Health risk analysis of the Rio de Janeiro water supply using Geographical Information Systems

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Abstract Assessment of health risk in population groups is based on environmental, socio-economic, and health data. A Geographic Information System (GIS) was used to simultaneously analyse databases with different origins. The case of health risk related to vulnerability of water supply in the city of Rio de Janeiro was examined using information on the water supply system with epidemiological, and socio-economic indicators. The water-distribution system covers nearly all the city territory, and the main treatment plant produces water that meets water quality guidelines. However, important factors remain harmful to public health due to the presence of contamination sources throughout the distribution system and vulnerable small springs. Problems detected involve characteristic city areas constituting one third of the total city population.

INTRODUCTION

Health risk is the result of a complex interaction between environment and population. Risk factors comprise a number of social, environmental, and health variables such as the presence of contamination sources, fate and transport of contaminants in the environment, behaviour of the population, and the accessibility of exposed groups to education and health care. The integrated analysis of health risks is based on the choice of specific environmental health indicators and their spatial projection (Briggs, 1992). Data on each of these factors have different origins and characteristics. Geographical Information Systems (GIS) have been used for the gathering, organization, and analysis of large databases on health and environment (Loslier, 1995). These systems allow the capture, storage, manipulation, analysis, and display of geo-referenced data (data related to graphic entities representing spatial elements).

The case of water supply in Rio de Janeiro is used here as an example of assembling risk maps from complementary and exchangeable sources. Several Brazilian sources of information contain data on the water supply and health conditions. In this work, four information layers were built and analysed: demographic and socio-economic characteristics, the water supply system, the distributed water quality, and infant deaths by diarrhoea.

About 95% of the households in the city of Rio de Janeiro are linked to the public water supply system which has a main treatment plant (Guandú WTP, Fig. 1), that produces certified quality water. However, some water supply issues persist that may lead to negative outcomes in population health. These issues include water contamination by micro-organisms throughout the distribution system and the

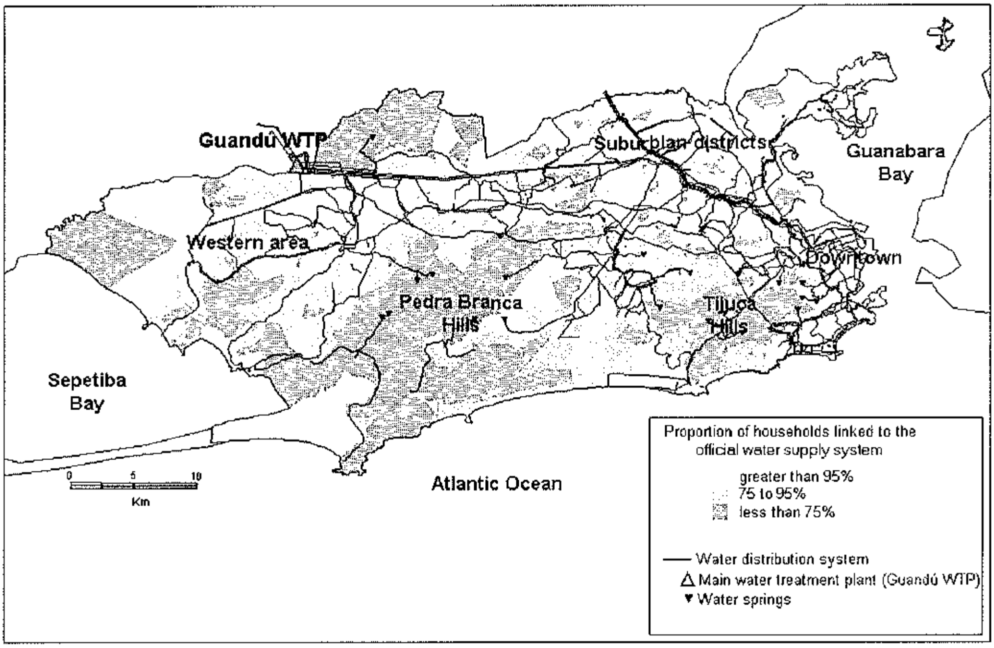

Fig. 1 The Rio de Janeiro water distribution system (location of pipes, Guandú WTP and small water springs) and the water supply of households in census tracts.

vulnerability of the system due to the contribution of small and untreated water sources (Fig. 1). Rio de Janeiro is characterized by extreme variability in land use of the urban area and steep topography. In mountainous areas, poor settlements ("favelas") and luxury residences share contiguous neighbourhoods. A preserved rain forest, protected by a national park, covers a large portion of the hills, where small water springs are located.

This work aims to identify the main risks to Rio's water supply. Key questions include who and where are the exposed populations? Procedures for assembling and cross analysing information layers related to the water supply and epidemiological data are described so as to demonstrate different ways of using GIS in ecological health analysis.

DATA ACQUISITION AND MANAGEMENT

Each information source will constitute one layer, with a distinct origin, purpose, and constructive characteristic, enabling spatial operations and population-at-risk calculations in a GIS environment. The city plan of the water distribution system demonstrates the capacity to serve portions of the city located near the pipes. However, the effective provision of water to households depends on other features such as water pressure, flow regime, and the ability of users to pay for this service. During the demographic census, individuals are asked about water origin (official system, wells, or local springs) and domestic provision. The answer to this item should be treated as unequivocal evidence of the predominant way the household is provided. Data on water quality are collected by monitoring programmes that check water quality indicators such as the presence of coliform bacteria. These indicators do not imply an immediate health impairment or necessarily reflect the overall health-risk condition (Battalha & Parlatore, 1977; Barcellos & Machado, 1991). Use of epidemiological indicators for assessment of sanitation impact is limited by the availability and quality of disease registers. Furthermore, a variation in indicators (e.g. infant mortality or diarrhoea incidence rates) can not be specifically attributed to water contamination, since they are also influenced by educational and economic status and by health service access (Esrey *et al.*, 1991; Heller, 1997).

Census tracts layer Approximately 6400 census-tract polygons were digitized from analogue data obtained from the Brazilian census bureau (FIBGE), at a scale of 1:5000. Demographic census variables, which include demographic and sanitation information, were geographically referenced through census-tract codes.

Layer of the epidemiological data The neighbourhood polygons were obtained from the aggregation of census tracts and stored in a specific layer. Health registries—births and deaths—were geo-referenced to 153 neighbourhoods.

Layer of water distribution system An analog map (1:25 000 scale) of reservoirs, water treatment facilities, pumping stations, and the main distribution network was obtained from the waterworks agency (CEDAE).

Layer of water quality Data on water quality were obtained from the State Environmental Protection Agency (FEEMA) monitoring programme. A total of about 400 sampling stations addresses were digitized and associated with 12 000 analyses of concentration of free chlorine, pH, fluoride, colour, and turbidity, as well analyses for the presence of faecal coliforms, and total coliforms.

IDENTIFICATION OF RISK AREAS

The buffer technique was used to establish the areas of influence of risk factors, projected in space. The choice of the radius of influence was based on theoretical assumptions. Areas and population affected were identified using the following environmental, epidemiological, and socio-demographic criteria:

(1) Areas with a high frequency of coliform contamination, indicating a high risk of water-related disease transmission. These areas were identified on the basis of buffers of 1 km radius around the monitoring points where more than 20% of the samples showed contamination by faecal coliforms.

(2) Areas predominantly served with water of local origin, i.e. obtained from the small springs that are concentrated in Tijuca and Pedra Branca hills (Fig. 1). Due to the increasing occupation of the hills, local water may eventually be contaminated by human wastes. These areas were identified on the basis of buffers of 2 km around small springs.

(3) Areas distant from the water distribution pipes, identified by buffers of 0.5 km around the main distribution network. Large distances from households to the

water distribution network can elevate the cost of house-connection to pipes, and result in inadequate local delivery practices (Drangert & Lundguist, 1990).

(4) Census tracts, identified on the map, where more than 50% of the residents are not supplied by the official water supply system. This proportion may indicate a collective impairment to access to the public service.

Table 1 lists the population and area of these four identified risk areas. Contamination of distributed tap water by coliforms (criterion 1) influences the greatest proportion of the city population at risk, representing about 35% of the total municipal population. Use of small local springs (criterion 2) or absence of water distribution pipes (criterion 3) can also represent risks for a significant portion of the population (10%), that is mainly localized in areas with low population density. A small portion of the population (about 2%) lives in areas where the supply is mostly obtained from alternative water sources (criterion 4), such as wells and local springs not served by the official sanitation company. However, this 2% of the population occupies a considerable area, nearly 16% of the city territory. These are the areas of the city with low population density, where wells (in the western semi-rural region) or springs (mainly in the high areas of the Tijuca Hills) provide sufficient water. These alternatives are not available in the densely populated eastern areas.

An accumulation of risk factors is verified for some specific socio-spatial groups, which could explain the absence of household connection to the official water supply system. These groups are mainly localized in city areas served by low-quality water supply service with incomplete urbanization, affecting both poor "favelas" and luxury residences. The epidemiological impact of the poor sanitation services on each of these groups is divergent. In contrast to the poor residents, privileged residents can obtain an alternative water supply, are more informed about water-related diseases, and can be promptly treated in health-care facilities.

Fluoride is added at the main Rio de Janeiro water treatment plant (Guandú WTP), which supplies the large majority of the municipality area. In other minor water supply systems, only chlorine is added to the water. The waters from the different systems are mixed in the general distribution network in the low-altitude areas of the city. Fluoride concentrations can therefore indicate the relative amount of water from the main water treatment plant in the distribution network. Areas with low fluoride concentration are mainly located in the Tijuca Hills area (Fig. 2), where small springs are a significant source of supply.

Distances from water sources to sampling points were calculated by using GIS techniques. The correlation matrix relating water quality parameters and the distance to

Table 1 Location, number of inhabitants and area of risk areas according to different water supply risk criteria.

Risk criteria	Population (no. of residents)	Area (km^2)	Location
(1) Water contamination	1 900 000	349	Tijuca Hills northern slope, part of the western region
(2) Proximity to local springs	700 000	392	On the city elevated areas
(3) Absence of water distribution pipes	600 000	156	Western region, isolated areas of the northern zone
(4) Usage of alternative sources of water	90 000	206	Western region, and city elevated areas

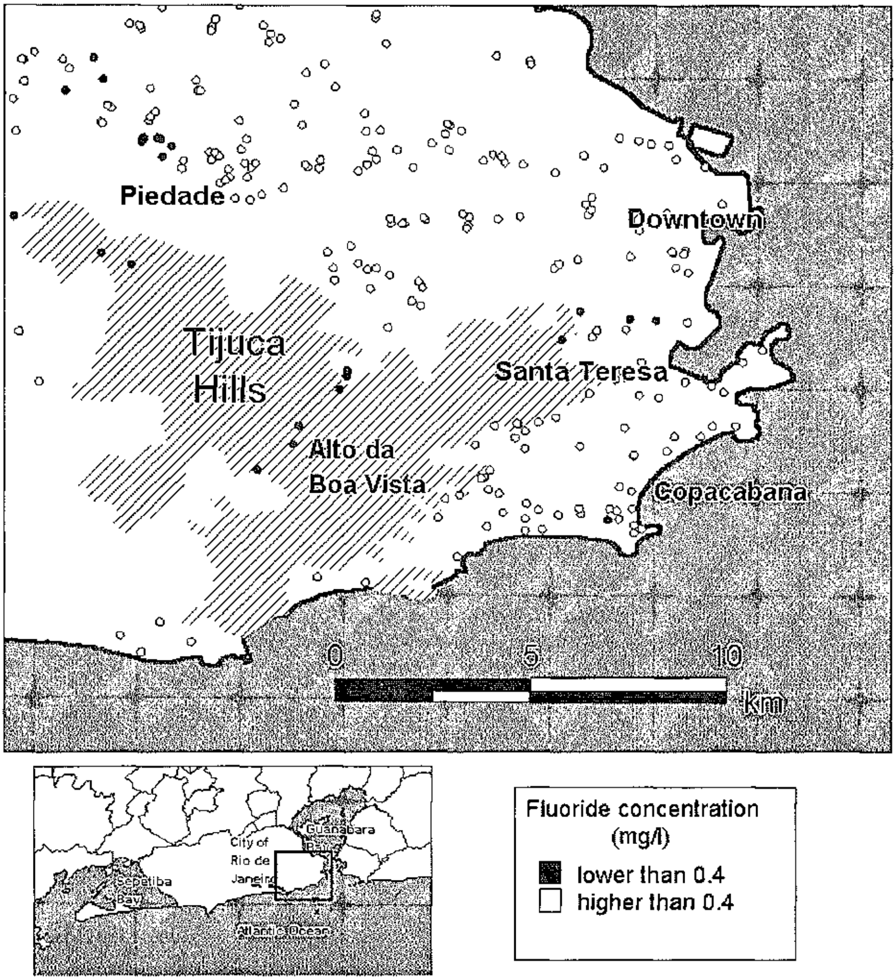

Fig. 2 Fluoride concentration in water at monitoring stations.

water sources is presented in Table 2. Both fluoride concentrations and colour decrease with the distance from the main WTP. Chlorine concentrations do not undergo significant decay along the distribution pipes, perhaps reflecting the presence of re-chlorination stations in the distribution network. The proximity to local water springs implies lower mean chlorine concentrations and more frequent coliform contamination. These water sources were thus considered vulnerability factors to the supply system.

Another risk criterion is the presence of a "sentinel event" in the neighbourhood. Diarrhoea deaths are dispersed in northern poor areas. In these areas, households are potentially supplied by water from the main system, but occasional water contamination is observed. Diarrhoea events were used to identify risk neighbourhoods. According to this risk criterion, about 2.8 million Rio inhabitants can be considered as being exposed to water-related diseases or suffering serious

Table 2 Correlation coefficient between the distance from water sources and water quality parameters in the sampling stations (Pearson method, $n = 403$).

	Fluoride	Chlorine	Colour	Turbidity	Presence of coliforms
Distance to the main water treatment plant	**−0.12**	0.07	**−0.11**	−0.02	−0.09
Distance to local water springs	−0.06	**0.11**	−0.02	0.05	**−0.13**

Bold numbers represent statically significant associations (∝ <0.05).

impairments in their access to health care services. In this case, the "sentinel event" should activate investigation of possible related factors of each death: water contamination and lack of access to primary health units (Rutstein *et al.*, 1976).

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