ASSESSMENT, MONITORING AND PROTECTION OF GROUNDWATER POLLUTION IN URBAN AREAS - *CORDOBA CITY - ARGENTINA*

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Abstract

Urbanization increases the impervious surfaces. These impervious surfaces result in increased storm-water runoff, which consequently carries with it any dirt, chemicals, or pollutants which have been dripped, spilled, or leaked into these surfaces. Whether the runoff eventually percolates into the ground or enters a nearby stream or Wadi, the carried pollutants will eventually reach and contaminate the groundwater. On the other hand, activities such as improper waste disposal and neglected cesspits can also contaminate the watershed groundwater resources.

The main objective of this research is to develop guidelines for governments, water managers, spatial planners and environmental managers in order to understand the impacts of polluting activities on groundwater resources in urban catchments and use them in order to develop strategies for groundwater protection.

Aquifer under Cordoba City consists of Quaternary sediments with moderate hydraulic conductivity. Groundwater chemistry shows high concentrations of Sulphate and Chloride. In some industrial areas, concentrations of Nitrates, Arsenic, Fluorine and Bacteria Coliformes exceed tolerable limits. Major sources of pollution are urban wastewater, urban storm water, solid waste disposal sites. Analysis shows that urban storm waters consist of very high concentrations of TSS, BOD, COD, $N\text{-}NH^{4+}$, $N\text{-}NO^{3-}$, and PO^{4}.

The vulnerability map of Cordoba city shows zones of moderate and high vulnerability. The DRASTIC index has values ranging from 101 to 193.

Aware of the need to more extensive knowledge for the protection of the groundwater resource, a hydro geological modeling of the phreatic aquifer was made by means of the MODFLOW code in order to study the dynamics of the groundwater system and have a tool for future predictions.

Keywords: Groundwater, pollution, monitoring , urban areas

Introduction

The combined forces of population growth and urbanization are creating rapid population growth in urban areas. By 2030, the urban population will have risen to 5 billion, 60 per cent of the world's population. Growing cities are the engines of the world's economic development. One of important resources to sustain urban growth is water resources.

Groundwater has historically provided a locally available low-cost source of water for public supply and domestic use. As groundwater is generally of good quality and requires less treatment, groundwater is increasingly being exploited in preference to surface water for drinking water supply.

Apart from the problem of the over-exploitation, groundwater pollution in urban areas is a growing environmental problem in the world. Worldwide, surface water and shallow groundwater have been found polluted from diffusive sources of intensive agricultural activities and urban runoff. Direct waste water discharge and solid waste disposal from rapid urbanization and industrialization have polluted many rivers and groundwater. In developing countries, groundwater pollution commonly results from indiscriminate disposal of municipal and industrial wastes, extensive use of on-site sanitation systems and urban agriculture. Urban areas include a wide diversity of land uses. The increased diversity and intensity of these land uses generate a wider variety of pollutants at higher concentrations than are found in rural or wild land areas.

Urbanization creates serious challenges for protecting water quality and aquatic ecosystems. The management and control of water quality within large urban catchment demand an integrated and interdisciplinary approach. With the increasing pressures on groundwater resources, strategies for protecting urban groundwater should be formulated based on unbiased scientific information from monitoring and assessment of groundwater quality.

Groundwater is increasingly used for urban water supply in Argentina. Pollution sources generated in urban areas are threatening groundwater quality. The research project on urban groundwater pollution and protection will contribute to better understanding of potential groundwater pollution problems and development of effective strategies for groundwater resources protection.

The main objectives of the research programme were envisaged as:

- To identify most hazardous pollution sources so that a priority list can be established for controlling and mitigating pollution sources;
- To assess groundwater vulnerability to pollution so that the resulting vulnerability map can be used for better urban land use planning for preventing potential groundwater pollution;
- To propose a groundwater quality monitoring program so that hazardous groundwater pollution can be detected in an early time;
- To develop guidelines for groundwater protection so that policy makers, water managers, spatial planners, environmental managers and public can all contribute to groundwater resources protection and sustainable use.

Main Text

A general research framework is presented in Figure 1. A conceptual understanding/model of hydrogeological system should be established to understand how the groundwater system is believed to behave. It serves the basis to assess groundwater vulnerability to pollution, to identify possible pathways of pollutant transport to groundwater, and to interpret the monitoring results to assess the quality status of the groundwater system.

Chemical characteristics and processes in the unsaturated zone have profound impacts on retardation and degradation of pollutants. The spatial variations of groundwater quality may be caused by differences in land uses, geological settings, climate variations, and hydrological conditions. All these factors are combined to create a groundwater vulnerability map. Investigation of sources of groundwater pollution is necessary to identify potential threats of groundwater pollution. The combination of vulnerability mapping and pollution sources rating leads to the assessment of groundwater pollution risk. The groundwater pollution risk map serves the basis to locate important sites for groundwater quality monitoring. Groundwater samples can then be taken to assess groundwater quality status. All these assessments will contribute to formulating effective strategies for groundwater resources protection.

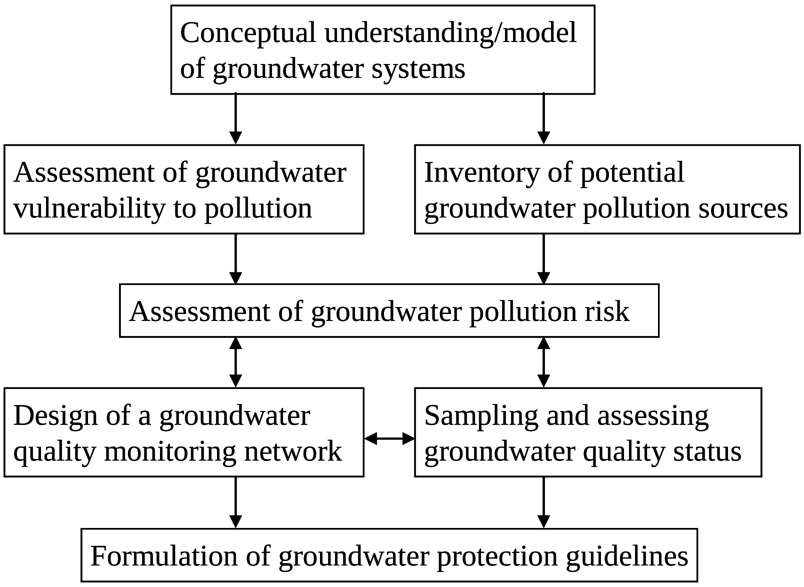

Figure 1 Framework for conducting monitoring, assessment and protection of groundwater resources.

Inventory of pollution sources.

All existing and potential sources of groundwater pollution should be identified using a protocol of pollution source inventory and evaluated using some rating methods (Zaporozec, 2004). The sequence of methods for inventory of pollution sources used by U.S. EPA (1991) is presented in Figure 2.

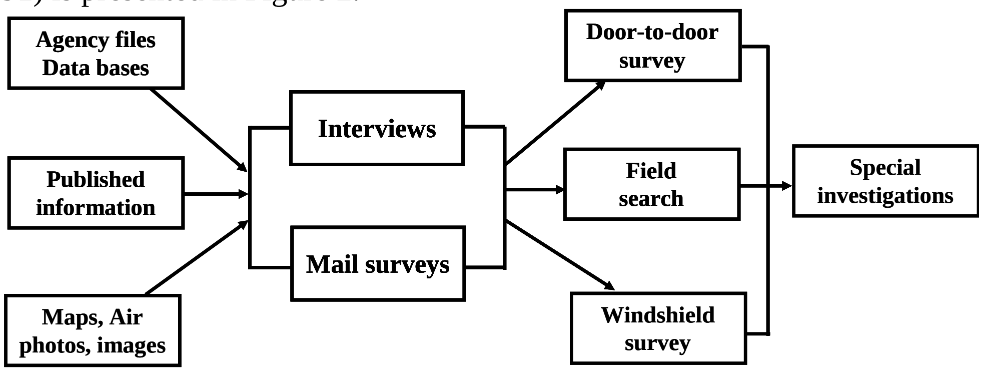

Figure 2 Sequence of methods for pollution sources identification (US EPA, 1991)

The following pollution sources were investigated:

- Domestic wastewater
- Industrial wastewater
- Urban storm water
- Solid waste disposal sites
- Polluted rivers/sewer drains
- Diffusive sources

Vulnerability assessment.

The concept of groundwater vulnerability is based on the assumption that the soil-rock-groundwater system provides some natural protection to groundwater against human impacts, especially with regard to contaminants entering groundwater from land surface. Over the last 20 years many methods for vulnerability assessment have been developed

(NRC, 1993; Vrba and Zaporozec, 1994). The most widely used methods are overlay and index method called DRASTIC (Aller et. Al., 1987), and newly developed European approach (Zwahlen, 2003) for Karst aquifers.

Drastic index method

DRASTIC is a standardized system developed by U.S. EPA for the evaluation of the groundwater pollution potential. The name DRASTIC is taken from the initial letters of the 7 hydrogeological factors used to evaluate the intrinsic vulnerability of aquifer systems:

- D= Depth to water table,
- R= net Recharge,
- A= Aquifer media,
- S = Soil media
- T = Topography
- I = Impact of vadose zone
- C = hydraulic Conductivity

Each factor is assigned a rating ranging from 1-10, according to the proportion of the degree of vulnerability. Then, the rating is multiplied by a weight to reflect the importance of this factor to the vulnerability. The DRASIC index is made up of the sum of the products of rating and weights of the seven factors:

DRASTIC index = DRDW+RRRW+ARAW+SRSW+TRTW+IRIW+CRCW

Where:

R =Rating ,W = Weight

The higher the DRASIC index is, the greater the groundwater pollution potential. The index is usually classified into 5 vulnerability categories (very high, high, moderate, low, and very low). The method is suited to implement in a GIS environment using map overlay method (Evans and Myers, 1990). The resulting DRASTIC map is a relative indictor of groundwater vulnerability to pollution. The method is widely used in USA for state-wide groundwater vulnerability assessment. DRASTIC method has been applied to Cordoba.

Design of groundwater quality monitoring networks.

Methods for designing groundwater quality monitoring networks depend on the objectives of the monitoring. An overview of methods is shown in Table 1.

Table 1 Methods for designing groundwater quality monitoring networks

Objectives of monitoring	Design methods	Sources of information
Assessment of groundwater quality status	Stratified random site selection	USGS (Scott, 1990)
	Arithmetic mean and confidence interval	EU WFD (2001)
Monitoring of diffusive source pollution	Groundwater pollution risk map	IHP-VI (2004)
	Prospective monitoring	US EPA (1998)
Monitoring of point source pollution	Detection monitoring system	US EPA (1992)
Sampling frequency	Power of trend detection	Zhou (1995)
	Regression test	EU WFD (2001)
	Conceptual system	EU WFD (2003)

The groundwater pollution risk map and detection monitoring system were used to propose groundwater quality monitoring networks for the study area.

Formulation of groundwater protection guidelines.

Table 2 lists possible strategies for groundwater resources protection. The current practices in this study case were analyzed. Proposals for improvement were formulated.

Table 2 Groundwater resources protection strategies

Strategy	Methods	Actions
Prevention of groundwater pollution	Reduction of pollution sources	Integrated land use planning; re-use of waste products and wastewater; treatment of solid wastes and wastewater, etc.
	Mitigation of pollution risk	Reduction of agricultural chemical use; isolation of waste disposal sites and storage, etc.
	Protection of wellhead and water supply sources	Delineation of protection zone; restriction of pollution activities in the protection zone.
Institutional framework	Governments	Policy, regulation, standard settings, and law enforcement.
	Private sectors	Use of clean technology, adoption of environment-friendly approach.
	NGOs	Monitoring, information campaigning, etc.
Legislation	Water law	Definition of basic water quality standards
	Pollution prevention law	Directives for isolation of pollution sources; restrictions in land use; Penalty measures.
	Safe drinking water act	Dinking water standard; delineation of protection zone; restrictions in protection zone.
Public awareness	Workshop of stakeholders	Information dissemination; Acceptance of protection measures.
	Public information campaigning	Posters; brochures; games; roleplays; outreach to school students.

Conclusion

Due to the time and financial constraints, assessments were made mainly based on the available data collected from various government agencies and survey organizations. Limited urban runoff samples and groundwater samples were taken for the analysis of pollutant concentrations. Table 3 summarizes main outputs of the research from the study case.

Table 3 Main outputs of the research

Research themes		Cordoba city
Inventory of pollution sources	Identified potential sources	100 solid waste disposal sites 50 wastewater discharge outlets 100 ha irrigated area
	Pollution sources map	Map of point and diffusive sources of

		pollution
Vulnerability assessment	Thematic maps	7 thematic maps
	Vulnerability map	DRASTIC index map
Pollution risk assessment		
	Validation	10 Samples Main pollutants:
Design of groundwater monitoring network	Selection of monitoring sites	100 monitoring wells
	Samples analysis	100 groundwater samples 100 urban runoff samples
Guidelines design for groundwater protection	Protection strategy	Prevention Institution Regulation

Cordoba City

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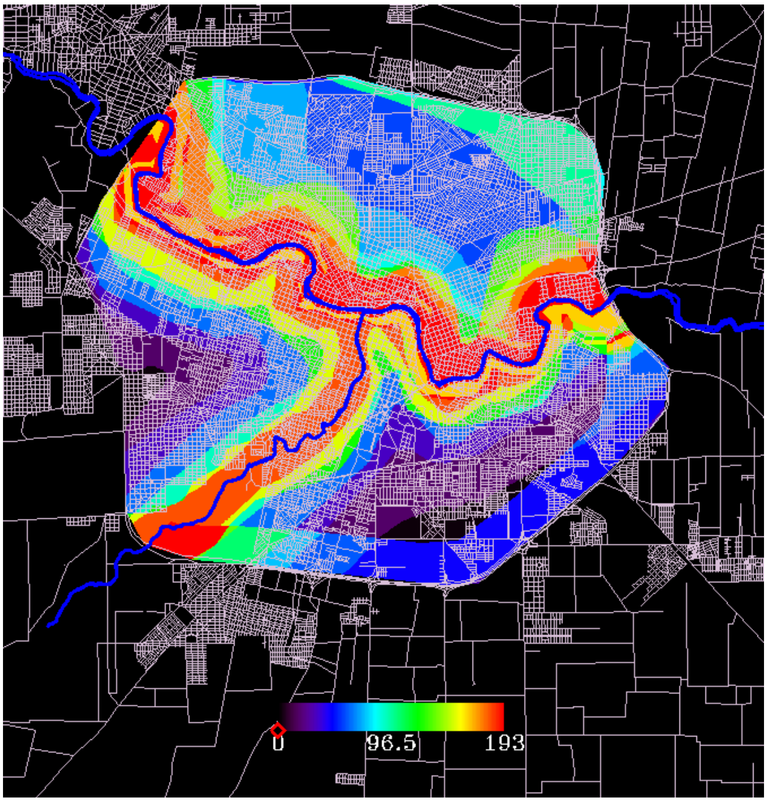
The vulnerability map of Cordoba city shows zones of moderate and high vulnerability. The DRASTIC index has values ranging from 101 to 193. The DRASTIC index in the northern and shourthen part of the area is minimum and the value increases towards center of the area attaining maximum values near Suquia River and Cañada stream. In the study area it is possible recognize two levels of vulnerability: moderate vulnerability with values to 101 to 159 in the most part of the city and highly vulnerable area for ground water pollution near the Suquia river and cañada stream with values from 160 to 230.



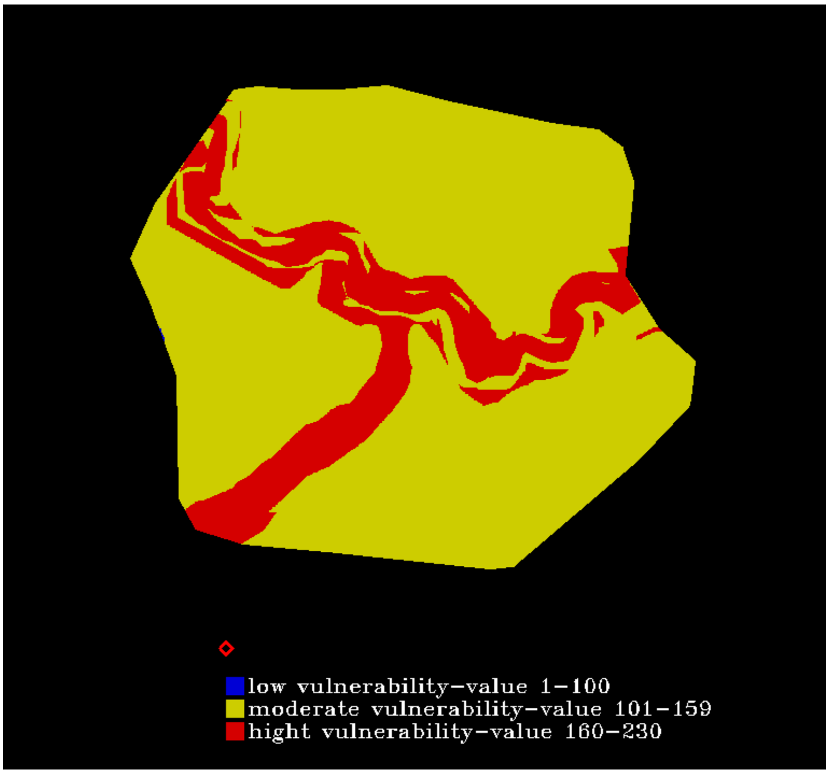


Figure 5 DRASTIC index vulnerability map of Cordoba city

Groundwater is not used for drinking water supply in Cordoba city. There is no systematic groundwater quality monitoring in the area. However, groundwater is used for industrial water supply and will be used to supplement domestic water supply in future with increasing water demand and during low flow of surface water. A groundwater quality monitoring network is recommended for the assessment of groundwater quality and identify potential place of groundwater supply sources.

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