Pesticide use in Nepal: Health effects and economic costs for farmers in the central mid-hills

Bruk av pesticider i Nepal: Helse-effekter og økonomiske kostnader for bønder i Central mid-hills-regionen

Philosophiae Doctor (PhD) Thesis

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Ås 2013

Thesis Number: 2013:20
ISBN: 978-82-575-1086-2
ISSN: 1503-1667

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Acknowledgement

This dissertation is submitted in partial fulfilment of the requirements for the Doctor of Philosophy (PhD) degree at the Department of International Environment and Development Studies (Noragric) within the Norwegian University of Life Sciences.

I have received material and moral support from several individuals and institutions both in Nepal and Norway. My foremost gratitude goes to my principal supervisor, Prof. Bishal Kumar Sitaula, for his continuous academic, moral and practical guidance. I sincerely acknowledge my co-supervisors Prof. Fred Håkon Johnsen, Dr. Hans Overgaard, Prof. Roshan Man Bajracharya, and Prof. Subodh Sharma for their professional guidance and support. I express my heartfelt thanks to the Aquatic Ecology Centre, Kathmandu University, Nepal for field and laboratory support. Dr. Prabesh Neupane, a medical professional, deserves sincere thanks for helping with this study, particularly with regard to blood sampling and analysis for acetylcholinesterase activity.

I am greatly indebted to those who contributed financially. I express my sincere gratitude to the following funders: (i) The Norwegian Program for Development, Research and Education (Research Grant No. NUFUPRO 2007/10109); (ii) Quota scholarship from the Norwegian State Educational Loan Fund; and (iii) the UMB Health Program – coordinated by Dr. Cassandra Bergstrøm.

I am very grateful to the Noragric/UMB staff. I thank my fellow PhD students, especially Nani Raut and David Tumusiime for interesting discussions and support. I would like to thank the Noragric librarian Liv Ellingsen and PhD coordinator Josie Teurlings for their kind assistance.

I am greatly indebted to my field assistants Mr. Kumar Thapaliya, Basu Gautam, Sanubhai Khadka and Maheshwor Dahal. I am also grateful to all the respondents in my study area. I am very grateful to the members of Nepalese Society in Ås (NEPSA) for making my stay very interactive and homely. Last but not least, I want to express my sincere gratitude to my family. My loving wife Sujata and son Anwesh deserve special thanks for their support and encouragement.

Kishor Atreya

Ås, 2013

Abstract

The thesis evaluates the negative effect that intensive agriculture brings, particularly in terms of the effect of pesticide use on human and on the environment, and the associated economic cost. Vegetable production is an important source of farm income, but this has become increasingly reliant on the excessive use of chemical pesticides. This not only pollutes the environment but also affects farmers' health. The thesis hypothesises that the excessive and injudicious use of pesticides in intensive farming will adversely affect human health and increased economic costs for the farmer.

A study was carried out in Ansi khola and Jhikhu khola watersheds of central mid-hills of Nepal, during 2008 and 2009 to observe the effect of the use of chemical pesticides on intensive farming. The objectives were (i) to review factors affecting pesticide use in developing countries; (ii) to assess risks of pesticide use for farmers by assessing erythrocyte acetylecholinesterase activity (AChE); (iii) to value the risk of pesticide use for farmers and for environmental health; and (iv) to assess the impact of the associated economic costs of pesticide use for vulnerable populations within an agrarian society. Data was collected through household surveys, group discussions, and individual interviews. The Test-mate ChE Cholinesterase Test System was used to monitor erythrocyte AChE activity before and after pesticide application seasons. Cost-of-illness, defensive expenditures, and willingness to pay (WTP) approaches were applied for valuing health and environmental costs of pesticide use. To this, an opportunity cost of spraying time, and amount spent on purchasing chemical pesticides were added for estimating total cost of pesticide use.

The objectives have been addressed in four separate but interrelated studies. The synthesis of these studies revealed that farmers were significantly exposed to chemical pesticides. The use of chemical pesticides resulted in acute health symptoms, increased economic costs, and the costs of pesticide use in proportion to household cash incomes was likely to be higher for the most vulnerable group within the society, the small farmers.

Specifically, the first paper reviews "*continuing issues in the limitations of pesticide use in developing countries"* and found that impact of pesticide use in crop production is complex and inter-connected. This topic requires an interdisciplinary approach; without this, farmers in the developing world will tend to incur economic costs as a result of health and environmental degradation.

The second study, *"Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal*" found low levels of care with regard to pesticide use and high level of awareness among the farmer with regard to the environmental impacts of pesticide use. However, farmers failed to take adequate safety precautions. Current levels of use of pesticides were sufficient to cause acute health symptoms and AChE depressions.

The third study, "*Health and environmental costs of pesticide use in vegetable farming in Nepal*" takes account of both the health and environmental cost of pesticide use for farmers, and revealed that exposed farmers were likely to have to carry increased economic costs as a result of pesticide use. If provided with safe alternatives to chemical pesticides, farmers were willing to pay more than the cost of existing pesticides in order to protect their health and environment.

The final study, "*Distribution of costs of pesticide use by household economy*" showed an uneven distribution of the cost of pesticide use between households. On average, the health costs of illness associated with pesticide use was equivalent to nearly 5% of agricultural cash income, which was likely to be higher for small-scale households (5.7%) than the large-scale (3.6%). Similarly, the total economic costs of pesticide use for farmers amounted to 15% of agricultural cash income, and/or 5% of total household cash income. The medium-scale households likely to incur the highest economic costs of pesticide use; however, the cost in proportion to household cash incomes was likely to be higher for small-scale households.

The thesis recommends an increased emphasis on seeking alternative ways of controlling pests, such as the use of IPM along with further education, training and awareness for local farmers.

Sammendrag

Avhandlingen evaluerer den negative effekten som intensivt jordbruk medfører, spesielt når det gjelder effekten av sprøytemiddelbruk på mennesker og miljøet samt den resulterende økonomiske kostnaden. Grønnsaksproduksjon er en viktig inntektskilde for bønder, men det har blitt stadig mer avhengig av et overforbruk av kjemiske sprøytemidler. Dette forårsaker ikke bare forurensning av miljøet, det påvirker også bøndenes helse. Avhandlingen setter frem hypotesen om at for stor og lite gjennomtenkt sprøytemiddelbruk i intensivt jordbruk har en negativ effekt på menneskers helse, og at det medfører økte økonomiske kostnader for bonden.

Det ble gjennomført en undersøkelse i vannskillene Ansi khola og Jhikhu khola i de sentrale mellomliggende åsene i Nepal i løpet av 2008 og 2009 for å observere effekten av sprøytemiddelbruk i intensivt jordbruk. Formålet var (i) å gjennomgå faktorer som påvirker bruk av sprøytemidler i utviklingsland; (ii) å gjennomgå risikoen ved bruk av sprøytemidler for bønder ved å vurdere acetylcholinesterase-aktivitet (AChE) i røde blodceller; (iii) å verdsette risikoene ved sprøytemiddelbruk for bønder og miljøet; og for (iv) å vurdere påvirkningen av den resulterende økonomiske kostnaden ved sprøytemiddelbruk for sårbare befolkningsgrupper i et jordbrukssamfunn. Informasjonen ble innhentet gjennom undersøkelser i husholdninger, gruppesamtaler og intervjuer med enkeltpersoner. Testsystemet Test-mate ChE Cholinesterase ble brukt til å overvåke AChE aktiviteten i røde blodceller før og etter sprøyting. Tilnærminger som kostnader ved sykdom, forsvarsutgifter og villighet til å betale (WTP) ble brukt til å vurdere helse- og miljøkostnadene ved sprøytemiddelbruk. Til dette ble det lagt til mulighetskostnaden ved sprøytetid og kjøpsprisen på kjemiske sprøytemidler for å kunne anslå den totale kostnaden ved sprøytemiddelbruk.

Målene beskrives i fire separate, men sammenknyttede undersøkelser. Undersøkelsene viser at bøndene ble utsatt for kjemiske sprøytemidler i betydelig grad. Bruk av kjemiske sprøytemidler resulterte i akutte symptomer og økte økonomiske kostnader. Det var også sannsynlig at kostnadene ved sprøytemiddelbruk i forhold til husholdningens kontantinntekt var høyere for den mest sårbare gruppen i samfunnet, nemlig småbønder.

Spesifikt fremgår det av den første undersøkelsen, "*kontinuerlige problemer med begrensning av bruk av sprøytemidler i utviklingsland*"" (*continuing issues in the limitations of pesticide use in developing countries*), at innvirkningen av sprøytemiddelbruk på avlinger er kompleks og sammenkoblet. Dette temaet krever en tverrfaglig tilnærming – uten det vil bønder i utviklingsland fortsette å generere økonomiske kostnader som følge av negativ innvirkning på helse og miljø.

Den andre undersøkelsen, "*Kunnskaper, holdning og bruk av sprøytemidler og depresjon relatert til acetylcholinesterase blant bønder i Nepal*" (*Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal*), fant at bøndene utviste liten forsiktighet med bruken av sprøytemidler, men at de var svært bevisste på sprøytemidlenes påvirkning på miljøet. Bøndene tok imidlertid ikke tilstrekkelige sikkerhetshensyn. De gjeldende nivåene for bruk av sprøytemidler var tilstrekkelige til å forårsake akutte helsemessige symptomer og AChE-depresjon.

Den tredje undersøkelsen, "*Helse- og miljøkostnader ved bruk av sprøytemidler ved dyrking av grønnsaker i Nepal*" (*Health and environmental costs of pesticide use in vegetable farming in Nepal*), viser både den helsemessige og miljømessige kostnaden for bønder ved bruk av sprøytemidler, og den avslørte at utsatte bønder sannsynligvis ville måtte bære økte økonomiske kostnader som et resultat av sprøytemiddelbruk. Når bøndene ble introdusert til sikre alternativer til kjemiske sprøytemidler, var de villige til å betale mer enn kostnaden for de eksisterende sprøytemidlene for å beskytte helsen sin og miljøet.

Den siste undersøkelsen, "*Distribusjon av kostnader ved sprøytemiddelbruk etter husholdningsøkonomi*" (*Distribution of costs of pesticide use by household economy*), viste en ujevn fordeling av kostnader ved sprøytemiddelbruk mellom husholdninger. I gjennomsnitt tilsvarte helsekostnader ved sykdom relatert til sprøytemiddelbruk nesten 5 % av kontantinntekten fra jordbruket, noe som mer sannsynlig var høyere for småskala husholdninger (5,7 %) enn for storskala husholdninger (3,6 %). Den totale økonomiske kostnaden ved sprøytemiddelbruk for bøndene tilsvarte 15 % av kontantinntekten fra jordbruket og/eller 5 % av den totale kontantinntekten til husholdningen. Det er mest sannsynlig at mellomskala husholdninger genererer de høyeste økonomiske kostnadene ved sprøytemiddelbruk, mens derimot kostnaden i forhold til kontantinntekten til husholdningen var mest sannsynlig høyere for småskala husholdninger.

Det anbefales i avhandlingen av det legges større vekt på å finne alternative måter å kontrollere skadedyr på, for eksempel ved bruk av IPM i kombinasjon med utdanning, opplæring og bevisstgjøring for lokale bønder.

List of papers

Paper I:

Atreya K, Sitaula BK, Johnsen FH, Bajracharya RM. 2011. Continuing issues in the limitations of pesticide use in developing countries. *Journal of Agricultural and Environmental Ethics* 24: 49-62.

Paper II:

Atreya K, Sitaula BK, Overgaard H, Bajracharya RM, Sharma S. 2012. Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal. *International Journal of Environmental Health Research*. 22: 401-415

Paper III:

Atreya K, Johnsen FH, Sitaula BK. 2012. Health and environmental costs of pesticide use in vegetable farming in Nepal. *Environment, Development and Sustainability* 14: 477-493.

Paper IV:

Atreya K, Sitaula BK, Bajracharya RM. 2012. Distribution of costs of pesticide use by household economy. Manuscript.

1. Introduction

Changes in agricultural technology in the 20th Century have revolutionised food production in parts of the world. The generally held belief until 1960s was that, the benefits of these technological changes (such as chemical pesticide use) in terms of increased food production far outweigh their negative impact on human health and the environment. However, the Rachel Carson's revolutionary book the *Silent Spring* made people aware of the negative effects of pesticides. In fact, the book "touched off the debate on the use of chemical pesticides, the responsibility of science, and the limitations of the technological progress" (Lear 2002). It is now believed that, pesticide use in crop cultivation has two main effects. The first is an income gain as a result of a reduction in crop losses; the second is a negative effect on human and environmental health.

Pesticides are chemical substances used to control harmful organisms. Globally, agricultural sector consumes significant amount of pesticides – approximately 85 percent of the estimated 2.9 million tones used each year (Raven et al. 2008). Pesticide use is increasing worldwide, but at a rapid rate in developing countries. The developing nations utilize only 20 percent of world total pesticides applied. Despite increasing application of tons of pesticides worldwide, more than 40% of all potential food production and another 20% of the harvested crop is lost due to pests (Paoletti and Pimentel 2000). Only a small amount of the applied pesticide actually reaches the intended target organism and the vast majority ends up elsewhere in the environment (Pimentel 1995, Pimentel and Burgess 2012). Less than one percent of pesticides applied to the agriculture reach their target pests, and more than 99 percent of it adversely affects unintended targets including the public and environmental health (Pimentel 1995). The World Health Organization (WHO) of the United Nations has estimated that use of pesticides cause 26 million non-fatal poisoning; among them 3 million cases are hospitalized, 220 thousand deaths and about 750 thousand suffered chronic illnesses every year worldwide (WHO 2006).

1.1. Health and environmental effects of pesticide use

Because of continued use of the chemical pesticides in agriculture, its effects to human and ecosystems health are immense. The literature from developing countries around the world shows that use of pesticides in agricultural farms frequently leads to acute health symptoms. The use of pesticides in agricultural farms has been reported to have adverse short-term acute health effects. These include headaches, skin irritation, eye irritation, respiratory and throat discomfort, etc. (Beshwari et al. 1999, Dung and Dung 1999, Murphy et al. 1999, Yassin et al. 2002). Beshwari et al. (1999) and Murphy et al. (1999) reported significantly more signs and symptoms to pesticides sprayer compared to the control subjects. In India, Mancini et al. (2005) found 16.4% asymptomatic, 39% mild poisoning, 38% moderate poisoning, and 6% severe poisoning among the household surveyed due to pesticide use. Also, in addition, long-term, low-dose exposures to pesticides are increasingly linked to health problems such as immune-suppression, hormone disruption, diminished intelligence, reproductive abnormalities, and cancer (Gupta 2004). Ample evidence exists concerning the carcinogenic threat related to the use of pesticides (Pimentel 2005). There are probable linkages between long-term pesticide exposure and human health problems like neurological effects, endocrine disruption, reproductive health and cancer (EPA 1999).

The use of pesticides can have an effect on the multiple of interacting factors in the environment, for example soil, surface and ground water, crop productivity, micro and macro flora and fauna (Pimentel 2005). Loss of ecosystem resilience, biodiversity loss, pest resurgence and resistance, bioaccumulation and biomagnifications of the pesticides, and food contaminations are other examples of indiscriminate use of chemical pesticides (Raven et al. 2008). Generally these negative impacts are not accounted for estimating cost of pesticides use in agriculture. The conventional economic analysis weighs the conventional costs and benefits of pesticide use. In general, farmers benefit an estimated USD 3 to 5 in crops for every USD 1 that they invest in pesticides (Raven et al. 2008). The estimates of benefits, however, are conventional. Also do not sufficiently the estimate take into account of pesticides effects on ecosystems and human health. In addition, possible linkages among pesticide use, international transport, and arctic degradation are emerging issues (Cone 2006). Chemical pesticides that have been used in the United States, Europe, and Asia can not only have effects on-site, but can also have significant negative impacts in areas that are thousands of kilometers away from the origin, for example the Arctic region (Cone 2006). Human health impacts and social implications (like suicide attempts by consuming pesticides, unintentional poisoning by contaminated foods, etc.) of pesticides are also not adequately considered. Moreover, the cost does not capture the physical and psychological pain and discomfort experienced as a result of acute and long-term illnesses (Wilson 1998, Pimentel 2005).

1.2. Valuing health and environmental effects

A number of studies have attempted to value the costs of negative effects of pesticide use on human and environmental health. A comprehensive analysis of the environmental and societal impacts of pesticide use in the United States was found in Pimentel (2005). He has accounted different areas of the impacts, namely: (i) public health - intentional poisoning, chronic illness and associated days lost; (ii) domestic animal deaths and contaminations; (iii) beneficial natural predators and parasite destruction; (iv) pesticide resistance in pests; (v) reduced pollinations and bee poisoning; (vi) crop injury and losses due to drift; (vii) ground and surface water contamination; (viii) fishery losses; (ix) birds and other mammals; (x) soil microbes; and (xi) government funds for pesticide pollution control. For the US, he estimated the costs to be around USD 10 billion, and the saved crop through pesticides approximately USD 40 billions, which in a strictly cost/benefit approach, appears beneficial. In a trans-disciplinary study in the United Kingdom, Pretty et al. (2000) calculated the total external costs of UK agriculture in 1996 to be GBP 2.34 billion, of which the annual cost of pesticide-related acute health effects was GBP 1 million and that of drinking water contamination was GBP 120 million. The external cost of UK agriculture was equivalent to 89% of average net farm income, or 13% of average gross farm returns for the 1990s, or GBP 208/ha of arable land.

However, in developing countries, studies on health costs to farm workers and applicators are not adequately analyzed and some report suggested much lower numbers compared to the cost estimated in developed countries. A research from the interdisciplinary and interinstitutional team of scientists in Ecuador (Yanggen et al. 2003, 2004) showed severe health effects of pesticide use in potato production, and estimated immediate costs (costs of medical attention, medicines and days lost) of pesticides poisoning equal to 11 days of lost labor wages. The same study also showed neurological health effects (difficulties in carrying out basic physical tasks and farm management decisions) to the two-thirds of the farmers, which was not included in the costs analysis due to methodological difficulties. In Sri Lanka, a study using the cost-of-illness and defensive expenditure approaches (Wilson 1998) estimated that a farmer incurred an average annual cost of USD 98 and 7 in handling and spraying of pesticides, respectively. The same study also used contingent valuation, in which an individual was asked an open-ended question regarding the maximum amount they would be willing to pay in order to avoid direct exposure to pesticides and the resulting health effects. This inquiry yielded a value of USD 205 per individual per year. In India, Devi (2007) adopted the cost-of-illness, and estimated annual health care costs of pesticide use to be around USD 36 per applicator.

The pesticide-induced health care costs estimated in different countries shows significant variation, which could be attributed to different methods adopted, for example, Wilson (1998) used recall periods of a year. Similarly, Pimental (2005) and Wilson (1998) measured long-term chronic illnesses as well as intentional poisoning. Devi (2007) considered only short-term acute health effects of short-term exposure. Clearly, health costs of pesticide use exist and have shown great variation. The magnitude of costs of pesticide use depends on the types of health/environmental effects considered, methods adopted in valuations, and the local perception on the risk of pesticide use. Therefore, the economic cost of pesticide use needs to be calculated closely by looking at ground realities of farmers because it also may constrained by their socio-economic factors and biophysical hardship of the environment they live in.

1.3. Pesticide use in Nepal

There has been an increased expansion and intensification of agriculture over the past few decades in many parts of Nepal. The changes include a shift towards the increased use of chemical fertilizers and pesticides for the production of vegetables and food crops. Because of the high demand for vegetable crops (Brown and Shrestha 2000, Brown and Kennedy 2005), a clear trend of increased pesticide use in semirural (rural cities) and peri-urban (bordering major cities) areas was observed. Also agriculture intensification has resulted in increased farm incomes (Brown and Kennedy 2005, Tiwari et al. 2008, Dahal et al. 2009); increased surface water pollution (Dahal et al. 2007), acidification (Brown and Shrestha 2000, Raut et al. 2012) and greenhouse gas emission (Raut et al. 2012); the health and environmental costs of pesticide pollution have increased as a result (Atreya 2008a). Pesticide use in Nepal started in the early 1950s with the use of DDT (dichlorodiphenyltrichloroethane) for malaria eradication. This was followed by other organochlorines [such as BHC (benzene hexachloride), dieldrin, chlordane], organophosphates (such as ethyl parathion, methyl parathion, malathion, and oxydemeton methyl), carbamates and finally synthetic pyrethroids (Neupane 2001). Country-level data shows increased consumption and importation of pesticides over years. A total of 356 tons of pesticides was imported in 2008, with fungicides (>57%) and insecticides (<30%) making up the bulk (Atreya and Sitaula 2010).

The intensity of pesticide use in Nepal is relatively low if measured on a total area basis (0.15 g/ha) compared to other countries like India (0.5 kg/ha), Korea (6.6 kg/ha) and Japan (12 kg/ha); however, its use as a result of agricultural intensification in the certain pocket areas, nevertheless poses a serious concern to human health and to the environment. This is largely due to a lack of knowledge regarding the proper use of pesticides, a lack of awareness among users about health impact, and a lack of extension support to ensure safety and compliance with government regulations. Jha and Regmi (2009) estimated pesticide use at around 2.6 kg/ha for vegetable crops (four times higher than the recommended level) in an area close to Kathmandu, the capital of Nepal. They showed the marginal productivity of pesticides was close to zero, indicating excessive use at present. This unsustainable use of pesticides may have major implications for future agriculture development and for human health and environment.

1.4. Focus of the study

The thesis has considered one aspect of pesticide use i.e., short-term health effects of pesticide use in commercial areas of Nepal. It only concentrated on the short-term exposure to the chemical pesticides, its short-term health effects and the associated health and other associated costs of pesticide use. It neither values long-term chronic illness and intentional poisoning nor social costs or benefits of pesticide use.

The indiscriminate use of chemical pesticides result in short-term health effects, which is harmful to health. The affected individuals experience discomfort and pain, a loss of productive time, and their expenditure on medicine and medical treatment increases. Individuals who are exposed to pollution have to take action to reduce the adverse impact on their health (Freeman 1993), so the defensive expenditure increases. Therefore, the proposition that informs this thesis is that when chemical pesticides are used on a farm, it is likely that individuals who are exposed to these pesticides will exhibit short-term acute health symptoms, and these can be detected by monitoring AChE activity. Use of pesticides may result in sickness, loss of earnings and increased medical expenses. On this basis, we selected rural areas of Nepal for study where agriculture is becoming increasingly commercialised and local farmers are beginning to use relatively high levels of pesticides.

2. Research problems and justification

The use of pesticides on farms adversely affects the environment and human health. Examples of the environmental effects of pesticide use in agriculture (Pimentel 2005, Raven et al. 2008) are the deaths of domestic animals, the loss of natural predators of pests, increased pesticide resistance, bird and fishery losses, and surface and sub-surface water contamination. The linkage between agricultural intensification with its increased pesticide use and the harmful effect on the environment and human health (Wilson 2000, Atreya 2005, 2008b) is becoming clearer. Studies have shown the acute health effects of exposure to pesticides on farms. The acute illnesses, such as headaches, skin irritation, eye irritation, and respiratory and throat discomfort are likely to increase when farmers are exposed to pesticides (Beshwari et al. 1999, Dung and Dung 1999, Murphy et al. 1999, Yassin et al. 2002, Maumbe and Swinton 2003, Devi 2009a).

Increased use of chemical pesticides may result in acute health symptoms that will increase the health cost for farmers such as medical bills and treatment costs (Pingali et al. 1994, Antle et al. 1998, Wilson 1998, Devi 2007). However, farmers continue to use pesticides in increasing quantities, as the existing agricultural system has locked farmers into a system of pest-control technology involving the use of pesticides (Wilson and Tisdell 2001). This is because, in the short term, profits from farming are likely to increase (Tiwari et al. 2008, Dahal et al. 2009); in the long term however, the system's sustainability is in doubt. In the long term, increased and incompetent pesticide use is likely to have a detrimental effect on human and environmental health, and this may lead to decline in human productivity and in economic and social integrity. The effects of the use of pesticides may be very complex and inter-connected; therefore it may require a holistic way of analysis in order to account for both the human and environmental impacts to ensure the long-term sustainability of the agricultural system (Paper I). The negative effects of pesticide use on human and environmental health are seldom accounted for in the analysis of agricultural returns because of either data unavailability or methodological difficulties in evaluating the costs of negative impacts.

Farmers are regularly reported to exhibit short-term acute symptoms of poisoning after exposure to pesticides on farms. These symptoms include headaches, irritation and burns, and acute symptoms of poisoning is often verified through clinical examination. Furthermore, knowledge about pesticides and attitudes to pesticides, and the use of pesticide on farms are factors that affect the degree of exposure. It is likely that individual beliefs regarding the potential risk of pesticides, the adoption of safety precaution, and the appropriate of handling pesticides will influence the degree of exposure. Therefore, combining erythrocyte acetylcholinesterase (AChE) activity with self-reported acute health symptoms could offer better prospects for identifying the effects (Lotti 1995, Keifer et al. 1996, Quandt et al. 2010) than simply acknowledging acute health symptoms through surveys. Acetylcholinesterase is an enzyme that helps to maintain the proper functioning of the nervous system. When farmers are exposed to organophosphorus and carbamate pesticides, the acetylcholinesterase function is blocked. The use of AChE as a biological indicator of exposure to pesticides is becoming better known, but in Nepal such studies are still very limited (Paper II).

Increased pesticide use may cause short-term acute health effects that result in the loss of working days and in increased medical expenses for farmers (Freeman 1993). It also tends to increase the cost of measures taken to reduce the health impact of exposure (Wilson 1998). A few studies have attempted to estimate the loss of productivity, the cost of safety measures, and environmental degradation caused by pesticide pollution. Despite their understanding of the complex phenomenon of the impact of pesticides, economic valuations have studied either the effect on health or on the environment– but not the combined effects. In general, the environmental dimension of pesticide use has not been sufficiently studied (Travisi et al. 2006), leading to a distortion in economic valuations of the impact of pesticides. In practice, both the health and environmental impacts need to be estimated together in order to find optimal solutions for reducing exposure in any agricultural system. The World Development Report (World Bank 2007) claimed that the environmental cost of pollution from pesticides could be reduced. This report further argues that policies to reduce the use of pesticides can benefit profitability, as well as benefitting the environment and human health (in the case of intensive agricultural systems). Also because of lack of appropriate methodologies and reliable data, the health and environmental impacts of pesticide use have traditionally been omitted from the analysis of returns on agricultural research and from the evaluation of specific agricultural policies (Pimentel et al. 1992, Antle and Pingali 1994). Therefore, the present study, conducted in Nepal, tries to fill these research gaps, by taking into account both the health and environmental impacts (Paper III).

In Nepal, a few studies (Atreya 2008b, Jha and Regmi 2009) have reported heavy use of pesticides with minimal attention to hygiene and safety. However, there is little empirical research focusing on farmers' occupational health and safety in Nepal. For example, Poudel et al. (2005) cited only seven scientific studies of occupational health from 1966 to 2004, none of which addressed the use of pesticides and their impact on health. Similarly, Joshi et al. (2011) reported only 15 studies of Nepal's occupational health and safety from 2003 to 2011 and concluded that the status of occupational safety and health for Nepal was unsatisfactory. This indicates that, at first, there are very few scientific studies on pesticide use and its impact on human and environmental health; and second, there are limited attempts to estimate the economic cost of pesticide use in Nepal. Paper III of this thesis addresses the health effects of pesticides on farmers and estimates the economic cost of pesticide use on human health and the environment.

Studies on the health cost of pesticide use around the developing world are emerging: for example, in the (i) Ecuador (Antle et al. 1998, Cole et al. 2000, Yanggen et al. 2003), (ii) India (Devi 2007), (iii) Nepal (Atreya 2008a), Philippines (Antle and Pingali 1994), (iv) Sri Lanka (Wilson 1998), (v) Tanzania (Ngowi et al. 2007), (vi) Vietnam (Dung and Dung 1999), (vii) West Africa (Ajayi 2000), and (viii) Zimbabwe (Maumbe and Swinton 2003). However the cost associated with pesticide use by household economy is ignored. In Nepal, literature has shown an uneven distribution across households of the benefits of agricultural intensification (Brown and Kennedy 2005, Tiwari et al. 2008, Dahal et al. 2009, Nepal and Thapa 2009). It is likely that large-scale farming household receives most of the benefits of agriculture intensification. However, these studies are silent on another side of intensification, namely, increased pesticide use and its effects on human health. Small-scale farmers may be more vulnerable to pesticide use as they are less likely to appreciate the risk associated with the use of pesticides. Moreover, they often apply pesticides without adequate protection (FAO 2011). Paper IV focuses on estimating the health effects of using pesticides, and disintegrates the total cost of pesticide use by household economies. It attempts to determine whether large- or small-scale farmers incurred the highest economic costs of pesticide use in the commercial farming.

3. Objectives

This study has the broad aim of evaluating the negative effects that intensive agriculture brings, particularly in terms of the effect of pesticide use on human health and on the environment in the central mid-hills of Nepal.

The thesis has the following specific objectives:

1. To identify factors limiting pesticide use and to explore the research gaps in evaluating the economic and social consequences of pesticide use in Nepal (Paper I);
2. To document knowledge, attitudes and practices of individual farmers with regard to pesticide use, and to assess risk of pesticide exposure to these individuals by monitoring erythrocyte acetylcholinesterase activity (Paper II);
3. To address human health effects of pesticide use and to estimate the economic costs of health and environmental degradation (Paper III);
4. To identify which category of households in Nepal incurred the most economic costs from pesticide use (Paper IV).

The following hypotheses were tested:

1. Pesticide use in agriculture not only provides yield benefits but also affects human health, local environment, and a multitude of interacting factors of the environment, and the complexity of its effects demands a holistic approach in order to make an economic appraisal of pesticide use (rather than a simple traditional approach) (Paper I).
2. Individuals in the study area applying pesticides lack adequate knowledge, lack the appropriate attitudes and are not sufficiently aware of appropriate practices with regard to pesticide use. As a result they are exposed to levels of pesticide that reduce acetylcholinesterase activity and cause short-term acute health symptoms (Paper II).
3. Use of chemical pesticides on farms increases acute health symptoms and degrades the local environment; this may result in a loss of productivity and in medical and defensive expenses. Estimation of these health and environmental cost along with other associated costs of pesticide use may enable policy makers for the effective analysis of the pesticide reduction programs (Paper III).
4. The health and the total economic cost resulting from the use of chemical pesticides in commercial farming differ according to the type of farming households (Paper IV).

4. Theoretical framework

Agricultural intensification has enabled sufficient food production to keep up with the population growth over the past 50 years (Matson et al. 1997) – this is the opposite of the Malthusian theory of demography. Bosserup's counter-Malthusian theory helps to explain why population growth increases the level of food production. Bosserup says an increase in population leads to greater food production through intensive agriculture and the use of innovative technologies. These two main theories, the Malthusian theory and Bosserup's, are the starting points for postulating different causes for agricultural changes. Later, as a contribution to post-Bosserup literature, Brookfield and Stone have examined the different dimensions and complexities of agricultural change. Agricultural changes are determined by ecological, social and political factors (Brookfield 2001, Stone 2001). However, changes in agriculture vary according to context and are also determined by many other factors, such as the capital available to farmers and their level of organisational skill. Farmers' investment in agricultural land enhances production and reduces risks (Brookfield 2001). One of these investments is the use of pesticides to increase profits through minimizing crop losses. However, the use of pesticides in agricultural crop production can have both positive (e.g. increased income) and negative effects on human and environmental health (Pimentel 2005). The negative aspects of pesticide use may be greatest when the pesticide users are unaware of the possible harm to their health and fail to take adequate safety measures. The negative implications of agricultural intensification, particularly pesticide use, and the respective hypotheses or studies are described in Figure 1.

It is recognized that pesticide use carries significant risk of injury and illness. When a farmer is exposed to pesticides, short-term acute illnesses such as headaches, irritation, and burns are common. The illness may require total bed rest. Thus, there is loss of productivity due to pesticide-related illness, loss of time and the labour of family member(s) (the victim may require nursing), and leisure-time loss (Wilson 1998, Ajayi 2000, Atreya 2008a). Similarly, medical expenditure, transportation costs, the value of time spent travelling, and dietary expenses due to illness are among the expenses incurred when a person is suffering from pesticide-induced illnesses (Maumbe and Swinton 2003, Devi 2007). The cost of protective clothing, gloves, facemasks, etc. which are needed for protection (Wilson 1998, Atreya 2008a) adds to the expenses incurred.

The increased economic costs of pesticide use in an agrarian society may have different implications for different categories of households. This thesis explores the theoretical background, and provides a detailed account of the economic and health consequences of the pesticide use.

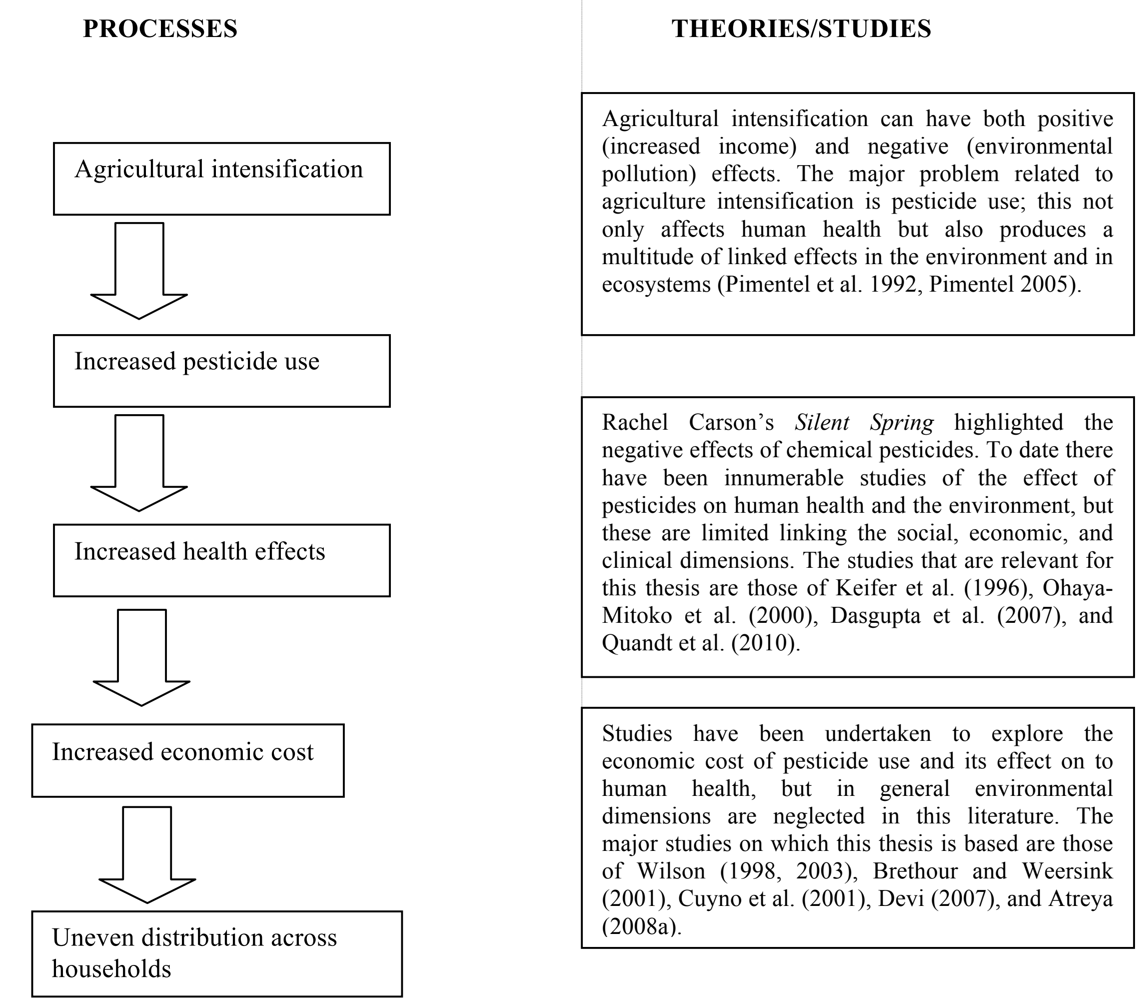

Figure 1: The links between major theories or studies dealing with agricultural intensification, the health effects of pesticide use, and economic valuation.

5. Scope and limitations of the study

The thesis focused on the short-term exposure to chemical pesticides and resulting short-term health effects and the costs of pesticide use for local farmers in an intensive farming system. The study did not take account of long-term illness, as well as, increase in farm income due to reduction in crop losses as a result of chemical pesticide use. Moreover, the effect of pesticide use on consumer health was beyond the scope of this work.

The thesis has a number of limitations due to both biophysical and socio economic diversities and locally evolved realities in mid-hills of Nepal. The research was done in the mid-hill watersheds of central Nepal; therefore, findings may not be generalized all over Nepal and elsewhere around the world. Sample size for clinical analysis was small. Field level enumerators were deployed for data collection, which might have resulted in data collection errors; although they were well experienced with the local realities and have had prior knowledge in the household survey. It should be mentioned, however, that large data set collected from difficult terrain may serve as important baseline information for further analysis; and there could be room for further analysis and improvement in interpretation of results using suitable models. These were limited by constraints in time and available resources.

6. Materials and methods

A brief description of the methods used is presented in this section. This covers (1) the study area; (2) household sampling and sample size; (3) data collection methods; (4) AChE analysis; (5) economic valuation; (6) probability and cost estimation; (7) household classification; and (8) statistical analysis. For more details please refer to the individual papers.

6.1. The study area

The study was conducted in the Ansi khola watershed and lower areas of Jhikhu khola watershed of Kavrepalanchowk district of central Nepal. The Ansi khola watershed, situated approximately 45 km north of Kathmandu – the capital of Nepal (Figure 2) – lies between N 27° 41'-44' latitude and E 85° 31'-37' longitude. The elevation ranges from 800 to 2000 meters above sea level (masl) and covers an area of 13 km^2. The Ansi khola watershed comprises four Village Development Committees (VDCs), namely Mahadevsthan, Nayagaun, Anaikot, and Devitar. A lower area of the Jhikhu khola watershed comprises four VDCs, namely Mithunkot, Patlekhet, Kharelthok, and Kavre.

National highways link both watersheds. Both watersheds are close to the capital and to three other cities along the way. In these areas, farming families are moving from subsistence rice production system to market-based vegetable production systems. The irrigated lower reaches of the watersheds support three harvests per year (rice-rice-potato/other vegetables). The upper rain-fed areas support maize and millet in the monsoon period, and potato or other vegetables during the winter season. The major vegetable crops grown at the time of the study were potato, tomato, cauliflower, chilli pepper, cucumber, bitter gourd, cabbage, brinjal, lady's fingers, pumpkin, sponge gourd, radish, and green leafy vegetables.

The study mainly focuses on the Ansi khola watershed; however, Paper II considers both Ansi khola and Jhikhu khola watersheds. The latter watershed was used as a reference for the comparison of the research findings with those from the Ansi khola watershed. This is because some past studies (Atreya 2005, 2008a) have reported significant health and environmental costs in the area as a result of the continuous and indiscriminate use of pesticides over a long period of time. We assumed that the lowland of the Jhikhu khola watershed would have a higher frequency of pesticide use and intensity¸ and that the consequences would also be greater for Jhikhu khola than for the Ansi khola watershed.

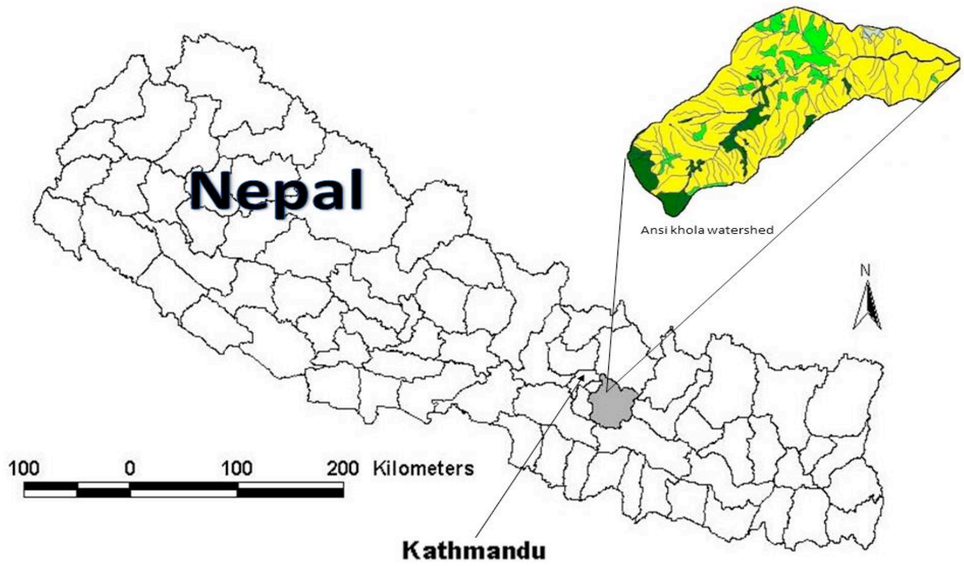

Figure 2. Location of the Ansi khola watershed

6.2. Household sampling and sample size

Figure 3 is a graphic representation of the important factors taken into consideration in the sampling process. The households residing in the Ansi khola watershed has been grouped by Dahal et al (2009) into three categories, large-scale, medium-scale, and small-scale, based on social and economic characteristics. The lists of these households were our sampling frame for the Ansi khola watershed. We divided these households into two categories according to elevation: (1) lowland (<1000 masl); and (2) upland (>1000 masl). This reflected altitudinal biophysical variation. There were a total of 402 households in the lowland sector and 636 households in the upland sector. Proportional random sampling (based on farming household category and elevation) was used to provide a total sample of 403 households from the watershed.

For Jhikhu khola watershed, a random sample of 200 households from lowland areas covering four village development committees (VDCs) – namely Mithunkot (85 households), Patlekhet (40 households), Kharelthok (36 households), and Kavre (19 households) – was considered.

In total, 403 + 200 = 603 households were sampled for the study.

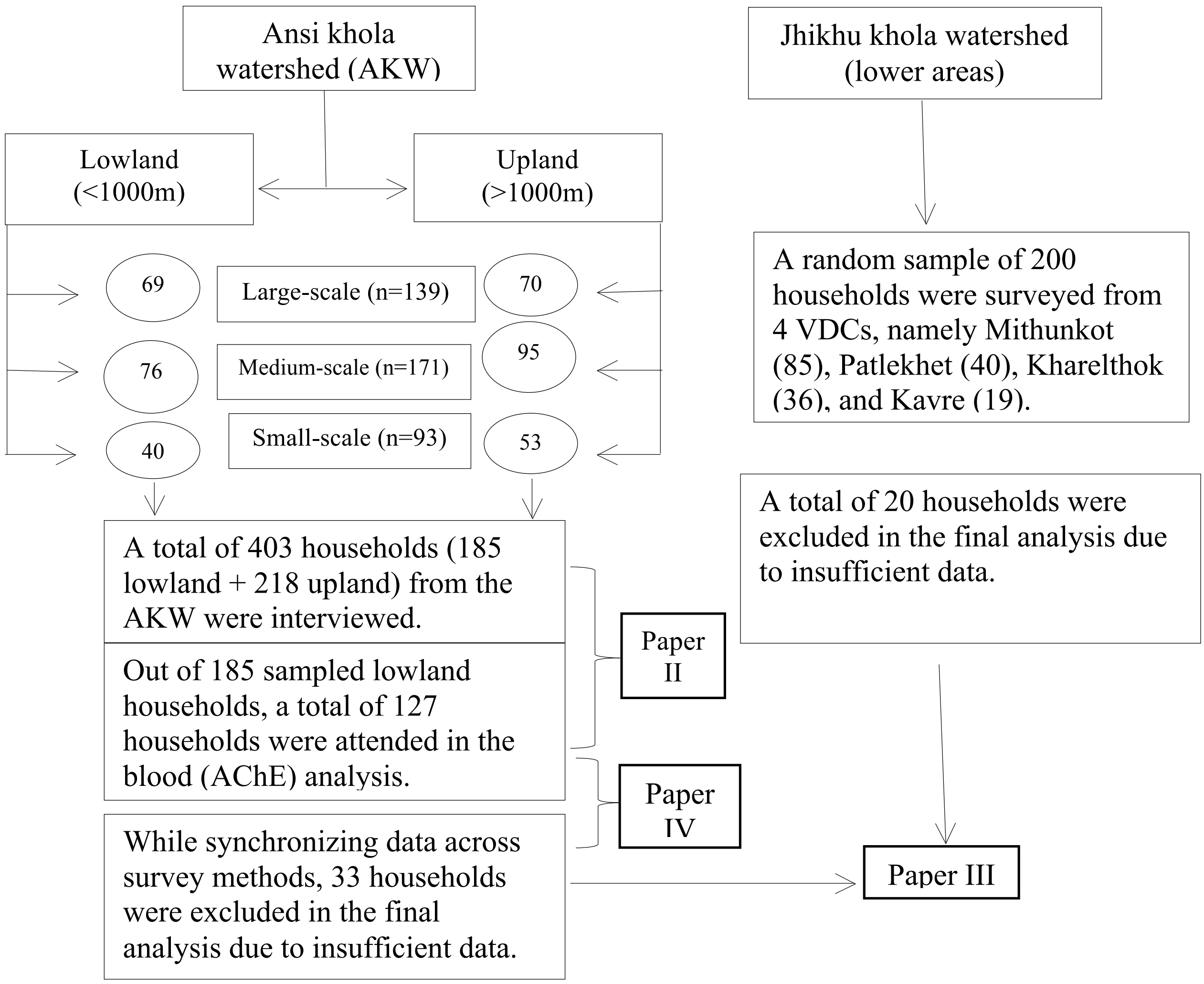

Figure 3. A systematic diagram showing household sampling procedures and sizes from the Ansi and Jhikhu khola watersheds of Nepal.

6.3. Data collection methods

Data was collected through (1) an initial household survey, (2) monthly household surveys, (3) a final household survey, (4) group discussions, and (5) individual interviews during medical check-ups. The initial and final survey questionnaires were pretested on 25 households close to the study area. The design of the survey questionnaire was based on the World Bank questionnaire for Bangladesh, and on other studies conducted in Sri Lanka (Wilson 1998), Nepal (Atreya 2007a), and India (Devi 2007). Four field assistants (two in each watershed) with previous experience of questionnaire surveys were recruited, trained and guided at regular intervals for the duration of the surveys.

6.3.1. Initial household survey

The initial household survey, conducted from May to June 2008, collected information on household demography; health care costs and services; land use and agricultural production, cash income and sources; frequency and intensity of pesticide use; and individuals' knowledge, attitudes, and practices regarding pesticide use and safety measures.

6.3.2. Monthly household surveys

The surveys were conducted from June to November 2008. The monthly surveys collected information on pesticide dosage, exposure, and safety at monthly intervals for six months. Information was also collected on the incidence of acute illness, on associated medical treatment costs and on days lost due to illness.

6.3.3. Final household survey

The final household survey, conducted from November to December 2009, was designed to ascertain willingness to pay for safe pesticides. In addition, significant supporting information, such as farm characteristics, the history and intensity of pesticide use, individual perceptions of the pesticide impacts, etc. was collected.

6.3.4. Group discussions

Five full-day (4-5 hours) focus group discussions were organised at different locations in the Ansi khola watershed in between the initial and final household surveys. A group consisted of 30-50 individuals, both males and females. Invitees were schoolteachers, local businessmen, innovative farmers, and other farmers in the small-scale to large-scale categories. We conducted three group discussions in the lower areas, and two in the upper areas of the watershed. These discussions gathered information that was used for designing the final household survey questionnaire, especially the willingness-to-pay question. Other relevant information about the pesticide use and its effects was also documented. Attention was given to both the positive and negative sides of the pesticide use with regard to its impact on the local environment, on human health and possible measures to minimise exposure.

6.3.5. Individual interviews during medical check-up (Paper II)

A two-page checklist was prepared for interviewing participants who attended the blood analysis sessions. The front-page was filled in by the field assistant, and contained a one-month history of pesticide doses and exposure, associated acute illnesses, and safety measures. The second page was filled in by the medical professional and contained information on such things as weight, height, blood pressure, short-term acute illness, long-term chronic illness (if any), and AChE analysis results.

Blood samples were only gathered in the Ansi khola watershed. All participants signed an informed consent form. Blood was sampled and analysed twice during 2009: first, before the pesticide application season (March), and second, after the pesticide application season (December).

6.4. Erythrocyte acetylcholinesterase (AChE) analysis (Paper II)

Blood was analyzed using the Test-mate ChE Cholinesterase Test System (Model 400) with the AChE Erythrocyte Cholinesterase Assay Kit (Model 460) (EQM Research Inc., Cincinnati, USA) (EQM Research Inc. 2003). Testing for erythrocyte cholinesterase is commonly used to monitor exposure to organophosphate and carbamate pesticides. Ohayo-Mitoko et al. (2000) and Dasgupta et al. (2007) also adopted this test system to study the link between pesticide exposure and acetylcholinesterase activity in agricultural workers. (For additional details please refer to Paper II.)

6.5. Economic valuation methods (Paper III)

This study measured (1) cost of illness, (2) defensive expenditure and (3) contingent valuation willingness to pay in order to calculate the monetary value of health and environmental effects of pesticide use and exposure at the local level.

6.5.1. Cost of illness

Cost of illness (COI) is defined as lost productivity due to sickness, plus the costs of medical treatment resulting from sickness (Freeman 1993). Because of its ease in application and explanation (EPA 2000), this method was adopted to estimate the economic costs of the health effects from exposure to pesticides (Pingali et al. 1994, Wilson 1998, Cole et al. 2000, Maumbe and Swinton 2003, Devi 2007).

For this study "health effect" or "being sick" were defined as the incidence of any one or more than one short-term acute health symptoms out of a set of fifteen symptoms during or within 48 hours of pesticide application. Whether or not an individual felt such symptoms constituted the health effect and the costs of illness was strictly restricted to the treatment of these symptoms. The cost of illness was estimated adding up the days lost due through pesticide-induced sickness and the costs of medical care treatment – such as consultation fees, medication costs, travel costs to and from health care facilities, time spent in travelling, and dietary expenses resulting from such illness.

6.5.2. Defensive expenditure

The defensive expenditures (DE) approach was used to value the negative consequences arising from pesticide use. Wilson (1998), and Maumbe and Swinton (2003) adopted this method for estimating pesticides risk to health. Defensive expenditure included the cost of safety measures taken prior to spraying to reduce direct exposure to pesticide. Expenditure covered such items were masks, handkerchiefs, long-sleeved shirts/pants, and sprayers. These items may have multiple uses, but each individual was asked whether the item was used only during the application of pesticides. Only those safety items that were explicitly used while spraying with pesticides were annualized, with their expected life span.

6.5.3. Willingness to pay

The contingent valuation willingness-to-pay (WTP) approach was adopted for assessing the impact of pesticide use on the local environment. Farmers' WTP for an economic valuation of the health and environmental impacts arising from pesticide use has been adopted by various researchers, including Wilson (1998), Brethour and Weersink (2001), Atreya (2007b), and Garming and Waibel (2009). It is likely that when a person is asked how much he/she would be willing to pay for safe environment, he or she may consider much of the environmental impacts incurred in revealing his/her true willingness to pay along with other costs such as medical treatment and defensive costs, pain and discomfort.

During the final household survey, an open-ended WTP bid for "new" hypothetical pesticides was administered. It was assumed that the new pesticides were similar to the ones currently in use in terms of their efficacy at killing pests; the only difference was that the new pesticides were harmless in terms of human and environmental health.

We approached valuing the local environmental effects of pesticide use into the field during household survey though questionnaire. The question at first asked was the amount of rupees that the respondent spent on the chemical pesticides last year; and each respondent was informed that such chemicals might have potential to affect his/her health and local environment. Second, we introduced an alternative to the current one, the completely "new" hypothetical pesticide. We further mentioned that the new hypothetical pesticides efficacy to kill pests was also at par with the existing pesticides. But, the new pesticides were harmless to human health and to the environment; specifically to local resources such as fishes, birds, beneficial insects like honeybees, drinking and river water, and air. Third, individuals were requested to assume that they would purchase the new pesticides for the coming year. For this, we assumed crop types, area and productivity; pest types and severity; and weather conditions similar to the last year. Finally, keeping last year's pesticides cost as a reference point, and bearing in mind the aforementioned harmful effects of current pesticides and the budget constraints, farmers were asked, "for the whole next year, how much (please state the highest value) would you be willing to pay for the use of new pesticides that are safe for your health and local environment?"

As mentioned earlier, WTP question was administered at the final survey. By this time, we have had few focus group discussions in which WTP question was developed. Many issues on the WTP formats were raised during discussions and final WTP instrument was modified accordingly. For example, we realized that future expenditure on the new pesticides depends on the types of crop grown, pest infestation severity, and weather conditions, so we made such variability constant in the final instrument. Further, acknowledging indicators of environmental degradation due to pesticide use at local level was also discussed. We agreed on the loss of fishes in the local river, and birds and honeybees at their farms- were the major indicators, therefore, included while designing final WTP question. Further, we discussed on the payment method as well. Instead of cash payment, it was suggested to include kind payment. But the WTP bid question was designed for direct cash payment because (i) this was the method at present used for purchasing pesticides in the local area, and (ii) households' previous year expenditures on pesticides were taken as the starting point for departure.

6.6. Probability and cost estimation

For this study, the probability of falling sick (P_s) and the probability of taking defensive action (P_d) were calculated for each individual. Monthly survey data was used for the calculation. The proportions $P = m/N$ estimates the probability that an individual in each group will experience the event; m measures the individual experiencing the event, N measures the total number of observations. The m denotes "health effect" in estimating P_s and "spraying events with safety precautions" in estimating P_d.

These probabilities were adopted while calculating predicted cost-of-illness and defensive expenditure from periodic use of chemical pesticides. The predicted cost-of-illness (COI) and defensive expenditure (DE) of pesticides exposure were calculated for each individual as follows:

$$COI = P_s * C_i \qquad \text{(Eq. 1)}$$

$$DE = P_d * C_d \qquad \text{(Eq. 2)}$$

Where C_i is the annual labour lost and cost of treatment and C_d is the annual defensive expenditure.

For estimating the overall cost of pesticide use (TC) we further added two additional costs.

$$TC = COI + DE + O + C_p \qquad \text{(Eq. 3)}$$

O stands for opportunity costs of time lost in spraying, calculated by multiplying the total frequency of applications with hours per application and the wage rate; and C_p is the expenditure on chemical pesticides. For this research, an estimated constant wage rate of NPR 150 per day (USD 1≈NPR 70) for both males and females was used.

There was no government subsidy for chemical pesticides at the time of study, and farmers spray pesticides on their farms (the use of hired labour for pesticide application in the field was not observed). We assumed that these costs were borne by the farming households when they decide to use pesticides on their farms. Therefore, we estimated percentage share of the cost of pesticide use to household's (agricultural and total) cash incomes. Here, the (i) agricultural cash income denotes the annual cash received from selling agricultural produce such as vegetables, fruits and cereals crops; and (ii) total cash incomes represents the annual cash received from selling agricultural produce, livestock products (milk and milk products, meat, eggs, etc.) as well as off-farm cash incomes such as salaries, wages, remittance, and small business if any.

6.7. Household classification

As one of the objectives of the study (Paper IV) was to investigate the potential relationship between pesticide-induced costs and household economy, we grouped sampled households into three categories, "large-scale" households [those owning more than 20 Ropani (≈1 ha) (1 Ropani = 508.74 m^2) of agricultural land], and "small-scale" households (those owning less than 10 Ropani), while "medium-scale" households were those owning between (>0.5 and < 1 ha). This is because, when ranking according to wealth, farmers in the study area considered agricultural landholding size to be the most important criterion for differentiating households: they demarcated <0.5 ha, 0.5 – 1ha, and >1 ha of agricultural land to differentiate themselves into the three categories of small-, medium- and large-scale farmers (see Dahal et al. 2009). The present classification does not consider other criteria listed in Dahal et al. (2009). It is assumed that adoption of intensive farming; pesticide use and its associated costs to the households will vary according to land size.

6.8. Statistical analysis

In addition to descriptive statistics (means, standard deviations, and frequencies) of the variables examined, we also performed independent sample t-tests for comparing equality of means of different variables of two watersheds such as pesticide use and working hours, COI, and DE (Paper III), and AChE activity across agricultural seasons (Paper II). One-Way Analysis of Variance (ANOVA) was also used to compare means across household categories (Paper IV). Pearson's correlation matrix was used to observe the relationships between AChE depression and individual exposure and farmers who reported acute health symptoms (Paper II). In addition, we performed three Ordinary Least Square regressions (Paper III) for identifying factors affecting cost of illness (COI), defensive expenses (DE), and willingness to pay (WTP). The Data Analysis and Statistical Software (STATA/IC 10.1 for Windows) was used for fitting the ordinary least square regressions.

7. Results and discussions

The synthesis of research described in the four papers provides an overall analysis of the negative impacts of pesticide use in Nepal. The first review paper highlighted issues affecting pesticide use that are common to many developing countries. This paper also explored the economic and social consequences of pesticide use by different mechanisms and pathways. The second paper documented existing individual knowledge, attitudes and practices with regard to pesticide use in Nepal and attempted to link pesticide use with the results of the clinical examination of the erythrocyte AChE depressions. The third paper identified the health effects of pesticide use and did an economic valuation of the effects on human and environmental health. The fourth paper disintegrated the total cost of pesticide use by household category and estimated the economic cost of pesticide use for different category of farmers in the intensive farming system.

7.1. The complexity of pesticide use impact requires an interdisciplinary approach for proper appraisal (Paper I)

The review and synthesis of diverse studies focusing on toxicology, economics, the social sciences, and the agricultural aspects of pesticides indicated that exaggerated and incompetent pesticides use in agriculture was likely to have adverse effects on human and environmental health, leading to decline in human productivity, with serious economic and social consequences. These may include the marginalisation of vulnerable groups in an agrarian society, where livelihoods depend solely on agriculture. The review paper (Paper I, Figure 1) illustrated the factors affecting pesticide use in developing countries and the resulting environmental problems; it also provided examples of mechanisms and pathways for the marginalisation of the rural farmers. It is likely that many developing countries lack proper institutions or mechanisms for regulating the production and sale of pesticides. These countries do not have the knowledge or mechanisms needed to refuse highly toxic pesticides given as "aid" and they lack access to relevant information on the effects of the chemicals. Furthermore, weak national/international policies together with limited research on the use of pesticides make developing countries more vulnerable to the impact of pesticides. Our review showed three possible ways in which individuals are marginalised by current use of pesticides: (i) reduced levels of health and productivity; (ii) an increased economic cost, and (iii) (in extreme cases) changes in social behaviour.

However, these negative consequences of pesticide use are seldom included in the costs of pesticide use in the benefit-cost analysis. The conventional economic analysis of pesticide use in agriculture weighs the input costs and benefits of pesticide use. However, in addition to the yield benefits, pesticide use was likely to mean an increased risk to human health, to the natural environment, and to social capital. Therefore, theoretically, pesticide use cannot be viewed in isolation; rather it should be addressed from a holistic interdisciplinary perspective.

This is an approach for studying a particular complex problem at different levels with specific theories/methods, and attempts to find the best possible solution to the problem. For example, development of, or introduction of concepts such as ‘integrated pest management’, ‘integrated crop management’, ‘integrated plant nutrient management system’ etc. have, to some extent tried to minimize their respective problems by addressing both a social and ecological approach. For Nepal, as an alternative to the current use of chemical pesticides, an integrated pest management (IPM) programme can be recommended. The IPM is not only be beneficial in terms of reducing pesticide expenses and limiting environmental and health damage (Paper I, Table 1) but it also appears that it may enhance the capability of local people to participate in decision making, as well as empowering them to influence policy changes (van der Berg and Jiggins 2007) (Paper I, Table 2).

The interdisciplinary work, however, requires tremendous effort in generating knowledge at different levels of the complex problem though different methods. Being a complex nature of the impact of pesticide use to human and environmental resources, a better understanding of causal relationships at different level of the problem is required. We attempted to investigate this by conducting a study in Nepal which examined individual knowledge regarding pesticide use and the effects from exposure to pesticides by monitoring acetylcholinesterase depressions and valuing the health and environmental impacts of pesticide use at local levels. As mentioned earlier, the present study considered negative sides of pesticide use and values the negative impacts for farmers in Nepal because we find limited knowledge on the understanding of the relationship between pesticides use and associated economic costs for farmers. These studies are presented in the subsequent papers.

7.2. Pesticide use and AChE depressions (Paper II)

7.2.1 Pesticide use knowledge, attitude and practice

The average frequency of pesticide applications per crop was five per season, but as many as 60 applications could take place in a particular year. Fungicides, especially mancozeb, were widely used in the study area. Most farmers (67%) were not aware of the toxicity labels on pesticide containers and most (63%) did not understand the meaning of the labels. Only about 40% of the farmers appeared to take a shower after use, while about 54% changed their clothes after the application of pesticides. The pesticide-contaminated utensils were used by as many as 60% of individuals in the kitchen and livestock sheds. More than 50% agreed that pesticide use could adversely affect their health, and more than 90% were aware of the possible contamination of local water sources as a result of pesticide use (Paper II, Figure 2). One in four farmers reported merely wearing a handkerchief over the nose and mouth as a safety measure to avoid health effects of the chemical. Only 10% of the total respondents made use of recommended scientific safety measures, such as wearing a mask and gloves during pesticide application.

Our study revealed an inadequate knowledge of safe practice in the use and handling of pesticides. Several studies (Kishi et al. 1995, Sivayoganathan et al. 1995, van der Hoek et al. 1998, Wilson 1998, Gomes et al. 1999, Murphy et al. 1999, Yassin et al. 2002, Matthews et al. 2003, Gupta 2004, Salameh et al. 2004, Damalas et al. 2006, Recena et al. 2006, Devi 2009b, 2010) have shown similar results. These literature suggest low levels of education, a lack of training, low income levels, and limited awareness, all of which could lead to the minimal use of safety hygiene by those engaged in subsistence agriculture. Furthermore, the poor observance of safety measures revealed in this study could be a result of the widespread use of fungicides. Farmers recognise that fungicides, especially mancozeb, are relatively harmless (compared to insecticides), and this could have led to the use of minimal safety measures during the application of pesticides. The attitude that risks or illness are simply a part of daily “farm life” might also have led to the failure to adopt proper safety measures. Awareness programmes, as well as education, training and other support services for local farmers are recommended to mitigate the health effects from periodic pesticide use.

7.2.2 Acetylcholinesterase depression

We found a significant variation in erythrocyte acetylcholinesterase activity before and after the pesticide application season (Paper II, Table 2). The haemoglobin-adjusted acetylcholinesterase activity was significantly reduced across seasons ($p < 0.001$). The reduced activity of cholinesterase across seasons indicates that farmers were exposed to the pesticides, especially organophosphates and carbamates. Jintana et al. (2009), Ntow et al. (2009) and Quandt et al. (2010) also found reduced AChE activity due to pesticide use in agriculture. Although there was no statistically significant correlation between individual and household characteristics and acetylcholinesterase depression (Paper II, Table 3), we found a significant correlation between AChE depression and the history of pesticide use over the previous thirty days (Paper II, Table 5). AChE depression was also found correlated with exposure to organophosphates ($r = 0.317$, $p<0.01$) – and not to exposure to organochlorines, pyrethroids or fungicides (Paper II, Table 6). The presence of acute health symptoms was correlated with exposure to pyrethoid insecticides ($r=0.217$, $p<0.05$), and fungicides ($r=0.473$, $p<0.001$) (Paper II, Table 6), but not to exposure to the organochlorines and organophosphates. The reduced seasonal activity of acetylcholinesterase indicates greater exposure to organophosphates, but this was not enough to cause clinical effects. However, exposure to the pyrethroid insecticides and fungicides was sufficient to cause acute symptoms. The levels of acetylcholinesterase-inhibiting pesticides such as organophosphorus and carbamates in the study area were found minimal, which could explain the weak relationship between self-reported symptoms and AChE depression. Similar observations were found in the Ohayo-Mitoko et al. (2000), Ngowi et al. (2001), Dasgupta et al. (2007), and Jintana et al. (2009).

The reduced activity of acetylcholinesterase across seasons indicates that farmers were exposed to pesticide levels, and were suffered from acute health symptoms of pesticide use. This may reduce individual productivity and increase the economic cost of treatment. It is important to establish the health and environmental costs of pesticide use at the local level. We have explored these costs in addition to other associated costs of pesticide use in the Paper III.

7.3. Health and environmental costs of pesticide use (Paper III)

7.3.1. Probability and predicted health care costs

A comparison was made between two areas, namely Ansi khola and lower areas of Jhikhu khola, in terms of pesticide usage, pesticide-induced short-term acute symptoms, and the associated costs of pesticide use. This showed significant differences between locations. Individuals residing in Ansi khola watershed were at higher risk of acute symptoms from pesticide use than those living in the Jhikhu khola watershed. This is because of the following factors: households in the Ansi khola watershed had (i) higher vegetables cultivated area, (ii) higher frequency of applications (ten as opposed to eight applications), (iii) more working hours on the farms in spraying and non-spraying days, and (iv) increased spraying time (Paper III, Table 5). These factors may have increased the incidence of acute symptoms such as headaches, skin irritation, chest pains, eye irritation, throat discomfort etc. in the Ansi khola watershed (Paper III, Table 6). For example, the probability of being sick due to pesticide-induced illness was estimated at 0.58 for Ansi khola, 0.32 for Jhikhu khola. The predicted individual costs of illness (Eq. 1) and defensive expenditures (Eq. 2) were higher in the Ansi khola watershed, where they were estimated to be NPR 477 (USD 6.81)[1] and NPR 155 (USD 2.21) (Paper III, Table 7). The corresponding figures for Jhikhu khola were NPR 182 (USD 2.60) and NPR 71 (USD 1.01). If one takes account of annual expenditure on pesticides and spraying time, the annual per capita costs of pesticide use (Eq. 3) were USD 27.23 for Ansi khola and USD 35.14 for Jhikhu khola (Paper III, Table 8). The study found significant geographical variation in terms of pesticide use, exposure, health effects, and associated costs.

7.3.2. Willingness to pay for new 'safe' pesticides

Farmers from the Jhikhu khola watershed were willing to pay an amount of NPR 2781for safe pesticides, which is 1.5 times higher than farmers from Ansi khola watershed were willing to pay. The willingness to pay of farmers in Ansi khola increased by 80%, compared to 44% in Jhikhu khola; these figures are based on current expenditure on pesticides, and assume that safe alternatives will be available (Paper III, Table 8). Other studies demonstrate a WTP bid increment range from as low as 28% (Garming and Waibel 2009) to as high as 94% (Atreya 2005).

We had assumed that WTP bids would exceed the total cost of illness, defensive expenditure and other expenses. This is because when a person affected by pesticide exposure is asked for a maximum WTP bid in order to avoid exposure, he or she will (we assume) consider all the costs associated with the illness. These include the costs of treatment and defensive expenses, as well as intangible costs such as pain, suffering and discomfort. The possible local environmental problems may also be taken into account when bidding. Wilson (2003) showed that 'WTP > COI + DE' provides a validity check for WTP bids. In this study we have found "willingness to pay > pesticides expenditures + cost of illness + defensive expenditure". This

[1] USD 1≈NPR 70 during study period

supports Wilson's findings and thus confirms that the methods used in our valuation are theoretically consistent.

7.3.3. Factors affecting cost of illness, defensive expenses and WTP

The regression analyses (Paper III, Table 10) indicated that the predicted health cost (COI) was significantly affected by exposure to pesticides, frequency of use of pesticides, by the sex of the farmer, and by location. That means increased exposure and more frequent contact lead to increased health costs. The COI for males was higher than that for females.

Similarly, increased predicted defensive expenditure (DE) was observed when an individual was exposed to organophosphates (OP) and pyrethroid insecticides (PI), or frequent applications of pesticides (FREQ), and had previous training in IPM. It is worth noting that exposure to fungicides (FUN) does not necessarily lead to an increase in DE, and that both watersheds had similar DE.

An individual's willingness to pay (WTP) was significantly affected by OP, PI, FUN, FREQ, location, and IPM training. Individuals with increased exposure to either OP, or PI, or FUN and frequency of use tend to express higher WTP. IPM-trained individuals appear to make higher WTP bids in order to avoid or reduce the risks from pesticide exposure.

The published literature (Wilson 1998, Dung and Dung 1999, Maumbe and Swinton 2003) shows that exposure to chemical pesticides and frequency of use leads to increased health costs and increased defensive expenses. This is consistent with the findings of this study, with the exception of the effect of fungicides on defensive expenditure. It is surprising that increased exposure to fungicides does not necessarily lead to increased defensive expenses. This could be a result of lack of awareness of the potential risk involved in the use of fungicides, especially with respect to mancozeb (the most frequently used fungicide in the study area), which was often regarded simply as a "powder".

There were significant differences between the studied watersheds with regard to COI and WTP, but this was not the case with DE. Individuals in the Jhikhu khola watershed incurred less COI and had similar DE to farmers at Ansi khola, but they were willing to pay more for the safe alternatives. Jhikhu khola watershed has a long history of pesticide use and many organizations [for example, International Centre for Integrated Mountain Development

(ICIMOD), Kathmandu University (KU) and Centre for Environmental and Agricultural Policy Research, Extension and Development (CEPREAD)] have made farmers aware of the potential dangers in the use of chemical pesticides (through research and dissemination of information). This helps to explain why these individuals were willing to pay more for safe pesticides. This finding supports the view that individual awareness and knowledge of pesticide pollution are crucial for implementing alternative methods to reduce exposure to chemical pesticides.

From a policy perspective, the results showed that individuals attending IPM training were likely to have high COI, but they also adopted more safety measures and were willing to pay more for alternatives to pesticides. This implies that use of safety measures or an increase in defensive expenditure (in this study at least) does not seem to decrease health costs. This can be explained as follows: (i) there was minimal use of safety measures; (ii) the same unwashed items were repeatedly used for pesticide application. Therefore, increased spending on safety by IPM-trained individuals did not necessarily result in a COI reduction. This suggests a need to review the IPM program from a health perspective.

Paper III found that when a household applies pesticides, the household incurs economic costs as a result of acute health and environmental effects from periodic use of pesticides. The increased cost for small-scale households would have far-reaching implications for their livelihoods. Therefore, a study of the distribution of the estimated costs of pesticide use by households would help to identify the most vulnerable farmers in the study area (see Paper IV).

7.4. Distribution of costs of pesticide use by land size (Paper IV)

Based on the monthly survey data, the probability that an individual would take safety measures when applying pesticides was highest for large-scale farmers (0.61) and lowest for small-scale farmers (0.43). Similarly, the probability of becoming sick as a result of pesticide use was 0.53 for small-scale farmers, and 0.64 for both medium and large-scale farmers (Paper IV, Table 1). There were similar days lost, defensive and medical expenses of pesticide use for the sampled households (Paper IV, Table 2); however, the predicted defensive expenditure and treatment costs differ significantly according to land-holding size (Paper IV, Table 3). The overall cost of pesticide use was the highest (USD 33.4) for medium-scale farmers, followed by large-scale farmers (USD 31.0) and small-scale farmers (USD 21.2)

(Paper IV, Table 4). This study showed that much of the cost of pesticide use was borne by medium-scale households. This was because these households were producing a combination of subsistence and commercial crops, which though likely to decrease production failure risk, may have led to greater use of chemicals (e.g. higher opportunity costs of application and higher pesticides expenses), and this may have resulted in these households carrying a higher economic cost.

The study showed highest costs as a result of pesticide use for medium-scale households; however, in proportion to household cash incomes (Paper IV, Table 5), it is likely that small-scale households possess the higher proportion (significant at 10% level). Although the significance is weak, there are a number of reasons to believe that the small-scale household will be more impacted by the pesticide-associated costs. First, small-scale households have fewer windows of opportunities due to small size of landholdings. Second, they presumably have less coping mechanisms due to lower income diversities; and third, they have less possibility to use incomes for safety measures. Greater insights will be required through rigorous study in the future, however.

Overall, the cost of pesticide use and exposure amounted 15% of agricultural cash income, and/or 5% of household total cash income (Paper IV, Table 5). For small-scale households, the cost was equivalent to 18% of agricultural cash income and 6% of total cash income. Similarly, on average the health costs of illness associated with pesticide use was equivalent to nearly 5% of agricultural cash income that was found significantly higher for small-scale households (5.7%) than the large-scale (3.6%). It has been observed that much of the benefits of intensive farming likely to favor large-scale households (Brown and Kennedy 2005), however; its negative effects of pesticide use (in terms of pesticides induced economic costs in proportion to household cash incomes) likely to be higher for small-scale households. Such disparities in the distribution of the benefits and the cost of pesticide use in the opposite direction may widen household inequalities; however, further investigation considering both pesticide pollution costs and income opportunity from the intensive farming systems can be recommended.

So far, results of all the papers have been presented and discussed. However, there is a need to say more on the costs of pesticide use estimated in the Paper III and Paper IV. The costs estimated in those papers could be considered as an indicator of the danger posed by pesticides in the local area. However, this cannot be generalized across Nepal, and also it cannot be compared to the other studies around the world. This is because the costs of pesticide pollution depend on the specific type of risk, the nature of the risk scenario, and on people's subjective perceptions of risk (Travisi et al. 2006). Other factors include survey design, types of safety device, and chosen payment methods for measuring WTP (Florax et al. 2005).

The estimated cost of pesticide use in this study may be relatively small compared to the total farm outputs (the share of pesticide costs to total cash income was less than 6%, and the cash income for this study excluded home consumption), thus, when a farmer face a trade-off between the cost from pesticide use and the farm outputs through the use of pesticides, s/he may tend to underestimate the negative effects of pesticide use and may continue to use pesticides (Ajayi 2000). However, the cost from pesticide use for the society is likely to be significantly higher than the costs estimated here because the present study has considered only short-term acute symptoms associated with pesticides. Furthermore, ascribing a value to human and environmental health is also difficult because of the complex nature of the impact of pesticides (see Paper I), but the estimated cost may work as an indicator of the pesticide effects, and may be considered as a lower end of pesticide pollution costs in the analysis of intensive farming system. The pressure for continued progress in food production to feed growing population (the benefit) and the concern about the human and environmental health impacts (the cost) of pesticides will always be a challenge (Sexton et al. 2007) at the situation where the current scientific finding in the complex matrix of negative effects (see paper I) and positive effects (see Cooper and Dobson 2007) are limited.

Like the costs of pesticide use, measurement of pesticide benefit is also important; however it is difficult to measure (Norwood and Marra 2003). Pesticides do not enhance crop productivity like other factors such as land, labor, and capital; rather they help farmers to combat pest pressure that would otherwise reduce production (Lichtenberg and Zilberman 1986, Ajayi 2000, Jha and Regmi 2009, Chambers et al. 2010). At first, Lichtenberg and Zilberman (1986) mentioned pesticides as damage control agent. For the US agriculture, with zero pesticides, the crop losses estimated ranged from 17% to 20% (US National Academy of Sciences 2000). A study in Nepal showed that with no pesticides at all, vegetables (cauliflower and cabbage) production may go down as high as 68% (Jha and Regmi 2009) - the avoided crop losses from the pesticide use. However, the same study also found no significant yield reduction if use of pesticides was reduced significantly, because the level of its use was nearly four times higher than the optimal. Also elsewhere, there are good examples of pesticide reduction with no losses on the potential crop yields. For example, Peshin et al. (2009) documented that Sweden reduced pesticide use by 68% and public health poisonings by 77%, and that reduction did not result in increased crop losses. Similarly, Indonesia reduced pesticide use by 65% and increased rice yields by 12%. In India, the pesticide use reduced by nearly 50% from 1990/91 to 2006/07.

However, increasing consumption of chemical pesticides for Nepal has been observed (Atreya and Sitaula 2010). The policy instruments that either help reduce the frequency of applications or exposure could help reduce health and environmental costs. At present, farmers continue to use chemical pesticides, because in the explicit cost/benefit context, it seems to be beneficial. Farmers continue overuse of pesticides substantially because of uncertainty of the effectiveness of the chemicals, as well as the risk of pest pressure uncertainty. Also, Wilson and Tisdell (2001) pointed out that (i) ignorance on the pesticide use sustainability, (ii) lack of feasible cost-effective alternatives to pesticides, (iii) underestimating short- and long-term costs of pesticide use, and (iv) weak enforcement of national laws and regulations, were the main reasons for continuing misuse of chemical pesticides in the developing countries. These factors seemed to be valid in the case of our study for continued use of pesticides for intensive farming to fetch farm incomes. However, the use of chemical pesticides in the intensive agriculture not only increases farm incomes through reduction in crop losses, but also causes negative effects to human and environmental health, which should be taken into account while making decisions on the pesticide use. This demands an interdisciplinary approach for studying pesticide related issues and to rationalize its use for agriculture to be socially beneficial.

8. Conclusions and recommendations

With regard to the literature review, it can be concluded that excessive and incompetent pesticide use in farms has many complex negative effects. For these reason, a simplistic economic analysis is insufficient measure to pesticides efficacy. If use is not made of holistic approach to account for both costs and benefits of pesticide use, vulnerable communities may continue to be affected in the developing world.

It was found that individuals were quite knowledgeable about the local environmental impacts of pesticide use; however, low levels of their hygiene and inadequate adoption of safety measures led to increased health effects. Exposure to organophosphates, in spite of reduced acetylcholinesterase activity, was not at a level that would cause clinical symptoms. Pyrethroid insecticides and fungicides, however, were used at levels that were sufficient to cause clinical symptoms. Thus, the use of self-reported symptoms as an indicator of organophosphate exposure may not necessarily be reliable in an area where different types of pesticide are being used in low concentrations for different crops. In future studies, the use of fungicide and pyrethroid metabolites as biological indicators to assess human exposure could provide more reliable information.

The use of pesticides has negatively affected human health and resulted in an increased economic cost for users. The degree of exposure and the frequency of contact were significant determinants of the cost carried by farmers. Policy instruments that target reductions in either exposure or frequency of use may help reduce the cost. Although the IPM training led the safer use of pesticides, this in itself was not likely to reduce the health cost of exposure. For this reason we recommend a review of IPM programmes from a health perspective. Nepal's vegetable farmers are willing to pay more for safer alternatives in order to protect their own health and that of the environment.

The economic cost of pesticide use was found skewed by the household economy. The medium-scale households incurred the highest costs of pesticide use; however, in proportion to household cash incomes, it is likely that small-scale households possess the highest proportion. Such disparities may widen inequalities between households unless agricultural development strategies focus on small farmers. However, we recommend more rigorous and detailed studies including a social benefit-cost analysis taking account of both negative and positive aspects of pesticide use in agriculture.

The use of chemical pesticides because of intensive farming has reduced people's welfare by increasing the incidence of acute health symptoms; and also resulted in increased health and environmental costs. This could be minimized in Nepal by the (i) implementation and expansion of IPM, (ii) by introducing better and safer protective measures, (iii) by improving the education and awareness of the users, and (iv) by the careful enforcement of governmental rules and regulations. This thesis emphasises the need to prioritise alternative methods of controlling pests (for instance through community-based IPM), as well as through increased education and training for farmers

9. References

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Appendix - Research Papers

Paper I

Atreya K, Sitaula BK, Johnsen FH, Bajracharya RM. 2011. Continuing issues in the limitations of pesticide use in developing countries. *Journal of Agricultural and Environmental Ethics* 24:49-62.

J Agric Environ Ethics (2011) 24:49–62
DOI 10.1007/s10806-010-9243-9

ARTICLES

Continuing Issues in the Limitations of Pesticide Use in Developing Countries

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Accepted: 1 February 2010 / Published online: 21 February 2010

Abstract The rationale for pesticide use in agriculture is that costs associated with pesticide pollution are to be justified by its benefits, but this is not so obvious. Valuing the benefits by simple economic analysis has increased pesticide use in agriculture and consequently produced pesticide-induced "public ills." This paper attempts to explore the research gaps of the economic and social consequences of pesticide use in developing countries, particularly with an example of Nepal. We argue that although the negative sides of agricultural development, for example-soil, water, and air pollution; pest resistance and resurgence; bioaccumulation, biomagnification; and loss of biodiversity and ecosystem resilience caused by the use of pesticides in agriculture, are "developmental problems" and are "unintentional," the magnitude may be increased by undervaluing the problems in the analysis of its economic returns. Despite continuous effort for holistic system analyses for studying complex phenomena like pesticides impacts, the development within the academic science has proceeded in the opposite direction that might have accelerated marginalization of the third world subsistence agricultural communities. We hypothesize that, if these adversities are realized and accounted for, the benefits from the current use of pesticides could be outweighed by the costs of pollution and ill human health. This paper also illustrates different pathways and mechanisms for marginalization. In view of potential and overall negative impacts of pesticide use, we recommend alternative ways of controlling pests such as community integrated pest management (IPM) along with education and training activities. Such measures are likely to reduce the health and environmental costs of pesticide pollution, and

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also enhance the capabilities of third world agricultural communities in terms of knowledge, decision making, innovation, and policy change.

Keywords Benefit-cost analysis · Developing countries · Interdisciplinary · Integrated pest management · Marginalization · Pesticides

Introduction

Pesticide use in agriculture provides yield benefits. Also pesticide use is likely to increase risks to human health, the natural environment, and social capital. The benefits of pesticide use in agricultural crop production are often assessed by the yield increase obtained versus the cost of buying inputs like seed, fertilizers, pesticide, and labor. But realistic assessments must take broader social and environmental impacts into account. First, pesticide use may reduce peoples' well being (degradation of human resources) and, because of sickness, result in loss of productivity, wages, and an increase in medical expenses (Freeman 1993; Antle and Pingali 1994; Wilson 1998; EPA 2000). Second, degradation of the environment or ecosystems also indirectly increases costs (Antle and Pingali 1994; Antle et al. 1998; Ajayi 2000; Yanggen et al. 2004). There could be significant costs of, for example, bioaccumulation, biomagnification, pest resistance and resurgence, mismanagement of toxic chemicals and its implications for contamination of ground water, among others (see Wilson 2000; Pimentel 2005).

A general principle is that an increase in pollution level increases the human, natural, and social costs that could decrease the livelihood security of subsistence farmers. Farmers in the polluted environment try to justify (or accept) potential health and ecosystems hazards as long as the perceived benefits exceed the costs. At first, they try to protect themselves from pesticide exposure by using masks, gloves, aprons, etc.; applying recommended doses of pesticides, or incurring the opportunity costs of the days involved in activities like Integrated Pest Management (IPM), Farmer Field Schools (FFS), and so on. But when the cost of sickness and environmental degradation are substantial and recurrent, then individuals or the farming families eventually adopt the coping strategies of selling their land and livestock (Sauerborn et al. 1996; McIntyre et al. 2006), and, finally, might be victimized by what is called degradation and marginalization (Robbins 2004). This paper attempts to explore the research gaps of the economic and social consequences of pesticide use in developing countries, particularly with an example of Nepal. Although the negative sides of agricultural development, for example-soil, water, and air pollution; pest resistance and resurgence; bioaccumulation, biomagnification; and loss of biodiversity and ecosystem resilience (Raven et al. 2008), caused by the introduction of pesticides in agriculture, are "developmental problems" and are "unintentional," the magnitude may be increased by under-valuing the problems in the analysis of its economic returns. We hypothesize that, if these adversities are realized and accounted for, the benefits from the current use of pesticides could be outweighed by the costs of pollution and ill human health. We argue that traditional economics "oversimplified the complex world" in estimating benefits of pesticide use, which increased pesticide use and consequently pesticide-induced "public ills," and marginalized third world subsistence farmers.

Complexity of Pesticide Use

The Brundtland Report (WCED 1987) has already addressed the importance of economic development without degrading the environment and ecological integrity. But the use of certain pesticides may degrade both environment and ecology and has major implications for "our common future." Then why are toxic chemical pesticides still in use despite its social and environmental impacts? It is highly unlikely that we can find a simple answer due to the contextual nature and complexity of agricultural change.

Valuing benefits of pesticide use through simple economic analysis may increase pesticide use in crop production. The economic analysis weighs the conventional costs and benefits of pesticide use and claims that pesticide use is beneficial. In general, literature raises the argument that farmers benefit an estimated US $ 3 to $ 5 in crops for every $ 1 that they invest in pesticides (Raven et al. 2008). It maintains that pesticide use has revolutionized food production and the benefits of production far overweigh negative externalities caused to human beings and the environment. This position argues that the technologies embody the positive values to the human society (Meghani 2008), with population growth, hunger, poverty, and malnutrition providing the basis for the argument (FAO 2004).

Pesticide use cannot be viewed out of context, but rather should be addressed from a holistic system perspective. Several studies argue that pesticide use produces overall low economic returns (increased risk over investment) if social and ecosystem health impacts are accounted for (Antle and Pingali 1994; Wilson 1998, 2000; Pimentel 2005; Atreya 2008). As discussed earlier, the estimates of benefits are, first, conventional and localized; second, do not take into account environmental impacts like pollution of natural resources and ecosystems disturbances. It does not acknowledge long term low dose intermittent exposures to pesticides and its linkages to hormone disruption, diminished intelligence, reproductive abnormalities, and cancer (Gupta 2004; Abhilash and Singh 2009). It also does not recognize issues like bioaccumulation, biomagnifications, pest resistance, and resurgence that are the most discussed issues and threat to human society. In addition, dumping of obsolete pesticides is likewise a major health threat (WHO 2007); and possible linkages among pesticide use, international transport, and arctic degradation are emerging issues (Cone 2006). Chemical pesticides that have been used in the United States, Europe, and Asia can not only have effects on-site, but can also have significant negative impacts in areas that are thousands of kilometers away from the origin, for example the Arctic region (Cone 2006). Third, public health impacts and social implications (like suicide attempts by consuming pesticides, unintentional poisoning by contaminated foods, etc.) of pesticides are also not adequately considered. Moreover, the estimate does not capture the physical and psychological pain and discomfort experienced as a result of acute and long-term illnesses (Wilson 1998; Pimentel 2005; Atreya 2008). Furthermore, the causes of hunger and malnutrition in developing countries can, in fact, be explained by an interaction of many biophysical, political, economic, and social factors and forces that are partly external to these countries. A recent and straightforward example is the ambitious “Millennium Development Goals” that have been prepared almost exclusively by advanced nations and thrust upon developing countries without adequately addressing their interests, capacity, and achievability of the goals. This effectively amounts to “goals set for the poor, goalposts set by the rich” (Saith 2007).

We recommend perceiving the pesticide dilemma through an interdisciplinary perspective. Interdisciplinarity is an approach to studying a particular complex problem at different levels with specific theories/methods, and attempts to find the best possible solution to the problem. For example, development of, or introduction of concepts like IPM, Integrated Crop Management (ICM), Integrated Plant Nutrient Management System (IPNS), etc. have, to some extent tried to minimize their respective problems by addressing both a social and ecological approach. These concepts are intended to identify optimum levels of pesticide usage with respect to human society as a whole.

Because of the complex nature of pesticides impacts, a simple benefit cost analysis is an insufficient measure of pesticide efficacy. Interdisciplinary holistic systems analyses, taking a multitude of interacting factors into account, while estimating the costs of pesticide use, are needed. We believe that ascribing values for a multitude of interacting impacts (for example, human health, environmental and ecosystems, etc.) is difficult and much more subject to controversy as the true costs of these impacts may not be quantifiable in a single monetary unit. However, different methods (Bowles and Webster 1995; EPA 2000; Romero and Rehman 2003; Wilson 2003; Travisi et al. 2006) developed in a wide range of disciplinary sciences are seldom grouped for estimating the costs of pesticide pollution. We can achieve tangible progress in valuing costs of pesticide use only if we examine the pesticide issues in the broader context of social, environmental, and ecological implications in alliance with others from different disciplinary sciences. For example, a close collaboration among economists, social scientists, agricultural experts (soil, agronomy, and entomology), public/occupational health experts, ecologists, environmentalists, and probably others as well; in conjunction with local stakeholders would yield better results. An attempt can be found in Yanggen et al. (2004). However, interdisciplinary work could have a tremendous cost in terms of leadership, support, knowledge, perception, responsibilities, and professional ethnocentrism. Here, we are not only prescribing a group of people working together and to just adding different ideas from different disciplines, but rather we are suggesting coming to a consensus through developing a well defined theoretical perspective on cost effectiveness analysis by mutual professional respects and creative “tension.” Otherwise, the estimates for complex problems are always underestimated. Despite the longstanding lobby for interdisciplinarity to study any complex phenomenon; the development within the academic world has proceeded in the opposite direction (Høyer and Naess 2008), which might have accelerated adverse health and ecological consequences—marginalizing subsistence farmers, especially in developing countries.

Pesticide Use and Marginalization

It is evident that increased pesticide inputs have a marginal effect on total agricultural produce (Ghatak and Turner 1978; Rahman 2003; Jha and Regmi 2009). But pesticide use causes 3 million poisonings and 220 thousand deaths and about 750 thousand chronic illnesses every year worldwide (WHO 2006). The majority of these are reported in developing countries (Paoletti and Pimentel 2000). Moreover, it is said that these developing nations utilize only one-fifth of the pesticides applied in the world and the numbers of casualties due to pesticides are further underestimated as many such cases are not reported. Millions of farmers, millions of other people living in agrarian communities and the innumerable consumers are exposed to the chemical pesticides through inhaling contaminated air, drinking contaminated water, consuming contaminated food, etc.

Regardless of the prevailing reality, subsistence farmers from developing nations continue to use pesticides at an increasing rate. Why? Before looking at the possible reasons, it is worthwhile mentioning how the World Bank (2007:1) has described the actuality of agrarian society of developing countries. It illustrates the harsh reality of the rural struggle for livelihood and survival.

> An African woman bent under the sun, weeding sorghum in an arid field with a hoe, a child strapped on her back—a vivid image of rural poverty. For her large family and millions like her, the meager bounty of subsistence farming is the only chance to survive.

The African woman and many other subsistent farmers like her are under increasing pressure for using pesticides for their subsistence livelihood. They are directly or indirectly forced by "outsiders" to use chemical pesticides on their farms. Farmers in developing nations are often not well educated, trained, or aware of danger, and they also lack resources and have limited power to "control" the external forces like markets and trade liberalization, international policies, treaties, etc. The agricultural pest control system, which was developed and advertised as a piecemeal by the "outsiders," has in fact, locked farmers in pesticide technology (Wilson 2000; Wilson and Tisdell 2001).

The responsible use of pesticides requires the ability to read and follow label directions. Farmers also often lack the resources to purchase equipment and supplies specified on the label to properly apply a pesticide. Pest identification is lacking and risks from pests are often not properly assessed. Pesticide and application equipment availability is too often determined by government or aid agency use of "surplus" goods from elsewhere and often not well suited to solve the problems at hand. Thus, the wrong materials are often used in the wrong amount in the wrong place at the wrong time with improper protective gear for the applicator and improper safeguards for the environment.

In what follows, we briefly discuss regional and global "outsiders" that are likely to enhance pesticide use and exacerbate marginalization, and secondly, we try to elaborate the pathways of marginalization (Fig. 1) by degradation of human health at local levels.

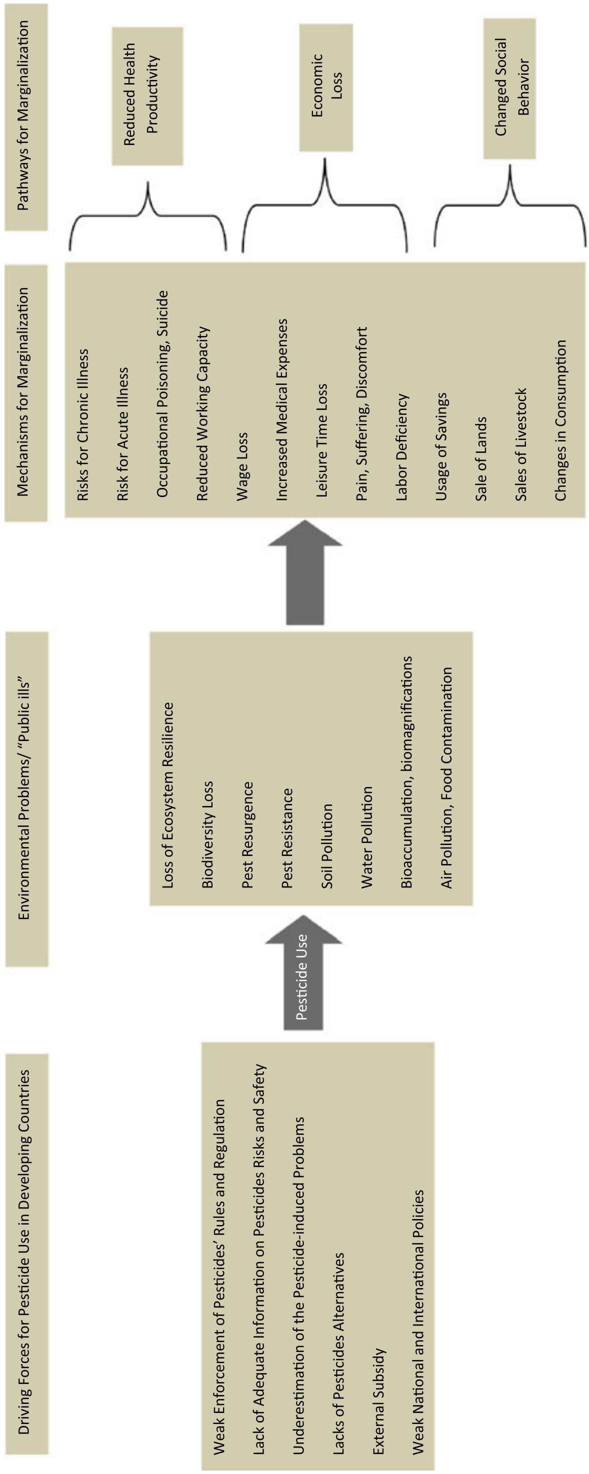

Fig. 1 Linking pesticide use to environmental degradation and marginalization

Macro-level Forces for Marginalization

There is an apparent lack of proper institutions governing the production and sales of pesticides in developing countries. Pesticides are some of the most stringently regulated chemicals in the world. But developing countries lack laws and regulations that properly regulate pesticide imports/exports and use (Ecobichon 2001). The countries having such mechanisms may still lack strict enforcement; for example, in Nepal, despite having the necessary legislation (Pesticides Act 1991 and Regulation 1994; Environmental Protection Act 1997 and Regulation 1998) farmers continue to succumb to market and peer pressures to buy highly toxic obsolete pesticides.

Additionally, export of chemicals banned in Western countries to developing countries without adequate warnings and precautions would cause people to become marginalized. Indeed, developed nations have, in the past, deliberately or otherwise, "dumped" highly toxic and expired chemicals into less developed countries as "aid." For instance, more than 74 metric tons of highly toxic and persistent chemical pesticides were donated by multinational companies to Nepal (Shah and Devkota 2009), essentially becoming an "ecological time bomb" that could go off in the near future. The ingredients of this "ecological time bomb" include DDT, dieldrin, and chlorinated organo-mercury compounds. A global surveillance of DDT levels in human tissues discovered higher levels in Africa, Asia, and Latin America than in Europe and the United States (Jaga and Dharmani 2003). The use of these compounds has been either banned or restricted in many developed countries; however, still many industries from these countries market these products to the developing world. For example, from 1997 to 2000, the US pesticide companies exported over 30,500 metric tons of pesticides forbidden from use in the United States (Raven et al. 2008). Frey (1995) has examined the problem of the flow of pesticides from developed countries to less developed countries in terms of increased human and environmental health risks, and social and economic costs, and argued that political-economic forces characterized the increased flow to the less developed countries.

Furthermore, while there is easy access to information about these toxic chemicals in the developed world, very few farmers in developing countries are properly informed or made aware of the risks. It is also a fact that farmers in developing countries adopt significantly fewer safety precautions while using pesticides. In spite of this, there are innumerable companies advertising chemical pesticides through the media in developing countries, but very few advocating safety precautions while handling and applying pesticides.

Indeed, the intellectual communities, including research scholars and scientists, have not yet achieved adequate accuracy in estimating the potential health and environment damage and consequently in evaluating its impacts. Scholars who tried to evaluate the pollution costs of pesticide use have also underestimated the effects because of incomplete accounting of the range of negative externalities. For instance, Devi (2007) calculated the costs of pesticide pollution in India to be US $ 37 per person per year. Similarly, Atreya (2008) estimated a value of only $ 2 per individual per year for the similar effects in Nepal. Further, studies in Africa (Ajayi 2000; Maumbe and Swinton 2003) have also yielded a similar range of costs. This cost appears very small compared to the increase in farm production, thus when a farmer is faced with a choice between the pollution costs and increases in farm production, s/he underestimates pesticide's effects and continues to use pesticides without proper safety precautions (Atreya 2008). The costs of pesticide pollution for the society is likely to be significantly higher than the costs estimated in many studies because most of them consider only a fraction of the full impacts of pesticide use. Furthermore, weak national and international policies also seem to be faulty. For example, the *World Development Report 2008* of the World Bank, which is regarded as a key document of global action for development, proposes a new vision to "revolutionize" agricultural production at household level through subsidies to inputs like chemical pesticides. The report recommends subsidies for agricultural inputs in the developing world, which have been removed earlier, for example in 1997 for Nepal. Such a policy move is likely to increase use of pesticides in the future, causing yet more adverse consequences.

Micro-level Pathways for Marginalization

Now let us consider mechanisms that cause farmers to be marginalized by pesticide use. These are site-specific, therefore, contextual even within a country, local environment, or household. Degradation of the local environment may lead to marginalization. For micro-level mechanisms of marginalization, three pathways are discussed, namely: decline in health and productivity, direct and indirect economic loss, and in extreme cases, changes in household social behavior (Fig. 1).

Decline in Health and Productivity

It is recognized that agricultural work related to pesticide use carries significant risk for injury and illness, and it is only recently that these matters have been addressed. As discussed earlier, pesticide use is linked to acute and chronic illness, suicide attempts, occupational poisoning, and lead to significant mortality and morbidity. Mortality is a complete health tragedy, but in case of morbidity, a farmer is unable to work with full energy; and, either takes rests at frequent intervals (partial productivity loss), or takes bed rest with total loss of labor (complete productivity loss). In addition, sickness may decrease managerial or analytical skills of farmers affecting the decisions-making process. Thus, labor productivity loss due to pesticide-related illness, loss of time and labor of family member(s) nursing the victim, and leisure time loss (Wilson 1998; Ajayi 2000; Atreya 2008) are some of the micro-level health-related pathways of marginalization.

Economic Loss

The World Bank acknowledges that "out-of-pocket" payments for health services—specially hospital care—can make a difference between a household being poor or not (Claeson et al. as cited in McIntyre et al. 2006). The medical expenditure, transportation costs, value of time on traveling, and dietary expenses due to illness are the payments when a person is victimized with pesticide poisoning (Maumbe and Swinton 2003; Devi 2007). Similarly, cost of protective clothing, gloves, mouth and nose protection, etc., add averting costs against pesticide risks (Atreya 2007a, 2008). Additionally, crop losses/damage due to inability to look after the farm, costs associated with hiring labor due to inability to work on the farm, and any income foregone due to illness (Wilson 1998) further increases the total losses and marginalizes the vulnerable groups.

Changes in Social Behavior

McIntyre et al. (2006) showed evidence of households being pushed into poverty or forced into deeper poverty when faced with substantial medical expenses, particularly when combined with a loss of household income due to ill-health. The economic loss due to ill health or ill environment may also force households or society to change social behavior within or between groups, for example, labor substitution, sales of assets, changing consumption pattern, etc., to cope with the substantial economic loss and changing environment (Sauerborn et al. 1996; McIntyre et al. 2006). In a pesticide polluted environment, vulnerable members (children, pregnant women, elderly persons) in a household may initiate spraying pesticides to minimize crop failure risks. Farmers may shift from less toxic pesticides to more toxic or more frequent application; and low dose to high dose of pesticide applications.

The final point is that exaggerated and incompetent pesticides use in agriculture is likely to degrade human and environmental health that leads to decline in human productivity, economic and social consequences marginalizing the vulnerable groups whose livelihood depend solely on agriculture.

Approaches to Reduce Pesticide Use in Agriculture

Ignorance of pesticide induced "developmental problems" and the "public evils" have caused serious damage to human society, therefore, during 1960s, at its very infancy, a new concept of pest control called Integrated Pest Management (IPM) emerged. This was actually a realization of the "public evils" of pesticide use. The revolutionary book *Silent Spring* (Carson 1962) also served as an agent for change. The initial objective of IPM changed to the concept of "pest control" to that of "crop and eco-health." The benefits of IPM in terms of reduced pesticide expenses and increased yields and reduced environmental and health costs are documented (Table 1). Nowadays, IPM is believed to enhance capability of local people for decision making in response to context-dependent pest problems, and also to their capability for adaptive management (van den Berg and Jiggins 2007).

Only a few scholars have considered the environmental and ecological aspects in evaluating the IPM benefits. Cuyno et al. (2001) assessed IPM induced reduction not only to pesticide usage and yield, but also to risks to humans, birds, aquatic species, beneficial insects, and other animals. In Nepal, Atreya (2007b) also considered negative externalities of pesticides on human health and environment including livestock, birds, wildlife, air, water, and soil while estimating farmers' willingness to pay for community IPM training. Recently, van den Berg and Jiggins

(2007) broadly categorized the benefits of IPM into two types: immediate and developmental (Table 2). They argue that the changes of the IPM concept, from “pest control” to “crop health” and the realization of its capabilities (educational, social, political) for managing agro-ecosystems, should now look beyond the immediate impacts to broader developmental impacts such as innovation, community agenda setting, or policy changes.

The success story of IPM can be found in countries like Bangladesh, Cambodia, China, India, Indonesia, Pakistan, Sri Lanka, Thailand, Vietnam (see van den Berg and Jiggins 2007). Yet, the adoption and coverage is not sufficient to meet the global objective. IPM is knowledge intensive and ideally designed for literate farmers of the developing world (Raven et al. 2008). This could be a reason why some scholars (Atreya 2007a; Jha and Regmi 2009) have recommended reviewing the IPM curriculum and implementation strategies for Nepal.

IPM programs such as FFS in developing countries are often donor-driven, which might not last for a long time. This is evident in Nepal where very few IPM-trained individuals practiced the knowledge gained from FFS into their farms. In some cases, they completely abandoned the ideas. At first, the trained individuals are

Table 1 The examples of the benefits of IPM to developing countries

SN	Country	Findings	Source
1	Indonesia	Application of IPM techniques saved about $1200 a year per farm through reduced pesticide use	ADB (1999)
2	Nepal	High demand for community IPM. Per household annual welfare gain by five days of training was estimated to be $25.23	Atreya (2007b)
3	Philippines	The per capita environmental benefits of IPM was estimated to be around $32.6	Cuyno et al. (2001)
4	Vietnam	A 400 kg/ha increase in rice yields with concurrent lower health costs for IPM farmers ($6.82) as compared to non-IPM farmers in a cropping season documented	Dung and Dung (1999)
5	India	Decreased conventional pesticide use by 50% on average. Incomes increased by Rs 1000–1250/ha and rice yields increased by 250 kg/ha	FAO (2002)
6	Indonesia	Increased rice yields by an average of 500 kg per hectare and the number of pesticide applications decreased from 2.9 to 1.1 per season	
7	Sri Lanka	Reduced insecticide use (from 3 to 1 applications per season) and increased yields (by 12–44% for rice) observed	
8	Nepal	Lower use of pesticides as compared to control. IPM farmers use 2.7 times more than optimal dose as compared to 4.4 times that of control	Jha and Regmi (2009)
9	Developing countries	A review of 25 impact evaluation studies reported substantial and consistent reductions in pesticide use and convincing increase in yield due to training	van den Berg (2004)
10	Developing countries	The IPM benefits are to be evaluated in terms of immediate and developmental impacts such as innovation, community agenda setting, or policy changes	van den Berg and Jiggins (2007)

Table 2 Examples of immediate and developmental impacts of the IPM

Domain	Immediate impact	Developmental impact
Technical	Knowledge about ecology, experimentation skills, improved crop management, pesticide reduction, yield increase, profit increase, risk reduction, reduced water contamination, reduced pesticide poisoning	More sustainable production, improved livelihoods, ability to deal with risks and opportunities, innovation, more cost-effective production, reduced public health risks, improved biodiversity, improved marketability of produce, and poverty reduction
Social	Group building, communication skills, problem solving skills	Collaboration between farmers, farmer associations, community agenda setting, farmer study groups, formation of networks, farmer-to-farmer extension, area-wide action
Political	Farmer-extension linkage, negotiating skills, educational skills	Strong access to service providers, improved influence, awareness campaigns, protests, policy change

Source: modified from van den Berg and Jiggins (2007)

socially diverse and physically scattered so they could not often disseminate the practices learnt in FFS; second, farmers face peer pressure for pesticide use on the farm as the neighbors continuously apply it to minimize crop failure risks; third, "top–down" approach has been used for selecting individuals for the IPM programs. Therefore, a "bottom-up" approach—the community IPM program—is recommended for introduction of IPM in low-income countries. Community IPM is a strategy for sustainable agriculture development where farmers act on their own initiative and analysis, identify and resolve relevant pest and crop-related problems, conduct their own local IPM research and education, establish or adapt local organizations that enhance the influence of farmers in local decision making, employ problem solving and decision-making processes, create opportunities for all farmers in their communities to develop themselves, and promote a sustainable agricultural system (Pontius et al. 2000). Atreya (2007b) found positive farmers' willingness to pay for such community IPM; hence it could be (re)implemented with local support. Although the methodology for impact evaluation of the FFS is still under development (van den Berg and Jiggins 2007), benefits to participants from immediate and developmental impacts of IPM training are likely to be higher than the costs of participation. For other countries, studies such as Kishi et al. (1995), van der Hoek et al. (1998), Konradsen et al. (2003) have recommended either a shift from highly toxic pesticides to less toxic or to restrict the availability of highly toxic pesticides. But in Nepal, farmers have been using comparatively less toxic pesticides frequently without protective measures. So, the adoption of community IPM as an alternative to chemical control, along with educating the population to make them aware of the safe handling of pesticides and safety gear and its impacts to health and environment, are the possible options to minimize pesticide use. Current national strategy of IPM-FFS extension approach is to minimize chemical pesticide use by altering cultivation practices (intercropping, rotation, fertilization, etc.); using biological control agents, pheromones traps, selective breeding, etc. But for its long term sustainability, we should also look at the institutionalizing FFS groups, exploring continuous economic sources, involving teams of experts in training/evaluation, establishing public–private partnership for extension and research, and searching markets for safe agricultural products.

Conclusion

The dominance of simple economic analysis for estimating benefits of pesticide use seems to have had increased "public evils." If these "public evils" are not realized and accounted for through a holistic systems perspective in the analysis of economic returns, vulnerable communities or societies may be continuously marginalized. The paper recommends significant importance to alternatives ways of controlling pests, for instance community IPM, along with education and training activities. In a situation where the entire earth has become one via globalization and trade liberalization, it would be very worthwhile to get farmers acquainted with sustainable management of the local agro-ecosystems with a major focus on pesticide-induced unintentional developmental problems. And it also allow farmers to be informed of the changes in market demands, opportunities, and threats arising from international and national rules, regulations, policies, treaties, etc.

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Paper II

Atreya K, Sitaula BK, Overgaard H, Bajracharya RM, Sharma S. 2012. Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal. *International Journal of Environmental Health Research*. 22: 401-415.

International Journal of Environmental Health Research
Vol. 22, No. 5, October 2012, 401–415

Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal

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(*Received 5 July 2011; final version received 19 November 2011*)

Assessing erythrocyte acetylcholinesterase (AChE) activity in farm workers across agricultural seasons can be used to monitor risks of pesticide exposure. We surveyed a total of 403 households in Nepal and adopted the Test-mate ChE Cholinesterase Test System to monitor AChE activity across season on the 127 individuals of the sampled households. The study aims to (i) document knowledge and practices of pesticide use among farmers and (ii) present the relationship between farmers' reported acute health symptoms and erythrocyte acetylcholinesterase depression. We found low levels of pesticide use hygiene and high levels of individuals' knowledge on the local environmental impacts of pesticide use. Safety measures taken against potential risks of pesticides exposure were inadequate. Exposure to organophosphates significantly reduced AChE activity across season, but was not sufficient enough to claim clinical symptoms whereas exposure to the pyrethroid insecticides and fungicides were sufficient enough to claim acute symptoms of poisoning.

Keywords: pesticides; exposure assessment; acetylcholinesterase; vegetables; Nepal

Introduction

Farm workers are regularly exposed to a variety of health hazards during farm work, particularly with respect to agricultural intensification and associated pesticide use. Numerous studies have shown that overuse of pesticides in agricultural farms has adverse health consequences, such as headache, skin irritation, eye irritation, respiratory and throat discomfort, etc. (Antle and Pingali 1994; Beshwari et al. 1999; Dung and Dung 1999; Murphy et al. 1999; Yassin et al. 2002; Maumbe and Swinton 2003; Atreya 2008a, 2008b; Devi 2009a). These studies documented self-reported acute health effects which were not verified through clinical examination. There may be some degree of recall bias when relying on self-reported symptoms because farm workers may not accurately associate their health symptoms with pesticide exposure (Dasgupta et al. 2007) or distort in the hope of secondary gain or to avoid adverse outcomes (Ohaya-Mitoko et al. 2000). Furthermore, they may not be interested in

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ISSN 0960-3123 print/ISSN 1369-1619 online

http://dx.doi.org/10.1080/09603123.2011.650154
http://www.tandfonline.com

sharing their experiences with interviewers. Monitoring erythrocyte acetylcholinesterase (AChE) activity in farmers, in addition to self-reported acute health symptoms could offer better results for assessing individual risks of exposure (Lotti 1995; Keifer et al. 1996; Quandt et al. 2010). Acetylcholinesterase is an enzyme found at neuromuscular junctions, which degrades acetylcholine and actively serves to terminate synaptic transmission, thereby maintaining proper function of the nervous system. When farm workers are exposed to organohosphorus and carbamates pesticides, the acetylcholinesterase function is blocked causing excessive accumulation of acetylcholine that result in an array of both acute and chronic neurotoxic symptoms like twitching, trembling, paralyzed breathing, convulsions and in extreme cases, death (Extension Toxicology Network 1993). The use of clinical evidence to relate self-reported health symptoms and exposure to pesticides has been emerging in other parts of the world, but limited for Nepal.

It is hypothesized that farm workers in the study area who apply pesticides lack knowledge and practices of pesticide use and are exposed to levels of pesticides that cause symptoms of poisoning which is detectable through acetylcholinesterase analysis. The present study aims to: (i) document knowledge and practices of pesticide use among farmers and (ii) examine the relationships between farmers reported acute health symptoms and erythrocyte acetylcholinesterase depression. For this purpose, we carried out a study in a Nepalese watershed where traditional subsistence cereal farming systems have been replaced by market-based high input pesticide-intensive vegetable farming.

In the following section, we described the study area and sampling procedures, followed by survey methods and blood analysis. The results and discussions section are in three parts. In the first section, we documented and discussed knowledge, attitude and practices of pesticide use. The second section contains blood analysis results and the final section shows the relationships of AChE depressions with household and individual characteristics, and exposure to the pesticides. In the concluding section, the article highlights major findings of the study.

Methods and materials

The study area

Farmers in Nepal apply pesticides at rates nearly four times higher than the optimal for vegetables (Jha and Regmi 2009).Vegetable production is an important source of farm income (Brown and Kennedy 2005; Tiwari et al. 2008; Dahal et al. 2009). A few studies revealed that the shift from need-based cereal farming to market-based vegetable farming (intensive agriculture) has improved socio-economic conditions of farmers (Dahal et al. 2009), but at the costs of surface water pollution (Dahal et al. 2007), decreasing soil fertility (increasing acidification) and increasing green house gas (N_2O) emissions (Raut et al. 2010). The vegetable farming system is increasingly reliant upon pesticide applications. Yet, studies are limited on chemical pesticide use and its risks of exposure to local farmers.

This study was conducted in the Ansi khola watershed which is situated approximately 45 km north of Kathmandu, the capital of Nepal (Figure 1). The watershed lies between N 27°41′–44′ latitude and E 85°31′–37′ longitude. The elevation ranges from 800 to 2000 masl covering an area of 13 km^2. The watershed comprises of four Village Development Committees (VDC), namely Mahadevsthan, Nayagaun, Anekot and Devitar. The communities of the watershed are primarily

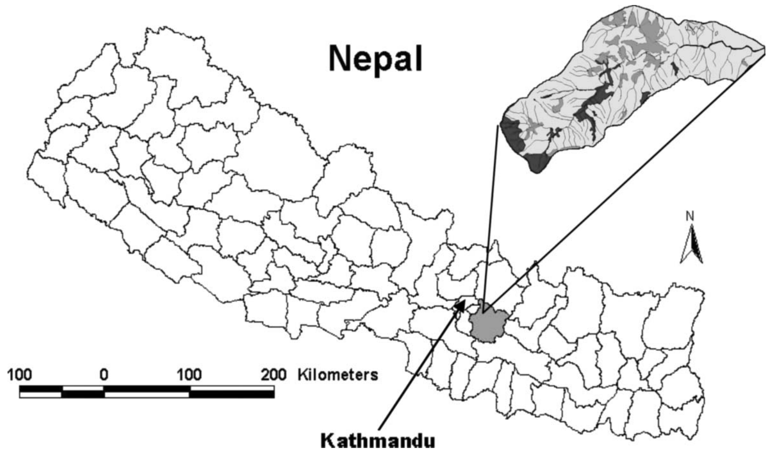

Figure 1. Location of the Ansi khola watershed.

engaged in intensive agriculture. The irrigated lower reaches of the watersheds support three harvests per year (rice–rice–potato/other vegetables). The upper rainfed areas support maize and millet in the monsoon period, and potato or other vegetables during the winter season.

Household sampling procedures and size

There are 1038 households in the watershed. These have been categorized into large-scale, medium-scale and small-scale farmers based on social and economic characteristics (Dahal et al. 2009). These 1038 households were our sampling frame. There were 423, 428 and 187 households under large-scale, medium-scale and small-scale farmers, respectively. We further divided these households into lowland (<1000 masl) and upland (>1000 masl) to reflect altitudinal biophysical variation. There were a total of 402 households in the lowland and 636 households in the upland. A proportional random sampling (based on farmers' category and altitudinal variation) was used to draw a total sample of 403 households from the watershed.

Household survey

A questionnaire-based household survey was undertaken during the period May–June 2008. Information was collected on household demography, pesticide application frequency, individual knowledge, attitudes and practices on pesticide use; use of safety equipment; and their adoption and constraints. The survey questionnaire was pretested on 25 households in a nearby area.

Information was collected at the time of "after-season" blood analysis, using a check-list, on individual exposure to the chemicals. The data included are, e.g. types of pesticides used and their concentrations, pesticide expenses, number of days of pesticide application, working hours, acute illness, etc. These variables were only documented for the 30 days of exposure to correlate results obtained from blood analysis.

Blood analysis

The pesticide use is likely to be higher in lowland areas compared to upland because of increased cropping intensity through introducing vegetables into the annual cereal-based crop cycle. Therefore, blood sampling was only carried out in the lowland area. An informed consent form was signed by all participants. Blood was sampled and analysed twice during 2009: (i) before pesticide application season (March) and (ii) after pesticide application season (December). For the before-season samples, a total of 127 individuals participated, of which four individuals were excluded from the final statistical analysis because they were not from the sampled households. For the after-season samples, the 123 individuals who participated in the initial blood analysis were invited. There were 90 individuals in the second reading.

Blood was analysed using Test-mate ChE Cholinesterase Test System (Model 400) with the AChE Erythrocyte Cholinesterase Assay Kit (Model 460) (EQM Research Inc., Cincinnati, OH) (EQM Research Inc. 2003). Testing for erythrocyte cholinesterase is commonly used to monitor exposure to organophosphate and carbamate pesticides. The measurement of erythrocyte AChE yields a more reliable and clinically significant result than measurement of plasma cholinesterase activity in the same individual (Bissbort et al. 2001). We considered a longer post-spray season assessment because of the longer mean recovery time ($\sim$82 days) of AChE activity as compared to plasma cholinesterase ($\sim$50 days) to baseline post-exposure (Mason 2000).

The following data were collected: (1) AChE (erythrocyte acetylcholinesterase) activity (unit/mL), (2) AChE percentage (relative to its normal value, 4.71 units/mL), (3) Haemoglobin (g/dL), (4) Haemoglobin percentage (relative to its normal value, 15.0 g/dL), (5) Haemoglobin adjusted erythrocyte acetylcholinesterase activity (Q) (units/g) and (6) Q percentage (relative to normal value, 31.4 units/g). The Q is computed by dividing the AChE results by the haemoglobin results. The Q parameter improves the assay precision by minimizing biological and sample variability.

Data analysis

Samples *t*-test for comparing equality of means of AChE activity across time was performed at 95% confidence interval using Predictive Analytics Software (PASW) Statistics 18. We also performed bivariate correlation to measure the relationship of acetylcholinesterase depressions with variables such as individual characteristics, pesticide use knowledge, attitudes and practices. The bivariate correlations procedure computes Pearson's correlation coefficient that measures the associations between two variables. In our case, farmers apply more than one type of pesticide in mixtures, thus the effects (AchE depressions and reported symptoms) caused by exposure could be affected by mixtures applications. To know the real balance of each type of pesticide in the health of workers, partial correlation coefficients would be more appropriate. The partial correlations procedure computes correlation coefficients that describe the linear relationship between two variables while controlling for the effects of one or more additional variables. Therefore, we performed partial correlations for correlating AChE depression values to the individual's exposures to pesticides and reported acute health symptoms.

Results and discussions

Respondent characteristics

The sample population covered all the VDCs of the watershed, of which 38.5% resided in Mahadevsthan, 17.6% in Anekot, 41% in Nayagaun and 3% in Devitar. The sample comprised of both males (63.3%) and females (36.7%) and many individuals (83%) had not attended integrated pest management (IPM) training.

As the blood sampling was carried out in the lowland areas of the watershed, most individuals (79%) reside in Mahadevsthan VDC and a few individuals from Anekot and Nayagaun VDCs were also found. The sample comprised of both males (83%) and females (17.8%). The majority (69%) had no IPM training.

Pesticide use in vegetable crops

Pesticides were used frequently in the study area. These can be grouped into (1) organochlorines – endosulfan (WHO hazard category II) and gamaxine; (2) organophosphates – methyl parathion (Ia), phorate (Ia), dichlorvos (Ib), monochrotofos (Ib), chlorpyrifos (II), dimethiote (II), profenofos (II) and malathion (III); (3) pyrethroids insecticides – cypermethrin (II), fenvelerate (II) and deltamethrin (II) and (4) fungicides – matalaxyl (III), mancozeb (U) and carbindazim (U).

We documented monthly pesticide spray operations during the period June–November 2008 in the Ansi khola watershed (Atreya et al. 2011). A total of 1122 pesticide applications event were investigated. The organochlorines were used 188 times at average concentration ($\pm$SD) of 2.51 ml/L ($\pm$0.84). The organophosphates were used 441 times at concentration of 2.53 ml/L ($\pm$1.05). Similarly, 199 applications of pyrethroids insecticides at concentration of 2.60 ml/L ($\pm$0.83) were observed. The most widely used were the fungicides which were applied 743 times at 3.23 g/L ($\pm$1.33). Farm workers mix different kinds of pesticides while spraying at the farm so the sum total of the individual chemicals applications event may exceed the total event of pesticide application. Two-thirds of the total pesticides application events contained fungicides either mixed with other insecticides or sprayed alone.

Potato was the main cash crop grown by the majority of households, followed by tomato, chili, cauliflower, bitter gourd and cucumber (Table 1). The frequency of applying pesticides in these crops was about five applications per cropping season. The current trend of pesticide use in the study area is that farmers apply significant amount of fungicides. Farmers generally used fungicides and not insecticides for potato. Insecticides, but also fungicide–insecticide mixtures were common in the other vegetable crops. It is evident that households, especially in the lower watershed – due to the established road network – are likely to cultivate newly introduced vegetable crops in a greater extent that could ultimately increase exposure to hazardous insecticides. The application of fungicides, especially mancozeb, was widely used in the watershed. Mancozeb has both short- and long-term health consequences for people exposed to unsafe levels to this fungicide (Atreya and Sitaula 2010). The use of harmful insecticides is likely to increase as new crops are being introduced in the cropping systems, especially in the lower watershed, due to the established road network.

The total household expenses on pesticides were highest for potato but were actually the lowest per unit of land compared to the other vegetables. This is because, households cultivated potato in a larger area that received only fungicides which are

Table 1. Frequency of pesticide use and average expenses by vegetable crops in the Ansi khola watershed, Nepal.

Name of the vegetables	Number of households cultivating crops	Frequency of use (no. of pesticide applications per growing season)			Total expenses on pesticides* (NRs/ household)	Total cultivated area** (Ropani/ household)	Average expenses on pesticides (NRs/ Ropani)
		Min	Max	Average			
Potato	294	2	10	5.47	819	3.2	256
Tomato	94	3	10	5.12	475	1.4	339
Chilli	79	2	15	4.85	461	1.2	384
Cauliflower	58	2	15	5.19	503	1.5	335
Bitter gourd	44	2	15	5.75	467	0.8	584
Cucumber	22	2	15	5.95	564	1.0	564

Note: *US$ 1 ≈ NRs 70; ** 1 Ropani ≈ 1/20 hectare.

comparatively cheaper than insecticides. The late blight of potato caused by a fungus, *Phytophthora infestans*, is the major disease against which households apply fungicides; either mancozeb or a mixture of mancozeb and metalaxyl. Mixtures of fungicides and insecticides were observed but limited in potato.

Although households cultivated other vegetables such as tomato, chilli, cauliflower, etc. in a limited area, expenses of chemicals applied per unit of land were comparatively higher than for potato. This is because of the higher application frequency and use of mixtures of insecticides. Jha and Regmi (2009) showed that out of the total amount of pesticides used in cauliflower and cabbage in an area close to the capital of Nepal, 76% were insecticides and 19% fungicides.

Knowledge, attitude and practices of pesticide use

More than 60% of farmers apply pesticides based on visual signs of pest damage on their crops and 20% apply when they observe larvae and adult pests. Almost 40% of farmers make decisions on pesticide use based on their own experiences and only one-third (31.5%) consult pesticide shopkeepers for such decisions. Pesticides were commonly applied during day time, but very few (11%) paid attention to the wind direction during pesticide application. Most farmers were neither aware of the toxicity labels on pesticide containers (67%) nor understand the labels' meaning (63%). Only about 40% of the farmers take a shower after use and 54% changed their clothes after pesticide application work. As many as 60% of the individuals used pesticide-contaminated utensils for kitchen gardening and in livestock sheds. This indicates that the knowledge, attitudes and practices of farmers about pesticide use appears to be inadequate.

Most individuals (45%) believed that use of chemicals on their farm has "little effect" on human health. A few of them believed there to be a "large effect" of pesticide risks to both short-term (6%) and long-term (8%) health consequences. More than 50% of individuals agreed that pesticide use can affect their health, and >90% individuals were also aware of the possible contamination of local water sources due to pesticide use (Figure 2). But the use of safety measures during pesticide applications was found to be very low by any international standards. Only

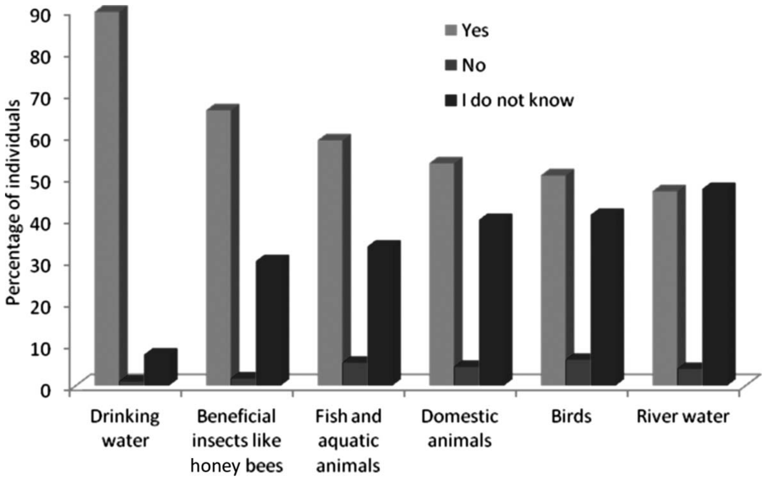

Figure 2. Individuals' opinion on the possibilities of adverse effects of pesticide use on their local environment.

one out of four farmers wears a mere handkerchief for safety from direct exposure to the chemicals. Uses of recommended and scientific safety measures such as mask and gloves during pesticide application were very minimal (<10%).

The low level of pesticide use knowledge and practices for this study is consistent with other studies done in the developing countries. Several studies (Kishi et al. 1995; Sivayoganathan et al. 1995; van der Hoek et al. 1998; Wilson 1998; Gomes et al. 1999; Murphy et al. 1999; Yassin et al. 2002; Matthews et al. 2003; Gupta 2004; Salameh et al. 2004; Damalas et al. 2006; Recena et al. 2006; Devi 2009b, 2010) have shown similar results arguing that low levels of education, lack of training, low income, limited awareness and discomfort could result in minimal use of safety hygiene while handling pesticides in subsistence agriculture. Farm workers may not choose to wear such gear because they perceived these items may create discomfort and reduce their working efficiency. For example, farmers believed that wearing a mask makes breathing difficult; wearing boots makes walking difficult and thus hinders their farm work. Farm workers tend to wear less safety measures in hot and humid climates due to additional warming effects of these items in their body. A significant negative relationship between maximum air temperature and adoption of safety gear is documented for Nepal (Atreya 2008b). Furthermore, low levels of safety measures could be explained by the types of pesticide used. Fungicides (particularly mancozeb) dominated the spray for this study which is believed to be less toxic than insecticides. Farmers perceived mancozeb as "powder," relatively harmless compared to insecticides which could have resulted in minimum safety at the time of application. Individuals are also unaware of the danger of pesticide use that is posed to their health and environment in the long-term.

Nearly 90% of the individuals perceived that pesticide use negatively affects their drinking water sources, and two-thirds knew that beneficial insects like honey bees are adversely affected, and more than half mentioned its negative effects on other local resources such as fish, domestic animals and birds. This indicated that majority of farmers were aware of the fact that current use of chemicals is degrading their local environment. During group discussions, many individual revealed indicators of environmental impacts at local levels – such as loss of fish and frogs in local rivers; reduced numbers of birds, snakes and honey bees on their farms – by the current use of chemical pesticides.

Despite such understanding of environmental impacts of the current use of chemicals, many farmers (83%) have increased pesticide use per unit of land by 24% in the past 5 years. During group discussion it was revealed that farmers will continue pesticide use at an increasing rate because of (i) lack of knowledge on feasible or cost-effective alternatives to chemicals such as integrated pest management, (ii) underestimation of the short- and long-term health effects of pesticides, (iii) introducing new vegetable crops into the cropping systems, (iv) weak enforcement of pesticide rules and regulations and (v) ignorance of the long-term sustainability of the input-dependent agricultural systems. Thus, it would be worthwhile to get farmers acquainted with sustainable management of the local agro-ecosystem with a major focus on pesticide induced health and environmental degradation. For this, we recommend regular training and environmental awareness activities at local level emphasizing local consequences of pesticide use and its proper management through appropriate measures, e.g. community integrated pest management (Pontius et al. 2000). The community IPM, for which Nepal's farm workers have shown positive willingness to pay (Atreya 2007), although limited in the study area, was found to reduce pesticide expenses, health and environmental degradation in many countries (ADB 1999; Dung and Dung 1999; Cuyno et al. 2001; van den Berg 2004; van den Berg and Jiggins 2007; Jha and Regmi 2009). The IPM intervention also enhanced capability of local people for decision-making in response to context dependent pest problems and provides immediate and developmental benefits (van den Berg and Jiggins 2007). However, its slow adoption in developing countries (Trumble 1998; Feder et al. 2003) suggests reviewing the IPM curriculum and implementation strategy for Nepal.

Blood test and acetylcholinesterase depression

We found a significant variation in erythrocyte acetylcholinesterase activity before and after pesticide application season, but not in blood pressure and haemoglobin (Table 2). The haemoglobin adjusted acetylcholinesterase activity (Q) was significantly reduced across seasons ($p < 0.001$). Jintana et al. (2009), Ntow et al. (2009) and Quandt et al. (2010) also found reduced AChE activity due to pesticide use in agriculture; however, Ngowi et al. (2001) found no effects between spraying and non-spraying seasons in AChE depressions. The reduced activity of cholinesterase across season for this study may indicate farm workers were exposed to the chemicals. We further categorized AChE reductions (Q) of $\geq$10% from an individual's highest value and considered evidence of meaningful cholinesterase activity depression. We found 30% individuals having $\geq$10% reduction in AChE activity.

The bivariate and partial correlations

We found insignificant Pearson's correlation coefficient between individual and household characteristics with acetyl cholinesterase depressions (Table 3). However, AChE depression correlated at 10% levels with prior IPM training. It indicates that

Table 2. Seasonal differences in erythrocyte acetylcholinesterase activity of the farm workers in the Ansi khola watershed, Nepal.

Parameters	Before-season ($N = 123$)		After-season ($N = 90$)		t-test significance
	Mean	SD	Mean	SD	
Blood pressure: systolic	112.52	13.65	112.81	14.24	−0.151
Blood pressure: diastolic	73.54	8.39	73.33	9.48	0.165
AChE (U/ml)	3.72	0.68	3.44	0.64	3.015**
AChE (% relative to 4.71 U/ml)	78.95	14.38	73.14	13.69	2.971**
Haemoglobin (g/dL)	12.24	1.45	12.21	1.67	0.116
Haemoglobin (% relative to 15.0 g/dL)	81.54	9.73	81.48	11.17	0.047
Q^{+} (units/g)	30.41	4.33	28.24	3.95	3.760***
Q (% relative to 31.4 units/g)	96.87	13.78	89.97	12.72	3.730***

Notes: ** and *** indicate significant mean difference at probability levels of the 0.01 and 0.001, respectively. $^{+}$The Q is the haemoglobin adjusted erythrocyte cholinesterase activity computed by dividing the AChE values by the haemoglobin values.

Table 3. Pearson's correlation between individual and household characteristics with acetyl cholinesterase depressions (%) ($N = 90$).

Variables	Unit of measurement	Mean (SD)	Pearson's correlation
Gender	1 male, 2 female	1.18 (0.384)	0.097
Age	Years	42.4 (11.20)	0.118
Education	Years of schooling	7.54 (3.18)	0.145
Body Mass Index	Weight/square height	20.68 (2.50)	0.073
Annual household pesticide expenses	Nepalese Rupees (NRs)	1479.8 (1112.4)	−0.081
Annual frequency of pesticide use	Numbers of applications	10.46 (9.15)	−0.073
Integrated pest management training	1 prior IPM trained, 2 otherwise	1.69 (0.46)	0.193^{+}

Note: + Correlation is significant at the 0.10 level.

individuals who were not trained in IPM were more likely to use AchE inhibiting pesticides compared to IPM trained individuals. Similarly, we found no significant relationships between individual pesticide use knowledge (such as being careful about wind direction while applying pesticides, understanding and awareness of the toxic labels on the containers, etc.) and AChE depression, but individuals who were not aware of the possibilities of adverse effects of pesticides on beneficial insects like honeybees tend to use more AchE inhibiting pesticides (Table 4).

AChE depression was also found to correlate significantly with the past 30 days of exposure variables, documented at after-season blood sampling, such as, numbers of days of pesticide application, pesticide expenditure and working hours (Table 5). The higher the number of days of pesticide use, the more pesticides were bought, and the higher the number of working hours on spraying days the more likely was an increased risk of exposure. Total incidence of illness reported also correlated with AChE depression only at the 10% levels.

Table 4. Pearson's correlation between acetylcholinesterase depressions (%) and individuals' knowledge of pesticide use ($N = 90$).

Variables	Unit of measurement	Mean (SD)	Pearson's correlation
Do you care about wind direction while spraying?	1 yes, 2 otherwise	1.48 (0.50)	0.116
Do you understand toxic labels present on the container?	1 yes, 2 otherwise	1.61 (0.49)	0.048
Are you aware of the toxic labels?	1 yes, 2 otherwise	1.67 (0.47)	0.068
Do pesticides adversely affect			
a. Human health	1 yes, 2 otherwise	1.06 (0.31)	−0.034
b. Drinking water sources	1 yes, 2 otherwise	1.07 (0.36)	0.159
c. Beneficial insects like honey bees	1 yes, 2 otherwise	1.16 (0.54)	0.209*
d. Fish and aquatic animals	1 yes, 2 otherwise	1.26 (0.65)	−0.048
e. Domestic animals	1 yes, 2 otherwise	1.42 (0.80)	0.148
f. Birds	1 yes, 2 otherwise	1.48 (0.83)	0.186

Note: *Correlation is significant at the 0.01 level.

Table 5. Pearson's correlation between acetylcholinesterase depressions (%) to individuals' one-month exposure variables ($N = 90$).

Variables	Unit of measurement	Mean (SD)	Pearson's correlation
Numbers of days of pesticide use	Days	0.43 (0.92)	0.312**
Rupees of pesticide purchased	Nepalese rupees (NRs)	51.20 (105.58)	0.348***
Working hours on spraying days	Hours	0.40 (1.01)	0.276***
Total numbers of acute illness reported	Numbers	0.73 (1.15)	0.200^{+}

Note: + Correlation is significant at the 0.10 level, ** correlation is significant at 0.01 level, and *** correlation is significant at the 0.001 level.

The partial correlation matrix developed to analyse the relationships of AChE depression and acute symptoms with recent exposure to the organochlorines, organophosphates, pyrethroid insecticides and fungicides are shown in Table 6. The zero-order correlations, without controlling effects of mixtures of pesticides applications, are also provided. With controlling effects of other types of pesticides, AChE depression is found correlated with exposure to the organophosphates ($r = 0.317$, $p < 0.01$) whereas the number of acute health symptoms was found correlated with exposures to the pyrethoids insecticides ($r = 0.217$, $p < 0.05$), and fungicides ($r = 0.473$, $p < 0.001$). With the effects of other types of pesticides removed, the correlation between exposures to the organophosphates with acute symptoms fall to statistical non-significance.

The haemoglobin adjusted acetylcholinesterase activity was significantly reduced across seasons. The bivariate correlation matrix showed a positive relationship between farm workers reporting acute symptoms and AChE depression only at the 10% level. The reduced activity of acetylcholinesterase across season indicates greater exposure to organophosphates and post-exposure was not sufficient to claim the clinical effects. It is likely that reduced activity of AChE may not always

Table 6. Partial correlation between exposure (previous month) to pesticides with acetyl cholinesterase depressions (%) and farmer reported acute health symptoms ($N = 90$).

			Partial correlation coefficients. Zero-order correlations are given in [ ]	
Variables	Unit of measurement	Mean (SD)	Vs. AchE depression	Vs. Acute symptoms
Exposure to the organochlorines (OCL)	Weight of OCL per liter of water exposed to spraying days	0.01 (0.74)	0.07 [0.03]	–0.08 [–0.104]
Exposure to the organophosphates (OP)	Weight of OP per liter of water exposed to spraying days	0.09 (2.22)	0.317** [0.333***]	0.097 [0.268*]
Exposure to the pyrethroid insecticides (PI)	Weight of PI per liter of water exposed to spraying days	0.02 (0.83)	–0.128 [–0.034]	0.217* [0.222*]
Exposure to the fungicides (FUN)	Weight of FUN per liter of water exposed to spraying days	0.55 (8.33)	0.124 [0.190]	0.473*** [0.480***]

Note: *Correlation is significant at the 0.05 level, ** correlation is significant at 0.01 level, and *** correlation is significant at the 0.001 level.

necessarily lead to clinically recognizable symptoms although AChE assessment is generally used to predict exposure to organophosphates and carbamates. No significant relationship between exposure to either pyrethroids or fungicides with AChE depression does not necessarily mean lacking any risk of exposure to such pesticides. Because, AChE activity is blocked when individuals are exposed to organophosphates and carbamate pesticides. Acute health symptoms were found affecting by exposure to pyrethoids and fungicides. This entails that although exposure to organophosphates significantly reduced AChE depression, its exposure was not sufficient to claim symptoms but the use of pyrethroid insecticides and fungicides in the study were sufficient to claim acute symptoms.

There should be an enzymatic survey, from key human enzymes with modified activities to support these self-reported symptoms biologically. For this study, use of fungicides and pyrethroid insecticides dominated the pesticide application, rather than organophosphates. The levels of acetylcholinesterase-inhibiting pesticides such as organophosphorus were too low to reveal symptoms of poisoning. This could be the reasons for a weak relationship between self-reported symptoms and AChE depression. A few studies by Ohaya-Mitoko et al. (2000), Ngowi et al. (2001), Dasgupta et al. (2007) and Jintana et al. (2009) also found very weak association of farmers' reported acute health symptoms with acetylcholinesterase depression. In general, farmers work in multiple crops where they decide about applying pesticides depending on pests and weather conditions. Thus, the use of number of self-reported symptoms as an indicator of organophosphate exposure may not necessarily reflect a good tool in an area where different types of pesticides are being used in low concentrations for multiple crops.

The results of this study should be interpreted with caution. We monitored AChE depression in the lowland areas of a mid-hill watershed in a small sample size where fungicides dominated pesticide usage rather than cholinesterase inhibiting pesticides. Therefore, the results may not be generalized for other parts of Nepal. Furthermore, we calculated AChE depression as initial minus final cholinesterase values of the same individuals. This method does not account for individual variations of cholinesterase activity by time intervals, which was found significant in a recent study (Quandt et al. 2010). More detailed work with measurement of AChE at frequent time intervals could have resulted in a better conclusion.

Despite the limited sample size and predominant use of fungicides, the findings of the study are noteworthy. Monitoring acetylcholinesterase activity in the defined individuals across seasons offers better insights on assessing exposure than a mere survey. Some previous studies, e.g. Kishi et al. (1995), Beshwari et al. (1999), Murphy et al. (1999), Yassin et al. (2002), Atreya (2008b) and Devi (2009a) reported acute health symptoms through household/individual surveys as an indicator of pesticide poisoning without blood analysis. In addition, the present study tries to establish linkages among cholinesterase depression with individual and household characteristics, pesticide use knowledge and hygiene, and types of pesticide use; where recent exposure variables such as days of application, hours of spraying and organophosphorus pesticides have been found significantly affecting AChE inhibition. The toxicological significance of the given inhibition of erythrocyte AchE to the reported symptoms, although found weak for this study, such measurement represents the best way to evaluate toxic effects of AChE-inhibiting pesticides. Although AChE inhibition is not an indicator of exposure to pyrethroids and fungicides, such pesticides are found to increase acute health symptoms, thus future research should include biological indicators for assessing exposure to these chemicals. Analyzing fungicide metabolite, ethylenethiourea (ETU) levels in urine (Colosio et al. 2002) and urinary excretion of pyrethroid metabolites (Leng et al. 1996) are a few biological indicators for future research to assess human exposure to fungicides and pyrethroid insecticides, respectively.

For this study, it was found that local farmers underestimate the risks of pesticide exposure. They also believe that such risks of pesticide exposures are a part of daily "farm life." Furthermore, it is uncommon that individuals adopt adequate safety precautions while applying pesticides. Farmers in the study area would be likely to increase pesticide application in vegetable farming with minimal safety precautions for better livelihoods; but they are at high risk of exposure and are reluctant to comprehend the pesticide risks unless they observe the risk are real. Community-level integrated pest management could reduce pesticide expenses, health and environmental effects and also enhance capability of local people for decision-making thus, promoting IPM as an alternative to chemical pesticides, along with education and awareness on the safe use and handling of pesticides is of great importance. Farmer training at regular intervals focusing on sustainable management of the local agro-ecosystems, emphasizing local understanding of pesticide risks of exposure to human and environmental resources along with safety measures are highly recommended.

Conclusion

The application of fungicides, especially mancozeb, was observed to be widely applied having both short- and long-term health effects to people exposed to its unsafe levels. The use of harmful insecticides is likely to increase as new crops are being introduced in the cropping systems.

Despite considerable knowledge of individuals about environmental risks of pesticide use, farm workers did not appear to adopt adequate safety precautions resulting in the greater risk of exposure to chemicals. Exposure to organophosphates significantly reduced AChE activity across seasons, but its uses were not sufficient to claim clinical symptoms whereas the use of pyrethroid insecticides and fungicides was sufficient to claim acute symptoms of poisoning.

Acknowledgements

The comments and suggestions from the two anonymous reviewers are appreciated. The authors acknowledge The Norwegian Program for Development, Research and Education (NUFU) for the financial support (Research Grant No. NUFUPRO 2007/10109). Mr. Prabesh Neupane, a medical professional, deserves sincere thanks for helping AChE assessment.

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Paper III

Atreya K, Johnsen FH, Sitaula BK. 2012. Health and environmental costs of pesticide use in vegetable farming in Nepal. *Environment, Development and Sustainability* 14:477-493.

Environ Dev Sustain (2012) 14:477–493
DOI 10.1007/s10668-011-9334-4

Health and environmental costs of pesticide use in vegetable farming in Nepal

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Received: 11 July 2011 / Accepted: 28 November 2011 / Published online: 7 December 2011

Abstract There is a growing concern of pesticide risks to human health, natural environment and ecosystems. Many previous economic valuations have accounted health aspects or environmental components, but rarely combined; thus, overall risk assessment is partially distorted. The study, conducted close to the capital of Nepal, addressed the health effects of pesticides on small-scale farmers and evaluated the monetary risks of pesticide use on human health and environmental resources. We also aim to establish the relationships among valuation methods. The paper adopts cost of illness, defensive expenditure and contingent valuation willingness to pay approach. The study concluded that the methods used for valuing pesticide risks to human and environmental health are theoretically consistent. The exposed individuals are likely to bear significant economic costs of exposures depending on geographical location, pesticide use magnitudes and frequency. Individuals are willing to pay between 53 and 79% more than the existing pesticide price to protect their health and environment. The integrated pest management training is less likely to reduce health costs of pesticide exposure, although it leads to higher investment in safety measures.

Keywords Pesticides · Cost of illness · Defensive expenditure · Willingness to pay · Vegetable farming · Nepal

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1 Introduction

Pesticides are used in agriculture to secure yields and sometimes, to improve quality of food. However, its heavy use in agriculture is likely to contaminate soils, ground and surface water and may increase health risk of farmers and consumers. Pimentel (2005) reported that pesticide use causes 26 million non-fetal poisonings, of which 3 millions are hospitalized, 220 thousand die and about 750 thousand come up with chronic illnesses every year worldwide. The total number of pesticide poisonings in the United States is estimated to be 300 thousand per year. Human exposure to pesticides may reduce peoples' well-being and result in loss of productivity and increase medical expenses. These costs that are significant in other parts of the world are seldom included in the economic analysis of agricultural systems that demands heavy use of pesticides in crop production, especially in developing countries.

The present agricultural systems of developing countries have "locked in" farmers in the system of pest control technology that "entrapped" them in pesticides (Wilson and Tisdell 2001) that resulted many unintentional risks. Quantification and economic valuation of pesticide risks to human health and environment are important for effective allocation of resources as well as formulation of new rules and regulations. The external costs of pesticide use have been occasionally omitted from the analyses of returns or in evaluation of specific agricultural policies or programs.

There is growing evidence showing pesticide's negative effects on human health in crop production (Rola and Pingali 1993; Antle and Pingali 1995; Antle et al. 1998; Ajayi 2000; Maumbe and Swinton 2003; Devi 2007). Some authors attempted valuing the risk of pesticides to human health. For instance, Devi (2007) in India and other studies in Africa (Ajayi 2000; Maumbe and Swinton 2003) valued the health risk of pesticides and yielded very smaller health costs. The low level of health costs may lead to sub-optimal decision-making on the use of pesticides (Ajayi 2000), and thus, when a farmer faced with a choice between the health costs and increases in farm benefits, the individual opts for pesticides (Atreya 2008). Pesticide use not only affects short-run health effects but can also result is chronic illness and environmental problems. Thus, a few other scholars (Mullen et al. 1997; Wilson 1998; Cuyno et al. 2001; Brethour and Weersink 2001; Pimentel 2005) included the environmental component into cost analysis and found substantially higher environmental costs of pesticide risk than health costs. In practice, both health and environmental risks need to be valued together to determine potential risk and to find the optimal solutions for reducing exposure. In general, the environmental dimension of pesticide risk is neglected in economic valuation literature (Travisi et al. 2006). Many previous economic valuations have either accounted health aspects or environmental components, but rarely combined; thus, overall risk valuation is partially distorted.

The paper addresses the health effects of pesticides to small-scale farmers and puts monetary value to the risks of pesticide use to the human health and environment and establishes the relationships among valuation methods. For this, we selected two watersheds of Nepal where pesticide exposure risks to humans and the environment are increasing as a problem.

2 Pesticide use in Nepal

At national level, pesticides import increased over years. The import more than doubled from 2006 to 2008 (Atreya and Sitaula 2010). Twenty-five percent of terai (southern plain area) land holdings use chemical pesticides, 9% of mid-hills and 7% of mountain (CBS 2003). Particularly, recent trends of increased use of chemical pesticides for vegetable crops, especially in semi-rural and peri-urban areas, are observed.

The average amount of pesticide use per unit of land is minimal for Nepal (Dahal 1995); however, very high rates are reported for vegetables. The marginal productivity of pesticides use in vegetables was found to be close to zero (Jha and Regmi 2009). Although the vegetable farming is improving socio-economic conditions of farmers in terms of profitability (Brown and Kennedy 2005; Tiwari et al. 2008; Dahal et al. 2009), it is only possible through increased use of agrochemicals that may leads to environmental degradation, therefore, threatening the sustainability of farming systems in the long run. Pesticide overuse in vegetable farming systems and health and environmental degradation is an emerging problem for Nepal.

3 The study area

The study was undertaken in Ansi khola watershed (AKW) and lower reaches of Jhikhu khola watershed (JKW) of Kavrepalanchowk district of central Nepal mid-hills. Both watersheds are linked by national highways. The areas are close to the capital and three other cities en route. Here, farm families are shifting from subsistence need-based rice (*Oryza sativa* L.) production system to market-based vegetable production systems. The irrigated lower reaches of the watersheds support three crops year-round (rice–rice–potato/other vegetables). The upper rain-fed areas support maize and millet in monsoon period and either potato or other vegetables during winter seasons.

4 Methodology

The methodology follows as (1) morbidity valuation methods adopted for assessing pesticide risks, (2) data collection methods, (3) costs estimation and (4) statistical analysis.

4.1 Morbidity valuation methods

The study adopts cost of illness (COI), defensive expenditure (DE) and contingent valuation willingness to pay (WTP) approach (Table 1).

4.1.1 Cost of illness

COI is defined as lost productivity due to sickness plus the costs of medical treatment resulting from sickness (Freeman 1993). This method is widely adopted for valuing health risk of pesticide (Pingali et al. 1994; Wilson 1998; Cole et al. 2000; Maumbe and Swinton 2003; Devi 2007) due to its ease in application (EPA 2000).

Health effects for this study are defined as the incidence of acute health symptoms to an individual within 48 h of pesticides application. The COI expresses the monetary value, estimated summing (1) days lost due to pesticide-induced sickness and (2) medical care treatment such as consultation fee, hospitalization cost, laboratory cost, medication cost, travel cost to and from, and dietary expenses resulting from such illness.

Table 1 The three methods for valuation adopted for this study

Method	Approach	Advantages	Disadvantages
Cost of illness	Measures direct costs such as medical expenses and indirect costs such as foregone earnings	Relative ease of application and explanation	Ignores important components of WTP such as pain and suffering
Defensive expenditure	Infers WTP from costs and effectiveness of actions taken to defend against illness	WTP estimates based on actual behavior	Difficult to isolate value of health from other benefits of averting action
Contingent valuation	Surveys elicit WTP for hypothetical changes in health effects	Flexibility allows application to variety of health effects. If designed properly, allows measurement of complete WTP, including altruism	Hypothetical nature introduces many sources of potential inaccuracy and imprecision. Method is controversial and often expensive

Source EPA (2000)

4.1.2 Defensive expenditure

The defensive expenditures (DE) approach was used to value willingness to pay from mitigation behavior practiced against potential risks of pesticide exposure. Wilson (1998), Maumbe and Swinton (2003) also adopted the method for valuing pesticide risk to human health. Defensive expenditures included are the costs of safety measures adopted prior to spraying to reduce risk of exposure to pesticides. Such measures include wearing mask, handkerchief, long-sleeved shirts/pants and boots. These items may also have multiple uses, but each individual was asked whether they have acquired such items only for pesticides application. Only those safety items that are explicitly used in spraying pesticides were annualized with their expected life span while estimating costs.

4.1.3 Willingness to pay

The costs of illness and defensive expenditures are not without limitations (see Table 1). The methods do not include costs of long-term illness, pesticide poisonings and mortality. Also, the methods do not capture individual pain, discomfort and suffering of illness. And contained are the limitations of these two methods for capturing environmental and ecological aspects of pesticide risks. The willingness to pay estimates the amount that an individual is willing to pay for avoiding risks of chemicals. Farmers' WTP for economic evaluation of the health and environmental impacts of pesticide use has been adopted by Wilson (1998), Brethour and Weersink (2001) and Cuyno et al. (2001). However, the WTP is also subject to controversy on the validity and reliability (Venkatachalam 2004) of the results obtained due to potential biases emerged with the different elicitation methods, but this is the only method for valuing environmental goods. There are ways to minimize such biases (Venkatachalam 2004; Whittington 2002) and to check the validity of the results, of which, Wilson (2003) demonstrated that the finding WTP $>$ COI $+$ DE provides a validity check for WTP bids.

4.2 Methods of data collection

Data were collected in three stages: (1) initial household survey May–June 2008, (2) monthly surveys for 6 months June–Nov 2008 and (3) final household survey Nov–Dec 2009. The survey questionnaire was pretested on 25 households nearby the area. We conducted five focus group discussions in between initial and final survey at different locations of the Ansi khola watershed, in which the research team collected information required for the final household survey. For example, alternatives to the pesticides, willingness to pay format and possible payment were discussed. Fifteen to twenty-five local farmers and leaders were invited to participate in the focus group discussions.

4.2.1 Initial household survey

The initial survey questionnaire gathered information on household demography, health care costs and services. Details are documented for pesticide use intensity and frequency by crops and for individual knowledge, attitude and practices on pesticide use. Also, contained were safety measures adopted prior to pesticide application and their constraints.

4.2.2 Monthly household survey

The questionnaire collected pesticide dose, exposure and safety at a monthly interval for 6 months. Also incidences of acute illnesses and associated medical treatment costs and work days lost due to illness were included.

4.2.3 Final household survey

The final survey measured individual willingness to pay. In addition, significant information on individual and farm characteristics, pesticide use intensity and history, and individual perception on pesticides impacts were also collected to complement the willingness to pay instrument.

4.2.4 Sampling procedures and size

The list of stratified households based on different social and economic factors (Dahal et al. 2009) forms the sampling frame for this study. In Ansi khola watershed, a proportional stratified random sampling was used to draw a sample of 403 households, of which 33 households were excluded in the final analysis due to limited data availability. The final sample comprises 370 households for Ansi khola watershed.

For Jhikhu khola watershed, a random sample of 200 households was drawn from the lowland areas of the watershed covering four village development committees (VDC) namely Mithunkot (85 households), Patlekhet (40 households), Kharelthok (36 households) and Kavre (19 households). The main objective of selecting households from this area is to compare the research findings with Ansi khola. Jhikhu khola households were considered reference households because a few past studies (Atreya 2005, 2007a, 2008) claimed notable health and environmental effects in the area due to continuous and indiscriminate use of pesticide for a long period of time. A total of 180 households were used in the final analysis from this watershed. In total, $370 + 180 = 550$ households (Table 2) from the study areas were analyzed. We hypothesized that lowland of the Jhikhu khola watershed

Table 2 Sampling size by watershed and household

Ansi khola watershed				Jhikhu khola watershed	Total
Large-scale	Medium-scale	Small-scale	Sub-total		
133	156	81	370	180	550

would have higher pesticide use frequency and intensity so that consequences would also be greater to these areas compared to Ansi khola watershed.

4.3 Estimating health costs

For this study, probability of falling sick (P_s) and probability of taking defensive action (P_d) were calculated. Monthly surveys data were used for the calculation. The proportions $P = m/N$ estimates the probability that an individual in each group will experience the event, where m measures the number of individuals experiencing events and N measures the total number of observation. The m describes "poisoning events" in estimating P_s and "spraying events with safety measures" in estimating P_d.

These probabilities were adopted while calculating predicted health costs and defensive expenditures from periodic exposure to chemical pesticides.

The predicted health costs (COI) and defensive expenditure (DE) of pesticides exposure are:

$$\mathrm{COI} = P_s * C_i \tag{1}$$

$$\mathrm{DE} = P_d * C_d \tag{2}$$

where C_i is the average annual labor lost and treatment costs and C_d is the average annual costs of defensive gadgets.

For estimating overall costs of pesticide use (TC), we further add two additional costs.

$$\mathrm{TC} = \mathrm{COI} + \mathrm{DE} + O + C_p \tag{3}$$

where O stands for opportunity costs of time lost in spraying, which was calculated multiplying total frequency of applications with hours per application and wage rate, and C_p is the expenditure on chemical pesticides. A constant wage rate of NRs 150 per day (US \$ 1 $\approx$ 70) for both male and female was used. In Nepal, subsidies of chemicals are rare and farmers spray pesticides on their farms. We assume that these costs are also borne by the households themselves.

4.4 Estimating environmental costs

During final household surveys, an open-ended WTP bid for the hypothetical "new pesticides" was administered. It is assumed that the new pesticides are almost similar to the current ones in terms of their market price and their efficacy in pests killing, but the only difference to the existing chemicals are that the new ones are harmless to human and environmental health.

The WTP question was administered at the final survey. By this time, we have had undertaken five focus group discussions, in which the WTP question was developed. Many issues on the WTP formats were raised during discussions, and final WTP instrument was modified accordingly. The final WTP questionnaire adopted household pesticides expenditures as a point of departure for elicitation. Brethour and Weersink (2001) and Garming and Waibel (2009) also estimated WTP to avoid pesticides risks departing from the current bills of pesticides.

We assumed that the WTP bids indirectly assess the costs of pesticide risks on farmers' health and the local environment. Therefore, the values would exceed sum total of cost of illness and defensive expenditure. The authors expect that a person when asked maximum willing to pay for safe pesticides is likely to consider much of the environmental costs incurred in revealing true willingness to pay along with lost productivity, health treatment costs and defensive costs as well as pesticides expenditures.

4.5 Statistical analysis

Independent samples *t* Test for comparing equality of means between watersheds was performed at 95% confidence interval using Predictive Analytics Software (PASW) Statistics 18. The Data Analysis and Statistical Software (STATA/IC 10.1 for Windows) was used for fitting the ordinary least square regressions (OLS) to identify the relationships of explanatory variables to the cost of illness, defensive expenditures and maximum willingness to pay.

4.6 Regression analysis

We constructed three OLS for household COI, DE and WTP with pesticide exposure, individual and household characteristics. We assume linearity because few individuals have zero COI, DE and WTP. The explanation of the independent variables and their expected relationships with the dependent variables are given in Table 3.

The exposures to pesticides were estimated following EPA (1992). Monthly data were used to estimate the exposure to organochlorines (OCL), organophosphates (OP), pyrethroid (PI) and fungicides (FUN). Standard regression analysis assumes that all observations in the sample are independent. If multiple observations on the same individual are not accounted for while analyzing monthly interval data, it leads to an underestimate of the variance and exaggerates the statistical significance of observed health outcomes (Heyse et al. 2006). So computed average values of exposure from the different time intervals for each household are fitted to the final regressions. It is hypothesized that individuals with greater exposure to these chemicals would have higher COI, DE and thus bids higher WTP to reduce pesticide risks to his/her health and environment.

In general, households grow many crops and apply pesticides many times, so the study focuses on only six major vegetables (potato, tomato, cauliflower, chill pepper, cucumber and bitter gourd) and documented pesticide use frequency only to these crops. FREQ refers to the sum total of the numbers of pesticides applications to these vegetables. It is believed that higher frequency leads to greater COI, DE; individuals with higher frequency bid higher WTP.

GENDER is dummy (male = 1; 0 otherwise) used to differentiate males and females. Females are at higher risk of pesticide exposures due to lower level of pesticide use safety and awareness (Atreya 2007b), but gender inequality constrains women's access to health care as they lack access to household resources even their own earnings (Furuta and Salway 2006); therefore, it is hypothesized that females are likely to have higher COI and lower DE and WTP bids. The individuals who worked on the farms for a long period of time may have better self-practices on sound use of pesticides and safety measures; thus, it is assumed that as the age of an individual (AGE) increases, COI decreases and DE increases, and WTP bid increases. CHRONIC, a dummy (if suffered = 1; 0 otherwise)

Table 3 Lists of explanatory variables and expected relationships to the dependant variables in the ordinary least square regressions

Sn	Variables	Explanation	Unit	Expected relationship		
				COI	DE	WTP
1	OCL	Exposure to the organochlorine insecticides	ml/l/h	+	+	+
2	OP	Exposure to the organophosphate insecticides	ml/l/h	+	+	+
3	PI	Exposure to the pyrethroid insecticides	ml/l/h	+	+	+
4	FUN	Exposure to the fungicides	g/l/h	+	+	+
5	FREQ	Total frequency of pesticide application to the five major vegetables.	Number of application	+	+	+
6	GENDER	Gender of the individual	Dummy, male = 1, 0 otherwise	−	+	+
7	AGE	Age of the individual	years	−	+	+
8	CHRONIC	Whether or not the individual suffer from chronic illness	Dummy, if yes = 1, 0 otherwise	+	+	+
9	WATERSHED	Watershed	Dummy, Jhikhu khola = 1, 0 otherwise	+	+	+
10	IPM	Whether or not the household members are IPM trained	Dummy, if yes = 1, 0 otherwise	−	+	+

refers to an individual's present health condition. It reflects whether an individual suffered from illness such as asthma, blood pressures, heart diseases, cancer and diabetes. Individuals suffered from such illness may have potentially higher COI and DE. It is assumed that such individuals have higher COI and DE. Also, these people might bid higher WTP for avoiding pesticide risks to their health and environment.

A dummy WATERSHED represents location, 1 for Jhikhu khola watershed, 0 otherwise. We assumed that use of pesticide will be higher for the Jhuikhu khola. The WATERSHED is therefore, likely to be positive, indicating higher COI, DE and WTP bids for the Jhikhu khola watershed. The integrated pest management (IPM) refers the household having prior IPM training. It is reported that IPM training reduces pesticide use, increases know-how of the safety measures and also increases awareness of the environmental consequences of pesticide use. It is assumed that IPM training reduces COI, increases DE and influences toward higher bids for better health and environment.

5 Results and discussions

5.1 Respondent statistics

The respondent's average age, percentage of males in the sample population and their education between watersheds are similar (Table 4). IPM-trained individuals are limited to the study area. Only 15% of the sampled population in Ansi khola and 8% in Jhikhu khola watersheds are trained in IPM. The finding is consistent with Atreya (2007b) who

Table 4 Respondent statistics by watersheds

Category	Ansi khola	Jhikhu khola
Age (years)	43.9 (15.3)	48.4 (13.8)
Males (%)	62	56
Education (years)	7.3 (2.9)	6.8 (2.7)
IPM training (%)	15	8

Standard deviations are in parenthesis

documented only 9% for the latter watershed. Despite many benefits of IPM (van den Berg and Jiggins 2007), its coverage and adoption in developing countries are minimal.

5.2 Pesticide use

The monthly data set contains 3,385 observations, of which 51% were pesticide spraying events, while the rest were non-spraying. Mixing more than one chemical before an application was common. Individuals were mainly exposed to fungicides, particularly that of mancozeb; thus, the magnitude of pesticide-induced illness and associated health and environmental risks estimated for this study may be incomparable to the other studies where the organochlorines and organophosphate dominate the pesticide use pattern.

Table 5 shows the area under vegetables, frequency of pesticides application, workload during spraying and non-spraying days, and opportunity cost of spraying time—all were found statistically higher in Ansi khola watersheds. The households in Ansi khola watershed, therefore, have higher risk of pesticide exposure because of higher number of pesticides applications and work load. The hypothesis that Jhikhu khola watershed has higher pesticide use intensity and frequency could be rejected. Besides Jhikhu khola watershed, empirical research on pesticide use for other areas of Nepal is hardly available. But we found significant geographical variation in the pesticide.

Table 5 Pesticide use and working hours

Category	Watershed	Mean	SD	*t* Test significance
Total area under vegetables (Ropani[a]/household)	Ansi khola	4.24	2.800	0.011
	Jhikhu khola	3.58	2.601	
Frequency of pesticides application (No/household)	Ansi khola	10.12	8.353	0.017
	Jhikhu khola	8.52	3.483	
Work hours on farm per spraying day (h)	Ansi khola	2.24	1.585	<0.001
	Jhikhu khola	1.40	0.598	
Work hours on farm per non-spraying day (h)	Ansi khola	6.41	0.904	<0.001
	Jhikhu khola	2.45	0.767	
Opportunity costs of spraying time (NRs/household)	Ansi khola	341.46	281.90	0.017
	Jhikhu khola	287.46	117.57	

[a] 1 Ropani equals 508.74 square meters

5.3 Incidence of acute illness

The individual experiences a set of acute illnesses within 48 h of pesticides application was documented in monthly intervals. The proportions estimate the probability that an individual experiences the symptoms. Headache, skin irritation, chest pain, eye irritation and throat discomfort were the major symptoms experienced frequently (Table 6). In general, incidence of acute symptoms was found higher in Ansi khola watershed.

5.4 Average costs, probabilities and predicted health care costs

The average annual individual costs of illness for the sample population are NRs 338 and 212 for Ansi and Jhikhu khola watersheds, respectively, which are found statistically different (Table 7). Similarly, average defensive expenditure is also varies by locations. The individual's likelihood of being sick and taking safety measures are also varied by the watersheds. For Ansi khola, the probability of being sick due to pesticide-induced illness

Table 6 Incidence of acute illness per 1,000 individuals per spraying

Acute illness	Ansi khola	Jhikhu khola
Headache	332	189
Skin irritation/burn	387	48
Chest pain	142	12
Eye irritation	96	42
Throat discomfort	101	30
Weakness	84	22
Hand crack	46	48
Excessive sweating	11	80
Muscle twitching/pain	1	97
Nausea	29	1

Table 7 Annual sample average cost of illness, sample probabilities of being sick and taking safety gadgets, and predicted costs of pesticide use

Category	Watershed	Mean	SD	*t* Test significance
Cost of illness (NRs/individual)	Ansi khola	338.13	422.95	0.004
	Jhikhu khola	212.38	146.19	
Defensive expenditure (NRs/individual)	Ansi khola	530.36	256.52	<0.001
	Jhikhu khola	372.87	145.45	
Probability of being sick (P_s)	Ansi khola	0.58	0.27	<0.001
	Jhikhu khola	0.32	0.18	
Probability of taking safety gadgets (P_d)	Ansi khola	0.51	0.33	0.006
	Jhikhu khola	0.44	0.18	
Predicted cost of illness (NRs/individual)	Ansi khola	476.76	560.36	<0.001
	Jhikhu khola	181.63	167.28	
Predicted defensive expenditure (NRs/individual)	Ansi khola	155.40	245.46	<0.001
	Jhikhu khola	71.06	107.83	

and taking safety measures is estimated to be 0.58 and 0.51, respectively. The average predicted cost of illness and defensive expenditure due to pesticide use were calculated multiplying the sample average costs with respective probabilities. Finally, the predicted individual costs of illness (Eq. 1) and defensive expenditures (Eq. 2) estimated are NRs 477 and 155 for Ansi khola, and NRs 182 and 71 for Jhikhu khola watershed.

The estimated costs of illness and defensive expenditures for the Jhikhu khola watershed are found comparable to that of Atreya (2008). But the study assumed all observations independent in the regressions despite having multiple observations on the same individual. Nevertheless, the values do not deviate much from the present estimates.

But for Ansi khola watershed, the estimated costs are significantly higher. Pesticides exposure variables, for example, area under vegetables, frequency of spraying and workload (see Table 5) are found higher for the Ansi khola, which may have lead to greater incidence of acute illness (see Table 6) and costs of exposure.

5.5 Total costs of pesticides use

To estimate the overall direct and indirect costs of pesticide use and exposure to the study area, we added two additional costs to the above predicted health care costs (Eq. 3): (1) annual expenditure on chemical pesticides and (2) opportunity costs of spraying time. This equaled to NRs 1,906 for Ansi khola and 2,460 for Jhikhu khola watershed per individual per year (Table 8). The expenditure on the pesticides occupies the major portion of the total costs of pesticide use—79% for Jhikhu khola and 53% for the Ansi khola.

WTP estimates also vary by watersheds (Table 8). Higher nominal WTP for Jhikhu khola than Ansi khola is obtained, but if we look at their willingness to increase their pesticide expenditures in terms of percentages, the opposite is true. Individuals in the watersheds are willing to increase their pesticide expenditures by 80% in Ansi khola against 44% in Jhikhu khola if provided with safe pesticides or other sound alternatives. Other studies also demonstrate that the WTP bid increment over pesticide expenditures to avoid pesticides risks range from as low as 28% (Garming and Waibel 2009) to as high as 94% (Atreya 2005).

5.6 The relationships between the three valuation methods

We hypothesized that the WTP bids exceed the total sum of cost of illness, defensive expenditure and other direct expenses. This is because a person affected by pesticide exposures when asked to bid maximum WTP to avoid the exposures would consider all the

Table 8 Annual overall costs of pesticide use and maximum willingness to pay to avoid pesticide exposures

Watersheds	Expenditure on chemical pesticides (NRs)	Total costs of pesticide use (NRs)	Proportion of pesticide expenditure over total costs (%)	Maximum willingness to pay to avoid risks of pesticides exposure (NRs)	% change of WTP bids over pesticide expenditures
Jhikhu khola	1,932.58 (1,341.44)	2,459.96 (1,445.40)	79	2,780.56 (1,814.46)	44
Ansi khola	1,006.11 (1,056.24)	1,905.89 (1,707.44)	53	1,812.79 (1,732.55)	80

Standard deviations are in parenthesis

costs associated with the illness—including costs of illness, defensive expenses as well as intangible costs such as pain, suffering and discomfort along with local environmental problems while bidding for the safe pesticides. We assumed opportunity cost of spraying new pesticides would be similar to that of current pesticides, so individuals may not take account of the opportunity cost while bidding their WTP for new pesticides.

Wilson (2003) established a relationship between three approaches of pesticides pollution valuation and showed that 'WTP > COI + DE' provides a validity check for WTP bids. For this study, we find similar relationship between such variables in both watersheds.

$$\text{Willingness to pay} > \text{pesticides expenditures} + \text{cost of illness} + \text{defensive expenditure}$$

The relationship is unidirectional and consistent as claimed by Wilson (2003). It shows the validity of the stated WTP results in our study.

5.7 Regression analyses

The descriptive statistics of the dependent and explanatory variables are reported in Table 9. The dependent variables include zero value as well. The estimated mean cost of illness, defensive expenditures and maximum willingness to pay are NRs 380, NRs 128 and NRs 2,130 per year, respectively. The highest exposure was found for the fungicides, which are 2.02 grams per liter of water exposed for an hour. Individuals apply pesticides at maximum 60 times with an average mean of eight applications per year. The sample comprised of 60% males. Only 12% individuals have been participated in IPM training.

The regression analyses (Table 10) showed that exposure to the OCL significantly increased costs of illness ($p = 0.003$) at the 1% level and increased defensive expenditure at the 10% level ($p = 0.057$). It relates negatively to the WTP bids (minus coefficient) but is not significant. Exposure to the OP was found positive, indicating greater exposure to the OP increased costs of illness ($p < 0.001$), defensive expenditure ($p < 0.001$) and WTP bids ($p = 0.009$). Similar relationships of PI to COI, DE and WTP are established as expected. Exposure to FUN was found positive, but significantly affecting COI and WTP

Table 9 Descriptive statistics of the dependent and explanatory variables used for the least square regressions

Variables	Mean	SD	Min.	Max.
Dependent variables				
COI	380.17	489.27	0	3,256.25
DE	127.80	214.14	0	1,360
WTP	2,129.51	1,815.92	0	12,000
Explanatory variables				
OCL	0.30	0.67	0	4.14
OP	0.65	1.00	0	7.62
PI	0.33	0.82	0	6.86
FUN	2.02	1.83	0	12.34
FREQ	8.00	7.29	0	60
GENDER	0.60	0.49	0	1
AGE	45.42	14.99	13	92
CHRONIC	0.21	0.41	0	1
WATERSHED	0.33	0.47	0	1
IPM	0.12	0.33	0	1

Table 10 Factors affecting cost of illness, defensive costs and maximum willingness to pay for safe environment

Variables	Cost of illness (COI)				Defensive expenditure (DE)				Max. WTP for "new pesticides"			
	Coefficient	SE	*t* Test	*p* Value	Coefficient	SE	*t* Test	*p* Value	Coefficient	SE	*t* Test	*p* Value
OCL	62.57	20.87	3.00	0.003	22.59	11.82	1.91	0.057	−20.85	116.12	−0.18	0.858
OP	99.88	15.62	6.39	0.000	59.48	8.85	6.72	0.000	228.91	86.94	2.63	0.009
PI	128.64	17.92	7.18	0.000	70.52	10.15	6.95	0.000	294.75	99.72	2.96	0.003
FUN	15.87	7.67	2.07	0.039	6.42	4.34	1.48	0.140	110.66	42.67	2.59	0.010
FREQ	32.59	1.91	17.08	0.000	5.74	1.08	5.31	0.000	43.64	10.62	4.11	0.000
GENDER	53.52	25.48	2.10	0.036	6.31	14.44	0.44	0.662	137.96	141.80	0.97	0.331
AGE	0.15	0.85	0.18	0.859	0.45	0.48	0.94	0.350	1.48	4.71	0.31	0.753
CHRONIC	−27.62	31.61	−0.87	0.383	−8.23	17.91	−0.46	0.646	293.29	175.88	1.67	0.096
WATERSHED	−166.27	29.67	−5.60	0.000	−10.16	16.81	−0.6	0.546	1,317.92	165.08	7.98	0.000
IPM	20.74	39.25	0.53	0.597	60.62	22.24	2.73	0.007	473.01	218.38	2.17	0.031
Constant	−18.71	44.60	−0.42	0.675	−25.58	25.27	−1.01	0.312	620.23	248.17	2.50	0.013
R-squared	0.6582				0.4272				0.2318			
Adj R-squared	0.6519				0.4166				0.2176			
Root MSE	288.67				163.56				1,606.3			
F value	103.81				40.21				16.27			
Prob > *F*	<0.001				<0.001				<0.001			
No. of observation	550				550				550			

bids, but not for DE. The number of times of pesticide application (FREQ) is statistically significant and positive. Higher the frequency higher will be the costs of illness and defensive expenditures. The individuals who spray pesticides frequently were willing to pay more to avoid pesticides risks.

The above relationships in general show that exposure to either organochlorines, or organophosphates, or pyrethroid insecticides and high contact frequency lead to increased costs associated with pesticides-induced illness and defensive expenditures. Individuals bid higher willingness to pay to avoid potential risks of existing harmful pesticides. But exposure to fungicides only increased COI and WTP bids, but not necessarily DE. Either individuals are unaware of the potential risks of the fungicides or they might have underestimated the potential danger of the fungicides. Individuals may account of little risks of fungicides so were reluctant to wear safety gadgets while applying fungicides.

GENDER is positively related and significant only for COI at 5% level of significance. The positive coefficient signals higher COI for males compared to female counterparts because males are responsible for most of the spraying works. Age was supposed to be a proxy of farm experience and was found positive for COI, DE and WTP but is non-significant. Individuals suffering from other illness (CHRONIC) were less likely to have lower COI and DE. But these individuals bid higher for their environment. These individuals may spend less time in pesticide application than others. We found significant location variation in COI and WTP bids but not in DE. As expected, the watershed dummy is negative to COI and DE, but positive to WTP. This implies that households who reside in Jhikhu khola incur less costs of illness and incur similar defensive expenditure as of Ansi khola but show higher willingness to pay for the safe pesticides. Jhikhu khola watershed might have higher environmental impacts due to long history of pesticide use, so individuals were willingness to pay higher for safe pesticides to preserve their environment despite of lower exposure to chemicals.

The IPM training is positive to COI but non-significant. It implies that individuals who are trained in IPM are less likely to have lower costs associated with pesticide exposure compared to non-IPM-trained individuals. But IPM-trained individuals adopt significantly higher safety gadgets ($p = 0.007$) and value higher to avoid pesticide risks of exposure ($p = 0.031$). The use of safety gadgets and increase in defensive expenditure for this study does not necessarily decrease risks of exposure because at first, the use of safety gadgets is minimal and second, same unwashed gadgets are used several times. This is reflected by the finding that IPM training significantly increased spending on safety gadgets but not necessarily reflects its efficacy in reducing COI.

Pest control research that focuses on the ecology of pests and on the agroecosystem as a whole indicates that pesticide use can be reduced substantially without reducing grain yields. Peshin et al. (2009) documented that Sweden reduced pesticide use by 68% and public health poisonings by 77%. The reduction in pesticide use did not result in increased crop losses. Similarly, Indonesia reduced pesticide use by 65% and increased rice yields by 12%. In India, the pesticide use reduced by nearly 50% from 1990/1991 to 2006/2007. However, we found increasing consumption of chemical pesticides for Nepal. National pesticide reduction efforts without sacrificing grain yields are warranted. The community IPM, although limited in the study area (<15%), was found to reduce pesticide use, health and environmental degradation in other parts of the World. It is reported that the extent of pesticide overuse differs between farmers trained on IPM and untrained. In Nepal, an estimate shows that farmers with IPM use 2.7 times more than optimal dose as compared to 4.4 times that of control (Jha and Regmi 2009). The present study also showed that IPM trainings significantly increased safety measures and make farmers aware of the environmental impacts of pesticide use, but may not necessarily reduced health costs. This suggests a need for reviewing the IPM program from health perspective. The adoption of community IPM as an alternative to chemical control, along with educating people on the health and environmental consequences of the chemical use, is the possible options to minimize pesticide use. Regular training and environmental awareness activities emphasizing consequences of pesticide use and its proper management through community IPM could reduce pesticide use without reducing yields.

The costs of health and environmental impacts due to pesticide use estimated for this study could be an indicator of the hazard pesticide pose to the local area. The estimated costs of pesticide risks cannot be simply averaged over Nepal because the magnitude of costs depend on the specific type of risk, and the nature of the risk scenario considered as well as people's subjective perception of risks (Travisi et al. 2006). The WTP estimates also vary with survey design, type of safety device and chosen payment vehicle (Florax et al. 2005). This is the costs imposed to the vegetable producers in the hills of Nepal and those costs may differ from consumer sides as well as other regions of Nepal. We believe that ascribing values to human and environmental health is difficult and subject to ethical problems as the true costs of these impacts may not be quantified in a single monetary unit because of the complex nature of the pesticide impacts, but we assume that the estimated value would be at lower end of an individual costs of pesticide pollution at local levels in the analysis of agricultural sustainability. These costs should be incorporated in the analysis of agricultural returns. Further, the methodology of combining different measures—observed cost of illness, willingness to pay derived from mitigation behavior and stated willingness to pay—leads to consolidated and reasonable results, which indeed would be interesting for scientists and practitioners in the field of pesticide reduction, IPM and public health in rural areas.

6 Conclusion and recommendations

The study shows considerable health and environmental costs of pesticide use in vegetable farming. Nepal's vegetable farmers are willing to pay between 53 and 79% higher prices of the existing pesticide bills to protect own and environmental health. The study finds that exposures to the chemicals and contact frequency are significant determinants of these costs. IPM training leads to higher investment of farmers in safe use of pesticides but not to reduction in health costs; thus, reviewing the IPM programs from health perspectives can be recommended. Further study covering wide agroecological regions before designing national-level programs and policies on the pesticides for Nepal is recommended.

Acknowledgments The comments and suggestions from the anonymous reviewers are appreciated. The authors acknowledge The Norwegian Program for Development, Research and Education (NUFU) for the financial support (Research Grant No. NUFUPRO 2007/10109).

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Paper IV

Atreya K, Sitaula BK, Bajracharya RM. 2012. Distribution of costs of pesticide use by household economy. Manuscript.

Distribution of Costs of Pesticide Use by Household Economy

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Abstract

Literature shows skewed distribution across household of benefits of intensive farming. The intensive farming likely to demand higher use of chemical pesticides; however, the economic cost or harms of pesticide use between household economies is poorly studied. Thus, a study was conducted in the Ansi khola watershed of Kavrepalanchowk District of central Nepal. The primary aim of the study was to estimate total costs of pesticide use by household category. We grouped household into 'large-scale' who owns more than 1 ha of agricultural land, 'small-scale' having less than 0.5 ha and 'medium-scale' in between >0.5 and < 1 ha. The study adopted cost-of-illness and defensive expenditure approach to estimate health cost, and to this, an opportunity cost of spraying time and current expenses on chemical pesticides were added to calculate total costs of pesticide use. The study revealed that the health cost of pesticide-induced illness and the total cost of its use are distributed unevenly between households. These costs are likely to be lowest for small-scale households; however, in proportion to household cash incomes, small-scale households are likely to incur the highest proportion. Overall, the cost of pesticide use amounted 15% of agricultural cash income, and/or 5% of household total cash income. For small-scale households, the cost was equivalent to 18% of agricultural cash income and 6% of total cash income. Similarly, on average the health costs of illness associated with pesticide use was equivalent to nearly 5% of agricultural cash income that was found higher for small-scale households (5.7%) than the large-scale (3.6%).

Keywords: pesticide use, agricultural intensification, household category, cost-of-illness, Nepal.

1. Introduction

The pesticide application rate per hectare of arable land for Nepal is 151.2 g active ingredient (ai) (Atreya and Sitaula 2010), which is considered minimal compared to the other countries like India (0.5 kg/ha), Korea (6.6 kg/ha) and Japan (12 kg/ha) (Gupta 2004). Minimum use, however, does not necessarily entail minimal risk to human health, particularly with respect to increased pesticide use for vegetable crops in the urban and peri-urban areas due to a high demand of fresh vegetables by city dwellers in Nepal. In an area, close to Kathmandu, pesticide use was estimated to be 2.6 kg ai/ha, which is nearly four times higher than the optimal for vegetables (Jha and Regmi 2009). This is because, for many farmers, vegetable production is an important source of farm income (Brown and Shrestha 2000, Brown and Kennnedy 2005, Tiwari et al. 2008, Dahal et al. 2009). However, studies examining pesticide use in Nepal (Atreya 2007) highlighted poor knowledge of farmers regarding pesticide handling and applications. The indiscriminate use of pesticides and poor knowledge on its safe applications may increase health cost. Human exposure to pesticides results in loss of productivity, wages and increased medical expenses (Rola and Pingali 1993, Antle et al. 1998, Wilson 1998, Cole et al. 2000, Maumbe and Swinton 2003, Devi 2007, Atreya 2008, Atreya et al. 2012a). Also cost of protective clothing, gloves, etc., pose additional defensive expenses to the total economic cost of pesticide use.

On the one hand, evidences of strong linkage between intensive farming, pesticide use and human health effects are emerging (Wilson 2000, Hawkes and Ruel 2006), while on the other, studies on occupational health due to environmental pollution remain lacking in developing countries (Nuwayhid 2004). For Nepal, Poudel et al. (2005) cited only seven scientific studies relevant to occupational health from 1966 to 2004; however, none of which addressed the use of pesticides and economic impacts on households. Similarly, Joshi et al. (2011) reported only 15 studies of Nepal’s occupational health and safety from 2003 to 2011 and concluded that the status of occupational safety and health for Nepal was unsatisfactory. This indicates that, at first the scientific studies on pesticide use and farmers' health in Nepal are limited; and second, that valuations of the impacts of pesticide use on human health are minimum. Estimating health costs of pesticide use may not only entail the degree of toxicity risk but also the cost that households incur, such as, medical receipts and other costs (e.g. defensive expenditure, working days lost etc.) arising from dealing with the problem of pesticide use. These costs are important for effective allocation of resources and to formulate rules and regulation. Further, these costs have been occasionally omitted from the analysis of agricultural returns, particularly studies focusing on benefit- costs analysis.

To date, few studies (Rola and Pingali 1993, Antle et al. 1998, Wilson 1998, Cole et al. 2000, Maumbe and Swinton 2003, Devi 2007, Atreya 2008, Atreya et al. 2012a) have estimated health costs of pesticide use. However, these studies lack cost distribution by household economy. It is evident that market driven intensive agriculture (particularly vegetable production) is an important household strategy uplifting economic conditions of rural farmers, but creates uneven distribution of benefits across households (Brown and Kennedy 2005, Tiwari et al. 2008, Dahal et al. 2009, Nepal and Thapa 2009, Raut et al. 2011). Landholding size is an important factor affecting adoption of intensive agriculture in Nepal. It is likely that large landholding households can purchase farm implements to reduce the costs of production and thereby increase incomes through intensive agriculture (Nepal and Thapa 2009). Raut et al. (2011) showed that households with large landholdings tend to shift from traditional agriculture to intensive farming, because farmers with large landholding size tend to bear more risk of crop failure, and afford expenditure on farm inputs; so these households are more willing to adopt intensive agriculture for increased income through sale of vegetables as compared to small-scale farmers. Brown and Kennedy (2005) reported inability of small-scale farmers to take advantage of market opportunities despite their desire for vegetable production and thus remain deprived from maximum benefits of intensive agriculture. However, Tiwari et al. (2008) mentioned improved socio-economic conditions of 'poor' farmers in the rural Nepal because of vegetable production. It is likely that large farms may hold most of the benefits of agriculture intensification. In summary, on the one side we find literature observing the benefits of intensive agriculture; and observed skewed distributions of benefits across households – most likely to be higher for large-scale households.

On the other side, distributions of the economic costs of negative effects or harms on farmers' health due to pesticide use and exposure across household economy are seldom studied. For Nepal and elsewhere, studies on costs of pesticide use and exposure are emerging; however the health cost of pesticide exposure and other associated costs of pesticide use by household economy are seldom studied. It is likely that use of chemical pesticides in the intensive farming system may affect human health that could lead to an increase in health cost, which combined with other economic costs of pesticide use may lead 'poor' farmers more vulnerable to pesticide use. These farmers have little capacity to appreciate as well as assess risks and hazards associated with pesticides. Moreover, they also often apply pesticides without adequate protection (FAO 2011). For example, pesticide use, its use intensity, and indirect cost due to pesticide related illness might differ between large- and small-scale households. The present study thus values risk of pesticide exposure as health costs, and finds out the total economic costs of pesticide use by household economy. The main objective was to look at the risk of pesticide use and to estimate total cost of pesticide use in vegetable production by household category in order to determine who incur more economic costs from pesticide use, whether large- or small-scale households.

2. Household classification

As the primary focus of the study was to investigate between the potential relationships of costs associated with pesticide use to household category, we adopted agricultural landholding size to differentiate 'large-scale', 'medium-scale' and 'small-scale' households. We grouped households into 'large-scale' as those owning more than 20 Ropani (≈1 ha) (1 Ropani = 508.74m^2) of agricultural land, and 'small-scale' as those having less than 10 Ropani (0.5 ha), while 'medium-scale' was those owning between (>0.5 and < 1 ha). This is because, while ranking according to wealth, farmers in the study area considered agricultural landholding size as the most important criterion, and demarcated <0.5 ha, 0.5 – 1ha, and >1 ha of agricultural land to differentiate themselves into small-, medium- and large-scale farmers, respectively (see Dahal et al. 2009). The present classification does not consider other criteria listed in Dahal et al. (2009). It is assumed that pesticide use and its associated costs to the households may vary according to agricultural landholding size.

3. The study area

The study was conducted in Ansi khola watershed of Kavrepalanchowk District of Central mid-hills, Nepal (Figure 1). The Ansi watershed, covering about 13 km^2, has a dramatic elevation variation from about 800 m at the stream bank near the mouth of the watershed to nearly 2000 m at the upper ridge. The watershed lies between N 27° 41’-44’ latitude and E 85° 31’-37’ longitude. The rural communities of the watershed are primarily engaged in agriculture. The lower reaches have fertile soils, which support four crops (two of rice) year-round with some vegetable inter-cropping or mixed cropping. The intensified agriculture especially in the lower areas of the watershed has, over the past years, increasingly relied on chemical fertilizers and pesticides, particularly for vegetable crops such as potato, tomato, chili, cauliflower, bitter gourd and cucumber. The frequency of pesticides applications was five per crop season but maximum applications may reach up to 60 in a particular year (Atreya et al. 2012b). Farmers rarely use any special safety measures while handling and applying pesticides. The study area is representative to central mid-hills of Nepal. Introducing vegetables in the annual cropping pattern intensify the croplands in central mid-hills, which are linked by paved road and have access to the markets. Such areas are changing from rice-wheat farming system to rice-vegetable system. The present study area is linked to urban and semi-urban areas by highway, such as the capital Kathmandu, and other cities en route.

4. Methodology

The methodology follows (i) household sampling, sample size and survey methods, (ii) estimation of economic costs of pesticide use, and (iii) blood sampling and analysis.

4.1. Household sampling, sample size and survey methods

The list of stratified households based on different social and economic factors (Dahal et al. 2009) forms the sampling frame for this study. Applications of proportionate random sampling resulted in a sample size of 403 households. Data were collected in three stages: (i) an initial household survey undertaken during May - June 2008, (ii) monthly visit surveys accomplished during June - Nov 2008, and (iii) a final household survey conducted during Nov - Dec 2009. Additional details are described in Atreya et al. (2012a).

4.2. Estimation of economic costs of pesticide use

This study applied cost-of-illness (COI) and defensive expenditure (DE) approach to value health cost of exposure to pesticide use. To this, we added (i) an opportunity cost (O) of time lost in pesticides applications and (ii) current expenditures on chemical pesticides (C_p) for calculating total cost of pesticide use.

Cost-of-illness (COI) is defined as lost productivity due to sickness plus the costs of medical treatment resulting from sickness (Freeman 1993). For this study "health effect" or "being sick" were defined as the incidence of any one or more than one short-term acute health symptoms out of a set of fifteen symptoms during or within 48 hours of pesticide application. The cost of illness approach for this study has considered only acute health effects such as headache, burn, irritation, respiratory discomfort, etc. appeared from the short-term exposure to the chemical pesticides. Whether or not an individual felt such symptoms at monthly intervals constituted the health effect and the cost of illness was strictly restricted to the treatment of these symptoms. The COI was estimated adding up (i) the days lost (d) due through pesticide-induced sickness and (ii) the costs of medical care treatment (ME) such as consultation fee, medication cost, travel cost to and from health care facilities, and dietary expenses resulting from such symptoms.

Defensive expenditures (DE) included the costs associated with safety measures taken to reduce direct exposure to pesticides. It was the annual amount spent on purchasing mask, handkerchief, long-sleeved shirts/pants, and sprayer.

The opportunity cost of time lost in pesticides applications (O) was estimated multiplying total numbers of applications with hours per application and wage rate of Nepalese Rupee (NPR) 150 per day (USD 1≈NPR 70). And pesticides expenditure (C_p) was the amount spent by the household purchasing chemical pesticides in a year.

We use sample COI and DE for estimating predicted COI (P_{coi}) and DE (P_{de}) for the population. For this, we multiplied *COI* with the probability of being sick (P_s), and *DE* with the probability of taking defensive measures (P_d). Here, P_s is the probability of being sick due through pesticide-induced illnesses and P_d is the probability of taking defensive measures at the time of applications to avoid direct exposure – both calculated using monthly surveys data – were estimated as $P = m/N$, where m measures the number of individuals experiencing events ('health effects' in the case of P_s, and 'spraying events with safety measures' in the case of P_d) and N measures total number of observation. Alternatively, P_s gives probable incidence rate of any acute symptoms of the fifteen listed when an individual applies pesticides. Similarly, P_d

alternatively gives the probable adoption rate of defensive measures (such as mask, handkerchief, long-sleeved shirt/pants, boots, etc.) when an individual applies pesticides.

We summed predicted cost-of-illness (P_{coi}) and defensive expenses (P_{de}) to estimate health costs (HC) of pesticide-induced acute illness. Also we added opportunity costs of spraying time, and annual expenditure on chemical pesticides to calculate total costs (TC) of pesticide use. Additional details on the valuation methods, and costs estimations are described in Atreya et al. (2012a).

The estimated total cost of pesticide use unless describe in any perspective has little implications; therefore, we further estimated share of the health (HC) and total cost (TC) of pesticide use to household's agricultural and total cash incomes. This is because, use of hired labor for pesticides applications in the field was not observed and there was no government subsidy for chemical pesticides. Therefore, farmers themselves incur these costs when they decide to use pesticides on their farms.

Here, the agricultural cash income denotes the annual cash received from selling agricultural produce such as vegetables, fruits and cereals crops; and total cash incomes represents the annual cash received from selling agricultural produce (vegetables, fruits, and cereals), livestock products (milk and milk products, meat, eggs, etc.) as well as off-farm cash incomes such as salaries, wages, remittance, and small business if any. The cash incomes do not include home consumption of the food and other stuff produced on the farm.

4.3. Blood sampling and analysis

Blood sampling was carried out in the lowland area of the watershed. Blood was sampled and analyzed twice during 2009: (i) before pesticide application season (March) and (ii) after pesticide application season (December). For the before-season samples, a total of 127 individuals participated. For the after-season samples, individuals who participated in the initial blood analysis were invited. There were 90 individuals in the second reading. Blood was analyzed using Test-mate ChE Cholinesterase Test System (Model 400) with the AChE Erythrocyte Cholinesterase Assay Kit (Model 460) (EQM Research Inc., Cincinnati, OH) (EQM

Research Inc. 2003). Additional details on the sample analyses are described in Atreya et al. (2012b).

5. Statistical analysis

Thirty-three households were excluded in the statistical analysis due to insufficient data. One – Way Analysis of Variance (ANOVA) was used to compare means from at least three groups from one. The null hypothesis was that all the household group means were equal, and alternatively at least one of the household means differs from the others. When we observed overall mean differences between households, we performed Games-Howell *post-hoc* test (because of the unequal sample size of the household category) to determine differences in households.

6. Results

6.1. Costs of pesticide use

Table 1 shows overall risk of exposure in terms of probabilities of taking safety measures while spraying pesticides and probabilities of being sick due to pesticides application. The mean differences of the P_d and P_s were significant at the 1% level of significance. The P_d was the highest for large-scale farmers (0.61), which was almost equal for medium-scale farmers (0.57); however, it was the lowest for small-scale farmers (0.43). On average, when an individual applies pesticides, the chances that individual adopts at least one safety measures was 51%. Similarly, P_s was 0.53 for small-scale farmers, and 0.64 for both medium- and large-scale farmers.

For this sample population, pesticides user from each household category lost two working days. The *DE* and *ME* were statistically non significant. The *DE* ranged from NPR 509 for large-scale farmers to NPR 540 for small-scale farmers (Table 2).

However, the P_{de} and P_{coi} differed significantly (at the 1% level of significance) between households (Table 3). Also *HC* differed significantly at the 5% significance level. The small-scale farmers were likely to spend the lowest amount on safety measures, whereas large- and medium-scale farmers spent equal P_{de} but significantly higher than small-scale farmers. Also,

P_{coi} was the highest for medium-scale farmers and large-scale, and the lowest for small-scale farmers. When we summed up P_{de} and P_{coi}, the health costs of pesticide-induced illness was the lowest for small-scale farmers.

The opportunity cost of time lost in pesticides applications (O), and the amount spent on chemical pesticides (C_p) were statistically different between households at the 5% and 1% significance levels respectively (Table 4). Small-scale farmers relatively spent less time on spraying pesticides whereas medium-and large-scale farmers incurred almost similar opportunity costs and C_p. The mean difference of the total cost of pesticide use (TC) between households was significant at the 1% level. It was the highest (NPR 2440) for medium-scale farmers, slightly less for the large- (NPR 2170) and significantly less for small-scale farmers (NPR 1483).

The Table 5 shows the share of health costs and the share of total costs of pesticide use to household cash incomes. The health cost of pesticides exposure (associated with acute health effects) in proportion to household agricultural cash income was significantly different at the 5% level. The health cost for small-scale household was equivalent to 5.7% of the agricultural cash incomes. The health costs in proportion to household agricultural cash incomes for medium and large-scale household were almost similar. On average, in general, a farmer incurred 4.8% of the agricultural cash income as an additional cost of pesticides associated illness at the particular year of study.

The total cost of pesticide use in proportion to household cash incomes (both agriculture and total) was observed statistically different between households only at the 10% significance level (Table 5). On average, this amounted 15% of household agricultural cash income, and, or 5% of household total cash income. For the small-scale farmers, the total cost was equivalent to nearly 18% of agricultural cash income and 6% of total cash income that was likely to be higher than the large-scale farmers

6.2. AchE analysis

We monitored farmers' blood for erythrocyte acetylcholinesterase activity before and after pesticide application season. There was a significant reduction in the erythrocyte acetylcholinesterase depression across agricultural seasons (Atreya et al. 2012b). The reduced activity of acetylcholinesterase across season indicated exposure to the pesticides, especially organophosphates and carbamates. Jintana et al. (2009), Ntow et al. (2009) and Quandt et al. (2010) also showed reduced AChE activity due to pesticide use in agriculture. When we analyzed activity of acetylcholinesterase across households' land size, the depressions was statistically non-significant (data not shown here). It indicates that landholding size, at least for this study, has no effects on acetylcholinesterase activity.

7. Discussions

A greater probability of sickness through pesticide exposure for medium- and large-scale farmers, despite having greater safety measures compared to small-scale farmers, was observed. For this study, we can argue that adoption of safety measure may not necessarily reduce sickness. This suggests either the safety measures were ineffective in reducing the health effects of exposure or that large- and medium-scale farmers may have applied greater amounts and more concentrated chemicals. Figure 2 shows statistically no differences between households in the applications of chemical pesticides such as organochlorines and organophosphates; however, medium- and large-scale households have applied higher concentrations of pyrethroid insecticides and fungicides. A previous study (Atreya et al. 2012b) observed that use of either pyrethroids insecticides or fungicides was significantly correlated with acute illness. So the higher probability of illness for the medium- and large-scale households was likely due to the concentrated use of pyrethoids insecticides and fungicides.

It was also observed in the field that adoption of safety measures was minimal and same unwashed items were repeatedly used for pesticides application. Table 1 shows that on average an individual use at least one safety measure only 51 times out of 100 pesticide applications. This is low by any standard and could be a reason for higher sickness despite having relatively higher safety measures for medium- and large-scale households. However, it is noteworthy to mention here that adoption of safety measures could be affected by other individual, social and economic conditions. Nonetheless, it is indeed paramount to inform and educate farmers on the potential risk of pesticide use and how adoption of safety measures can minimize the health risk. The minimum levels of safety measure at the time of pesticide application are consistence with other studies conducted in developing countries (Kishi et al. 1995, Sivayoganathan et al. 1995, van der Hoek et al. 1998, Wilson 1998, Gomes et al. 1999, Murphy et al. 1999, Yassin et al. 2002, Matthews et al. 2003, Salameh et al. 2004, Damalas et al. 2006, Recena et al. 2006, Devi 2009). Low level of education, limited awareness, hot environment, low-income levels, unaffordable price, and discomfort; all of which could lead to the minimal use of safety measures by those engaged in subsistence agriculture. For this study, many farmers believed that wearing mask made breathing difficult, and wearing boots caused discomfort while walking, and wearing goggles was thought as fashionable. Farmer gave greater individual preference to comfort and fashion, hence were ignorant of the health hazards of pesticides. Also their perception on the illness simply as a part of daily "farm life" might have led to lower adoption of safety measures. And fungicide, especially mancozeb was widely used, which is less toxic compared to other pesticides used in the study area. The dominant use of mancozeb could be another reason for low adoption of safety measures in the area.

Because of the above reasons, the predicted amount spent on safety measures in a year for a sample household was a mere NPR 155 (USD 2.2). The small-scale farmers spent very minimum on safety measures (USD 1.5), which was nearly cent percent higher for other households (Table 3). The cost associated with pesticide induced acute symptoms (cost-of-illness) as well as total health cost was also lowest for small-scale farmers compared to other households. The health cost is increased when an individual exposed to the chemicals and apply pesticides more frequently (Dung and Dung 1999, Ajayi 2000, Atreya et al. 2012a) and apply highly toxic and concentrated doses (Maumbe and Swinton 2003). For this study, it seems that small-scale households may have applied pesticides less frequently (indicated by the lower opportunity cost, see Table 4) at the minimal concentrations (see Figure 2), which might have resulted lowest cost associated with pesticide-induced illness. The health cost of pesticide exposure (sum of P_{de} and P_{coi}) was also resulted lowest for small-scale farmers. However, it should be noted here that, short-term acute illnesses associated with pesticide exposure might not necessarily always result economic costs. This is because, at first, these symptoms may disappear over a few day, and second, many farmers accept these acute symptoms as a part of their 'farm life'. Also individual perception on the seriousness of the acute symptoms (Ajayi 2000) may affect costs. Similarly, when we added opportunity costs of pesticide application time, and annual amount spent on chemical pesticides, the total cost of pesticide use was also lowest for small-scale household. For this study, small-scale households incurred the lowest cost of pesticide use compared to medium- and large-scale household.

It is unlikely that small-scale households would invest cash for capital intensive vegetable farming, bear risks of yield and price variability, and take advantage of market opportunity (Brown and Kennedy 2005); therefore, they are willing to produce vegetables using minimal applications of pesticides for their subsistence livelihood. On the other hand, large-scale households may have the capacity to invest, bear the risks and take advantage of market opportunities, but they may be reluctant to allocate more land under commercial vegetable production. The area under vegetable cultivation was slightly higher for large-scale households (5.5 Ropani) compared to medium (4.9 Ropani) and small-scale (3.2 Ropani) households. The high demand of labor for vegetable production compared to cereals, higher opportunity costs, and off-farm incomes may be important factors limiting large-scale households for allocating land under vegetable production. According to Dahal et al. (2009), at least one family member of the large-scale household worked either in government services or as a schoolteacher or did local business, and they sold relatively more staple crops like rice, wheat and maize. The medium-scale households were found to be producing a combination of subsistence and commercial crops, which, while likely to reduce production risks, may lead to higher exposure to pesticides (eg. relatively higher opportunity cost of application and higher pesticides expenses), and consequently resulted in higher economic cost of pesticide use.

Small-scale household incurred less cost associated with acute health symptoms and its usage; however, the health cost of pesticide exposure as well as the total cost of pesticide use made up a higher proportion of annual cash income for them. The health cost of acute symptoms when compared in proportion to the annual agricultural cash income, it was likely to be higher (5.7%) for small-scale households than other category. Similarly, when comparing total cost in proportion to the household agricultural/total cash incomes, the share of overall cost of pesticide use was observed to be higher for the small-scale household (significant at the 90% confidence interval). Although it is somewhat weakly significant, we have number of reasons to believe that the small-scale household will be more impacted by the pesticide associated costs. First, small-scale households have fewer windows of opportunities due to small size of landholdings.

Second, they presumably have less coping mechanisms due to lower income diversities; and third, they have less possibility to use incomes for safety measures. Greater insights will be required by rigorous study in the future, however. From the literature (Brown and Kennedy 2005, Tiwari et al. 2008, Dahal et al. 2009, Nepal and Thapa 2009) we observed an uneven distribution of benefits of intensive agriculture in Nepal, and the benefits is likely to be higher for large-scale households. The present study also observed an uneven distribution of the cost associated with pesticide use in an intensive farming system. The cost of pesticide use was likely to be lowest for small-scale households; however, their proportions to household incomes say otherwise. Therefore, further detail investigation considering both pesticide pollution costs and income opportunity of intensive farming systems can be recommended.

Some limitations of this study should be noted, such as the assumption that only one member applies pesticides in a given household, which may not always be the case. Also, sickness may not necessarily result in costs, because farmers treat many symptoms as being unrelated to pesticide use and view them simply as a part of agricultural life. Even more important is the fact that pesticides do not only cause short-run health effects, but can also result in long-term chronic diseases, domestic animal deaths, environmental damage, insect resistance to pesticides, water pollution, etc. (Pimentel 2005). Also, uses of pesticide not only increase economic costs of pollution, but also may decrease agricultural production losses and increase household incomes (Brown and Kennedy 2005, Tiwari et al. 2008, Dahal et al. 2009). It is indeed paramount for more rigorous and detailed study taking account of both negative and positive aspects of pesticide use in the intensive agriculture. The costs of pesticide use estimated here, however, can be a conservative estimate and could be consider as a lower bound of the pollution cost in the benefit-cost analysis of any pesticide reduction programs.

This study, however, offers some valuable insights into the economics of pesticide use that could benefit policy-makers and conservation works. Studies on health cost of pesticide use in the intensive agriculture by household land size are limited, though a few dealt on benefits of intensification. Taking pesticide use as a feature of intensive agriculture, this is the first study of its kind in Nepal to focus on the distribution of negative effects of pesticide use across households. Knowing the share of the cost of pesticide use by household economy is of greatest importance to focus specific policy instrument. Also, many past studies that estimated health costs of pesticide use were based on either six months or one year of recall period. A longer recall period may distort assessment of costs. This paper adopted monthly interviews for estimating sickness. In addition, health costs of pesticide use estimated above are seldom included in the benefit-cost scenario of the agriculture intensification in the policy analysis decisions because of either data unavailability or methodological difficulties. Only input costs such as labor, land, fertilizers, and pesticides are accounted. But the total cost of pesticide use and exposure should take account of health costs of exposure as well as environmental costs of pesticide pollution plus other intangible costs if available. Otherwise the cost will be underestimated, which may lead farmers for sub-optimal decision-making (Ajayi 2000) on applying chemicals thinking minimal costs of use. This could be a reason why human health issues arising from pesticide use are given little attention in household decisions, which may further accelerate the use of pesticides on their farms.

8. Conclusions and recommendations

The study observed an uneven distribution between household of health and economic costs of pesticide use in an intensive farming system. Most likely the small-scale household incurred the lowest costs; however, their share in proportion to household cash incomes was found opposite. The cost in proportion to household cash incomes was likely to be higher for small-scale farmers. It is likely that much of the benefits of intensive farming favor large-scale households; however, its negative impacts (in terms of pesticides induced economic costs in proportion to household cash incomes) likely to be higher for small-scale households. This may result in household income inequality; however, we recommend more rigorous and detailed social benefit-cost analysis to verify this finding and to understand the issue better.

Acknowledgement

The financial support from the Norwegian Program for Development, Research and Education (Research Grant # NUFUPRO 2007/10109) to accomplish this study is highly appreciated.

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Table 1. Probability of taking safety measures and being sick grouped by household category (mean ± standard deviation)		
Household category by land size	Probability of taking safety measures (P_d)***	Probability of being sick (P_s)***
Small-scale	0.43[a] (0.32)	0.53[a] (0.26)
Medium-scale	0.57[b] (0.32)	0.64[b] (0.27)
Large-scale	0.61[b] (0.35)	0.64[b] (0.29)
Total	0.51 (0.33)	0.58 (0.27)
*** indicates mean differences significant at the 0.01 level. The means with the same letter are not significantly different from each other.		

Table 2. Sample average days lost, medical expenses, and defensive expenditure grouped by household category (mean ± standard deviation)			
Household category by land size	Days lost (d)	Medical expenditure (ME)	Defensive expenditure (DE)
Small-scale	2.2 (2.2)	367.5 (611.3)	540.2 (281.5)
Medium-scale	1.8 (1.0)	152.3 (103.1)	531.9 (268.5)
Large-scale	1.7 (0.8)	137.2 (146.5)	509.4 (176.9)
Total	2.0 (1.7)	191.8 (379.5)	530.4 (256.5)

Table 3. Predicted defensive expenditures and cost of illness grouped by household category (mean ± standard deviation)			
Household category by land size	Predicted defensive expenditure (P_{de})***	Predicted cost of illness (P_{coi})***	Health cost (HC)**
Small-scale	103.7[a] (222.2)	358.6[a] (513.7)	632.0[a] (769.7)
Medium-scale	208.6[b] (263.5)	617.0[b] (630.2)	915.7[b] (863.0)
Large-scale	212.8[b] (246.2)	568.7[b] (466.4)	855.2[b] (664.4)
Total	155.4 (245.5)	476.8 (560.4)	774.5 (797.1)
, and * indicate mean differences significant at the 0.05 and 0.01 levels respectively. The means with the same letter are not significantly different from each other.			

Table 4. Distribution of opportunity cost, current expenses on chemical pesticides, and overall total costs of pesticide use by household category (mean ± standard deviation)

Household category by land size	Opportunity cost of spraying time (O)**	Rupees spent on pesticides (C_p)***	Total costs of pesticide use (TC)***
Small-scale	299.7^{a} (190.1)	821.4^{a} (941.4)	1482.5^{a} (1473.7)
Medium-scale	398.5^{b} (382.1)	1258.2^{b} (1254.3)	2439.8^{b} (2011.4)
Large-scale	324.0^{b} (196.8)	1080.9^{b} (829.7)	2169.7^{b} (1343.4)
Total	341.5 (281.9)	1006.1 (1056.2)	1905.9 (1707.4)

, and * indicate mean differences significant at the 0.05 and 0.01 levels respectively. The means with the same letter are not significantly different from each other.

Table 5. Share of the health costs of exposure and total costs of pesticide use to household cash incomes for household category

Household category	Percentage share of *health costs of exposure* (HC) to household cash incomes (%)		Percentage share of total *costs of pesticide use* (TC) to household cash incomes (%)	
	Agricultural cash income**	Total cash income	Agricultural cash income*	Total cash income*
Small scale	5.7^{a}	1.7	17.7^{a}	5.7^{a}
Medium Scale	4.4^{ab}	1.6	14.2^{ab}	4.7^{a}
Large Scale	3.6^{b}	1.2	10.6^{b}	3.2^{b}
Total	4.8	1.6	15.0	5.0

*, and ** indicate mean differences significant at the 0.1 and 0.05 levels respectively. The means with the same letter are not significantly different from each other.

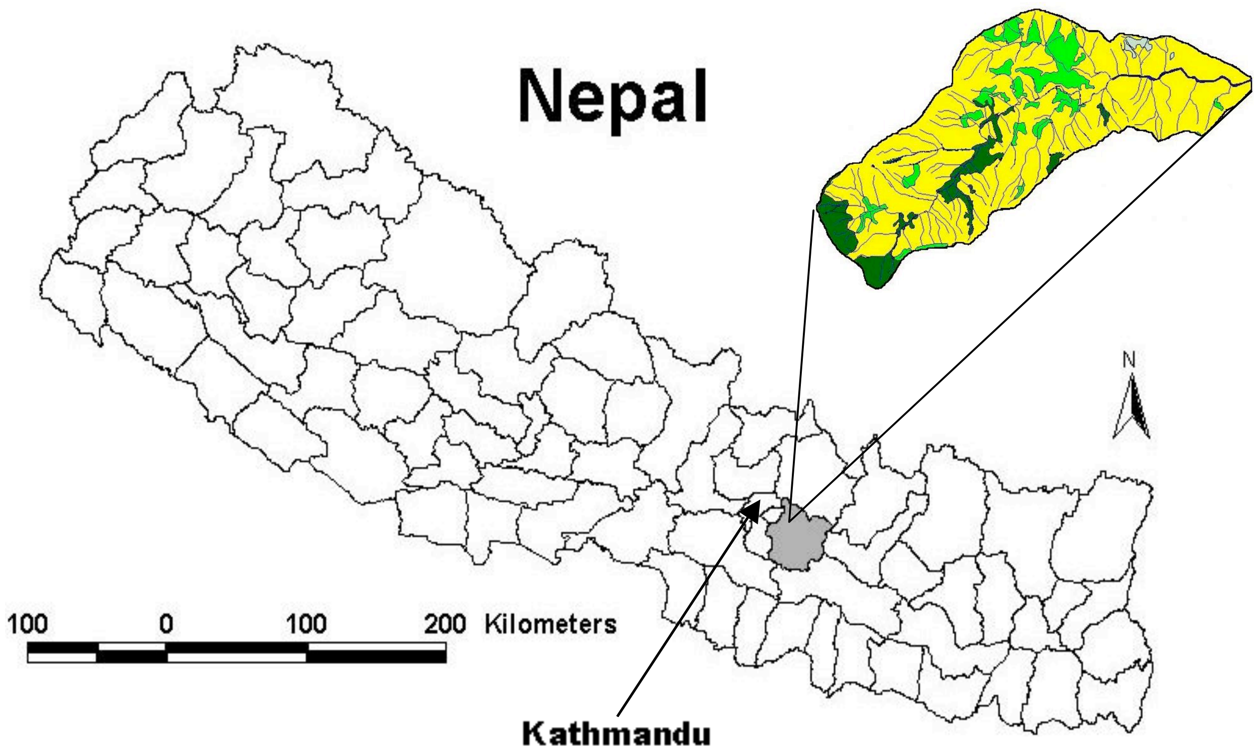

Figure 1. Location of the Ansi khola watershed.

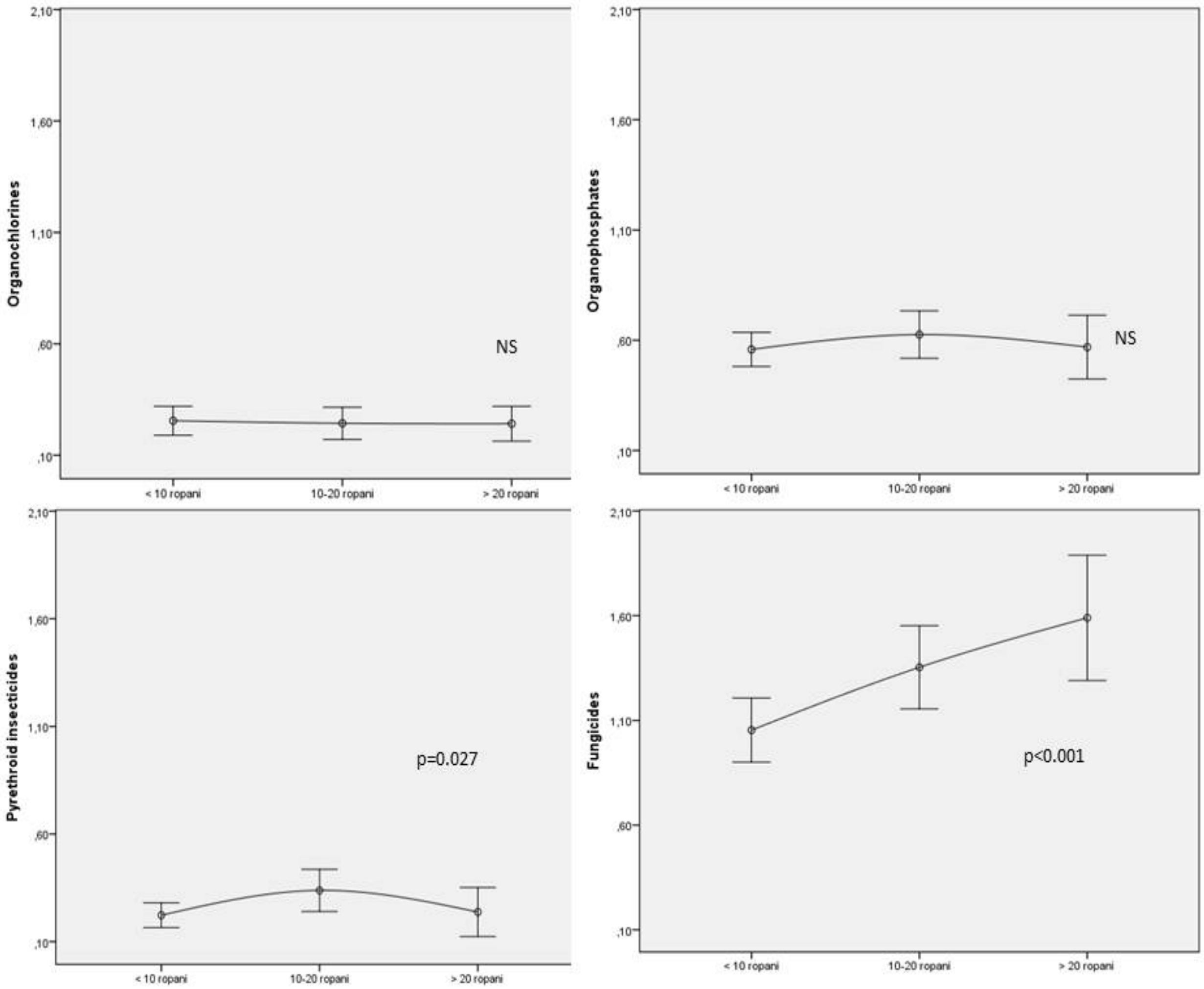

Figure 2. Use of pesticides by household landholding size. The Y-axis denotes the concentration of chemicals (unit/l of water) and the X-axis denotes land size. The NS indicates non-significant at the 5% significance level.