

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

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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 in 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:

$$\text{COI} = P_s * C_i \quad (1)$$

$$\text{DE} = P_d * C_d \quad (2)$$

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.

$$\text{TC} = \text{COI} + \text{DE} + O + C_p \quad (3)$$

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 Jhikhu 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	<i>t</i> 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	<i>t</i> 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.

Willingness to pay > pesticides expenditures + cost of illness + 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
OCIL	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.

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