Chapter 8
Characterization of the Vulnerability to the Contamination in Defined Areas of the Vento Aquifer, Validated with Geophysical Methods

I. Pedroso Herrera, M.J. Fundora, F. Méndez, M. Guerra, and I. González

Abstract In this paper an assessment of the specific vulnerability of the Vento aquifer by using geologic, geomorphologic and hydrologic considerations validated by geophysical methods (seismic and the electrical resistivity) is carried out. The application of geophysical methods allowed the determination of the presence of thin layers of clays that could protect the underlying aquifer and to know the thickness of the intermediate conductive layer, taking into account that to greater conductance greater protection of the aquifer. It also allows the evaluation of the presence of fractures, cracks and faults that are more vulnerable in the aquifer. Once obtained, the intrinsic vulnerability, the specific vulnerability of sectors of the basin, was obtained by means of the combination of the intrinsic vulnerability map with the zoning map of the potential contamination by heavy metals obtained by using techniques of environmental magnetism through the measurements of magnetic properties of soils in the field and laboratory.

Keywords Aquifer vulnerability • Vulnerability map • Heavy metals contamination • Environmental magnetism • Vento aquifer • Cuba

I. Pedroso Herrera (✉)
Agencia de Medio Ambiente del CTMA, Calle 20 esq. 18A Miramar, Playa, La Habana
e-mail: ida@ama.cu

M.J. Fundora
Department of Geosciences, Technical University of Havana "Jose A. Echeverria", MES, Calle 116 S/N esq. a 127, Marianao 15, La Habana, Cuba

F. Méndez
Department of Geology and Geophysics, Faculty of Geology, University of Pinar del Rio, MES, Pinar del Rio, Cuba

M. Guerra • I. González
Institute of Geophysics and Astronomy, CITMA, 212 N0 2906 esq. 31, Rpto "La Coronela", La Lisa, Cuba

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8.1 Introduction

The Vento aquifer is one of the four basins that supply water to the Cuban Capital and the one that gives the greatest volume of water (8.8 m^3/s) that it consumes. To be a non-confined karstic aquifer, the hydraulic groundwater resources exhibit a high vulnerability to contamination. At the basin there are more than fifty polluting sources, some of them contaminate the soils with toxic metals. If monitoring was performed by the conventional chemical techniques, it would be very expensive. This expense could be reduced by using measurements of the magnetic susceptibility of the soils as proxy indicators of probable contamination in those areas where intrinsic and specifically larger vulnerabilities are expected in the contamination by heavy metals. To achieve a more precise evaluation of the intrinsic vulnerability, estimated by geologic and geomorphologic methods as well as of the specific vulnerability to heavy metals, a geophysical investigation with the following objectives was carried out:

1. To specify the characteristics of the geological section unto the depth of 15, 00–20, and 00 m, as well as to estimate the main physical-mechanical characteristics for the different types of rocks and present soils in the area by using a seismic method.
2. To define the presence of faults, fractures and crackings, as well as to determine the thickness of the Unsaturated Zone (USZ) and the clay content, by using electrical methods of resistivity.
3. To evaluate the specific vulnerability of the aquifer starting from the combination of the cartography of the contamination for heavy metals, obtained with environmental magnetism techniques and the intrinsic vulnerability of the aquifer, by using a project SIG.

The first two objectives allow the estimation of important elements necessary to evaluate the intrinsic vulnerability of the aquifer to the contamination.

8.2 Materials and Methods

The cartographic materials used were the geologic, lithologic, geomorphologic and hydrogeologic maps of the basin.

The lithologic composition allowed the differentiation of the two main hydrogeologic units, a central one very karstified and one that constitutes the main aquifer of the basin and which is evaluated as a holokarst by its lithologic thickness; and another one is located in the borders of the basin, which is less karstified and is evaluated as a merokarst for its thickness and lithologic composition. To complete the required information, in order to evaluate the intrinsic vulnerability, the geophysical works of two seismic lines were carried out. The results of the electric profiles and Vertical Electrical Soundings carried out in previous works by the National Institute of Hydraulic Resources, were reinterpreted.

8.2.1 Seismic Method

Seismic lines in two areas were carried out, one of them characterized by marls rocks and the other by calcareous ones in order to determine the physics and mechanics parameters of these rocks for different degrees of conservation.

The seismic observations were carried out for the refraction variant using a base line of 24 channels, with the typical methodology followed for these works (Gurvich 1975). For the interpretation of the seismic data the software Winsim 9 was used and the following procedures: Method of interception points, interpretation of Retard (Delay – Method) and in some cases the Widespread Method of the Reciprocal ones was used (General Reciprocal Method or GMR; Mareš 1984).

8.2.2 Geoelectrical Methods

With the acquired data using the Vertical Electric Sounding (VES) and the combined electrical profiling variants for the measurements of the electric resistivity methods (Orellana 2007), the corresponding electric profiles were elaborated as well as maps of isolines for the apparent resistivity, with which resistive variations of the section could be pointed out, so much vertical as horizontally correlating this information with some anomaly. Seven profiles were carried out.

8.2.3 Environmental Magnetism

To assess the specific vulnerability of the Vento aquifer, an outline for the zoning of the pollution of the soils by heavy metals in the basin was used. This was built up by starting from surveys of the magnetic susceptibility on a 250 by 250 m grid to a scale of 1:250,000 as well as other surveys carried out on grids of different scales around some industries, roads and some others possible sources of pollution (Pedroso Herrera et al. 2005).

The measurements were processed statistically according to the standard procedure for the magnetic properties of the rocks (Mareš 1984; Pedroso Herrera et al. 2005; Pedroso et al 2004). To estimate the values of the magnetic susceptibility of the soils that characterize the non-polluted areas it was considered a value threshold by means of the processing of magnetic susceptibility measurements in non-polluted areas, taking as such those far away ones more than 5 km of the contamination sources. To characterize the susceptibility of the polluted soils, the measurements in areas close to the potential sources of contamination in a radius smaller than 500 m were processed statistically. For this processing the application Software STATISTICA was used for Windows version 5.0. To create the isolines map of the magnetic susceptibility, SURFER software, version 8.2 was used (Pedroso Herrera et al. 2005).

Using the Geographic Information System (GIS) elaborated in the frame of the project, the outline of the zonation of the contamination by heavy metals was made according to the cartography of the magnetic susceptibility.

8.3 Results and Discussion

8.3.1 Geologic Interpretation of the Seismic Information

8.3.1.1 Area of Antillana de Acero

The section in this area recognizes a layer of vegetable covering and underlying to this layer, there are clayed marls that have been referred by the seismic interpretation as impermeable and being developed until the depth of 3 m. Among the depths of 5–35 m, two levels of very defined karst are recognized which are composed by marl limestone or calcareous marl in an upper layer and by karstified limestone in a lower one. Starting from here one can interpreted that the area is impermeable only until the first 3 m deep.

8.3.1.2 Area of the Vocational School "V.I. Lenin"

In this section a first horizon is observed, which is formed by a vegetable layer composed of clayed sands with organic matrix and very porous and very plastic red clay that is developed until the 3 m deep. These results reveal a high permeability from the surface, as this area is very vulnerable.

The results show that the area of the Antillana de Acero is impermeable only until the first 3 m deep, while the area of the Lenin School has a high permeability from the surface, as this area is more vulnerable.

8.3.2 Interpretation of the Geoelectric Results

For each profile, a geologic and geomorphologic interpretation of the results given by the geophysical methods was carried out to estimate the vulnerability of the basin, considering the porosity, permeability and claying of the rocks, as well as the presence of possible faults. In this case it will show two cases as examples.

8.3.2.1 Profile I

In the geoelectric section prevail the calcareous marl, upward they have a greater content of clay, which is manifested in the vertical sections of the apparent

electrical resistivity. Downward this marl becomes calcareous with cracks and fissures. The vegetable layer has a thickness of about 5–8 m. In this section an anomalous area is manifested, similarly it occurs with the combined electric profiling. This anomaly corroborates the supposed fault of NW – SE direction.

8.3.2.2 Geologic and Geomorphologic Considerations

The geoelectric section indicates the presence of two lithologic layers that underlie a covering thickness of up to 8 m. The upper layer is constituted by calcareous marl with a high content of clay in the upper part. The lower layer is composed of that same marl, but here it is more calcareous, karstified and has cracks and fissures. In the vertical section of this profile, due to the lithologic changes that occur, the behavior in depth for the different layers of the profile causes the conditions to be of the intrinsic vulnerability that vary in depth. In this case the vulnerability is mean.

The possible presence of a fault can benefit the favorable conditions for the infiltration, being the direction of the flow is that of the fault.

8.3.2.3 Profile II–III

In this section the marl limestone has a manifested crack that leaves making it more compact and more calcareous. It is also manifested markedly in the combined profiling and in the section of the resistivity isolines. More below in the section calcareous marls and marl exist. In the profile there is another area of interest that can be related with the first tract of the fault guided in the SW-NE direction.

8.3.2.4 Geologic: Geomorphologic Considerations

The cracked marl limestone presents favorable conditions for the infiltration that occurs through the cracks. The presence of calcareous marl, more compact and more calcareous, should slow velocity of the flow that traffics the cracks; however, at the base of the section composed by calcareous marls and marls there should be another local screen that defuses the flow. The presence of faults favors conditions of the infiltration. In this case the vulnerability of the profile is high.

8.3.3 Map of Zonation of the Potential Contamination for Heavy Metals

In Table 8.1 are shown the ranges of values of the magnetic susceptibility for the classifications of levels of contamination to the zones established starting from the statistical analysis of the measurements of the magnetic susceptibility.

Table 8.1 Classification of the levels of contamination for the soils in areas of the Almendares – Vento basin and their ranges of values for the magnetic susceptibility

Classification	Range of kappa in 10^{-3} SI
Not polluted	0.0–0.627
Lightly polluted	0.628–1.65
Fairly polluted	1.66–2.6
Polluted	2.67–15.0
Very polluted	>15.1

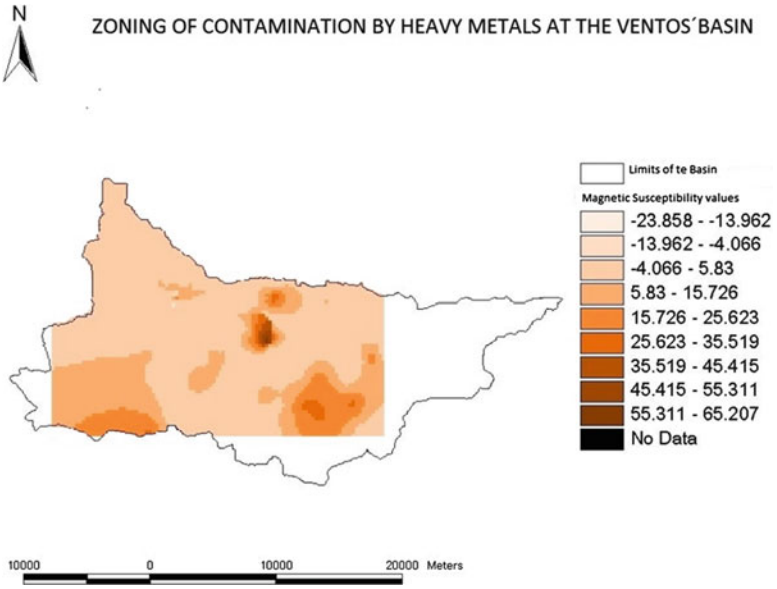

Fig. 8.1 Zoning of the pollution by heavy metals

In Fig. 8.1 is shown the map of Zoning of Potential Contamination of the soils by heavy metals in the Almendares – Vento Basin.

8.3.4 Maps of Intrinsic and Specific Vulnerabilities of the Vento's Aquifer

Starting from the geologic, geomorphologic and hydrogeologic data enriched by those obtained from the seismic method and the resistivity electrical methods, the following general characterization of the USZ could be carried out; and by using the GIS elaborated for the project, the map of the intrinsic vulnerability of the groundwater basin Vento was built. It is shown in Fig. 8.2.

The obtained map of intrinsic vulnerability was combined with the cartography of the magnetic susceptibility to evaluate the areas that had potentiality of being

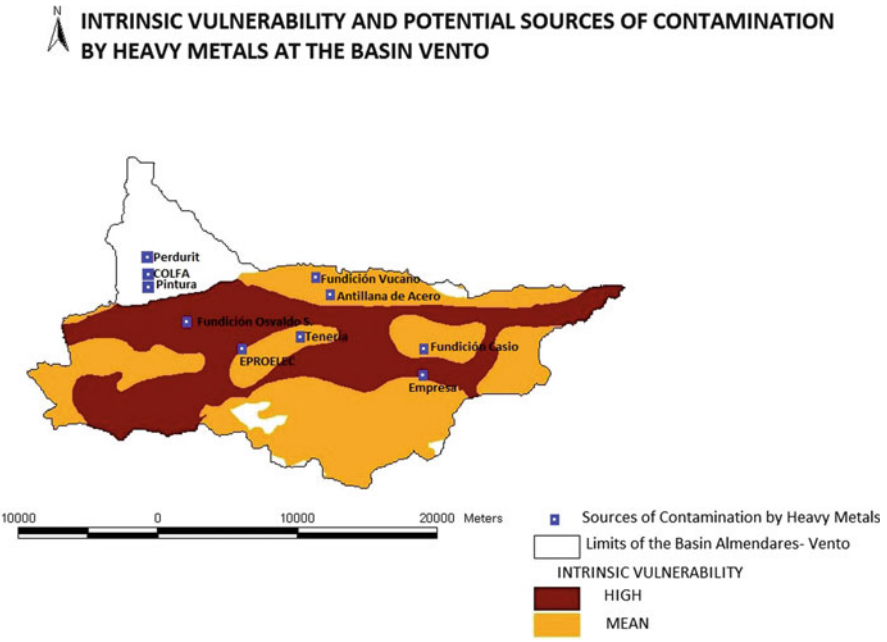

Fig. 8.2 Map of the intrinsic vulnerability for the Vento Basin

affected by contamination of heavy metals from the point of view of the vulnerability of the aquifer. Therefore, the map of specific vulnerability was obtained and it is shown in Fig. 8.3. To create this map the algebra of maps was used with the aid of a GIS.

8.4 Conclusions

The combination of several geophysical methods for the cartography of the contamination and the evaluation of the vulnerability of the aquifer revealed an understanding of the most vulnerable areas to the contamination for infiltration of the sector studied in the basin Vento.

The presence or absence of layers of low permeability in the USZ is a very important parameter when establishing strategies for the protection of the aquifers. The knowledge of the clay content that one obtains with the aid of the geophysical methods is an element that helps to evaluate this permeability.

The area of the industry "Antillana de Acero", according to the results given by the seismic methods, is impermeable only unto the first 3 m deep.

In the area of the "Vocational School Lenin", the results reveal a high permeability from the surface, as this area is more vulnerable.

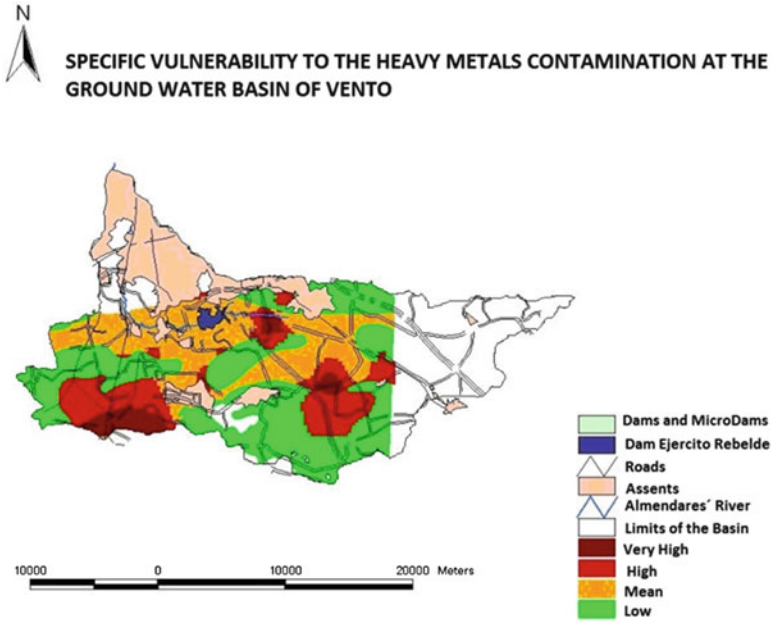

Fig. 8.3 Map of specific vulnerability for contamination by heavy metals in the basin Vento

The basin of Vento presents a high intrinsic vulnerability. For that reason when it is in the presence of potential hazards of contamination by heavy metals, it also possesses a high specific vulnerability for those polluting elements.

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