Design and implementation of a measuring campaign to model pesticide impacts in an Ecuadorian watershed

D. Matamoros*, J. Bonini*, E. Guzman*, G. Ramirez* and P.A. Vanrolleghem**

* Facultad de Ingeniería en Ciencias de la Tierra, Escuela Superior Politécnica del Litoral, Campus Gustavo Galindo Km. 30.5 vía Perimetral, Guayaquil, Ecuador (E-mail: *dmata@goliat.espol.edu.ec*)

** BIOMATH, Department of Applied Mathematics, Biometrics and Process Control, Ghent University, Coupure Links 653, B-9000 Gent, Belgium

Abstract The first important issue in pesticide assessment for a watershed is the availability of soil and water quality information in the form of charts, maps or records. However, developing countries generally do not have enough historical data. Thus, sampling programs are crucial for the success of the evaluation, although in developing countries they always represent a controversial task between limited available budget and a precise assessment. This paper shows the steps taken to generate soil and water data to be used in a pesticide assessment project for a 34,000 ha watershed in Ecuador, South America. Sampling campaigns are still being run, so the methodology and the first results are shown here.

Keywords Geographical Information System; modelling; monitoring; soil sampling; water sampling; watershed

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Introduction

Watershed management is a very difficult task if appropriate information is lacking or missing. For the case of pesticide impact assessment within a watershed, soil and water quality information is the first data needed for the entire basin because pesticides can attach to clay particles and organic matter present in soil or suspended/dissolved in water. These should be provided as soil maps and water quality profiles. In developing countries, these data are not usually recorded either on a periodical basis or on fixed monitoring stations. Thus, sampling campaigns must be planned for the entire river basin considering a limited budget and a desired degree of accuracy imposed by the specific purpose of the management task.

The Ecuadorian banana sector represents an agricultural activity that inputs a significant amount of pesticides in the country's environment and also is the second economic sector of Ecuador. In 1998, there were more than 135,000 ha of banana crops in Ecuador (Matamoros and Vanrolleghem, 2001; Ecuadorian Central Bank, 1998).

ESPOL (Escuela Superior Politécnica del Litoral, Ecuador) and BIOMATH, Faculty of Agricultural and Applied Biological Sciences (Ghent University, Belgium) are involved in a collaborative project to determine the environmental impacts of pesticides coming from the banana sector. The Chaguana river basin that is used as a case study in this research project is a 34,000 ha watershed located at the southwestern part of Ecuador (see Figure 1). Almost 30% of the surface area is covered by banana plantations.

As said before, it is necessary to have some important data such as soil characteristics and water quality in the evaluated watershed. Unfortunately, this data is missing or incomplete for many developing countries. In Ecuador, most of this important information is generally compiled in maps with a scale 1:50,000 or bigger (Table 1). Thus, existing data is too general for pesticide assessment.

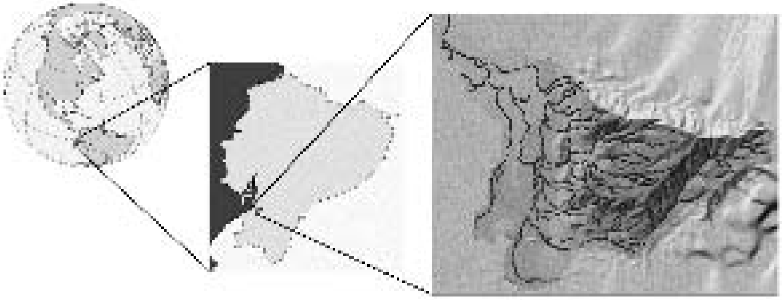

Figure 1 Location of Chaguana River Watershed. Image at the right corresponds to a Digital Elevation Model generated using GIS which is only valid for the area inside the basin

Table 1 Available datasets for the Chaguana river catchment

Existing maps	Scale	Source
Topographical sheets	1:50,000	Ecuadorian Army Geographical Institute
Geological sheet	1:100,000	Ecuadorian Army Geographical Institute
Edaphological sheet	1:100,000	PRONAREG-ORSTOM

Materials and methods

Use of GIS in the assessment

The pesticide impact assessment is going to be performed using a GIS platform (ArcView, ESRI) based on the scheme shown in Figure 2. GIS was also used to help in designing the sampling campaigns and in elaborating the final soil and water maps, as can be seen in Figure 3.

Collection of soil data

Sampling depth and soil properties. As previously stated, the available soil data was too general for the selected watershed. Thus, it was necessary to generate more specific soil maps for the study site. In the context of pesticide assessment, the surface soil is more important than deeper soils (Boesten *et al.*, 1999; Moorman *et al.*, 1999). Thus, the first 50 cm of soil below ground level was evaluated. In addition, soil properties such as soil-water content, bulk density, organic matter content and sand-silt-clay content were selected as the main objectives in the soil analysis.

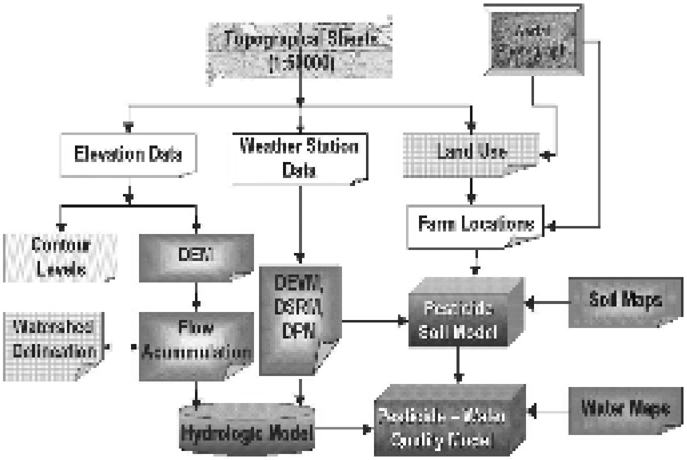

Figure 2 GIS methodology implemented in the project

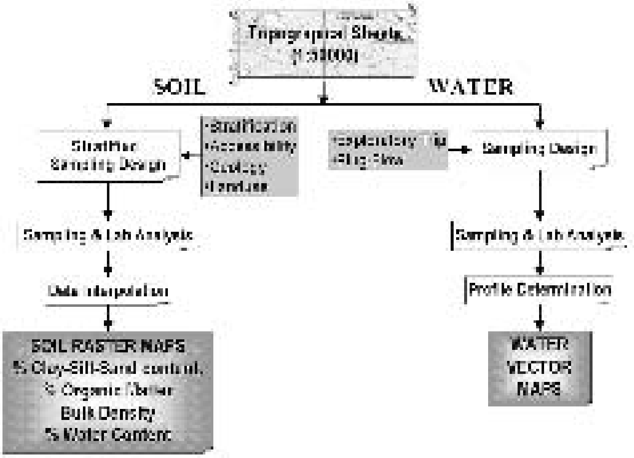

Figure 3 Soil and water maps, to be used in GIS, obtained with the sampling design

Number of sampling sites. The second problem was to answer how many sampling sites are sufficient for the assessment. To solve this problem, the following criteria were considered.

- Both geological and edaphological maps define zones where soils can have very similar properties.
- The locations of banana farms are very important from the pesticide assessment point of view.
- The sampling sites depend on accessibility (existing main roads, permits to enter service roads in the farms). Based on this, the potential surface area to be sampled in the watershed is defined by a variable buffer area of not more than 25 metres surrounding the existing and accessible roads.
- Although soil variability is a fact of nature, precision in watershed assessment is not the same as precision in farm assessment. From an agricultural point of view, the largest area representing a soil unit to be sampled is 40 hectares (Jacobsen, 1999). From a landscape point of view, around 3 to 6 samples could be taken per landscape unit (Government of Manitoba, 2000).
- It is necessary to use an adequate statistical technique to determine the minimum number of samples.
- The available budget for the sampling campaign is limited.
- The available time for the whole pesticide assessment is restricted to three years.

Thus, the most appropriate design is the stratified sampling design which has already been used in other types of assessment such as the prediction of organochlorine pesticides in sediments and animal tissues in a river basin (Black *et al.*, 2000). For the present study, the sampling size was determined on the basis of statistical analysis (Gilbert, 1987). Then, considering the other criteria, the recommended number of stratified sampling sites was fixed to 30 locations.

Considering only the watershed surface area (34,000 Ha), it apparently seems that very few samples are used to evaluate an important problem in the basin (around one sample per every 1,200 ha). However, evaluation seems more appropriate when zoning the sampling points. These can be better seen in Figure 4 where sampling points are put over geology, landuse, road and edaphology maps. In the road map (Figure 4d), it can be seen that a large area is difficult to be sampled due to the lack of roads.

Number of samples per site. Due to soil variability, it was necessary to have more than one soil sample per site. In every sampling site, two soil samples were obtained: a core

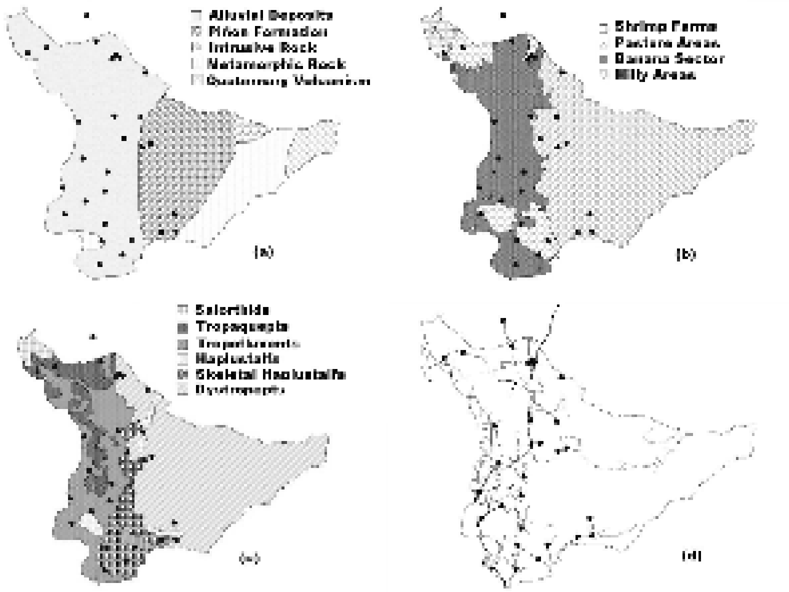

Figure 4 Soil sampling point locations compared to (a) geology map, (b) landuse map, (c) edaphology map, and (d) road map in the watershed

undisturbed sample and a composite disturbed sample (cross-shape sampling pattern). A cross-shape sampling pattern represents four sampling points a certain distance away from the core sample (centre of the cross), and separated 90° from each other with respect to the centre (Figure 5). The radius of the cross-shape pattern was variable depending on the topography. After collection, the sub-samples were mixed together to form a composite sample. The core sample was used to determine the soil bulk density and the composite sample was used to determine the other soil properties.

Collection of water quality data

Water quality properties. The Chaguana River Basin has no historical water quality records, so it was necessary to design and implement a sampling campaign to develop water quality profiles along its main streams. The environmental properties to be obtained are BOD, TOC, pH, solids content, temperature, dissolved oxygen, nitrate, ammonia and pesticide concentrations. Measuring these properties will give a profile of existing water conditions in which pesticides are transported.

Number of sampling sites. A preliminary exploratory field trip was conducted to get a better idea of the sampling points. A small boat was used to travel along the main tributaries in the

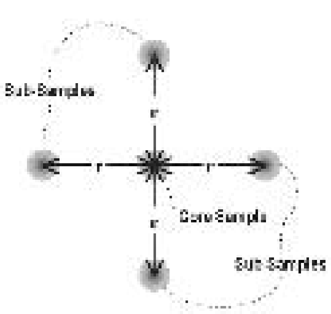

Figure 5 Cross-shaped sampling pattern adopted in soil exploration

Chaguana river system. The following information was obtained during this trip in as many points as possible:

- water depth, average flow velocity and river width
- delimitation of banana influence along the inspected rivers to determine which tributaries are more important from the pesticide impact point of view
- identification of point discharges (channels, pipes, etc.) coming from banana plantations
- ultimate accessible upstream location along evaluated streams.

Sampling campaigns. After the exploratory trip was completed, the sampling campaigns were planned with more confidence. The main objective was to cover a reasonable climate period during one year, so four sampling campaigns were defined in order to cover the following periods:

- transition between rainy and dry season
- dry season
- transition between dry and rainy season
- rainy season.

Sampling methodology. A plug-flow method will be used when sampling river water. Following the stream flow, the same water mass will be sampled at least every certain period of time. Average water velocity and sampling time will be recorded. The plug-flow method will give a better idea of degradation patterns and input of new pollution sources. At the confluence of tributaries, some kind of interpolation, extrapolation or superposition of results should be done. According to the exploratory trip, three main streams in the watershed are most important in getting runoff from banana plantations: Zapote River, Chaguana River and a big irrigation channel.

Results and discussion

Soil sampling campaign

Issues in sampling site determination. The soil campaign was conducted on the last week of March 2001. As written before, thirty locations were selected as sampling sites. However, during the sampling campaign, two main factors influenced the decision to obtain only 28 samples.

- Sampling sites were located using available topographical maps made in 1970. However, during the sampling campaign, it was discovered that many roads and access to sampling sites no longer exist or can be accessed only by mules so it was impossible to get to the sampling sites within the available time.
- Many farmers in the basin did not allow us to enter their properties to take soil samples. They claimed not to be interested in collaborating with the project.

Table 2 shows how the final sampling sites were distributed along the different criteria used in the sampling design (geology, landuse or edaphology). As can be seen, more sampling sites are located in these zones. Zones not important from the project point of view get less sampling weight or no samples at all, mainly based on following assumptions.

- Pesticides are mostly used in the banana sector.
- The banana sector is mainly located in alluvial deposits which primarily consist of silty sandy soils.
- From the point of view of edaphology, the banana sector is located in tropofluvents soils.

Table 2 Zoning of soil samples based on available information for Chaguana River Basin

Information type used in sampling design		Distribution of samples in a zone	
Geology	Alluvial deposits	22	78.57%
	Cretaceous formation	5	17.86%
	Metamorphic formation	1	3.57%
	Intrusive rock	0	0.00%
Land use	Banana sector	15	53.57%
	Pasture areas and other crops	5	17.86%
	Hilly areas	8	28.57%
	Shrimp farms' area	0	0.00%
Edaphology	Tropofluvents	10	35.71%
	Skeletal haplustalfs	6	21.43%
	Dystropets	6	21.43%
	Tropaquepts	3	10.71%
	Haplustalfs	2	7.15%
	Typic ustifluvents	1	3.57%
	Salorthids	0	0.00%

Soil tests results. Every sample was tested to determine parameters such as organic matter content, soil-water content, bulk density and texture. A summary of test results and some statistics are shown in Table 3. For each parameter data can be grouped in such a way, thus a normal distribution can be obtained. In this type of distribution, it is expected that around 68% of data will be found within one standard deviation for the total sampling population (see standard deviations for every measured parameter in 28 samples shown on the same table).

When evaluating the stratified sampling, it is desired that every stratum gets a representative number of samples within one standard deviation region and this for each sampling criterion. This statement should hold for every measured parameter. For every parameter data can fall in any of the following regions:

- Region S1: –1 standard deviation (s) to 1 standard deviation (s)
- Region S2: –2s to –1s, and 1s to 2s
- Region S3: –3s to –2s, and 2s to 3s

Table 4 shows the sampling distribution within every strata for every sampling criterion (landuse, geology and edaphology). As an example, for landuse criterion (banana farms, hilly areas and pasture areas; shrimp farms do not receive any sampling weight), the standard deviation for the organic matter content is 0.51% (see Table 3). If we consider the banana farm sector in the landuse criterion, it can be seen that around 73% of the 15 samples in that sector fall within the region S1, around 27% fall in region S2, and no samples in region S3. We observe that the distribution of samples fulfills the desires specified above and that therefore the sampling locations are representative for the type of assessment this study is aimed for, i.e. pesticides in banana plantations.

Water sampling campaign

Issues on the exploratory field trip. The trip was conducted in the second week of June 2001. Streams inspected during the survey were sections on the Chaguana River, Zapote

Table 3 Statistical parameters obtained from test results

	% Organic matter	% Water content	Bulk density (kg/m^3)	% Sand	% Silt	% Clay
Range	0.13–2.01	7.53–53.15	1,777–1,078	6–99.5	0.4–78	0.1–73
Mean (x)	1.16	31.11	1409.62	41.3	40.58	18.11
Standard deviation (s)	0.51	10.44	186.65	24.82	20.92	15.33

Table 4 Sampling distribution within standard deviation regions for three sampling criteria

Sampling criteria			**Soil parameters**					
			Organic matter	**Water content**	**Bulk density**	**% Sand**	**% Silt**	**% Clay**
Landuse	Banana farms (15 samples)	S1	73.3%	73.3%	66.7%	86.7%	86.7%	93.3%
		S2	26.7%	20.0%	33.3%	13.3%	13.3%	0.0%
		S3	0.0%	6.7%	0.0%	0.0%	0.0%	6.7%
	Hilly areas (8 samples)	S1	62.5%	25.0%	62.5%	50.0%	50.0%	37.5%
		S2	37.5%	62.5%	25.0%	25.0%	50.0%	62.5%
		S3	0.0%	12.5%	12.5%	25.0%	0.0%	0.0%
	Pasture areas (5 samples)	S1	60.0%	80.0%	40.0%	60.0%	60.0%	100.0%
		S2	20.0%	20.0%	60.0%	40.0%	40.0%	0.0%
		S3	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Geology	Alluvial deposits (22 samples)	S1	68.2%	72.7%	59.1%	77.3%	77.3%	90.9%
		S2	27.3%	22.7%	40.9%	22.7%	22.7%	0.0%
		S3	4.5%	4.5%	0.0%	0.0%	0.0%	9.1%
	Cretaceous formation (5 samples)	S1	80.0%	20.0%	80.0%	40.0%	40.0%	20.0%
		S2	20.0%	60.0%	0.0%	20.0%	60.0%	80.0%
		S3	0.0%	20.0%	20.0%	40.0%	0.0%	0.0%
	Metamorphic rock (1 sample)	S1	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%
		S2	100.0%	100.0%	100.0%	0.0%	0.0%	0.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Edaphology	Tropofluvents (10 samples)	S1	70.0%	70.0%	60.0%	90.0%	90.0%	100.0%
		S2	30.0%	20.0%	40.0%	10.0%	10.0%	0.0%
		S3	0.0%	10.0%	0.0%	0.0%	0.0%	0.0%
	Skeletal haplustalfs (6 samples)	S1	50.0%	50.0%	50.0%	50.0%	66.7%	83.3%
		S2	50.0%	50.0%	33.3%	33.3%	33.3%	16.7%
		S3	0.0%	0.0%	16.7%	16.7%	0.0%	0.0%
	Dystropepts (6 samples)	S1	100.0%	66.7%	83.3%	50.0%	66.7%	33.3%
		S2	0.0%	16.7%	16.7%	33.3%	33.3%	50.0%
		S3	0.0%	16.7%	0.0%	16.7%	0.0%	16.7%
	Tropaquepts (3 samples)	S1	66.7%	66.7%	33.3%	100.0%	66.7%	100.0%
		S2	0.0%	33.3%	66.7%	0.0%	33.3%	0.0%
		S3	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%
	Haplustalfs (2 samples)	S1	0.0%	50.0%	50.0%	50.0%	50.0%	100.0%
		S2	100.0%	50.0%	50.0%	50.0%	50.0%	0.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Typic ustifluvents (1 sample)	S1	100.0%	0.0%	100.0%	100.0%	0.0%	0.0%
		S2	0.0%	100.0%	0.0%	0.0%	100.0%	100.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

River and a big irrigation channel. The trip began near the end of the catchment's area at a town called Tendales, which is located around 6 km away from the seaside. The Chaguana River does not discharge directly to the sea, but this river basin is a tributary of a bigger river basin discharging to the sea: the Pagua River Basin. Table 5 shows the range of parameters measured during this exploratory trip. The following observations were made during the field trip.

- The river depth was too low in several locations (less than 0.5 m), so it was difficult to

Table 5 Parameters obtained during the exploratory survey in the inspected rivers

Inspected river	Traveled length	Mid-stream depth (m)	River width (m)	Water velocity (m/s)
Zapote	3.2 km	0.3–1.5	8–10	0.19–0.58
Chaguana	6.5 km	0.5–2.0	10–20	0.28–0.55
Big irrigation Channel[1]	–	< 0.3	–	–

[1] This stream could not be inspected due to very low water depth

continue traveling upstream the inspected streams. The observed low depth seems to be caused by low precipitation (dry season) occurring at this time of the year and the accumulation of sediments over a long period of time.

- Up to around 2 kilometres upstream from the intersection between Chaguana River and the Zapote River, it was possible to observe the tidal influence. This point could be used for future reference.
- The bottom of the Zapote river is less deep than the bottom of Chaguana river.
- The water depth at the irrigation channel was below 0.3 m, so it was not possible to inspect this stream.
- The boat used in this exploratory survey was not appropriate for existing conditions in the inspected streams because it had a keel beneath it. Due to this inconvenience, the use of a flat boat is planned for future sampling campaigns.

Number of water samples in future plug-flow sampling campaigns. The sampling size was decided on the basis of observations made on the exploratory trip and on existing map information. Assumptions made in determining the number of samples are:

- average water velocity of 0.4 m/s,
- using a flat boat, around 38 km of river length will be traveled in both the Chaguana and Zapote River crossing the majority of the banana sector in the watershed.

It was determined that 26 water samples would be enough to monitor the same mass of water while the boat is moving in the water flow. At the moment of writing this paper, the first water sampling campaign is being performed, thus it was not possible to include results from that campaign.

Conclusions

Soil sampling determination is always a critical decision-making strategy in a watershed assessment even more when important information is lacking or missing. There is always a possibility in not getting enough funding or time to conduct the assessment, especially in developing countries. With some existing information (maps) and the use of a GIS tool, stratified sampling can be an easy alternative to select sampling sites without risking the scope of the assessment. Perhaps, soil maps generated on these sampling data could not be used in farm specific assessment, but the level of information is good enough for the watershed evaluation, mainly as clay and organic matter content maps as indicators of pesticide presence. Although there are no data generated yet in the water sampling campaigns, the authors believe that sampling the same water mass along the river (follow-the-plug experiment) could give more important information that is more useful than taking samples at different times for the same river. Thus, both money and time are optimized by using this sampling procedure.

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