Suitability of pesticide risk indicators for Less Developed Countries: A comparison

Feola, G.[1,2*], Rahn, E.[1,3], Binder, C.R.[1,4]

[1] Department of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

[2] Potsdam Institute for Climate Impact Research, Telegraphenberg A62, 14473 Potsdam, Germany

[3] Federal Office for Spatial Development, Mühlestrasse 2, CH-3063 Ittigen, Switzerland

[4] Institute for System Science, Innovation and Sustainability Research, University of Graz, Merangasse 18/I, 8010 Graz, Austria

* Corresponding author: feola.giuseppe@googlemail.com

Supplementary data

A - Short description of the indicators

EIQ

The Environmental Impact Quotient (EIQ) (Kovach et al., 1992) estimates the environmental impact of a pesticide by aggregating the hazard posed to farm workers, consumers and the local environment in one score. Each of these three components in the equation is given equal weight, but within each component, factors are given a different weighting (1, 3 or 5) in order to represent their importance. Similarly, toxicological data, which are drawn from different sources and databases, are normalized into a three level scale depending on their danger, i.e. 1 for low, 3 for medium and 5 for high toxicity.

$$EIQ = \{C[(DT \times 5) + (DT \times P)] + [(C \times ((S + P)/2) \times SY) + L] + [(F \times R) + (D \times ((S + P)/2) \times 3) + (Z \times P \times 3) + (B \times P \times 5)]\} / 3$$

Where: DT = dermal toxicity; C = chronic toxicity; SY= systemicity; F = fish toxicity; L = leaching potential; R = surface loss potential; D = bird toxicity; S = soil half-life; Z = bee toxicity; B = beneficial arthropod toxicity; P = plant surface half-life.

An EIQ field use rating (FUR) allows the EIQ to be calculated for pest control strategies (equation 2).

$$EIQ\ (FUR) = EIQ \times (\%\ active\ ingredient) \times rate$$

Supplementary data associated with the article: Feola, G., et al., Suitability of pesticide risk indicators for Less Developed Countries: A comparison. Agric. Ecosyst. Environ. (2011), doi:10.1016/j.agee.2011.05.014

PestScreen

PestScreen was developed as a screening tool to provide a relative assessment of pesticide hazards to human health and the environment (Juraske et al., 2007). The indicator provides a ranking approach, which not only includes data on toxic effects and bioaccumulation, but also on persistence and mobility of pesticides in the environmental compartments. The indicator provides a simple categorical distinction between pesticides as a function of application dose, and three hazard categories, i.e. fate, exposure and toxicity.

$$PestScore = D^* [(\sum F_{i=2} /2) + E_{i=1} + (\sum T_{i=4} /4)]$$

Where: D = application dose; $\sum F_{i=2}$ is the sum of overall persistence and long-range transport potential; E is the intake fraction; $\sum T_{i=4}$ is the sum of toxicity for rats, bees, fish and humans.

Each hazard category is given the same weight, and is scored on a 1 to 4 scale, i.e, low to very high concern. The hazard category's sub-scores are calculated using physical and chemical properties and cut-off criteria.

POCER

The pesticide occupational and environmental risk indicator (POCER) was developed by Vercruysse and Steurbaut (2002). It consists of ten modules covering both human health and environmental risk, which are based on the modules of Directive 91/414/EC (CEC, 1994) for the evaluation and acceptance of plant protection products in the European Union. A risk index is calculated for each module as the quotient of the estimated human exposure of the predicted environmental concentration and a toxicological reference value. The latter are endpoints defined by the Annex VI of the Directive 91/414/EC (CEC, 1994). For example, the risk index for the worker is calculated as

$$RI_{worker} = DE \times Ab_{DE} / AOEL$$

Where DE is the dermal exposure (mg/person/day), Ab_{DE} is the dermal absorption factor (fraction), and the AOEL is the Acceptable Operator Exposure Limit (mg/kg body weight/day).

The ten risk indices are aggregated into a total risk indicator by transforming each index into a value ranging from 0 to 1. In order to do that, a lower and an upper limit have to be established for the ten risk indices. The risk of a pesticide to the different components depends on the extent to which the lower limit is exceeded. Finally, the total risk of a pesticide is calculated by summing the values of the ten components (i.e. assuming equal weight).

EPRIP

The Environmental Potential Risk Indicator for Pesticide (EPRIP) was first developed by Padovani et al. (2004) and then updated by Trevisan et al. (2009) to improve the indicator, and in particular its applicability to different weather conditions. EPRIP is based on an ETR approach, by using the predicted environmental concentration estimated at local scale divided by short-term toxicological parameters (i.e. LD_{50}, NOEL). The ETR values are then normalized into risk points (RP) using a scale ranging from 1 to 5, where 1 represents no risk and 5 represents very large risk. Finally, to obtain the overall EPRIP score, the RP values for the different compartments are multiplied as follows:

$$EPRIP = RP_{gw} \times RP_{sw} \times RP_{s} \times RP_{a} + 25 \times N4 + 50 \times N5$$

Where RP_{gw} is the risk point for groundwater, RP_{sw} is the highest risk point among six different values for surface water, RP_{s} is the risk point for soil, RP_{a} is the risk point for air, N4 is the number of RP values equal to 4 and N5 is the number of RP values equal to 5.

PIRI

The Pesticide Impact Rating Index (PIRI) (Kookana et al., 2005) assesses the off-site migration potential of pesticides and risk of surface and groundwater contamination. PIRI makes use of an exposure-toxicity ratio approach and is based on an ad hoc developed software package. The risk assessment is based on pesticide use; the pathway through which the pesticides are released to the water resources (drift, runoff, erosion, leaching) and the value of the water resources threatened. Each component is quantified using pesticide characteristics (e.g. toxicity to organisms at different trophic levels, i.e. fish, daphnia, algae), environmental and site conditions (e.g. organic carbon content of soil, water input, slope of land, soil loss, recharge rate, depth of water table).

OHRI

The Operator Health Risk Indicator (OHRI) (Bergkvist, 2004) provides a measure of risk to the pesticide operator. It combines data on hazard and exposure and combines them with data on intensity of pesticide use. The toxicity values were drawn from the EU risk phrases defined in Annex II of the EU Directive 67/548/EEC as amended by the EU Directive 2001/59/EC and scored by the authors. The protective factors of different pieces of personal protective equipment, used to calculate the indicator's value, are drawn mainly from the UKPOEM (1992).

$$OHRI = AT \times OT \times FT \times AMO \times PMO$$

Where: AT = area treated; OT = operator toxicity; FT = formulation type; AMO = application method; PMO = use of personal protective equipment.

Dosemeci et al. (2002)

Dosemeci et al. (2002) developed a quantitative method for estimating the intensity of exposure to pesticides in the agricultural sector. The algorithms developed, i.e. a detailed and a general one, consider different factors which contribute to the exposure of the operator to pesticides. The exposure scores assigned to each factor are mainly derived from empirical studies in the scientific literature.

$$\text{Intensity level} = [(Mix \times Enclosed) + (Appl \times Cab) + Repair + Wash] \times PPE \times Repl \times Hyg \times Spill$$

Where: *Mix* is a score for the method of pesticide mixing; *Enclosed* is a score for whether or not an enclosed mixing system is used; *Appl* is a score related to the application method; *Cab* refers to whether or not a tractor with enclosed cab and/or charcoal filter is used; Repair is a score for the status of maintenance of the equipment; *Wash* is a score for the practice of washing the equipment after pesticide application; *Repl* is a score for the rate of replacement of old protective gloves; *Hyg* is a score for the practices of personal hygiene; *Spill* is a score for whether or not clothes are changed after a spill.

B- Overview of data requirements

Table 7. Data used to calculate the indicators

Data	Indicators*						
	EIQ	Pest Screen	POCER	EPRIP	PIRI	OHRI	Dosemeci et al. (2002)
PESTICIDE APPLICATION							
Application method			*			*	*
Application rate	*	*	*	*	*		
Duration of re-entry			*				
Exposure area for bystanders			*				
Frequency of application	*	*	*	*	*		
Inhalation exposure for the applicator			*				
Minimum number of days from application of pesticides to first rainfall/irrigation					*		
Parcel area			*	*	*	*	
Parcel perimeter				*			
Safety practices (washing, changing clothes, etc.)							*
Use of personal protective equipment			*			*	*
Transfer factor for re-entry			*				
Width of buffer zone					*		
Work rate (ha/h)			*				
PESTICIDE PROPERTIES							
Henry constant				*			
k_{oc}				*	*		
Long range transport potential		*					
Mode of action	*						
Molecular weight				*			
Overall persistence		*					
Pesticide composition (active ingredients)	*	*	*	*	*		
Pesticide formulation (liquid/powder)			*			*	
Pesticide half-life in soil	*		*	*	*		
Pesticide solubility in water				*			
Plant surface residue half-life	*						
Vapour pressure				*			
TOXICITY							
Acceptable daily intake (ADI)		*					
Acceptable operator exposure limit (AOEL)			*				
EC_{50} algae			*	*	*		
EC_{50} daphnia			*	*	*		
LC_{50} earthworms			*	*			
LC_{50} fish	*	*	*	*	*		
LC_{50} rabbit/rat	*						
LD_{50} bees		*	*				
LD_{50} birds			*				
LD_{50} rat		*		*			
Long-term health effects	*						
Operator toxicity						*	
Toxicity to bees	*						
Toxicity to beneficial arthropods	*		*				
Toxicity to birds	*						

Supplementary data associated with the article: Feola, G., et al., Suitability of pesticide risk indicators for Less Developed Countries: A comparison. Agric. Ecosyst. Environ. (2011), doi:10.1016/j.agee.2011.05.014

Table 7 (continued). Data used to calculate the indicators

Data	EIQ	PestScreen	POCER	EPRIP	PIRI	OHRI	Dosemeci et al. (2002)
	Indicators*						
SOIL							
Bulk density of soil			*	*			
Estimated average soil loss during period of interest					*		
Slope of land to water body				*	*		
Soil depth			*				
Soil moisture					*		
Soil organic carbon content				*	*		
Soil type				*	*		
WATER BODIES							
Annual recharge rate				*			
Depth of nearest water body			*	*			
Depth of water table				*	*		
Diameter of nearest water body					*		
Distance from edge of crop to water body				*	*		
Groundwater and runoff potential	*						
Recharge rate during period of interest					*		
Water table thickness				*			
Width of nearest water body			*	*			
METEOROLOGICAL CONDITIONS							
Average maximum air temperature during period of interest					*		
Maximum daily rain				*			
Mean annual precipitation				*			
Mean annual temperature				*			
Total rainfall during period of interest					*		
OTHER DATA							
Body weight of birds			*				
Body weight of bystanders			*				
Crop interception factor			*	*			
Daily food intake by birds			*				
Dermal absorption factor			*				
Drift			*				
Drinking water standard				*			
Intake fraction		*					
Leaf area index			*				
Total irrigation during period of interest					*		

* An asterisk indicates that the data was used in calculating the respective indicator.

The specific values used to calculate the indicators, as well as sources and assumptions made, are to be found in Rahn, E., 2010. Environmental and health risk indicators to assess pesticide use. A comparison of different indicators for the case of potato production in La Hoya, Colombia. Master thesis, Department of Geography, University of Zurich, Switzerland.

C – Criteria for the comparison based on key indicator characteristics

Table 8. Criteria for the comparison based on key indicator characteristics and corresponding scores.

	Scores / Criteria	*	**	***
User friendliness	Data availability	Not available (additional assumptions needed)	Available for some pesticides	Easily available
	Calculation procedure	Calculation procedure knowledge-intensive and time-consuming	Calculation procedure either knowledge intensive or time-consuming	Calculation procedure neither knowledge intensive nor time-consuming
	Score interpretation	Relative comparison (ranking)	Risk classes given when single applications are considered	Risk classes given both when single applications and control strategy are considered
Ability to represent the specific system under study	Site specific data	No site specific data used	-	Site specific data used
	Compartments considered (environment)	One-two compartments	Three compartments	Four-Five compartments
	Compartments considered (health)	One compartment	Two compartments	Three compartments

D - Additional tables

Table 9. Correlation between rankings of the 581 pesticide applications for risk to soil (Spearman correlation test)

	EPRIP	POCER	Application rate
EPRIP	1.00		
POCER	0.82 **	1.00	
Application rate	0.07	0.42 **	1.00

* p > 0.05; ** p > 0.01

Table 10. Correlation between rankings of the 72 control strategies for risk to soil (Spearman correlation test)

	EPRIP	POCER	Application rate
EPRIP	1.00		
POCER	0.38 **	1.00	
Application rate	0.14	0.32 **	1.00

* p > 0.05; ** p > 0.01

Table 11. Correlation between rankings of the 581 pesticide applications for risk to beneficial arthropods (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	-0.50 **	1.00	
Application rate	0.98 **	-	1.00

* p > 0.05; ** p > 0.01

Table 12. Correlation between rankings of the 72 control strategies for risk to beneficial arthropods (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1,00		
POCER	0,09	1,00	
Application rate	0,99 **	0,09	1,00

* p > 0.05; ** p > 0.01

Table 13. Correlation between rankings of the 581 pesticide applications for risk to birds (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.43 **	1.00	
Application rate	0.94 **	0.25 **	1.00

* p > 0.05; ** p > 0.01

Table 14. Correlation between rankings of the 72 control strategies for risk to birds (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.35 **	1.00	
Application rate	0.96 **	0.28 *	1.00

* p > 0.05; ** p > 0.01

Table 15. Correlation between rankings of the 581 pesticide applications for risk to bees (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.05	1.00	
Application rate	0.96 **	0.90 *	1.00

* p > 0.05; ** p > 0.01

Table 16. Correlation between rankings of the 72 control strategies for risk to bees (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.43 **	1.00	
Application rate	0.97 **	0.34 **	1.00

* p > 0.05; ** p > 0.01

Table 17. Correlation between rankings of the 581 pesticide applications for risk to farm worker (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.56 **	1.00	
Application rate	0.91 **	0.51 **	1.00

* p > 0.05; ** p > 0.01

Table 18. Correlation between rankings of the 72 control strategies for risk to farm worker (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.49 **	1.00	
Application rate	0.97 **	0.46 **	1.00

* p > 0.05; ** p > 0.01