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Factors influencing groundwater quality: towards an integrated management approach

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Abstract

The safety of groundwater resources is a serious issue, particularly when these resources are the main source of water for drinking, irrigation and industrial use in coastal areas. In Italy, 85% of the water used by the public is of underground origin. The aim of this report is to analyze the main factors that make groundwater vulnerable. Soil characteristics and filtration capacity can promote or hinder the diffusion of environmental contaminants. Global climate change influences the prevalence and degree of groundwater contamination. Anthropic pressure causes considerable exploitation of water resources, leading to reduced water availability and the progressive deterioration of water quality. Management of water quality will require a multidisciplinary, dynamic and practical approach focused on identifying the measures necessary to reduce contamination and mitigate the risks associated with the use of contaminated water resources.

Background

The safety of groundwater resources is a serious issue, particularly in coastal areas where groundwater is the main water source for drinking, irrigation and industry (1). The World Health Organization (WHO) estimates that in 2008 2.5 million people died because of waterborne diseases (2). This is primarily a concern in the least developed countries because of poor water sanitation and hygiene, but it is also a concern in industrialized countries owing to the presence of microorganisms resistant to the drinking water treatment processes.

Waterborne diseases represent a worldwide public health challenge. They include gastrointestinal diseases (campylobacteriosis, cryptosporidiosis, microsporidiosis, mycobacteriosis), acute respiratory diseases (legionellosis) and skin infections (e.g. *Pseudomonas aeruginosa*) resulting from recreational and professional activities including bathing, swimming in swimming pools, and agriculture (3-5). Furthermore, some microorganisms that are of environmental origin are defined as "fastidious" and "undesirable" (e.g. protozoa, helminth, algae and fungi) and can constitute a hygienic and sanitary problem (6, 7).

In Italy, 85% of the water used by the population is of underground origin (8). This water is generally of good quality, because it is either filtered through permeable layers or protected by overlying impermeable ones. Unlike surface water, purification treatments are not usually carried out on groundwater.

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Nonetheless, groundwater is exposed to different contamination, hosting several microorganisms that interact in competitive or synergistic relations.

The Italian and the European Water Legislation (9) uses prokaryotic bacteria as indicators of fecal contamination (*Escherichia coli, total coliforms, Enterococci*). Microbiological testing for these fecal bacteria is compulsory in assessing the quality of Italian drinking water. Indicators defined as "accessories", including *Salmonella* and enteric viruses (e.g. *Adenovirus, Rotavirus and Norovirus*), are generally filtered by the soil because particulate matter adsorbs them. They can be assayed at the discretion of the competent authorities during specific epidemiologic situations.

In the United States, an active surveillance system (Waterborne Disease and Outbreak Surveillance System, WBDOSS) collects data on waterborne disease and outbreaks associated with recreational water, drinking water, and other non-recreational water exposures. WBDOSS helps to control infectious diseases caused by contaminated groundwater (10, 11). In Europe, the available data are limited and do not properly assess risk (12, 13). In Italy, the only reported gastroenteritis outbreak associated with groundwater contamination occurred in a vacation resort; the environmental investigation revealed serious fecal contamination and the presence of *Norovirus* in the seawater near the resort (14).

The main factors that make an underground water source vulnerable are: i) the characteristics of the soil and its filtration capacity, which can promote or hinder the diffusion of environmental contaminants; ii) the climate change, which in recent years has made the natural replenishment of aquifers increasingly critical; iii) the strong anthropic pressure that leads to considerable exploitation of water resources, contributing to reduced availability and the progressive deterioration of water quality. The following sections describe each of these factors in turn; subsequently, we evaluate the best practices for monitoring and improving water quality.

Influence of geological factors

Soil's filtration capacity depends on its mechanical characteristics (including the degree of fracturing, particle size, and porosity) and on its chemical and physical composition (including the presence of clay, soluble organic substances, cations, and pH). Contamination is more frequently detected in sedimentary rock than in igneous or metamorphic rock (15). Several microorganisms may be adsorbed and remain in the soil for a long time; these are affected by sunlight, temperature, moisture, and organic matter. For example, clay soils, which contain hematite and magnetite, promote the adsorption of viruses (16).

The degree of groundwater contamination is also affected by soil porosity. Sandy soils (defined as porous) may hinder the spread of microorganisms, while karst soils (non-porous) are known to be more vulnerable (17) and most influenced by agricultural activities and wastewater emissions. Porous soil therefore may better improve water quality compared to non-porous soils, because it causes real purification depending on several factors, including thickness, grain size, the chemical composition of soil, the type and quantity of pollutants, the rate of water percolation, and the degree of environment saturation. Groundwater quality also varies as a function of its chemical composition, influenced by the solubility of the soil it passes through and by aquifer depth (18). In particular, water will be low in salts if it passes through poorly soluble soils, follows short distances, and flows only for a short time. In contrast, water will be rich in salts if it passes through soluble soils (e.g. carbonate rocks) or remains in the subsoil for a long time.

Climate effects

Seasonal variation and climatic factors affect the quality and quantity of groundwater (19). Changes in groundwater recharge rate caused by seasonal variation also affect the concentration of water parameters (20). Under normal environmental conditions (for example, in the absence of heavy rain) microorganisms are retained efficiently by the soil and are only detectable in trace amounts in groundwater. Serious weather events, including high-intensity rain or drought, can greatly influence the water quality (21), contributing to the dissemination of pathogenic microorganisms to geographic areas in which they were previously absent. In certain regions, recent climate changes have led to a "tropicalization" of rain consisting of uneven rainfall distribution throughout the year and large and intense rains. As a result, gastrointestinal diseases are increasing, depending on temperature and soil overflow, causing the contamination of coastal waters and inland surfaces water (22, 23).

Global climate change also influences the availability of water: poor rain and an altered rainfall distribution during the year cause a significant reduction in the flow of water for aquifer recharge and for irrigation (24). In particular, in some coastal areas, decreased groundwater resources and their depletion by humans have caused marine intrusion. This increases the risk of microbiological contamination and of salinization of water. Some authors report that high salinity is associated with a remarkable increase in bicarbonate content during the crop-growing season because of more intense biological activity in irrigated soils (25).

Anthropogenic influences

Human activities can cause contamination of aquifers, resulting both from industrial activities (including uncontrolled discharges of potentially toxic chemical substances, processing residues, and waste) and agricultural activities (including the use of herbicides, antiparasitics, and pesticides) (26). In particular, intensive agriculture is often inadequate for the characteristics of the area and the chosen produce, creating a substantial increase of nitrates, which are usually present in low quantities in groundwater (27). Although nitrogen is a vital nutritive element for the growth of plants, it can be harmful to humans and to the environment in high concentrations. In Europe, Directive 91/676/CEE (28) regulating the use of nitrates aims to prevent pollution of groundwater and surface water caused by agricultural nitrates and to facilitate the use of correct practices.

Furthermore, herbicides and pesticides, which are mainly used in agriculture to kill fungi, weeds, parasites and insects, are combined with the fertilization procedure and are often overused. These substances are harmful and dangerous when used in excessive amounts because they overflow the soil and reach surface water and groundwater. The presence of these contaminants in groundwater is affected not only by their physicochemical properties (including biodegradability, potential for absorption, and solubility) but also by climatic, hydrological and agricultural conditions.

The intensive raising of livestock in confined areas can also contribute to groundwater contamination through animal manure discharged on areas overlying aquifers. In some regions, it is still customary to spread manure on the ground to fertilize it and make it more productive. Regrettably, this turns the nitrogen contained in the manure into nitrate, contaminating the underlying aquifers, especially when the soil temperature exceeds 5°. Additionally, the amount of nitrogen in groundwater from livestock waste or chemical fertilizers increases when overlain by permeable soil (29).

Another consequence of human activity is deforestation in favor of agricultural crops, overgrazing, and, more recently, photovoltaic systems. This causes soil to become more easily erodible, as it is not protected from the washing action of surface water, increasing the frequency of natural disasters, such as floods, and causing drastic variations of hydrological characteristics.

Conclusion

Water is an indispensable resource for human civilization and environmental needs, and for life on Earth. Groundwater availability varies geographically and temporally. Increasing groundwater exploitation is affected by anthropogenic impacts on coastal environments and is responsible for severe health and food security issues. An integrated approach to water management is recommended to address current water challenges, which are often interrelated with other environmental, economic and social issues.

Worldwide population increase, economic and infrastructure development, and changed use of soil have reduced the volume of surface water withdrawal in favor of underground sources, often reducing water quality in the process. It is therefore necessary to prepare a rational plan assessing the effects of all associated development sectors on all resources in a given geographic area.

The public can do a great deal to preserve water quality. The risk of water contamination is related to several factors, most of which are preventable. The first step is to work collaboratively to change the beliefs and behaviors of the population and to promote sustainable development. Sustainable water management is required to ensure quality supplies of vital water resources in the face of growing human demand for water, high levels of pollution, and increasing spatial and temporal variability associated with climate change.

Recently, "best management practices" have been outlined to control the origin and spread of pathogens through collective management intervention, based on the expertise of a multidisciplinary team and able constantly to monitor all factors influencing the water system. The experts necessary to manage the problems associated with water contamination include geologists, hydrologists, microbiologists, hygienists, soil scientists and agronomists. According to WHO (30), the integrated approach is required to properly manage water resources, including groundwater, to ensure the equitable distribution of water intended for human consumption, irrigation and recreation. This integrates health and environmental issues into sectoral policies and institutional mechanisms. The new approach, called the *Water Safety Plan*, was introduced in 2004 and implemented in 2005. It combines analytic data from laboratory investigations with epidemiological data (for instance, the incidence of water-borne diseases), endemic events, and territorial characteristics.

The present survey of the factors affecting the quality of groundwater suggests that managing water sanitation and hygiene will require a multidisciplinary, dynamic and practical approach, focused on identifying the measures necessary to reduce the contamination of water resources and to mitigate the associated health and environmental risks. Adequate management strategies to protect groundwater from contamination and overexploitation are of paramount importance, especially in arid-prone regions, where coastal aquifers often provide the main freshwater resource sustaining human needs (25).

Sustainable development is one of the guiding principles of modern societies. Water and sustainable development are closely linked, because the availability and quality of water affects the environment, society, industry, and the wellbeing of the generations to come. An integrated approach will apply a common, uniform methodology to water resource development and management and will facilitate identifying weaknesses in current practices and ongoing activities and implementing timely corrections.

Achieving these goals will require improving communication among experts in the disciplines involved and increasing cooperation among stakeholders in the field of water resources. The decision-making framework to be established must consider feedback mechanisms and negotiations involving political leadership, executive water resource management agencies and the affected public.

Riassunto

Fattori che influenzano la qualità delle acque sotterranee: verso un approccio integrato di gestione

La sicurezza delle risorse idriche sotterranee è un grosso problema, soprattutto quando queste risorse sono la principale fonte di acqua potabile, irrigazione e uso industriale in aree costiere. In Italia, l'85% dell'acqua utilizzata dal pubblico è di origine sotterranea.

Scopo di questo studio è analizzare i principali fattori che rendono le acque sotterranee vulnerabili. Esistono, infatti, alcuni fattori di rischio che possono favorire oppure ostacolare la diffusione di contaminanti ambientali: le caratteristiche e la capacità di filtrazione del suolo, il cambiamento climatico globale, l'impatto antropico. In particolare, l'uomo, attraverso l'espandersi delle attività industriali, agricole e zootecniche, provoca notevole sfruttamento delle risorse idriche, con conseguente depauperamento dell'acqua e il progressivo deterioramento delle sue caratteristiche igienico-sanitarie. Un approccio integrato può, pertanto, rappresentare una risoluzione finalizzata alla prevenzione della contaminazione e alla gestione dei rischi eventualmente associati.

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