Indiscriminate use of agro-veterinary pesticides in plague endemic foci in Tanzania: potential risk for development of insecticide resistance in flea vectors

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Research

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Abstract

Background: Agro-veterinary pesticides are increasingly associated with the development of resistance in arthropod disease vectors. However, no has been conducted so far to assess such risk in flea vectors despite the indiscriminate use of pesticides in plague endemic foci in Tanzania.

Methods: We identified risk factors associated with the use of agro-veterinary pesticides, which could enhance development of resistance in flea vectors in two plague endemic districts, using structured questionnaire and direct observations.

Results: Excessive and injudicious use of agricultural and veterinary pesticides was common in both Lushoto and Mbulu district. Most farmers (80%, n=73) were applying agricultural pesticides over three times per cropping season, did not adhere to manufacturers recommended doses, and had limited or no knowledge on safety procedures and adverse effects associated with pesticides. Up to 49% were applying pesticides more than twice the recommended doses. About 91% of respondents in Lushoto and 93% respondents in Mbulu reported using agricultural pesticides. The three (3) out of fourteen (14) most commonly used agricultural pesticides in Lushoto were master kinga72WP (mancozeb 640g/kg+cymoxanil 80g/kg) (44%), suracron720EC (profenos 500g/l EC) (25.3%) and Sumo 5EC (lambda-cyhalothrin) (18.7%). The three (3) out of seventeen (17) most commonly used agricultural pesticides in Mbulu were Dursban50W (Chlorpyrifos) (29%), Duduban 450EC (Cypermethrin 10g/lt+chloropyrifos 35g/lt) (18%) and Dursban+farmerzeb (Chlorpyrifos 48%, Mancozeb 80%WP). Cybadip (Cypermethrin) (≥45%) and paranex (alphacypermethrin) (≥13%) were the most commonly used livestock pesticides.

Conclusion: This study identified injudicious uses and/or other malpractices, which enhance contamination of environments/surfaces with pesticides and consequently the exposure of flea vectors. Therefore, the flea vector populations in Lushoto and Mbulu districts are putatively under high risk of resistance development. Further studies are underway to confirm the insecticide resistance status, unravel distribution of the resistance, and involved resistance mechanisms.

Introduction

Plague is a life-threatening disease caused by a highly infectious bacterium, *Yersinia pestis*. The disease is transmitted to humans primarily by fleas mainly from infected rodents [1]. More than eight flea species described so far can transmit the bacteria [2]. The most predominant and widely distributed flea vector species include *Xenopsylla cheopis*, *X. brasiliensis, Dinopsyllus lypusus* and *Pulex irritans* [3]. *Xenopsylla cheopis* and *X. brasiliensis* have played role in the past and recent plague outbreaks due to their overwhelming efficiency and broad host preference.[4]Several studies suggest that, the human flea, *Pulex irritants*, may be playing an important role in human-to-human transmission during plague outbreaks [5,6].

Commendable efforts have been made to develop plague vaccines; however, there is no any effective vaccine available to date. As such, measures targeted to flea vectors, mostly chemical insecticides, remain the most effective and widely used. This approach has significantly reduced plague in most if not all endemic countries; however, its long-term effectiveness is increasingly challenged by the development of resistance in the major flea vectors. Some endemic countries have reported resistance virtually against all WHO recommended classes of insecticide [7,8].

Based on the classical thinking, all cases of insecticide resistance in arthropod disease vectors including fleas are exclusively attributed to selection pressure from the public health pesticides. Meaning that, all quiescent plague endemic areas without long-standing chemical control operations are safe from insecticide resistance. This assertion might put such areas in a great danger during the disease outbreaks, which are often unpredictable. There are increasing reports in mosquitoes associating insecticide resistance development to agro-chemicals [9-12]. To the best of our knowledge, no study has been conducted so far to assess such risk in flea vectors despite the indiscriminate use of agro-veterinary pesticides in Tanzania and elsewhere in Africa. Many small-scale farmers in different parts of the country are increasingly reported to misuse agro-chemicals particularly pesticides, thus predisposing the non-targeted organisms and ecosystems to negative impacts associated with such chemicals [13-16]. Therefore, this study aimed to establish malpractices and misuse of agricultural pesticides, which could be enhancing the exposure of flea vectors of plague to the pesticides.

Materials And Methods

Study area

This study was done in the selected villages of Lushoto and Mbulu district, Southern Tanzania (Figure1). Lushoto district in Tanga region, is situated at the West Usambara Mountains, which forms part of the Eastern Arc Mountains (04^{o}22’-05^{o}08’S, 038^{o}05’-038^{o}38’E). The district lies at the altitude of 900 to 2,250 m above the sea level. The long rain season runs from March to May; and short rain season runs from November to December, with mean annual rainfall of 1070mm and temperature of 17^{o}C. The dry season runs from July to October. The district has a population of 492,441 people. Mbulu district in Manyara region, is bordered to the north by Arusha region and lake Eyasi; and to the west by Singida region (3^{o}57’1”S, 35^{o}18’ 40”E). It covers a total surface area of approximately 3,800km^{2}; and lies between 1000-2400 m above the sea level. The long rain season runs from January to May; and short rain season runs from November to December, with mean annual rainfall of 994mm and temperature of 17.5^{o}C.The dry season runs from June to October. The district has a population of 320,279 people [17].

Study population

In Lushoto, the study was done in four villages, all with a history of plague outbreak, namely Viti, Lukozi, Ndabwa and Mavumo. Crop cultivation is the main economic activity in the area, and the main crops include maize, beans, potatoes, vegetables and fruits. In Mbulu, the study was conducted in two villages, all with a history of plague outbreak, namely Arri and Mongahay. Crop cultivation and livestock keeping are the main economic activities; and the main crops include maize, beans, potatoes, wheat and vegetables.

Study design and data collection

We employed a cross-sectional study design. The study villages were selected based on the criteria of having experienced plague outbreaks at least twice, and proximity to active and/or fallow agricultural fields. Two hundred (200) households, 100 per district, were used for this study. Head of the household (father or mother) was the main respondents. Otherwise, another adult permanent resident in the household participated in the study. The inclusion criteria for respondents were having lived in the area for five years and above, ownership of active farmland and/or livestock and willingness to participate in the study. Salespersons from four agro-vet shops within the study villages were selected based on their involvement in such business within the last two years and above. The data were collected by means of a standard questionnaire with structured and semi-structured questions. The questionnaire was supplemented with direct observations to confirm certain responses where participants could provide evidence for example presenting containers of the pesticides they were using and demonstrating the preparation of spray solutions. Overall, the survey aimed at gathering information on indigenous knowledge (following manufacturers application instructions, safety procedures and health risks) and routine practices (commonly used chemicals, putting on protective attires, frequency of applying pesticides, use of agricultural pesticides on livestock and vice versa) in relation to the use of agricultural and veterinary chemicals.

Data analysis

The data were analyzed using Epidemiological Information, Epi Info^{TM} version 7.2.3.1(CDC). Descriptive results were expressed as frequencies and percentages.

Results

Socio-demographic characteristics

Majority of the respondents were males, 55(55%) in Lushoto and 58(58%) in Mbulu. Majority of the respondents were below 35 years of age followed by those of 36 and 45 years of age in Lushoto and

Mbulu respectively. Most respondents in Lushoto (n = 71, 71%) and Mbulu (n = 83, 83%) had primary education. The proportion of respondents with secondary education was higher in Lushoto (24%) than Mbulu (14%). Only three (n=3) respondents across the study districts had college education. The remaining respondents, 3(3%) in Lushoto and 2(2%) in Mbulu had formal education. The results are summarized in Table 1.

Table 1 Socio-demographic characteristics of respondents from Lushoto and Mbulu district (each n=100)

Characteristic	Percentage of respondents in Lushoto district (%)	Percentage (%) of respondents in Mbulu district (%)
Male	55	58
Female	45	42
Age categories		
Less than 35	41	20
36 to 45	25	52
46 to 55	21	18
More than 55	13	10
Education level		
Formal	3	2
Primary	71	83
Secondary	24	14
College/University	2	1

Use of agricultural pesticides for control of crop pests

Majority of the respondents, 91% in Lushoto and 93% in Mbulu, reported using agricultural pesticides during the cropping season. The remaining respondents, 9% in Lushoto and 7% in Mbulu, reported not using any agricultural pesticides. The results are summarized in Table 2.

Table 2 Percentage of Respondents using Agricultural Pesticides against Crop Pests

District	Question	Response	Percentage of respondents (%)
Lushoto	Do you use any pesticides during cropping?	Yes	91
		No	9
Mbulu	Do you use any pesticides during cropping?		
		Yes	93
		No	7

Commonly used agricultural pesticides

Fourteen (14) brands of pesticides were used against agricultural pests during the cropping season in Lushoto. These pesticides belong to five different classes: carbamates, pyrethroids, organophosphates, organochlorines and avermectins. The three most commonly used pesticides were master kinga72WP (mancozeb 640g/kg+cymoxanil 80g/kg) (44%), suracron720EC (profenos 500g/l EC) (25.3%) and Sumo 5EC (lambda-cyhalothrin) (18.7%). The results are summarized in Table 3.

Class of pesticide	Trade name	Active ingredient	Percentage of respondents (%)
Carbamates	Master kinga72WP	Mancozeb 640g/kg+Cymoxanil 80g/kg	44
Organophosphates	Suracron 720EC	Profenos 500g/l EC	25.3
Pyrethroids	Sumo 5EC	Lambda-cyhalothrin	18.7
Organophoshates	Profecron 720 EC	Profenos 500g/l EC	15.4
Pyrethroids	Karate 5EC	Lambda-cyhalothrin	15.4
Pyrethroids	Ninja plus 5%EC	Lambda-cyhalothrin	14.3
Avermectins/neonicoti noids	Dudumectin	Emamectin 4.8% +acetameprid 6.4%	14.3
Carbamates	Farmerzeb 80WP	Mancozeb 80%WP	11
Carbamates	AMSAC	Indoxacarb 14.5%SC	7.6
Carbamates	Indofil M45	Mancozeb 80%	4.4
Pyrethroids	Kungfu	Lambda-cyhalothrin	4.4
Organochlorines	DDT		3.3
Organophosphates	Wilcron	Profenos 720EC	3.3
Carbamates	Dithane M55	Mancozeb 80%	2.1

Table 3 Commonly used agricultural pesticides in Lushoto district (n = 91)

Seventeen (17) brands of pesticides were used during the cropping season in Mbulu. These pesticides belong to four (4) classes: pyrethroids, organophosphates, organochlorines and avermectins. The three most commonly used pesticides were Dursban50W (chlorpyrifos) (29%), Duduban 450EC (Cypermethrin 10g/lt+chloropyrifos 35g/lt) (18%) and Dursban+farmerzeb (Chlorpyrifos 48%, Mancozeb 80%WP). The results are summarized in Table 4.

Table 4: Commonly used agricultural pesticides against crop pests in Mbulu district (n = 93)

Class of pesticide	Trade name	Active ingredient	Percentage of respondents (%)
Organophosphates	Dursban	Chlorpyrifos48%	29
Pyrethroids/ organophosphates	Duduban	Cypermethrin 10g/lt+chloropyrifos 35g/lt	18
Organophosphates/Ca rbamates	Dursban, farmerzeb	Chlorpyrifos48%, Mancozeb 80%WP	9
	No pesticide use		9
Pyrethroids/Organoph osphates	Duduban, ninja	Cypermethrin 10g/lt+chloropyrifos 35g/lt	8
Carbamates	Farmerzeb	Mancozeb 80%WP	6
Pyrethroids	Ninja plus	Lambda-cyhalothrin 50g/lt	5
Pyrethroids/Organoph osphates	Duduban, dursban	Cypermethrin 10g/lt+chloropyrifos 35g/lt, Chlorpyrifos 48%	2
Pyrethroids/Organoph osphates/Carbamates	Duduban, farmerzeb	Cypermethrin 10g/lt+chloropyrifos 35g/lt, Mancozeb 80%WP	2
Pyrethroids/organoph osphates	Karate, dursban	Lambda-cyhalothrin, Chlorpyrifos 48%	2
Avermectins/neonicoti noids	Dudumectin	Emamectin 4.8%+ acetameprid 6.4%	1
Organophosphates/Py rethroids	Dursban, karate	Chlorpyrifos48%, Lambda-cyhalothrin	1
Carbamates/ Organophosphates	Farmerzeb, duduban dursban	Mancozeb80%WP,cype rmethrin 10g/lt+chloropyrifos 35g/lt, Chlorpyrifos48%	1
Carbamates/Pyrethroi ds	Farmerzeb, ninja	Mancozeb 80%WP, Lambda-cyhalothrin	1
Pyrethroids	Karate	Lambda-cyhalothrin	1
Pyrethroids/Organoph osphates	Karate, duduban	Lambda-cyhalothrin, cypermethrin 10g/lt+chloropyrifos 35g/lt	1
Pyrethroids	Karate, ninja	Lambda-cyhalothrin	1

Carbamates	Thionix	Zinc dimethyldithiocarbamate 98.2%	1

Commonly used veterinary pesticides against livestock pests

Three veterinary pesticides, all of which are pyrethroids, were used for control of livestock pests in Lushoto. Of these, Cybadip (Cypermethrin) was the most commonly used (45%) followed by paranex (alphacypermethrin) (15%) and tick-tick (permethrin) (10%) (Figure 2). These pesticides were mainly used on goats and cattle for control of ticks. In Mbulu district, five (5) veterinary pesticides were used against livestock pests. Of these, cybadip was by far the most commonly used (cypermethrin) (83%) followed by paranex (alphacypermethrin) (13%) (Figure 3).

Commonly used pesticides against fleas

In Lushoto and Mbulu district, the three commonly pesticides used against fleas belong to two main classes: pyrethroids and carbamates (Table 5). Small portable hand sprayers were used to spray pesticides to infested animals or on the floor. The animals, mainly calves and goats, were only sprayed on body parts preferred by the fleas. The powder formulation of carbamates was sprinkled inside living houses with hands. The targeted control of fleas is so much restricted to certain parts of the house and was often done during the dry season when the flea population is high. The same applied for Mbulu only that the problem of fleas seems to be relatively higher than in Lushoto district. Because of the cost of insecticides, most of the respondents reported to pour hot water inside their living houses as an alternative way of controlling fleas. The study also revealed that, most people in the study villages in Mbulu district are still keeping livestock (cattle, goats etc) inside their living houses. Table 5 summarizes the commonly used chemicals for flea control in Lushoto and Mbulu district.

Table 5 Commonly used pesticides against fleas in Mbulu and Lushoto district

District	Class of pesticide	Trade name	Active substance	Percentages of respondents (%)
Mbulu	Pyrethroids	Cybadip	Cypermethrin	42
		No Pesticide use		16
	Carbamates	Dudu dust	Carbaryl 75g/kg	14
	Organophosphates	Dursban	Chlorpyrifos 48%	12
	Pyrethroids	Paranex	Alphacypermethrin	8
	Carbamates	Akheri powder	Carbaryl5%w/w+ Lambdacyhalothrin 0.1%w/w	5
	Pyrethroids	Cybadip, dudu dust	Cypermethrin, Carbaryl 75g/kg	1
	Pyrethroids/Organophosphates	Cybadip dursban	Cypermethrin, Chlorpyrifos 48%	1
Lushoto	Carbamates/Pyrethroids	Akheri powder	Carbaryl 15%w/w +Lambda cyhalothrin 0.1w/w	4
	Pyrethroids	Paranex100EC	Alphacypermethrin	2
	Pyrethroids/Organophosphates	Duduban	Cypermethrin 10g/lt+chloropyrifos35g/lt	1

Frequency of applying agricultural pesticides

The respondents from Lushoto district reported the highest application of pesticides per cropping season of three months, particularly on vegetables. Most of them (n=73; 80%) repeated pesticides application over thrice per cropping season. About 11% (n=10) and 6% (n=5) of the respondents applied pesticides once and twice per season respectively. The rest of the respondents (n=2; 3%) reported that they were not using pesticides at all. Similarly, respondents from Mbulu district reported high use of agricultural pesticides particularly on vegetables; and most of them were applying pesticides twice (n=39;42%) or over thrice (n=35;38%) per cropping season. About 8% (n=7) were applying pesticides only once per cropping season. The rest (n=11, 12%) were not using pesticides at all.

Misuse of agricultural pesticides in Lushoto and Mbulu district

Although, all respondents reported that extension officers and salespersons provided them with necessary information regarding the use of pesticides, most of them did not adhere to manufacturers recommendations; 49(53.4%) and 39(42%) of the respondents in Lushoto and Mbulu respectively applied more than twice the recommended doses. About 18(19.8%) of respondents in Lushoto and 25(27%) in Mbulu district (Figure 4), claimed to apply the recommended dose; however we doubted that because they were unable to substantiate. The rest were using far lower doses than recommended.

Indigenous Knowledge on the use of agricultural and veterinary pesticides in Lushoto and Mbulu district

Half of the respondents (n=50, 50%) from Lushoto were not aware of the effects of excessive use of pesticides to human. The rest (n=50, 50%) of the respondents responded that excessive use of pesticides would lead to cancers. The majority of respondents (n=70, 70%) from Mbulu were not aware of the effects of excessive use of pesticides to human. The rest of the respondents (n=30, 30%) were aware of the effects of excessive use of agricultural and veterinary pesticides.

Discussion

This study aimed to establish risk factors associated with use of agro-veterinary chemicals, which could enhance the development of resistance in plague flea vectors. The thinking that resistance in arthropod vectors emanates exclusively from prolonged use of public health pesticides might predispose plague endemic countries to devastating outbreaks. Most of the studies conducted so far, mainly in mosquitoes, are increasingly emphasizing involvement of agricultural pesticides in the development of insecticide resistance [11,18-21]. Similarly, veterinary pesticides are purported to contribute to development of resistance in public health pests. These assertions are both reasonable because the chemistries of public health and agro-veterinary pesticides are closely related. In fact, most if not all public health pesticides are reformulations of pesticides that were once used in agriculture [23].

Crop, animal and human arthropod pests interact either directly or indirectly via habitats and hosts. Due to that, they coincidentally contact pesticides and other control agents not meant for them. This is substantiated by Gratz [24] who reported that indoor residual spraying (IRS) with DDT against mosquitoes affected susceptibility of the flea vector, *Xenopsylla cheopis* such insecticide. As such, injudicious uses/practices of agro-veterinary pesticides, for whatever reason, which promote their exposure to flea vectors of plague, will constitute risk factors for resistance development. The present study identified several risk factors with huge potential for enhancing the development of resistance in flea vectors of plague.

Small-scale farmers and livestock keepers dominate Lushoto and Mbulu districts; and control pests almost exclusively using pesticides. Over 91% of respondents across the districts reported using pesticides to control agricultural pests. The use of pesticides against both agricultural and livestock pests is a common practice throughout Tanzania and elsewhere in the region [16,23]. Similarly, use of pesticides constitutes the most widely used and powerful means of controlling fleas and other public health pests [1,25,26]. Pests are responsible for the largest burden in crop and livestock production [23,27-28].

Excessive and injudicious use of agricultural and veterinary pesticides was common across the study districts. Most farmers reported applying agricultural pesticides up to four times per cropping season, particularly on horticultural crops. Even more worrying, these farmers did not adhere to manufacturers recommended doses and had limited or no knowledge on safety procedures and adverse effects associated with pesticides. Similar surveys in other parts of Tanzania and elsewhere in Africa indicated misuse and overuse of pesticides, non-adherence, poor storage and disposal of pesticide containers, use of banned and counterfeit pesticides and the use of a mix of pesticides in a single spray [15,16,29,30]. Respondents of the current study never reported the last two malpractices. It could be that the respondents feared of being penalized if they disclosed such extreme information. Our co-workers however witnessed the two forms of malpractices in the study areas and the people claimed that banned and/or mixed pesticides were relatively more efficient in terms of pest control outcomes. The misuse and/or malpractices observed in this and other studies could have been contributed by poor education background and inadequacy of the training programs on safe use of pesticides, particularly at the local levels [16,23,31]. Up to 83% of the respondents in the present study were primary school leavers. Farmers with this literacy level are mostly unable to understand manufacturer's labeling and instructions, particularly because they are written in English. Other studies argue further that most extension workers and salesmen in retail shops across Tanzania are unable to provide quality services because they are either incompetent or they did not undergo the relevant training [14].

Farmers reported using over fourteen agricultural and three veterinary pesticides, most of which were pyrethroids. Other than pyrethroids, there were carbamates, organophosphates, organochlorines, and avermectins. Most of the identified individual pesticides are also common elsewhere, particularly in horticulture and cotton industry [13,14,16]. Interestingly, development of resistance in public health pests, for instance mosquitoes has been reported from cotton and horticulture growing areas consequent to large quantities and frequent applications of pesticides [13]. These crops are relatively vulnerable to pests and diseases. As such, any other areas growing either of the aforementioned and/or other vulnerable crops are at risk of resistance development in public health pests, like fleas, that are likely to contact contaminated soils and other surfaces/substrates. Horticultural production forms the largest agricultural industry in Lushoto and Mbulu district.

This study revealed infrequent application of pesticides recommended for flea control. At most, these pesticides were applied in cases of high flea infestations. The higher cost of these pesticides than that of agricultural pesticides could be a limiting factor. Farmers get tempted to use agricultural pesticides as alternatives against fleas and other public health pests. This was outside the scope of this study, but our co-workers witnessed such scenarios in their previous visits to the current study sites. Switching pesticides to unintended uses is also not new elsewhere [32].

Because of the aforementioned injudicious uses and other malpractices, indoor and outdoor environments/surfaces are contaminated with chemicals. Immature and adult fleas are constantly exposed to such surfaces, thus posing high risk of resistance development in Lushoto and Mbulu districts. Resistance to various chemicals in rodent fleas may be selected at either larval or adult stage. These fleas are always found in loose soils of rodent burrows in peri-domestic and agricultural fields or animal/human dwellings. During rains, soils in rodent burrows and other habitats become contaminated via run-off of agricultural chemicals. Many studies have reported alarming contamination of soils, water, air and other type of environments with agricultural chemicals [33-35]. Furthermore, fleas are exposed to chemicals via insecticide-treated livestock because these animals also serve as alternative blood-meal sources. This nature of exposure could be enhanced by high interactions between commensal rodents and domestic animals, particularly in areas where the tendency of keeping animals inside living houses during the night is still existent. The current study revealed that certain rural communities within Lushoto and Mbulu districts are still embracing such practice. As such, fleas are constantly exposed to veterinary chemicals on top of exposure to agricultural chemicals.

Conclusion

This study revealed a suite of either injudicious uses and/or malpractices; excessive use of agricultural chemicals, maluse of agro-veterinary chemicals as well as poor adherence to the application and safety procedures, all of which potentiate contamination of environments/surfaces and exposure of the chemicals to fleas thereof. As such, flea vector populations across Lushoto and Mbulu districts are putatively under high risk of insecticide resistance emanating from the indiscriminate use of agro-veterinary chemicals. Further studies are underway to confirm the trend of insecticide resistance in the study area and elsewhere in view of informing the course of action in terms of awareness creation and development/implementation of resistance management strategies.

Declarations

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Author's contributions

All authors contributed to data collection and analysis, drafting or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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Availability of data and materials

The datasets generated and/or analysed during the present study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All participants gave verbal consent prior to their participation in this study; and all personal data were excluded from the analysed data and final report.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

References

1. Boyer S, Miarinjara A, Elissa N. *Xenopsylla cheopis* (Siphonaptera: Pulicidae) susceptibility to deltamethrin in Madagascar. PLoS One. 2014;9(11):e111998. doi:10.1371/journal.pone.0111998.
2. Hinnebusch BJ. The evolution of flea-borne transmission in *Yersinia pestis*. Curr Issues Mol Biol. 2005;7(2):197-212.
3. Ziwa MH, Mattee MI, Hang'ombe BM, Lyamuya EF, Kilonzo BS. Plague in Tanzania: an overview. TJHR. 2013;15(4).doi: http://dx.doi.org/10.4314/thrb.v15i4.
4. Bramanti B, Dean KR, Walløe L, Chr. Stenseth N. The third plague pandemic in Europe. Proc R Soc B. 2019;286:20182429. doi.org/10.1098/rspb.2018.2429.
5. Ratovonjato J, Rajerison M, Rahelinirina S, Boyer *Yersinia pestis* in *Pulex irritans* fleas during plague outbreak, Madagascar. Emerg Infect Dis. 2014;20(8):1414–1415.doi:10.3201/eid2008.130629.
6. Deana KR, Krauera F, Walløeb L, Lingjærdec OC, Bramantia B, Stensetha NC, Schmid BV. Human ectoparasites and the spread of plague in Europe during the 391 second pandemic. PNAS 2018;115:390-392. doi: 10.1073/pnas.1715640115.
7. Rust MK. Insecticide resistance in fleas. *Insects.* 2016;7(1):10.doi:10.3390/insects7010010.
8. Miarinjara A, Boyer S. Current perspectives on plague vector control in Madagascar: susceptibility status of *Xenopsylla cheopis* to 12 insecticides. PLoS Negl Trop Dis. 2016;10(2):e0004414. doi:10.1371/journal.pntd.000441.
9. Hamon J, Garrett-Jones C. Insecticide-resistance in major vectors of malaria and its operational importance. Geneva: *WHO*
10. Brun L-O, Sales S. Evolution de la résistance à la dieldrined'unepopula-tionsauvage*d'Anophelesfunestus* Giles enl'absence de traitementssélectifsdélibérés. Bobo-Dioulasso, Burkina Faso: Institut de Recherche pour le Développement; 1975.
11. Yadouléton A, Martin T, Padonou G, Chandre F, Asidi A, Djogbénou L, Dabiré R, Aïkpon R, Boko MGlitho I, Akogbeto M. Cotton pest management practices and the selection of pyrethroid resistance in *Anopheles gambiae* population in Northern Benin. Parasit Vectors. 2011;4:60.doi:10.1186/1756-3305-4-60.

12. Luc DS, Benoit A, Laurette D, Michel M: Indirect evidence that agricultural pesticides select for insecticide resistance in the malaria vector *Anopheles gambiae*. J Vector Ecol.2016;41(1):34-40. doi:10.1111/jvec.12191.
13. Reid MC, McKenzie FE. The contribution of agricultural insecticide use to increasing insecticide resistance in African malaria vectors. Malar J.2016;15:107.doi 10.1186/s12936-016-1162.
14. Ngowi AVF. Health impact of exposure to pesticides in agriculture in Tanzania. PhD Thesis. University of Tampere, Finland, 2002.
15. Ngowi AVF. A study of farmers' knowledge, attitude and experience in the use of pesticides in coffee farming. AfrNewslett on Occup Health Saf. 2003;13:62-64
16. Nonga HE, Mdegela RH, Lie E, Sandvik M, Skaare JU. Assessment of farming practices and uses of agrochemicals in Lake Manyara Basin, Tanzania. Afr J Agric Res. 6(10);2216-2230.doi:10.5897/AJAR11.235.
17. National Bureau of Statistics, Population Census of 2012, Tanzania, 2013.
18. Yadouleton AW, Asidi A, Rousseau FD, Braïma J, Agossou CD, Akogbeto MC. Development of vegetable farming: a cause of the emergence of insecticide resistance in populations of *Anopheles gambiae* in Urban areas of Benin. Malar J. 2009;8:103. doi:10.1186/1475-2875-8-10.
19. Nwane P, Etang J, Chouaïbou M, Toto JC, Kerah-Hinzoumbé C, Mimp-foundi R, et al. Trends in DDT and pyrethroid resistance in *Anopheles gambiae* s. populations from urban and agro-industrial settings in southern Cameroon. BMC Infect Dis. 2009, 9:163. doi:10.1186/1471-2334-9-16.
20. Nkya TE, Akhouayri I, Kisinza W, David JP. Impact of environment on mosquito response to pyrethroid insecticides: facts, evidences and prospects. Insect Biochem Mol Biol. 2013;43(4):407–16.doi: 10.1016/j.ibmb.2012.10.006.
21. Luc DS, Benoit A, Laurette D, Michel M. Indirect evidence that agricultural pesticides select for insecticide resistance in the malaria vector *Anopheles gambiae*. *J Vector Ecol*. 2016;41(1):34-40. doi:10.1111/jvec.12191.
22. Maharaj R. Global trends in insecticide resistance and impact on disease vector control measures. *J Insect Physiol*. 2011;3:27–33. doi:10.2147/OAIP.S8620.
23. Gratz NG. Control of plague transmission, pp. 97–134, Plague manual: epidemiology, distribution, surveillance and control. WHO, Geneva, Switzerland 1999.
24. Rajabu J, Tarimo M, Hangali T. Health effects, trends and knowledge on pesticide use in Tanzania; Review. 2017;4:1.
25. Liu N. Insecticide resistance in mosquitoes: Impact, mechanisms, and research directions. **Ann Rev Entomol. 2015;**60(1):537-559. doi:10.1146/annurev-ento-010814-020828.
26. Katakweba AAS, Mhamphi G, Mwalimu DC, Mchau G, Mbise TJ, Lugendo RM, Borremans B, Kilonzo BS. Laboratory and field tests of Carbaryl 5% against fleas in Lushoto district, Tanzania. TJHR. 2015;17:2.http://hdl.handle.net/123456789/906.

27. Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N, Nelson A. The global burden of pathogens and pests on major food crops. Nat EcolEvol. 2019;3(3):430-439. doi:10.1038/s41559-018-0793-y.
28. Cardoso L. ‘Review of ‘Pests and vector-borne diseases in the livestock industry. Parasit Vectors. 2019;12:55. doi.org/10.1186/s13071-019-3315.
29. Śpiewak R. Pesticides as a cause of occupational skin diseases in farmers. Ann Agric Environ Med. 2001;8(1):1–5.
30. Lema E, Machunda R, Njau KN. Agrochemicals use in horticulture industry in Tanzania and their potential impact to water resources. Int J Biol Chem Sci. 2014;8(2):831-842. doi:10.4314/ijbcs.v8i2.38.
31. Bertrand PG. Uses and misuses of agricultural pesticides in Africa: Neglected public health threats for workers and population. 2019; doi:10.5772/intechopen.84566.
32. Yadav IC, Devi NL, Syed JH, Cheng Z, Li J, Zhang G, Jones KC. Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. Sci Total Environ. 2015;511:123-137. doi:10.1016/j.scitotenv.2014.12.041.
33. Mahmood I, Imadi SR, Shazadi K, Gul A, Hakeem KR. Effects of Pesticides on Environment. In book: Plant, Soil and Microbes Volume 1: Implications in Crop Science Edition: 2016 doi10.1007/978-3-319-27455-3_13.
34. Carlvalho FP. Pesticides, environment, and food safety. Food and Energy Secur. 2017;6:48–60. doi.org/10.1002/fes3.108.
35. Andrea ME, Carolina TA, José CT, Luis MJ, Carlos GL. Evaluation of contaminants in agricultural soils in an irrigation district in Colombia. Heliyon 2019; 5(8):e02217.doi:10.1016/j.heliyon.2019.e02217.

Figures

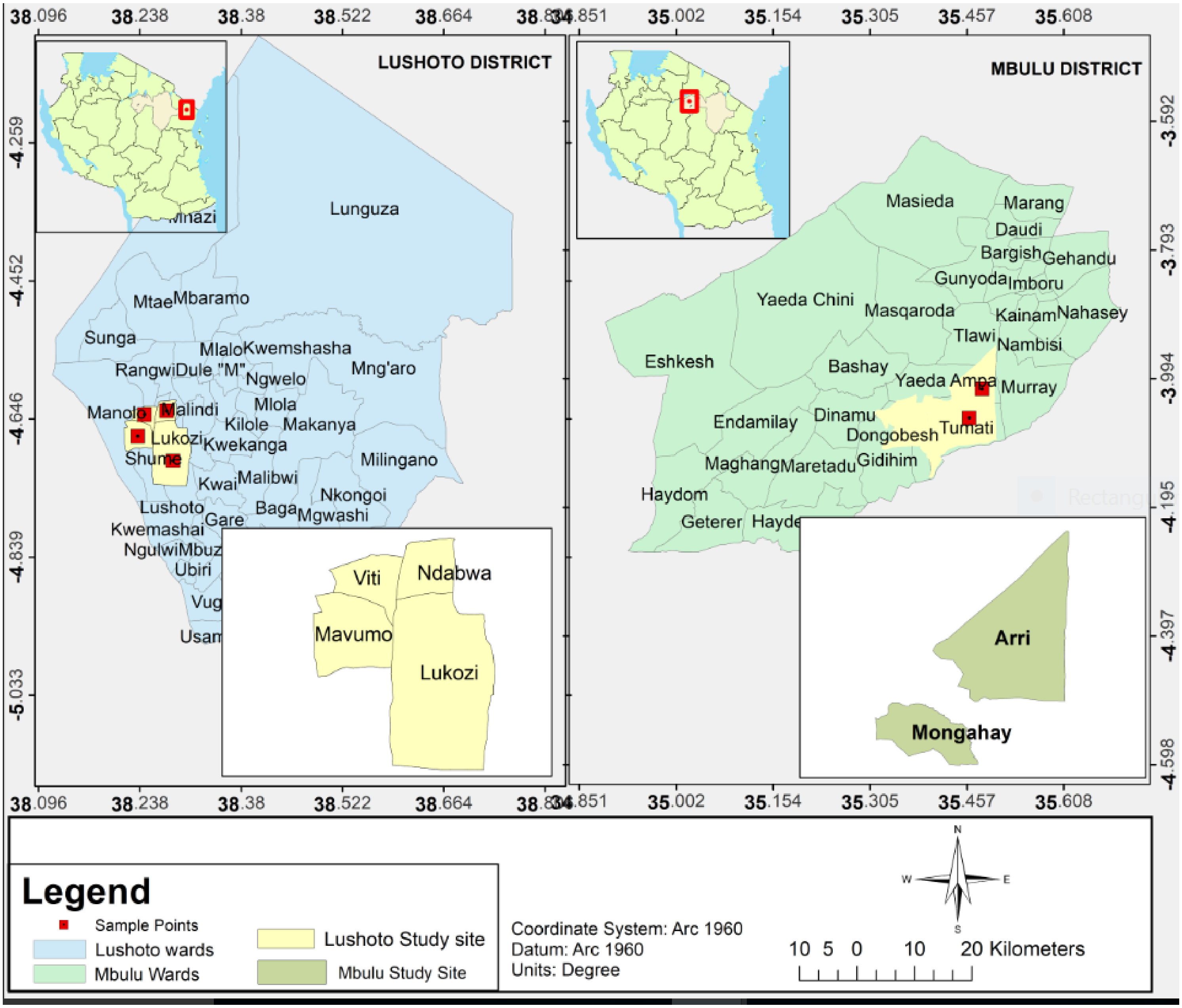

Figure 1

A map of Lushoto and Mbulu districts showing the study sites.

Rugalema et al. Figure 2

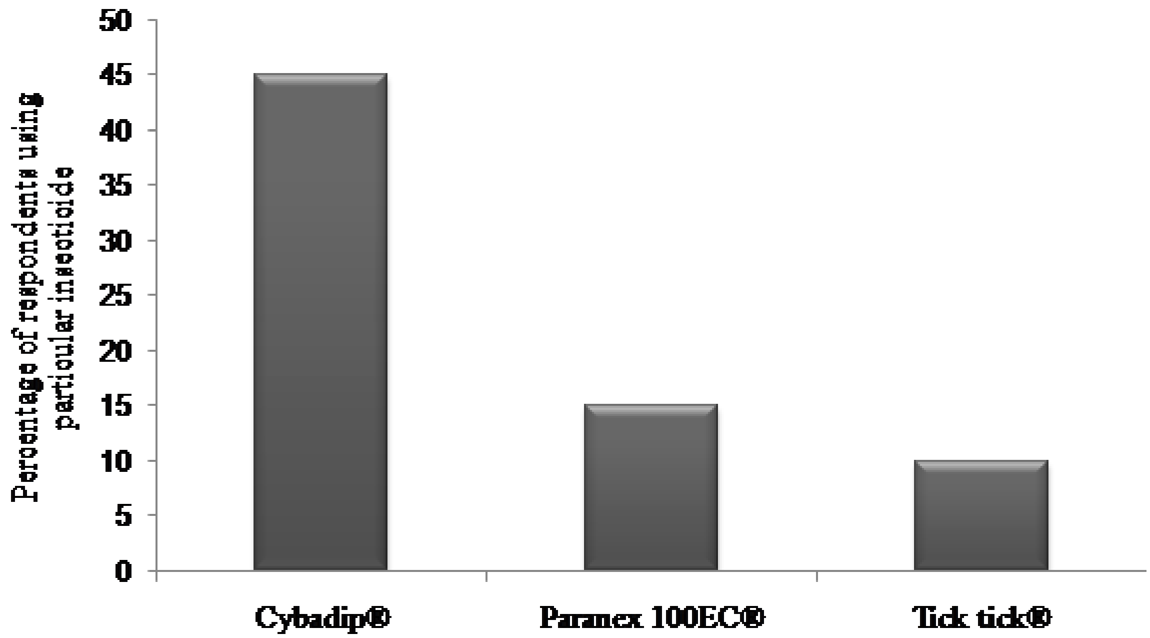

Figure 2

Veterinary pesticides commonly used against livestock pests in Lushoto district: Cybadip® (cypermethrin 15%m/v), Paranex100EC® (alphacypermithrin) and Tick tick® (permethrin). All of them are pyrethroids.

Rugalema et al. Figure 3

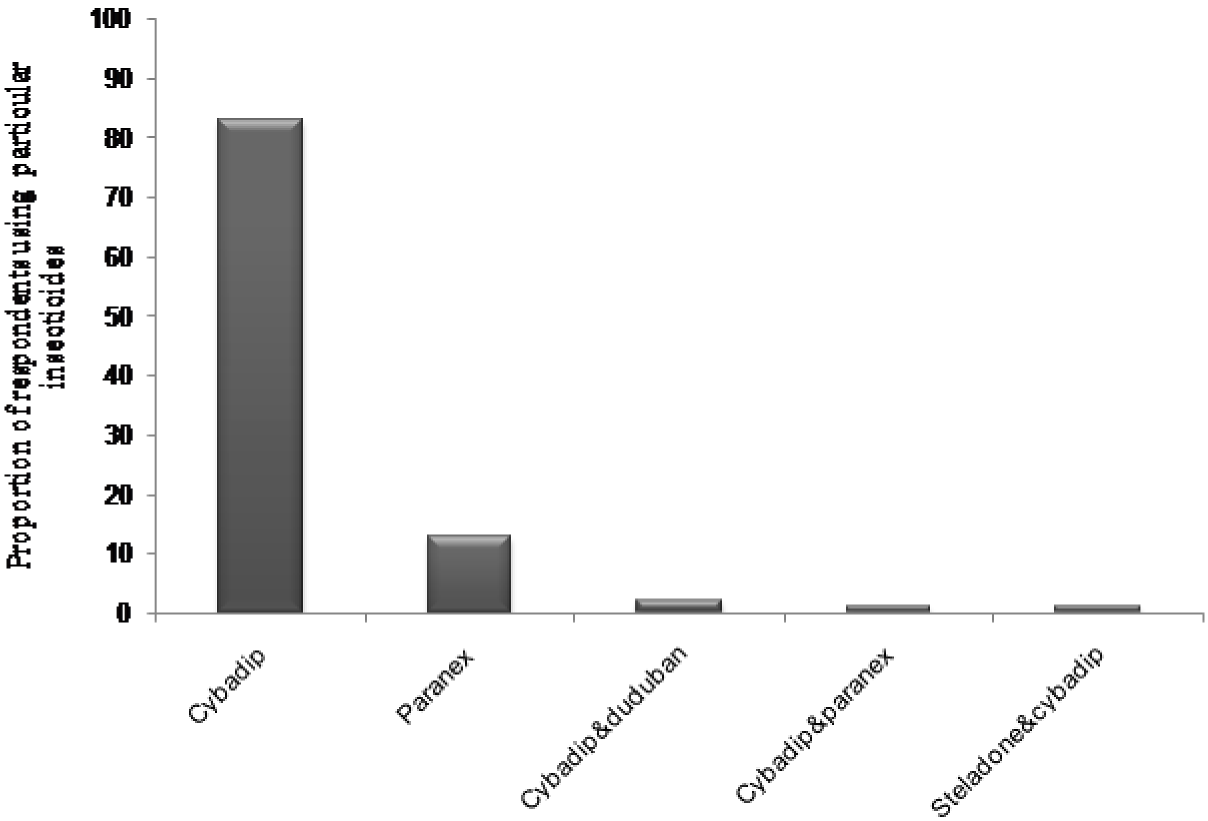

Figure 3

Veterinary pesticides commonly used against livestock pests in Mbulu district: Cybadip® (cypermethrin 15%m/v), Paranex® (alphacypermethrin), Cybadip® & Paranex® and Steladone® & cybadip®. The last two sets of insecticides represent cases where respondents reported to be using the two insecticides interchangeably.

Rugalema et al. Figure 4

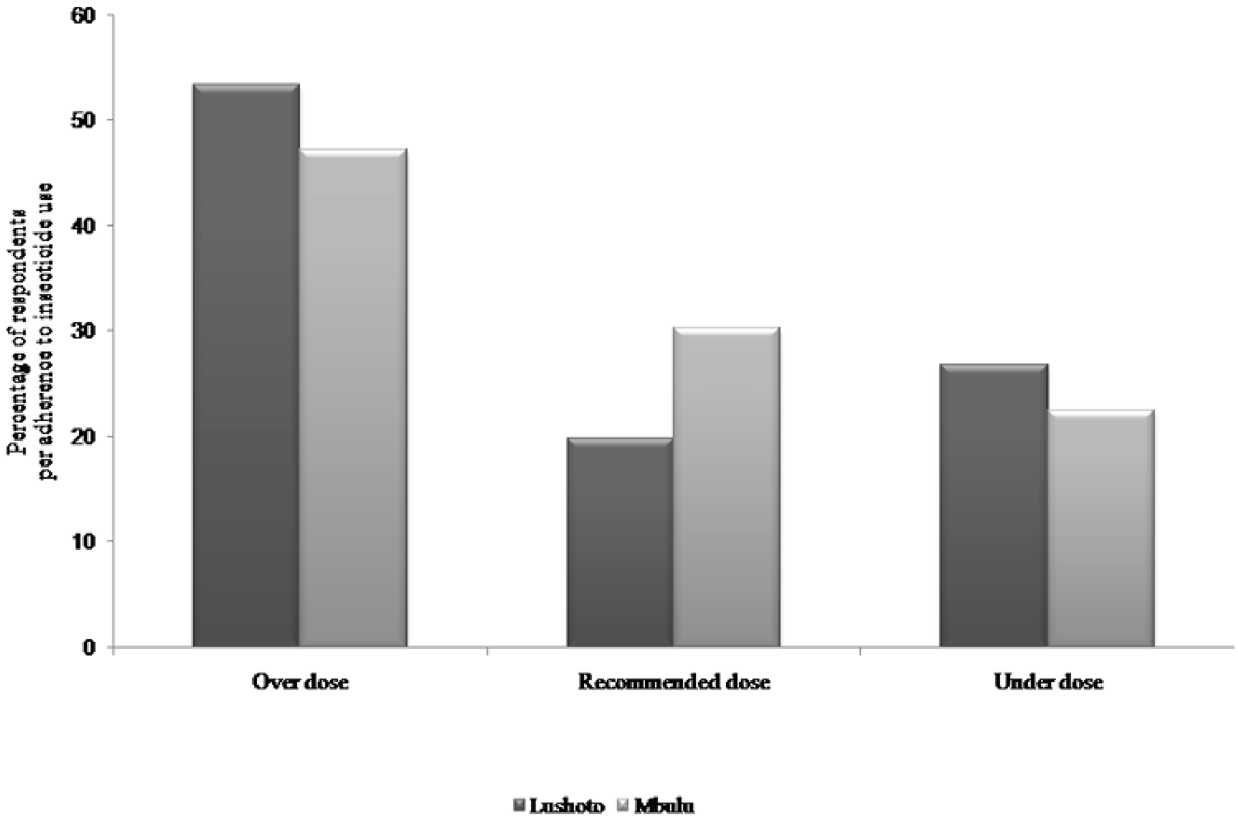

Figure 4

The respondents' adherence to manufacturers recommended doses of agricultural pesticides in Lushoto and Mbulu district.

Supplementary Files

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