected	Lowest value	Highest value	Mean ± SD	EU-MRL	Mean-difference (mean-EU-MRL)	P = value sig. (2 tailed)
OC	α-BHC	0.002	0.005	0.004 ± 0.001	0.01	−0.0065	≤0.001
	β-BHC	0.0001	0.01	0.001 ± 0.002	0.01	−0.0086	≤0.001
	Hepta-epoxide	0.006	**0.038**	**0.023 ± 0.014**	**0.01**	**0.0132**	0.069
	Heptachlor	0.0004	0.01	0.003 ± 0.004	0.01	−0.0017	0.083
	α-Endosulfan	0.001	0.003	0.002 ± 0.001	0.1	−0.0473	≤0.001
OP	Bromophos-ethyl	0.00004	0.003	0.0004 ± 0.0004	0.01	−0.0097	≤0.001
	Chlorpyrifos-methyl	0.0002	0.001	0.0005 ± 0.0002	0.01	−0.0095	≤0.001
	Diazinon	0.00004	0.0012	0.0001 ± 0.001	0.05	−0.0099	0.005
	Ethion	0.0004	0.001	0.0007 ± 0.0004	0.02	−0.0093	0.017
	Famphur	0.0001	0.001	0.0009 ± 0.0003	0.01	−0.0091	≤0.001
	Fenitrothion	0.0002	0.0005	0.0003 ± 0.0001	0.01	−0.0097	≤0.001
	Fenthion	0.001	0.003	0.002 ± 0.0005	0.01	−0.0082	≤0.001
	Malathion	0.001	**0.02**	**0.016 + 0.007**	0.02	**0.0059**	0.440
	Parathion	0.001	0.001	0.001 ± 0.0003	0.05	−0.0091	≤0.001
	Profenofos	0.0002	0.001	0.001 ± 0.0002	0.02	−0.0194	≤0.001
	Thionazin	0.00001	0.001	0.0003 ± 0.0001	0.01	−0.0097	≤0.001
C	Indoxacarb	0.0003	0.004	0.003 ± 0.002	0.02	−0.0170	0.006
	Propoxur	0.01	0.025	0.02 ± 0.01	0.05	−0.0345	≤0.001
OS	Propargite	**0.0004**	**0.112**	**0.042 ± 0.025**	0.01	0.0321	0.295
NA	Dichlobenil	0.0001	0.001	0.001 ± 0.0003	0.01	−0.0091	≤0.001

Note. OC = organochlorine; OP = organophosphate; *C* = carbamate; OS = organosulfite; NA = not assigned. Values in bold indicate the conc. above acceptable EU-MRL.

Table 4: Pesticide concentrations (mg/kg, wet weight) in tomato and onion from the study sites (mean ± SD, $n = 15$).

Vegetables	Pesticides	Site 1 (Abenea-Girmama)	Site 2 (Wellibulla)	Site 3 (Girrissa)	MRL (mg/kg)	
					CA	EU
Tomato	β-BHC	**0.037 ± 0.006^{a}**	**0.016 ± 0.011^{c}**	**0.026 ± 0.01^{b}**	0.01	0.01
	Heptachlor	**0.015 ± 0.003^{a}**	BDL	0.01 ± 0.004^{b}	NA	0.01
	α-Endosulfan	**0.575 ± 0.08^{a}**	0.264 ± 0.12^{c}	0.346 ± 0.248^{b}	0.5	0.05
	Malathion	0.01 ± 0.001^{b}	BDL	**0.031 ± 0.02^{a}**	0.5	0.02
	Propargite	BDL	**0.053 ± 0.004^{a}**	**0.012 ± 0.002^{b}**	2	0.01
Onion	α-BHC	0.01 ± 0.005^{a}	0.004 ± 0.002^{b}	*	0.01	0.01
	Heptachlor epoxide	0.01 ± 0.004^{b}	**$0.04 + 0.004^{a}$**	*	NA	0.01
	Heptachlor	BDL	0.01 ± 0.004	*	NA	0.01
	Malathion	BDL	0.02 ± 0.01	*	1	0.02
	Propargite	**0.04 ± 0.01^{b}**	**0.11 ± 0.001^{a}**	*	NA	0.01

Note. Mean values with different superscript letters in a row are different from each other. Values in bold are those above the maximum residue limit (MRL) in the diet of humans according to the EU-MRL standards and CA = Codex Alimentarius. BDL = below detection limit. Values in bold indicate values above the EU-MRL. * = sample from 3rd site was not available.

malathion in tomatoes was classified as follows: Site 3 > Site 1 > Site 2. In onion, the sequence reversed for heptachlor and malathion: Site 2 > Site 1. Propargite concentrations in tomatoes are found in the following decreasing order: Site 2 > Site 3 > Site 1; similarly, for onion: Site 2 dominates Site 1. The concentration of α-BHC in onions was summarized in the following decreasing order: Site 1 > Site 2, but for the heptachlor epoxide, the sequence reversed: Site 2 > Site 1.

Although pesticide residue concentrations vary between sites, one-way ANOVA did not reveal statistically significant difference ($P > 0.05$) among sites in mean pesticide residue concentrations in tomato and onion samples from these sites (Table 4). According to direct conversations with farmers in all areas, all get their seedlings from the same company called Flora Vege and use the same pesticide from vendors found in the market area, which is the most obvious explanation for this finding.

3.3. Comparison of Pesticide Residue with the MRL Set by International Authorities. The pesticide residues in tomato and onion were compared with the corresponding MRLs of each pesticide and are indicated in Tables 5 and 6. Ethiopia does not have a national MRL for any pesticide but relies on Codex Alimentarius as a member country [44]. However, due to the lack of available data on the present pesticides tested, we consider the MRL set by the EU. The current study found residues in 71.4% and 73.8% of the tomato and onion samples, respectively. Only 10.6% and 7.9% of the tomato and onion samples, respectively, exceeded the EU's maximum residue limit (MRL) (see Tables 5 and 6). According to this study, the use of pesticides in the study area is excessive. Additionally, the detected pesticides that exceeded the maximum residue limit (MRL) were outdated. The levels of heptachlor and heptachlor epoxide surpassed the MRL banned by the Stockholm Convention. Despite being a signatory to the Stockholm Agreement, Ethiopia continues to use obsolete chemicals in agriculture. The report is in line with the UNEP report of 2019. Although Ethiopia has ratified the Basel, Stockholm, and Rotterdam Conventions, the laws and regulations regarding hazardous chemicals and environmental protection are still insufficient to prevent the unauthorized use of outdated chemicals. Overall, pesticide concentrations that exceed the maximum permissible limit (MPL) may have acute or chronic health consequences if consumed regularly. Pesticides, for example, have been documented to cause nausea, dizziness, vomiting, migraines, stomach discomfort, rashes, and even death [45]. Pesticides have a wide range of long-term health effects, including respiratory and cognitive difficulties, cancer, diabetes, cardiovascular disease, neurological diseases such as Parkinson's disease, autism, infertility, congenital birth defects, and DNA damage [46–45].

3.4. Potential Health Risks from Vegetable Consumption

3.4.1. Target Hazard Quotient (THQ). Tables 7 and 8 show the THQ results for the research areas for those who consume tomatoes and onions one to seven times a week. THQ was estimated using only residue concentrations greater than or equal to the EU-MRL standard. The THQ values for α-endosulfan, heptachlor, malathion, and propargite residues in adults ranged from 0.0003 to 0.12, while in children they varied from 0.001 to 0.32 (Table 7). THQ values less than one (THQ < 1) were reported in both cases, indicating that consuming tomatoes from current research sites can pose negligible noncarcinogenic health risks to adults and children. This result was comparable to that of Oyeyiola et al. [41] from Nigeria for these pesticide residues (HQ < 1). Likewise, THQ levels in onion for residues of heptachlor, malathion, and propargite ranged from 0.001 to 0.08 for adults and 0.002 to 0.21 for children (Table 8). This result finds THQ values less than one (THQ < 1), showing that onions consumed at study sites may not cause noncarcinogenic health risks to children and adults. The THQ values for onion heptachlor epoxide ranged from 0.44 to 12.3 for adults and 4.69 to 32.82 for children, showing that onion consumption at study sites may pose noncarcinogenic health risks for both adults and children.

Regarding the site, the estimated THQ levels in onion for heptachlor epoxide were higher than one (THQ > 1) for all exposure periods for adults and children at Site 2, while at Site 1, adults were exposed more than three days a week and children were exposed two days a week.

Table 5: Pesticide residue concentration (μg/kg) in tomato samples collected from irrigated farmlands in the vicinity of Lake Ziway.

Site		α-BHC	β-BHC	H-epoxy	H-chlor	α-Endo	Aldrin	HCB	Bro-E	Chlor	Diazin	Ethion	Famphur	Fenitrothion	Fenthion
	*R*1	1.75	BDL	7.32	14.02	BDL	BDL	1.01	1.98	1.66	BDL	BDL	2.60	2.86	2.71
*S*1 (Abunea-Germama)	*R*2	5.04	42.06	BDL	12.99	518.49	BDL	1.70	0.38	0.69	BDL	0.65	BDL	0.16	1.70
	*R*3	3.75	32.87	3.41	18.22	630.52	BDL	BDL	0.80	1.12	BDL	1.14	1.26	0.74	1.95
	*R*1	2.24	BDL	BDL	BDL	189.04	0.39	BDL	3.29	2.60	1.19	BDL	2.90	2.39	2.70
*S*2 (Wellibulla)	*R*2	3.91	23.71	BDL	BDL	402.77	1.20	BDL	1.05	0.34	0.07	BDL	0.79	0.06	1.33
	*R*3	2.90	7.79	BDL	BDL	200.34	BDL	BDL	0.96	1.12	0.05	BDL	1.47	0.69	1.93
	*R*1	2.13	20.81	BDL	7.27	258.49	5.87	BDL	0.14	0.51	0.48	BDL	0.65	0.18	1.43
*S*3 Girrissa	*R*2	3.91	33.84	0.12	BDL	626.12	4.87	BDL	0.06	0.20	BDL	0.21	1.01	0.04	1.44
	*R*3	5.24	6.26	4.12	6.86	153.99	BDL	BDL	1.66	1.04	0.44	1.12	1.65	1.69	2.14
EU-MRL		10	10	10	10	50	10	10	10	10	10	10	10	10	10
Total detected		9	8	5	5	9	5	2	9	9	5	4	8	9	9
% (+ve) sample		100	88.9	55.6	55.6	100.0	55.6	22.2	100	100	55.6	44.4	88.9	100	100
Sample > EU-MRL		0	5	0	3	8	0	0	0	0	0	0	0	0	0
% (>EU-MRL)		0	55.6	0.0	33.3	88.9	0.0	0	0	0	0	0	0	0	0

Site		Malathion	Parathion	Profenofos	Thionazin	Propargite	Propoxur	Dichlobenil
	*R*1	14.156	3.62	BDL	0.02	BDL	8.75	0.02
*S*1 (Abenea-Girmama)	*R*2	BDL	1.52	0.53	0.46	BDL	30.88	1.34
	*R*3	7.6837	1.16	0.58	BDL	BDL	14.18	1.24
	*R*1	BDL	0.51	1.71	BDL	50.15	16.60	BDL
*S*2 (Wellibulla)	*R*2	BDL	0.56	1.42	BDL	BDL	36.05	BDL
	*R*3	BDL	0.45	0.37	BDL	55.35	17.79	BDL
	*R*1	47.75	1.16	0.77	BDL	10.02	16.53	1.26
*S*3 (Girrissa)	*R*2	15.16	0.72	1.64	BDL	BDL	38.46	0.51
	*R*3	BDL	1.66	ND	BDL	13.01	23.43	2.36
EU-MRL		20	50	10000	10	10	50	10
Total detected		4	9	7	2	4	9	6
Sample > EU-MRL		1	0	0	0	4	0	0
% (+ve) sample		44.44	100	77.78	22.22	44.44	100.00	66.67
% (>EU-MRL)		11.11	0	0.00	0.00	44.44	0.00	0.00

Table 6: Pesticide concentration (μg/kg) in onion samples collected from irrigated farmlands in the vicinity of Lake Ziway.

Site		α-BHC	β-BHC	Hepta-epoxide	Heptachlor	α-Endosulfan	Bromophos-ethyl	Chlorpyrifos-methyl	Diazinon	Thionazin	Ethion	Famphur
	*R*1	3.56	5.45	13.73	BDL	1.50	0.55	0.80	0.19	BDL	BDL	1.45
*S*1	*R*2	BDL	1.32	5.74	BDL	3.35	BDL	0.23	0.04	0.26	BDL	BDL
	*R*3	3.02	BDL	13.17	BDL	3.35	0.09	0.44	BDL	0.38	BDL	0.73
	*R*1	2.25	0.48	37.55	BDL	BDL	0.04	0.25	BDL	0.01	BDL	0.74
*S*2	*R*2	5.46	0.90	31.23	8.02	BDL	0.40	0.60	BDL	0.30	0.94	0.93
	*R*3	3.02	0.09	37.55	8.48	BDL	0.09	0.44	BDL	0.39	0.43	0.73
EU-MRL		10	10	10	10	100	10	10	50	10	20	10
Total detected		6	6	6	3	3	5	6	2	5	2	5
Sample > EU-MRL		0	0	5	0	0	0	0	0	0	0	0
% (+ve) sample		100	100	100	50	33.33	83.33	100	33.33	83.33	33.33	83.33333
% (>EU-MRL)		0	0	83.3	0	0	0	0	0	0	0	0

Site		Fenitrothion	Fenthion	Malathion	Parathion	Profenofos	PBO	Propargite	Propoxur	Indoxacarb	Dichlobenil
	*R*1	0.46	1.80	BDL	1.29	0.82	BDL	45.75	8.61	BDL	BDL
*S*1 (Abenea-Girmama)	*R*2	0.30	2.75	BDL	1.05	0.54	BDL	BDL	12.73	BDL	0.10
	*R*3	0.40	1.63	BDL	0.60	0.82	BDL	29.77	25.15	BDL	1.10
	*R*1	0.16	1.50	11.02	1.19	0.64	BDL	BDL	7.42	0.29	1.09
*S*2 (Wellibulla)	*R*2	0.25	1.45	20.74	0.73	0.23	BDL	112.36	13.74	4.30	BDL
	*R*3	0.40	1.63	BDL	0.60	0.82	BDL	112.36	25.15	4.30	1.10
EU-MRL		10	10.00	20.00	50.00	20.00	0	10.00	50.00	20.00	10.00
Sample detected		6.00	6.00	2.00	6.00	6.00	0	5.00	6.00	3.00	4.00
Sample > EU-MRL		0.00	0.00	1.00	0.00	0.00	0	4.00	0.00	0.00	0.00
% (+ve) sample		100	100.00	33.33	100.00	100.00	0	83.33	100.00	50.00	66.67

Table 7: Target hazard quotient (THQ) and hazard index (HI) of pesticide residues from consumption of tomato produced in the study sites at different levels (days per week) of exposure.

Sites	Levels of exposure (d/w)	Target hazard quotient (THQ)								Hazard index (HI)	
		α-Endosulfan		Heptachlor		Malathion		Propargite			
		A	*C*	*A*	*C*	*A*	*C*	*A*	*C*	*A*	*C*
*S*1	1	0.016	0.044	0.017	0.046	0.0003	0.001	—	—	0.034	0.090
	2	0.033	0.088	0.034	0.091	0.001	0.002	—	—	0.068	0.181
	3	0.049	0.131	0.051	0.137	0.001	0.002	—	—	0.102	0.271
	5	0.082	0.219	0.086	0.229	0.001	0.004	—	—	0.169	0.451
	7	0.115	0.307	0.120	0.320	0.002	0.005	—	—	0.237	0.632
*S*2	1	0.008	0.020	—	—	—	—	0.002	0.004	0.009	0.024
	2	0.015	0.040	—	—	—	—	0.003	0.008	0.018	0.048
	3	0.023	0.060	—	—	—	—	0.005	0.012	0.027	0.072
	5	0.038	0.101	—	—	—	—	0.008	0.020	0.045	0.121
	7	0.053	0.141	—	—	—	—	0.011	0.028	0.063	0.169
*S*3	1	0.010	0.026	0.011	0.030	0.001	0.002	0.000	0.001	0.023	0.060
	2	0.020	0.053	0.023	0.061	0.002	0.005	0.001	0.002	0.045	0.120
	3	0.030	0.079	0.034	0.091	0.003	0.007	0.001	0.003	0.068	0.180
	5	0.049	0.132	0.057	0.152	0.004	0.012	0.002	0.005	0.113	0.301
	7	0.069	0.185	0.080	0.213	0.006	0.017	0.002	0.006	0.158	0.421

Note. *A* = adult; *C* = children.

Table 8: Target hazard quotient (THQ) and hazard index (HI) of pesticide residues from consumption of onion produced in the study sites at different levels (days per week) of exposure.

Sites	Levels of exposure (d/w)	Target hazard quotient (THQ)								Hazard index (HI)	
		Heptachlor epoxide		Heptachlor		Malathion		Propargite			
		A	*C*	*A*	*C*	*A*	*C*	*A*	*C*	*A*	*C*
*S*1	1	0.440	1.172	—	—	—	—	0.001	0.003	0.441	**1.175**
	2	0.879	**2.344**	—	—	—	—	0.002	0.006	0.881	**2.350**
	3	**1.319**	**3.516**	—	—	—	—	0.003	0.009	**1.322**	**3.526**
	5	**2.198**	**5.861**	—	—	—	—	0.006	0.015	**2.204**	**5.876**
	7	**3.077**	**8.205**	—	—	—	—	0.008	0.021	**3.085**	**8.226**
*S*2	1	**1.758**	**4.689**	0.011	0.030	0.001	0.002	0.003	0.008	**1.773**	**4.729**
	2	**3.516**	**9.377**	0.023	0.061	0.001	0.003	0.006	0.017	**3.547**	**9.458**
	3	**5.275**	**14.066**	0.034	0.091	0.002	0.005	0.009	0.025	**5.320**	**14.187**
	5	**8.791**	**23.443**	0.057	0.152	0.003	0.008	0.016	0.042	**8.867**	**23.645**
	7	**12.308**	**32.821**	0.080	0.213	0.004	0.011	0.022	0.059	**12.414**	**33.103**

Note. Values in bold (>1) indicate potential noncarcinogenic health risk for humans. *A* = adult; *C* = children.

3.4.2. Hazard Index (HI). The estimated hazard index is shown in Tables 7 and 8 as the sum of THQ for tomato and onion consumption at the sample sites one to seven times per week. The HI values obtained from tomato consumption at all three sites were less than unity (HI < 1). The findings indicate that the consumption of all pesticide residues evaluated in this study through the consumption of tomatoes at the given exposure levels from each site poses potentially insignificant noncarcinogenic health hazards (Figure 1(a)). The HI values obtained from onion consumption were higher than 1 for children from Sites 1 and 2 and adults from Site 2 (Figure 1(b)). Therefore, farmers' families around the study areas and other individuals who consume this vegetable regularly are more vulnerable to pesticide toxicities. This result is similar to the findings of earlier epidemiological research by Faustman et al. [46] showing that pesticide exposure can affect children more than adults.

3.4.3. Carcinogenic Health Risks (CHRs). According to the Agency for Toxic Substances and Disease Registry [32], the EPA and the International Agency for Research on Cancer (IARC) listed heptachlor as a probable human carcinogen. Furthermore, the EPA classified heptachlor epoxide as a possible human carcinogen. Tables 9 and 10 summarize the CHRs due to the consumption of tomatoes and onions one to seven times a week. The highest CHR value obtained for seven-day exposure to heptachlor through tomato consumption was $2.16E-03$ for tomato intake from Site 1 (Table 9), which means that two cancer cases occur per 1000 children, while the lowest was $5.20E-05$ for onion consumption from Site 2 (Table 10) for adults with one exposure per week (approximately three cancer cases occur per 100,000 adult individuals) (Figure 2(a)). Similarly, for heptachlor epoxide, the highest CHR value was $1.16E-02$ from Site 2 for children to seven-day exposure per week, which means that one cancer case occurs per 100 children, and the lowest was

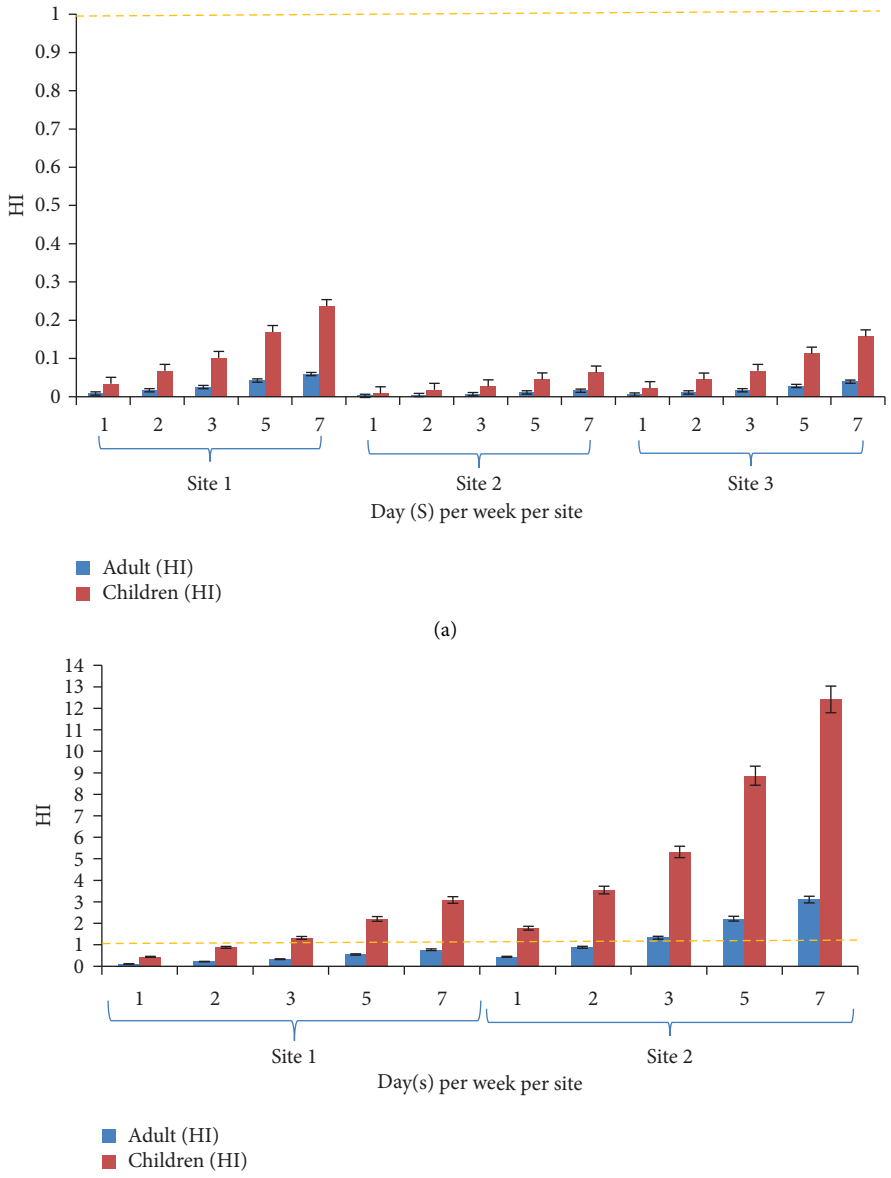


Figure 1: Noncarcinogenic risk (HI) due to the consumption of contaminated tomato (a) and onion (b).

Table 9: Carcinogenic risks (CRs) of heptachlor due to consumption of tomato from the study sites.

Levels of exposure (d/w)	Site 1		Site 3	
	A	*C*	*A*	*C*
1	3.86*E* – 05	3.09*E* – 04	2.6*E* – 05	2.06*E* – 04
2	7.71*E* – 05	6.17*E* – 04	5.1*E* – 05	4.11*E* – 04
3	1.54*E* – 04	9.26*E* – 04	7.7*E* – 05	6.17*E* – 04
5	3.09*E* – 04	**1.54E – 03**	1.29*E* – 04	**1.03E – 03**
7	2.70*E* – 04	**2.16E – 03**	1.80*E* – 04	**1.44E – 03**

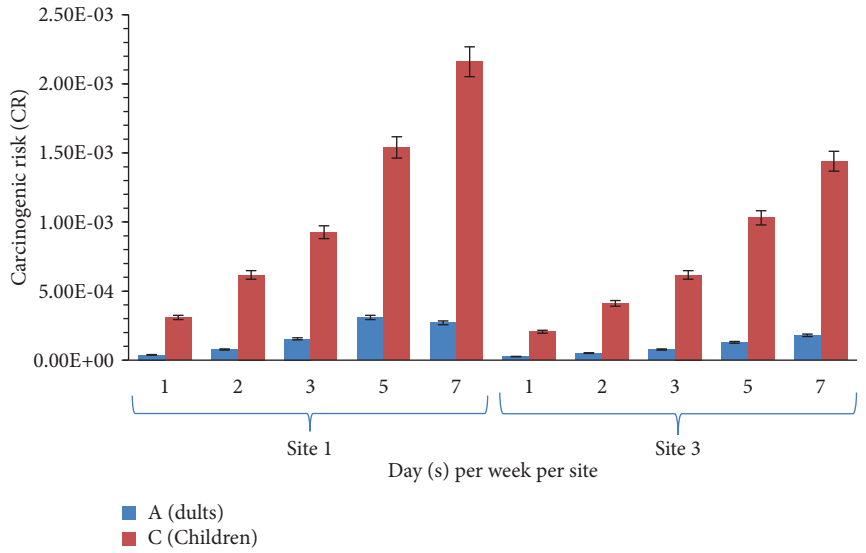
Note. Values in bold indicate TCR above acceptable limit (10^{-4}). *A* = adult; *C* = children.

5.2*E* – 05 from Site 1 for adults to once exposure per week (5 cancer cases per 100,000 adult individuals) (Figure 2(b)). The study revealed that the cancer health risk (CHR) for heptachlor was within the acceptable range ($<10^{-4}$) for a dose of 2 days per week or less for Site 1 when it comes to tomato consumption and 3 days per week or less for Sites 2 and 3 with respect to adult consumption of tomatoes and onions, respectively. This indicates that at this level of exposure, there is

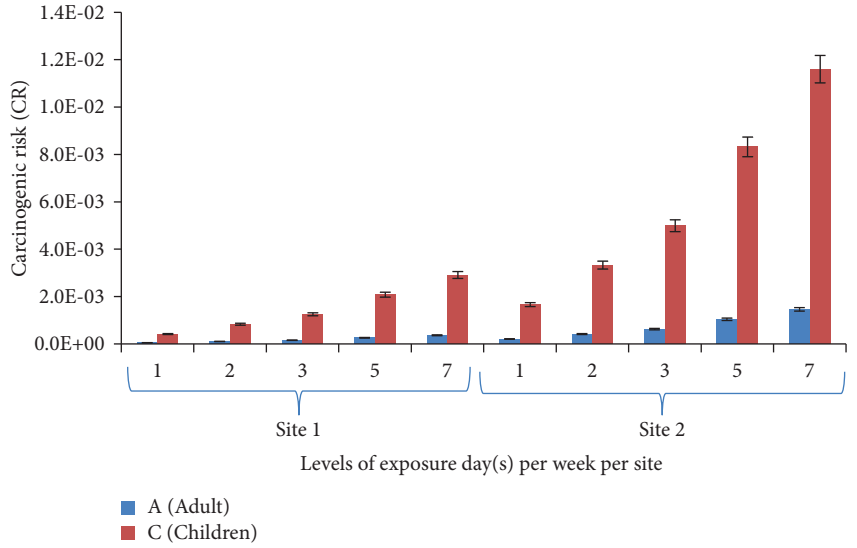
Table 10: Carcinogenic risks (CRs) of pesticides due to consumption of onion from the study sites.

Levels of exposure (d/w)	Site 1 Heptachlor epoxide		Site 2 Heptachlor epoxide		Site 2 Heptachlor	
	A	*C*	*A*	*C*	*A*	*C*
1	$5.20E-05$	$4.16E-04$	$2.08E-04$	**1.66E − 03**	$2.57E-05$	$2.06E-04$
2	$1.04E-04$	$8.32E-04$	$4.16E-04$	**3.33E − 03**	$5.14E-05$	$4.11E-04$
3	$1.56E-04$	**1.25E − 03**	**6.24E − 04**	**4.99E − 03**	$7.71E-05$	$6.17E-04$
5	$2.60E-04$	**2.08E − 03**	**1.04E − 03**	**8.32E − 03**	$1.29E-04$	**1.03E − 03**
7	$3.64E-04$	**2.91E − 03**	**1.46E − 03**	**1.16E − 02**	$1.80E-04$	**1.44E − 03**

Note. Values in bold indicate TCR above acceptable limit (10^{-4}). *A* = adult; *C* = children.



(a)



(b)

Figure 2: Carcinogenic risk (CR) due to the consumption of tomato (a) and onion (b).

no possible risk of developing cancer from ingesting heptachlor residues from tomato consumption for adults.

On the other hand, the CHR values for heptachlor exceeded the acceptable limit ($>10^{-4}$) in the case of children who consumed tomatoes and onions at all levels of exposure per week. Furthermore, for adults, the CHR values exceeded the acceptable limit at Site 1 with respect to tomato consumption of 3 days per week or more and at Site 3 for tomato

consumption of more than 5 days per week (Table 9). Therefore, it is reasonable to conclude that children at all levels of exposure and adults who consume tomatoes more than 3 days per week may face a potential risk of developing cancer in the study area and beyond.

The CHR values for heptachlor epoxide for all levels of exposure to children from Sites 1 and 2 and for adult exposure of two or more days of consumption per week from Site 1 and at all levels of exposure from Site 2 were higher than the permissible limit ($>10^{-4}$) (Table 10). Therefore, it is possible to conclude that consumption of heptachlor epoxide could pose substantial cancer risks to adults and children by eating onions, which is a component of the diet of residents of the research area.

In summary, the results of this study showed that the dietary intake of heptachlor and heptachlor epoxide at average exposure levels would create the possibility of developing cancer in children through the consumption of the investigated vegetables. Furthermore, this finding is consistent with previous research indicating that children appear to be particularly vulnerable to heptachlor and heptachlor epoxide poisoning [32]. As a result, immediate measures need to be taken to control and minimize heptachlor and heptachlor epoxide exposure through vegetable consumption in the research region.

4. Conclusion

This study found that the consumption of tomatoes and onions from all study sites at varying levels (days per week) of exposure could be safe from the noncarcinogenic risk of the toxicities of α-endosulfan, heptachlor, malathion, and propargite residues for adults and children. Concerning the carcinogenic risk, the consumption of tomatoes and onions from all study sites at varying degrees of exposure (days per week) may be safer in terms of residual heptachlor toxicities for adults and children (consuming <3 days per week). The carcinogenic risk of onion heptachlor epoxide was estimated to be 1.46×10^{-3} g/kg/day, which implies that the cancer risk of heptachlor epoxide in an adult is 1.46 per 1,000 individuals continuously exposed. In children, the risk was estimated to be 1.16×10^{-2} g/kg/day (1.16 per 100 individuals), with a threat multiplied by 10. The findings suggest that farmers and their families, as well as those who consume vegetables grown on soils contaminated by pesticides on a regular basis, are the most vulnerable risk group whose health must be protected. Therefore, it is critical to raise awareness among stakeholders while simultaneously implementing sound monitoring policy actions to protect the ecosystem and the health of the population.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Asrat Fekadu designed the study, carried out data collection, designed the experiments, performed the experiments, analyzed and interpreted the data, and wrote the manuscript. Girma Tilahun was responsible for conceptualization, design of the experiments, review and editing, supervision, investigation, project administration, and funding acquisition. Solomon Sorsa was responsible for writing, reviewing, and editing. All authors have read and approved the manuscript to reach its final form and agreed to its submission.

Acknowledgments

This study was financially supported by Hawassa University. We thank the Center for Ethiopian Rift Valley Studies (CERVaS) and the Office of the Vice President for Research and Technology Transfer (VPRTT) of Hawassa University for facilitating field work and laboratory analysis for heavy metals.

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