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GROUNDWATER RISK ASSESSMENT OF PESTICIDES USED BY SN-SOSUCO FOR SUGAR CANE CULTIVATION IN BURKINA FASO

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In the southwestern part of Burkina Faso, sugar cane is intensively cultivated by the SN-SOSUCO society (Nouvelle Société Sucrière de la Comoé) which is the largest private employer in the country. The sugar cane is grown on an area covering about 3850 ha. The intensive cultivation of the sugar cane is all the year round and involves the use of pesticides for pest control and to reduce the production losses. Groundwater risk assessment by pesticides used in the SN-SOSUCO cultivated area during the season 2007-2008 was the goal of the present study. Both Pesticide Impact Rating Index (PIRI) software developed by CSIRO Australia and the Groundwater Ubiquity Score (GUS) were used for the evaluation of the thirteen pesticides used by the society. Pichloram, carbofuran, trichlopyr, monosodium methanarsonate (MSMA) and the chlorimuron-ethyl have high leaching potential according to GUS index, and MSMA has mean risk of mobility to groundwater as shown by PIRI. To prevent groundwater pollution by pesticides, the implementation of a comprehensive environmental management system is mandatory.

INTRODUCTION

In order to satisfy the needs of the rapidly growing population, intensive agricultural practices including the use of pesticides to control pest and reduce other production losses are employed in Burkina Faso.

Besides the desired effects of pest control, non-target organisms and soil and water are usually contaminated by the applied pesticides resulting in high risks for human beings. Of the applied pesticides, less than 0.1% effectively reach the target organisms (Pimentel, 1995) and, concomitantly, pesticide residues are frequently found in the environment at considerable distances from the original point of their application (Van de Werf, 1996; Sutherland et al., 2002; Siddique et al., 2003; Calvet et al., 2005). Since the 1960s, studies have revealed the presence of pesticides in groundwater (Van de Werf, 1996; Ali and Jain, 2001; ORP, 2011) all over the world. Most of these contaminated areas belong to intensive agricultural practice zones.

In developing countries, the risks of pesticide usage on both the environment and human health are real and are responsible for much of recorded intoxications. Previous studies in Burkina Faso showed pesticides contamination in both soils and waters (Toe et al., 2004; Savadogo et al., 2006; Tapsoba et al., 2008) and thus revealed the potential risk of water resources contamination by pesticides (Toe et al., 2000; Toe et al., 2002 ; Toe and Coulibaly, 2006; Gomgnimbou et al., 2009).

In the South Western part of Burkina Faso, sugar cane is intensively cultivated by the SN-SOSUCO society (Nouvelle Société Sucrière de la Comoé), on an area covering 3850 ha. SN-SOSUCO, is a public-private partnership enterprise and it is Burkina Faso's largest private employer, with a workforce of over 3,000, including 800 permanent staff, 400 seasonal workers and more than 1,800 day workers. The total sugarcane production per year is about 300 000 tons of which 25 to 30 000 tons of the sugar is for country consumption (Hema, 2008). The sugar cane farming is an all year round activity. To supplement the annual rains, the cane is irrigated by an 18 x 18 irrigation system pivot front-mounted spray booms and micro irrigation. Here, water is fed by gravity from the Comoé, Toussiana and Lobi dams and other surrounding lakes.

In order to meet their production targets and to reduce production losses, the SN-SOSUCO society imports lots of fertilizers and pesticides for the cultivation. These inputs are supplied to all the permanent and temporary farmers, with well schedule application pattern (MEE, 2001). During the 2006/2007 season, 55,155 Kg of pesticides were used by this society for sugar cane cultivation (Ouattara, 2007). In 2001, some pesticide residues measurements have shown the presence of Atrazine in the piped water lines and also in the waters of surrounding lakes at concentrations of 0.39 and 0.72 ìg/l respectively. From the aforementioned cases, the assessment of the groundwater pollution in the area is required in order to set tools and strategies for better management of the groundwater resources, for the groundwater in the area is used as the source of both drinking water and for household supply. The aim of this study was to evaluate the risk of the groundwater contamination by pesticides used in the cultivated area of the SN-SOCUCO during the season 2007-2008. To achieve this goal, Pesticide Impact Rating Index (PIRI) software developed by CSIRO Australia (Kookana et al., 2005) and the Groundwater Ubiquity Score (GUS) (Gustafson, 1989) were used.

MATERIAL AND METHODS

Description of the study area

The SN-SOSUCO cultivated area is located in the South-Western part of Burkina Faso, of the Cascades region, and lies between latitude 10°41' to 10°47' north and longitude 4°38' and 4°39' west (Figure 1). The climate is Sudanese Sahelian with an average annual rainfall and temperature from years 1974 to 2004 respectively of 1,100 mm and 27 °C (Millogo et al., 2004). Soil organic matter varied from 1.06% to 1.36% within the perimeter (SN-SOSUCO, Irrigation service, 2008).

Soils from the study area are of three types: i) raw mineral soils with sandstone out crops; ii) the tropical ferruginous soils characterized by sandy and sandy clay structure; iii) and hydromorphic soils generally found in swampy areas while sands are around the lakes (Millogo et al., 2004).

The study area has two lakes: Lake Karfiguela and Lake Lemouroudougou located respectively at 70 m and 100 m from the cultivated area (see Figure 1), as well as two small rivers: River Yannon and River Berega, located at 30 m from the cultivated area. These two rivers join together to form one river. The average depth of groundwater in the area is 13 m. Slope of the study area is estimated at 4% and soil erosion of 5 t/ha. The total amount of water used for irrigation during the study period was 395.5 mm and the cumulative rainfall from November 2007 to August 2008 was 800 mm (SN-SOSUCO, Irrigation service, 2008).

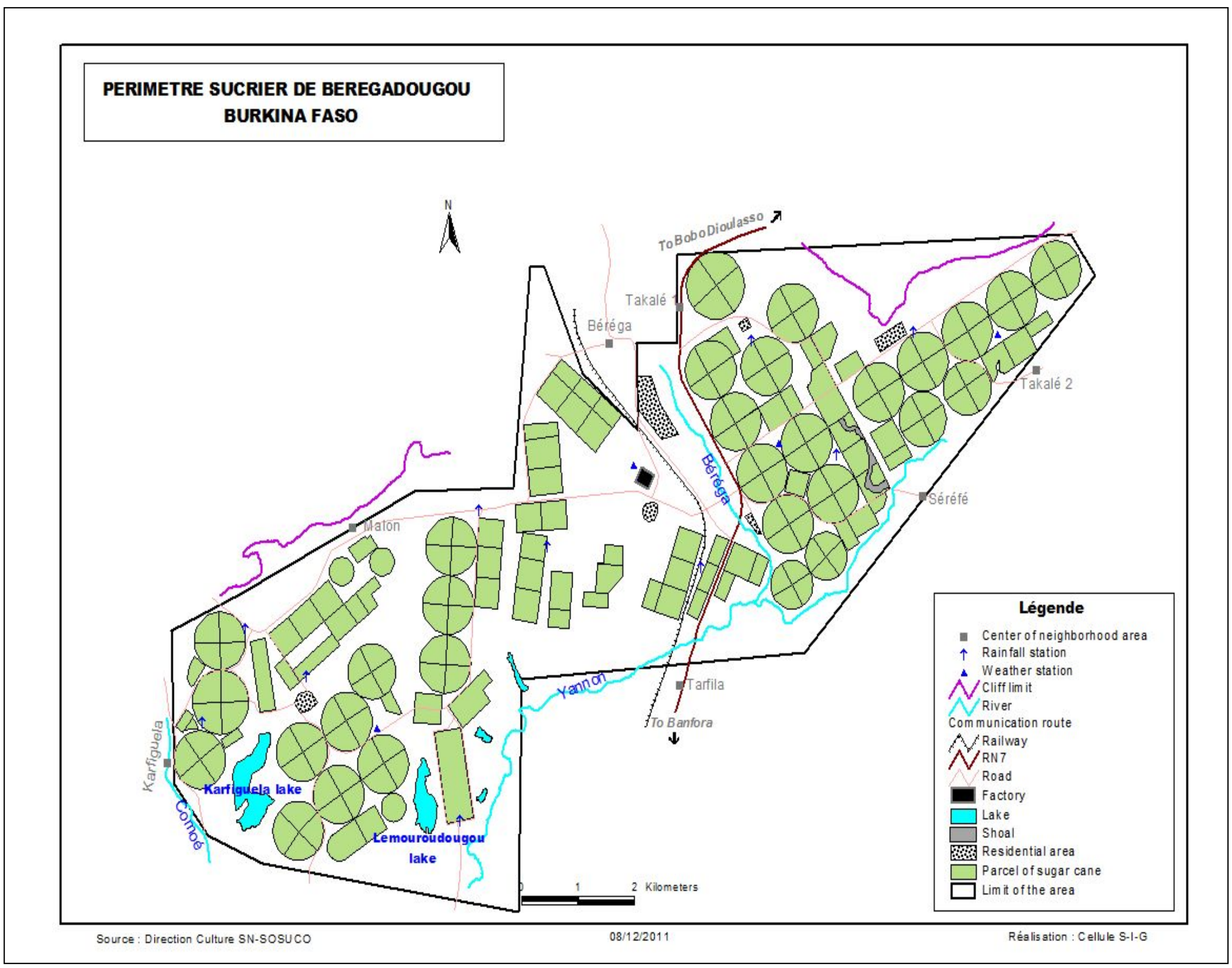

Figure 1. Map of the study area (From: Direction Culture/SN-SOSUCO, 2008).

Risk evaluation methods

Two methods have been used in this study to assess groundwater pollution potential by pesticides, i.e. Groundwater Ubiquity Score (GUS) and Pesticide Impact Rating Index (PIRI).

GUS index

For comparative evaluation of groundwater contamination potential by leaching for the investigated individual pesticides in this study, the Groundwater Ubiquity Score (GUS) (Gustafson, 1989) was used. It's an empirical regression model which incorporates only the properties of pesticides such as the chemical's adsorption (Koc) and persistence (half-life in soil $t_{1/2}$) as is expressed by Equation 1.

$$GUS = \log t_{1/2}[4 - \log Koc] \quad (1)$$

GUS is usually interpreted as follows:

GUS > 2.8 high leaching potential

GUS 1.8-2.8 medium leaching potential

GUS < 1.8 low leaching potential

Pesticide Impact Rating Index (PIRI)

The Pesticide Impact Rating Index (PIRI) is a software package developed by CSIRO with support from Land and Water Australia and other agencies. PIRI is a model to predict the potential for pesticides to move off-site and pollute adjacent waterways (CSIRO, 2001) based on quantitative risk management, and taking into account the pesticides mobility to surface water, the pesticides mobility to groundwater and the risk for water quality.

The evaluation and calculation of parameters needed for PIRI software are carried out according to the methods developed by Kookana et al., (2005). These authors (Kookana et al., 2005) had taken into account the decreasing organic carbon (OC) content and microbial population density with the soil profile depth. Therefore, the soil profile was divided into three horizons with the following assumption: i) Surface zone from the top soil to 0.1 m depth where organic carbon content as well as microbial population density is constant, ii) transitional zone from 0.1 to 1.0 m depth with exponential decrease of both organic carbon content and the microbial population density, iii) and the residual zone, below 1.0 m with constant organic carbon content as well as microbial population density.

For each horizon, the attenuation factor (AF) is determined and the global AF factor (AF_{GW}) is expressed by the following Equation 2:

$$AFGW = AFSZ \times AFTZ \times AFRZ \quad (2)$$

where AF_{SZ}: AF Surface zone, AF_{T}: AF transitional zone and AF_{RZ} : AF residual zone.

The study focused on pesticides used in the study area during the season 2007-2008 as listed in Table 1. Therefore, data in Table 1 was then used by the GUS and PIRI in this study. In the case of PIRI, the study focused on the leaching potential of the lakes, and the rivers to groundwater.

RESULTS AND DISCUSSION

Results of pesticides risk assessment for groundwater by lixiviation obtained by the GUS index shows that from the investigated pesticides listed in Table 1, pichloram, carbofuran, trichlopyr,

Table 1. Physico-chemical properties of the pesticides used by the SN-SOSUCO during the season 2007–2008.

Pesticide formulation	Usage	Active ingredient (a.i.)	Concentration (g/L or g/kg)	Koc (mL.g^{-1})[a]	$t^{soil}_{1/2}$ (days)[a]	Total quantity used (kg*or L**)
EXTREME PLUS WP	Herbicide	Metribuzin	643	38	11.5	4565*
		Chlorimuron-ethyl	107	106	40	
PARAGON 500 EC	Herbicide	Pendimethalin	500	15744	90	4540**
VOLCANO acetochlor 900 EC	Herbicide	Acetochlor	900	156	14	10685**
DINO 800 W	Herbicide	Diuron	800	1067	75.5	1078*
KALACH 360 SL	Herbicide	Glyphosate	360	21699	12	6407**
VOLCANO MCPA 400 SL	Herbicide	2,4 MCPA[b]	400	74	15	1889**
MASTER 720 SL	Herbicide	MSMA[c]	720	250	200	2194**
TRICLON 480 EC	Herbicide	Trichlopyr	480	48	39	151**
BROWSER	Herbicide	Pichloram	240	35	90	96**
DIAFURAN 10 G	Insecticide	Carbofuran	100	23.3	29	500*
COSMOPOL 15 G	Insecticide	Terbufos	150	500	8	23000*
BAYLETON 250 EC	Fungicide	Triadimefon	250	300	26	50**

*Solid formulation **Liquid formulation [a]data collected from (FOOTPRINT, 2008) [b]4-Chloro-2-methylphenoxyacetic acid

[c] Monosodium methanarsonate $t^{soil}_{1/2}$:half-life in soil.

MSMA and the chlorimuron-ethyl have high leaching potential, with GUS index value greater than 2.8 (Figure 2). Pichloram had the highest leaching potential with a GUS index value of 4.8. However, as shown in Table 1, only a limited quantity of 96 L of the formulation BROWSER, whose active ingredient (a.i.) is pichloram, was applied, which represents approximately 25 mL per hectare cultivated. Nevertheless, this formulation ought to be used with good agricultural practice, and on the supervision of the SN-SOSUCO technicians. For the pesticides with high leaching potential, MSMA and chlorimuron ethyl are widely used in the area with applied quantity of 2194 Kg and 651 Kg respectively (Table 1) and with the calculated leaching potential value of 3.68 and 3.16 respectively (Figure 2). As such, a special focus on survey of these pesticides is needed in order to prevent groundwater pollution.

Five pesticides namely acetochlor, metribuzin, MCPA, diuron, triadimefon have medium calculated leaching potential. In the study area, up to 10,685 Kg, with a mean rate of 2.78 Kg per

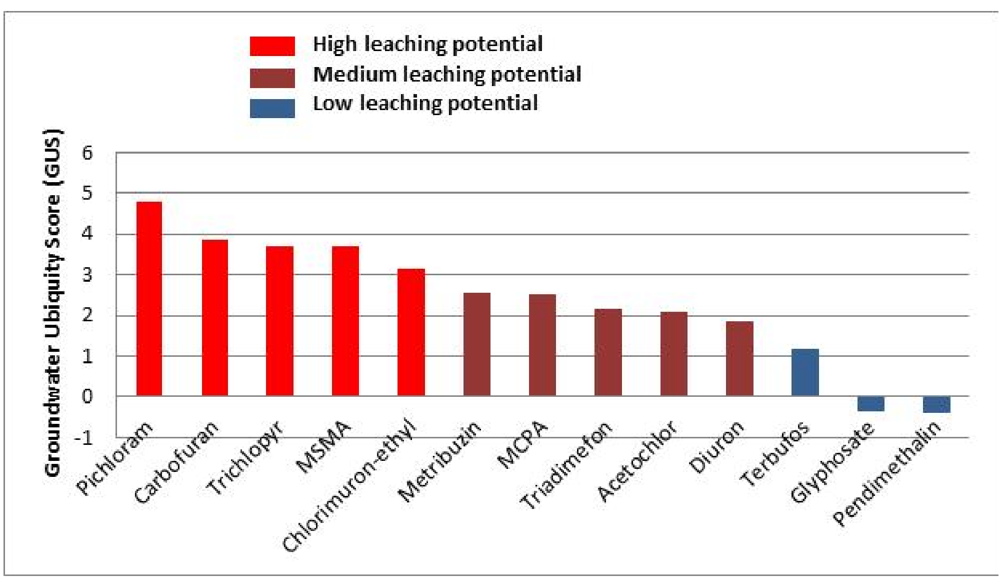

Figure 2. Groundwater Ubiquity Score (GUS) of pesticides used by the SN-SOSUCO in the season 2007-2008.

hectare of the formulation VOLCANO acetochlor900 EC was applied (Table 1). This formulation is highly concentrated in the a.i. acetochlor. Therefore, it is mandatory for the society to monitor and regulate the used of this formulation, or better still to substitute it by another formulation of low leaching potential in order to avoid long term contamination of groundwater resources in the area.

The rest of the active ingredients applied in the area have low leaching potential (Figure 2). Among them, terbufos, the relatively low concentrated active ingredient of the formulation COSMOPOL 15 G, was largely applied with a quantity of 20,000 Kg during the study period.

Risk assessments of pesticides for groundwater contamination by PIRI are given in Tables 2, 3 and 4, which represent groundwater pollution potential from the surface waters, i.e. rivers Berega and Yannon, lake Lemouroudougou and lake Karfiguela respectively.

Results obtained by PIRI reveal that MSMA has mean risk of mobility to groundwater. The risk is low for the other pesticides, with a similar trend for the two lakes and the rivers. The MSMA is the active ingredient of the formulation MASTER 720 SL, with a concentration of 720 g/L. 2,194 L of this formulation was used during the study period, approximating to a ratio of 570 mL per hectare.

The GUS index allows a simpler classification of pesticides from their intrinsic properties of Koc and $t_{1/2}$. However, the error from the experimental measurement of these parameters will impact the GUS value (Gustafson, 1989; Calvet et al., 2005). The GUS method doesn't consider the usage of the active ingredient (quantities apply, target organism) nor the environment characteristics (water bodies, rate of organic matters, etc.). The above mentioned factors are integrated by PIRI model which evaluates the aptitude of pesticides to contaminate groundwater. However, the dilution factor, the decomposition of active ingredient in water or the pesticide formulation (CSIRO, 2001) are not integrated in the PIRI method.

From the risk assessment, the pesticide MSMA, used by the SN-SOSUCO, shows potential risk

Table 2. Groundwater pollution potential from rivers Berega and Yannon.

Pesticides	Attenuation factor (AF)	Groundwater pollution potential(kg/ha)	Mobility Risk
MSMA	0.06452	0.02816	Medium
picloram	0.14339	0.00062	Very low
carbofuran	0.00486	$7.11315\ 10^{-5}$	Very low
triclopyr	0.00634	$6.36077\ 10^{-5}$	Very low
chlorimuron-ethyl	0.00058	$1.24132\ 10^{-5}$	Very low
metribuzin	$1.59280\ 10^{-7}$	$1.02417\ 10^{-7}$	Very low
MCPA	$9{,}51097\ 10^{-8}$	$6.13077\ 10^{-9}$	Very low
acetochlor	$1.14596\ 10^{-12}$	$2.91216\ 10^{-12}$	Very low
diuron	$4.84585\ 10^{-12}$	$1.04845\ 10^{-12}$	Very low
triadimefon	$2.47271\ 10^{-11}$	$3.77088\ 10^{-15}$	Very low
terbufos	$4.70575\ 10^{-54}$	$3.41715\ 10^{-54}$	Very low
glyphosate	$1.00000\ 10^{-99}$	$7.62120\ 10^{-100}$	Very low
pendimethalin	$1.00000\ 10^{-99}$	$5.88000\ 10^{-100}$	Very low

Table 3. Groundwater pollution potential from Lemouroudougou lake.

Pesticides	Attenuation factor (AF)	Groundwater pollution potential(kg/ha)	Mobility Risk
MSMA	0.03490	0.01524	Medium
picloram	0.11845	0.00051	Very low
carbofuran	0.00327	$4.79250\ 10^{-5}$	Very low
triclopyr	0.00346	$3.47373\ 10^{-5}$	Very low
chlorimuron-ethyl	0.00016	$3.37463\ 10^{-6}$	Very low
metribuzin	$3.13928\ 10^{-8}$	$2.01856\ 10^{-8}$	Very low
MCPA	$8.41745\ 10^{-9}$	$5.42589\ 10^{-10}$	Very low
acetochlor	$4.79371\ 10^{-15}$	$1.21820\ 10^{-14}$	Very low
diuron	$4.66368\ 10^{-15}$	$1.00903\ 10^{-15}$	Very low
triadimefon	$8.51593\ 10^{-14}$	$1.29868\ 10^{-17}$	Very low
terbufos	$2.14633\ 10^{-67}$	$1.55859\ 10^{-67}$	Very low
glyphosate	$1.00000\ 10^{-99}$	$7.62120\ 10^{-100}$	Very low
pendimethalin	$1.00000\ 10^{-99}$	$5.88000\ 10^{-100}$	Very low

Table 4. Groundwater pollution potential from Karfiguela lake.

Pesticides	Attenuation factor (AF)	Groundwater pollution potential(kg/ha)	Mobility Risk
MSMA	0.04462	0.01948	Medium
picloram	0.12786	0.00056	Very low
carbofuran	0.00383	$5.61257\ 10^{-5}$	Very low
triclopyr	0.00441	$4.42468\ 10^{-5}$	Very low
chlorimuron-ethyl	0.00027	$5.68184\ 10^{-6}$	Very low
metribuzin	$6.01122\ 10^{-8}$	$3.86521\ 10^{-8}$	Very low
MCPA	$2.22023\ 10^{-8}$	$1.43116\ 10^{-9}$	Very low
acetochlor	$4.28618\ 10^{-14}$	$1.08922\ 10^{-13}$	Very low
diuron	$7.50560\ 10^{-14}$	$1.62391\ 10^{-14}$	Very low
triadimefon	$8.23016\ 10^{-13}$	$1.25510\ 10^{-16}$	Very low
terbufos	$4.65660\ 10^{-62}$	$3.38146\ 10^{-62}$	Very low
glyphosate	$1.00000\ 10^{-99}$	$7.62120\ 10^{-100}$	Very low
pendimethalin	$1.00000\ 10^{-99}$	$5.88000\ 10^{-100}$	Very low

for groundwater contamination. Therefore, for better management, this pesticide ought to be substituted otherwise the farmers need to apply prudent agricultural practices.

CONCLUSION

Risk assessment of groundwater pollution by pesticides used on sugarcane by the SN-SOSUCO during the study period, using the index GUS and the PIRI model, has shown the pollution potential of certain pesticides. From the thirteen pesticides investigated, five are of high leaching potential, resulting in high risk for groundwater pollution and five of the pesticides present intermediate risk according to GUS. However, according to PIRI, only the MSMA have medium mobility risk to groundwater. Thus, the two methods used in this study for risk assessment point out that MSMA is a potential pesticide to pollute groundwater.

PIRI and the index GUS allow the risk assessment, but not the actual rate of pesticides residue in water. Therefore, regular monitoring of pesticides residues in the surface as well as in groundwater, used in the cultivated area of the SN-SOSUCO, by chromatographic analysis is mandatory. Hence, evaluation of pesticides residues by in-situ measurement will be our next investigation. This next stage will be associated with bio-ecological methods including the use of bioindicators and biomarkers for assessing chemical pollution for the implementation of an environmental management system.

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