Development of a geographical information system for pesticide assessment on an Ecuadorian watershed

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Abstract Banana production is very important for the Ecuadorian national income, but it is also a potential source of river pollution in the country. Current research is focusing on the use of GIS to perform pesticide assessment of a river basin that includes banana as its main agricultural activity. The Agricultural Non Point Source Model (AGNPS) is being used to perform pesticide assessment in the basin. The model structure and type of needed data was identified. By applying GIS methodology, a complete set of cartographical information was obtained to supply input data to the pesticide model. In addition, ready-to-print maps were useful by-products for farmers.

Keywords AGNPS; data collection; environmental risk assessment; GIS methodology; mathematical modelling

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Problem definition

Banana is one of the main exportation products in Ecuador. Therefore, the understanding of environmental problems occurring in that agricultural activity could help in facing new upcoming regulations in world banana markets. That is the main goal of an ongoing interuniversity cooperation between ESPOL University (Ecuador), Ghent University and Free University of Brussels (Belgium): assessing environmental impacts of pesticide usage in the banana sector in Ecuador.

The Ecuadorian banana activity covers approximately 139000 ha distributed over 7 provinces, according to the Ecuadorian Central Bank. However, the banana activity is not always the only crop affecting a specific site; so, the impact assessment of pesticides coming only from banana plantations could be impossible to be performed. Sometimes, other crops use the same agrochemicals as banana crops (e.g. glyphosate). For that reason, the current project selected a site in such a way that the main goal could be achieved i.e. by minimizing other crop interference. The criteria applied for site selection were:

- as pesticides are transported mainly through the hydrological cycle, a river basin should be the most acceptable site to perform the assessment;
- the basin should be median or low size (less than 50000 ha) in order to avoid multiple crop activities.

After visiting some potential study sites, the Chaguana river basin was selected. It is located in the El Oro Province in the south-western part of Ecuador (Figure 1). This river basin is approximately 31200 Ha large. The watershed land use distribution shown in Table 1 is based on information given by the Ecuadorian Centre of Integrated Remote Sensing Survey (CLIRSEN).

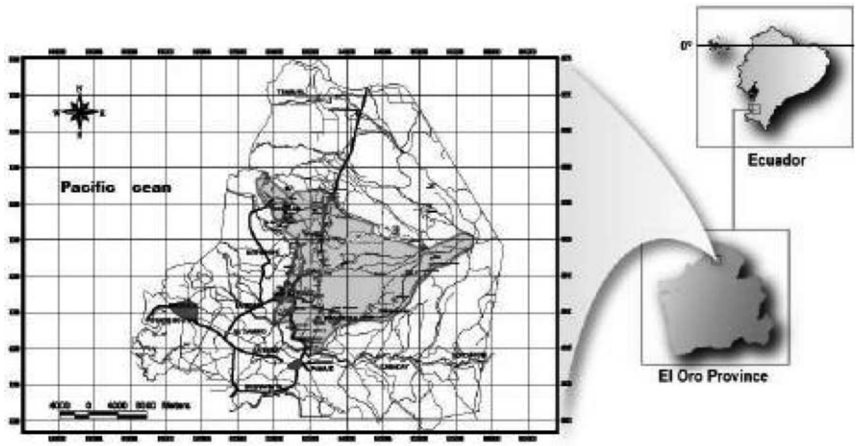

Figure 1 Location of the Chaguana river basin

To evaluate the pesticide movement in the basin, the AGNPS model, developed by an USDA-ARS (United States Department of Agriculture, Agriculture Research Service) team, was selected. In view of this, the second step in the project was to collect data to supply the model inputs. This step was accomplished by using Geographical Information Systems (GIS) in managing that information. There have been other experiences in using AGNPS interactively with GIS tools such as nutrients and fertilizer assessment on watersheds (Ma *et al.*, 2001). Also, GIS have proven to be useful in watershed-related problems such as erosion (Brady *et al.*, 2001) and management (Melancon, 1999).

Methodology

As a first step in implementing GIS, ArcView 3.2a from ESRI was selected as the GIS tool for data processing and evaluation. All needed information has been converted into spatial data (vector and raster data) in order to handle them with ArcView by using shapefiles and grid data. Data was georeferenced to the Universal Transverse Mercator Coordinate System as shown in Table 2.

Next, the project team identified the AGNPS model structure in order to optimise the available data sources in the basin. The model needs around 160 input variables to evaluate pesticide usage in a watershed (USDA-ARS, 2002). The input data are distributed over 28 data sections (Figure 2). Data can be alphanumeric or numeric values, which both ca be handled with a GIS. In the figure, the shaded boxes represent the minimum needed data sections for pesticide evaluation.

Table 1 Land use distribution in Chaguana river basin

Land use type	Percent area
Banana crop	26.21%
Humid forest	26.08%
Pasture	19.78%
Wet brushes	9.45%
Cocoa crop	6.17%
Mixture of crops and pasture	4.05%
Shrimp farms	3.02%
Other crops	2.99%
Mixture of crops, pasture and forest	1.03%
Barren area	0.84%
Mangroves	0.28%
Populated areas	0.10%

Table 2 Projection characteristics of evaluated data

Projection	UTM – Zone 17 S
Datum	Provisional South American Datum 1956
Spheroid	International 1924
Units	Metres
Latitude of origin	0°
Central meridian	−81°
False easting (meters)	500000
False northing (meters)	10000000

Based on the AGNPS structure, the available data was grouped into the following data.

Primary data were collected from available national databases and direct measurements in the field. These data were evaluated according to the source, year of publication and scale in order to optimise information extraction (Table 3). For example, edaphology data were extracted initially from printed maps (only existing soil taxonomy groups in the area); later, these data were complemented with own soil sampling campaigns (Matamoros *et al.*, 2002) and lab analysis (texture, soil moisture content).

Secondary data were generated from primary data by using kriging interpolation, accepted equations or methodologies applied in similar situations. The majority of the generated information was obtained on raster format because AGNPS is a grid-based model. The cell size for the generated raster data was 1 hectare. Multiple thematic maps were developed to extract input data for the model (Table 4)

AGNPS input data have to be spatially variable because the model works on a subwatershed basis. All subwatersheds in the basin are divided in three zones (Figure 3): upstream, left and right drainage area. Each zone represents what it is called "the cell" in the model. AGNPS cells are different than raster cells, although many raster cells could be included within an AGNPS cell. The cell division depends on the drainage pattern and

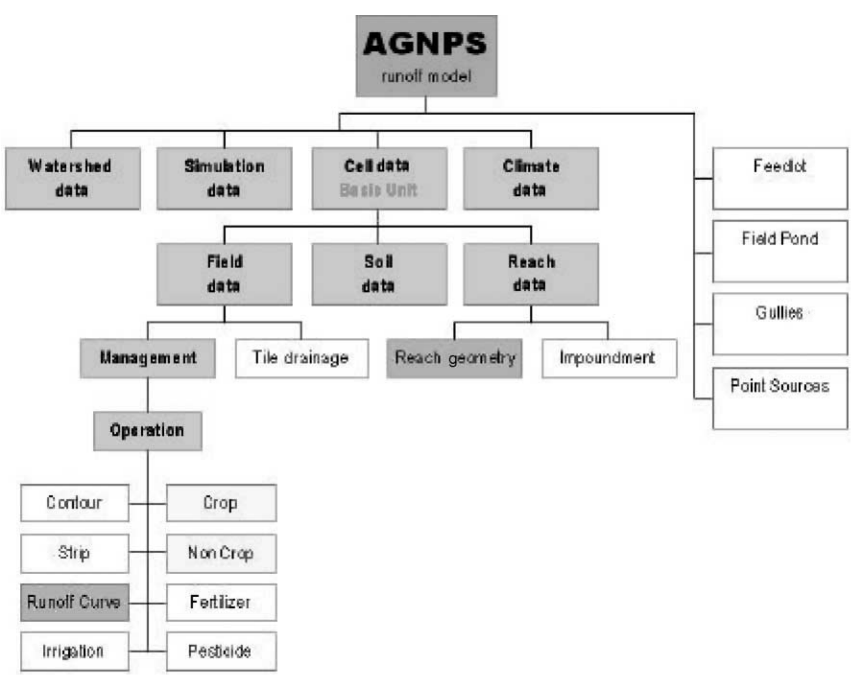

Figure 2 AGNPS model structure based on Bosch *et al.* (1998)

Table 3 Primary data obtained in the Chaguana river basin

Data	Primary Source	Year	Scale	Data extraction procedure
Topography	Printed map	1970	1:50000	Scan of 4 topographical sheets
Geology	Printed map	1970	1:250000	Scan of 1 geological sheet
Edaphology	Printed map	1970	1:250000	Scan of 1 edaphological sheet
Land use	Digital data	1998	1:50000	Visualization in ArcView
climate	Database	Depends on station	Not applicable	Georeferencing of 5 weather stations
Soil	Field measurement	2001	Not applicable	Georeferencing of 30 sampling sites
Water quality	Field measurement	2002	Not applicable	Georeferencing of 26 sampling sites

a threshold value to form a cell. Thus, a watershed could be divided as many times as needed in order to capture data spatial variability.

By overlaying the secondary data with the "*AGNPS cell*" thematic map, the input data for the model was obtained. However, in some cases a data aggregation of many raster maps into a single thematic map had to be done. Aggregation is performed by overlaying the "*AGNPS cell*" thematic map with the corresponding raster map for data extraction. For example, the complete soil information was attached to the general soil taxonomic map (polygons) in order to have a more detailed soil map for AGNPS usage.

Results and discussion

All gathered primary data were processed and converted into thematic maps (secondary data) based on a previous methodology, as shown in Figure 4 for the soil information.

Table 4 Thematic maps generated from primary data on the Chaguana river basin

Thematic Maps	Geographic Feature	Generation procedure	Reference
Elevations	Point	Digitising from scanned maps	GIS procedure
Digital elevation model	Grid	Interpolation procedure	GIS procedure
Slope	Grid	ArcView Avenue statement	GIS procedure
Geologic units	Polygon	Digitising from scanned maps	GIS procedure
Taxonomic units	Polygon	Digitising from scanned maps	GIS procedure
Weather stations	Point	Event theme in ArcView	GIS procedure
Precipitation	Grid	Interpolation procedure	GIS procedure
Runoff erosivity factor	Grid	Use of RUSLE equations in map calculator	USDA-ARS (1996)
Sampling sites	Point	Event theme in ArcView	GIS procedure
Clay content	Grid	Interpolation procedure	GIS procedure
Silt content	Grid	Interpolation procedure	GIS procedure
Sand content	Grid	Interpolation procedure	GIS procedure
USDA soil texture	Grid	Boolean algebra	Benham *et al.* (2001)
Very fine sand content	Grid	Interpolation procedure	GIS procedure
Soil moisture content	Grid	Interpolation procedure	GIS procedure
Saturation content	Grid	Map calculator	Saxton *et al.* (1986)
Field capacity content	Grid	Map calculator	Saxton *et al.* (1986)
Wilting point content	Grid	Map calculator	Saxton *et al.* (1986)
Bulk density	Grid	Map calculator	Saxton *et al.* (1986)
Hydraulic conductivity	Grid	Map calculator	Saxton *et al.* (1986)
Hydraulic soil group	Grid	Boolean algebra	USDA-NRCS (1986)
Organic matter content	Grid	Interpolation procedure	GIS procedure
Soil albedo	Grid	Map calculator	
Soil map	Polygon	Data aggregation from soil grids by using Taxonomic Map as a mask	

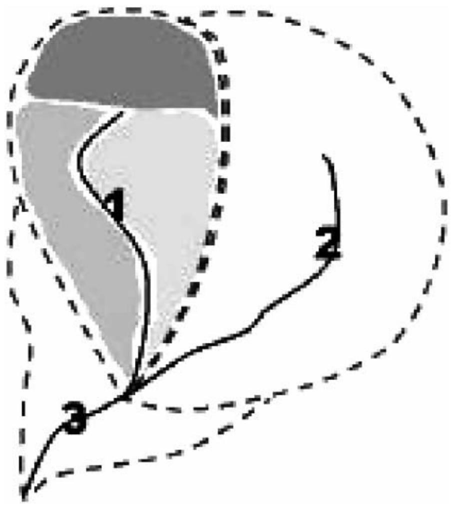

Figure 3 AGNPS cells created from watershed subdivision

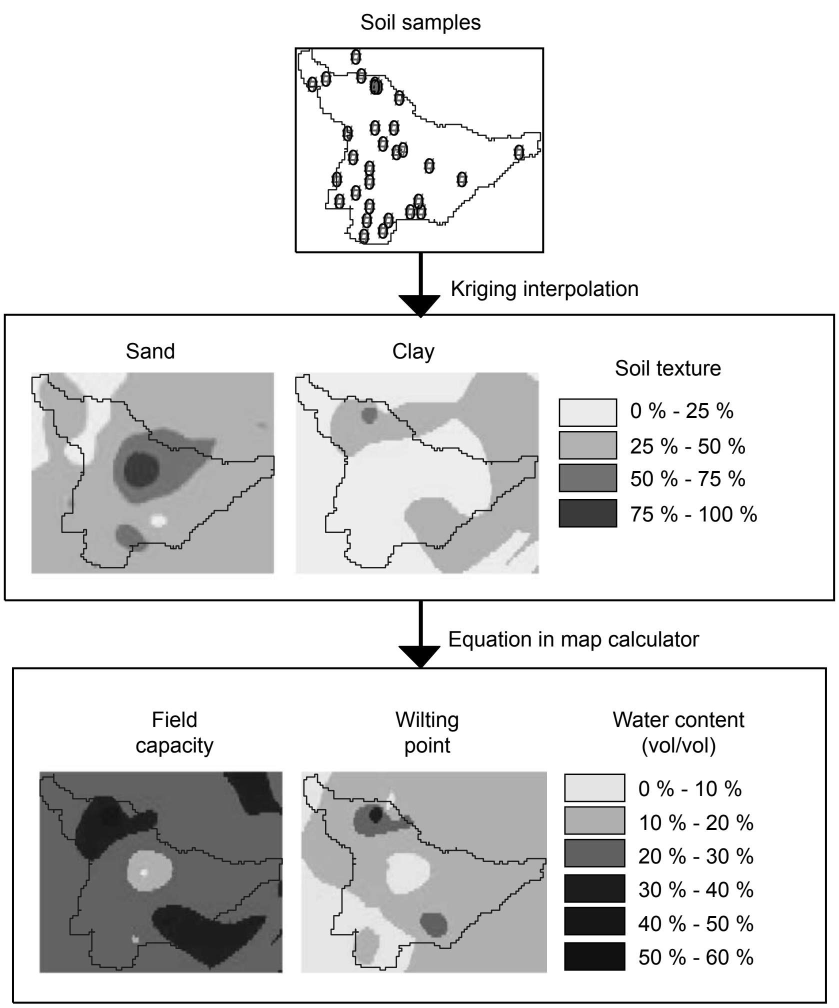

Figure 4 Example of data processing with soil information

When performing the overlaying procedure, a limitation was observed: an AGNPS cell can only have one soil type and one land use type. However, most of the time more than one soil/land use type falls into one AGNPS cell. The ArcView interface that comes with the model performs a joint spatial analysis to solve this problem by assigning the soil/land use ID with more surface area to the entire cell. The main drawback of this procedure is the loss of information across the basin. Table 5 shows the maximum information loss percentages depending on the number of characteristic types falling in a single AGNPS cell.

For the analysis, the Chaguana River Basin was divided into 192 AGNPS cells which drain into 78 river reaches. The resulting cell areas vary between 1 and 829 Ha. When overlaying the soil thematic map, 80 AGNPS cells corresponded to more than one soil type (Table 6). Due to the joint spatial analysis, the soil information for around 15% of the basin surface area was not included as input data. The same assessment was done with land use as shown in Table 7. Land use information for around 18% of the basin surface area was not included as input data.

From the tables, it follows that there is more chance to have two types of characteristics falling in one cell than more types. Although it seems that the soil information loss is quite significant (around 15%), the regional soil characteristics are pretty similar in the region (silty sandy soils) and so the loss percentage is acceptable for the assessment. In the case of land use, the loss percentage could also be significant, but only 2% of the not considered area corresponds to cropland. Therefore, also the land use loss is considered acceptable for the assessment. A more detailed watershed subdivision could decrease the information loss. However, the extra effort would probably not be cost-effective. Moreover, more data should be collected to get to the more detailed analysis.

Table 5 Maximum information loss by assigning the object ID with the largest area in a cell

# of ID's falling in a single AGNPS cell	Maximum information loss based on area
1	0%
2	50%
3	66.67%
4	75%
n	(n − 1) 100/n %

Table 6 Spatial joint analysis on soil information

# soil types per AGNPS cell	Number of occurrences out of 192 cells	Total area not considered after joint spatial analysis	% of total basin area
2	51 cells	1951 Ha	6.26%
3	22 cells	1953 Ha	6.26%
4	7 cells	759 Ha	2.43%
Total	80 cells	4663 Ha	14.95%

Table 7 Spatial joint analysis on land use information

# land use types per AGNPS cell	Number of occurrences out of 192 cells	Total area not considered after joint spatial analysis	% of total basin area
2	74 cells	2199 Ha	7.05%
3	34 cells	2839 Ha	9.10%
4	7 cells	377 Ha	1.21%
5	1 cell	123 Ha	0.39%
Total	80 cells	5538 Ha	17.75%

Conclusions

The applied GIS methodology is demonstrated to be very helpful in handling input data for the pesticide model. A complete set of cartographical information was obtained by applying GIS methodology. However, transfer of data to the input file could only be done automatically for the topographical, cell and reach data through two modules in AGNPS (TopAGNPS and AgFlow). The rest of the data (climate, soil and operation management) had to be entered manually through an input interface (INPEDIT). Some information could be extracted from the GIS. There is ongoing research to develop new interfaces to enter data into AGNPS through GIS. In the meantime, the Geographic Information System was used to handle and manage the information for later use in the model.

Based on the AGNPS cell division, some information is lost when a joint spatial analysis with GIS data is performed. However, the information loss was considered acceptable for the basin under study.

Finally, the generated digital information is also going to be used as ready-to-print maps to help farmers in their own activities, such as precision agriculture.

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