



Title: Un esquema para la evaluación de riesgo del agua subterránea por disposición de desechos sólidos.
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Abstract:

Se presenta un método para clasificar un sitio de disposición existente o prospecto en un marco de riesgo a la contaminación del agua subterránea examinando los controles del transporte de contaminantes que emanan del sitio, así como los parámetros que son importantes para establecer el mencionado riesgo. Los factores que son necesarios considerar se agrupan de la siguiente manera: (a) grupo del sitio: tamaño del sitio; clima del lugar; composición de los desechos y composición del lixiviado; (b) grupo geológico e hidrogeológico: carácter de la zona no saturada; propiedades del acuífero; gradiente hidráulico y recarga; (c) grupo de riesgo: proximidad de la población local; distancia a la fuente de extracción más cercana; volumen de agua subterránea extraída; distancia al agua superficial más cercana.

El esquema de evaluación de riesgo propuesto se basa en el tiempo de recorrido de un contaminante conservativo proveniente de un sitio de disposición de desechos.

Se puede utilizar para delimitar una zona de riesgo alrededor de un basurero para diferentes escenarios climáticos e hidrogeológicos. Se diseñó un modelo determinístico, genérico, para examinar un número de escenarios hidrogeológicos. El modelo tiene simuladores de transporte de contaminantes uni- y bidimensionales. El impacto de la disposición de desechos se evalúa no solamente inmediatamente debajo del sitio, sino también en el ambiente circundante al mismo y en este aspecto es novedoso comparado con los esquemas existentes.

Se presenta el caso del basurero municipal de Mérida, Yucatán, México, para demostrar el esquema propuesto y comparar la metodología con esquemas de evaluación empíricos existentes de vulnerabilidad del agua subterránea (DRASTIC, GOD y WASP).

PALABRAS CLAVE

Aguas subterráneas, clasificación de riesgo, calidad del lixiviado, modelación, sitio de disposición de desechos.

A Groundwater Hazard Assessment Scheme for Solid Waste Disposal

An approach for a robust means of ranking an existing or prospective waste disposal site within a hazard framework is presented examining the controls on contaminant migration from waste facilities and the parameters which are important in establishing the hazard posed by a site to groundwater quality identified. The factors which need to be considered, have been grouped as follows: (a) site group: site size; site climate, waste composition and leachate composition; (b) geological and hydrogeological group: unsaturated zone character; aquifer properties; hydraulic gradient; recharge; (c) fate group: proximity of local population; distance to nearest abstraction borehole/spring; volume of groundwater abstracted; distance to the nearest surface water.

The hazard scheme proposed is based on the travel time of a conservative contaminant from a waste facility. It can be used to establish a hazard zone around a waste site for different hydrogeological and climatic

settings. A generic, deterministic model was designed to examine a number of hydrogeological scenarios. The model has both 1-D and 2-D numerical, contaminant transport simulators. The impact of waste disposal is assessed not only directly below the waste site, but also in the environs of the site and in this respect the approach is novel compared with existing schemes.

The case of Merida, Yucatán, Mexico, municipal waste disposal site is presented to demonstrate the proposed scheme and compare it with existing empirical methods (DRASTIC, GOD and WASP) in evaluating groundwater vulnerability.

KEYWORDS

Groundwater vulnerability, hazard ranking, leachate quality, modeling, waste disposal site.

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[ILUSTRACIÓN OMITIR]

1. INTRODUCTION

A procedure is suggested to hazard ranking a waste disposal site which can be adopted both to evaluate the impact of a single site on the groundwater system or to compare a number of sites for their suitability for waste disposal. This procedure is summarized as follows (chart in Figure 1):

[FIGURA 1 OMITIR]

(i) carry out a preliminary desk study of the prospective area; (ii) if basic information is not available, a site visit is essential; (iii) apply GOD, using the information to rank the sites; (iv) the sites with the lowest GOD score should then be modeled using the WASP scheme or the 1-D transport numerical simulator. The sites with the lowest barrier factor scores in WASP and the longest travel times using the simulator should then be considered for waste disposal. The effect of the waste disposal operation on the fate group can be assessed using the 2-D contaminant transport simulator; (v) after preferred site selection, a more detailed site characterization programme can be performed to allow a site-specific hydrogeological model to be parameterized.

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The above procedure is applied to the Merida municipal waste disposal site which is situated on the northern outskirts of the city of Merida (Figure 2) and used to be operated by the municipality. The site has a long history of uncontrolled dumping and waste burning with commercial, industrial and domestic waste being tipped. From 1993 to 1998 an attempt was made to place the waste into a compacted raise with a soil cover. This methodology reduced the risk of the waste catching fire and also nuisance from air borne pollution and smells.

[FIGURA 2 OMITIR]

2. SITE GROUP

The waste disposal site is estimated to cover an area of five hectares to an average depth of six metres. Leachate analysis are given in Table 1 and because of the very high evaporation rate from the waste are strongly mineralized. Data averaged over 50 years show that during most months evaporation exceeds precipitation (Salazar, 2002). Most of the infiltration into the waste occurs during the rainy season. Over the year recharge is of the order of 200 to 300 [mma.sup.-1] with strong leachates being produced. Rapid

recharge to the underlying aquifer via fissures is assumed.

3. GEOLOGY AND HYDROGEOLOGY GROUP

The Merida landfill site is emplaced directly onto a karstic, Tertiary, marine limestone of Miocene-Pliocene age, (DGGTN, 1984), with a thin (< 1 m; DGGTN, 1985) to non-existent soil cover. The following hydraulic data are used to assess the hazard ranking: (a) the hydraulic conductivity is very high due to the fissured nature of the rock. Mendez (1993) indicates values of the order of $[10.\text{sup.}-3]$ to $[10.\text{sup.}-4]$ $[\text{ms.}\text{sup.}-1]$, while Sanchez (1992) quotes values ranging from $3.7 \times [10.\text{sup.}-5]$ for calcarenites to $3.38 \times [10.\text{sup.}-8]$ $[\text{ms.}\text{sup.}-1]$ for recrystallised limestone.; (b) both matrix and fissure porosity are high, the former ranging between 40 and 50% (Sanchez, 1992; Brewerton, 1993); (c) the water table is about 5 metres below ground level; (d) the hydraulic gradient is low at $7.5 \times [10.\text{sup.}-5]$ $[\text{ms.}\text{sup.}-1]$ with flow in northwesterly and westerly direction towards the coast; (e) most of the recharge occurs in August and September. Rapid bypass flow can be assumed during rainfall events and a high percentage of rainfall is estimated to go to recharge, i.e. 150 $[\text{mma.}\text{sup.}-1]$.

FATE GROUP

A contaminant plume has been detected moving away towards the west. The nearest population center under threat is Dzityá about two kilometres from the site (Gonzalez et al., 2002). Groundwater is the main source of water for agriculture, industry and domestic consumption.

5. HAZARD RANKING OF THE MERIDA WASTE DISPOSAL SITE

A weighted DRASTIC score (Aller et al., 1987) has been calculated as follows: Depth to groundwater score = 50; Net Recharge (150 $[\text{mma.}\text{sup.}-1]$) = 30; Aquifer media (karst) = 30; Soil media factor (thin) = 20; Topography factor (flat) = 10; Impact of vadose zone media factor (karst) = 50; Evaluation of Hydraulic Conductivity factor = 30.

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Using GOD (Foster, 1987; Foster and Hirata, 1991) a rating of 1.0 is given for groundwater occurrence, 1.0 for the overall lithology and 1.0 for depth to groundwater. The overall score is 1.0 with an extreme aquifer pollution vulnerability.

The WASP index (Parson and Jolly, 1994a; 1994b) is calculated to be 9.7 with a highly unsuitable rating. Both the threat factor and the barrier factor scores are at a maximum of 10, the former because of the hazardous nature of the waste. The resource factor is 9.3.

This site is represented by a 225 m by 225 m square in the simulation. The hydraulic gradient was allowed to be determined by the recharge and was not fixed at 7.5×10^{-5} since this caused a large recharge mound around the waste disposal site. Recharge was set at 150 $[\text{mma.}\text{sup.}-1]$ regionally and 200 $[\text{mma.}\text{sup.}-1]$ over the site. Porosity was taken as 0.45 and density was assumed to be 2500 $[\text{kgm.}\text{sup.}-3]$. The base of the aquifer was set at zero masl and the eastern fixed head boundary was set to 1 m. Observation points were set at a distance of 2 km along the flow path, and 450 to it, and at a distance of 500 m at 90° to it. No borehole abstraction was considered. Times for C1/C0 to reach 0.1 were: $5.2 \times [10.\text{sup.}-8]$ s and $4.4 \times [10.\text{sup.}-9]$ s for a hydraulic conductivity of $1 \times [10.\text{sup.}-3]$ and $1 \times [10.\text{sup.}-4]$ $[\text{ms.}\text{sup.}-1]$, respectively.

Generally, depending on the dispersion coefficients, the observation points away from the main flow path did not display significant contamination. Although contamination is obviously a problem close to the site, as is illustrated by the extreme ratings given by the other schemes, the distance to the fate group means that this site gives a large travel time. However, the limestone is known to be highly fissured and these fissures will

provide rapid flow paths through the aquifer.

Infiltration through the 5 m of limestone making up the unsaturated zone was calculated to take 2.94×10^8 s (9.33 years) assuming a worst-case hydraulic conductivity of 10^{-3} [ms⁻¹], a porosity of 0.45, infiltration of 200 [mma⁻¹] and characteristics similar to a sandstone. This decreases to 6.53×10^6 s (75 days) if a porosity of 1% is used. Again, it is believed that heavy rainfall events on the waste will cause rapid leachate discharge via fractures to the groundwater table.

6. CONCLUSIONS

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This study has assessed whether it is possible to use a generic simulator for any site utilizing the same amount of information that might be available through a desk-study for other, more empirical assessment schemes. Whilst the results from the simulator can not be considered to be accurate scientific prediction, because of uncertainties in key parameters such as: dispersion coefficients, unsaturated zone characteristics and infiltration rate, the model has been successfully applied. Therefore it does provide a useful and cheap quantification tool to be used alongside other methods.

Using the model and its guidelines, it should be possible to derive an approximate time at which the waste disposal site starts to pose a hazard at a distance of interest. Results and the assessment of uncertainty from the numerical simulator in combination with a dose-response analysis could form the basis for a risk assessment.

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