Vulnerability assessment of aquifers in an urban-rural environment and territorial ordering in León, Mexico

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RESUMEN

Evaluaciones regionales de vulnerabilidad acuífera, DRASTIC y AVI, son adecuadas a una escala local para analizar el uso de suelo en la zona sudoeste de la ciudad de León, Guanajuato, México. Los mapas temáticos a base de isolíneas son transformados en mapas de rejilla para ser utilizados en un Sistema de Información Geográfica, GIS. Las principales fuentes potenciales de contaminación acuífera son incluidas en el análisis del ordenamiento territorial. Se analizan conjuntamente tendencias de vulnerabilidad y usos de suelo. Se revisan las tendencias de expansión urbana de acuerdo con la vulnerabilidad que presenta el acuífero. Se definen áreas restrictivas para el desarrollo urbano por su alta vulnerabilidad.

PALABRAS CLAVE: AVI, DRASTIC, uso de suelo, ordenamiento territorial, León, Guanajuato.

ABSTRACT

Regional assessments of aquifer vulnerability, DRASTIC and AVI, are adapted to a local scale for land use in the southwest zone of León, Guanajuato, Mexico. The isoline maps were transformed to grid maps to be used by a Geographical Information System, GIS. The main potential sources of aquifer pollution were included in the territorial ordering analysis. The vulnerability tendencies and land uses were analyzed. The urban expansion tendencies were revised taking into account the aquifer vulnerability zoning. Vulnerability areas were restricted for urban development.

KEY WORDS: AVI, DRASTIC, land uses, territorial ordering, León, Guanajuato.

INTRODUCTION

In the industrial corridor of the Bajío Guanajuatense region of the Mexican Highlands, accelerated industrial and population growth, technification of the agriculture, and environmental uncontrolled human activities represent contamination risk of the aquifer systems. The southwestern area of León city, Guanajuato state, central Mexico, is taken as an example of potential environmental impacts that could occur on groundwater when the aquifer vulnerability status is not taken into account in urban planning.

León is an important development pole of the Bajío region. It is one of the more important leather and footwear industrial centers in Mexico. Aquifer contamination has been reported in the León valley. Some pollution is related to inadequate disposal of industrial wastes, handling of urban and industrial sewage and leakage of natural chromium from Jurassic ultramafic rocks (Rodríguez and Armienta, 1985). A major indicator of affectation of the aquifer system in the urban area is a high content of chlorides in the groundwater (BGS, 1996).

Future urban expansion, human settlements and industrial corridors, must consider aquifer vulnerability to potential contamination sources like garbage dumps, active landfills, cemeteries, gas stations, leakage (in water pipelines, sewage, industrial ducts) handling of liquid and solid wastes of micro-industry, residual agrochemicals and the use of wastewaters in agriculture (Zektser *et al.*, 1995).

The urban area will contain more than a million inhabitants by the beginning of this century. This population growth will require more than 10 000 new homes that mean the endowment of new services. Modifications of land use are also contemplated. New projects include a wastewater treatment plant and a landfill, that require environmental impact assessments where elements like the DRASTIC and AVI indexes can contribute valuable approaches for urban planning considering the preservation of the groundwater quality.

In urban and territorial planning, the appropriate use of the land is a decisive factor in the preservation of resources; therefore, it is important to implement programs and appropriate policies for land use.

The population of León represented 23% of the total population of the state of Guanajuato in 1995 (IMPLAN, 1999). SAPAL, the municipal institution entrusted with water supply, proposes for the year 2020, to limit downtown growth, reduce the density of the urban area as well as the maximum density of the future area of growth "taking in consideration the potential sources of water and their origin", and channel growth toward the most suitable areas in terms of cost of hydraulic infrastructure and distance to "the studied water sources" (SAPAL, 1999).

The situation of water in the León valley depends of population size and on the nature of activities which demand large volumes of water. If the present conditions of water use and demand prevail, the situation will become unsustainable in less than 30 years. The problem of water in León valley is a similar to other regions of the Bajio Guanajuatense and other regions of Mexico.

BRIEF DESCRIPTION OF VULNERABILITY ASSESSMENT METHODS

The aquifer vulnerability of León valley, as assessed and represented in thematic maps of regional scale, 1:100,000, AVI and DRASTIC (Rodríguez *et al.,* 1999), can be interpolated to smaller scales to analyze the risk of the human activities in urban and rural areas. The data, ranges and classes of both methods are described in the report elaborated by Rodríguez *et al.* (1999). An analysis of this risk could be done by incorporating the maps of vulnerability indexes DRASTIC and AVI, by means of cartographic overlapping, to the current use of the land in a selected area between the cities of León and San Francisco del Rincón. This area is representative of the transition between urban and rural environments.

The DRASTIC method, developed by EPA (Aller *et al.*, 1985), includes seven representative factors of a predefined hydrogeologic scenario. The initials of the seven parameters form the acronym DRASTIC and usually include existing data. The DRASTIC index is calculated by the sum

$$\mathbf{D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W =}$$ **DRASTIC Index**

where

D Depth to water **R** = Rating (Index)
R (Net) Recharge **W** = Weight
A Aquifer Media
S Soil Media
T Topography (Slope)
I Impact of the Vadose Zone
C Conductivity (Hydraulic) of the Aquifer

The AVI method (Van Stempvoort *et al.*, 1992) only includes two parameters and is one of the simplest methods to assess aquifer vulnerability. The hydraulic conductivity and the thickness of each layer or strata of the vadose zone are applied in the following expression:

$$\mathbf{c = \Sigma bi/Ki} \qquad i=1,2,3...j$$

where

bi = thickness
Ki = hydraulic conductivity
C = hydraulic resistance

The regional DRASTIC and AVI maps of León valley (Rodríguez *et al*, 1999) were built with stratigraphic information from new municipal wells. Geoelectrical information was used to integrate geological profiles. Hydraulic conductivity values were obtained from pumping tests and from *in situ* measurements using a constant head permeameter.

The maps of land use were elaborated mainly from digital information of INEGI vectorial data, digital models of elevation and the topographic, geologic and land use maps and other maps that were digitized with Auto Cad, at scale 1:50,000. This data set was integrated to a Geographical Information System, GIS, in Arc View and IDRISI. The potential sources of aquifer pollution were geo-positioned.

THE STUDY AREA

The study area is between the boundaries of the municipalities of San Francisco del Rincón, León and Purísima de Bustos, mostly within the limits of the municipality of León (Figure 1). The main locality is Plan de Ayala. Among the criteria for the selection of the place, we took into consideration the physical characteristics and relationship with the socio-economic environment. The zone comprises an agricultural area irrigated with untreated wastewater. In this area, special conditions exist around urban growth and its corresponding hydrogeologic scenario. The local aquifer is a part of the León valley aquifer (Rodríguez *et al.*, 1991).

The area is 164.25 km^2, in a rectangle of 15 km by 10.95 km. It is located in the west-central Trans-Mexican Volcanic Belt, TMVB, composed of volcanic rocks of all types accumulated in many successive volcanic episodes that began by mid-Tertiary. The TMBV contains volcanoes, lava flows, dispersed and grouped volcanic cones, basaltic shield-volcanoes, and deposits of sand and ash over extensive plains (INEGI, 1980). The area is included in two topographic subprovinces (plateaus and plains); the plateau is located to the Northwest (Altos de Jalisco subprovince) whereas the southeast plain corresponds to the Bajío Guanajuatense subprovince (Martínez, 1992). The features are due to tec-

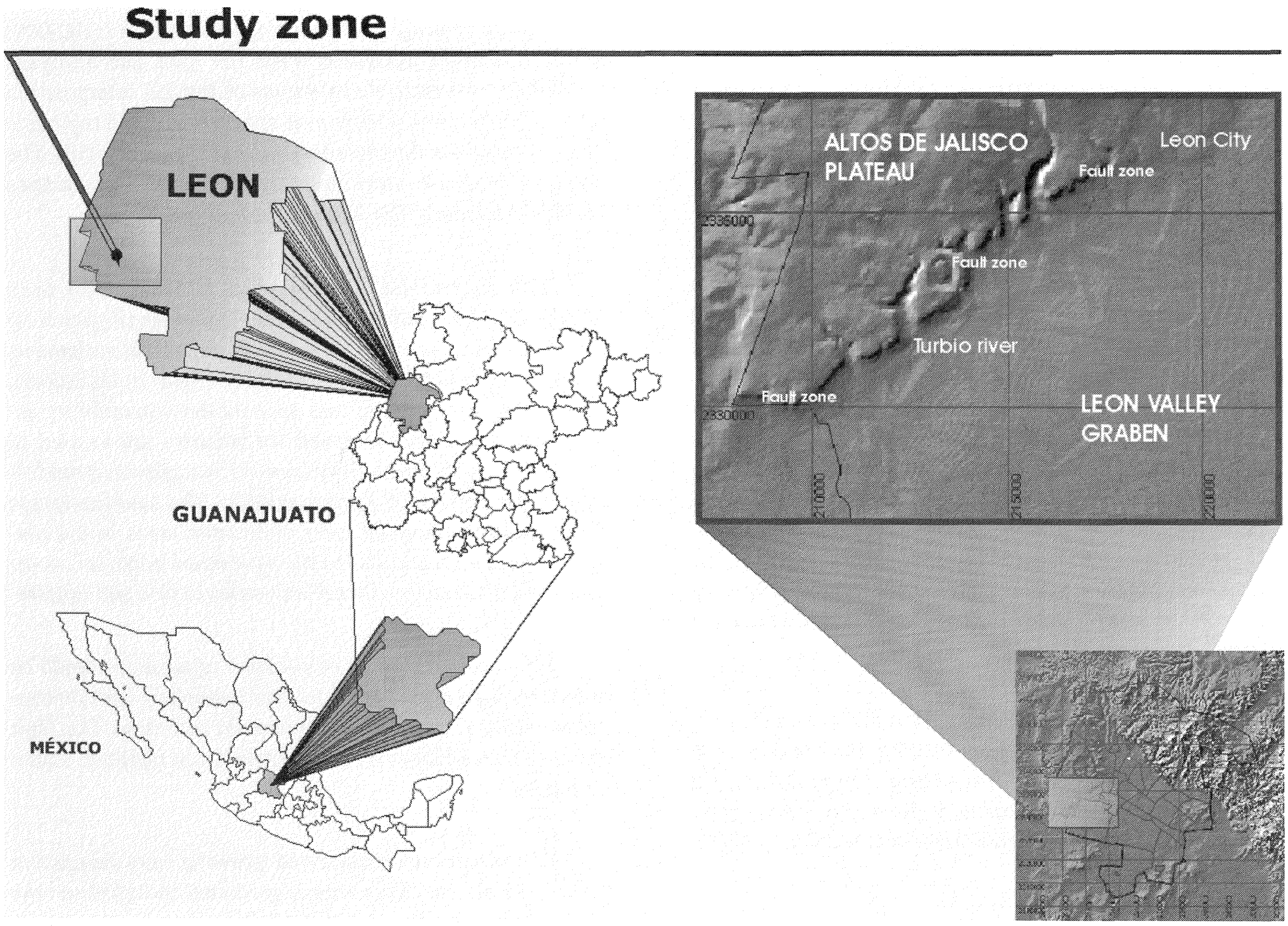

Fig 1. The Study area in León valley, Guanajuato state, Mexico.

tonic activity. They are divided by a SW-NE fault. This fault intersects the Bajío Fault outside of the study area. Both faults are considered active (Martínez, op cit; Quintero, 1986). The fault facilitates the incorporation of rising regional flow into the aquifer under the plain (Rodríguez and Gutiérrez, 1992). The Altos de Jalisco suprovince is part of a system of tectonic pillars that bounds partially the León valley graben; this graben was filled with Quaternary sediments of different grain sizes and consolidation. The sediment column may be more than 1000 meters thick in some areas.

The aquifer system is formed by a shallow unit and a semiconfined aquifer. Permeable tuff layers define the semiconfined aquifer. Shallow aquifer units include gravels, sands and clay lenses. Paleochannels define locally perched aquifers (Castelan and Villegas, 1995). Both aquifers have some hydraulic communication. The semiconfined unit is tapped by urban and agriculture wells. The vulnerability assessment was done for the shallow watertable.

The Altos de Jalisco Plateau contains mainly extrusive igneous rocks and sediments of volcanic origin: Quaternary basalts and five upper Tertiary units, two sedimentary (gravel, gravel-conglomerate). The rest is largely formed by rhyolites, andesites and ignimbrites. The plateau is part of the recharge areas of the aquifer system in the plain.

GIS VULNERABILITY MAPS

The DRASTIC and AVI isoline maps were cut and exported by IDRISI. IDRISI generated a new data set. The extreme values were conserved and fell inside the same ranges. New vulnerability gradients were generated by means of automatic interpolation with IDRISI. These points were re-interpolated from the regional scale, 1:100,000 to a local scale of 1:50 000, generating a raster image incorporating vectorial features. The thematic maps (geology, edaphology, land use, topography, etc.) were digitally processed, integrating a GIS scale of 1:50,000. The maps of land use were upgraded with LANDSAT satellite images in the bands TM-7 and air orthophotograph. The main potential sources of contamination were located. The vulnerability maps were superimposed on the GIS layers (agriculture areas, human settlements, potential pollution sources, industry and the urban development tendencies).

DISCUSSION

The lower ranges in the vulnerability index AVI, according to the results of the new interpolation (Figure 2), vary from -0.24 to 0.34 (weeks to 2 years in transit times). They are located in the southeast of the area, in the plain. The geology is formed mainly by Quaternary alluviums of variable permeability. The clay predominance confers low vulnerability. In this low vulnerable area there are no located individual pollution sources. This portion is irrigated with untreated wastewater. High vulnerability was found along portions of the fault trace and in Plan de Ayala, where Mastranzo Dam is located. To the southwest, San German Dam is located over a highly vulnerable area. The southwestern part of León City is located in a medium vulnerability area. Medium vulnerability areas are also dispersed in the Alto de Jalisco plateau where only small scattered are located.

The Turbio river crosses the vulnerable areas. This river received urban and industrial untreated wastewater. In León there are more than 500 small tanneries. Before installation of the urban wastewater treatment plant, the Turbio river was considered one of most polluted rivers in Mexico (BGS, 1996).

The vulnerability zoning obtained with the DRASTIC index (Figure 2), shows some differences with the AVI map. The extreme DRASTIC values were 99.44 as minimum and 173.86 as maximum. The DRASTIC and AVI tendencies are quite similar. The high values (in red) are located in three separate areas, the highest west and east of the Alto de Jalisco plateau, while the others are near Mastranzo Dam and in the municipal area of León city. The lowest vulnerability (green) is in the León valley plain. The San Germán dam area is a medium vulnerability area. The low vulnerability corresponds to predominant clay units. As in AVI the vulnerable areas correspond to fractured rock locations. Low permeable tuffs underlie the permeable Cuatralba ignimbrite that outcrops in the plateau.

CONCLUSIONS

The population growth in the Bajío Guanajuatense region has gradually impacted the environment. In some areas, industrial activity, the uncontrolled handling of resources and inadequate use of land, have caused contamination of groundwater and soil. The prevailing social and economic inequalities have impacte§ natural ecosystems; it was reported that four in five inhabitants of León City are poor (AM, 2001).

The re-scaling of regional vulnerability (1:100,000) maps to a more adequate scale for land use analyses (1:50,000), was possible by means of IDRISI interpolation criteria. The isoline scheme was changed to a grid representation to facilitate the incorporation of the maps to GIS. The maps of land use were upgraded with satellite images LANDSAT (bands TM-7) and air photographs.

The Territorial Zoning map of León City area (IMPLAN, 1997) defines three main land uses (Figure 3-A) in the study area; ecological (green colors), urban settlements (orange colors) and medium industry (light violet colors). This zoning did not take into account the vulnerability assessment. The zones reserved for industry are located in DRASTIC high vulnerability areas. Urban growth is not following the Territorial Zoning criteria. The satellite image shows small settlements over vulnerable areas in the plateau (Figure 3-C) and also in the agriculture zone. It is common to find hazardous illegal industries in new settlements.

Infrastructure works in informal urban areas could be done over long periods of time thus increasing the environmental risks of uncontrolled industrial activities. The fault represents an additional risk because it can facilitate solute migration.

The urban area must avoid growing into the eastern part of the plateau. This area is predicted to be vulnerable by both methods. The ignimbrite fracture level makes it vulnerable; on the other hand it is part of the recharge area. The urban growth in this part of the city could extend to the plain, but it is agricultural land. If this activity prevails the use of untreated waste water must be stopped.

The vulnerability of the local aquifer system is proven by the high content of chloride in local wells (Báez, 2001). The municipal landfill is located in a high vulnerability AVI area, but in a medium vulnerability DRASTIC zone. AVI only considers two parameters, whereas DRASTIC considers seven. A solute generated in the landfill can quickly reach the water table, if it gets through the first thin tuff layers.

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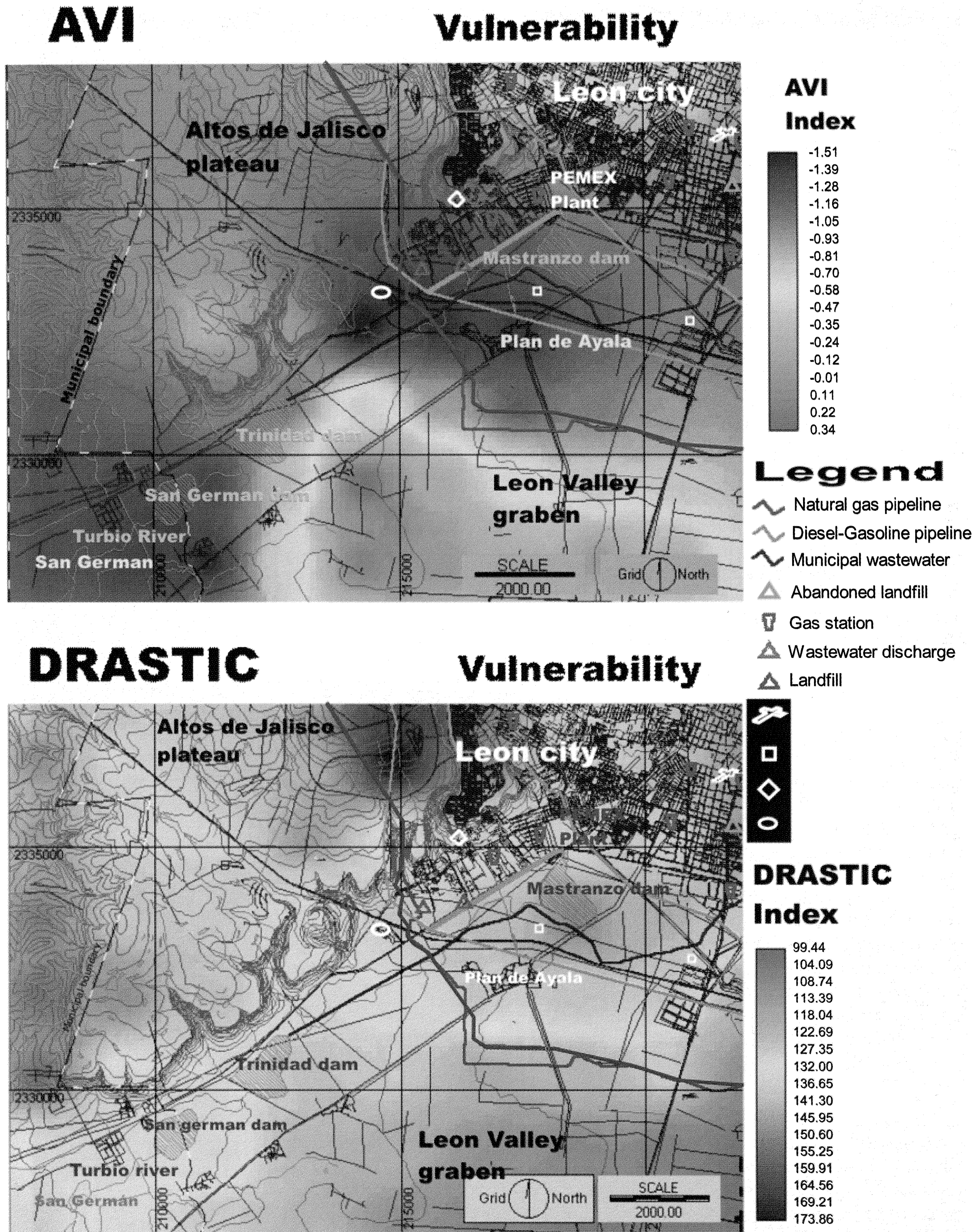

Fig. 2 Contamination potential sources and vulnerability maps of Plan de Ayala zone.

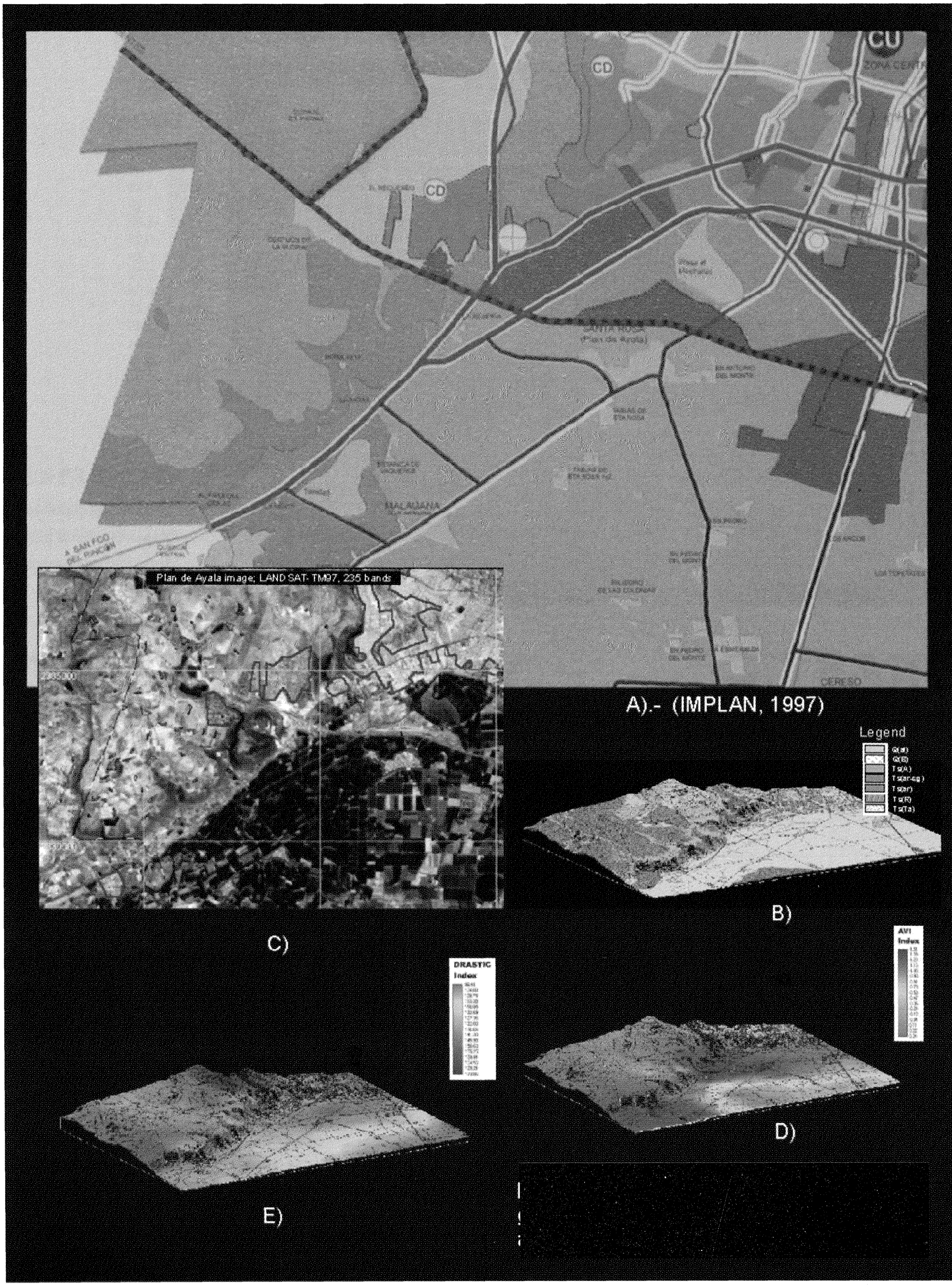

Fig 3. Territorial planning (A). Geology (B), vulnerability 3d views (D, E) and satellite image (C) of the study area.

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