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WELL PROTECTION ZONE LIMITS IN URBAN AREAS: KENITRA CITY, MOROCCO

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Protection zones surrounding pumping groundwater wells play a significant role in maintaining good water quality. The importance of this concept has resulted in its introduction into laws regulating the use and the protection of groundwater resources. In Morocco, law 10/95 relating to water, institutes protection perimeters in Chapter VII, Article 63. The establishment of the protection zone is easy in a rural or suburban zone but not in an urban zone. Indeed, the protection of wells in this zone becomes complicated because the sources of pollution in the urban zone are many and varied. The most significant risk within the urban zone perimeter is domestic pollution resulting from the infiltration of runoff water from the urban surfaces after rains. In this context a well has little chance to escape pollution. In the urban zone of Kénitra city in northwest Morocco, several pumping wells are inside the urban perimeter. The outdated network of storm water drainage, the infiltration of rainwater from urban runoff and the shallow saturated zone threaten the quality of water and pose a problem for the city drinking water supply.

INTRODUCTION

In many countries, groundwater is one of the major drinking water resources. Groundwater is generally enriched with mineral salts, pure, colorless and without disagreeable flavor, which reduces its treatment to simple disinfection against bacterial contamination. As such it must be managed and protected carefully if we want to put it to the most beneficial use.

Aquifers become more and more exposed to infiltration of residuals and chemical toxic products, which are the results of man's activities associated with development and socioeconomic needs. We mainly note pollution caused by the proliferation of agricultural activity, the frequent use of fertilizers and pesticides, the network of sewers in urban and industrial zones, and by direct or accidental releases. It is clear that the protection of the vital groundwater resource around wells of public groundwater supply is highly important as an efficacious way of protecting the population from pollutants. Furthermore, to be a real tool of protection, these need to be legally institutionalized.

Almost every country has adopted the groundwater well protection zone concept (El Mansouri, 1999). A protection zone is defined as a surface surrounding a pumping well, in which arrangements must be taken to prevent polluting agents from migrating to and contaminating groundwater near and in the well (Banton and Bangoy, 1999).

There are three different kinds of protection zones can be adopted (Lallemand-Bares and Roux, 1988). Around a pumping well, an inner mandatory perimeter can be established. It is acquired by and enclosed by the local community to protect the wellhead, to keep the pumping station in a perfect state of cleanliness, and to prevent all infiltration into the well. A second close protection zone can be established, inside which risky activities that might cause pollution are forbidden or regulated. Finally, an optional perimeter of more remote protection can be established. In this last kind of protection zone, the activities and installations are only regulated. The two last perimeters are established by an approved hydrogeologist, and are designed to allow a sufficient lapse of time for purification by natural filtration, or for intervention in the case of serious accidental pollution.

Morocco is situated in a semiarid region, and is largely dependent on groundwater resources. This has resulted in the water resources quality laws adopted in 1995 which regulate protection zones in Chapter XII, Article 63 (El Mansouri, 1999). The adoption of these perimeters for our wells, and their reinforcement by direct legislative and regulation tools, will constitute efficient operations for groundwater resources protection, particularly around the pumping wells.

However, pumping wells located in urban areas are especially threatened by urban pollution due to the quality of the rainfall runoff water from the impervious surfaces of the city, which drain through antiquated networks and the infrastructure of the road network (Legret et al., 1997; Lee and Touray, 1997). The intensive exploitation of these wells can cause ground subsidence and problems of a geotechnical nature for buildings (Chen et al., 2003). In an urban zone in a natural environment where the ground is permeable and where the water table is not very deep, pumping wells are vulnerable to the imminent danger of pollution from the urban environment. Indeed, some wells could be in the vicinity of the network of antiquated sewers.

The establishment of a secondary close protection zone or the optional perimeter of more remote protection in the urban zone encounters the problem of urban infrastructure and other factors of pollution belonging to the urban zone. These factors place limits on the effectiveness of the concept of groundwater protection zones when applied to urban areas.

DELINEATION METHODS FOR WELL PROTECTION ZONES

Delineation criteria of protection zones are spatial and temporal in nature. It is necessary to take into consideration the distance to wells, draw down, travel time, pollutant degradation rate, flow limits, and the ability of the aquifer to purify groundwater. The use of one of these criteria depends simultaneously on technology, socioeconomic and regulatory considerations.

The tools used for protection zones delineation are varied. They include geological cartography, aquifers tests, water balance calculations, the well environment, and hydrogeologic and numerical modeling.

The establishment of protection zones was made at first in a transient regime based on Theis formula. Bear and Jacobs (1965) proposed an analytic formula which stems from potential functions for isochrone calculation. The isochrone is the limit beyond which a water particle cannot reach a well in a time limit lower than a fixed period, which is generally 50 days (Kinzelbach, 1986). Analytic formulas have been developed to determine the protection zone perimeters by calculating the transfer time (Lallemand Bares and Roux, 1988). On the other hand, Crampon (1987) proposed graphical methods to determine protection zones.

Tracking techniques have been used to establish chemical pollution isochrones (Roux, 1988). Kinzelbach's methods (Kinzelbach, 1986) consist of following upstream a number of particles adjacent to the pumping well along streamlines. By using a numerical approach, which consists of inverting flow direction on the pumping well and following the pollution to a determined time, taking into account dispersion phenomenon, El Mansouri et al. (1999) established protection zones by using a numerical model.

IMPACT OF THE URBANIZATION ON THE NATURAL ENVIRONMENT

Specific studies show that the effects of urbanization on the water cycle are numerous.

- Impervious surfaces constitute one of the most visible consequences of urbanization. This phenomenon limits the infiltration of water. It produces an increase in volumes of stormwater runoff, and is often the cause of urban floods.

- A direct consequence of the urbanization or the adjustment of suburban zones is the very large increase the rates of surface flow, involving a considerable increase in the peak output. The increase in the flow rates is due to the alteration of the natural hydrographic network.

- Urbanization is always accompanied by construction of networks of roads and streets. They are usually always built by raising the ground level or by lowering the level, effectively placing the road in a trench. These roads superimpose on the natural relief an artificial relief that, in particular in the not very sloped zones, can modify the surface water runoff patterns considerably. Their effects on flow depend on their orientation according to the direction of the slope (perpendicular or parallel or at some angle to the slope).

- Urbanization is also responsible for building artificial river channels to contain flow in downtown areas. The consequences can be catastrophic. Indeed, the city that is adequately protected when the level of water remains lower than that of the channel banks can be abruptly submerged if the water level continues to increase.

- In addition, and on a qualitative level, urbanization generates a very significant rate of pollution. The circulation of pollution in urban zone comprises three main stages: atmospheric pollution deposition, runoff, and the flow in the sewer network. The air pollution is composed of various gases produced by vehicles and industrial activities. The latter also cause pollution by heavy metals and hydrocarbons. These pollutants are present at concentrations much stronger in surface waters than in domestic and industrial wastewater (Table 1; Tassin and Chebbo, 2000).

Table 1. Concentrations of Pollutants in Rain Water of Urban Zones (Tassin and Chebbo, 2000).

Pollutant	**Urban Rain Water Concentration (mg/l)**
pH	4-7
MES	5-70
DCO	8-27
P. Total	0.02-0.37
NO_3	0.5-4.4
SO_4	4.8-46.1
Na	0.5-2
Cu	0.5-2
Zn	0.05-0.38
Pb	0.03-0.12

HYDROGEOLOGICAL CHARACTERISTICS OF THE URBAN ZONE OF KENITRA

The urban zone of Kenitra, with a surface area of 32 km^2 is located in the low drainage basin of Sebou, one of the large rivers of the Moroccan territory. This zone, in the Rharb plain, is within a few kilometers of the Atlantic Ocean (Figure 1). The zone is bordered in the west by old sand dunes, which separates it from the beaches of the sea.

The urban zone of Kenitra is built on a natural environment characterized by the presence of a shallow aquifer. The aquifer facies is mainly sand, calcarenite and sandstone, with a thickness which varies from 50 to 100 m according to the geometry of the impermeable substrate, formed of the blue

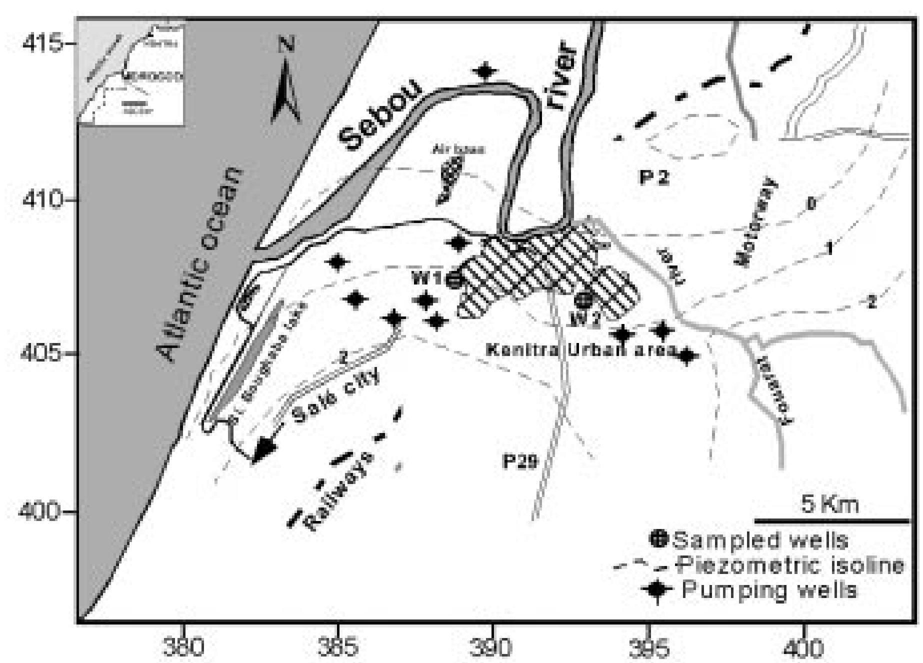

Figure 1. Location of the Kenitra city urban zone and pumping wells.

marls of Miocene age which outcrop 30 km south of Kenitra in the area of Sale city. The hydrodynamic parameters of the aquifer are very favorable for flow. The transmissivity calculated by modeling is approximately $2x10^{-2}$ m^2/s (El Mansouri, 1999). The groundwater is affected by the intensity of the pumping practiced in the zone. This pumping, which supplies the population of the town of Kenitra (400,000 inhabitants), is sustained by about a tenth of the pumping wells, which produce a total of 0.6 m^3/s.

VULNERABILITY AND PROTECTION OF PUMPING WELLS IN THE URBAN ZONE OF KENITRA CITY

As noted previously, the urban zone of Kenitra is characterized by the typical elements which make any urban zone, such as road networks and storm drainage, and the public water supply. The establishment of several production facilities and service companies also characterizes the zone. All these activities are potentially polluting.

The nature of the ground in the urban zone of Kenitra is characterized by the presence of permeable formations. These formations also constitute the unsaturated zone and they cannot slow the transfer of surface pollutants to the water table of the unconfined aquifer. Wells W1 and W2 sampled in the urban zone show abnormally high contents of heavy metals, which exceed by far the limit of the concentration fixed by the Moroccan standard (S.G.G., 1995) (Table 2). The origin of the concentration of these elements in well W2 is most probably related to a bus maintenance facility located near the well. As for the other well, the heavy metal concentration is correlated to runoff water from the city.

Table 2. Content of Heavy Metals (mg/l) of Water of Well in the Urban Zone of Kenitra
*: Kacimi (2003), **: S.G.G.(1995), (Well 1 & 2: see Figure 1)

	As	Pb	Ni	Cr	Zn	Cu	Cd	Mn	Al	Fe
Well 1*	1287	48	657	17230	28680	609.25	105	3441	658	0.06
Well 2*	1260	218	583	16070	21240	431.57	70	2596	481	0.06
Puits témoin *	0.95	0.02	1.56	6.4	84.40	0.95	0.01	1.56	0.46	0.06
Limite admissible**	50	50	50	50	5000	1000	5	50	50	300

The concept of a close protection zone surrounded by a remote protection zone often used for protection of wells cannot be efficient in this case. This is due to the fact that all the potentially polluting activities and elements are inside the water divide (separating stream line), which surrounds the pumping wells (Figure 2). A pollutant particle would be automatically included in this field. Therefore, only the inner perimeter can be set up to protect the pumping point, and keep the station in a perfect state of cleanliness and avoid all infiltration in the well.

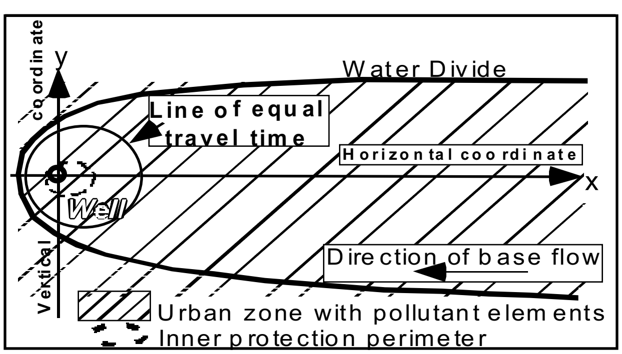

Figure 2. Situation of a part of an urban zone inside the pumping well zone.

The protection of the aquifer can thus only be carried out by the installation of a system or network of protective mechanisms to prevent any releases of wastewater, including urban runoff and domestic wastewater, that could occur within the larger protection zones.

CONCLUSION

The urban zone of Kenitra will undergo significant development due to the strategic location of the city in an area characterized with natural richness such as water, the soil, fishing, and tourism. In addition, significant potential exists for industry, particularly agro-industries which are dependent on the water resources in the area. The share of the water resources intended for the public water supply is very vulnerable and is seriously threatened by the proliferation of the urban and suburban zones. The unhealthy conditions of leaking wastewater pipes and cesspools and the industrial activities in the zone present a real danger to the groundwater quality, particularly pollution by heavy metals.

Scientific research in the field of urban hydrology, particularly the modeling of rainfall runoff and modes of transfer of pollution have yet to be applied to our sites. They could certainly bring answers and propose solutions for the conservation of water resources in and around this urban area.

The official authorities as the water supply company should supervise the evolution of the quality of the public water supply wells in the urban zone of Kenitra city, and evaluate the concentration of heavy metals in these wells. In addition to the technical actions for which the objective is to protect our water resources, corrective actions should be taken, but they require political decisions. These actions include establishing lawful measures to require industries to improve pollution prevention, and to promote the development of public transport and clean energy sources.

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