LANCASTER ENVIRONMENT CENTRE

LANCASTER UNIVERSITY

An Assessment of Pesticide Use, Contamination and Impact on the Environment and the Health of People in Sierra Leone

Sankoh Alhaji Ibrahim

A thesis submitted in fulfilment for the degree of Doctor of Philosophy

September 2016

Abstract

One of the biggest challenges faced by Sierra Leonean farmers is pest control. Birds, insects, rodents, crustaceans and other organisms can drastically reduce yields. In order to prevent these organisms from destroying their crops, farmers use pesticides. However there are reports that these chemicals are being misused and are having negative impact on the environment and the health of the farmers. This research aimed to investigate pesticide use in rice fields and its potential effects on the environment and the health of rice farmers. The research also studied the fate of chlorpyrifos (the most widely used pesticide) in Sierra Leone soils when applied using local methods used by farmers in Sierra Leone. Five hundred farmers and one hundred health workers across the country were interviewed. Fifty focused group discussion were done. Field observations were also done. Two experimental plots (one on a boliland and one on a riverine ecosystem) on which rice cultivated were setup. Three concentrations of each of chlorpyrifos diethyl, chlorpyrifos dimethyl and a 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl were applied. Soils and rice samples from the plots were analysed for residual chlorpyrifos. Soils, rice and biota samples were from rice fields were also analysed for residual chlorpyrifos. It was found that the prevalence of pesticide use on rice farms is high and the chemicals are misused. Farmers are exposed to pesticides. Cases of pesticide related symptoms investigated in this research were found to be more prevalent among farmers that use pesticides than those not using pesticides. Chlorpyrifos is not persistent in Sierra Leone soils when recommended doses are applied. Levels of chlorpyrifos in rice samples are far below the UK and WHO recommended maximum limits when recommended doses are applied during cultivation. Soils from farms are highly contaminated. Rice and biota samples from the farms are contaminated and their consumption can expose humans to levels that could cause chronic effects.

Acknowledgements

ALLAH HU AKBAR!! To ALLAH be the glory for great things HE hath done and will continue to do in my life!!

I thank the Islamic Development Bank for funding this study under the Merit Scholarship Scheme. Special thanks go to Brother Haitham Mohamad Alsalahi - Scholarships Officer who broke the good news and sent me an official letter of the scholarship award - and to the many who administered the Scholarships especially, brothers Abulmayeen Shahruqul Huq and Lakhdhar M Kadkadi.

This work has been produced through the invaluable continued guidance and support of my supervisors, Professor Kevin C. Jones and Dr Andrew J. Sweetman to whom I am very grateful. My thanks also go to my secondary supervisor, Professor Kirk T. Semple, for providing support when I require it. Thanks to Dr Rebecca Whittle for her great guide in the social aspect of my research. Thanks also to the Lancaster University postgraduate statistics team for their support.

I appreciate the great motivation and valuable support Dr Abu Conteh, gave to me throughout this struggle. I am grateful to Carola Graf, Dr Justina Ukpebor, and Dr Auladell-Mestre, Montserrat and Tim Gregson for their motivation and support during my analytical work in the laboratory. To members of my research team, I thank you for your hard work. Thanks to my wonderful office mates especially Benjamin Jackson, Ying Zhu and Vito Abbruzzese for their motivation and various other supports.

Last but not the least I thank Nancy Sesay, Gibril Koroma, Vinnette J. Powell, Janile Clottey, Dr and Mrs Otto and Foday S. Kabba for their various supports throughout my stay in England.

Table of Contents

Acknowledgements III

List of papers and declaration XII

List of appendices XIII

List of tables XIV

List of Figures XV

List of acronyms and abbreviations XIX

Chapter 1 1

Introduction 1

- Background 1
- Study area 2
- Agriculture in Sierra Leone 5
- Pesticides used in Sierra Leone, their health effects and fate in the environment 7
    - Chlorpyrifos ($C_9H_{11}C_{l3}NO_3PS$) 7
    - Furandan (carbofuran $C_{12}H_{15}NO_3$) 9
    - Carbolineum 10
    - Diazinon ($C_{12}H_{21}N_2O_3PS$) 11
    - Malathion ($C_{10}H_{19}O_6PS_2$) 11
    - Endosulfan ($C_9H_6Cl_6O_3S$) 11
    - Propanil ($C_9H_9Cl_2NO$) and 2,4-D ($C_6H_6Cl_2O_2$) 11
- Susceptible populations and their living conditions 12
- Perspective of the farmer’s general awareness of the negative impact of pesticides 16
- Research questions 19
- Justification 19
- Aims and Objectives 20
- The Objectives included: 20

Research and data collection strategies 21
Data collection 21
Ethics 21
Analytical method 21
Structure of thesis 22
References 24
Chapter 2 29
An assessment of the impacts of pesticide use on the environment and health of rice farmers in Sierra Leone 29
Abstract 29
Introduction 29
Background 29
Pest control in Sierra Leone 30
Materials and methods 30
Study area 30
Methods 30
Data analysis 31
Results and discussion 31
Prevalence of pesticide use by rice farmers in Sierra Leone 32
Types of pesticides used in Sierra Leone rice fields 32
Sources of pesticides 33
Training and Education 33
Storage, handling, application and exposure 33
Storage 33
Handling, application and possible exposure routes 33
Environmental effects 34

Health 35
Conclusion 36
Recommendations 36
Acknowledgement 36
References 36
Chapter 3 38
The fate of chlorpyrifos when applied using field methods employed by Sierra Leonean farmers 38
Abstract 38
Introduction 39
Background 39
Materials and method 41
Experimental design 41
Sample Collection 43
Soil samples collection and treatment 43
Laboratory analysis 44
Reagents and standards 44
Sample preparation 45
Extraction and clean-up 45
Analytical instrument setup 46
Determination of soil density 46
Determination of percentage moisture content and percentage organic carbon 46
Data analysis 47
Analytical method validation 49
Results and discussion 49
Pesticide residues in soils 49
Experimental plot 1 (Riverine ecosystem) 50
Experimental plot 2 (boliland ecosystem) 53
Fate of chlorpyrifos in soil 55

Fugacity modelling 57

Chlorpyrifos residues in rice grains 61

Human Exposure 66

Conclusion 67

References 69

Chapter 4 76

An assessment of chlorpyrifos contamination in aquatic biota, rice and soils from riverine swamp farms in Sierra Leone 76

Abstract 76

Introduction 77

Background 77

Pesticide use and its impact 78

Materials and Method 80

Sample Collection 80

Soil samples collection and treatment 80

Soil sample collection 81

Rice sample collection 81

Biota samples collection 82

Laboratory analysis 82

Reagents and standards 82

Sample preparation 83

Extraction and clean-up 83

Analytical instrument setup 84

Determination of soil density 84

Determination of percentage moisture content and percentage organic carbon 84

Data analysis 85

Results and discussion 85

Validation of analytical method 85

Levels of chlorpyrifos 85

Soils 85
Rice 87
Crabs 88
Fish 90
Mudskippers 91
Shrimps 93
Chlorpyrifos contamination at different sites 94
Human exposure through food 95
Rice 95
Fish 96
Mudskippers 96
Crabs and shrimps 97
Combined food 97
Conclusion 97
References 99
Chapter 5 107
Summary, conclusion and recommendation 107
Pesticide use and its impacts in Sierra Leone 107
Research instrument 110
Prevalence and use of pesticides in Sierra Leone 111
Types of pesticides used on rice farms in Sierra Leone 116
Sources of pesticides 117
Supply of pesticides 117
Levels of application of pesticides on rice farms 120
Fate of pesticides on the environment 123
Chlorpyrifos in food and human exposure 124
Exposure 124
Literacy and training 126
Health impact 127

Environmental Impact 130
Economic impact 131
Conclusion 133
Prevalence of pesticide use among rice farmers in Sierra Leone 134
Handling 135
Potential risks to the environment 135
Possible exposure routes for farmers 136
Impact of pesticides on human health 138
Economic impact of pesticides to Sierra Leone 139
Recommendations 140
References 142
Appendix A 149
Structured Interview Schedule for Farmers 149
Appendix B 158
Questionnaire for Health Workers 158
Appendix C 164
Krio Version of Questionnaire for Farmers 164
Appendix D 168
Data collection instruments 168
Data collection 168
Development of questionnaires 168
Training of field assistants 169
Implementation techniques 170
Appendix E 171
Development of analytical method 171
Laboratory extraction methodology 171

  - Clean-up 172
  - The GC/MS instrument method 173

Appendix F 175

Ethics approval letter 175

Appendix G 177

Participants Information Sheet 177

Appendix H 180

CONSENT FORM 180

Appendix I 182

Interview close form 182

List of **papers and declaration**

Alhaji I. Sankoh, Rebecca Whittle, Kirk T. Semple, Kevin C. Jones and Andrew J. Sweetman. An assessment of the impacts of pesticide use on the environment and health of rice farmers in Sierra Leone. Environment International 94 (2016) 458-466

Alhaji I. Sankoh design the study, developed the questionnaires the help of Rebecca Whittle. The data was collected, analysed and reported by Alhaji I. Sankoh with the supervision of Andrew J. Sweetman, Kevin C. Jones and Kirk T. Semple.

Alhaji I. Sankoh, Kirk T. Semple, Kevin C. Jones and Andrew J. Sweetman. The fate of chlorpyrifos when applied using field methods employed by Sierra Leonean farmers

Alhaji I. Sankoh designed, conducted and reported this research with the supervision of Andrew J. Sweetman, Kevin C. Jones and Kirk T. Semple.

Alhaji I. Sankoh, Kirk T. Semple, Kevin C. Jones and Andrew J. Sweetman. An assessment of chlorpyrifos contamination in aquatic biota, rice and soils from riverine swamp farms in Sierra Leone

Alhaji I. Sankoh designed, conducted and reported this research with the supervision of Andrew J. Sweetman, Kevin C. Jones and Kirk T. Semple.

All Figures in this thesis are original and nothing was obtained from another source. Maps were developed from shape files from gis-arc maps.

List of appendices

Appendix A: Structured Interview Schedule for Farmers……………………..148

Appendix B: Questionnaire for Health Workers………………………………158

Appendix C: Krio Version of Questionnaire for Farmers……………………..164

Appendix D: Data collection instrument……………………………………….168

Appendix E: Development of analytical method………………………………171

Appendix F: Ethics approval letter……………………………………………...175

Appendix G: Participants information sheet……………………………………177

Appendix H: Consent form………………………………………………………179

Appendix I: Interview close form………………………………………………...181

List of tables

Chapter 2

Table 1: The distribution of respondents in the study area…………………………….34

Chapter 3

Table 1: Soil-crops transfer factors of pesticides at different input concentrations ………………………………………………………………………..65

Table 2: The annual per capita consumption of pesticides in Sierra Leone when rice from the experimental plots are consumed………………………………………………65

Chapter 5

Table 1: A table showing the distribution of farmers interviewed and the number using pesticides on their farms in Sierra Leone………………………………………..........115

List of Figures

Chapter 1

Figure 1: Map of Sierra Leone showing rivers and their tributaries…………….3

Figure 2: Rice cultivated on a boliland at Babara Wallah……………………….6

Figure 3: A farmer manually tilling his field for rice cultivation…………………7

Figure 4: The transport path ways of pesticides on the environment………...9

Figure 5: Solid granule carbofuran found in Sierra Leone……………………..10

Figure 6: 2,4-D herbicide killing weeds on a rice farm in Sierra Leone………12

Figure 7: Typical house in farming communities………………………………..13

Figure 8: A source of portable water for farmers at Conakrydee in Sierra Leone………………………………………………………………………………..14

Figure 9: Organisms from rivers by farmlands that people eat………………..15

Figure 10: Famers eating lunch at the farm after applying pesticides………..15

Figure 11: A woman carrying and serving food to farmers on the farm………16

Figure 12: A child farmer working on a farm after the application of furandan……………………………………………………………………………..16

Figure 13: Mixing pesticides using unprotected hands………………………...17

Chapter 2

Figure 1. Map of Sierra Leone showing rivers and districts……………………30

Figure 2. Containers in which most pesticides are sold………………………..33

Figure 3. Supply routes for pesticides to and within Sierra Leone. The bar chart shows the percentage coming from various routes……………………...36

Figure 4. a: Level of education of respondents. b: cross tabulation bars showing the education levels of respondents that use pesticides and those that do not use pesticides…………………………………………………………37

Figure 5. Places where pesticides are stored…………………………………...37

Chapter 3

Figure 1 Design of experimental field plots showing sub plots and blocking with a river…………………………………………………………………………..42

Figure 2: A photo showing a trench separating two sub-plots in experimental plot 1……………………………………………………………………………50

Figure 3: Mean concentrations (+/-200 pg/g of soil) of chlorpyrifos in surface soil samples collected from experimental plot 1 (riverine swamp) 30 days after treatment…………………………………………………………………………52

Figure 4: Mean percentage of added pesticide remaining in surface soils from experimental plot 1 (riverine swamp) after 30 days……………………………53

Figure 5: Mean concentrations (+/-200 pg/g of soil) of chlorpyrifos in soil samples collected from experimental plot 2 (boliland) 30 days after treatment…………………………………………………………………….54

Figure 6: Mean percentage of added pesticide remaining in soils from experimental plot 2 (boliland) after 30 days……………………………………..55

Figure 7: A curve showing the decrease of chlorpyrifos residue on riverine soil predicted by the soil fugacity model in 8 rain events when 1.1 µg of pesticide/g of soil was applied………………………………………………………………….59

Figure 8: loss processes of chlorpyrifos predicted by the soil fugacity model in six rain events……………………………………………………………………59

Figure 9: The concentration of chlorpyrifos found in rice from experimental plots on riverine swamps (a) and boliland (b)…………………………………...62

Chapter 4

Figure 1: A map of Sierra Leone showing the sample collection areas……...81

Figure 2: A bar chart showing the average and range of chlorpyrifos in soil samples collected from Conakrydee, Babara Wallah and Kychom…………..86

Figure 3: Average mass of chlorpyrifos on rice samples collected from Conakrydee, Babara Wallah and Kychom……………………………………88

Figure 4: Average Concentrations of chlorpyrifos on crab samples collected from Conakrydee, Babara Wallah and Kychom………………………………...89

Figure 5: Average concentrations and ranges of chlorpyrifos in fish samples collected from Conakarydee. Babara Wallah, and Kychom…………………...90

Figure 6: Average concentration of chlorpyrifos in mudskippers collected from Conakrydee, Babara Wallah and Kychom……………………………………92

Figure 7: Average concentration of chlorpyrifos on shrimp samples collected from Conakrydee, Babara Wallah and Kychom………………………………94

Chapter 5

Figure 1: A pest controller spraying cyfluthrine at a residence in Freetown..114

Figure 2: Some of the pesticides commonly used by rice farmers in Sierra Leone……………………………………………………………………………117

Figure 3: Supply sources of pesticides used by rice farmers in Sierra Leone……………………………………………………………………………118

Figure 4: Levels of chlorpyrifos on soils from rice farms against maximum recommended dose and expected residue 14 days after application of the pesticide…………………………………………………………………………122

Figure 5: Time of the year pesticides are applied to the farms………………124

Figure 6: The distribution of the number of patients that go to health centres in farming communities…………………………………………………………..129

Figure 7: The number of patients that reported pesticide related symptoms per week in local health centres (Hospitals)……………………………………..131

Figure 8: The cost of pesticide imported by the Sierra Leone government from 1961 to 2012 (WHO, 2013)…………………………………………………133

List of acronyms and abbreviations

ANOVA	Analysis of variance
BCF	Bio-concentration factor
CARD	Coalition for African Rice Development
CCOHS	Canadian Centre for Occupational Health
CEDAC	Community Economic Development Assistance Corporation
EPA –	Environmental Protection Agency
EPA-SL	Environmental Protection Agency Sierra Leone
EU	European Union
EXTOXNET	Extension Toxicology Network
FAO	Food and Agriculture Organisation
GC/MS	Gas Chromatography/ Mass Spectrometer
GDI	Global Development Index
GDP	Gross Domestic Product
GTZ	German Technical Cooperation Agency
Ha	Hectares
HPLC	High Performance Liquid Chromatography
IFDC	International Fertilizer Development Centre

IRIN	Independent Radio Information Network
JICA	Japan International Cooperation Agency
LD50	Lethal dose
LEC	Lancaster Environment Centre
MAFS	Ministry of Agriculture and Food Security
PAN-UK	Pesticide Action Network - United Kingdom
POP	Persistent Organic Pollutant
PSEP	Pesticide Safety Education Program
TCP	3,5,6-trichloro-2-pryidinol
TF	Transfer factor
TMP	3,5,6-trichloro-2-methoxy pyridine
TPP	Triphenyl phosphate
UK	United Kingdom
UNICEF	United Nations International Children Emergency Fund
USA	United State of America
USAID	United State Agency for International Development
WHO	World Health Organisation

Chapter 1

Introduction

Background

The use of pesticides in most developing countries is becoming an increasingly serious environmental problem due to factors such as water contamination, ecosystem disruption and habitat contamination (Marquis 2013). Pesticides, in general, can be very harmful especially to the people coming into contact with them as part of their daily lives. However, the challenges that pests pose on crop production, has resulted in farmers developing more interest in the use of pesticides in agriculture fields. In developing countries, most of the farmers are illiterate and do not know how these chemicals should be handled safely. The unsafe application and interaction with these agrochemicals can have negative health impacts upon farmers, chemical applicators on commercial farms and on small-holder farms (Marquis, 2013). This practice is resulting in negative health impacts in local populations.

In Sierra Leone it is estimated that 70% of a population of about six million people are farmers (Sannoh, 2011). However, 90% of the Agriculturists are illiterate subsistence farmers who most often could not achieve up to 60% of their basic annual subsistence from their farms as a result of low yields (FAO, 2007). Both the farmers and the government of Sierra Leone want this trend to change as it is very important to the government's "agenda for prosperity". One of the aims of the Sierra Leone government is to achieve food self-sufficiency which could only be done through enhanced food production. Factors driving the country's high-input agriculture are rooted in the socio-economic development in the country. The government is encouraging the commercialization of agricultural produce with the aim of improving the national economy. Furthermore, the Sierra Leone government is supportive of all activities that would promote food crop production especially rice which is the most widely consumed in the country. Since pest control is one of the major obstacles in achieving these goals the use of pesticides in agricultural fields is gaining popularity. Consequently, farmers are becoming increasingly dependent on pesticides, in order to transform their farms into profit and production-oriented businesses, rather than simply a subsistence farm (Rother et al 2008). However, the level at which pesticides are used in the country has never been fully studied and therefore is always under estimated (FAO, 2009; CARD, 2009; Ighobor 2015). The estimate is based on the limited government supplies and the economic status of the farmers.

Study area

Sierra Leone is located on the west coast of Africa between the latitudes 7 - 10º north of the Equator and between longitude 10 - 13º west of the Greenwich meridian. Sierra Leone is bordered with the Atlantic Ocean from the northwest to the south west, with the Republic of Guinea from the northwest to southeast and Liberia from the southeast to the south west. The country has a total area of 71,740 km2, divided into a land area of 71,620 km2 and water of 120 km2. Sierra Leone has four distinct geographical regions: coastal lowland, interior lowland, interior plateaux and the Peninsula Mountains

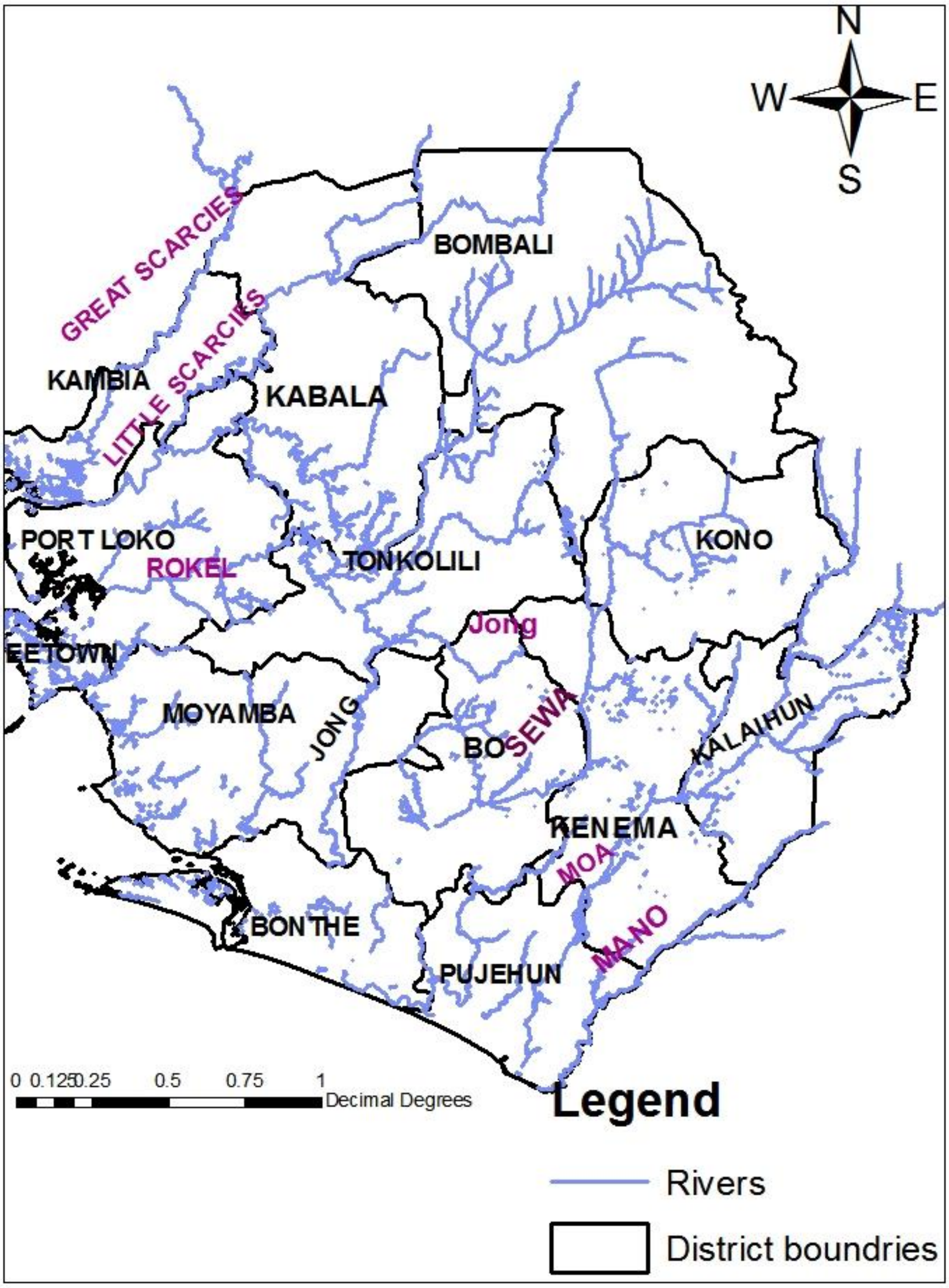


Figure 1: Map of Sierra Leone showing rivers and their tributaries (developed from arc-gis shape files)

Sierra Leone has seven major rivers (the Sewa river, the great Scarcies, the little Scarcies, the Mano river, the river Rokel, Moa river and the river Young) which drains directly into the Atlantic Ocean and borders the country from the north-west to the south-west (a coast line of 340 miles). These rivers are perennial and have many tributaries which drain into them. This network of rivers and tributaries often flood their plains and make most parts of the country well irrigated especially during the rainy season. This results in the lowlands having a high potential for agricultural activity.

Sierra Leone experiences two major seasons; the rainy season and the dry season. The rainy season runs from May through October whilst the dry season runs from November to April. The average rainfall ranges from 4,000mm in the west to 2,000 mm in the North. The average temperature ranges from 23 to 29^{0}C. The country experiences both South-East and North-West trade winds. The North-West trade winds are experienced in December through February bringing about a micro season in the dry season known as the Harmattan Season. During this period, hot and dry winds from the Sahara Desert blow through the country. This enhances the drying of crops and hence is the most common harvest time in the country, especially for rice which is the most cultivated crop in the country. This type of climate favours crop production.

Sierra Leone has five major cultivable ecologies. These are; upland (4.42 million ha), bolilands (145,000 ha), riverine lowlands (130,000 ha), mangrove swamps (20,000 ha) and inland valley swamps (690,000 ha). The agricultural sector is the major employer in the country. The geographical location, the natural conditions and the human resources gives Sierra Leone the potential to develop through agriculture.

Agriculture in Sierra Leone

Agriculture in Sierra Leone is controlled by the Ministry of Agriculture, Forestry and Food Security (MAFS). The ministry employs trained field and extension workers for support in the field. There are also research institutes such as the Sierra Leone Research Institute (SLRI) and Njala University that support agricultural activities. Crop production is divided to cash crop and food crop production. Pesticides are used in both types of production. About 90% of farmers are involved in food crop production (Abdelrasoul et al, 2013). Food crops cultivated in Sierra Leone include; rice, cassava, sweet potatoes, millet, yam, maize, peanuts, bananas plantain, sesame, sorghum, okra, garden eggs, aubergines and a host of leafy vegetables. According to Ighobor (2014), rice production accounts for 75% of agricultural per capita income in Sierra Leone.

Rice is the major staple food of the country and is the most widely cultivated crop throughout Sierra Leone. It is cultivated in all the five major cultivable ecologies (Figure 2). Before 1970, Sierra Leone was able to produce enough rice to be self-sufficient and even export excess crops to some extent. The trend started to decline from 1970 and in 1980 Sierra Leone only produced 66% of the rice needed to feed the nation (CARD, 2009). Since then Sierra Leone has become a major rice importer. The situation became worse during the 11 years of civil war. This was one of the major factors that led to the decline of Sierra Leone’s GDP to US$139 in 2003 (CARD 2009). Since that time until 2007, Sierra Leone was classified as the poorest country in the world (GDI report, 2007). Currently, the government is making positive strides to improve the agricultural sector. Sierra Leone was on the verge of achieving food self-sufficiency from 2012 to 2014 but the situation was reversed by the outbreak of Ebola (2014 - 2016). A good number of farmers are now moving from subsistence farming to mechanized farming. Fast growing rice cultivars such as nerica, have been developed and are now being used. This together with mining led to the rapid growth in the Sierra Leone’s economy from 2012 to 2014

Figure 2: Rice cultivated on a boliland at Babara Wallah (original)

Although the Ministry of Agriculture is supporting mechanised farming activities, the majority of the farmers in Sierra Leone still depend on manual labour in their farming activities (Figure 3). Farmers are poor and cannot afford the running cost of the few machines available such as tractors, power tillers thrash harvesters.

Figure 3: A farmer manually tilling his field for rice cultivation (original)

Pesticides used in Sierra Leone, their health effects and fate in the environment

A wide range of pesticide active ingredients are used in Sierra Leone. The most commonly used in rice cultivation includes; chlorpyrifos, furandan, carbolinium, diazinon, Malathion, endosulfan, cyfuthrine, propanil and 2,4-D.

Chlorpyrifos ($C_9H_{11}C_{l3}NO_3PS$)

Chlopyrifos is a broad-spectrum chlorinated organophosphate insecticide which has been classified as the most widely used pesticide worldwide (Watts, 2012). It is used in animal husbandry, cereal fields, vegetable farms, domestic gardens, paints and other building materials, such as wood products (Watts, 2012). It is also used as a domestic pesticide against household pests like bed bugs, cockroaches, termites and rats. Chlorpyrifos is sold in several forms such as liquid, flowable concentrates, granular, and dust under different trade names such as Dursban, Lorsban, Suscon Green, Empire and Equity (Watts, 2012). However chlorpyrifos exists in two chemical forms; O,O-dimethyl O-3,5,6-trichloro-2-pyridyl phosphate and O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphate. Both are broad spectrum pesticides and can used as substitutes for each other or can be used mixed together at any proportion to form a single pesticide as both are effective in pest control.

Although chlorpyrifos is effective in pest control, it has been established that it can have negative effects in humans. According to Noro et al (2013), chlorpyrifos is an acetylcholinesterase inhibitor which affects the metabolism of acetylcholine between nerve endings. This leads to an accumulation of acetylcholine and hence the disruption of the nervous system in man and other animals. At low levels of exposure, chlorpyrifos is a known potent developmental neurotoxin which could trigger fatal acetylcholinesterase inhibition (Watts, 2012; Noro et al, 2013). Chlorpyrifos is also an endocrine disruptor and can affect the production of oestrogen, androgen, testis and the thyroid hormones (Aldrige, 2004; Watts, 2012). Early childhood exposure could lead to abnormal behaviour in adulthood and has been linked with delayed cognitive and psychomotor development. Acute exposure has been known to induce hyperglycaemia and hyperlipidaemia (Acker et al, 2012). Symptoms of chlorpyrifos exposure include: lacrimation, headache, stomach ache, nervous disorder, loss of appetite and nausea. If action is not taken and exposure is continued the chronic effects stated above can occur.

The environment and living organisms within the environment can also be affected when exposed to chlorpyrifos. The widespread use of pesticides can lead to a reduction of beneficial insect populations, thereby creating an imbalance in the ecosystem and can also reduce microorganism populations in paddy soil and water which help to sustain soil fertility (Pingali, 2013). Pesticides can also be highly toxic to fish, frogs, annelids, myriapods, crustaceans and birds (Antle and Capalbo, 1995; Warburton et al, 1995; Sande et al, 2011). According to van der Werf, (1996), most studies indicated that a small fraction (e.g. <0.3%) of the pesticides applied come in contact with the target pest, so the remainder are dispersed into the environment (Figure 4). This could lead to an impact on non-target facets of the environment.

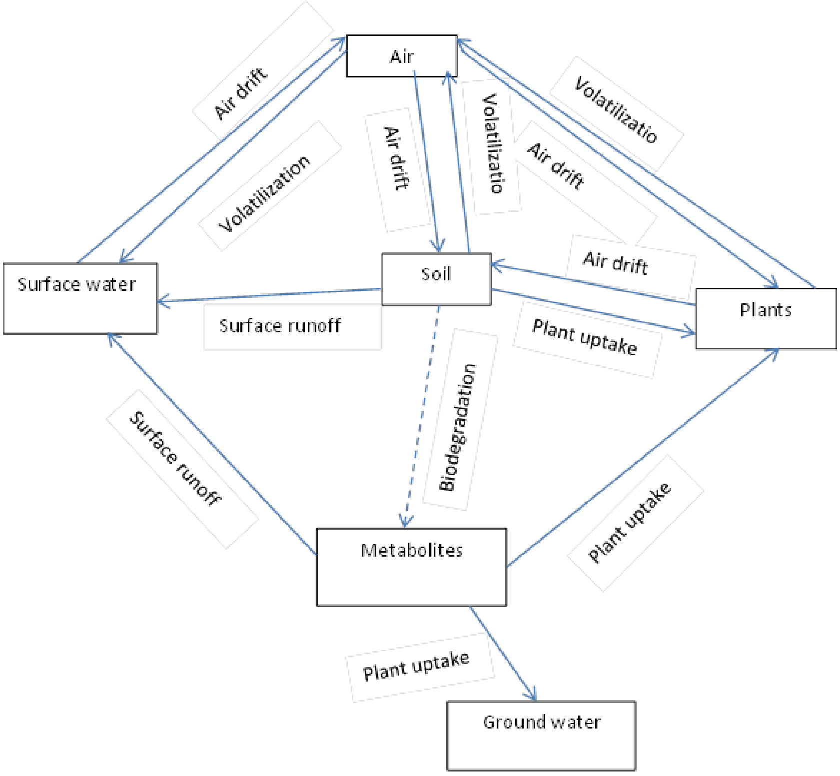


Figure 4: The transport path ways of pesticides on the environment (adapted from van der werf, 1996)

Furandan (carbofuran $C_{12}H_{15}NO_3$)

Carbofuran is the second most widely used pesticide in rice farms in Sierra Leone. It is used to control beetles, nematodes and root worms but in Sierra Leone it is mainly used to control rodents such as cane rats and birds.

Carbofuran is a highly toxic carbamate which can result in deaths in humans when acute exposure occurs. It is a cholinesterase inhibitor but this effect can be easily reversed (Foley, 2009). Symptoms of carbofuran poisoning include nausea, vomiting, abdominal cramps, sweating, diarrhea, excessive salivation, weakness, blurred vision, imbalance, breathing disorder and high blood pressure.

Carbofuran is highly soluble in water and highly toxic to aquatic organisms, birds and insects.

The solid granules (Figure 5) which are most commonly found in Sierra Leone have been banned by the Environmental Protection Agency (EPA) since 1994 and the use of the liquid pesticide is restricted.

Figure 5: Solid granule carbofuran found in Sierra Leone (original)

Carbolineum

Carbolineum is widely used to control termites in rice fields, and can be very hazardous when exposed to the skin, eye or when ingested. Acute exposure can result to death in humans. Inflammation of the eye is characterized by redness, watering, and itching. The substance is toxic to the kidneys, lungs, nervous system, liver and mucous membranes. Repeated or prolonged exposure to the substance can produce target organ damage. Repeated exposure may lead to general deterioration of health by an accumulation in one or many human organs.

Diazinon ($C_{12}H_{21}N_2O_3PS$)

Diazinon is an organophosphate pesticide used to control pest insects. It is readily metabolised by humans and does not accumulate in tissues. High exposure within a short period can affect the nervous system. Very high exposure can cause severe damage to the nervous system within 30 to 40 minutes.

Malathion ($C_{10}H_{19}O_6PS_2$)

Malathion is an endocrine disrupter. If exposure is low, it can cause nervous disorders. It can harm babies when inhaled by pregnant women. It is also carcinogenic and has been associated with tumour developments in both humans and animals.

Endosulfan ($C_9H_6Cl_6O_3S$)

Endosulfan is an organochlorine pesticide which can accumulate in human tissues and can affect the nervous system when after exposure. It is an endocrine disrupter and it is teratogenic and carcinogenic. Exposure to pregnant women can lead to abnormal births (Mergel, 2011). Endosulfan has been banned by EPA since 2010 and it is also banned in some West African countries including Sierra Leone. However, it is still in use in Sierra Leone.

Propanil ($C_9H_9Cl_2NO$) and 2,4-D ($C_6H_6Cl_2O_2$)

Propanil and 2,4-D are herbicides. They can easily contaminate water bodies and are toxic aquatic organisms. They can also exhibit some minor effects on human

(Lorenz, 2009). The use of herbicides is not a common practice in Sierra Leone but there is evidence that they are in use (Figure 6).

Figure 6: 2,4-D herbicide killing weeds on a rice farm in Sierra Leone (original)

Susceptible populations and their living conditions

Farmers are susceptible to pesticide contamination. They handle pesticides and stand the risk of being directly exposed. The farming sector in Sierra Leone includes some of the most poverty-stricken people in the country. Farmers, both men and women, are among the least educated, least literate sub-populations in Sierra Leone. They do not understand the nature of the pesticides which they work with (Naidoo et al. 2010). It must be noted that agrochemical poisoning can occur as a result of not only the hazardous chemicals that are being used, but from confounding factors such as inappropriate use, poverty and a poor healthcare system.

Most of the farmers in Sierra Leone live in poorly built houses or homesteads (Figure 7). Most of their shelters are made of mud and do not have proper roofing materials making them very uncomfortable when it rains. These shelters are also used for food storage and for storage of pesticides. Details on the storage of pesticides are discussed in Chapter 2. Some farmers spend the day on temporary homesteads near the farms. They use these homesteads to rest when they take breaks from work. The homesteads are also used for food preparation and as temporal stores for agrochemicals such as pesticides.

Figure 7: Typical house in farming communities (Original)

Although few of the farming communities in Sierra Leone depend on well or stream water that are less likely to be contaminated by pesticides, the vast majority of farmers use open water sources near their farms for cooking, drinking, bathing and laundering (Figure 8). The use of hygienic and sanitation practices is almost always directly correlated with access to a clean water source (Mekonnen and Agonafir 2002). Farming communities should have access to clean water from an uncontaminated and accessible source, but unfortunately this is not the case in many communities in Sierra Leone. The water that is accessible near agricultural areas may be contaminated with agrochemicals (Konradsen et al. 2003). Even in cases where farmers are aware of general toxicity issues associated with agrochemicals, water-scarcity presents a fundamental obstacle that prevents sanitation practices (Ajayi 2000).

Figure 8: A source of portable water for farmers at Conakrydee in Sierra Leone (original)

Most of the lowland farms are close to major water bodies such as streams and rivers. Farmers near these ecosystems depend on these streams for their supply of protein based food. Organisms farmers depend on from these water sources include; fish, crabs, shrimps, mudskippers and bivalves (Figure 9). The level of exposure to pesticides in some of these organisms is discussed in details in Chapter 4.

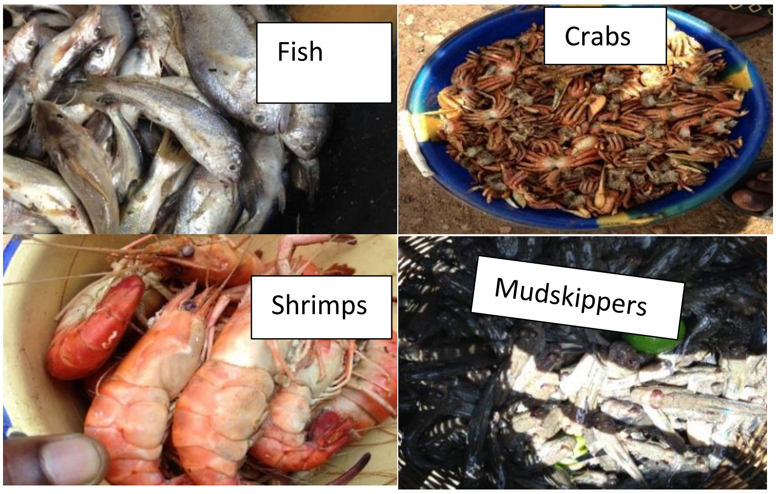


Figure 9: Organisms from rivers by farmlands that people eat (original)

In Sierra Leone it is a common practice that farmers take lunch or dinner on or by the farm (Figure 10). Farmers use their hands to eat even after usage of pesticides with unprotected hands. Exposure through food is discussed in more detail in Chapters 2, 3, and 4. In most families food preparation and service is the responsibility of women. Even when the food is prepared at home they have to bring it to the farm (Figure 11). This could expose them to the pesticides especially after application and hence make them a susceptible group. Susceptibility to pesticide exposure is not only limited to adults. Children of all age groups are also susceptible (Figure 12).

Figure 10: Famers eating lunch at the farm after applying pesticides (original)

Figure 11: A woman carrying and serving food to farmers on the farm (original)

Figure 12: A child farmer working on a farm after the application of furandan (original)

Perspective of the farmer’s general awareness of the negative impact of pesticides

Different studies that have been conducted throughout Africa have explored farmers’ perspectives on the dangers of agrochemicals (Rother, 2008; Marquis 2013). Different indicators of farmers’ relationships with pesticides are their use of personal protective wear, their hygienic and sanitation practices and their abilities to understand labels, colour codes and pictograms on the sides of agrochemical containers (Rother, 2008). In one rural farm context, a researcher found that only 2%

of the farmers that were interviewed agreed with the statement "pesticides have potential negative side effects on rivers and the environment" (Ajayi 2000). These results clearly demonstrate that the toxicity risks to the environment involving pesticides are not being properly communicated within agricultural systems in developing countries including Sierra Leone. Farmers in Sierra Leone are aware that pesticides are dangerous but their knowledge is limited to acute intoxication when large quantities are taken in orally or when thick fumes are inhaled (Etzel et al, 1987). Farmers mix and apply pesticides using their bare hands and with no protection (Figure 13). See Chapter 2 for details on pesticide handling.

Figure 13: Mixing pesticides using unprotected hands (original)

Farmers in Sierra Leone know pesticides as chemicals that help to protect their plants from crabs, birds, rodents and insects and can also promote the growth of the plant through the developmental stages (tillering and panicle initiation). Farmers claim to have better harvest when these chemicals are used. In addition to the insects and crabs the chemicals are also known to control birds which eat the rice. Farmers have no idea of the effects these chemicals could have on non-target organisms. Most farmers in Sierra Leone believe that pesticides do not affect fish. However, Norman (2012), reported that people are using insecticides for fish hunting which implies that insecticides have effects on fish. Farmers probably do not notice this as concentrations reaching the fish are generally below the critical lethal concentration (LD_{50}) for fish.

Insecticides have the tendency to accumulate in the tissues of both the flora and fauna in the ecosystem (Levitan et al, 1995; Boateng et al, 2006). After absorption, insecticides can be transported and magnified along the food chain. Insecticides can also accumulate in soils and sediments and from this they can be transported to other areas by water and air (van der Werf, 1996; Chindah et al 2003; Deb & Das, 2013). This might pose threats to others environments which are far away from the initial point of contamination. See Chapters 4 and 5 for more details.

When an insecticide enters the human system it can cause harm and the extent of damage depends on the type of insecticide or the level of intake. For instance, when organophosphates are taken in, they inhibit the enzyme cholinesterase which leads to the accumulation of acetylcholine in the system which can lead to nerve disorders. Organophosphates can also cause headaches, excessive salivation, and tearing (lacrimation), nausea, diarrhoea, respiratory depression, seizure, loss of consciousness and pinpoint pupils (Lorenz, 2009). According to Reigart and Roberts (2006), herbicides do not have acute effects on humans and other animals. The most common effects are, skin irritation, vomiting, diarrhoea, and nausea.

With this brief explanation, it is clear that the uncontrolled use of these chemicals is a potential threat to man and the environment in Sierra Leone. If this trend continues in the advent of obtaining food security this might have negative impact on the health of people.

Research questions

- Are the insecticides used in the agricultural fields accumulating in the soil sediments, fish and edible living organisms including the crops, within the environment?

- Are the insecticides being transported by air and water to other areas away from the point of use?

- Is there any evidence that the insecticides are affecting people living in the exposed environments in Sierra Leone?

- To what extent are insecticides being used in rice fields in Sierra Leone?

Justification

- It is an established fact that pesticides and some of their metabolites can cause harm to human and the environment (UNEP, 2010). It is therefore necessary to study the levels of pesticides in environments where they are used in Sierra Leone. Such a study should raise awareness of the potential threats of pesticides in Sierra Leone.

- To avoid health hazards as a result of the indirect consumption of insecticides and/or their metabolites, it is important to study the levels of these chemicals in food chains. It was the intention of this research project to address this directly.

- It is an illegal practice to import harmful chemicals including pesticides without an approval by the government. However, illegal importation of pesticides is a common practice in Sierra Leone but the government does not regulate the influx of these chemicals to avoid jeopardizing with the food security programmes. The government is of the opinion that the scale is low and therefore the expected negative impact is minimal. These expectations have never been justified by any research.

- Human exposure to pesticides through food, water and handling could have a negative impact on the health of people. This cannot be regulated effectively if the level at which this occurs is not known. This was investigated in this study.
- The soil to rice transfer factor and the fate of chlorpyrifos in Sierra Leone soils has never been reported. This is reported in Chapter 2 of this thesis. Knowing this would serve as a base for the regulation of pesticide use.

Aims and Objectives

The main aims of this research were to study how pesticides are used in rice fields in Sierra Leone and how these use impact the health of rice farmers and the environment.

The Objectives included:

- To study the prevalence of pesticide use among rice farmers in Sierra Leone
- To observe how pesticides are handled and deduce potential risks to the environment and study the fate of chlorpyrifos (the most commonly used pesticide) on soils in Sierra Leone and determine the levels that occurs in rice under common agricultural use patterns.
- To study the impact pesticides have on the health of the rice farmers and observe possible exposure routes and determine the levels of chlorpyrifos in soils, rice and some organisms in the adjacent water bodies which are

consumed by people living in ecosystems where the pesticide is used for rice cultivation.

Research and data collection strategies

Data collection

The data used for the study reported in chapter 2 was collected using a structured interview schedule (Appendix A) targeting house hold farmers and a structured questionnaire (Appendix B) targeting community health workers. The interview schedule was also used in focus group discussions. Both the interview schedule and questionnaires were prepared with the aid of experienced social science researchers at LEC (Appendix D). These were reviewed by the Postgraduate Statistics Centre in Lancaster University. The farmer’s interview schedule was interpreted to Krio (Appendix C). Data collection was carried by the researcher and five trained field assistants.

Ethics

The purpose of the research and the content of the questionnaires was explained to each respondent/participant using the approved information sheet (Appendix G). A consent form (Appendix H) and an interview close form (Appendix I) were completed and signed/thumb printed before and after interview respectively.

Analytical method

The analytical method used in this research was developed by modifying the method used by Gonçalves & Alpenddurada (2005). See Appendix E.

Structure of thesis

This thesis is an in-depth assessment of the use of pesticides and impact on the health and people of Sierra Leone. The core of the thesis is comprised of four chapters each designed to be a stand-alone study. However, each of these chapters is interconnected all focused on human and environmental exposure to pesticides.

Chapter 2 is entitled “An assessment of pesticide use and its impact to the people and environment of Sierra Leone”. This was a report written from data obtained using structured interview schedules that targeted 500 household heads farmers in rice farming communities across the country and semi-structured questionnaires responded to by 95 out of 100 health workers in health centres in the farming communities. Focus group discussions and discussions with various stakeholders were also used to collect data reported in this chapter. Field observations were also reported in this chapter. The method of pesticide application in the field experiments discussed in Chapter 3 was obtained from the work reported in Chapter 2.

Chapter 3 is entitled “The fate of chlorpyrifos when applied using field methods employed by Sierra Leonean farmers”. In this chapter, findings from two field experimental plots set in a riverine swamp and a boliland were reported. The field was divided to 72 subplots on which rice was cultivated. Chlorpyrifos diethyl, chlorpyrifos dimethyl, and 1:1 chlorpyrifos dimethyl and chlorpyrifos dimethyl were applied at three different concentrations. Soil and rice samples were collected and analysed using a GC/MS. Results obtained are discussed in chapter 3. Results were also obtained from a soil fugacity model which was used to interpret the field data. Results obtained from the analysis of rice samples were used to calculate the soil/rice transfer factors. They were also used to assess the level of human exposure to chlorpyrifos that would result when rice is cultivated under controlled conditions.

The low levels of residual chlorpyrifos reported in this study required further research to determine the fate of chlorpyrifos in the environment and see if the applied pesticide could enter the food web. This was the basis of the study reported in Chapter 4.

Chapter 4 is entitled “An assessment of pesticide contamination in aquatic biota, rice and soils from riverine swamp farms in Sierra Leone”. This study discussed results obtained from the analysis of soil, rice, and biota samples collected from randomly selected rice farms and from rivers bordering the selected farms in Sierra Leone. The study in chapter 4 discussed the levels of residual chlorpyrifos found in soils from active farms. Results obtained from the analysis of rice and biota samples were used to determine the level of human exposure and possible transport along food chains in the food web.

Chapter 5 is a summary of pesticide use in Sierra Leone and how it is impacting the health and economy of the country. This chapter provides a summary of the studies reported in Chapters 2, 3 and 4 with the aim of highlighting the key issues of pesticide use in Sierra Leone in a wider perspective. Findings not reported in Chapters 2, 3 and 4 are also discussed in this study. This chapter also summarised major findings in a concluding section. Recommendations were made based on the overall findings.

References

Abdelrasoul A, Childs A, Clerisme J, et al. (2013) Pioneering high-yield rice production in Sierra Leone: Recommendations for an out grower model. West African Rice Company. https://new.sipa.columbia.edu/sites/default/files/WARC%20Final%20Report.pdf *(accessed 05/07/15)*

Acker CI and Nogueira CW. (2012) Chlorpyrifos acute exposure induces hyperglycemia and hyperlipidemia in rats. Chemosphere 89: 602-608.

Aldrige JE, Seidler FJ and Slotkin TA. (2004) Developmental exposure to chlorpyrifos elicits sex-selective alterations of serotonergic synaptic function in adulthood: critical periods and regional selectivity for effects on the serotonin transporter, receptor subtypes, and cell signalling.: Environmental Health Perspectives, 112: 148 - 155.

Antle JM and Capalbo SM. (1995) Agriculture as a Managed Ecosystem: Policy Implications (2002). Journal of Agricultural and Resource Economics, 23: 1-15.

Boateng JO, Nunoo FKE, Dankwa HR, et al. (2006) A toxic effects of deltamethrine on tilapia, Oreochromis niloticus (Linnaeus, 1758). West Africa Journal of Applied Ecology, 9: 1 - 5.

Chindah AC, Sikoki FD and Vincent-Akpu I. (2003) Chances in haematological characteristics of a bony fish, Tilapia guineensis (Bleeker, 1862), exposed to common pesticides in the Niger Delta wetland, Nigeria. Accra: National Science & Technology press: Ghana Jnl agric Sci, 8: 59-67.

Coalition for African Rice Development (CARD). (2009) National Rice Development Strategy (NRDS) Sierra Leone. JICA https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/sierraleone_en.pdf (accessed: 20/10/15)

Craven A and Hoy S. (2004) Pesticide persistence and bound residues in soil-regulatory significance. Elsevier: Environmental Pollution, 133: 5-9.

Deb N and Das S. (2013) Chlorpyrifos toxicity in fish: A review. Current World Environment, 8: 77-84.

Etzel RA, Forthal DN, Hill RH, et al. (1987) Fatal parathion poisoning in Sierra Leone. Bulletin of the World Health Organization, 65: 645 - 649.

FAO. (2004) All about rice in Sierra Leone. http://www.fao.org/RICE2004/en/p18.htm (accessed: 10/09/15)

FAO. (2011) Moving beyond subsistence farming in Sierra Leone. www.fao.org/news/story/en/item/52423/icode/ (accessed: 10/09/15)

Gender Development Index (GDI). (2007) Sierra Leone: General Indicators and Indices. WHO, http://apps.who.int/gho/data/node.cco.ki-SLE?lang=en (accessed 10/09/15)

Ighobor K. (2014) Sierra Leone: nursing agriculture back to health. Africa Renewal, http://www.un.org/africarenewal/magazine/special-edition-agriculture-2014/sierra-leone-nursing-agriculture-back-health (accessed: 10/09/15)

Jeyaratnam J. (1990) Acute pesticide poisoning: A major global health problem. world health statistics quarterly, 139-144.

Larbi A. (2012) Country pasture/forage resource profile - Sierra Leone. FAO. http://www.fao.org/ag/agp/agpc/doc/counprof/Sierraleone/Sierraleone.htm (accessed; 20/10/15)

Levitan L, Merwin I and Kovach J. (1995) Assessing the relative environmental impacts of agricultural pesticides: the quest for a holistic method. Agriculture, Ecosystems and Environment 55: 153-168.

Lorenz ES. (2009) Potential health effects of pesticides. Pesticide Safety Network Pennstate university. http://extension.psu.edu/pests/pesticide-education/applicators/fact-sheets/pesticide-safety/potential-health-effects-of-pesticides/extension_publication_file (accessed: 15/07/16)

Marquis S. (2013) Agrochemical use in South Africa: The toxicological and sociological impacts of agrochemicals on susceptible populations in South Africa’s agricultural sector. Final thesis. Environment. Cape town University SA. ENSC 501: 2013

Naidoo S, London L, Rother H, et al. (2010) Pesticide safety training and practices in women working in small-scale agriculture in South Africa. Occupational and environmental medicine, 67: 823–828.

Norman A. (2012) Pesticide use in Sierra Leone. Ontario Education Program, Njala university. https://www.opep.ca/index.cfm/information/news/pesticide-safety-in-sierra-leone/ (accessed: 13/10/15)

Noro Y, Tomizawa M, Ito Y, et al. (2013) Anticholinesterase insecticide action at the murine male reproductive system. Bioorganic & Medicinal Chemistry Letters 23: 5434-5436.

Pareja L, Fernandez-Alba AR, Cesio V, et al. (2011) Analytical methods for pesticide residues in rice. Trends in Analytical Chemistry, 30: 270 - 290.

Pingali PL and Roger PA. (2012) Impact of pesticides on farmer health and the rice environment. Springer, 7: 612- 614

Roberts J. (1989) Research methods in cultural-anthropology - bernard,hr. American anthropologist 91: 253-254.

Rother H-A. (2008) South African farm workers' interpretation of risk assessment data expressed as pictograms on pesticide labels. Environmental Research 108: 419-427.

Rother H-A, Hall R and London L. (2008) Pesticide use among emerging farmers in South Africa: contributing factors and stakeholder perspectives.: Development Southern Africa, 25: 399–424.

Sande D, Mullen J, Wetzstein M, et al. (2011) Environmental Impacts from Pesticide Use: A Case Study of Soil Fumigation in Florida Tomato Production. International Journal of Environmental Research and Public Health, 8: 4649-4661.

Sannoh IJ. (2011) Agricultural and Rural Development Statistics in Sierra Leone - Key Aspects of Institutional Arrangements & Performance. In: FAO (ed). http://www.fao.org/fileadmin/templates/ess/pages/rural/wye_city_group/2011/documents/session6/Sannoh_-_Paper.pdf (accessed 10/09/15)

van der Werf HM. (1996) Assessing the impact of pesticides on the environment. Agriculture, Ecosystems & Environment, 60: 81 - 96.

Watts M. (2012) Chlorpyrifos as a possible global POP. Pesticide Action Network, https://www.researchgate.net/publication/265160074_Chlorpyrifos_as_a_possible_global_POP (accessed: 10/10/15).

Weber J, Halsall CJ, Muir D, et al. Endosulfan, a global pesticide: A review of its fate in the environment and occurrence in the Arctic. Science of the Total Environment 408: 2966-2984.

Chapter 2

An assessment of the impacts of pesticide use on the environment and health of rice farmers in Sierra Leone

Abstract

Introduction

Background

Pest control in Sierra Leone

Materials and methods

Study area

Methods

Data analysis

Results and discussion

Prevalence of pesticide use by rice farmers in Sierra Leone

Types of pesticides used in Sierra Leone rice fields

Sources of pesticides

Training and Education

Storage, handling, application and exposure

Storage

Handling, application and possible exposure routes

Environmental effects

Health

Conclusion

Recommendations

Acknowledgement

References

Chapter 3

The fate of chlorpyrifos when applied using field methods employed by Sierra Leonean farmers

Alhaji I. Sankoh, Kirk T. Semple, Kevin C. Jones, Andrew J. Sweetman*

Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK

Abstract

Rice cultivation is the predominant agricultural activity in Sierra Leone. However, pest control is a major challenge in rice production which results in the widespread use of pesticides by farmers. One of the most commonly used pesticides in rice farms in Sierra Leone is chlorpyrifos. The misuse of chlorpyrifos could have negative impact on the health of people and the environment. This study was undertaken to determine the fate of chlorpyrifos when applied to soils in Sierra Leone and also determine the levels taken into the rice crops. The levels of human exposure through the consumption of rice were also determined. To achieve this, two experimental plots of 1.2 ha each were established. One of the experimental plots was set up in a riverine ecosystem and the other on a boliland ecosystem. Different concentrations of chlorpyrifos diethyl, chlorpyrifos dimethyl and 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl were applied to randomly distributed subplots within each experimental plot during the cultivation of rice. Soil samples from the plots and rice produced were analysed using a GC/MS. It was observed that 30 days after cultivation only <1% of pesticides remained in the surface soils sampled. The levels of pesticides found on the rice produced were below the recommended maximum limits set by both the European Union and WHO.

Introduction

Background

In Sierra Leone, a third of all agricultural activities involve the cultivation of rice, which is the major staple food in the country (Larbi, 2012). Rice is cultivated in all the five major cultivable ecologies. The consumption rate of rice (200 kg annual per capita consumption) in Sierra Leone is among the highest in sub Saharan Africa (FAO, 2004). One of the biggest problems Sierra Leonean farmers are facing is pest control. Birds, rodents, insects, crustaceans and other life forms can drastically destroy yields. These organisms are capable of reducing yields by 40 to 50% (CEDAC 2010). To stop these organisms from destroying their crop, farmers use pesticides. However, there are reports that these chemicals are being misused and they are supplied to illiterate farmers without training on how to use them.

As in other West African countries, chlorpyrifos is the most commonly used pesticide in Sierra Leone (Barron, 1995; Bairy et al, 2007; Sankoh et al, 2016). It is mainly used on lowland ecologies, which include, inland valley swamps, mangrove swamps, riverine swamps, and bolilands where paddy rice is mostly cultivated. All of these ecologies are associated with water bodies. This field research was undertaken on a riverine swamp and in a boliland. These two ecologies are among the most widely used for paddy rice production. They are often close to rivers which could be contaminated when agro-chemicals are used on crops cultivated on them. The fate of pesticides in an environment depends on several factors which include the type of soil, the chemical properties of the pesticide, temperature and other climatic conditions. The pesticide used in this research was chlorpyrifos.

The impact of pesticide to the environment depends on the level of exposure and the toxic properties of the pesticide (Li et al, 2015).

When pesticides like chlorpyrifos are applied to soil, a fraction is degraded by soil micro-organisms; a fraction undergoes chemical degradation such as hydrolysis and some bind with soils and sediments (van der Werf, 1996). Pesticides can also be taken up by plant roots, volatilized and diluted by water (van der Werf, 1996). Sorption of pesticides on soil surfaces depends on both the physical and chemical properties of the soil as well as the molecular structure of the pesticide (Mackay and Paterson, 1991; van der Werf, 1996). Sorption on the soil decreases pesticide mobility and hence makes them less susceptible to leaching that could lead to the contamination of ground water.

Several studies on the fate of chlorpyrifos in the environment have been carried out (Clegg, 2008; de Silva et al, 2010; Chishti et al, 2012) and it has been established that the fate of chlorpyrifos varies from one environment to the other depending to the environmental conditions such as soil type and climate. It has been reported that chlorpyrifos is widely used by rice farmers in Sierra Leone (Sankoh et al, 2016). However, no study has ever been done to study the fate of chlorpyrifos when applied to Sierra Leone soils under typical conditions.

This study was undertaken to determine the fate of chlorpyrifos diethyl and chlorpyrifos dimethyl pesticides on soils of riverine and boliland ecologies in Sierra Leone and the levels of pesticides transferred to rice grain when pesticides were applied within test/experimental plots using local methods (i.e. measuring the pesticide using a 70 ml tomato tin, mixing the pesticide with the seeds and broadcast evenly on the plots). A soil fugacity model was also used to describe the fate of pesticide residues on soil in Sierra Leone using the same input levels as used in the test/experimental plots. The measurement data and model predictions were combined to provide a holistic description of fate of chlorpyrifos in soils under common agricultural practices in Sierra Leone. A soil fugacity model is a pesticide model which treats a fiel as made up of compartments representing the soil, soil water, soil air and overlying air. Rainfall amount is required. It works on rain events basis to calculate pesticide loss through degradation, volatilization, runoff and residual amount in the soil in each event (Di Guardo et al, 1994).

The focused objectives were therefore three fold:

i) To apply a typical locally used dose of chlorpyrifos and to then determine the levels of residues on soils and hence calculate the percentage of pesticides remaining in the soil over time;

ii) To compare the behaviour of chlorpyrifos on soils of riverine and boliland ecologies;

iii) To determine levels in rice grains produced and hence determine the potential for consumer exposure

Materials and method

Experimental design

Two experimental plots, each having a land area of 1200 m^2, were set up on two years fallow land farms at Babara Wallah in Port Loko district northern Sierra Leone. Nerica rice (a fast growing variety of rice developed by cross breeding *Oryza sativa* and *Oryza glaberrima*) was cultivated on the plots. One of the experimental plots was on a boliland and the other on a riverine swamp. Each of the two experimental plots was divided into three vertical blocks, A, B and C and three horizontal blocks 1, 2 and 3. These blocks were divided into a total of 72 sub plots each having an area of about 17 m^2. The sub plots were labelled 1P1, 1P2, 1P3, 2P1, 2P2, 2P3, 3P1, 3P2, 3P3, C1, C2 ………..C9 (Figure 1). Each label was replicated 6 times, except for the control plots which had 18 sub plots. Nine of the 18 control plots were allocated as standing points for field observations. They were labelled CX. The remaining 63 sub-plots were distributed randomly with reference to a river which was at the edge of the plots. Each treatment was replicated 6 times and randomly distributed throughout the plot. Cross contamination was minimised or eliminated by separating the sub-plots using shallow trenches. Control plots within the same plots were included.

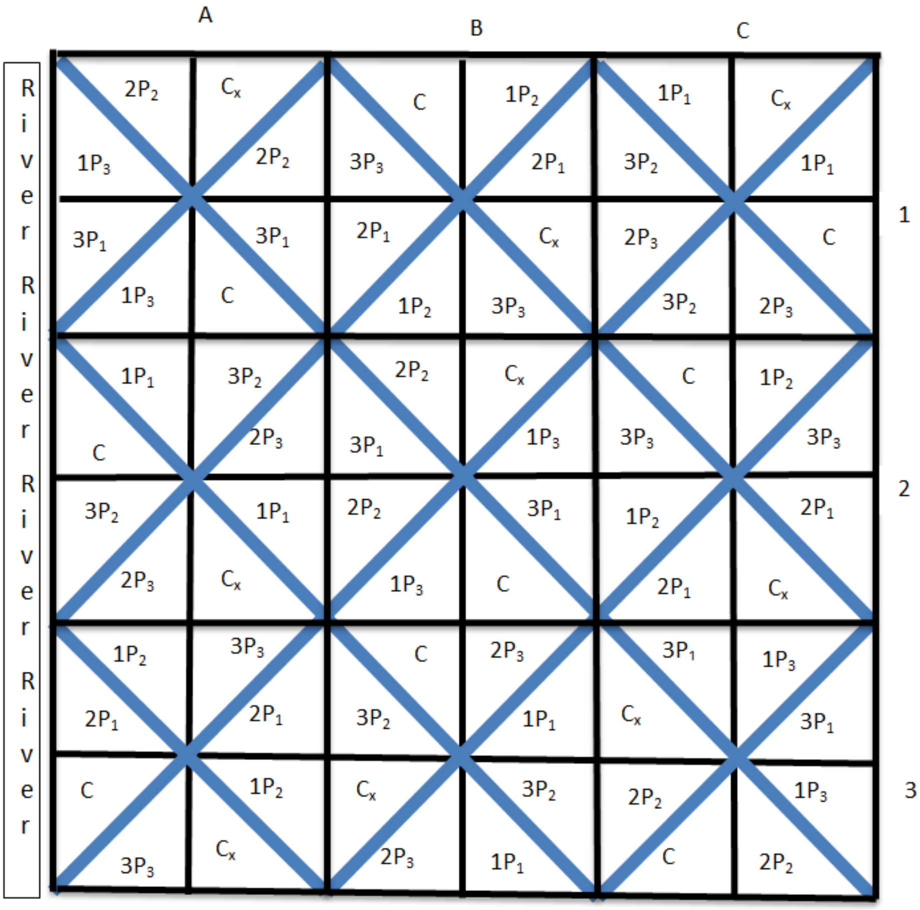


Figure 1 Design of experimental field plots showing sub plots and blocking with a river (original)

Three sets of pesticides were used: 1 - chlorpyrifos diethyl, 2 - 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl, 3 - chlorpyrifos dimethyl. This setup is represented by the number before the P.

Three concentrations of each set of pesticide were used; 1 – 35 ml per bushel (27 kg) of rice; 2 – 70 ml per bushel of rice and 3 – 140 ml per bushel of rice. These numbers are indicated after the P. The 35, 70, and 140 ml give loadings of 84, 168, 336 g of active ingredient/ha respectively.

The rice was soaked with water, covered and kept indoors for three days to allow germination before it was transported to the farm. The 35 ml of the pesticides were mixed with about 3 l of water in an open bowl and the mixture was thoroughly mixed with the germinated rice (Sankoh et al, 2016). The mixed rice was broadcast on the appropriate plots. The process was repeated with 70 ml and then 140 ml of each set of pesticides. This gave a total of 9 mixtures. This method of application was the same as that which the farmers use in Sierra Leone. Two weeks after the application, the seedlings were up-rooted and replanted on the same plot but the population of the plants were reduced to a third. No pesticide was applied to the control plots, C1 to C9.

Sample Collection

Soil samples collection and treatment

Soil samples were collected 30 days after the application of the pesticides on the field. Within this period there were 8 major rain events that measured between 70 mm to 130 mm and lasting at least 12 hours.

The top 2 cm of the soils were collected using a monolith auger. Five samples were collected at random from various points within a plot and mixed thoroughly to form a homogeneous sample representing the plot. The samples were then transferred to polythene bags and stored at freezing point until ready for analysis.

Rice samples were collected using a knife, when the rice was fully matured and ready for harvest 90 days after cultivation. Five strands of rice were collected from each plot. Strands from the same plots were put together to form a composite sample. The samples were sealed in polythene bags and stored at freezing point until ready for analysis.

Laboratory analysis

Reagents and standards

Ethyl acetate, hexane and acetone were HPLC gradient grade solvents from Fisher Scientific UK. Sodium sulphate (Na_2SO_4) was obtained from Sigma Aldrich and alumina was obtained from Merck in Germany. The recovery standard labelled used was d-10 chlorpyrifos diethyl, obtained from Cambridge Isotope Laboratories Inc. The stock solution of the recovery standard was 100 µg/ml in nonane and was diluted to 1 µg/ml in hexane. Analytical grade triphenyl phosphate (TPP-d15) was purchased from QMX Laboratories Ltd, Thaxted, UK. TPP-d15 was used as internal standard. A 100 µg/ml TPP-d15 was prepared using acetone as the solvent. A stock solution of 1000 µg/ml chlorpyrifos was prepared in acetone using analytical grade chlorpyrifos- ethyl obtained from Sigma- Aldrich UK. From the stock solution, seven calibration standard solutions (150, 200, 300, 400, 700, 1000 and 1500 pg/ul) were prepared and the solvent was exchanged to hexane. A blank containing hexane was included.

Sample preparation

Soil samples from the freezer were allowed to thaw and then 1 g of sample was transferred into a centrifuge tube. The soil sample in the centrifuge tube was dried using 3 g of baked anhydrous Na_2SO_4. The soil/Na_2SO_4 mixture was thoroughly mixed until a fine dry powder was obtained. The dried sample was spiked with 50 µl of 1 µg/ml d-10 chlorpyrifos in hexane as a recovery standard. A blank containing 3 g of Na_2SO_4 was included after every 10 samples.

Rice samples were ground using a coffee grinder and then sieved with a 125 µm sieve and 5 g of the rice powder obtained was dried with 2 g baked anhydrous Na_2SO_4 in a centrifuge tube. The dry mixture was spiked with 50 µl of 1 µg/ml d-10 chlorpyrifos in hexane. A blank with 2g of baked anhydrous Na_2SO_4 was included after every 10 samples.

Extraction and clean-up

The samples were extracted with 30 ml 2:3 Hexane: Ethyl acetate mixture. To the spiked Na_2SO_4 dried samples in the centrifuge tube, 10 ml of the extracting mixture was added, shaken by hand for 10 minutes and centrifuged at 2000 rpm for 2 minutes. The extract was decanted and the extraction was repeated three times. The three extracts were merged. The volume of the extracts was reduced to about 1 ml using a slow stream of nitrogen gas at a temperature of 40^{o}C. The extract was cleaned using a solid phase chromatography glass column in which 6 g of alumina and about 1 cm thick sodium sulphate were added. The column was rinsed with 20 ml ethyl acetate before adding the samples. The extract was eluted through the column with 20 ml ethyl acetate. The volume was reduced to about 0.5 ml using a slow stream of nitrogen gas and then transferred to a two ml vial to which 10 µl of

100 µg/ml TPP-d15 solution were added. The resulting solution was blown to dryness and re-dissolved with 1 ml Hexane.

Analytical instrument setup

The samples were analysed using a Finnigan TRACE GC-MS system, equipped with a Phenomenex ZB-MultiResidue-2 GC column (30 m x 0.25 mm x 0.2 µm). The initial oven temperature was 70^0 C (held for 2 minutes), then increased to 150ºC at a rate of 25ºC min^{-1}, further increased to 220ºC (3ºC min^{-1}), and finally to 300ºC (10ºC min^{-1}), where it was held for 10 minutes. The GC interface temperature was set to 300ºC, and the MS source temperature to 250ºC.

Determination of soil density

The volume of the soil was determined with a graduated cylinder containing water. The density was determined using the equation:

$$density\ \left(\frac{g}{cm^3}\right) = \frac{mass(g)}{volume\ (cm^3)}$$

Determination of percentage moisture content and percentage organic carbon

The soil samples were placed in an oven and heated over night at 105°C. The percentage moisture content (%MCF) was calculated using the equation below:

$$\%MCF = \frac{(M1 - M2)}{M1}\ X\ 100$$

The oven dry soil was placed in a furnace and heated to 440°C overnight. The organic matter content (%C) was calculated using the following equation:

$$\%C = \frac{(M2 - M3)}{(M2)}\ X\ 100$$

Where, M1 = mass of moist soil; M2 = mass of oven dry soil; M3 = mass of soil residue from furnace.

Data analysis

Averages of data obtained were displayed using bar charts with standard error bars. The data was expressed as a logarithmic function and tested for normality using Sapiro-Wilks test. The data was parametric and therefore analysed using parametric tests. Comparison between the plots was done using a one-way ANOVA at 95% confidence level and Tukey was used as a post hoc test. The results obtained from experimental plot 1 and experimental plot 2 were compared using paired t-test statistics tool at 95% confidence level.

The soil fugacity model

The results were compared to the predicted time trends from the soil fugacity model. Whilst the measurement data provided a snap-shot of the concentrations in the soil, the model was used to predict pesticide fate over time. Such models are widely used to determine the fate and behaviour of pesticides from agricultural basins (di Guardo et al (1994). Using input data such as chemical properties of the pesticide, soil properties and environmental conditions such as rain events, atmospheric pressure, and temperature are given, the model can be used to predict pesticide lost through volatilization, runoff, and degradation and that remaining in the soil. The model was run three times for each rain event. A plot of the predicted pesticide residue remaining in the soil against the number of days at which rain events that are high enough to cause flooding of the area to which pesticides were applied, gives a trend line which could be used to determine the expected level of pesticide residues at a given number of days after application. The soil fugacity model is a simple model that does not require the input extensive environmental and chemical data but has shown to provide reliable results (Paterson et al, 1991). Peruzzo et al (2008) found that soil fugacity model simulations provided good predictions of glyphosate concentrations over time.

Soil and rice samples for this study were collected 30 days after application and the collection was done only carried out on one occasion. Therefore, results obtained were not adequate to fully describe the time trend of pesticide concentrations. To aid the interpretation of the measurement data, the soil fugacity model was used. The model was also used to predict the processes through which the pesticides are lost from the soil to which the pesticides were applied. The predicted residual chlorpyrifos concentrations in the soil obtained from the soil fugacity model were plotted against time of rain events. The exponential curve was used to compare results obtained from the analysis of the soil samples to the level predicted by the soil fugacity model at day 30. The model was run over eight major rain events which occurred within 45 days after the date of pesticide application (15th July to 30th August 2013) in the region where the experimental plots were constructed. The input data were as follows:

Environmental conditions: rainfall (70 mm – 130 mm), soil bulk density (calculated from the soil density), atmospheric temperature (25°C), percentage organic matter (20% and 11% for experimental plot 1 and 2 respectively) and the atmospheric pressure (760 mmHg).

Chemical properties: name of chemical (chlorpyrifos), molecular mass (351 g/mol), aqueous solubility (1.4 mg/l at 25°C, vapour pressure (3.35x10-3) and log octanol-water partition coefficient (5.2 at 25°C)

Analytical method validation

The effectiveness of the analytical method was tested by measuring the percentage d10-chlorpyrifos extracted with reference to the d10-chlorpyrifos which was used to spike the samples before extraction. The recoveries obtained range from 80% to 106%.

Results and discussion

Pesticide residues in soils

Results obtained from laboratory analysis of soils showed that all soil samples collected from various sub-plots on both experimental plots, including control sub plots contained some levels of pesticides. Pesticides were not applied to any of the control sub-plots. The pesticide levels found on the control sub-plots give an indication that there was cross contamination between sub-plots within each of the experimental plots. However, these levels are significantly lower than those obtained from the plots to which pesticides were applied ($p = 0.002$). It is possible that pesticides could be transported to other areas by transport media such as air and water. It is also possible that a small fraction of the pesticides remains on the soil even after being allowed to fallow for two years, if the area had been treated previously. The trenches between sub-plots helped to minimise cross contamination (Figure 2). When flooded water flows out of the plot, it goes through the trenches without flowing to the adjacent plot. This implies that the most probable source of pesticides on the control sub-plots is from historical contamination, although aerial drift is also possible.

Figure 2: A photo showing a trench separating two sub-plots in experimental plot on the riverine ecosystem (original)

Experimental plot 1 (Riverine ecosystem)

The results obtained from the analysis of soil samples collected from experimental plot 1 indicated that the average levels of pesticide residues is higher on soils to which higher volumes of pesticides was added, except for the sub-plots to which chlorpyrifos dimethyl was applied (Figure 3). In the case of chlorpyrifos dimethyl, the average pesticide residue was lowest on samples to which 70 ml of the pesticide was applied. In general, the higher the quantity of pesticides used, the higher the residue in the soil. The average residual pesticide concentrations found in soil samples from experimental plot 1 are shown in Figure 3. The levels of residual pesticides range from a minimum of 300 pg/g of soil to a maximum of 5700 pg/g. However, this range of values is <1% of the levels of pesticides applied to the plots during cultivation (0.7 – 0.04% of 1.1, 0.6 and 0.3 µg/g of soil applied, Figure 4). This implies that <99% of the applied chlorpyrifos was either degraded or transported from the plots. This indicates that chlorpyrifos is not persistent in these riverine ecosystems. It was observed that the percentage retention of pesticides decreased with an increase of pesticide volume except for the plots where of 1:1 chlorpyrifos diethyl and chlorpyrifos dimethyl was applied. Plots to which 70 ml of the pesticide was applied have percentage residues that are higher than that of plots to which 35 ml was added by 0.06%. According to Roger and Bhuiyan (1990) when the quantity of organic pesticides is increased there is an increase in the rate at which the pesticide is lost. Processes like volatilization increases with an increase in the quantities of pesticides as the fraction that would not bind with the surface soil increases (Zhang et al, 2012). That is why sub-plots to which 35 ml of pesticides were added show the least percentage loss of the pesticides when compared to sub-plots to which 70 ml of pesticides were applied. Sub-plots to which 140 ml of pesticides were applied had the highest percentage loss. In addition to volatilization, biodegradation can also increase with an increase in concentration.

Analysis of results using ANOVA confirmed that there is a significant difference between plots treated with different volumes of chlorpyrifos diethyl and 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl ($p = 0.005$ for chlorpyrifos diethyl, $p = 0.022$ for 1:1 mixture of chlorpyrifos dimethyl). There is no significant difference of average residual chlorpyrifos levels on experimental plot 1 sub-plots treated with different volumes of pesticides ($p = 0.052$). However, for experimental plot 1, Tukey post hoc test shows that there is no significant difference between pesticide residues found on samples from plots on which 35 ml of chlorpyrifos diethyl were applied and those from which 70 ml of the pesticide was applied ($p = 0.147$) and no significant difference between samples treated with 70 ml and those treated with 140 ml of chlorpyrifos diethyl ($p = 0.163$). Average chlorpyrifos diethyl residues found on samples from sub-plots treated with 140 ml of the pesticides are significantly higher than those treated with 35 ml chlorpyrifos diethyl. A similar trend was also observed with the 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl, but with different p values (p = 0.087 for 35 ml vs70 ml, p = 0.778 for 70 ml vs 140 ml and p = 0.027 for 35 ml vs 140 ml)

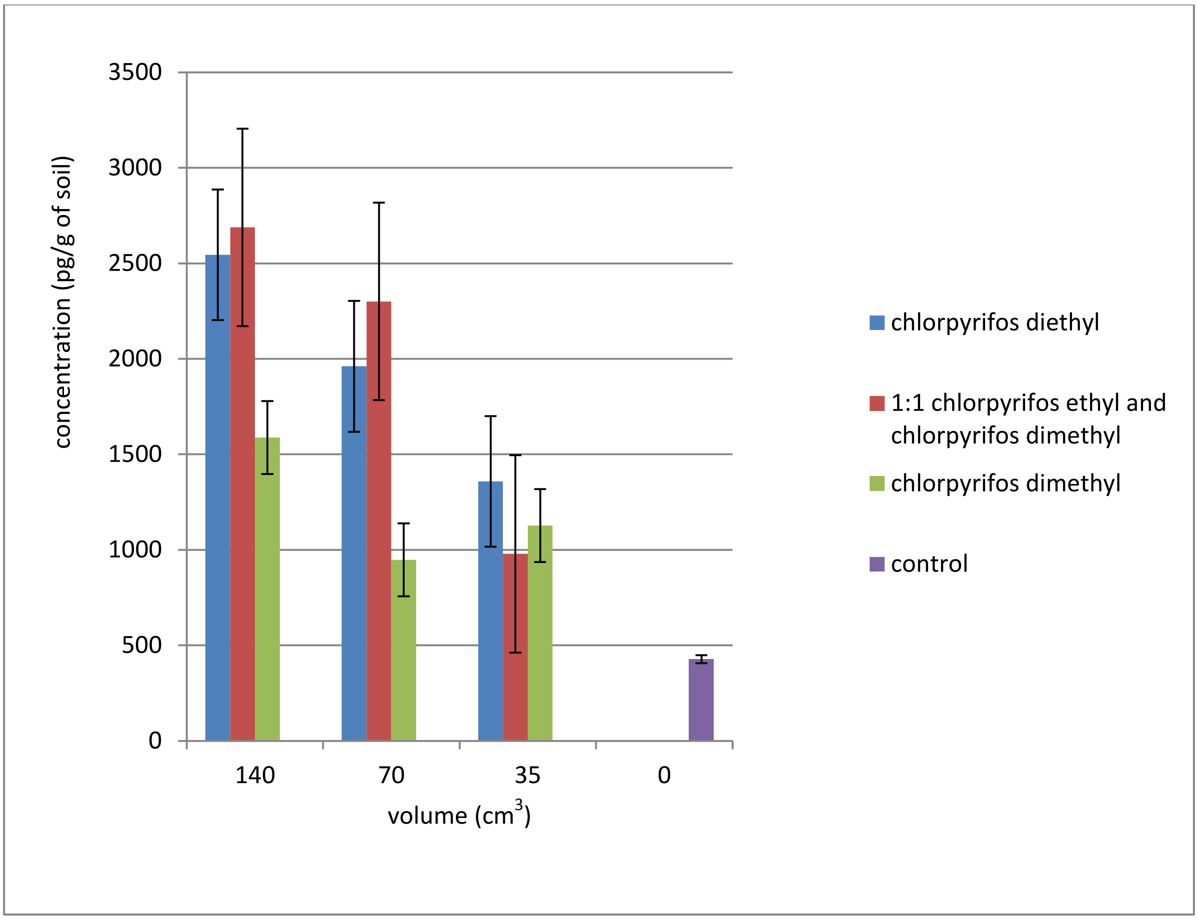


Figure 3: Mean concentrations of chlorpyrifos (n=6, +/- SE of mean) in surface soil samples collected from experimental on riverine swamp 30 days after treatment

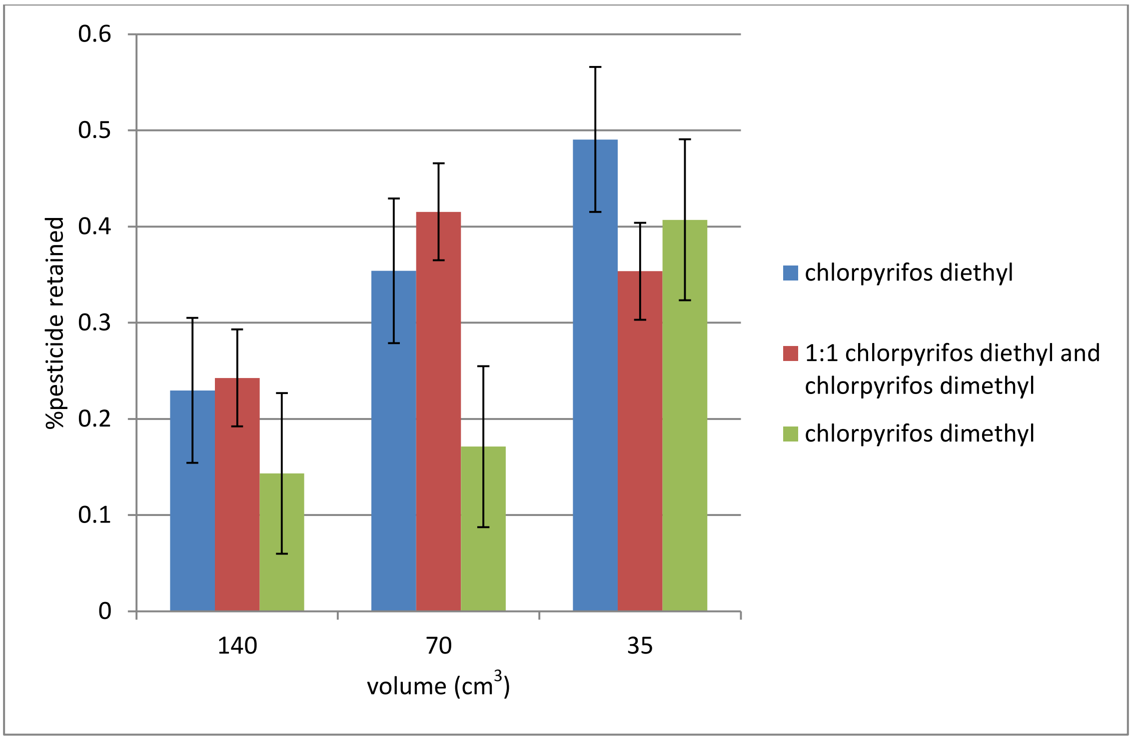


Figure 4: Mean percentage of added pesticide (n=6, +/- SE of mean) remaining in surface soils from experimental on riverine swamp after 30 days.

Experimental plot 2 (boliland ecosystem)

Results obtained from the boliland plots indicated that for all the pesticides used the higher the volume of pesticide applied the higher the residue (Figure 5). All the control plots had some chlorpyrifos present. The average level of pesticides found on the control plots in experimental plot 2 is 480 pg/g of soil (Figure 5). Analysis using ANOVA indicated that there is significant difference of pesticide residues for different volumes of pesticides used ($p = 0.000$ for all the pesticides used). However, the Tukey post hoc test revealed that for all the sets of pesticides used there is no significant difference of average levels of pesticide residues on samples from plots on which 70 ml and 30 ml of pesticide were used for chlorpyrifos diethyl, 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl and chlorpyrifos dimethyl respectively).

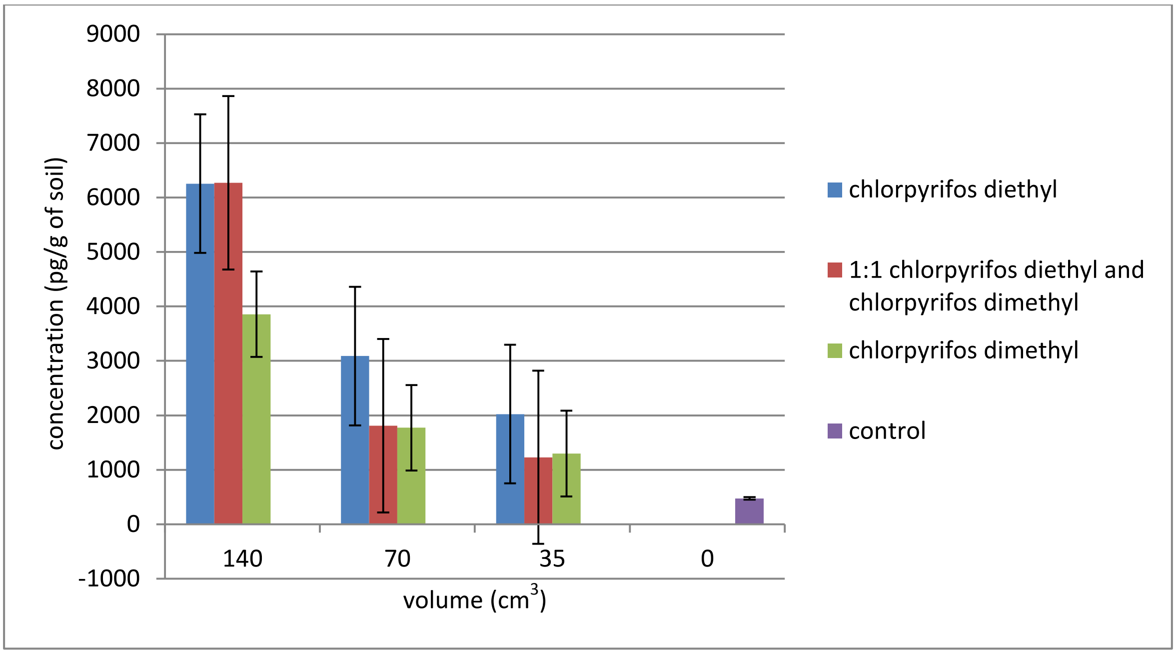


Figure 5: Mean concentrations of chlorpyrifos (n = 6, +/- SE of mean) in soil samples collected from experimental on boliland 30 days after treatment

Results indicate that 30 days after application, the mass of chlorpyrifos retained on soils is <1% (Figure 6). This means more than 99% of the applied chlorpyrifos is lost. For the experimental plot on boliland, it was observed that plots on which 70 ml of pesticide was added have the lowest percentage mass of pesticide retained on the soil for all the three sets of pesticides.

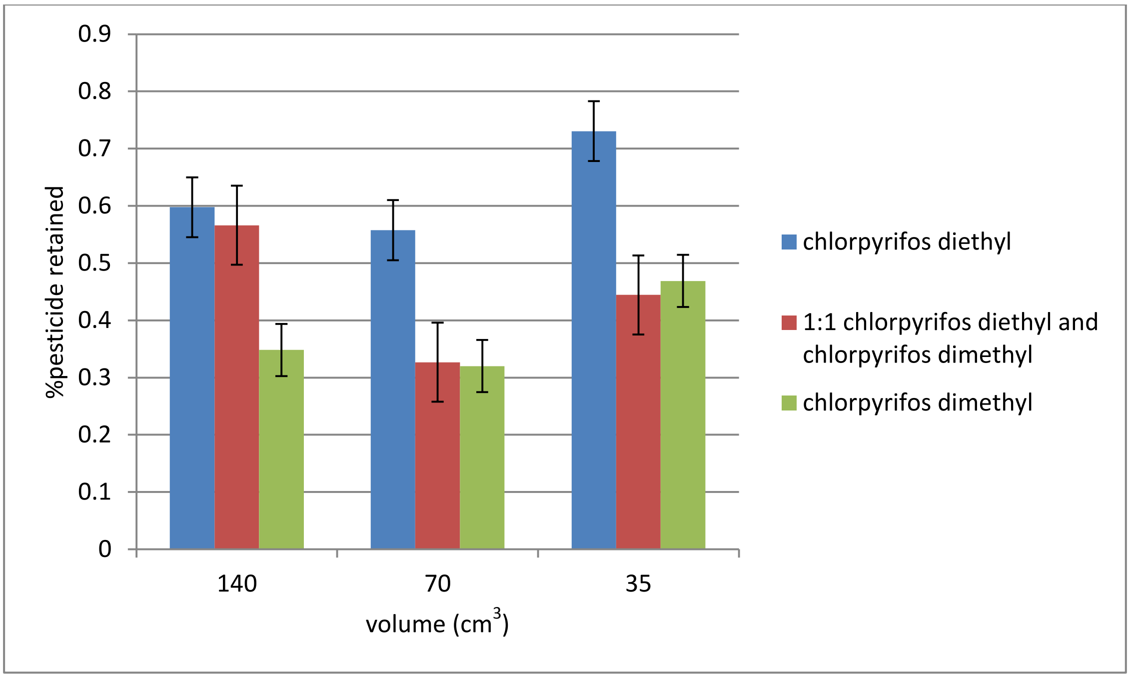


Figure 6: Mean percentage of added pesticide (n = 6, +/- SE of mean) remaining in soils from experimental on boliland after 30 days.

Fate of chlorpyrifos in soil

For both experimental plots 1 and 2, analysis of results using paired t-test shows that the residual pesticides obtained from plots treated with the three types of pesticides used are not significantly different.

Organic pesticides like chlorpyrifos are retained by soil organic matter (Singh et al, 2004; Gilani et al, 2010). This retention occurs at the surface of the soil (de Silva et al, 2010). This implies that the level of chlorpyrifos retained by the soil depends on the soil's organic matter content rather than the quantity of pesticide applied. Hence the higher the quantity of pesticides applied the higher the levels that enter other environmental compartments (de Silva et al, 2010).

This loss can be through biodegradation, chemical degradation and transport through surface runoff (Timchalk et al, 2015). Chlorpyrifos is hydrophobic and has a high potential to be absorbed by surface soil. Therefore, transport by leaching is less likely (Risher, 1997; Giuseppe et al, 2010). According to Pingali & Rogers (2012), when chlorpyrifos is applied to the soil, microorganisms act on it and the type of action depends on the prevailing environmental conditions. Under both aerobic and anaerobic conditions, bacteria - especially cyano-bacteria - could act on chlorpyrifos to release either phosphates and/or nitrates (Singh, 2004; Timchalk et al, 2015; Chen et al 2012; Gilani et al, 2010). Thermal disintegration and hydrolysis can also occur. This could lead to the release of several metabolites, which includes 3,5,6–trichloro–2–pyridinol (TCP) and chlorpyrifos-oxon, to the environment (Chen et al, 2012). Some of these metabolites are more toxic to man than the parent compound (Timchakl et al, 2015). However, volatilization is the most important process when compared to both biodegradation and chemical degradation on environments with temperatures higher than 35°C (van der Werf, 1996; Gramatica and Gaurdo, 2002; Clegg, 2008). Volatilization is less important in environments with lower temperatures, since chlorpyrifos has a low vapour pressure and hence is difficult to vaporise (Hinderliter et al, 2011). The atmospheric temperature in Sierra Leone during the rainy season is 25°C (Sweeney et al, 2015).. As a result of the high temperature and prevailing wind conditions in Sierra Leone, volatilised pesticides could be transported rapidly to other areas within and out of the country (Levitan et al 1995; Levitan, 2000; Moore et al, 2002). Biodegradation is also expected to be high, because of the high organic matter (experimental plot 1 (riverine ecology) %C = 20%; experimental plot 2 (boliland ecology) %C = 11%) and moisture content of the soil. These are conditions that favour microbial activities which can increase biodegradation (Chishti et al, 2012; Chen et al 2012). This explains why the percentage retention on soils is low. Both parent compounds and metabolites which occur as a result of degradation can be transported to adjacent water bodies by surface runoff, especially when the soil surface is eroded. In Sierra Leone, where torrential and heavy rainfall is common during the cropping season, when pesticides are applied on farms, surface runoff is expected to play a significant role in removing pesticides from their area of application. Surface runoff is far higher in riverine ecosystems than bolilands as flooding is more common in riverine ecosystems.

Fugacity modelling

The soil fugacity model was used to predict the levels of residual pesticides for the environmental conditions and chemical properties of the pesticides used. The model was run in eight rain events. These rain events are the major rains which caused the plots to be flooded within 45 days after the application of the pesticides (Sweeney et al, 2015). Results obtained from the soil fugacity model prediction shows that when chlorpyrifos is applied to riverine or boliland soils there is an exponential decrease of the pesticide from the soil until after 35 days when the residual pesticides on the soil tends remains constant (Figure 7). This is in agreement with reports from Roger and Bhuiyan (1990), Timckalk (20015) and Li et al (2015). The levels of chlorpyrifos residues predicted to be on the soil 30 days after application by the soil fugacity model are, 0.47% when 1.1 μg/g of soil was applied, 0.37% when 0.55 μg/g of soil was applied and 0.42% when 0.28 μg/g of soil was applied, whilst results obtained from the laboratory analysis of the field samples, the percentage residues obtained were 0.23%, 0.35% 0.49% for levels of applications of 1.1, 0.6 and 0.3 μg/g of soil respectively. Taking note that the soil fugacity model does not account for some of the factors such as the fraction of pesticides absorbed by plants and animals (Roger and Bhuiyan, 1990), the laboratory results are comparable to the prediction of the soil fugacity model. This implies that a time series analysis of soil samples would result to an exponential curve similar to that which is predicted by the soil fugacity model. Results predicted by the soil fugacity model also suggest that volatilization of pesticides is not an important factor through which pesticides are lost from the point of application in Sierra Leone, especially after the first rain event (Figure 8). The model also suggests that chlorpyrifos loss through runoff is low (3%), although higher than volatilization during and after the first rain event. According to results obtained from the soil fugacity model, biodegradation is the most prominent process through which chlorpyrifos is lost (Figure 8). The loss process predicted by the soil fugacity model indicates that immediately after the application of chlorpyrifos to the soil, volatilization is active but rapidly drops from 25% to 1% whilst runoff and biodegradation increases from 0% to 3% and from 50% to 96% respectively. Volatilization of organophosphate pesticides is most prominent when the pesticide is just added to the soil (di Guardo et al, 1993; van der Werf, 1996; Reus et al, 2001; Grammatica and di Guardo, 2007). During this period the pesticide does not have full binding with the soil. During and after application, there would be no loss due to runoff if there is no rain that could cause the field to flood. Most microbial activities of pesticides occur after binding with the soil organic matter (Das and Adhya, 2015).

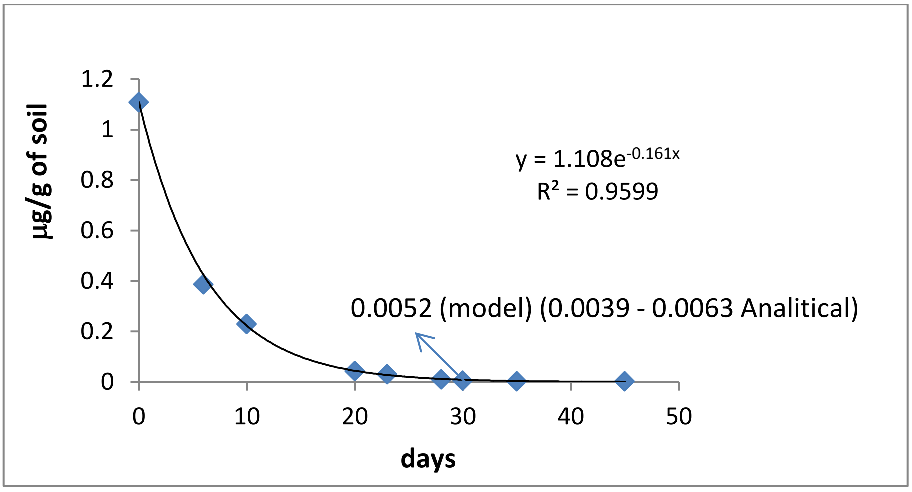


Figure 7: A curve showing the decrease of chlorpyrifos residue on riverine soil predicted by the soil fugacity model in 8 rain events when 1.1 µg of pesticide/g of soil was applied.

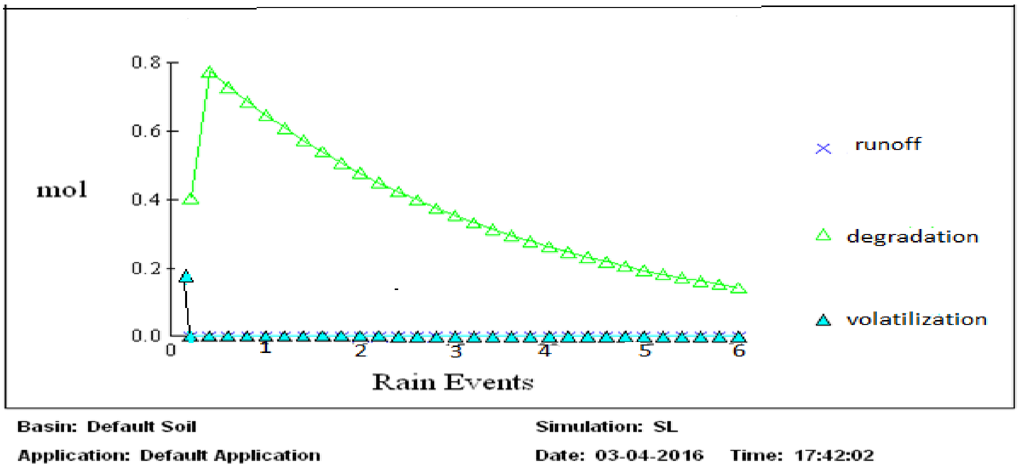


Figure 8: Loss processes of chlorpyrifos predicted by the soil fugacity model in six rain events

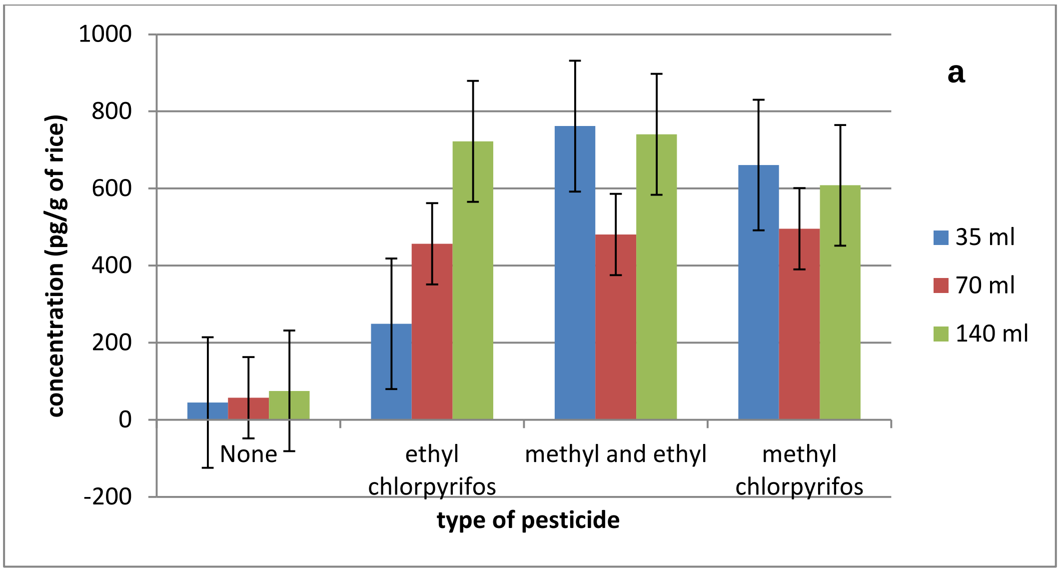
When chlorpyrifos is applied to soil, the fraction that is lost could be more harmful to man and the environment (van der Werf, 1996). According to Tsaboula (2016), chlorpyrifos is one of the pesticides that occur at levels that have high environmental risk in adjacent water bodies when applied to agriculture fields. Results obtained from the soil fugacity model suggested that degradation is the most prominent route of pesticide loss based on the environmental conditions of the experimental plots areas. This implies that most of the applied pesticides are transformed to other chemicals which could be more harmful to man and other organisms in the environment (Xie et al, 1997). Most of the metabolites are more soluble in water and therefore can be transported to ground water through leaching, in addition to the fraction transported by surface runoff. People living around these areas depend on untreated underground water for drinking. Metabolites could enter the food web, bio-transform, bio-accumulate and biomagnified (Chishti et al, 2012; Deb & Das, 2015). These could be a threat to organisms within the environment as well as organisms in the higher trophic levels far away from the source. Farmers as well as others living around the environments could inhale the volatilised fraction, especially when higher doses of chlorpyrifos are applied to the soil (Roger and Bhuiyan, 1990). This could pose health problems. The volatilised fraction could also affect birds and insects (Foohr and American Chemical Society. Division of Agrochemicals, 1998). Since the results show high loss of chlorpyrifos from the experimental plots it is possible that the lost fraction could cause such problems to the environment.

The findings in this study indicate that chlorpyrifos is more persistent on boliland soils than riverine soils. The levels of chlorpyrifos residues on boliland soils are significantly higher than those on the riverine soils (p= 0.001 for chlorpyrifos diethyl, p= 0.025 for the 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl and p= 0.001 for chlorpyrifos dimethyl). Riverine soils are water logged and have higher organic matter content. This implies that riverine ecologies have higher anaerobic bacteria, which are more effective in metabolizing chlorpyrifos (Levitan et al, 1995). The tidal influence on the riverine environments could also lead to the abrasion of the soil surface washing away surface sediments containing chlorpyrifos molecules.

The major causes of the loss of chlorpyrifos from boliland soils are volatilization and biodegradation. These could also be routes of loss in riverine ecologies especially during low flow. Although chlorpyrifos is more persistent in boliland ecologies, chlorpyrifos applied in riverine ecologies have higher potential to pollute other facets of the environment than when applied to boliland ecologies. Chlorpyrifos applied to riverine ecologies poses more threats to aquatic organisms (Levitan et al 1995; Levitan, 2000). Riverine ecologies are submerged in water during high tides, making the environment more accessible to aquatic organism searching for food. These organisms could absorb contaminants or feed on contaminated food (Rahman, 2012). This could lead to bioaccumulation and if they are eaten by other organisms in the higher trophic level, bio-magnification could occur. Surface runoff could also transport pesticides into the aquatic environment and contaminate food. This could be a route of pesticide contaminants into the food web.

Chlorpyrifos residues in rice grains

It was observed that chlorpyrifos residues were found in all the rice samples (Figures 9a and 9b). Since the rice crops used for this experiment were obtained from pesticide free fields, it was assumed that all pesticides found in the crops are from those used during cultivation. Pesticide levels found on rice samples range from 249 to 762 pg/g of rice and 284 to 785 pg/g of rice for riverine and boliland plots respectively. Levels of pesticides found on rice from the control plots are 59 and 23 pg/g of rice for riverine and boliland plots, respectively. This is a clear indication that pesticides are taken by rice and stored in the grains (Kim et al, 1998; Hinderliter et al, 2011; Pareja et al, 2011; Li et al, 2015). It is possible that pesticide residues could be found on other plant tissues, but this research cannot justify this claim as only the grains where analysed. However, the transfer factors calculated from the soil fugacity model indicate, that higher levels of pesticides are taken in by plants (table 1).



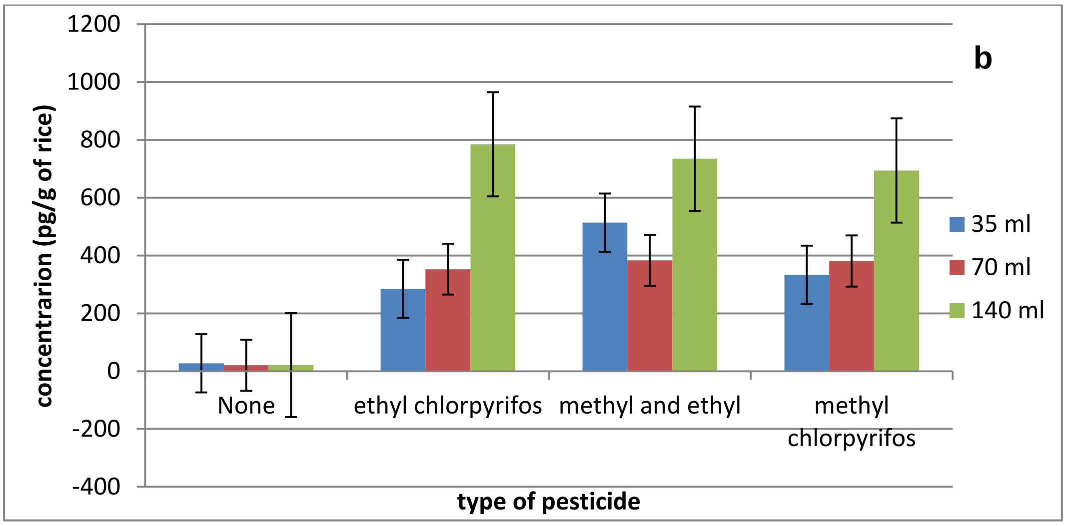


Figure 9: The mean concentration of chlorpyrifos found in rice (n = 6, +/- SE of mean) from experimental plots on riverine swamps (a) and boliland (b).

The presence of pesticide in rice obtained from control sub plots is an indication that there was cross contamination and or previous contamination within the experimental plots. The levels of pesticides on rice samples from all the control subplots, to which no pesticide was added, are significantly lower than rice samples from plots to which pesticides were applied ($p = 0.000$). The levels of pesticides in rice samples from control plots of experimental plot 2 are significantly lower than those from experimental plot 1 ($p = 0.042$). This suggests that cross contamination is higher in experimental plot 1 than in experimental plot 2. Cross contamination can be caused by surface runoff. However, since cross contamination is higher on experimental plot 1 (riverine ecology), it implies that the principal cause for cross contamination is runoff which is more prevalent in riverine ecology than boliland ecosystem.

Analysis of rice results from both experimental plot 1 and experimental plot 2 using one-way ANOVA shows that there is a significant difference in chlorpyrifos levels in rice from plots treated with different volumes of pesticide ($p = 0.00$). However, both the Tukey and Bonferroni post hoc test proved that there is no significant difference on levels of chlorpyrifos in rice samples from plots treated with 70 ml of pesticides with those treated with 35 ml of the same pesticides (experimental plot 1, Tukey; $p = 0.989$, Bonferroni; $p = 1.000$: experimental plot 2, Tukey; $p = 0.999$, Bonferroni; $p = 1.000$). This means the relationship between the levels of pesticide applied and plant uptake is not linear. This is an indication that there are other factors that could influence the transfer of the pesticides from the soil to the plant.

From the results it was observed that the type of chlorpyrifos used can influence the uptake of the pesticide by plant. One-way ANOVA analysis also indicates that, the levels of pesticides in rice samples are significantly different when the types of pesticide used are compared (experimental plot on riverine swamp: $p = 0.000$; experimental plot on boliland: $p = 0.002$). The levels of 1:1 chlorpyrifos diethyl and chlorpyrifos dimethyl are significantly higher in rice samples than chlorpyrifos dimethyl which is significantly higher than chlorpyrifos diethyl. For experimental plot

2, even though levels of chlorpyrifos dimethyl are higher in the rice samples than chlorpyrifos diethyl, the Tukey post hoc test proved that the difference between the levels of the two pesticides found in rice are not significantly different ($p = 0.643$). The results indicate that transferred levels are lower when chlorpyrifos diethyl is used than when chlorpyrifos dimethyl is used. However, when the two pesticides are combined the transferred level increases significantly ($p = 0.001$).

The environments can also influence the uptake of pesticides by rice plants. There is no significant difference between levels of chlorpyrifos diethyl in rice samples from experimental plot 1 with chlorpyrifos diethyl from experimental plot 2 ($p = 0.721$). Chlorpyrifos dimethyl and 1:1 chlorpyrifos diethyl and chlorpyrifos dimethyl levels in rice samples from experimental plot 1 is significantly higher than rice samples from experimental plot 2 ($p = 0.011$ for 1:1 chlorpyrifos diethyl and chlorpyrifos dimethyl; $p = 0.035$ for chlorpyrifos dimethyl).

Soil-crop transfer factor

Soil-crop transfer factors were calculated using the equation used by Taha et al (2013);

$$TF = \frac{[P]crop}{[P]soil}$$

Where; TF is the transfer factor, [P]crop is the pesticide dry weight concentration in the crop and [P]soil is the pesticide concentration on soil.

The transfer factors of pesticides in this research to rice are summarised in Table 1. The TFs on the riverine samples range from about $5x10^{-4}$ to $2x10^{-3}$ whilst those from the boliland ranges from about $6x10^{-4}$ to $1x10^{-3}$ g of soil/g of rice.

Table 1: Soil-crops transfer factors (TF) of pesticides at different input concentrations (IC)

	Riverine					
IC (pg/g of soil)	C1 (pg/g of rice)	TF1	C2 (pg/g of rice)	TF2	C3 (pg/g of rice)	TF3
1.1×10^6	722	6.5×10^{-4}	741	6.7×10^{-4}	608	5.5×10^{-4}
5.5×10^5	456	8.2×10^{-4}	481	8.7×10^{-4}	496	9.0×10^{-4}
2.7×10^5	249	9.0×10^{-4}	762	2.8×10^{-3}	661	2.4×10^{-3}
	Boliland					
IC (pg/g of soil)	C1 (pg/g of rice)	TF1	C2 (pg/g of rice)	TF2	C3 (pg/g of rice)	TF3
1.1×10^6	785	7.1×10^{-4}	735	6.6×10^{-4}	694	6.3×10^{-4}
5.5×10^5	353	6.3×10^{-4}	383	6.9×10^{-4}	381	6.9×10^{-4}
2.8×10^5	284	1.0×10^{-3}	514	1.9×10^{-3}	333	1.2×10^{-3}

Where; C1, C2, and C3 are the concentrations of ethyl chlorpyrifos, methyl and ethyl chlorpyrifos and methyl chlorpyrifos respectively and TF1, TF2 and TF3 are the transfer factors corresponding to C1, C2 and C3 respectively.

According to Zhang et al (2012), chlorpyrifos persists mainly in the rice straw and rice hull. This implies higher levels of pesticides might be taken in by the plant but the results indicate that levels that reach the rice grains are low when the use of pesticides is regulated. These findings are similar to those from other research (Roger & Bhuiyan, 1994; Hinderlite et al, 2011; Li et al, 2015).

Human Exposure

The acceptable daily intake of chlorpyrifos in humans is 0 – 0.01 mg/kg of body weight (Hinderliter, 2011, Li et al, 2015). However, although chlorpyrifos is considered to be persistent, it hardly accumulates in human body. About 99% of the chlorpyrifos taken in by man is excreted. Only 1% is stored in the fat adipose tissues (Hinderliter, 2011).

According to FAO (2004) the annual per capita consumption of rice in Sierra Leone is 200 kg. Based on this figure, the levels of pesticide intake annually per capita were calculated for each application and results are displayed in Table 2. These values are significantly lower than the maximum limit of permissible intake. To reach this intake limit one needs to consume 127 kg of the most contaminated rice from the field experiments in a day (785 pg/g of rice). If the annual per capita consumption is 200kg it implies the daily intake is 0.5 kg per person. This implies that the daily consumption of the rice produced would not pose major threats to man. This is in conformity with research done by Roger and Bhuiyan (1990) and Li et al (2015). However, rice is consumed in Sierra Leone with vegetables, fish or other protein sources which are likely to also be contaminated. In such a case the fraction in rice would contribute to the total daily intake. The mass of pesticides in all the rice samples are below the maximum limit (0.05 mg/kg) recommended by the European food safety guideline (Commission Regulations (EU), 2016).

Table 2: The annual per capita consumption of pesticides in Sierra Leone when rice from the experimental plots are consumed

		Plot 1	Plot 2
pesticide	volume	mass in 200 kg (mg/kg per capita)	mass in 200 kg (mg/kg per capita)
chlorpyrifos diethyl	35	0.05	0.06
	70	0.09	0.07
	140	0.14	0.16
1:1 chlorpyrifos ethyl &dimethyl	35	0.15	0.10
	70	0.10	0.08
	140	0.15	0.15
Chlorpyrifos dimethyl	35	0.13	0.07
	70	0.10	0.08
	140	0.12	0.14
none	0	0.0118	0.00

Conclusion

From the results obtained, < 1% of chlorpyrifos is retained by the soil after 30 days, under field conditions in Sierra Leone. This is also supported by the prediction of the soil fugacity model. The remaining 99% or more is either transported to other environmental compartments or transformed to other compounds, some of which could be more toxic and some more soluble (van der Werf, 1996). This implies chlorpyrifos is not highly persistent on riverine and boliland soils in Sierra Leone.

Chlorpyrifos diethyl, 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl and chlorpyrifos dimethyl are more persistent in boliland soils than riverine soils.

Chlorpyrifos can be absorbed by the rice plant and stored in the grains. This could serve as an exposure route to man. The levels found in the rice grains are lower than the EU recommended maximum levels for food safety in this study, which aims to mimic typical agricultural practice in Sierra Leone. However, since higher levels give higher pesticide levels in the rice, it is an indication that misuse of these pesticides could result to levels higher than the recommended levels. This is likely to happen when the users are not trained.

Results indicate that when chlorpyrifos methyl and chlorpyrifos diethyl are mixed the uptake by rice increases significantly. This is therefore expected to happen when Yarifos, which is a 1:1 mixture of chlorpyrifos diethyl and chlorpyrifos dimethyl, is applied.

References

Bairy KL, Vidyasagar S, Sharma A, et al. (2007) Controversies in the management of organophosphate pesticide poisoning. Educational Forum 39: 71-74

Barcel D and Hennion M-C. (1997) Trace determination of pesticides and their degradation products in water, Amsterdam ; New York: Elsevier Science. Ebook 1st edition, p540

Barron MG and Woodburn KB. (1995) Ecotoxicology of Chlorpyrifos. In: Ware GW (ed) Reviews of Environmental Contamination and Toxicology: Continuation of Residue Reviews. New York, NY: Springer New York, 3: 1-93.

CEDAC. (2010) Grass-root development: The African development foundation. U. S. Congress 88: 45-60.

Chakaraborty SR, Azim R, Rahman AKMR, et al. (2013) Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and Plants in the Chittagong City of Bangladesh. Journal of Physical Science 24: 95-113.

Chen S-F, Zhang H and Lin Q-Y. (2013) Effect of different water conditions on dissolution of Nano silver. Water Science and Technology 68: 1745-1750.

Chishti Z, Hussain S, Arshad KR, (2012) Microbial degradation of chlorpyrifos in liquid media and soil. Journal of Environmental Management 114: 372-380.

Clegg HMAF and Lancaster University. Theses. (2008) The fate and behaviour of pesticides in soil : implications for regulatory testing. Lancaster University, Lancaster University, 2008., Various paging.

Das S and Adhya TK. (2015) Degradation of chlorpyrifos in tropical rice soils. Elsevier: Journal of Environmental Management, 152: 36-42.

Deb N and Das S. (2013) Chlorpyrifos toxicity in fish: A review. Current World Environment, 8: 77-84.

de Silva P, Mangala CS, Pathiratne A, et al. (2010) Chlorpyrifos causes decreased organic matter decomposition by suppressing earthworm and termite communities in tropical soil. Environmental pollution (Barking, Essex : 1987) 158: 3041 - 3043

Di Guardo A, Calamari D, Zanin G, et al. (1994) A fugacity model of pesticide runoff to surface water development and validation. Elsevier: Chemosphere, 1: 511-531.

FAO. (2004) All about rice in Sierra Leone. . http://www.fao.org/RICE2004/en/p18.htm (accessed: 10/09/15)

Fenlon KA. (2007) Fate, behaviour and bioavailability of pesticides in soils. Thesis LEC: Lancaster University

Fernández-Pérez M, Garrido-Herrera FJ and González-Pradas E. Alginate and lignin-based formulations to control pesticides leaching in a calcareous soil. Journal of Hazardous Materials 190: 794-801.

Gilani STSA, M Shah, HRaza, S. (2010) Chlorpyrifos degradation in soil and its effect on soil microorganisms. The Journal of Animal & Plant Sciences, 20: 99 -102.

Giuseppe F, Rahn E and Binder CR. (2010) Testing environmental and health pesticide use risk indicators. The case of potato production in Boyacá, Colombia. Conference paper. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Tropentag.

Gramatica P and Di Guardo A. (2002) Screening of pesticides for environmental partitioning tendency. Elsevier: Chemosphere, 47: 947-956.

Hinderliter PM, Price PS, Bartels MJ (2011) Development of a source-to-outcome model for dietary exposures to insecticide residues: An example using chlorpyrifos. Regulatory Toxicology and Pharmacology, 61: 82 - 92.

Kim DH, Heo GS and Lee DW. (1998) Determination of organophosphorus pesticides in wheat flour by supercritical fluid extraction and gas chromatography with nitrogen-phosphorus detection. J. Chromatogr. A 824: 63-70.

Larbi A. (2012) Country pasture/forage resource profile - Sierra Leone. FAO. http://www.fao.org/ag/agp/agpc/doc/counprof/Sierraleone/Sierraleone.htm (accessed; 20/10/15)

Levitan L. (2000) "How to" and why": assessing the enviro-social impacts of pesticides. Crop Protection, 19: 629 - 636.

Levitan L, Merwin I and Kovach J. (1995) Assessing the relative environmental impacts of agricultural pesticides: the quest for a holistic method. Agriculture, Ecosystems and Environment 55: 153-168.

Li R, He L, Wei W, et al. (2015) Chlorpyrifos residue levels on field crops (rice, maize and soybean) in China and their dietary risks to consumers.: Food Control, 51: 212-217.

Mackay D and Paterson S. (1991) Evaluating the multimedia fate of organic chemicals: A level III fugacity model. Environmental Science and Technology, 25: 427-436.

Marshall WK and Roberts JR. (1978) Ecotoxicology of chlorpyrifos. National research council of Canada. 1st edition, pp 115 - 116

McSweeney C, New M and Liecano G. (2015) UNDP climate change profiles: Sierra Leone. Oxford University. http://country-profiles.geog.ox.ac.uk/ (Accessed 10/10/15)

Moore MT, Cooper CM, Smith SJ, et al. (2002) Pesticide mitigation capacities of constructed wetlands. Gen Tech 50: 191 - 195.

Paterson S, Mackay D and McFarlane C. (1994) A model of organic chemical uptake by plants from soil and the atmosphere. Environmental Science and Technology, 28: 2259 - 2266

Peruzzo PJ, Porta AA and Ronco AE. (2008) Levels of glyphosate in surface waters sediments and soils associated with direct sowing soybean cultivation in north Pampasic region of Argentina Environmental Pollution. 156: 61 - 66

Pingali PL and Roger PA. (2012) Impact of pesticides on farmer health and the rice environment. Springer, 7: 612- 614

Reus J, Leendertse P, Bockstaller C,. (2002) Comparison and evaluation of eight pesticide environmental risk indicators developed in Europe and recommendations for future use. Elsevier: Agriculture, Ecosystem and Environment, 90: 177-187.

Risher JF. (1997) Toxicological profile of chlorpyrifos. u.s. department of health and human services Public Health Service Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/ToxProfiles/tp84-p.pdf (Accessed 12/02/16)

Roger PA and Bhuiyan SI. (1990) Behaviour of pesticides in rice-based agro systems : A review. Impact of pesticides on farmer health and the rice environment International rice research paper series: International rice research paper series, 7: 111-148.

Sankoh AI, Whittle R, Semple KT, et al. (2016) An assessment of the impacts of pesticide use on the environment and health of rice farmers in Sierra Leone. Environment International. 94:458-66

Singh BK, Walker A, Morgan JAW, et al. (2004) biodegradation of chlorpyrifos by Enterobacter strain B-14 and its use in bioremediation of contaminated soils. Applied and Environmental Microbiology, 70: 4855-4863.

Taha KK, Shamou MI, Osman MH, et al. (2013) Soil-Plant Transfer and Accumulation Factors for Trace Elements at the Blue and White Niles. Journal of Applied and Industrial Science 1: 97-102.

Timchalk C, Weber TJ and Smith JN. (2015) Computational strategy for quantifying human pesticide exposure based upon a saliva measurement. Frontiers in Pharmacology 6: 115 120

Tsaboula A, Papadakis E-N, Vryzas Z, et al. (2016) Environmental and human risk hierarchy of pesticides: A prioritization method, based on monitoring, hazard assessment and environmental fate. Environment International 91: 78-93.

van der Werf HM. (1996) Assessing the impact of pesticides on the environment. Agriculture, Ecosystems & Environment, 60: 81 - 96

Xie H, Guetzloff TF and Rice JA. (1997) Fractionation of pesticide residues bound to human. Soil Science, 162: 421-429.

Zhang X, Shen Y, Yu X-y, et al. (2012) Dissipation of chlorpyrifos and residue analysis in rice, soil and water under paddy field conditions. Ecotoxicology and Environmental Safety 78: 276-280.

Chapter 4

An assessment of chlorpyrifos contamination in aquatic biota, rice and soils from riverine swamp farms in Sierra Leone

Alhaji I. Sankoh, Kirk T. Semple, Kevin C. Jones, Andrew J. Sweetman*

Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK

Abstract

Pesticides are widely used in rice cultivation especially in lowland swamps in Sierra Leone. Most Sierra Leonean farmers have not been trained to use pesticides properly and misuse is causing contamination of the environment. This could lead to the exposure of living organisms to pesticides and hence introduce pesticides to the food web. This would lead to the exposure of organisms in the higher trophic levels including humans. Misuse could also lead to high plant uptake. Chlorpyrifos is the most widely used pesticide in lowland rice cultivation in Sierra Leone. This study determined the levels of contamination of chlorpyrifos in soil, rice and some aquatic biota commonly eaten by people, in order to assess possible human exposure to chlorpyrifos and potential threats to other organisms in the ecosystem. Samples were collected from riverine ecosystems in three farming communities from the rice cultivation main bowl in Sierra Leone. The samples were analysed using a GC/MS. Results indicate that chlorpyrifos is higher than those obtained when manufacturer's recommended doses of pesticides were used in all samples. However, chlorpyrifos levels in rice are not high enough to expose human consumers to levels higher than the daily tolerable intake.

Introduction

Background

West Africa has 57% of Africa’s rice cultivation land (Oteng and Sant’Anna, 2015). However, pests such as blast, rice stem borers, termites, birds, rodents and other organisms are negatively affecting rice production (Gianessi; 2014; Oteng and Sant’Anna, 2015; Samado et al 2015). Sierra Leone is used as a case study in this research and is a major rice producing country in West Africa. Agricultural practices in Sierra Leone are similar to other West African countries such as the Republic of Guinea, Liberia, Senegal, and Banjul. These countries face similar food production and pest control challenges (theguardian, 2015; Samado et al 2015). Therefore, issues affecting one country might be applicable others.

About 74% (5.4 million ha) of the land in Sierra Leone is considered arable but only <15% is currently being cropped (Asenso et al 2009; CARD, 2009; Sannoh, 2011). Sierra Leone has five major cultivable ecologies. These are upland (4.42 million ha), bolilands (145,000 ha), riverine lowlands (130,000 ha), mangrove swamps (20,000 ha) and inland valley swamps (690,000 ha). The agriculture sector is the major employer in the country, estimated at 70% of a population of about six million people (Sannoh, 2011). However, 90% of the agriculturalists are subsistence farmers who most often do not achieve up to 60% of their basic annual sustenance from their farms (Sannoh, 2011). The geographical location, the natural environment and the human resources provides Sierra Leone with the potential to develop through increasing agricultural production. However, a major challenge to such development is pest control. Pests affect agricultural production on all the cultivable ecologies. Therefore, pesticides are required to sustain and grow agricultural production.

Pesticide use and its impact

Pesticide use is becoming more popular in rice farming in Sierra Leone to control pests, reduce labour and increase yields. For paddy rice cultivation in lowland ecologies such as the mangrove and riverine swamps, the application of pesticides would prevent pests like crabs from destroying the seedlings. This makes it safe for farmers to use the farms for nursing the seedlings instead of using the less fertile uplands as nurseries. This not only enhances plant development, it also reduces labour as farmers do not need to transport seedlings from uplands nurseries which could be miles away to the farms.

According to the 2010 Ministry of Agriculture's report, the common pesticides used in Sierra Leone are: malathion ($C_{10}H_{19}O_6PS_2$), propanil ($C_9H_9Cl_2NO$) malatox ($C_{14}H_8N_3SO_4$), fenthion ($C_{10}H_{15}O_3PS_2$), kocide ($Cu(OH)_2$) and Brestan ($C_{20}H_{18}O_2Sn$). Malathion, malatox and fenthion are broad spectrum insecticides that can be used on a wide variety of crops. Propanil is used exclusively for rice, while Kocide and Brestan are used for the production of cocoa (MAFS, 2010). The use of these chemicals is controlled by the Ministry of Agriculture. However, there are reports that these chemicals are being misused and they are supplied to illiterate farmers without any training on how to use them safely and effectively (USAID, 2009). They are often supplied by minor traders selling them in small unlabelled sachets. Such practice could lead to misuse and hence can be detrimental to man and the environment.

The most predominantly used pesticides on lowland paddy rice farms in Sierra Leone include: Yarifos, which contains chlorpyrifos-dimethyl ($C_7H_7Cl_3NO_3PS$) and chlorpyrifos-diethyl, Sarifos, which contains chlorpyrifos-diethyl ($C_9H_{11}Cl_3NO_3PS$). These pesticides can accumulate in the tissues of both exposed flora and fauna in ecosystems (USAID, 2009). After absorption, pesticides can be transported and magnified along the food chain. Pesticides can also accumulate in soil and sediments and are potentially transported to other areas within Sierra Leone and neighbouring countries by water and air. This might pose threats to other environments, which are far away from the point of contamination.

Humans can be exposed to pesticides through skin contact, inhalation, drinking water and food. This can result in a range of harmful effects with the extent of damage dependent on the type of pesticide and/or the level of intake. For example, exposure to organophosphates such as chlorpyrifos can result in the inhibition of the enzyme acetylcholinesterase which can result in nervous disorder. Organophosphates exposure has been associated with headache, excessive salivation, lacrimation, nausea, diarrhoea, respiratory depression, seizure, loss of consciousness and pinpoint pupils (PSEP, 2015; Medline plus, 2015). Chronic effects such as cognitive impairment in adulthood as a result of prolonged parental exposure, hyperglycemia and hyperlipidemia, may also occur (Acker et al 2012; Chen et al 2012). The biological effects connected to the exposure of chlorpyrifos are hazardous since they interact with the receptors, enzymes, proteins and transcription factors (Alcocer et al, 2000; Androutsopoulos et al 2012). According to Atreya et al (2015), the cost of handling the health effects created by the use of pesticides is 53 – 79% more than the cost of pesticides. This is an indication that the uncontrolled use of these chemicals represents a potential threat to humans and the environment in Sierra Leone.

This paper investigates the levels of chlorpyrifos in selected organisms that are living in the rivers flooding the rice fields and that are widely eaten by people in Sierra Leone. These organisms include: mudskippers, tilapia fish, crabs and shrimps. The levels of chlorpyrifos in the rice cultivated on the farms where pesticides were added and chlorpyrifos residues in soil were also investigated. This study focused on possible human exposure and potential threats to organisms within the ecosystem. The paper also gives an indication to the levels of contamination in the swamp soils and the adjacent aquatic environments.

Materials and Method

To investigate the levels of chlorpyrifos in the ecosystems where pesticides are applied, soil, rice, fish, mudskipper, crab and shrimp samples were collected from various farms in Sierra Leone and analysed by gas chromatography mass spectrometry (GC/MS).

Sample Collection

Soil samples collection and treatment

Samples were collected from Conakrydee, Babara and Kyschom farming communities (Figure 1). Three farms labelled A, B and C were selected at random from each of these communities. Three samples were collected from each farm. Each farm was divided into three portions (left - 1, middle - 2 and right – 3) using the adjacent river as the border. All the samples were collected from riverine swamps.

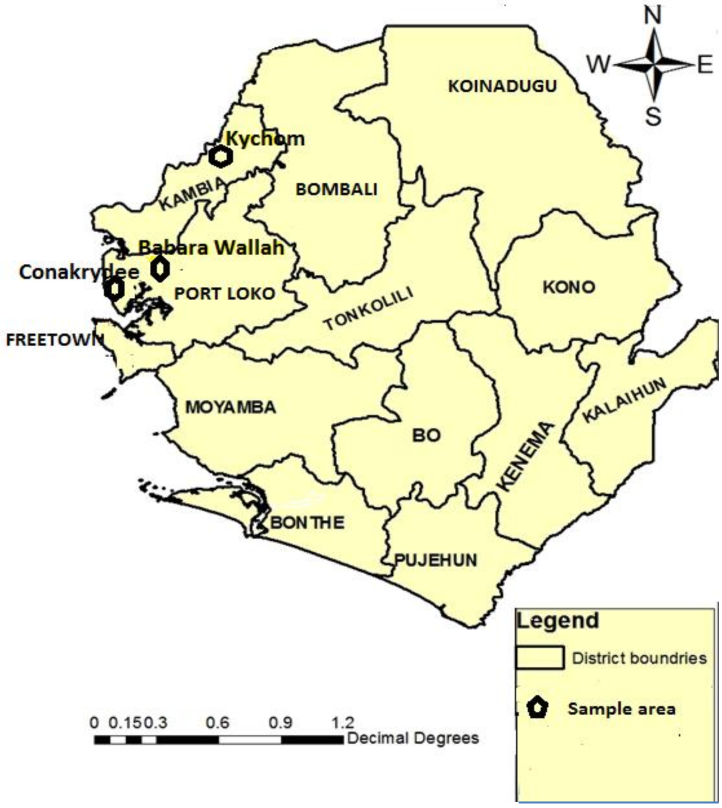


Figure 1: A map of Sierra Leone showing the sample collection areas (developed from arc-gis shape files)

Soil sample collection

The top 2 cm of the soils were collected using a monolith auger. Five samples were collected at random from various points within a portion and mixed thoroughly to form a homogeneous sample representing the plot. Plots from which samples were collected were all bigger than four hectares. The samples were then transferred to polythene bags and stored frozen.

Rice sample collection

Rice samples were collected using a knife, when the plants were fully matured and ready for harvest (90 days after cultivation). Five strands of rice were collected from each portion. Strands from the same portion are put together to form a composite sample. The samples were sealed in polythene bags and stored at freezing point until analysis.

Biota samples collection

Tilapia fish (*Pelmatolapia mariae*), crabs (*Sudononautes kagoroensis*), shrimps (*Penaeus notialis*) and mudskippers (*Periophthalmus barbarous*) were collected from either the portion or from the adjacent river using local methods. Each biota sample was sealed in a polythene bag just after collection using a vacuum sealer and then stored below 0°C.

Laboratory analysis

Reagents and standards

Ethyl acetate, hexane and acetone were HPLC grade solvents from Fisher Scientific UK. Sodium sulphate (Na_2SO_4) was obtained from Sigma Aldrich and alumina and florisil were obtained from Merck in Germany. Labelled d-10 chlorpyrifos diethyl used as the recovery standard was obtained from Cambridge Isotope Laboratories Inc. The stock solution of the recovery standard was 100 µg/ml in nonane and was diluted to 1 µg/ml in hexane. Analytical grade isotope-labelled triphenyl phosphate (TPP-d15) was purchased from QMX Laboratories Ltd, Thaxted, UK. TPP-d15 was used as internal standard. A 100 µg/ml TPP was prepared using acetone as the solvent. A stock solution of 1000 µg/ml chlorpyrifos was prepared in acetone using analytical grade chlorpyrifos-ethyl obtained from Sigma-Aldrich UK. From the stock solution, seven calibration standard solutions in hexane (150, 300, 400, 500, 700, 1000, 1500, 2100, 3000 and 3500 pg/µl) were prepared.

Sample preparation

Soil samples from the freezer were allowed to thaw, homogenised and then 1 g of sample was transferred into a centrifuge tube. The soil sample in the centrifuge tube was dried using 3 g of baked anhydrous Na_2SO_4. The soil/Na_2SO_4 mixture was thoroughly mixed until a fine dry powder was obtained. The dried sample was spiked with 50 µl of 1 µg/ml d-10 chlorpyrifos in hexane as a recovery standard. A blank containing 3 g of Na_2SO_4 was included after every 10 samples.

Rice samples were ground using a coffee grinder and then sieved with a 125 µm sieve, and 5 g of the rice powder obtained was dried with 2 g baked anhydrous Na_2SO_4 in a centrifuge tube. The dry mixture was spiked with 50 µl of 1µg/ml d-10 chlorpyrifos in hexane. A blank with 2 g of baked anhydrous Na_2SO_4 was included after every 10 samples.

Each of the biota samples was ground using a mortar and pestle to a smooth paste. 2 gram of the paste was dried with 6 g of Na_2SO_4 in a centrifuge tube. The dried sample was spiked with 50 µl of 1 µg/ml d-10 chlorpyrifos in hexane. A blank with 2 g of baked anhydrous Na_2SO_4 was included after every 10 samples.

Extraction and clean-up

The samples were extracted with a 30 ml 2:3 hexane: ethyl acetate mixture. To the spiked and Na_2SO_4-dried samples in the centrifuge tube, 10 ml of the extracting mixture were added, hand-shaken for 10 minutes and centrifuged at 2000 rpm for 2 minutes. The extract was decanted and the extraction was repeated three times. The volume of the extracts was reduced to about 1 ml using a slow stream of nitrogen gas at a temperature of 40^0 C. The soil and rice extracts were cleaned using a solid phase chromatography glass column filled with 5 g of alumina, 3 g of florisil and about 1 cm layer of sodium sulphate. The column was rinsed with 20 ml ethyl acetate before adding the samples. The extract was eluted through the column with 20 ml ethyl acetate. The biota extracts were cleaned with gel permeation chromatography columns to remove the fat content before cleaning with the solid phase chromatography glass columns. The volume was reduced to about 0.5 ml using a slow stream of nitrogen gas and then transferred to a two ml vial to which 10 µl of 100 µg/ml TPP-d15 solution were added. The resulting solution was blown to dryness and re-dissolved with 1 ml hexane. Samples that exceeded the calibration range were diluted with hexane and the dilution factor was noted.

Analytical instrument setup

The samples were analysed using a Finnigan TRACE GC-MS system, equipped with a Phenomenex ZB-MultiResidue-2 GC column (30m x 0.25mm x 0.2µm). The initial oven temperature was 70^0 C (held for 2min), then increased to 150^0 C at a rate of 25^0 C min^{-1}, further increased to 220^0 C (3^0 C min^{-1}), and finally to 300^0 C (10^0 C min^{-1}), where it was held for 10 minutes. The GC interface temperature was set to 300^0 C, and the MS source temperature to 250^0 C.

Determination of soil density

The volume of the soil was determined with a graduated cylinder containing water. The density was determined using the equation:

$$density\ \left(\frac{g}{cm^3}\right) = \frac{mass(g)}{volume\ (cm^3)}$$

Determination of percentage moisture content and percentage organic carbon

The soil samples were placed in an oven and heated over night at 105°C. The percentage moisture content (%MCF) was calculated using the equation below:

$$\%MCF = \frac{(M1 - M2)}{M1} X\ 100$$

The oven dry soil was placed in a furnace and heated to 440°C overnight. The organic matter content (%C) was calculated using the following equation:

$$\%C = \frac{(M2 - M3)}{(M2)} X\ 100$$

Where, M1 = mass of moist soil; M2 = mass of oven dry soil; M3 = mass of soil residue from furnace.

Data analysis

Averages of data obtained were displayed using bar charts with standard error bars. Comparison of masses obtained between the locations was done using ANOVA at 95% confidence level and Tukey was used as a post hoc test. The results obtained from the various farms within a community or between communities were compared using the paired t-test statistics tool at 95% confidence level.

Results and discussion

Validation of analytical method

The analytical method was tested with d – chlorpyrifos as recovery standard. The recoveries obtained ranged from 80 to 95%. The detection limit of the analytical instrument was 100 to 4000 pg/µl.

Levels of chlorpyrifos

Soils

The levels of chlorpyrifos found in soil samples collected from Conakrydee, Babara Wallah and Kychom range from 2.3 to 13.0, 1.2 to 9.6 and 1.9 to 17.0 µg/g of soil respectively. The mean of chlorpyrifos levels on soils are, 4.0, 3.0 and 8.1 µg/g of soil, for Conakrydee, Babara Wallah and Kychom respectively (Figure 2). The levels of chlorpyrifos of samples collected from Conakarydee, Babara Wallah and Kychom on average, are 4, 3, and 7 times higher than the recommended maximum application dose on the label of the pesticide's container (1.1 μg of chlorpyrifos/g of soil (140 ml of pesticide/acre of land)). Roger (1990) also stated that application rates should not be greater than 1.1 ppm. This means the soils are contaminated with chlorpyrifos. Chlorpyrifos is significantly higher in soil samples from Kychom than those from Conakrydee and Babara Wallah. This high contamination could either be a result of the accumulation of the pesticide in the soil or a result of overuse. When chlorpyrifos is applied to soils, most of it is bio-degraded, volatilised and washed away by runoff, so that the levels retained after a cropping season are low (van der Werf, 1996; Das & Adhya 2015; Wang et al 2016). This suggests that the dominant factor responsible for the high levels of pesticides in these soil samples is overuse. According to Roger & Bhuiyan (2016), farmers in developing countries frequently ignore recommended pesticide application regimes and both excessive and reduced application rates have been reported.

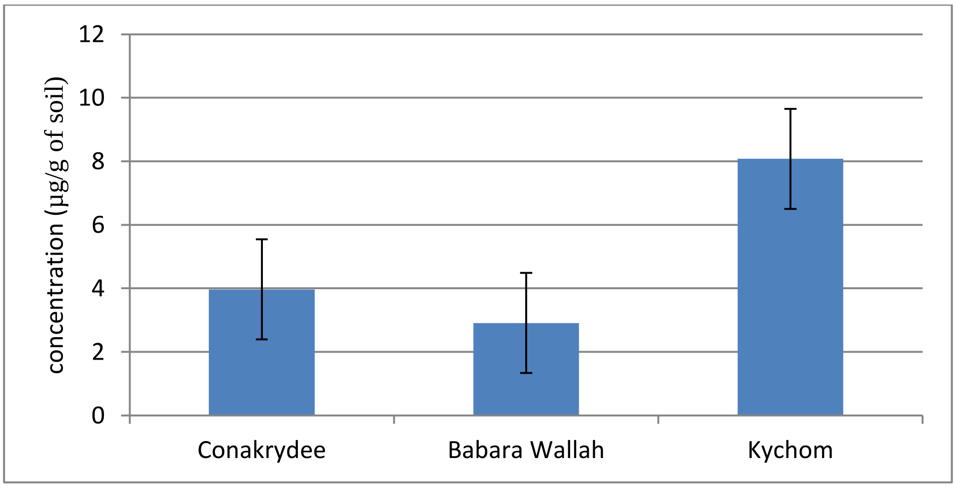


Figure 2: A bar chart showing the average and range of chlorpyrifos in soil samples (n = 9, +/- SE of mean) collected from Conakrydee, Babara Wallah and Kychom

The soil is a reservoir for the contamination of the other facets of the environment and for the uptake by plants (Caravan & Hoy, 2005; Roger & Bhuiyan, 2016). Therefore, the high levels of chlorpyrifos in the biota and rice samples could be attributed to the high levels applied to the soil. However, high concentrations in soils do not necessarily equate to high concentrations in water (Levitan et al, 1995; Das & Adhya, 2014, Roger and Bhuiyan, 2016).

Rice

The range of chlorpyrifos concentrations found in rice samples are from 2-18, 4-13 and 8-45 ng/g of rice for Conakrydee, Babarah Wallah and Kychom respectively. Analysis using ANOVA showed that there is no significant difference between samples from the three locations ($p = 0.094$). The average levels of chlorpyrifos found in rice (Oryza glaberrima) are; 7, 7 and 16 ng/g of rice from samples collected from Conakrydee, Babara Wallah and Kychom, respectively (Figure 3). All these levels are within the European recommended maximum limit which is 50 ng/g of rice (Commission regulation (EU), 2016). Levels of chlorpyrifos ranging from 1 - 2,200 ng/g in rice have also been reported (Pareja et al 2011). According to Li et al (2015), levels of chlorpyrifos do not exceed the recommended maximum limits when normal dosages of the pesticide are applied to the soil. Contaminated soils levels of up to 3.23 µg/g appear to be the highest that have been reported (Li et al, 2015).

According to CARD (2009), the national rice self-sufficiency in Sierra Leone is about 70%. More efforts to improve this are ongoing. This means the majority of the Sierra Leone population depends on locally produced rice for consumption. Babara Wallah and Kychom are among the highest paddy rice producing communities. This is the reason why paddy rice (Oryza glaberrima) is locally known as ‘Wallah’ rice in Sierra Leone. The farming practices within these communities are similar. Therefore, an effect on one community would be similar to the other. It is therefore expected that similar levels of chlorpyrifos would be found on rice cultivated on farms at these communities. This suggests that the long term consumption of locally produced rice could have negative effects on the health of the consumers.

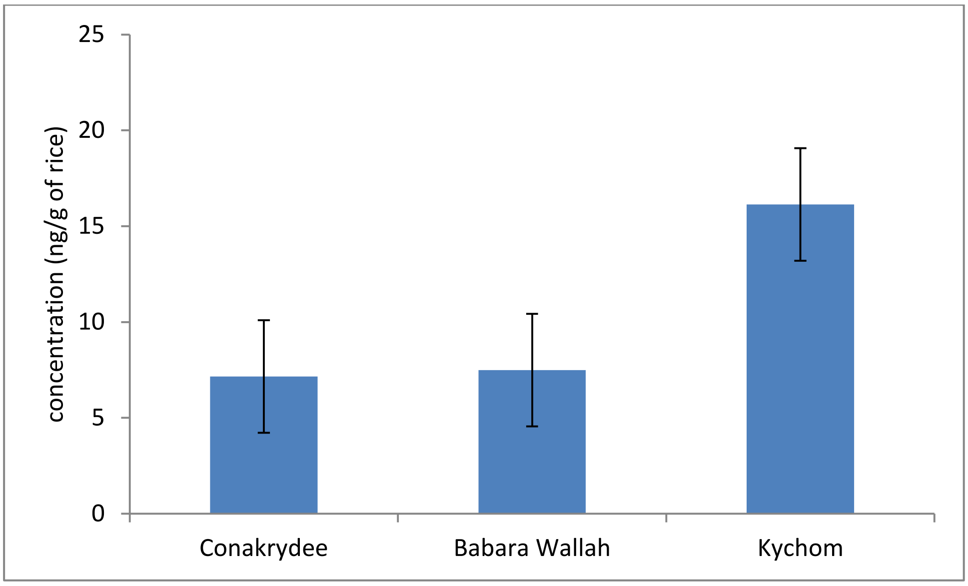


Figure 3: Average mass of chlorpyrifos on rice samples (n = 9, +/- SE of mean) collected from Conakrydee, Babara Wallah and Kychom.

The fraction of chlorpyrifos that is stored in rice grains is low (Zhang et al, 2012). For levels of chlorpyrifos to be so high in rice samples the soil has to be highly contaminated (Li et al, 2015). The high contamination of soil is an indication of an over use of chlorpyrifos by farmers.

Crabs

Another set of organisms sampled and analysed were crabs which are also widely consumed by people especially farmers in Sierra Leone. Crabs are the target pests in lowland paddy rice fields when pesticides like chlorpyrifos are applied. The levels of chlorpyrifos in crabs range from 14 - 334 ng/g of crab. The average levels of chlorpyrifos on crab samples are as follows: 20, 20 and 200 ng/g of crab for samples from Conakrydee, Babara Wallah and Kychom, respectively (Figure 4). The levels of chlorpyrifos found in samples from Kychom are far higher than those from Conakrydee and Babara Wallah. The consumption of such crabs can be a major exposure route of chlorpyrifos for man and other consumers. Exposing crabs to a single dose of 200 ng of chlorpyrifos would kill the organism (Narra et al, 2013; Mararajan et al, 2015). However, chlorpyrifos concentrations of up to 330 ng/g of crab were found in living crabs from Kychom. This is an indication that crabs are becoming more tolerant to the pesticide and can only be killed by applying more pesticides (Haung et al, 2005). This practice could lead to more environmental pollution. Levels of chlorpyrifos in crab samples collected from Kychom are significantly higher than those of both Conakrydee and Babara Wallah (p = 0.000 (Tukey)).

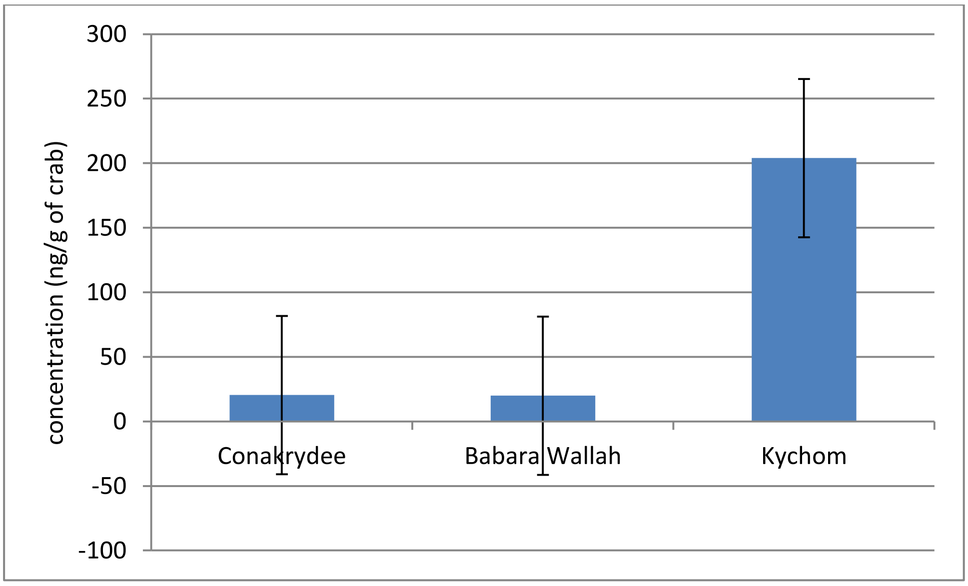


Figure 4: average Concentrations of chlorpyrifos on crab samples (n = 9, +/- SE of mean) collected from Conakrydee, Babara Wallah and Kychom

Crabs are omnivorous but their feeding habits depend on the type of crab species. However, their diverse feeding habits could lead to the ingestion of toxins like chlorpyrifos. Crabs from the sampled environments live in borrows and hardly leave their habitats. Predators are attracted to the environments to hunt for crabs. This could bring about transfer of the toxin and transport through the food web.

Fish

Tilapia fish is one of the most widely eaten fish is Sierra Leone, as it is a source of cheap protein (Oceanic Development, 2006) and can be easily captured. The levels of chlorpyrifos in fish samples ranged from 2 to 256 ng /g of fish. Average levels of chlorpyrifos in fish samples are 45, 30, 41 ng/g of fish for samples collected from Conakrydee, Babara Wallah and Kychom, respectively (Figure 5). According to Axe (2008), the consumption of tilapia fish is not advisable as a result of its ability to absorb contaminants such as pesticides. The fish is very good in storing organic chemicals in its high levels of omega 6 fats (Axe, 2008; Boateng, 2006). The levels of chlorpyrifos found in the fish samples are not significantly different (p = 0.798 (ANOVA)). This is also expected to be true for the consumption of other species of fish found in these environments.

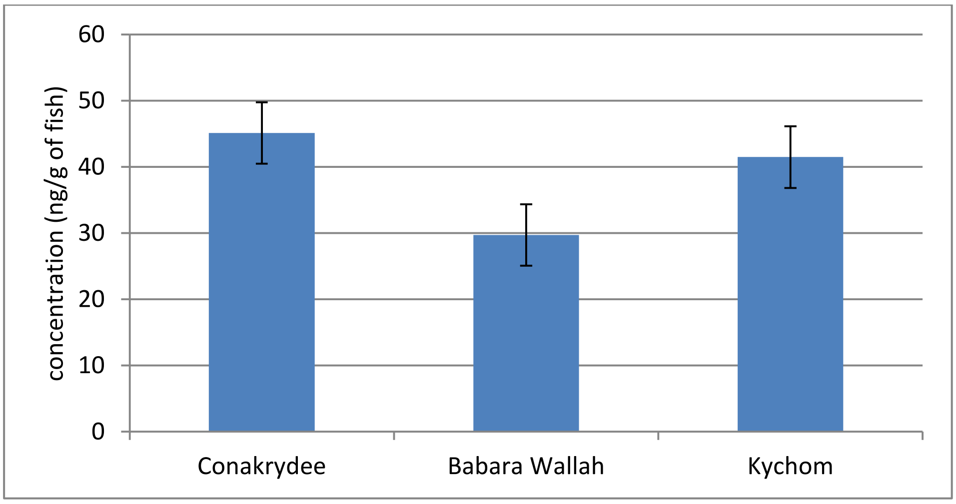


Figure 5: Average concentrations and ranges of chlorpyrifos in fish samples (n = 9, +/- SE of mean) collected from Conakarydee. Babara Wallah, and Kychom

Tilapia feeds mainly on the lower trophic level. It feeds on phytoplankton, algae, duckweed and other materials. It is mainly herbivorous but can be omnivorous and even carnivorous (Hutchison, 2012; Milstein, 2000). This feeding habit gives it the ability to absorb contaminants from sediments since its most preferred food is found on the sediments. This organism can move from one aquatic environment to another and could transfer toxic chemicals when eaten by predators that sometimes live far away from the original source of the contaminant. The common predators of tilapia fish include the African catfishes such as *Clarias gariepinus, Clarias anguillaris, Heterobranchus bidorsalis and Heterobranchus longifilis (FAO, 1996; Milstein et al, 2012)*. These are also widely eaten fish species. By feeding on tilapia, the toxins would accumulate on the predators. This could cause problems on organisms on the upper trophic levels.

The presence of chlorpyrifos in fish in general affects reproduction negatively (De Silva and Samayawardhena, 2015). This implies that population growth of both tilapia fish and its predators would be affected. This together with fishing could lead to the extinction of endangered species along the food chain. The exposure of fish to chlorpyrifos is not only limited to tilapia fish but also many other fish species within the ecosystem (Marshall and Roberts1998).

Mudskippers

Mudskippers are omnivorous organisms. They feed on algae, shrimps, insects, and some other life forms such as bivalves. All of these organisms are capable of absorbing chlorpyrifos either directly or indirectly (Gabremariam, 2012; Watts, 2012). Therefore, mudskippers are potentially exposed to chlorpyrifos through their food or through contaminated water in their habitat.

Mudskippers are widely eaten in Sierra Leone and the neighbouring West African countries such as the Republic of Guinea and Liberia, especially by farmers. From the results chlorpyrifos concentrations found in mudskippers range from 7 to 127 ng/g of organism. The average mass of chlorpyrifos found on mudskipper samples collected from Conakrydee, Babara Wallah and Kychom are 19, 9 and 34 ng/g per of organism respectively (Figure 6). A robust test of equality of means using Welch analysis showed that there is a significant difference between samples from Conakrydee, Babara Wallah, and Kychom (p = 0.045). However, LSD post hoc test showed that chlorpyrifos levels in mudskippers from Babara Wallah are significantly lower than those from Kychom.

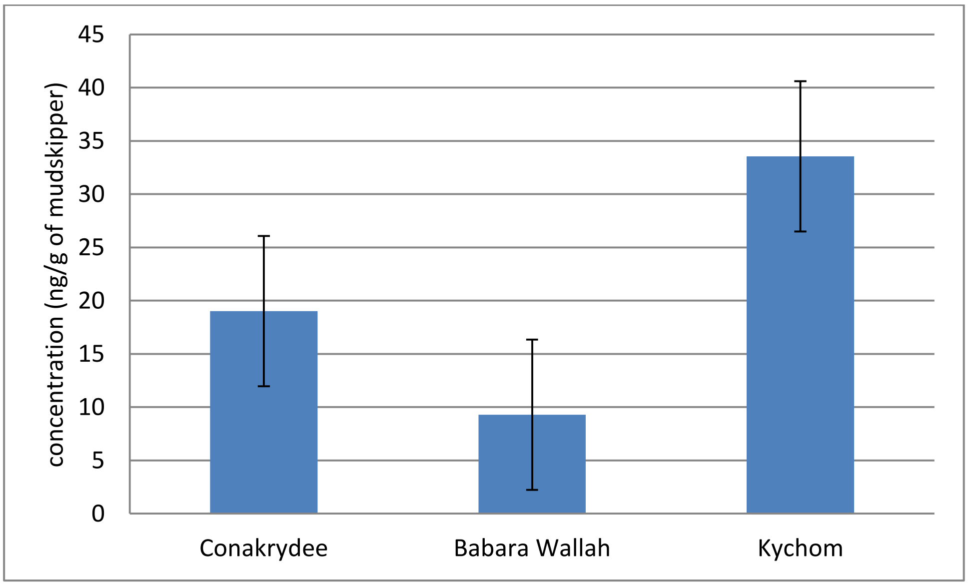


Figure 6: Average concentration of chlorpyrifos in mudskippers (n = 9, +/- SE of mean) collected from Conakrydee, Babara Wallah and Kychom

Chlorpyrifos has a low bio-concentration factor (BCF) in living organisms including mudskippers (BCF = 2.50 to 3.54 (EXTOXNET, 2016)). Therefore, for high levels of chlorpyrifos to occur in the tissues of the organisms, there needs to be high levels of the pesticide in the environment. According to Flores (2007), the lowest concentration of chlorpyrifos in water that can affect mudskippers is 4 μg/l and they survive at concentrations of up to 100 μg/l. Debilitating effects caused by chlorpyrifos concentrations of up to 64 μg/l can be reversed within few hours if the organism is moved to a non-contaminated environment (Flores, 2007). The level of chlorpyrifos in mudskippers is an indication that the chemical is accumulating in the tissues of the fish and hence could serve as an exposure route to man and other organisms in the food web that feed on mudskippers.

Although the levels of chlorpyrifos found in mudskipper are below the lethal level of the organism, these levels could affect their reproductive performance (De Silva and Samayawardhena, 2015). This could have a negative impact to their population growth. According to Marshall and Roberts (1998), mudskippers are an endangered species of fish in the tropics. Therefore, any negative impact on the reproductive performance of these animals could lead to the extinction of the organisms.

Shrimps

Shrimps are a delicacy and highly cherished sea food in Sierra Leone. Chlorpyrifos levels in shrimps range from 1 - 55 ng/ g of shrimp. Average levels of chlorpyrifos found in shrimp samples collected from Conakrydee, Babara Wallah and Kychom are 31, 32 and 21 ng/g of shrimps, respectively (Figure 7). Shrimps can be eaten by several predators including man, fish and birds in all their different developmental stages. This implies contaminants picked up by shrimps can easily enter the food web. This could lead to bio-concentration and bio-magnification. Shrimps migrate from one environment to another, giving them the ability to easily disperse or transport contaminants. There is no significant difference between shrimp samples ($p = 0.092$ (ANOVA)).

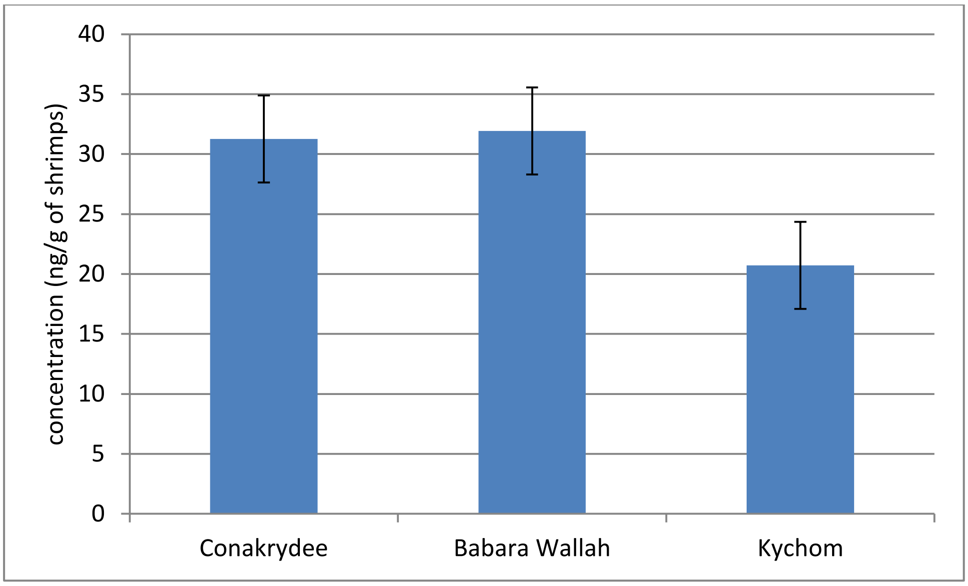


Figure 7: Average concentration of chlorpyrifos on shrimp samples (n = 9, +/- SE of mean) collected from Conakrydee, Babara Wallah and Kychom

Shrimps feed mainly on plant materials, filamentous algae and diatoms (Oluboba, 2015). All of these organisms could be reservoir for agro-chemicals like pesticides. Therefore, the uptake of pesticides by shrimps is likely through its food.

Chlorpyrifos contamination at different sites

In general, all samples from Kychom appear to be more contaminated, except the shrimp samples, although the differences are not significantly different in some of the cases. This is probably because Kychom has a long history of using pesticides which are imported from the Republic of Guinea. Kychom is near the border between the Republic of Guinea and Sierra Leone. The people speak Susu which is the most widely spoken local language in the Republic of Guinea. Because of the common language most of the inhabitants of Kychom and its environs share dual citizenship of the Republic of Guinea and Sierra Leone. This makes it easier for the farmers in Kychom to access pesticides from the Republic of Guinea which has processing factories. Secondly, the cultivation of nerica rice which is a fast growing cultivar is more popular in Samu and Mambolo chiefdoms in which Kychom is found. This makes it possible for farmers to cultivate rice twice within a cropping season (May to December). Pesticides are used whenever new crops are cultivated. Rice cultivation in Conakrydee can only start in July when the salinity of the soil and the adjacent river is low because according to farmers, salt destroy yields and can give rise to poor quality grains. In Babara Wallah, farmers prefer to cultivate rice on bolilands during the first few months of the cropping season. The farmers get their seeds for swamp rice cultivation from the produce of the boliland farms. This means, more pesticides are used on swamps in Kychom than Conakrydee and Babara Wallah.

Human exposure through food

The daily exposure of people in Sierra Leone could involve the consumption of a combination of pesticide contaminated food. A normal dish could contain rice, fish, crabs, and/or shrimps cooked with vegetables which might also be contaminated (Hinderliter et al 2011; Chen et al, 2012). The concentration in the human body depends on both the amount consumed and the body weight. According to Walpole et al (2012), the average body weight in Africa is 60.7 kg and the WHO recommended daily limit of exposure is 0 - 0.01 mg/kg body weight. The daily exposure of 5×10^{-4} mg/kg of body weight of chlorpyrifos over a long period could cause chronic effects such as infertility, cognitive impairment and nervous disorder (Haung et al, 2005, Harper, 2009).

Rice

Rice is the most widely eaten food in Sierra Leone. According to the WHO (2015), the per capita consumption of rice in Sierra Leone is 200 kg/ year. This implies that the daily consumption of rice is ~0.5 kg. The consumption of 0.5 kg of rice from Conakrydee, Babara Wallah and Kychom would expose typical consumers to 3.5, 3.5 and 8.0 µg of chlorpyrifos respectively. These levels could expose consumers to 5.8×10^{-5} and 1.3×10^{-4} mg/kg body weight for 3.5 and 8.0 µg for a typical Sierra Leone man respectively. Hence this should not cause acute problems when consumed. However the long-term consumption of such rice by farmers who consume far above the average consumption, levels that can lead to chronic effects might be consumed.

Fish

The fish consumption rate in Sierra Leone is estimated as 22 kg per capita per annum (Seto et al 2015). This implies about 60 g of fish is eaten per person per day. The consumption of 60 g of this fish species from these environments could expose consumers to 2.7, 1.8, and 2.5 µg of pesticide per meal for Conakrydee, Babara Wallah and Kychom, respectively. The consumption of 60 g of fish from Conakrydee, Babara Wallah and Kychom can lead to concentrations of 4.4×10^{-5}, 3.0×10^{-5} and 4.1×10^{-5} mg/kg of body weight in consumers respectively. This implies the levels of chlorpyrifos in fish from Conakrydee, Babara Wallah and Kychom are not high enough to expose consumers to harmful concentrations of the pesticide.

Mudskippers

The results indicate that eating 60 g of mudskippers per day from Conakrydee, Babara Wallah and Kychom would expose man to 1.14, 0.54, and 2.34 µg of chlorpyrifos respectively. This means consumers of 60 g of mudskippers from Conakrydee, Babara Wallah and Kychom would lead to a pesticide concentration of 1.8×10^{-5}, 8.2×10^{-6}, 3.8×10^{-5} mg/ kg of per body mass respectively. In Kychom levels of up 127 ng/g of mudskipper were found. The consumption of 60g of mudskippers from Kychom could lead to the intake of up to 1.3×10^{-4} mg /kg of body mass. This concentration is close to the levels that can lead to chronic effects and hence can easily reach harmful levels when consumed with other pesticide containing food.

Crabs and shrimps

Levels of up 330 ng/g are found in crabs from Kychom which can lead to concentration of 3.3×10^{-4} mg/kg of body weight in consumers when 60 g is consumed. This is only 1.7×10^{-5} mg/kg of body weight. For shrimps the most contaminated was 55 ng/g of shrimps and it was from Babara Wallah. When 60 g of shrimps is consumed, the concentration of chlorpyrifos in man would be 5.4×10^{-5} mg/kg of body weight. However, crabs and shrimps are not as widely eaten as fish and mudskippers.

Combined food

As mentioned above, a typical Sierra Leonean dish is a combination of mainly rice, fish vegetables and oil. Sometimes crabs, shrimps and chicken and meat are included. All of these foods can be exposed to pesticides. Consider a dish containing rice and fish only. The daily intake of 0.5 kg of rice and 60 g of fish could lead to an intake of chlorpyrifos of up to 38 µg of the pesticide. This could lead to a dose of 6.3×10^{-4} mg/ kg of body weight. This is above the reference chronic dose of 5×10^{-4} mg/kg of body mass/ day. This is an indication that the consumption of food from these communities could lead to chronic effects of chlorpyrifos to consumers.

Conclusion

From the results it was observed that the pesticide residues are high in all the soil samples. This is an indication that pesticides are misused and extremely high levels are applied to the farms. High levels enter the adjacent water bodies and contaminate the living organisms in the aquatic environment. This is the reason for the high levels of chlorpyrifos in all the mudskippers, fish, crabs and shrimps. The high levels of chlorpyrifos contaminants in the adjacent rivers is an indication that high levels of pesticide contaminants are transported to other areas including areas out of Sierra Leone, especially when the contaminated rivers discharge into the Atlantic Ocean, which borders Sierra Leone from the north/west to the south/west.

The high level of chlorpyrifos on rice samples is as a result of the high levels in soils. According to Flores (2007) and Sankoh et al (2016), the uptake of a pesticide by plants depends on the quantity of pesticide applied. Out of the total uptake by plants only a small fraction ends up in the grains (Zhang et al, 2012). The levels chlorpyrifos in rice obtained from this research, can only occur if the soil is highly contaminated. This supports the results obtained from the analysis of the soil samples. Such levels could be harmful to a wide range of terrestrial organisms. Furthermore, in a tropical climate like Sierra Leone, when the level of pesticides is high, there is an increase in the rate of biodegradation and volatilization. The biodegraded pesticide could release toxic metabolites to the environment (Aislabie and Lloyedjones, 1995). The volatilised fraction would be transported by wind to other areas and could also expose arboreal organisms to the toxic contaminant.

Rice, mudskippers, fish, crabs and shrimps are highly consumed food resources for people in Sierra Leone. Results indicate that the level of chlorpyrifos in the samples is not high for human consumption. However, when the food is combined to produce a typical meal, levels that exceeds that could pose threat to human health may occur. The routine consumption of such food could expose consumers to high levels of pesticides capable of causing chronic effects. This could lead to a negative impact on a large proportion of the population.

References

Acker CI and Nogueira CW. (2012) Chlorpyrifos acute exposure induces hyperglycemia and hyperlipidemia in rats. Chemosphere 89: 602-608.

Alcocer MJ, Doyen C, Lee HA, et al. (2000) Properties of polyclonal, monoclonal, and recombinant antibodies recognizing the organophosphorus pesticide chlorpyrifos- ethyl. Journal of Agricultural and Food Chemistry 48: 4053-4060.

Androutsopoulos VP, Hernandez AF, Liesivuori J, et al. (2012) A mechanistic overview of health associated effects of low levels of organochlorine and organophosphorous pesticides. Toxicology. 15: 115 - 121

Asenso-Okyere K, Workneh S, Rhodes E, et al. (2009) Rebuilding after Emergency: Revamping Agriculture Research in Sierra Leone. International Food Policy Research Institute. https://www.asti.cgiar.org/pdf/Sierra-Leone-Note.pdf (Accessed 20/04/16)

Atreya K, Johnsen F, Sitaula B, et al. Health and environmental costs of pesticide use in vegetable farming in Nepal. A Multidisciplinary Approach to the Theory and Practice of Sustainable Development 14: 477-493.

Boateng JO, Nunoo FKE, Dankwa HR, et al. (2006) A toxic effects of deltamethrine on tilapia, Oreochromis niloticus (Linnaeus, 1758). West Africa Journal of Applied Ecology, 9: 1 - 5.

Chen C, Qian Y, Lui X, et al. (2012) Risk assessment of chlorpyrifos on rice and cabbage in China. Elsevier: Regulatory Toxicology and Phermacology, 62: 125-130.

Chindah AC, Sikoki FD and Vincent-Akpu I. (2003) Chances in haematological characteristics of a bony fish, Tilapia guineensis (Bleeker, 1862), exposed to common pesticides in the Niger Delta wetland, Nigeria. Accra: National Science & Technology press: Ghana Jnl agric Sci, 37: 59-67

.

Coalition for African Rice Development (CARD). (2009) National Rice Development Strategy (NRDS) Sierra Leone. JICA https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/sierraleone_en.pdf (accessed: 20/10/15)

Commission RE. (2016) amending annex II and III to regulaion (EC) >o 396/2005 of the Europian Parliament and of the Council as regards maximum residue levels for chlorpyrifos in or on certain products. Official Journal for the European Union, 36: 40- 42.

Craven A and Hoy S. (2004) Pesticide persistence and bound residues in soil-regulatory significance. Elsevier: Environmental Pollution, 133: 5-9.

Das S and Adhya TK. (2015) Degradation of chlorpyrifos in tropical rice soils. Elsevier: Journal of Environmental Management, 152: 36-42.

de Silva P, Mangala CS, Pathiratne A, et al. (2010) Chlorpyrifos causes decreased organic matter decomposition by suppressing earthworm and termite communities in tropical soil. Environmental pollution (Barking, Essex : 1987) 158: 3041 3045.

Deb N and Das S. (2013) Chlorpyrifos toxicity in fish: A review. Current World Environment, 8: 77-84.

Desneux N, Decourtye A and Delpuech J-M. (2007) The Sublethal Effects of Pesticides on Beneficial Arthropods. Annual Review of Entomology, 52: 81 - 106.

Extension Toxicology Network (EXTOXNET). (2016) Pesticides toxicology information brief. A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Michigan State University, Oregon State University, and University of California at Davis. Major support and funding was provided by the USDA/Extension Service/National Agricultural Pesticide Impact Assessment Program. https://www.oregon.gov/ODA/shared/Documents/.../ExtoxnetPesticideInfoProfiles.pd (Accessed: 14/03/16)

FAO. (1996) Artificial reproduction and pond rearing of the African catfish Clarias gariepinus. Fisheries and Aquaculture Department. http://www.fao.org/docrep/003/w3595e/w3595e08.htm (Accessed 23/05/16)

Flores F. (2007) Cholinesterase inhibition in mudskippers (Periophthalmus novaeguineaensis) by chlorpyrifos Thesis School of Marine and Tropical Biology, James Cook University

Gainessi L. (2014) Importance of pesticides for growing rice in Sub-Sharan Africa. CropLife International. Study no 101 https://croplife.org/case-study/importance-of-pesticides-for-growing-rice-in-sub-saharan-africa/ (Accessed: 12/05/16)

Gebremariam SY, Beutel MW, Flury M, et al. (2012) Nonsingular adsorption/ desorption of chlorpyrifos in soils and sediments: experimental results and modeling. Environmental science & technology 46: 869- 874.

Hinderliter PM, Price PS, Bartels MJ, et al. (2011) Development of a source-to-outcome model for dietary exposures to insecticide residues: An example using chlorpyrifos. Regulatory Toxicology and Pharmacology, 61: 82 - 92.

Hung H, Blanchard P, Halsall CJ, et al. (2005) Temporal and spatial variabilities of atmospheric polychlorinated biphenyls (PCBs), organochlorine (OC) pesticides and polycyclic aromatic hydrocarbons (PAHs) in the Canadian Arctic: Results from a decade of monitoring. Science of the Total Environment 342: 119-144.

Levitan L, Merwin I and Kovach J. (1995) Assessing the relative environmental impacts of agricultural pesticides: the quest for a holistic method. Agriculture, Ecosystems and Environment 55: 153-168.

Li R, He L, Wei W, et al. (2015) Chlorpyrifos residue levels on field crops (rice, maize and soybean) in China and their dietary risks to consumers.: Food Control, 51: 212-217.

Lorenz ES. (2009) Potential Health Effects of Pesticides. Pennstate university.

Nara M.R., Rajendera K, Rao JV, Bequm G.. (2013) Evaluation of the biochemical stress response to chlorpyrifos in tissues of the edible crab Barytelphusa guerini: withdrawal of exposure improves the nutritional value. Pub Med.org: Pub Med, 25: 318 - 326.

Maharajan A, Narayanasamy Y, Ganapiriya V, et al. (2015) Histological alterations of a combination of Chlorpyrifos and Cypermethrin (Nurocombi) insecticide in the fresh water crab, Paratelphusa jacquemontii (Rathbun). The Journal of Basic & Applied Zoology 72: 104 - 112.

Marshall WK and Roberts JR. (1978) Ecotoxicology of chlorpyrifos. National research council of Canada. 1st edition, pp 115 - 116

Medline Plus. (2015) Insecticide poisoning. US National Library. www.nlm.nih.gov › Home › Medical Encyclopedi (Accessed 03/11/15)

Milstein A, Eran Y, Nitzan E, et al. (2000) Tilapia wild spawning control through predator fishes: Israeli trial with red-drum and hybrid bass. Kluwer Academic Publishers. Printed in the Netherlands: Aquaculture International, 8: 31 - 40.

Ministry of Agriculture and food security (MAFS). (2012) Pesticides in Sierra Leone. Chemical Information Exchange.

Oceanic Developement. (2006) Ex ante evaluation of existing conditions in the fisheries sectors of Sierra Leone. Mega PESCA Lda.

Oteng JW and Sant'Anna R. (2015) Rice Production in Africa: current situation and issues. Intrenational Rice Commission Newsletter 48.

Pareja L, Fernandez-Alba AR, Cesio V, et al. (2011) Analytical methods for pesticide residues in rice. Trends in Analytical Chemistry, 30: 270 - 290.

Pesticide Safety Education Program (PSEP). (2015) Symptoms of Pesticide Poisoning. psep.cce.cornell.edu (Accessed: 20/04/15)

Roger PA and Bhuiyan SI. (1990) Behaviour of pesticides in rice-based agrosystems : A review. Impact of pesticides on farmer health and the rice environment International rice research paper series: International rice research paper series, 5: 111-148.

Samado EA, Guel RG and Nguyen N. (2015) Overview: Rice in Africa. http://www.africarice.org/publications/nerica-comp/module%201_Low.pdf (Acessed: 20/10/15)

Sankoh AI, Whittle R, Semple KT, et al. (2016) An assessment of the impacts of pesticide use on the environment and health of rice farmers in Sierra Leone. Environment International. 94:458-466

Sannoh IJ. (2011) Agricultural and Rural Development Statistics in Sierra Leone - Key Aspects of Institutional Arrangements & Performance. In: FAO (ed). www.fao.org/fileadmin/templates/ess/pages/rural/wye_city_group/2011/documents/session6/Sannoh_-_Paper.pdf (Accessed 15/10/2015)

Seto K, Belhabib D, Copeland D, et al. (2015) Colonialism, conflict, and fish: a recostruction of marine fisheries catches for Sierr Leone, 1950-2010. Fisheries Center, 74: 1 - 23.

TheGuardian. (2015) Soil: the sustainable alternative to oil income in Africa. theguardian. http://www.theguardian.com/global-development-professionals-network/2014/dec/30/soil-the-sustainable-alternative-to-oil-income-in-africa (Accessed: 02/11/15)

USAID. (2009) Sierra Leone Workshop USAID Pesticide Procedures. importalnet/library/content/food-for../sierra-leone—pesticides (Accessed: 02/11/15)

van der Werf HM. (1996) Assessing the impact of pesticides on the environment. Agriculture, Ecosystems & Environment, 60: 81 - 96.

Walpole SC, Prieto-Meruno D, Edwards P, et al. (2012) The weight of nations: an estimation of adult human biomass. BMC Public Health, 12: 439 - 440.

Wang P, Rashid M, Lui J, et al. (2016) Identification of multi-insecticide residues using GC-NPD and the degradation kinetics of chlorpyrifos in sweet corn and soils. Elsevier: Food Chemistry, 212: 420-426.

Watts M. (2012) Chlorpyrifos as a possible global POP. Pesticide Action Network, 80: 1-34.

Xie H, Guetzloff TF and Rice JA. (1997) FRACTIONATION OF PESTICIDE RESIDUES BOUND TO HUMIN. Soil science 162: 421-429.

Zhang X, Shen Y, Yu X-y, et al. (2012) Dissipation of chlorpyrifos and residue analysis in rice, soil and water under paddy field conditions. Ecotoxicology and Environmental Safety 78: 276-280.

Chapter 5

Summary, conclusion and recommendation

Pesticide use and its impacts in Sierra Leone

This section is a summary of pesticide use in Sierra Leone and how these uses impact the health of people and the environment. In particular, this section focussed on the prevalence of pesticide use among rice farmers in Sierra Leone, paying particular attention to the application methods, to assess potential impacts and risks to human health and the environment.

Pesticide use is highly linked to the social life of the users. To understand the effects of pesticides on the environment and human, both a scientific and a social point of view should be considered. This brought about the idea of using questionnaires formulated to complement the scientific findings reported in this thesis. Pesticide use in Africa is low compared to the levels used in the other continents of the world (PAN-UK, 2007). According PAN-UK (2007), only 4% of the global pesticide production is used in Africa. However, as a result of economic problems and high illiteracy levels among pesticide users in Africa, cases of excessive pesticide exposure are high (Rother, 2008). Pesticide exposure could be through various routes. These include dermal exposure, oral exposure and exposure through inhalation. Dermal exposure is the most common exposure route that occurs during application. This is pronounced as a result of poor personal protection. Oral exposure is mostly through food and to some extent water. Exposure could affect human health. According to Koh and Jayaratnam (1996), pesticide exposure can occur under different circumstances and the vulnerable groups are people working with pesticides. Exposure could be suicidal (intentional), occupational, and un-occupational (non-intentional). The vulnerability is more pronounced in developing countries where governments do not have adequate funds for the implementation of safe use, even where there are safe use policies. Even though the quantity of pesticides used in Africa is low when compared to other continents, the massive misuse of pesticides in Africa is impacting negatively on the health of the people. A case of 49 people poisoned and 15 deaths caused by parathion in Sierra Leone was reported (Etzel et al, 1987).

Pesticides misuse is also affecting the environment (Wilson and Tisdell, 2001). When pesticides are applied, a fraction is volatilised, some degrades, some leaches to underground water, washed off by surface runoff, taken up by plants and absorbed by soils. According to Centofanti et al (2001), degradation, surface runoff, volatilization, and leaching of pesticides could lead to long range transport of both the parent compounds and their metabolites. This means other environments would be contaminated.

In Sierra Leone pesticides are widely used but existing evidence shows that the use of these chemicals is not adequately monitored and it is not well documented (Bennet et al, 2012, IFDC, 2008). Pesticides are used in offices, homes and agricultural fields. In homes and offices, pesticides are used against mosquitoes, flies, cockroaches, termites, bedbugs and rats. All of these organisms could be vectors for various diseases causing organisms. In agricultural fields pesticides are used to eradicate pests which can destroy crops and hence destroy yields. Some of these organisms include insects, rodents, crabs, birds, and bugs. Some apply pesticides on the heads of people, especially children, for the eradication of head lice. Insecticides such as spiritex, mosquito coils, permethrin (used for treating bed nets), carbolineum, malathion, diazinon, chlorpyrifos, cyfluthrine and furandan are widely used in Sierra Leone. These insecticides can have negative impacts on humans when exposed excessively. For example, tetramethrin and beta-cypermethrin the active ingredients in Spritex, are carcinogens (Boateng, 2006). The burning of mosquito coils could lead to the release of bis-chloromethyl ether which is an extreme potent carcinogen (World of Chemicals, 2016). Even though these pesticides are widely used, there is no record that shows the impact of these substances on the people of Sierra Leone.

In Sierra Leone pests are affecting the productivity of all major food and cash crops, which includes rice, maize, cassava groundnuts, coffee, cocoa, oil palm and sweet potatoes. According to CABI (2006), pests destroyed up to 51% of rice, 60% of cassava and 58% of maize in Sierra Leone from 2003 – 2005. This means the use of pesticides in Sierra Leone is necessary for the success of food self-sufficiency programmes. However, given the economic status of the country and the sanctions on pesticides as a result their toxic effects, the Sierra Leone government could not support adequate import and distribution of pesticides. However, farmers find ways to get their pesticide supplies to enhance productivity. Most of these ways are considered to be illegal (IFDC, 2008). According to IFDC (2008), only 5% of farmers in Sierra Leone use pesticides. This level is considered to be too low to cause serious problems to the environment and affect the health of people significantly. According to CABI (2006), this is because the farmers are poor and could not afford to buy expensive pesticides. This means the government of Sierra Leone pays less attention to issues pertaining to pesticides.

EPA – SL (2000) stipulated that pesticide use must be regulated to avoid the negative impacts of pesticides and their metabolites to the health of the people and the environment. Internationally banned pesticides are banned from entering Sierra Leone and legislative measures were set to ensure enforcement (EPA – SL, 2006). Sierra Leone has also ratified the Stockholm Convention on persistent organic pollutants (POPs) for the protection of life and the environment. Institutions are put in place to address such issues. According to the legislation, pesticides should only be imported by licensed importers and these licenses should be obtained from the Ministry of Trade. However, these laws do not appear to be enforced effectively and pesticides are still entering the country illegally and are been imported by unlicensed business people (Sankoh et al, 2016, IFDC, 2008). The quality of all commodities, including pesticides, entering the country should be assessed by the Sierra Leone Standards Bureau but according to IFDC (2008), the Bureau does not have the laboratory facilities to assess pesticides. This implies pesticides are what the importers say they are.

Research instrument

Structured interview schedules were applied to farmers to study the prevalence and handling of pesticides in Sierra Leone. This interview schedule was designed to study the social aspect of pesticide use. It investigated the method of application, handling, storage and safety. It also studied the impact of pesticide use on the health, economic and social activities on users and the wider Sierra Leonean population. Structured questionnaires were applied to health workers to also investigate the impact of pesticides on the health of farmers. However, impact on health needs more parameters such as the body mass/weight of farmers which were not considered in this reach. Hence results obtained could only be indicators but not and absolute health impacts.

Focus group discussions and discussions with government stake holders also were done.

Prevalence and use of pesticides in Sierra Leone

According to IFDC (2008), only 5% of farmers in Sierra Leone use pesticides. Smith (2012) stated that 90% of the farmers in Sierra Leone are poor and could only undertake subsistence farming which cannot give them sufficient funds to buy pesticides. However, the results obtained from interviews in this study indicate that 86.4% of respondents (432 out of 500 questioned) use at least one type of pesticide on their farms.

This suggests that the use of pesticides in rice cultivation is common in Sierra Leone. From interviews it was revealed that pesticides are used on farms in all the 12 districts of Sierra Leone (table 1). All respondents from Kambia and Portloko stated that they are using pesticides on their farms. Only 40% of respondents from Karleh and Mokainsumana in Bonthe and Moyamba districts respectively use pesticides on their farms. From the interviews and focus group discussions, farmers stated that the use of pesticides reduces labour and promotes crop yield. A farmer in Kychom said during an interview:

“The use of pesticides has brought some relief to us. We no longer have to nurse our crops on infertile upland soils. We used to spend a lot of money on labour to prepare the nursery and to transport seedlings to the farms for transplanting. Secondly, these chemicals also act like fertilizers. When applied the yield would be far higher than when not used”.

This implies farmers see the use of pesticide as a cost effective process. Buying the pesticides would cut down cost. In addition to this, most of the farmers do not have to pay cash for the pesticides. Vendors give them the pesticides on loan. They pay back using their produce after harvesting. Furthermore, the pesticides can be loaned in small fractions. This makes it easier for the farmers to access pesticides. Therefore, even the poorest farmer can have access to pesticides. Hence poverty is not stopping farmers from using pesticides. Although IFDC (2008), reported that only 5% of respondents uses pesticides, the levels of furadan use reported (21%) is in conformity with that which is reported by this study (20%).

It was stated that 60 – 70% of the work force in Sierra Leone are farmers (FAO, 2011) and 80% of these are rice farmers (Nation's Encyclopaedia, 2014). Exposure to pesticides is not only limited to people considered to be within the work force age which is between 18 and 65 years. It was observed that children as young as 8 years and farmers as old as 75 years are also involved in farming activities which involves direct exposure to pesticides (Sankoh et al, 2016). Both male and female farmers could be exposed, but from the focus group discussions it was found that mainly boys and men between 15 to 60 years handle and apply pesticides on the farms. Pesticide use in Sierra Leone is not just limited to agricultural activities. Almost every household in Sierra Leone uses pesticides at home for the eradication of mosquitoes, house flies, cockroaches, rats, bed bugs, head lice, black flies and termites. In Freetown for instance, discussion with three pest control teams revealed that pesticides like malathion, chlorpyrifos, diazinon, cyfluthrine, abamectine and permethrin, are applied at most homes by pest control personnel. Pesticides are applied in the houses, especially bed and living rooms. They are also applied to toilets and drainages (Figure 1). Propanil and 2,4-D and often used to get rid of plants growing on the walls of buildings or fences which belong to people who can afford to pay for that service. Mosquito coils, spritex, shelltox, insecticide treated bed nets and other insect killer sprays are also widely used in Sierra Leone. This is an indication that most of the population in Sierra Leone is in contact with pesticides which could lead to negative health effects if these harmful substances are not handled properly (Sankoh et al 2016).

Figure 1: A pest controller spraying cyfluthrine at a residence in Freetown (original)

Table 1: A table showing the distribution of farmers interviewed and the number using pesticides on their farms in Sierra Leone

Province	District	Chiefdom	Town/village	Number of farmers interviewed	Number using pesticides	% using pesticides
Eastern Province	Kono	Soa	Kamadu	10	9	90
		Sando	Kayima	10	8	80
		Gbane-Kandor	Koardu	10	8	80
	Kailahun	Kpengewea	Bunumbu	15	12	80
	Kenema	Tonkia	Gorahun	15	8	73
Southern province	Bonthe	Sogbani	Karleh	15	6	40
	Bo	Kakua	Sembehun 17	28	25	89
		Lugbo	Bontiwo	10	10	90
	Pujehun	Yekomo Kpukumu Krim	Boma	12	11	92
		Sowa	Geo Jagor	10	8	80
	Moyamba	Kargboro	Mokainsumana	20	8	40
		Kargboro	Lawana	12	6	50

		Bompeh	Moya	12	8	67
Northern Province	Bombali	Sella Limba	Kapethe	15	10	67
		Sanda Magbolontho	Mayata	15	13	87
		SandaTaindaren	Rogbin	20	15	80
	Tonkolili	Cholifa	Mathora	16	13	88
		Gbokorlenken	Patifu-Mayopoh	20	16	85
	Kambia	Samu	Kychom	45	45	100
		Mambolo	Mambolo	20	20	100
		Mambolo	Rokupr	20	20	100
		Mambolo	Katima	20	20	100
	Port Loko	Lokomassama	Babarawallah	40	40	100
		Lokomassama	Kalangba	25	25	100
		Lokomassama	Gbentiwallah	25	25	100
		KaffuBullom	Conakrydee	10	10	100
	Koinadugu		Kabala	30	28	93

Types of pesticides used on rice farms in Sierra Leone

Results obtained from the interviews and focus group discussions indicate that a wide range of pesticides are used in Sierra Leone. These include EPA banned pesticides such as diazinone. However, the most commonly used pesticides for rice production include chlorpyrifos (60%), furadan (20%), Malathion (5%), and cabolinium (5%). Herbicides like propanil and 2,4-D are in use but not very common. These pesticides are sold in different brand names such as “Sarifos”, “Yarifos”, “Tricel” (Figure 2). In Bo district, 5 farmers stated that they use Indocin to try to kill rats on their farms. Indocin is a drug normally prescribed for pain symptoms in health centres. The types of pesticides farmers use depend more on availability rather than the type of pest. The most common pests that farmers target are birds, rodents, crabs, insects and other bugs such as the stem borer. Various pesticides have various effects on both exposed people and the environment (Alcocer et al, 2000; Acker and Nogueira, 2012; Alves et al, 2012; Androutsopoulos et al, 2012; Ali et al, 2014; Mahmood et al, 2014; Bedi et al 2015). This is an indication that the use of pesticides in Sierra Leone can be hazardous to both the people exposed to pesticides and the environment.

Figure 2: Some of the pesticides commonly used by rice farmers in Sierra Leone (original)

Sources of pesticides

Supply of pesticides

Results also indicate that 75% of the pesticides used by rice farmers in Sierra Leone are bought from local traders (Figure 3). About 80% of these local traders import their supply of pesticides from the Republic of Guinea where there are packaging and processing factories. About 90% of the local traders cannot read and understand the instructions written in French. Most of the small fraction (11%) that comes from the Government (Ministry of Agriculture) also ends up in the hands of local traders, as in the case of the farmer discussed above.

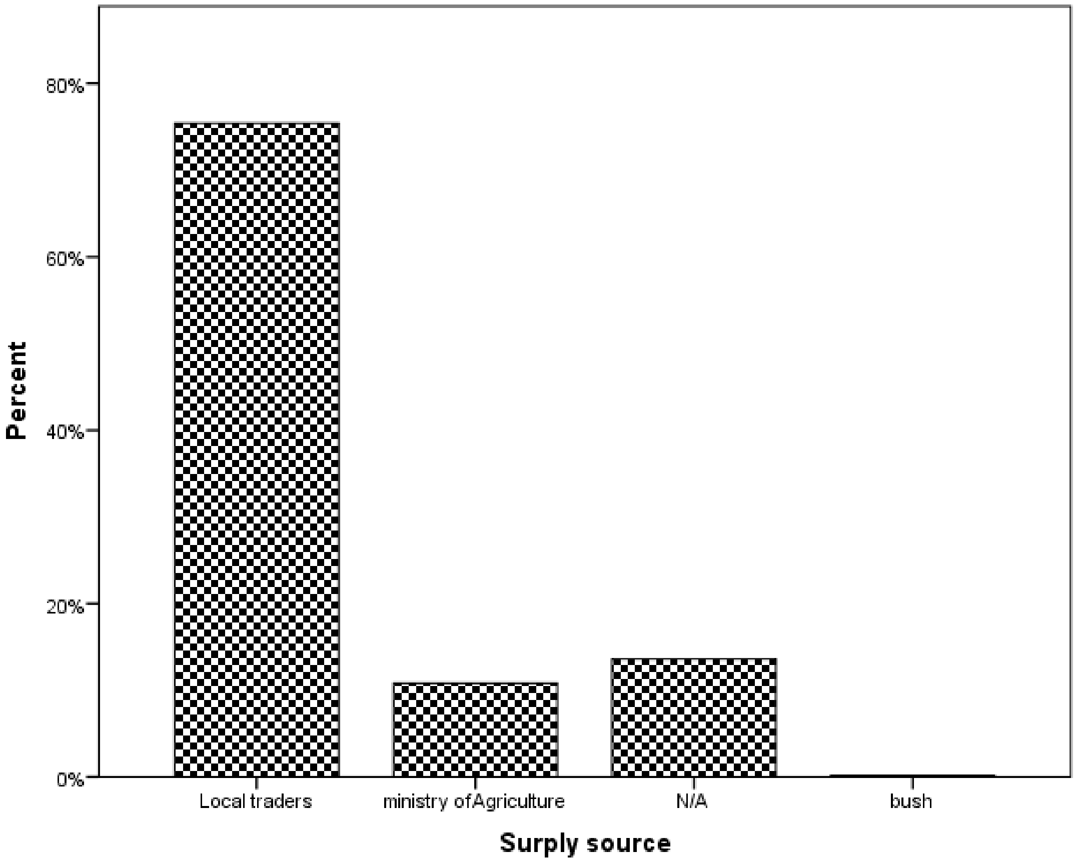


Figure 3: Supply sources of pesticides used by rice farmers in Sierra Leone

According to the discussions with the government stakeholders, it is an illegal practice to import harmful chemicals - including pesticides - without government approval. However, illegal importation of pesticides is a common practice in Sierra Leone, but the government could not regulate the influx of these chemicals to avoid jeopardizing successes of the food security programmes. The government is of the opinion that the scale is low and therefore the expected negative impact is minimal. These expectations have never been justified by any research. A prominent person in the pest control unit of the Ministry of Agriculture stated in a discussion:

> *"We in the national oversight committee for agriculture are aware that pesticides are coming into the country illegally through our borders but since this activity is towards promoting the food self-sufficiency agenda, no move is taken to stop or control it. The government do not have enough money to import enough quantity for every part of the country. It should be noted however that the committee would recommend stringent measures to minimize or stop the illegal activity if there is evidence that pesticides are causing harm to the people".*

An honourable member of parliament who is also a master farmer stated during an interview:

> *"All we know is the pesticides are coming from the Ministry of Agriculture. When we want our farms to be fumigated, we apply to the district agriculture office. They come in and apply pesticides to our farms because they believe for people to handle pesticides they must*

> *be well trained………………..Government does not allow untrained people to handle pesticides that is why there is one extension worker in every chiefdom"*

The honourable also stated:

> *"There is a government regulation that no unauthorized person should bring chemicals into the country and if caught you would be cautioned in a court of law"*

There appear to be differences between what is operating in the country and legislation. Most of the pesticides come into the country illegally and even the honourable admitted to buying it from illegal vendors sometimes. This was also stated on the IFDC report (2008) that pesticides enter the country illegally. He stated that only trained personnel handle pesticides and there is only one extension worker per chiefdom. However, it is practically impossible for one person to apply pesticides to all the farms in a chiefdom. Some chiefdoms such as Samu, Lokomassama, Mambolo, have thousands of farms.

The official route is for government to import pesticides and distribute them to various pest control units across the country. These are the units that are supposed to regulate and monitor the use of pesticides, but instead of doing this they end up selling the supplied stock to the street vendors who would in turn sell them to the farmers.

It was found that 26.4% of the respondents do not know the source of the pesticides they use. Even the honourable clearly demonstrated that. Respondents just go to the market and buy from minor traders. There is evidence that minor traders sometimes mislead their customers (the case of the farmer mentioned above). This means there is high risk of buying the wrong pesticides. From the focus group discussions, farmers said sometimes the pesticides they buy from petty traders have lost their power so when they apply them they do not work. This is an indication that the farmers do not know what they are buying. In practice, it appears that any type of pesticide can be applied, even if it is not suitable for the target pest. Some pesticides are highly mobile and could be easily transported by water (Edwards, 1973; Wauchope, 1978; Khan, 1982; Calderbank, 1989; Dogheim et al, 1996; Grung et al, 2015), while others tend to cling on to soil surfaces after hours of application (Wauchope et al, 1992; Gevao et al, 2000; Getenga et al, 2004; Akogbeto et al, 2006; Singh et al, 2007).

Levels of application of pesticides on rice farms

Results from the interview of farmers indicate that an average area of 9 Ha of land is used for cultivating rice per farmer in every cropping season. For chlorpyrifos, the average volume applied per bushel of rice is 85 ml (calculated from interview results). According to the farmers, they broadcast two bushels of rice per acre (0.4 Ha) of land. This implies an average of 1.8 kg of active ingredient is applied per farmer. For most farmers these are not the only farms they have. Some can have vegetable farms, cassava (the second most widely consumed crop in Sierra Leone), millet, maize, and yam farms. Pesticides are also used in some of these farms. The levels of residual chlorpyrifos found in soils from farms (Chapter 4), was compared to the highest recommended dose and the residual chlorpyrifos when the recommended dose is used (Figure 4). The residual chlorpyrifos found in soils from farms is significantly higher than the highest recommended dose. This indicates that the soils from the farms are highly contaminated. This can lead to the contamination of other facets of the environment.

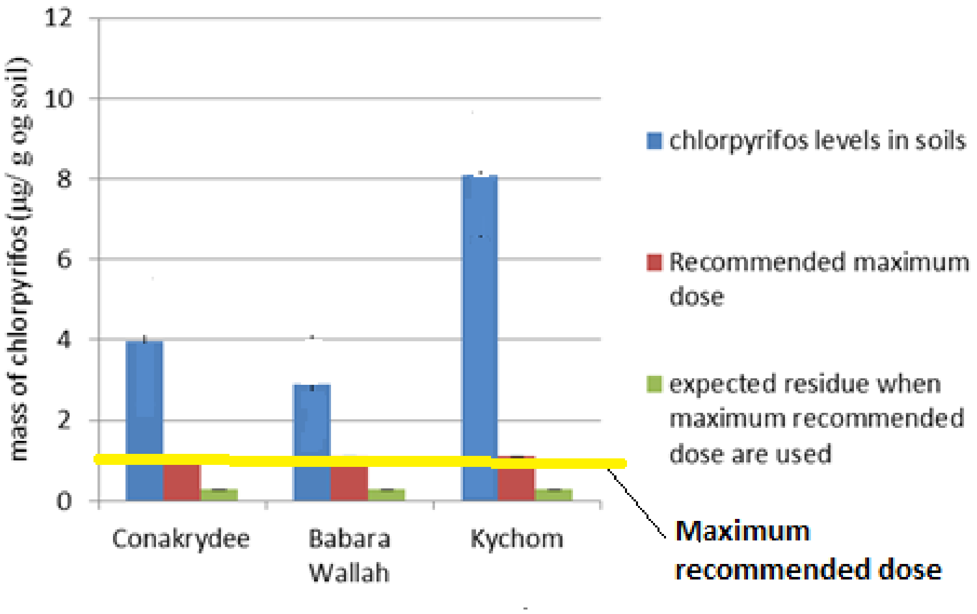


Figure 4: Concentrations of chlorpyrifos in surface soils from rice farms against maximum recommended dose and expected residue 14 days after application of the pesticide

The recommended dose on the label of the pesticide is 75 to 140 ml mixed with 3 l of water per hectare of land. Pesticides in solutions are diluted with a non-specified volume of water, mixed with the seeds and then broadcast to spread evenly across the farm. The quantity of seeds used is proportional to the size of the farm and it is also directly proportional to the volume of pesticides required. Therefore, the bigger the size of the farm the higher the volume of pesticide required. Interviews and field observation showed that the volume of liquid pesticide used per bushel (27kg) of rice varies from farmer to farmer. Sixty-one percent of the respondents who use these types of pesticides use 70ml per bushel (27 kg) of rice, 15% used 35ml per bushel, 11% use 140ml per bushel and 9% use 105ml per bushel. About 4% uses from 200ml to 500ml of pesticide per bushel. The volume used depends on the purchasing power of the farmers and the size of the farm. There is no prescribed threshold to limit the use. Secondly, most of the farmers have no idea about the area of their farms. They describe the area in terms of the quantity of rice seeds they can cultivate. This again is different among different farmers. Some farmers nurse two (54 kg), or three (81 kg) bushels of rice per acre (0.4 hectare) of land. This implies the quantity of pesticides applied to the farms is at least two times higher than the recommended dose. Such practice can lead to over application and if this happens for a long time it can lead to chronic effects (Gevao et al, 1999). Chen et al (2012) associated the overuse of pesticides in China to illiteracy. According to Sankoh el (2016a), 79% of 500 farmers interviewed were illiterate or semi-illiterate and cannot read instructions on pesticide labels. This could also be a reason for the high contamination levels.

To promote food sufficiency programmes, the Sierra Leone government encourages farmers to use nerica rice (a hybrid of *Oriza sativa* and *Oriza glaberima*), which is a fast growing rice variety and can thrive well on both upland and lowland ecologies, even if waterlogged. With this variety, farmers could cultivate twice per cropping season (May to December). This means more pesticide application. This could explain why there is a massive overdose of pesticides on farm soils. Results obtained from farmer's interviews showed that pesticides are applied from May to September (Figure 5). About 29% of pesticide application is done in June and 46% in July. Application in May, August and September is done by farmers who cultivate rice twice within a cropping season.

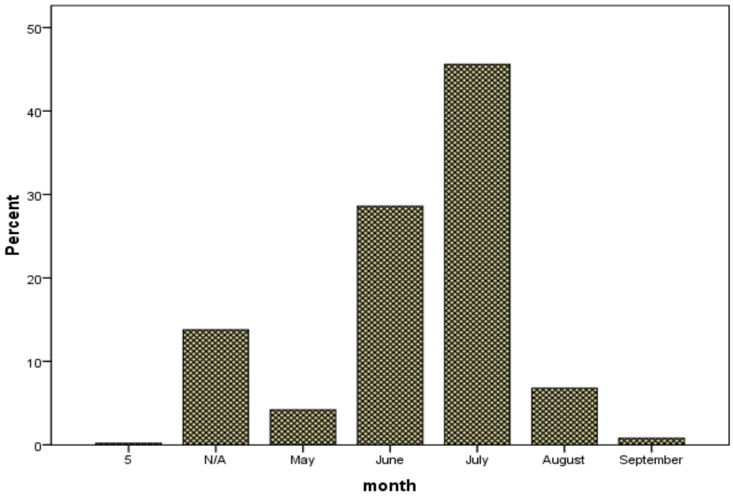


Figure 5: Time of the year pesticides are applied to the farms

Fate of pesticides on the environment

From the interview it was observed that farmers have various beliefs about the fate of pesticide in the environment. About 81% of farmers believe that pesticides remain active up to 7 days, although 90% of the farmers have no idea what happens to the pesticides after application. The rest believe the pesticide vaporises slowly from the soil. They believe it is the inhaled vapour that causes the death of organisms.

All the interviewed farmers accepted that water can wash pesticides away when the farm is flooded. That is why pesticides are always applied when there is neither rain nor wind. From the focus group discussions, farmers stated that a repeat application is done if the farm is flooded within a day after application because they strongly believe that the water would wash away all the applied pesticides. Pesticides and their degraded metabolites can be transported to adjacent water bodies by surface runoff especially when the soil surface is eroded. In Sierra Leone surface runoffs are expected to play a significant role in removing pesticides from their area of application. According to Tsaboula (2016), chlorpyrifos is one of the pesticides that occur at levels that have high environmental risk in adjacent water bodies when applied to agriculture fields.

No farmer questioned had knowledge of degradation and the ability of the pesticides to bind to the surface soil. However, several researches have reported pesticides like chlorpyrifos can degrade to different metabolites, some of which can be more toxic and water soluble than the parent compound. Figure 6 illustrates the degradation pathways of chlorpyrifos. Most of the applied pesticides are transformed to other chemicals which could be more harmful to man and other organisms in the environment (Xie et al, 1997). Most of the metabolites are more soluble in water and therefore can be transported to ground water through leaching in addition to the fraction transported by surface runoff. People living around these areas depend on untreated underground water for drinking. Metabolites could enter the food web, bio-transform, bio-accumulate and biomagnify (Hinderliter et al, 2011). These could be a threat to organisms within the environment as well as organisms in the higher trophic levels far away from the source.

Chlorpyrifos in food and human exposure

Exposure

The main oral exposure route for pesticides is through food (see Chapter 4). In Sierra Leone, the normal meal is rice served with one of several different types of soup, cooked with fish, crabs, shrimps, meat or chicken. Most times two or more of these protein sources are combined. However aquatic animals are most widely eaten. Considering the levels of pesticides in rice and the aquatic animals, a meal combining them could lead to levels above the recommended daily intake by man. For instance, the daily intake of 0.5 kg of rice and 60 g of fish could lead to an intake of chlorpyrifos of up to 38 μg of the pesticide. This could lead to a dose of 6.31×10^{-4} mg/ kg of body mass (chapter 4). This is above the reference chronic dose of 5×10^{-4} mg/ kg of body mass/ day. Farmers also eating animals that are directly killed by pesticides and using pesticides to hunt animals including fish could expose them to the chemicals (Norman, 2012; Sankoh et al, 2016). Farmers were observed eating on the field after pesticide application using the unprotected hands used to apply the pesticides to eat (Sankoh et al, 2016). This could expose them to pesticides. Accidental deaths were reported during focus group discussions. This involves the accidental oral intake of pesticides by both adults and children. Focus group discussions also reported cases of furadan been added to food for murder, but no case of deliberate suicide was reported.

Exposure to pesticides could also be through inhalation of pesticide aerosols and volatilised fractions during and after application. Farmers in Sierra Leone do not use personal protective gear when applying pesticides. They depend on wind direction which often fails (Sankoh et al, 2016). These pesticide molecules could be transported to others by wind. However, exposure through inhalation of chlorpyrifos is considered to be moderately toxic (NPIC, 2012).

Dermal exposure is another important exposure route. When working especially in swamps farmers do not use protection on their feet. This means their feet are always in contact with the pesticides. Farmers use their hands without protection to mix the seeds with pesticides. They also use their hands to spread the seeds mixed with pesticides on the farm. There is no specific protection, except clothes to cover the other parts of the body and these clothes could themselves become contaminated and remain in contact with the body for extended periods. The use of water close to farms for domestic purposes such as bathing, cooking and washing could also be potential routes of exposure, especially if the pesticide is water soluble.

Literacy and training

Poverty, lack of training and illiteracy among farmers using pesticides are the major reasons for exposure. All the farmers are aware that pesticides are harmful, but they do not know how to handle and use them safely.

Most of the farmers in Sierra Leone are poor and could only do subsistence farming (Rhodes, 2005). This type of farming could not give them enough money to buy sprayers and personal protection equipment. They rely on working against the wind and drinking palm oil. They believe that palm would remove the poison from the pesticides and make them harmless.

It was found that 71% of 500 respondents have never received any form of training on the safe use of pesticides. Only 17% received some form of training and 80% of these trained farmers received informal training from untrained farmers (Sankoh et al, 2016). As a result, the application methods are haphazard and largely by trial and error. This is having important implications for both the environment and the health of the farmers.

According to Sankoh et al (2016), 56.4% of 500 farmers interviewed have no formal education. Twenty-three percent (primary and junior secondary levels) are not educated enough to understand instructions written on the labels. Only 20.6% of the respondents are considered to have adequate education to read and fully understand instructions written on the labels. However, 90% of those considered having adequate education cannot read the instructions in French.

The perception of people with no formal education can be much more difficult to change than those with formal education (Ecobichon, 2001; Gaber and Abdel-latif, 2012). They tend to confine themselves to the first concept they learn. This means most of the farmers would be unlikely to accept new methods, especially if they are more laborious and involve a higher cost. Lack of training and education of farmers using pesticides can clearly lead to the misuse of these chemicals and hence increase the risk of harm to both the farmers and the environment.

Health impact

According to results obtained from interviews, 64% of the health workers stated that an average of more than 15 people report sick in the local hospital or health centres per week (Figure 6). Most of the community health centres are small and could not hold up to 10 patients at a time. They are headed by dispensers called community health officers. They are to treat only minor illness. They should refer major cases to the district headquarter hospitals where there are qualified doctors. A community health centre that is visited by more than 10 patients per week in rural settings in Sierra Leone is considered to be active, except when there are free supplies and immunizations. Rural people, especially farmers do not believe in going to the hospital. They prefer traditional treatments. The Jonckheere- Terpstra test showed that there is a significant difference between the groups of number of patients that visits hospitals (p=0.04). The Bonferroni post hoc test confirmed that the group >15 patients is significantly higher.

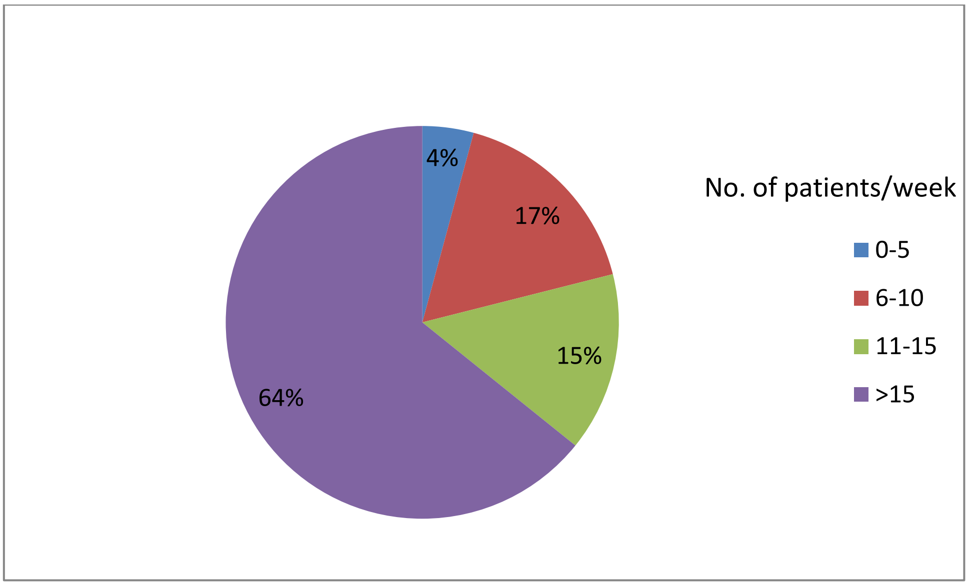


Figure 6: The distribution of the number of patients that go to health centres

Out of the patients that go to health centres for treatments, 92% are children between the ages 0-10 years. This is an indication that the majority of the active farmers do not go to health centres for treatment.

Pesticide poisoning - whether intentional or occupational - poses a health risk, especially when not handled properly (Yadav et al, 2015). The use of pesticides could lead to many health problems such as skin problems, nausea, seizure, respiratory disorder, blurred vision, loss of appetite, lacrimation, nervous disorder, head ache and stomach ache and more (CCOHS, 2010; Lah, 2011; Toxic Action Centre, 2012; EPA, 2014). Effects of pesticides can be acute when exposed to high levels within a short period or chronic when the intake or exposure is over a long period of time (Ecobichon et al 1990; Chen et al, 2012). No matter what type of exposure, pesticides have the potential to impact negatively on the health of people.

Results obtained from health workers indicate that 85, 67, 74, 92, and 99% of people who reported skin problems, nausea, respiratory disorder, blurred vision, and nervous disorder respectively, are from the group 0-10 patients/week (Figure 7). According to Sankoh et al (2016a), cases of skin problems, nausea, seizure, respiratory disorders, blurred vision, loss of appetite, lacrimation and nervous disorder were significantly higher among farmers who use pesticides than those who do not. This indicates that the use of pesticides maybe having a negative impact on the health of farmers. Importantly, none of the health workers questioned indicated that health issues connected to pesticide poisoning were being investigated (Sankoh et al, 2016a). All symptoms were being treated as malaria, typhoid or other diseases not related to pesticide exposure. Since the people do not get cured after they have been treated in hospitals as a result of wrong diagnosis, farmers prefer treatments by local herbalists rather than professional health practitioners. Therefore, few farmers go to hospitals for treatment.

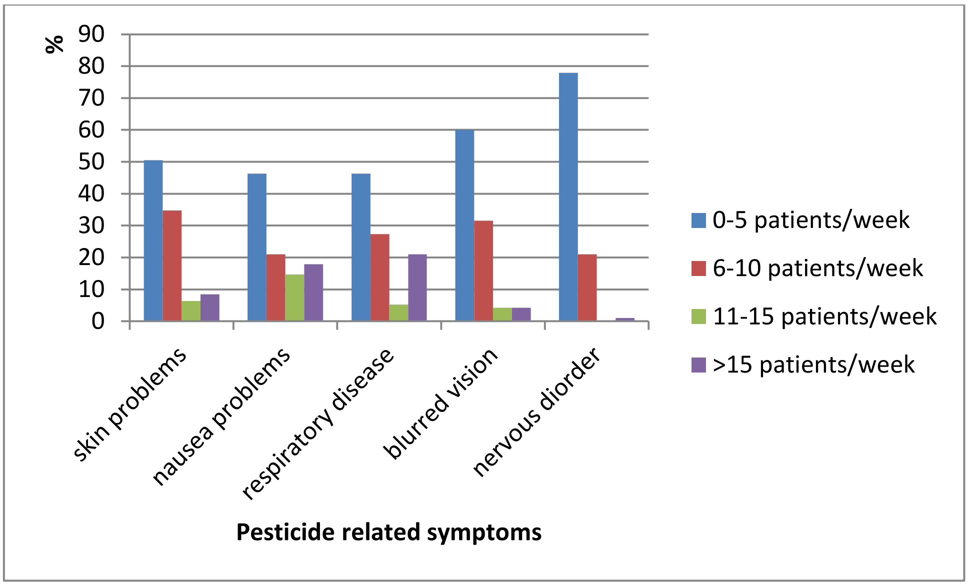


Figure 7: The number of patients that reported pesticide related symptoms per week in local health centres (Hospitals)

Environmental Impact

Results from this research indicate that there is gross misuse of pesticides in Sierra Leone and agricultural fields can be overloaded with these chemicals. When applied, pesticides can affect both pests and beneficial organisms. Snakes, insects, worms, frogs and some other organisms die as a result of pesticide poisoning in Sierra Leone (Sankoh et al, 2016a). Most of these organisms do not destroy crops and some of them can contribute to the improvement of soil fertility which is required for plant growth. The killing of these organisms could lead to reduced soil quality. The killing of beneficial insects such as honey bees and butterflies destroys their benefits (Pimentel et al 1992). Pesticides can also kill endangered species and bring their populations to extinction (Keefe et al, 1990). The levels of pesticides on aquatic organisms is an indication the adjacent rivers are polluted. Since chlorpyrifos has a short half-life and low persistence in water, it indicates that most of the contaminating chlorpyrifos is found on sediments, flora and fauna in the rivers. This could serve as reservoir for pollutants which could be transmitted along food chains in the food web. Since there is evidence that different types of pesticides are used and the users cannot tell their differences, it is likely that other pesticide contaminants are also getting into the rivers. The major rivers in Sierra Leone empty into the Atlantic Ocean. This means contaminants can be transported into the ocean either by the polluted water and/or living organisms moving from one environment to another in search of food. This could not only bring about transboundary transportation of contaminants, but also affects the quality and quantity of marine resources. Birds can also be affected by pesticides applied to farms either directly by eating poisoned seeds or crops, or indirectly through the food web. Pesticides like furandan which is also widely used by farmers in Sierra Leone, can kill rodents and hence create stress on the food web. The contaminated rodents can be eaten by carnivores, and hence expose them to the contaminants.

Economic impact

There is neither a pesticide processing nor a manufacturing factory in Sierra Leone. This means all pesticides in Sierra Leone are imported into the country either legally or illegally. The legal importation is done by the Sierra Leone government and licensed importers. Figure 9 shows the expenditure of the Sierra Leone government on pesticides from 1961 to 2012. According to IFDAC (2000), 70% of the pesticides imported by government go to the health sector for the control of pathogen and disease vectors. The remaining is agriculture for food production and cash crop production. This supply is not enough to meet the demands of the intensified food production. For instance, in 2006, the recommended need for pesticides for crop production was about 500,000 kg. During this period, the government could not import up to $1,000,000 worth of pesticides for both the health and the agriculture sectors (Figure 8). To meet their demands, farmers find alternative ways to get their own supply of pesticides. This makes the illegal trade of pesticide lucrative. This trade is not monitored according to findings of this research.

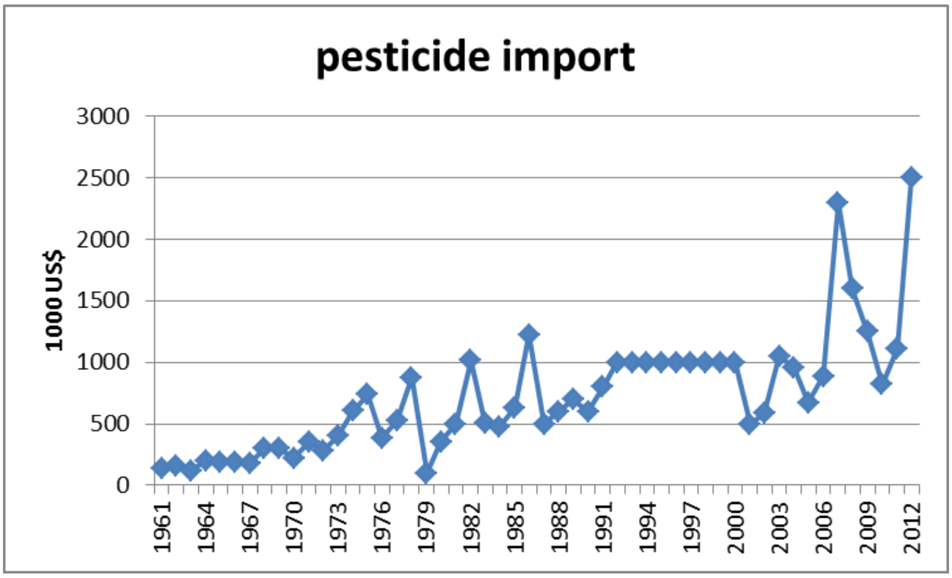


Figure 8: The budget for pesticide imported by the Sierra Leone government from 1961 to 2012 (WHO, 2013)

As already mentioned there is a clear misuse of pesticides, which has resulted in high risk of possible human exposure in Sierra Leone. This exposure has the potential to impact the health of people. This could lead to high economic impact on the people and the government in trying to maintain good health. According to Etzel et al (1987), the inappropriate handling of parathion, caused the poisoning of 49 people out of whom 14 of the poisoned people died in Kenema and Lalehun in Sierra Leone. Treatment of these people involves money which could be higher than the benefits gained by the use of pesticides (Rother, 2000; London & Rother, 2001; Rother, 2008).

When pesticides are discharged into aquatic environments it can lead to a reduction of the populations of marine organisms which could serve as food for people. This could lead to scarcity and hence a rise in price. The transport of pesticides through the aquatic food web could lead to poor quality of marine resources, which could be a potential reason for the rejection of the resources at international markets.

Conclusion and Recommendations

Conclusion

The widespread use of pesticides in Sierra Leone was considered to be of minor importance and did not seem to attract the attention of policy makers because there is little or no research on the use of these chemicals. This research in this thesis was aimed at assessing the impact of pesticide use on the environment and health of rice farmers in Sierra Leone. To achieve this 500 rice farmers and 100 health workers were interviewed using structured questionnaires across the country. Focus group discussions and field observations were undertaken. In parallel to the interviews two field experiments were setup to study the behaviour and behaviour of chlorpyrifos on the Sierra Leone soils, and in particular to quantify the soil to crop transfer of chlorpyrifos. Soils, biota, and rice samples from selected farms were analysed for chlorpyrifos residues to determine the level of environmental contamination, and human exposure. From the findings obtained by these studies, the conclusions taken are discussed in the following section.

Prevalence of pesticide use among rice farmers in Sierra Leone

Based on findings from this research, pesticides are widely used in Sierra Leone contrary to the speculations of various stake holders. The majority of rice farmers (432 out of 500 interviewed) are using pesticides, although there are a few areas such as Kargboro Chiefdom in the Moyamba District, where the use of pesticides is less common. From the interviews and focus group discussions it was established that various types of pesticides are currently in use by rice farmers most of whom are illiterate and not trained in their safe and effective use. The most widely used pesticides in rice fields in Sierra Leone include, chlorpyrifos, furandan, carbolinium and Malathion. All of these have the potential to cause harm to the environment and humans. There are regulations in the country against illegal importation of harmful chemicals in to the country. However most of the pesticides are imported to the country illegally by unlicensed traders. These traders make pesticides easily accessible to farmers by selling them in small quantities which even the poorest farmer can afford. Neither the traders nor the farmers can read the instructions written in French on the containers. The Government do not seem to be willing to enforce laws to regulate the use of pesticides either to avoid jeopardising the food self-sufficiency programs or a lack of knowledge on the prevalence of pesticide use and its impact to the people and the environment. A large number of pesticides are entering the country illegally and there is no indication that the Government is aware of the size of this trade. Hence the prevalence of pesticide use in Sierra Leone is high.

Handling

It is clear from this research that storage, preparation and application methods are not appropriate. Farmers store pesticides in their houses or homesteads in places that can be easily accessed by people including children or from which the pesticides can easily contaminate food or drinking water. From the focus group discussions, it was revealed that inappropriate storage of pesticides has caused deaths of humans. Farmers handle pesticides without personal protective equipment and hence expose various parts of their bodies to the harmful chemicals. They do not follow standard methods when preparing them for use, as a result inappropriate methods which can lead to overdose are used. Pesticides are applied using hands and hence skin is unprotected. It is clear that the handling of pesticides by rice farmers in Sierra Leone is not appropriate.

Potential risks to the environment

Results from this research indicate that when recommended doses of chlorpyrifos are applied, the pesticide is not persistent in riverine and boliland soils as < 1% of chlorpyrifos is retained by the soil after 30 days, under field conditions in Sierra Leone. This is also supported by the prediction of the use of a soil fugacity fate and behaviour model. The remaining 99% or more is either transported to other environmental compartments or transformed to other compounds. However, soils from farms under active cultivation were found to be highly contaminated. This suggests that pesticides are misused on farms. Contaminated soils can act as a reservoir for the contamination of other facets of the environment. Results also indicate that pesticide application has a negative impact on biodiversity. All the farmers using pesticides agree that pesticides kills both target and non-target organisms. In Sierra Leone where the use is uncontrolled the level at which this occurs is high. The methods of application are likely to lead to the pollution of adjacent water bodies. This is confirmed by the high levels of chlorpyrifos in tilapia fish, mudskippers, crabs and shrimps collected in rivers bordering the farms. The high levels of chlorpyrifos contamination in adjacent rivers is an indication that high levels of pesticide residues are transported to other areas including out of Sierra Leone, especially when the contaminated rivers discharge into the Atlantic Ocean, which borders Sierra Leone from the north/west to the south/west. The high levels of pesticides used on the farms and the continuous use of the chemicals could result in accumulation in soils and sediments, some of which could be transported to other areas by erosion especially during the rainy season when the adjacent water bodies flood their plains. This suggests that the uncontrolled use of pesticides is having a negative effect on the environment.

Possible exposure routes for farmers

Rice farmers in Sierra Leone can be exposed to pesticides through several pathways including via skin, respiratory tracts and the digestive system. Skin exposure occurs primarily through handling. Pesticides are handled with little or no personal protective equipment. Pesticides come into contact with the hands, feet and other parts of the body of farmers during preparation and application. Respiratory tracts are exposed through inhalation. All farmers agreed that people within the surrounding of the farm inhale pesticides during or just after application. Exposure through the digestive system occurs through food ingested either directly or in directly. The habit of eating with unprotected hands and contaminated after applying pesticides without washing the hands effectively and eating on the farm immediately after applying pesticides can lead to oral exposure. Farmers are also consuming animals directly killed by pesticides which provide another exposure route. Organisms such as fish, mudskippers, crabs, and shrimps which were found to be contaminated are used as a food source by people within the environs. Rice, which is the staple food in Sierra Leone, is also contaminated. However, levels of chlorpyrifos found in rice from both the field experiments where recommended doses of chlorpyrifos were applied and those from the field did not exceed 0.05 mg/kg which is the recommended maximum limit set by the European Union. Hence the consumption of rice cultivated in Sierra Leone is not likely to cause harm to consumers provided the crop is not consumed with other pesticide contaminated meals. A typical Sierra Leonean meal will have levels that could lead to chronic effects when the meal is prepared using a combination of these contaminated food sources. As a result, human exposure to pesticides is likely to be high and may result in harm to people. Chlorpyrifos can be absorbed by the rice plant and stored in the grains. This could serve as a human exposure route. However, since higher application rates result in higher pesticide concentrations in rice, it is an indication that misuse of pesticides could result in higher levels of contamination than recommended. This is likely to happen when the users are not trained. According to Flores (2007) and Chen et al (2016), the uptake of a pesticide by plants depends on the quantity of pesticide applied. Out of the total uptake by plants only a small fraction ends up in the grains (Zhang et al, 2012). The levels chlorpyrifos in rice obtained from this research, are only likely to occur if the soil is highly contaminated. This supports the results obtained from the analysis of the soil samples. Such concentrations could be harmful to a wide range of terrestrial organisms. Furthermore, in a tropical climate like Sierra Leone, when the level of pesticide use is high, there is an increase in the rate of biodegradation and volatilization. The biodegradation of pesticide may result in the formation of toxic metabolites in the environment (Aislabie and Lloyedjones, 1995). The volatilised fraction is likely to be transported by wind to other areas and could also expose arboreal organisms to the toxic contaminant. The routine consumption of such food could expose consumers to high levels of pesticides capable of causing chronic effects. This could lead to a negative impact on a large proportion of the population.

Impact of pesticides on human health

Looking at the human possible exposure routes, the results from health workers' interviews and farmers interviews, it is clear that pesticide application is affecting the health of rice farmers. Cases of pesticide exposure related symptoms appear to be significantly higher among farmers using pesticides than those not using pesticides. This is an indication that pesticides are having negative impacts on farmers. Most of the farmers at the age at which they can handle pesticides do not go to the hospital when they are sick as they believe in traditional treatments. Hospitals do not know how to diagnose pesticide related symptoms for possible pesticide contamination. All the laboratory investigations carried out in hospitals are for pathogens and not for any symptoms of chemical intoxication. As a result of the lack of monitoring of health effects due to pesticide use, farmers are liable to experience chronic effects of pesticide poisoning. Since most of the population of Sierra Leone are farmers, and exposure especially through food is not only limited to farmers, this implies that uncontrolled use of pesticides may result to health problems for the majority of the people in Sierra Leone.

Economic impact of pesticides to Sierra Leone

Rice is the most widely consumed crop in Sierra Leone, and its importation has been having a negative impact on the economy of Sierra Leone. This economic impact can be avoided if Sierra Leone is able to become self-sufficient for rice production. One of the major factors that have been preventing the country from achieving food self-sufficiency is pest infestation. The use of pesticides is therefore unavoidable. From the results of the interviews and questionnaires, farmers reported that in addition to pest eradication, the use of pesticides is promoting yield. According to lowland farmers, the use of pesticides leads to reduced labour costs because the use of pesticides makes it possible for them to nurture the seeds directly on the farms. Before the introduction of pesticides, farmers used to nurture their seeds on infertile upland soils and then transport them to the farms. This process is more expensive and less effective. Hence the use of pesticides is believed to lead to reduced cultivation costs. In addition to crop protection, farmers also use pesticides to eradicate disease vectors such as mosquitos, parasites such as head lice and also for the eradication of bed bugs. These uses are not likely to be safe but they have their advantages. However, misuse and exposure could lead to health problems which result in economic costs. This might overshadow the gains made as a result of pesticide use especially when the use is not appropriate.

Recommendations

The following recommendations can be made based on the findings:

i) The Sierra Leone government should regulate the import of pesticides into the country and illegal importation should be minimized if not stopped.

ii) Pesticides should be handled and distributed by trained personnel and should not be sold openly in local markets by unlicensed traders.

iii) Farmers should be trained on how to handle and apply pesticides before been allowed to use them on their farms. The Ministry of Agriculture and Food Security should team up with agricultural institutions like Njala University to train more field instructors that would train farmers how to handle pesticides safely.

iv) Farmers should be educated on the dangers of pesticides and they should be supported with personal protection equipment.

v) Manufacturers should use labels including pictograms to help illiterate farmers understand how to handle pesticides safely. Pesticides in containers labelled in French should be avoided because even literate farmers cannot read and understand such instructions.

vi) Farmers should be advised to regulate the use of pesticides and in areas where there is an overload in soil they should be encouraged to skip application.

vii) Health workers should be trained to test for symptoms of pesticide poisoning in patients and the health sector should be supported by government and its development partners such as WHO, EPA, JICA, UNICEF and GTZ with the necessary health facilities to accurately diagnose pesticide related symptoms and administer appropriate treatment.

viii) The Sierra Leone government in collaboration with its development partners should equip the Sierra Leone Standards Bureau with analytical instrumentation that would help them monitor the types of pesticides imported into the country.

ix) The Environmental Protection Agency (EPA-SL), should monitor pesticide use and minimize environmental contamination.

x) It was found that a wide range of pesticides are in use in Sierra Leone but this research only studied chlorpyrifos. It is recommended that further studies are undertaken to study the behavior of other pesticides in the environment.

xi) This research did not study the fate of pesticide metabolites. These could have negative impact on the health of humans and the environment and should be involved in future research programmes.

xii) Rice is not the only crop cultivated in Sierra Leone on which pesticides are used. Studies of other crops should be included in future research.

xiii) Experimental plots should also be setup on other ecosystems on which pesticides are used.

References

Acker, C. I. & Nogueira, C. W. 2012. Chlorpyrifos Acute Exposure Induces Hyperglycemia and Hyperlipidemia in Rats. Chemosphere, 89: 602-608.

Aislabie, J. & Lloydjones, G. 1995. A Review of Bacterial-Degradation of Pesticides. Australian Journal of Soil Research, 33: 925-942.

Akogbeto, M. C., Djouaka, R. F. & Kinde-Gazard, D. A. 2006. pesticide residues in soil and water samples from agricutural settings. malaria journal. 5: 22

Alcocer, M. J., Doyen, C., Lee, H. A. & Morgan, M. R. 2000. properties of polyclonal, monoclonal, and recombinant antibodies recognizing the organophosphorus pesticide chlorpyrifos- ethyl. Journal of agricultural and food chemistry, 48: 4053.

Álvarez, M., Du Mortier, C. & Cirelli, A. F. 2013. Behavior of Insecticide Chlorpyrifos on Soils and Sediments with Different Organic Matter Content from Provincia De Buenos Aires, República Argentina. Springer Science+Business Media Dordrecht.

Alves, P. R. L., Cardoso, E. J. B. N., Martines, A. M., Sousa, J. P. & Pasini, A. 2012. Earthworm Ecotoxicological Assessments of Pesticides Used to Treat Seeds under Tropical Conditions. Chemosphere. 224: 1 - 6

Androutsopoulos, V. P., Hernandez, A. F., Liesivuori, J. & Tsatsakis, A. M. 2012. A Mechanistic Overview of health associated effects of low levels of organochlorine and organophosphorous pesticides. Toxicology. 24: 3 - 6

Asenso-Okyere, K., Workneh, S., Rhodes, E. & Sutherland, J. 2009. rebuilding after emergency: revamping agriculture research in sierra leone. international food policy research institute. www.researchgate.net/publication/46442035 (accessed 10/10/2015)

Boateng, J. O., Nunoo, F. K. E., Dankwa, H. R. & Ocran, M. H. 2006. A Toxic Effects of Deltamethrine on Tilapia, Oreochromis Niloticus (Linnaeus, 1758). West Africa Journal of Applied Ecology. 9: 1 - 5

Calderbank, A. 1989. The Occurance and Significance of Bound Pesticide Residues in Soil. Springer: Reviews of environmental contamination.108: 71- 103

Canadian Centre For Occupational Health (CCOH) 2015. Pesticides- Health Effects. https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/sierraleone_en.pdf (accessed: 20/10/15)

Centofanti, T., Hollis, J. M., Blenkinsop, S., Fowler, H. J., Truckell, I., Dubus, I. G. & Reichenberger, S. 2008. Development of Agro-Environmental Scenarios to Support Pesticide Risk Assessment in Europe. Science of the Total Environment, 407: 574-588.

Chen, C., Qian, Y., Lui, X., Tao, C., Liang, Y. & Li, Y. 2012a. Risk Assessment of Chlorpyrifos on Rice and Cabbage in China. Elsevier: Regulatory Toxicology and Phermacology, 62: 125- 130

Chen, X.-P., Chen, W.-Z., Wang, F.-S. & Liu, J.-X. 2012b. Selective Cognitive Impairments Are Related to Selective Hippocampus and Prefrontal

Cortex Deficits after Prenatal Chlorpyrifos Exposure. Brain Research, 1474: 19-28.

Dogheim, S. M., Mohamed, E. L. K. & Gad Alla, S. A. 1996. Monetoring of Pesticide Residues in Human Milk, Soil, Water and Food Samples Collected from Kafr El-Zayat Governorate. Journal of AOAC.213: 56 - 63

Ecobichon, D. J. 2001. Pesticide Use in Developing Countries. Department of Pharmacology and Toxicology, Queen's University, Kingston, Ont., Canada K7L 3N6: Toxicology on Science Direct. 160: 27 - 33

Eddleston, M., Karalliedde, L., Buckley, N., Fernando, R., Hutchinson, G., Isbister, G., Konradsen, F., Murray, D., Piola, J. C., Senanayake, N., Sheriff, R., Singh, S., Siwach, S. B. & Smit, L. 2002. Pesticide Poisoning in the Developing World—a Minimum Pesticides List. The Lancet, 360: 1163-1167.

Edwards, C. A. 1973. Environmental Pollution by Pesticides, London, New York,: Plenum Press. 23: 542 - 544

Etzel, R. A., Forthal, D. N., Hill, R. H. & Demby, A. 1987. Fatal Parathion Poisoning in Sierra Leone. Bulletin of the World Health Organization.

FAO 2011. Moving Beyond Subsistence Farming in Sierra Leone. www.fao.org/rice2011/en/p18.htm (Accessed: 20/11/15)

Flores, F. 2007. Cholinesterase Inhibition in Mudskippers (Periophthalmus Novaeguineaensis) by Chlorpyrifos. Thesis School of Marine and Tropical Biology, James Cook University

Gaber, S. & Abdul-Latif, S. H. 2012. Effect of Education and Health Locus of Control on Safe Use of Pesticides: A Cross Sectional Random Study.

Journal of Occupational Medicine and Toxicology . http://www.occup-med.com/content/7/1/3 (Accessed 26/10/15)

Gebremariam, S., Beutel, M., Yonge, D., Flury, M. & Harsh, J. 2012. Adsorption and Desorption of Chlorpyrifos to Soils and Sediments. PubMed. 46: 869- 874

Getenga, Z. M., Keng'ara, F. O. & Wandiga, S. O. 2004. Determination of Organochlirin Pesticide Residues in Soil and Water from River Nyando Drainage System within Lake Victoria Basin, Kenya. Springa: Buletin of Envitomental pollution. 27: 35 - 40

Gevao, B., Semple, K. T. & Jones, K. C. 2000. Bound Pesticide Residues in Soils: A Review. Environmental Pollution, 108: 3-14.

Hinderliter, P. M., Price, P. S., Bartels, M. J., Timchalk, C. & Poet, T. S. 2011. Development of a Source-to-Outcome Model for Dietary Exposures to Insecticide Residues: An Example Using Chlorpyrifos. Regulatory Toxicology and Pharmacology. 61: 82 -92

Jayaratnam, J. 1990. Acute Pesticide Poisoning: A Major Global Health Problem. World Health Statistics Quarterly. 43: 139 - 144

Khan, S. U. 1982. Bound Pesticide Residues in Soil and Plants. Springar: Residue reviews.215: 66 - 71

Koh, D. & Jeyaratnam, J. 1996. Pesticide Hazards in Developing Countries. The Science of the Total Environment. 1: 578 - 585

Lah, K. 2011. Effects of Pesticides on Human Health - Toxipedia.

London, L. & Rother, H. A. 2001. People, Pesticides and the Environment: Who Bears the Brunt of Backward Policy in South Africa. A journal of environmental and occupational health policy. 10: 43 - 51

Nandamudi, S., Murthy, V. A., Ramakrishna, Y., Boreddy, T., Kumar, S. B. R. & Prakash, S. G. R. 2014. Effects of Delebrate Ingestion of Organophosphate Pesticide on Distortion Product Oto-Acoustic Emission. Pub Med. 10: 36 - 43

National Pesticide Information Center, N. 2016. Chlorpyrifos Technical Fact Sheet. http://npic.orst.edu/factsheets/archive/chlorptech.html (Accessed 08/08/16)

Norman, A. 2012. Pesticide Use in Sierra Leone. Ontario Education Program, Njala niversity.

O'Keefe, D. P., Tepperman, J. M., Dean, C., Leto, K. J., Erbes, D. & Odell, J. T. 1994. Plant Expression of a Bacterial Cytochrome P450 That Catalyzes Activation of a Sulfonylurea Pro-Herbicid. Plant Physio.105: 473 - 482

Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A. & D'amore, M. 1992. Environment and Economic Cost of Pesticide Use. Oxford University Press.

*Rother, H.-A. 2008. South African Farm Workers' Interpretation of Risk Assessment Data Expressed as Pictograms on Pesticide Labels. Environmental Research, 108**:** 419-427.*

Rother, H.-A., Hall, R. & London, L. 2008. Pesticide Use among Emerging Farmers in South Africa:Contributing Factors and Stakeholder Perspectives.: Development Southern Africa. 25: 399 - 424

Rother, H. A. 2000. Influence of Pesticide Risk Perception on the Health of Rural South African Women and Children. African Newsletter on Occupational Health and Safety. 10: 2 - 11

Sankoh, A. I., Whittle, R., Semple, K. T. & Jones, K. C. 2016. An Assessment of the Impacts of Pesticide Use on the Environment and Health of Rice Farmers in Sierra Leone. Environment International. 94: 458 - 466

Sannoh, I. J. 2011. Agricultural and Rural Development Statistics in Sierra Leone - Key Aspects of Institutional Arrangements & Performance. In: FAO (ed.). www.fao.org/fileadmin/templates/ess/pages/rural/wye_city_group/2011/documents/session6/Sannoh_-_Paper.pdf (Accessed 15/10/2015)

Singh, B. K., Walker, A., Morgan, J., Alun, W. & Wright, D. J. 2004. Ibiodegradation of Chlorpyrifos by Enterobacter Strain B-14 and Its Use in Bioremediation of Contaminated Soils. Applied And Environmental Microbiology. 70: 4855-4863.

Toxic Action Centre 2012. Problem with Pesticides. www.toxicsaction.org/problems-and-solutions/pesticides (accessed 15/10/2015)

*Tsaboula, A., Papadakis, E.-N., Vryzas, Z., Kotopoulou, A., Kintzikoglou, K. & Papadopoulou-Mourkidou, E. 2016. Environmental and Human Risk Hierarchy of Pesticides: A Prioritization Method, Based on Monitoring, Hazard Assessment and Environmental Fate. Environment International, 91**:** 78-93.*

Wauchope, R. D. 1978. The Pesticide Content of Surface Water Draining from Agricultural Fields - a Review. Journal of Environmental quality. 23:10 - 15

Wauchope, R. D., Buttler, T. M. & Hornsby, A. G. 1992. The Scs/Ars/Ces Pesticide Properties Database for Environmental Dicision-Making. Springer. 10: 45 - 49

*Wilson, C. & Tisdell, C. 2001. Why Farmers Continue to Use Pesticides Despite Environmental, Health and Sustainability Cost. Ecological Economics, 39***:** *449-462.*

World Of Chemicals 2016. The Annual Worldwide Consumption of the Four Major Types of Residential Insecticide Products. General Chemicals. www.worldchemicals.com (Accessed: 22/06/16)

Xie, H., Guetzloff, T. F. & Rice, J. A. 1997. Fractionation of Pesticide Residues Bound to Human. Soil Science. 162: 421 - 429

Yadav, I. C., Devi, N. L., Syed, J. H., Cheng, Z., Li, J., Zhan, G. & Jones, K. C. 2015. Current Status of Persistent Organic Pesticides Residues in Air Water and Soil and Their Possible Effect on Neighboring Countries: A Comprehensive Review of India. Elsevier: Science of the Total Environment. 311: 123 - 136

Zhang, C., Wu, Y. J., Jin, S. F. & Yang, H. 2013. Analysis of Chlorpyrifos and Chlorpyrifos-Methyl Residues in Multi-Environmental Media by Cloud-Point Extraction and Hplc. Anal. Methods, 5: 3089-3095

Appendix A

Structured Interview Schedule for Farmers

Objective: To study how pesticides are used and the impact they have on people living closer to the environments in which they are used.

Note:

General information

Date__/___/______ Name of city/ town/ village ……………………………………………………………………………................................. ....

Name of chiefdom…………………………………………………………………………… ……………………………………………………

Name of district ……………………………………………………………………………………… ……………………………………………

Name of Province………………………………………………………………………………… ………………………………………………….

Designation of respondent ……………………………………………………………Sex

Male Female.

Age: A 16 – 25 B 26 – 35 C 36 – 45 D 46 – 55

E 56 and above

Number of people in the house hold: Men…………………..

Women…………………. Children………………….

SECTION A

Application

1. How many acres of land do you cultivate per year?

………………………………………………………………………………………

……………………………………………………..

2. Do you apply any pesticide in your farm? A. Yes B. No

3. What type(s) of pesticide(s) do you apply?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

…………………………………..................

4. How do you get this/these pesticide(s)?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………………………………………………………

5. Where are these pesticides coming from?

…………………………………………………………………………………………

…………………………………………………………

6. Where do you store the pesticides at home?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………

7. How much pesticide do you apply per acre?

…………………………………………………………………………………………

………………………………………………………

8. When do you normally apply this/these pesticide(s)?

a) Time of year

…………………………………………………………………………………………

………………………..

b) Time of day

……………………………………………………………………………………………

………………………….

c) Weather

…………………………………………………………………………………………

9. How do you prepare the pesticide(s) for application in your farm?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

………………………………………………………………………………………

10. How do you apply this/these pesticide(s)?

……………………………………………………………………………………………

……………………………………………………………………………..

....

....

....

....

11. How often do you apply this/these pesticide(s)

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………

12. Have you ever received any form of training? A. Yes B. No

13. If yes, where did the trainer comes from?

A. Ministry of Agriculture and Forestry B. Rice Research Station

C. Institute of Agriculture Research D Njala University

E. Others …………………………………………………………. (specify)

14. If no how do you know how to use the pesticide?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

………………………………………………………………………………

15. What equipment do you use to apply the pesticides?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………..

16. Do you protect yourself and your family members? A. Yes B. No

17. If your answer is yes for question 14, how do you protect yourself and your family during the application?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

18. How long do you take to apply the pesticides per day?

……………………………………………………………………………………

…………………………………………………………….

19. How many days do you take to apply the pesticide(s) on the whole farm?

……………………………………………………………………………………

……………………………………………………………

20. How many times do you apply the pesticide (s) per farming season?

……………………………………………………………………………………

……………………………………………………………

21. Do people work on the other side of the farm when you are applying pesticides? A. Yes B. No

22. Do you and family members work on your farm when someone is applying pesticide on a farm adjacent or close to yours? A. Yes B. No

23. Do you or any other person in close proximity inhale the pesticide(s) during application? A. Yes B. No

24. What are the target pests you apply this/these pesticide(s) for?

……………………………………………………………………………………

……………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………

25. Apart from your target pests what other organisms do these pesticides kill?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………

26. How long do these pesticides remain active after application?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

…………………………

27. In addition to the eradication of pest, what other benefits do you get from the use of pesticides?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………

28. What would you say about the effectiveness of these pesticides?

………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………..................

SECTION B

Health Effects

29. Have you or any member of your family ever experienced any health problem that requires an emergency medical attention after the application of pesticides? A. Yes B. No

30. If yes how long did this problem last?

A Few minutes B. Few hours C. A day D more than a day.

31. Have you ever experience any change on your skin since you started using pesticides?

A Yes B. No

32. If yes please describe the observed changes on your skin?

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………………

33. Have you or any member of your house hold suffered from the following diseases:

Disease Yes No

Nausea

Seizure

Respiratory disorder

Blurred vision

Loss of appetite

Lacrimation

Nervous disorder

Stomach ache

Head ache

Others

34. Do you eat living organisms caught from your farm's Environment? A. Yes B. No

35. How far is your drinking water source from your farm?

……………………………………………………………

36. Is the drinking water source covered or exposed. A. covered B. Exposed.

37. What measures do you take to prevent pesticides from contaminating food?

………………………………………………………………………………………

Appendix B

Questionnaire for Health Workers

Objective: To study the impact pesticides have on people living closer to the Environments in which they are used.

Name of Health Centre/Hospital

………………………………………………………………………

Date__/___/______

City/ town/ village

…………………………………………………………………...............................

.....

Chiefdom………………………………………………………………………………

…………………………………………………

District

…………………………………………………………………………………………

…………………………………………

Province……………………………………………………………………………

……………………………………………….

Designation of respondent

…………………………………………………………………………………………

………………………….

1. How long have you been working as a health practitioner?

A Less than one year, B. between one and two years. C. more than two years but less than five years   D. Five years and above

2. How long have you been working in this health centre?

A Less than one year, B. between one and two years. C. more than two years but less than five years D. Five years and above

3. Have you ever worked in any health centre apart from this? A. Yes B. No

If your "no" go to question 8

4. Where is/are the health centre (s) you have worked before located?

…………………………………………………………………………………………
…………………………………..

5. How long did you work at the last health centre before coming to work here?

A Less than one year, B. between one and two years. C. more than two years but less than five years D. Five years and above

6. How would you compare the Environmental sanitation of the community of your previous work station to the current one?

A. Differences ……………………………………..

………………………………… ………………………………

B. Similarities ……………………………………

…………………………………….. ………………………………..

7. How would you compare the health related cases at your previous station to the current?

A. Differences ………………………………..

………………………………………..

……………………………………

B. Similar ……………………………………

………………………………………..

……………………………………

8. What is the average number of patients that come to your health centre per week?

A 0 - 5 B. 6 - 10 C. 11 - 15 D. Above 15

9. What is the average number of skin problems cases reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

10. If skin problems are reported, what age bracket are these problems common?

A. 0 to 5 years B. 6 to 10 years C. 11 to 15 years D above 15 years

11. What is the average number of nausea problems cases reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

12. What is the average number of respiratory disease cases reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

13. What is the average number of blurred vision cases reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

14. What is the average number of nervous disorder cases reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

15. What is the average number of lacrimation problems reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

16. What is the average number of stomach ache problems reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

17. What is the number of head ache problems reported per week?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

18. What is the average number of patients that reported loss of appetite?

A. 0 - 5 B. 6 - 10 C. 11- 15 D. above 15

19. Do you have a laboratory for testing urine, blood and stool samples? A. Yes B. No

20. If your answer is ‘yes’ for question 14 what do you test for?

A Pathogen B Sugar C toxic chemicals D others (specify)

Blood

………………………………..

Stool ……………………………………

Urine ……………………………………

21. If your answer for question 14 is “no”, how far is your nearest referral centre? ……………………………………

22. How often do you come across cases of chemical intoxication?

A. Not at all B. rarely C. Sometimes D. Often

23. Do people die as a result of chemical intoxication in your area of operation? A. Yes B. No

24. If “yes”, how many chemical intoxication deaths have you recorded with in the past one year?

…………………………………………………………………………………….

25. Have you ever discussed chemical poisoning issues to the community elders? A. Yes B. No.

26. If you answer to question (20) is ‘yes’, what is the response of the elders towards this issue?

....

....

....

....

....

27. Please give additional information on chemical intoxication affecting the people in your area of operation.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………..

Thanks for your cooperation.

Appendix C

Krio Version of Questionnaire for Farmers

Information way we dae gether from the people way we get for talk to go only be used for get watin we want. En the people way we get for talk to get for gree en all waytin concern we sef get for be secret.

- How mus people dae under you care?

Section A

Background

1. How mus acres of land you dae use for plant for the year?
2. You dae put merehsin way den tin dem nor dae able amborg you plant?
3. Wus kind merehsin way you kin put pan the plant? You know den name?
4. How you kin get den merehsin ya
5. Wusai una kin get den meresin demy a?
6. Wusai una kin keep then meresin them ya

Application

7. Waytin you kin do way you want for put this meresin nar you farm?
8. Armus meresin way you kin put?

9. Wus tem you dae put den merehsin:

a. Per di year?

b. Per the day?

c. How the place kin look lek way you kin put dis merehsin?

10. How you kin put dis merehsin na you farm?

11. Way tin en way tin you dae use for put the merehsin?

12. How long you dae take for put dis merehsin in sai one day?

13. Arm us days you kin take for put di merehsin na the wan whole farm?

14. Arm us tem you dae put the merehsin from di tem wae you plant tae you cut di res per di year?

Effectiveness

15. Way tin you want for kill wae make you kin put den merehsin ya?

16. Wus other tin dem wae dis merehsin dae kill?

17. Way you don put this merehsin how long e go take way e go still able kill den tin dem?

18. Wus other benefit way ou dae get from the merehsin?

19. Dis meresin betteh or e nor betteh?

Training

20. Den don ever learn you how for yus this merehsin?

21. Wusai the person wae can learn you commot?

22. How you learn for use the merehsin?

23. Di wan dem wae dae put the merehsin na you farm arm us year den old?

24. The people dem wae dae put the merehsin dem nar you farm go school?

25. Watin wuna kin do for mek the merehsin nor amborg una?

26. Watin you kin do for protect yousef en you family di tem wae you kin put the merehsin?

27. Wae you kin put the merehsin nar you farm other people dem kin wok nar the other sai?

28. Wae una kin wok nar you farm other people dem kin wok nar den yone farm?

29. You en any other person kin smell this merehsin way una kin put am?

Section B

Health effects

30. U sabi anybody wae dis merehsin bin don amborg before?

31. If na so ebi, na for how long?

32. Any tin happen wit u body from way u start for use dis merehsin?

33. If na so ebi, how u body been look lek?

34. U en any person wae dae na u care don ever get kind sick ya wae ar dae cam call so?

	Sickness	Yes	No
1	Run nose		
2	Feel bad		
3	Choke up(breathing)		
4	U nor dae see fine		
5	U nor dae eat betteh		
6	Wae water dae run you eye		
7	Unsteady(lek u hand kin trimble)		
8	Belleh hat		
9	Head hat		
10	others		

35. U kin eat animal dem wae u kin catch na u farm?

36. How far di sai wae u dae get u water for drink dae from u farm?

37. Di water cover or e nor cover?

38. Wus kin tin dem wae u kin do for mek dis merehsin nor amborg u food?

Appendix D

Data collection instruments

Data collection

Structured questionnaires and interviews were used to study pesticide use, handling and impact to human health. The structured interview schedule (appendix 1) was applied to 500 house-hold farmers and the structured questionnaire (appendix 2) was applied to 100 community health workers. The interview schedule was also used in focus group discussions. Both the interview schedule and questionnaires were prepared with the aid of experienced social science researchers at LEC. These were reviewed by the Postgraduate Statistics Centre in Lancaster University.

Development of questionnaires

Pesticide contamination on rice farms has both a social and scientific implications. This is because the contamination of pesticides on farms depends on how the pesticides are used and handled. Therefore, to fully understand the scientific aspects of pesticide contamination, the social interaction of pesticides and its users is vital. This was the motivating factor that led to the use of questionnaires in this research. A semi-structured questionnaire and a structured were designed for farmers and health workers respectively. A semi-structured questionnaire was used for farmers to allow respondents give more details on some questions that require some explanation. A structured questionnaire was developed for health workers to avoid medical information which might be irrelevant to the scope of this research. The study was designed to target Sierra Leonean rice farmers.

Most of these rice farmers are illiterate and cannot complete a questionnaire by themselves. Therefore, the semi-structured questionnaire was modified to a structured interview schedule.

Questions were drawn based on the aims and objectives designed to address the research problem. The two sets of research instruments were reviewed by a professional social scientist in the Lancaster Environment Centre. Ambiguous questions were modified and the instruments were divided to various sections. The research instruments were further reviewed by the Lancaster University postgraduate statistics centre to ensure that the instruments can collect data which can be analysed statistically. The interview schedule and the questionnaire for health workers were tested with a pre-survey in which 10 farmers and 4 health workers were interviewed at Gbintiwallah. Results and video recordings of the survey were sent to the social scientist for further modification. The revised questionnaire and interview schedule were then interpreted to Krio before implementation.

Training of field assistants

Data collection was done in all the twelve districts in Sierra Leone. This can only be achieved with the help of people who are well informed about the requirements of the research. A team of five field assistants were trained by the researcher on techniques to conduct interviews and focus group discussions. The structured interview schedule was studied such that all the participants have the same understanding of all the questions. As a team the questionnaire was translated into Krio, the most commonly spoken language in Sierra Leone (Appendix 3). Each assistant was given two interview schedules and asked to interview any two people after observing the main researcher conducting an interview. The responses obtained were discussed and areas that needed clarification were addressed. The Krio version of the interview schedule was given to a Krio teacher for translation to English. The translated version was compared to the original schedule. The implementation of the schedule was explained in Chapter 2.

Implementation techniques

To achieve high response rate, the tribal/section heads are the first contacts. After explaining the purpose of the research to the heads, they would then invite their subjects and encourage them to take part. Religious leaders were also visited. Questionnaires for health workers were given to the tribal/section head who then give them to the head of the health centre. Questionnaires were collected either the same day or the following day. Personal discussions were also done to encourage respondents to participate.

Appendix E

Development of analytical method

Laboratory extraction methodology

The laboratory extraction method was developed from Gonçalves & Alpenddurada (2005). According to Gonçalves & Alpenddurada (2005), chlorpyrifos is soluble in most organic solvents and therefore can be extracted using a range of solvents. However, the most effective extracting solvent were reported as; ethyl acetate, acetone, dichloromethane and hexane (Gonçalves & Alpenddurada, 2005). One gram of pesticide free soil was dried with prebaked Na_2SO_4 and spiked with 50 µl of 10 µg/ml chlorpyrifos solution in acetone. The soil/pesticide mixture was thoroughly mixed and then extracted three times with a total 30 ml of ethyl acetate (10 ml at a time). The process is repeated five times and was also repeated with acetone, dichloromethane, hexane, 1:1 mixture of ethyl acetate and acetone, 1:1 ethyl acetate and dichloromethane, 1:1 ethyl acetate and hexane, 1:1 acetone and dichloromethane, 1:1 acetone and hexane and 1:1 dichloromethane and hexane. A blank was included in each set of extractions. The extracts were purified or 'cleaned' using an open chromatography column (see Chapter 3 for detailed method). The percentage recoveries obtained are shown in Table 1. The 1:1 ethyl acetate and hexane mixture gave the highest recoveries (92%). Therefore, ethyl acetate and hexane mixture was selected. Further testing was carried out using 3:2 ethyl acetate and hexane, 1:1 ethyl acetate and hexane and 2:3 ethyl acetate and hexane mixtures. The 3:2 ethyl acetate and hexane mixture gave recoveries of between 95 to 99%. None of the other mixtures gave that such high recoveries. Hence the 3:2 ethyl acetate and hexane mixture was used as the extraction solution.

To determine the number of extraction steps, one gram of soil was spiked with 50 µl of 10µg/ml solution of chlorpyrifos in a centrifuge tube. The pesticide was extracted with 10 ml 3:2 ethyl acetate and hexane mixture. The extract was transferred to an amber vial. The extraction was repeated four more times and each of the 10 ml extracts was collected using a different vial. The process was repeated using three sets of pesticide free soils. It was found that 92% of chlorpyrifos was in the first fraction, about 8% in the third. Levels of chlorpyrifos in the fourth and fifth vials were below detectable limits. Hence the extraction was done with 30 ml of the extracting solution (10 ml at a time). Similar results were obtained when ground rice was used in place of soil.

Clean-up

The extracts were purified or ‘cleaned’ using a glass column chromatography column. One column was packed with silica, the other with florisil and the third one was packed with alumina. Each of the columns was topped with about one cm thick anhydride sodium sulphate. Hexane was used as an eluent. Extracts cleaned with florisil and alumina gave similar and better chromatograms than those cleaned with silica. However, only alumina was used for cleaning of rice and soil samples from the experimental plots (see Chapter 3). In Chapter 4, extracts were cleaned using a combination of both florisil and alumina because the extracts from the farms were more coloured.

In addition to the glass column chromatography clean-up, biota samples were also ‘cleaned’ using gel permeation chromatography column to remove lipids.

This step preceded the glass chromatography column clean-up. The eluent used was a 1:1 dichloromethane and hexane mixture. To determine the volume range in which chlorpyrifos eluted and 40 ml eluent were collected in eight fractions of 5 ml each. It was found that the first 10 ml did not contain chlorpyrifos. The third fraction has about 1% chlorpyrifos with a high background noise. No chlorpyrifos was found on the sixth vial. Therefore, the first 15 ml were discarded and the next 20 ml were collected.

The GC/MS instrument method

A vial containing 500 pg/ml each of the calibration, recovery, and internal standards in hexane were analysed by GC/MS. It was observed that both the recovery and calibration standards elute almost at the same time. The method was readjusted to separate the two peaks (Figure 10). The results were calculated based on external calibration standards and on peak areas obtained. The chromatographic data acquisition was divided into four different segments in order to include the most common fragments of chlorpyrifos for improved sensitivity.

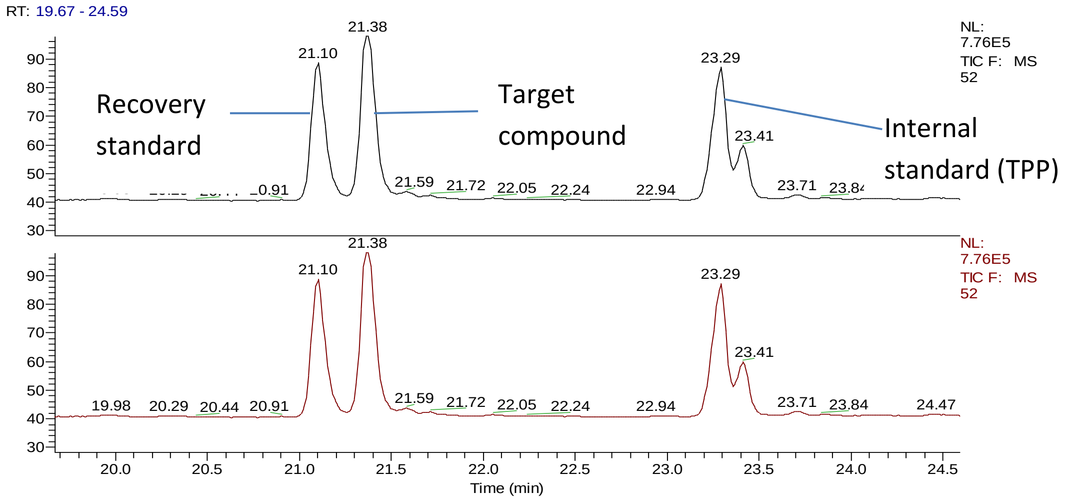


Figure 14: A sample chromatographic data showing peaks of the recovery standard, target compound, and the internal standard

The precision was evaluated based on repeated analysis. Five replicates were prepared for each test.

Appendix F

Ethics approval letter

Dear Alhaji

Thank you for submitting your completed stage 1 self-assessment form for **An assessment of the Chemical Contamination to the Environment & people of Sierra Leone**. I can confirm that approval has been granted for this project.

As principal investigator your responsibilities include:

- ensuring that (where applicable) all the necessary legal and regulatory requirements in order to conduct the research are met, and the necessary licenses and approvals have been obtained;
- reporting any ethics-related issues that occur during the course of the research or arising from the research (e.g. unforeseen ethical issues, complaints about the conduct of the research, adverse reactions such as extreme distress) to the Research Ethics Officer;
- submitting details of proposed substantive amendments to the protocol to the Research Ethics Officer for approval.

Please contact the Research Ethics Officer, Debbie Knight (ethics@lancaster.ac.uk 01542 592605) if you have any queries or require further information.

Kind regards,

Debbie

Debbie Knight
Research Ethics Officer
Research Support Office
B58, B Floor,
Bowland Main
Lancaster University
Lancaster, LA1 4YT

Appendix G

Participants Information Sheet

Researcher:

Alhaji Ibrahim Sankoh

PhD Student

Lancaster University

Lancaster – United Kingdom

Research Topic:

An Assessment of the Chemical Contamination on the Environment and People of Sierra Leone

Background Information:

This research is aimed at assessing the types and levels of chemical contaminants and their impact on the environment and people of Sierra Leone. This research is divided into two parts. The first part would investigate chemical contaminants from the waste dumps in Freetown and the second part would look at the impact of pesticides on the environment and the health of the people.

To achieve these goals, I would collect soil, plants, air and biota samples for laboratory analysis conduct interviews and set up a field experiment.

The results obtained would be analyzed and used to write reports which would be published in scientific journals. These reports would also be collated to form my thesis in partial fulfillment of the requirement for a PhD degree.

Request:

To help me achieve these goals, I would like to ask that you participate by volunteering to respond to this interview at your convenience. I would also like to record our discussion if you give me the permission.

Assurance:

I would like to assure you that;

i) Your participation would be totally anonymous and no personal information about you or any other person would be published.

ii) The information I collect from you would be protected and would not be used for any other purpose apart from the use stated above.

Note that your participation would be purely voluntary. You have the right and free will to participate, not to participate or withdraw at any time.

Do you have questions or comments?

Please feel free to ask questions or make comments at any time you thought of them.

Please complete the consent form if you would like to volunteer.

Appendix H

Participant Identification Number:

CONSENT FORM

PROJECT TITLE: An Assessment of the Chemical Contamination to the Environment and People of Sierra Leone

Name of Researcher: Alhaji Ibrahim Sankoh

Please initial box

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

3. I understand that any information given by me may be used in future reports, articles or presentations by the researcher. ☐

4. I understand that my name will not appear in any reports, articles or presentations. ☐

5. I agree to take part in the above study. ☐

______________________________	____________________ ____________________	
Name of Participant	Date	Signature

Appendix I

Interview close form

Title of Study: An Assessment of the Chemical Contamination To the Environment and People of Sierra Leone

---

Name of Researcher: Alhaji Ibrahim Sankoh

Please tick the box

1. I would like to receive a summary report of the study and am happy for the researcher to store my address details on a secured server in order to post the report to me when it is available. ☐

2. I agree to being contacted again for a second interview should the need arise. ☐

Name of Participant	Date	Signature/Left thumb print