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SEDIMENT ENVIRONMENT, POLLUTION AND REMEDIATION

Stock status, urban public perception, and health risk assessment of obsolete pesticide in Northern Ethiopia

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Abstract
Pesticides are widely used chemicals in the agricultural sector to control pests, diseases, and other plant pathogens. This study aimed to assess the storage conditions of pesticides, the community perception, and health risk of pesticide exposure. The study was conducted in three different zonal cities in Ethiopia, East Africa, namely Mekelle, Aksum, and Alamata. Community perception was studied in a community living near a pesticide stockpile with a cross-sectional study of 384 randomly selected households. In addition, questionnaires were administered, a field investigation was conducted, and focused group discussions with responsible bodies were held to assess storage condition. Accidental ingestion and inhalation were considered to determine average daily exposure (ADE) and incremental lifetime cancer risk (ILCR). This study reveals that all obsolete and banned hazardous pesticides were stored in one area. The storage sites were only secured with simple locks and exposed to rain, sunlight, and temperature variation. The majority of the residents perceived that pesticides pose risk to human health (46.6%), to the environment (28.4%), and to animals (25%). The association between residence proximity of respondents to the store and side effect of obsolete pesticides is statistically significant (p = 0.008). Children aged 2 years and below have higher ADE when exposed to the same concentration of contaminant via inhalation. The probability of a person developing cancer was very low with a risk value of 2.54E−08 and 1.65E−07 as a result of exposure to air containing heptachlor and dichlorodiphenyltrichloroethane (DDT), respectively.

Keywords Stockpiles · Obsolete pesticide · Soil · Average daily exposure · Health risk assessment

Introduction

Persistent organic pollutants (POPs) are toxic and bioaccumulative chemicals that have long-range atmospheric transport potential (Isogai et al. 2016; Wang et al. 2017). Some organochloride pesticides are classified as POPs which are banned for manufacturing, importing, and its usage under the Stockholm convention in May 2004 (World Bank and CIDA 2001).

The use of toxic POPs pesticides to manage pest problems has become a common practice worldwide (Phung et al. 2018). Pesticides are used to control vector-borne diseases and raise agricultural production in developing countries (Pan et al. 2016; Wong 2018). However, when pesticides remain unused for an extended period of time, they become expired and unsafe for use.

Pesticides have a wide range of human health hazards (Maele-fabry et al. 2017; Budzinski and Couderchet 2018), ranging from short-term to chronic impacts like cancer (Patel and Sangeeta 2018), subfertility, neurologic disorders, and endocrine disorders (Chourasiya et al. 2015; Sankoh et al. 2016; Cheng et al. 2017). Humans are exposed to the pesticides via ingestion of food, inhalation of air, and water contaminated with pesticide residue (Grung et al. 2015; Donkor et al. 2016; Phung et al. 2018).

Due to inappropriate storage like broken or damaged storage containers, rotten bags, rusted metal drums, and unsafe

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handling, pesticides can leak out or continue to leak (Riwthong et al. 2016; Toichuev et al. 2017; Wang et al. 2017). Globally obsolete pesticides are sometimes disposed of or leaked into the environment (Donkor et al. 2016; Wang et al. 2017). Pesticides are used almost everywhere in agricultural fields, and sometimes at homes, on buildings, and in the forests (Lammoglia et al. 2017).

Ethiopia has been accumulating obsolete pesticides since pesticides were first imported in the 1940s for malaria eradication (MoH 2006), locust control, and handling pest infestation (Haylamicheal and Dalvie 2009; Mesfin 2017). Ethiopia is the second most pesticide-contaminated country in Africa after Morocco (FAO 1997, 2005). The prolonged storage, loose control over pesticide importation, inappropriate storage conditions due to poor storage facilities, lack of trained staff, and lack of a pesticide monitoring system have resulted in the accumulation of outdated pesticides.

Ethiopia imports large volumes of pesticides annually. For instance, in the period 2013 to 2016, the Ministry of Agriculture imported 15,717.5 tons of pesticide (FAOSTAT 2018). In the period 2000 to 2012, the Ministry of Agriculture imported 17,853 tons that included 2979.3 tons of insecticide, 13570.3 tons of herbicide, and 1303.9 tons of fungicide and bactericide (Donkor et al. 2016).

Pesticides of different categories such as endosulfan, dichlorodiphenyltrichloroethane (DDT), Sevien, heptachlor, dieldrin, and endrin were distributed by the Ministry of Agriculture and stored in different parts of Ethiopia for the purpose of improving agricultural productivity (MoH 2006; Haylamicheal and Dalvie 2009; MoA 2016). Even though some of these pesticides are banned in the country, many people still use them illegally (Teklu 2016). Around 1500 tons of obsolete banned pesticides was disposed by a Finland company known as Ekokem in collaboration with FAO in the period 2003 to 2007 (Haylamicheal and Dalvie 2009).

Stockpiles of obsolete pesticides in Ethiopia are found in inappropriate conditions (Ligani 2016; Mesfin 2017), poorly stored, and located close to agricultural fields, residential areas, and water supplies. Therefore, stockpiles of obsolete pesticides can present a serious risk to human health and the environment (Margni et al. 2002; Li et al. 2012; Harmouche-karaki et al. 2018; Ndunda et al. 2018). The impact is greater on people with low socioeconomic status who gather empty pesticide containers (Damalas et al. 2007; Fang et al. 2014), to be used for carrying food, water, and kerosene without awareness of the possible harmful effects of pesticides (Mesfin 2017; Budzinski and Couderchet 2018).

Previous studies were inadequate in their assessment on the storage conditions which led to the main cause of the negative impacts of pesticides on the environment and human health (Amera and Abate 2008; Haylamicheal and Dalvie 2009; Teklu et al. 2016; Mesfin 2017). These previous studies conducted were on pesticide use on farmlands and their impacts on farmers. The aim of this study was to determine the status of the stockpiles in 3 zonal cities, namely Mekelle, Aksum, and Alamata, to estimate average daily exposure (ADE) level and incremental lifetime cancer risk (ILCR), and to assess the perception of the community regarding the health risk of pesticides due to its location in an urban setting. They were stored under deteriorated conditions which later exposed humans and animals to pesticides.

Method and materials

Study area

Ethiopia has nine regional states and two administrative cities. The study was conducted in Tigray regional state in the northern part of Ethiopia. The data was collected from the Tigray regional state southern zone (Alamata), Central zone (Aksum), and Mekelle zone at Mekelle city. Mekelle city is the capital city and a special zone of Tigray regional state. Mekelle lies between 13° 29′ 0″ N and 39° 28′ 0″ E with a population of 219,818, whereas Aksum lies between 14° 07′ 15″ N and 38° 43′ 0″ 15 E with a population of 56,500; Alamata lies between 12° 25′ 0″ N and 39° 33′ 0″ E with a population of 85,403. Mekelle is characterized by Tropical Savanna climate with an elevation of 2254 m above sea level, whereas Aksum is a subtropical highland with an elevation of 2131 m above sea level and Alamata is tropical with an elevation of 1520 m above sea level. The storage facilities in the study areas were constructed before 1991 and had accumulated pesticide chemicals for over 25 years (Fig. 1).

Study design, sample size calculation, and study participants

A community-based cross-sectional study was conducted between July and September 2018. Pesticide stores were selected based on set criteria such as the condition of pesticide store, obsolete pesticides overstocking, pesticide accumulation, and proximity of local residents to pesticides store by a field visit in the region before the study. Participants were interviewed using a structured interview from a randomly selected household representative. Each selected household for this study was located within a radius of 400 m from the stockpile storage. The sample size was calculated using a single of formula $ni = p(1-p)z2/d2$ with the assumptions of 95% confidence level, a margin of error (d) of 5%, and 50% of selecting the representative (Sankoh et al. 2016).

Data collection

The data collection was conducted by face-to-face interviews, in addition to field investigation and expert level discussions.

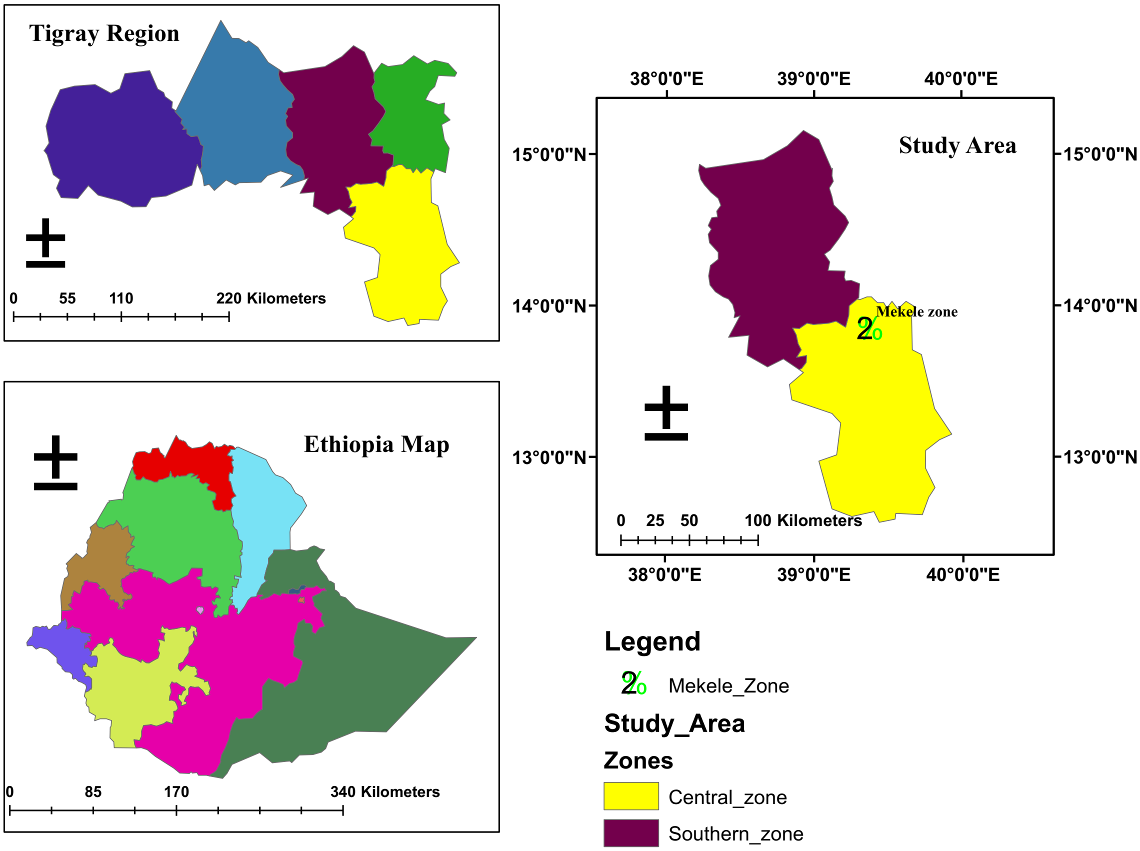

Fig. 1 Map of Ethiopia showing study areas

Various management aspects of pesticide storage, chemical arrangements, labeling, store status, building materials, fence, surrounding activities, leakage, sorting active ingredients from expired ingredients, visual inspection of interim storage, and handling of the study site store were observed and assessed by a checklist developed for this study.

The questionnaire administered to household representatives collected data on the general knowledge and perception of households on the safety of pesticide storages, exposure duration (ED), exposure frequency, exposure of residents to the toxic effects of pesticides and use of pesticides and empty pesticide containers, protective measures undertaken during pesticides utilization, and the possible impacts on human health and the environment. The interviewers were academically qualified, familiarized with the topic and they were selected from the Agricultural Bureau of the study area.

Human health risk assessment

In all study areas, the residential houses are constructed at ground level and are square-shaped. All surrounding communities had ready access to a nearby communal open space. As a result, there is the likelihood of long-term exposure through inhalation and accidental ingestion to the contaminant. In view of the aforesaid, ADE was estimated.

ILCR of heptachlor and DDT were estimated for carcinogenic risk of inhalation exposure. Inhalation unit risk factor (URF) from cancer slope factor of heptachlor 1.3E−3 $(\mu g/m^3)^{-1}$ and DDT 9.5E−5 $(\mu g/m^3)^{-1}$ was used to estimate ILCR (USEPA 1987a, b, 2000). Ingestion and inhalation exposure were estimated based on standard equation (USEPA 1992, 2002; WHO 2008; Whanda Shittu 2018) as well as lifetime carcinogenic risk USEPA (2009). In Ethiopia, there are no officially documented estimates for ingestion, inhalation rates, and increased lifetime cancer risk. The concentration data used in this study were obtained from another study in East Asia based on similarities of store history, the location of pesticides store, storage condition of obsoleted pesticides, and proximity of local residents to pesticide stores. However, the influence of climate, time, geography, inhalation, and ingestion rate is considerably different. Henceforth, the USEPA recommended inhalation and ingestion rates value for each age group were used, in addition to incremental of 95% inhalation rate to investigate the implication of higher inhalation rates on average daily exposure. The age-wise variation in intake via air inhalation and soil ingestion was demonstrated by ADE. The age group related parameters used for estimation of ADE such as body weight, ingestion, and inhalation were recommended by USEPA (USEPA 2011a).

A recommended equation was used to an estimate ADE.

$$ADE = \frac{C \times IngR \times Fing \times EF \times ED}{BW \times AT} \quad (1)$$

$$ADE = \frac{C \times IahR \times Fiah \times EF \times ED}{BW \times AT} \quad (2)$$

where *ADE* is the average daily exposure to chemical from soil (mg/kg/bw/day) in long term, *C* is the concentration in (mg/kg or mg/m^3), *IingR* is the ingestion rate (mg/day), *Fing* is the unit conversion factor for ingestion (10^{-6}), *EF* is the exposure frequency (days year^{-1}), *ED* is the exposure duration (year), *BW* is the human body weight (kg), *AT* is the averaging time (days), *IahR* is the inhalation rate (m^3/day), and *Finh* is the unit conversion factor for inhalation (10^{-9}).

Equations (3) and (4) have been used to calculate the cancer risk of inhalation pathways as proposed by USEPA (2009). Based on an ED of 70 years (lifetime exposure period), exposure time (ET) of 9 h day^{-1}, and exposure frequency (EF) of 280 days/year based on respondent answer, *F* is the unit of conversion factor, and average time (lifetime in years × 365 days/year × 24 h/day). The estimation of exposure concentration (EC) of assessing cancer risks is characterized by an IUR. The equation for estimating an EC and IUR is presented below.

$$EC = \frac{CA \times ET \times EF \times ED}{AT} \times F \quad (3)$$

$$ILCR = \text{Exposure Concentration} \times \text{URF} \left(\mu g/m^3\right)^{-1} \quad (4)$$

EC (μg/m^3) is the exposure concentration; CA (μg/m^3) is the contaminant concentration in air; lifetime cancer risks which can be qualitatively described were very low when the estimated cancer risk value is $\leq 10^{-6}$ (NYS DOH 2007).

Data analysis and quality control

The data were checked daily and re-checked again prior to data entry by the researcher. Data were entered into SPSS version 20.0 and analyzed to see distribution and association between variable using chi-square, and cross tabulation. The differences in proportions were compared to determine the significance using the chi-squared test and a p value < 0.05 was found and is considered significant.

Result and discussion

Socio-demography characteristic and background

A total of 384 selected households participated in this study and were divided equally for the above-mentioned study areas. 94.01% (361) of the participants responded to the questions. The mean age of the participants was 36.9 ± 5.74 years. The age range of the participants was from 16 to72 years.

Store condition and its status

In the study areas, two obsolete pesticide stores were located in Mekelle on the same compound and the other two cities had one store each. The stockpiles of obsolete pesticides in Mekelle and Alamata were not in good condition. Both were constructed from mud, wood, and ragged tin sheet walls. The pesticides were poorly stored and resulted in major leakage. A similar result was attained from the study done before in Ethiopia and Pakistan (Haylamicheal and Dalvie 2009; Ahad and Mohammad 2010; Teklu 2016). Obsolete and banned pesticides along with other mixed chemicals were stored in an open field (Maele-fabry et al. 2017). The store sites were only secured with simple locks; no permanent security or protective measures were taken (Furlong et al. 2015). This lack of security and protection resulted in the exposure of stockpile to rain and sunlight, the variation of temperatures, and other damaging factors. In addition, it was observed that there was easy access to enter into the stores' areas and remove chemicals for domestic purposes and storage containers.

The Aksum stockpile was constructed from concrete and was relatively secured, well organized, and had a good arrangement. In all study areas, no separation was made between obsolete, banned, and new pesticides. In addition, the chemicals were placed in wooden boxes and leaking metal drums without labeling. The contents of these outdated chemicals drained within the storage area without taking corrective measures. The responsible persons for the safekeeping of the stockpiles wore no protective gears in handling these obsolete pesticides, due to inadequate training in handling expired chemicals. All the study areas were used as a permanent storage area for safekeeping of the chemicals until the moment of writing this manuscript.

Tables 1, 2, 3 shows that all stockpiles within the study areas contained POPs, which are banned internationally by the Stockholm Convention. Moreover, they are classified as highly, moderately, and slightly hazardous to human (WHO 2009). Our findings are consistent with other studies (Curtis et al. 2004; Li 2018).

Table 1 Pesticide concentration in soil and air

Pesticides	Concentration in soil mg/kg Ahad and Mohammad (2010)	Concertation in air pg/m^3 Alamdar et al. (2014)
Heptachlor	43	52
Dieldrin	3	
Endrin	5	
DDT	333	3000

Table 2 Socio-demographic characteristic of participants of Alamata, Mekelle, and Aksum, 2018

	Residence of respondents							
	Alamata		Mekelle		Aksum		Total	
	N	%	*N*	%	*N*	%	*N*	%
Educational level								
Illiterate	35	28.7	18	15.1	20	16.7	73	20.2
1–8 grade	29	23.8	22	18.5	25	20.8	76	21.1
9–12 grade	19	15.6	37	31.1	30	25.0	86	23.8
Certificate	5	4.1	11	9.3	23	19.2	39	10.8
Diploma	17	13.9	22	18.4	14	11.7	53	14.7
Degree and above	17	13.9	9	7.5	8	6.7	34	9.4
Occupation								
Merchant	10	8.19	22	18.5	21	17.5	53	14.7
Housewife	12	9.83	33	27.7	15	12.5	60	16.6
Government employee	29	23.78	17	14.3	29	24.2	75	20.8
Farmer	21	17.22	5	4.3	16	13.3	42	11.6
Student	27	22.13	13	10.9	24	20.0	64	17.8
Other	23	18.85	29	24.4	15	12.5	67	18.5
Sex								
Male	80	65.6	48	40.3	68	56.7	196	54.3
Female	42	34.4	71	59.7	52	43.3	165	45.7

The storage sites were located in close proximity to residential areas and livestock (Maele-fabry et al. 2017). Within this close proximity residence, animals were directly exposed to harmful chemicals; this was similar to a study done previously by Food and Agriculture Organization of the United Nations (FAOUN 2001).

Table 3 Describe stored active ingredient pesticide in the study areas stores

Trade name	Mekelle		Alamata		Aksum	
	kg	liters	kg	liters	kg	liters
Thionex 35% EC		225		310		110
DDT 75%	1250.5		412.5		925.2	
Sevien 85% WP	3155					
Actellie 2% dust	58.4					
Diazinone 60% EC		713		250		750
Malathion 50% EC		5040.5		2316		3500
Malathion 96% EC		360		210		295
Dimethot 50%		540		192		123
Dirusban 48%		240		125		95
Dirusban 240%		1214		489		210
Fenethrothion 95% ULV		3425		1250		1320
Fenethrothion 50%		4796.5		1200		340
Aldrin	595	125	249	150	554	170
Heptachlor	580		271		672	
Dieldrin	250		231		140	

Table 3 describes the amount of active ingredient of POPs found in three study areas. Some of these pesticides are banned and restricted under Stockholm convention due to transboundary effect, toxicity to human and living things. In long-term exposure, it affects health. Nevertheless, there were high accumulations of obsoleted and banned pesticides which were handled in a poor condition. Similarly, unsafe handling of obsoleted pesticides in developing countries has been widely documented (FAO 1997, 2002; FAOUN 2002; Curtis et al. 2004; Sankoh et al. 2016; FAOSTAT 2018). The driving factors behind these chemical accumulations were lack of import controls, prolonged storage, late delivery, and distribution, requesting and purchasing policies, lack of well-trained expertise, weak continuous pesticide monitoring system, coordination among donor agencies, poor stock controlling, and mislabeled or labeling with varied mark.

Perception and knowledge of the obsoleted pesticides

The study indicated that participants used pesticides to suppress plant and insect pests (44.2%), domestic use and for ant grain borers (38.2%), and for ant grain borers and industrial products (17.6%). The haphazard use of DDT for both crops and domestic purpose was also documented by other studies (Tsaboula et al. 2016; Maele-fabry et al. 2017), backyards, for ticks, lice, mosquitoes (FAO 2005; MoH 2006), and grain borers. This exposure to toxic chemicals can cause cancer (Patel and Sangeeta 2018), Parkinson's disease (Furlong et al. 2015) endocrine disruption, and immune impairment after reproduction (Loague et al. 1990; Margni et al. 2002; MoH 2006; Donkor et al. 2016; Nakagoshi 2018; Wong 2018).

For observation of leak and exposure to obsolete pesticide, 74.9% of the participants were exposed to pungent smell. The minority of participants complained of headache (17%) and vomiting (8.1%). 31.3% of participants reported that they observed obsolete pesticide storage leaks on the outside of the store site, 65.4% in nearby open land, 23% in the sewer line and river stream, and 11.6% in the nearby garden. Regarding training on the handling impact of pesticide, 54.8% of participants have not taken any training and 33.9% do not remember whether they took the training or not. A study in Sierra Leone reported that 71% of respondents had no training (Sankoh et al. 2016); this may be due to the educational background of each respondent and location of the stores within study areas. On the other hand, it was reported in the same study that Sierra Leone had 17% of the farmers who were formally trained (Sankoh et al. 2016). This may be due to regular supervision of farmers.

Chemicals and their containers were used by 31.3% of respondents. However, the total uses of chemicals from various households were 75.2%, while 24.8% containers were used respectively. Half of the respondents (54.4%) complained about stockpile storage. The majority (61.0%) were in favor of relocating the storage far away from the residential area, whereas 9.0% of the participants were in favor of disposing of the stockpile and 30.0% of the respondents recommended store protection.

The Ministry of Agriculture and both the Ministry of Agriculture and Ministry of Health were held responsible for the disposal of the obsolete chemicals by 46.5% and 27.0% of respondents respectively. In the present study, participants demanded the Ministry of Agriculture to remove the pesticide stores from their residential areas due to pungent smell which pollutes the atmosphere. The respondent answers conform to those of previous studies reported in the country (MoA 2006; Amera and Abate 2008; Haylamicheal and Dalvie 2009; Teklu 2016; Mesfin 2017). Humans were considered to be most affected by pesticides (46.6%), followed by environment (28.4%) and animals (25%). For environmental pollution, 50% of the respondents reported that the surrounding air of the stockpile areas was polluted due to the leakage of obsolete pesticides into the atmosphere which easily produces a bad odor.

Disposing mechanism

63.3% of the respondents stated that pesticide residues should be disposed using technology, 32.5% stated that leftover pesticides should be disposed of after excess of obsoleted pesticide stock is generated, and the rest had no idea. The study participant perceptions varied based on their educational status. According to the results of the study, 34.9% of study participants reported that burying obsolete pesticide is the best technique to managing and disposing of the chemicals, 51.1% of the respondents opted for burning, and 14% for dumping in open field.

Chi-square, inferential analysis, and cross tabulation

Tables 4 and 5 illustrates that the perception of side effects by respondents was directly related to the distance of residents' household to the store. Majority of the respondents (46.9%) living near the stores within 100 m radius perceived the side effects of the obsoleted pesticide on human health and environment. Besides, nearly 17.3% of the respondents were residing within a radius of 300–400 m. Thus, the perception of the respondent trend was directly related to the distance of residents from the store. However, some respondents did not believe the side effects that might arise from the poor management of the obsoleted pesticide.

From total sampled study participants, the Pearson Chi-square was computed to understand the perception of the respondents near the pesticide stores and the health effects in addition to distance cross tabulation. Thus, it would conclude that people living close to the store are less likely to experience side effects.

On the risk perception of health problem attributed to the usage of the chemicals and their containers from the stores, majority of the participants 257(71.1%) in all the study areas did not believe the occurrence of health effect even if they use both chemicals and their containers. However, some participants 98 (27.1%) perceived that health problems occur due to the usage of these pesticide chemicals and containers from the stores. Thus, for the perception of the protection of the stores from humans and animals, the majority of the participants 211 (58.4%) responded that they were not protected. Nevertheless, some participants 40 (11.1%) had no idea about the storage conditions and others 110 (30.5%) believed the stores were protected.

Health risk assessment

Exposure duration, frequency, and averaging time

The community has been exposed continuously to pesticides due to polluted media around homesteads. To determine the magnitude of exposure, the duration and frequency of outdoor daily activities were used. Exposure duration (ED) is the time spent near a stockpile. Averaging time (AT) is the total number of days in 1 year multiplied by the age in years, thus representing the total number of days in the receptors' lifetime (Environmental Agency 2009; Whanda Shittu 2018). For example, the AT of a 5-year-old child is 1825 days, calculated by multiplying 365 days with the age of the child (5 years). In our study, the majority of respondents spend more than 5 h per day in their homes for 6 days per week. This data was used to extrapolate exposure duration.

Determining critical human receptor

The average daily exposure is the amount of chemical intake per kilogram of body weight per day causing a health problem, over a long period of time. Long-term average daily exposure was analyzed using the concentration of heptachlor, adrien, dieldrin, and DDT in soil (Eq. (1)), and DDT and heptachlor in the air average daily exposure were calculated (Eq. (2)). The data was obtained from other studies due to the condition with pesticide management and comparable usage trend in the past few years of the study area (Ahad and Mohammad 2010; Alamdar et al. 2014).

The USEPA recommended reference dose of heptachlor (RfD is 1.3E−5) and DDT (RfD is 5.0E−4) is lower than the calculated ADE (Tables 6 and 7) in our study population (USEPA 1987a, b). According to the qualitative description of New York Procedure for Evaluating Potential Health Risks for Contaminants, equal to or less than the risk reference dose falls to minimal (NYS DOH 2007). Thus, it concludes that ADE or daily intake levels of both heptachlor and DDT for all age groups were low compared with the recommended

Table 4 Duration of stay of a respondent, distance to the store, and residence of the respondent cross tabulation

Residence of respondent				The distance of store from household				
				< 100 m	100–200 m	201–300 m	301–400 m	Total
Alamata	DST	5 years	% DPC	66.7	33.3	0	0	100
			% DSRH	10.3	9.1	0	0	7.6
		6–10 years	% DPC	70.0	20.0	0	10	100
			% DSRH	12.1	6.1	0	14.3	8.4
		11–15 years	% DPC	50.0	31.2	18.8	0	100
			% DSRH	13.8	15.2	14.3	0	13.4
		16–20 years	% DPC	71.4	14.3	0	14.3	100
			% DSRH	8.6	3.0	0	14.3	5.9
		> 21 years	% DPC	41.6	28.6	23.4	6.5	100
			% DSRH	55.2	66.7	85.7	71.4	64.7
Mekelle	DST	5 years	% DPC	58.6	10.3	10.3	20.7	100
			% DSRH	27.9	13.6	37.5	24.0	25
		6–10 years	% DPC	59.1	18.2	0	22.7	100
			% DSRH	21.3	18.2	0	20.0	19
		11–15 years	% DPC	50.0	16.7	16.7	16.7	100
			% DSRH	9.8	9.1	25.0	8.0	10.3
		16–20 years	% DPC	30.0	10	10.0	50.0	100
			% DSRH	4.9	4.5	12.5	20.0	8.6
		> 21 years	% DPC	51.2	27.9	4.7	16.3	100
			% DSRH	36.1	54.5	25.0	28.0	37.1
Aksum	DST	5 years	% DPC	66.7	16.7	0	16.7	100
			% DSRH	6.1	5.3	0	4.8	5
		6–10 years	% DPC	52.9	23.5	11.8	11.8	100
			% DSRH	13.6	21.1	14.3	9.5	14.2
		11–15 years	% DPC	43.5	21.7	17.4	17.4	100
			% DSRH	15.2	26.3	28.6	19.0	19.2
		16–20 years	% DPC	55.6	11.1	5.6	27.8	100
			% DSRH	15.2	10.5	7.1	23.8	15
		> 21 years	% DPC	58.9	12.5	12.5	16.1	100
			% DSRH	50.0	36.8	50.0	42.9	46.7

DPC duration of participant's stay in the cities, *DSRH* distance of store from the respondent's household, *m* meter

tolerable daily intake. However, the overall estimated ADE of contaminants at 95% inhalation rate is higher than the recommended inhalation rate.

Figure 2 demonstrates the comparative assessment of estimated ADE through inhalation of heptachlor and DDT at higher (95%) and recommended inhalation rate. Children aged 2 to 6 have a higher average daily exposure of heptachlor in terms of concentration on an mg/kg/bw/day basis at 95% inhalation rate. This shows that if all age groups are exposed to the same concentration of pollutant, lower age groups are more affected than adults due to their lower body weight and attenuation time (Whanda Shittu 2018; NATO 2009). In

Table 5 The perception of the association between distance of store from the respondent's house and the side effect of obsolete pesticide

The side effect of obsolete pesticide	The distance of store from respondent household						
	< 100 m	100–200 m	200–300 m	300–400 m	Total	$\chi2$ value	*p*
Yes	122 (46.4%)	56 (21.3%)	40 (15.2%)	45 (17.1%)	263 (100%)	11.842	0.008**
No	64 (65.3%)	19 (19.4%)	7 (7.1%)	8 (8.2%)	98 (100%)		

Significant at $p < 0.05$

Table 6 The perception of health problems related to the usage of pesticides and their containers, and how store protection is perceived in the residence of respondents cross tabulation

	Residence of the respondent			Total
	Alamata	Mekelle	Aksum	
Occurrence of health problem due to pesticides and containers usage				
Yes	21.2%	37.4%	23.5%	98 (27.2%)
No	78.8%	62.6%	71.3%	257 (71.1%)
No idea			5.2%	6 (1.7%)
Total	100.0%	100.0%	100.0%	100.0%
Stock protection from animal and human exposure				
Yes	9.8%	45.4%	36.7%	110 (30.5%)
No	73.8%	53.8%	47.5%	211 (58.4%)
No idea	16.4%	0.8%	15.8%	40 (11.1%)
Total	100.0%	100.0%	100.0%	100.0%

addition, at higher inhalation rate (95%), the estimated ADE of DDT was increasing from birth to 2 years.

Using the equation above (Eq. (4)), the calculated possibility of a person developing cancer in his or her lifetime from breathing air containing heptachlor and DDT was very low with an estimated risk value of 2.54E−08 and 1.65E−07, respectively (NYS DOH 2007).

Table 8 illustrates the estimated ADE via accidental ingestion of heptachlor, DDT, dieldrin, and endrin. The estimated ADE of DDT is higher than the recommended reference dose of USEPA for all age groups except adults. This could be explained by children playing more frequently in the soil around the house than adults. Therefore, communities should be informed about the potential health risks for children due to daily exposure to DDT (NYS DOH 2007). The recommended reference doses for heptachlor, dieldrin (RfD is 5.0E−5), and endrin (RfD is 3.0E−04) are higher than the calculated ADE in our study population (USEPA 2002). These pesticides are therefore unlikely to cause adverse effects on health.

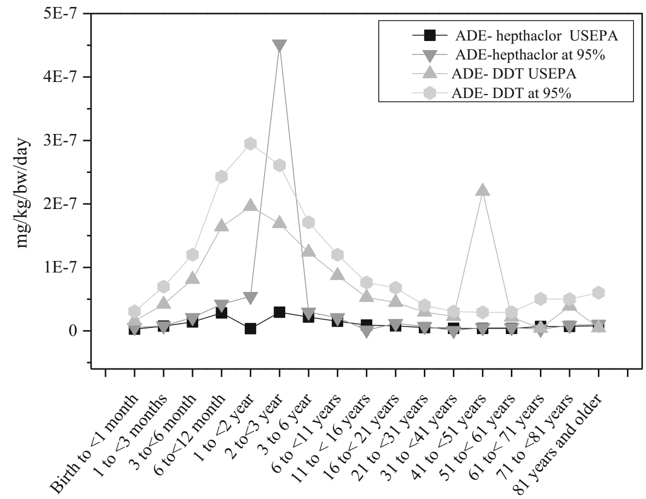

Fig. 2 Comparative assessment of average daily exposure (inhalation) by age group of heptachlor and DDT

Table 7 The calculated average daily exposure (mg/kg/bw/day) with percentage increment, stratified by age group

Age	*BW (kg)	AT (day)	EF (day)	ED (year)	*Inhalation rate (m^3/day)		Heptachlor		DDT	
					USEPA	95%	ADE	ADE 95%	ADE	ADE 95%
Birth to < 1 month	4.8	30	25	0.083	3.6	7.1	2.69E−9	5.31E−9	1.55E−8	3.06E−8
1 to < 3 months	5.9	90	85	0.25	3.5	5.8	7.48E−9	7.77E−9	4.20E−8	6.96E−8
3 to < 6 months	7.4	182	178	0.5	4.1	6.1	1.40E−8	2.09E−8	8.12E−8	1.20E−7
6 to < 12 months	9.2	365	340	1	5.4	8.0	2.83E−8	4.21E−8	1.64E−7	2.43E−7
1 to < 2 years	11.4	730	320	2	8.0	12.8	3.39E−9	5.43E−8	1.96E−7	2.95E−7
2 to < 3 years	13.8	1095	320	3	8.9	13.7	2.93E−8	4.52E−7	1.69E−7	2.61E−7
3 to 6 years	18.6	2190	281	6	10.1	13.8	2.17E−8	2.96E−8	1.24E−7	1.71E−7
6 to < 11 years	31.8	4015	281	11	12.0	16.6	1.51E−8	2.07E−8	8.71E−8	1.20E−7
11 to < 16 years	56.8	5840	240	16	15.2	21.9	9.14E−9	1.31E−9	5.27E−8	7.60E−8
16 to < 21 years	71.6	7665	240	21	16.3	24.6	7.77E−9	1.16E−8	4.49E−8	6.78E−8
21 to < 31 years	78.4	11,315	180	31	15.7	21.3	5.13E−9	6.91E−9	2.96E−8	4.01E−8
31 to < 41 years	80.8	14,965	140	41	16.0	21.4	3.94E−9	5.2E−10	2.27E−8	3.05E−8
41 to < 51 years	83.6	18,615	140	51	16.0	21.2	3.81E−9	5.04E−9	2.20E−7	2.91E−8
51 to < 61 years	83.4	22,265	140	61	15.7	21.3	3.75E−9	5.05E−9	2.16E−8	2.93E−8
61 to < 71 years	82.6	25,915	280	71	14.2	18.1	6.85E−9	2.57E−9	3.95E−9	5.04E−8
71 to < 81 years	76.4	29,565	280	81	12.9	16.6	6.92E−9	8.66E−9	3.88E−8	5.00E−8
81 years and older	68.5	29,565	320	81	12.2	15.7	8.11E−9	1.04E−8	4.68E−9	6.02E−8

*USEPA (1992, 2011a); *BW* body weight, *AT* average time, *EF* exposure frequency, *ED* exposure duration

Table 8 The calculated intake of different pesticides via ingestion and average daily exposure, stratified by age group

Pesticides	Age	*BW (kg)	AT (day)	EF (day)	ED (year)	*Ingestion USEPA	ADE
Heptachlor	6 weeks to < 1 year	9.2	365	320	1	30	1.22E−4
	1 to < 6 years	19	2190	305	6	50	9.45E−5
	6 to < 21 years	66.4	7665	281	21	50	2.49E−5
	Adult	78	28,470	156	78	20	4.71E−6
Dieldrin	6 weeks to < 1 year	9.2	365	320	1	30	8.57E−6
	1 to < 6 years	19	2190	305	6	50	6.59E−6
	6 to < 21 years	66.4	7665	281	21	50	1.73E−6
	Adult	78	28,470	156	78	20	3.23E−7
Endrin	6 weeks to < 1 year	9.2	365	320	1	30	1.42E−5
	1 to < 6 years	19	2190	305	6	50	1.09E−5
	6 to < 21 years	66.4	7665	281	21	50	2.89E−6
	Adult	78	28,470	156	78	20	5.47E−7
DDT	6 weeks to < 1 year	9.2	365	320	1	30	5.51E−4
	1 to < 6 years	19	2190	305	6	50	7.32E−4
	6 to < 21 years	66.4	7665	281	21	50	1.93E−4
	Adult	78	28,470	156	78	20	3.64E−5

*USEPA (2011a, 2011b)

Conclusion

This is the first study to present novel information on how these POPs pesticides have been managed in Ethiopia following the global banning on their production, use, and other restrictions. All storage areas in this study were located in densely populated areas. The public health problem and the environmental consequences resulting from poorly stored obsolete and unused pesticides in the study area are alarming. The storage areas in Alamata and Mekelle were in substandard condition without special security measures. The stockpiles were accumulated over more than 25 years and were generally mixed with non-pesticide chemicals and other articles. The accumulation of pesticides was mainly due to excessive purchase by the government and non-government agencies combined with poor stock management and inadequate storage facilities. All stockpiles within the study area contained POPs pesticides, which are banned internationally by the Stockholm Convention. The pesticides were exposed to various damaging factors. Pesticides were stored in unsafe conditions including many containers leaking chemicals into the environment.

Participants opined that the use of pesticides was important to increase agriculture productivity and suppress pests. Respondents living in close proximity to the storage sites had a greater awareness of the negative impact of obsolete pesticides on the environment and human health. However, some participants used obsolete pesticides to control mosquitoes and other insects without any personal protective equipment, and most respondents used empty pesticide containers haphazardly. This may result in potential health risks, in addition to exposure to contaminating nearby soil and air. Average daily exposure and daily intake of DDT, heptachlor, dieldrin, and endrin were estimated. Our findings revealed that residents below 21 years of age are exposed to DDT above the reference dose threshold, posing a moderate potential health risk. The lifetime risk of cancer as a result of breathing air containing heptachlor and DDT is very low.

Our findings underline the need for improved storage conditions and disposal of large stockpiles of banned pesticides to decrease the risk of environmental pollution around the storage sites. This will reduce the average daily exposure of residents to pesticides, and could avert the moderate potential health risk of children and adolescents due to DDT exposure. Furthermore, education of communities on the potential health risks by using empty pesticide containers and pesticides in the household can improve public health.

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