Geochemistry of the Chiltepec sanitary landfill, Puebla, Mexico

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RESUMEN

El relleno sanitario de Chiltepec recibe diariamente entre 800 – 1100 toneladas de basura de la ciudad de Puebla. Las rocas que subyacen a la ciudad de Puebla consisten de basaltos intercalados con calizas. El relleno sanitario empezó a recibir residuos sólidos a finales de 1995. Algunos parámetros son monitoreados cuatrimestralmente, de acuerdo con las normas oficiales mexicanas. La evolución temporal entre dos períodos de muestreo, mayo y noviembre de 1996, demuestran que las concentraciones de algunos de los parámetros se han incrementado de manera importante. La conductividad específica se ha incrementado tres veces. La concentración de aluminio se incrementó once veces. Las concentraciones de cromo, zinc, y nickel se han incrementado media, tres, cinco, y media vez más, respectivamente. La modelación geoquímica utilizando datos químicos de un pozo cercano demuestra que la mayoría de los metales analizados no pueden ser movilizados en este medio ambiente geológico.

PALABRAS CLAVE: Puebla, Chiltepec, relleno sanitario.

ABSTRACT

The Chiltepec sanitary landfill receives daily between 800-1100 metric tons of domestic waste from the City of Puebla, which is underlain by basalts intercalated with limestones. The landfill started operating at the end of 1995. Selected parameters sampled from the leachate are monitored on a quarterly basis in accordance with Mexican environmental laws. The temporal evolution between the two sampling periods, May and November 1996, shows dramatic increases in the parameters that are being monitored. The specific conductance has tripled; the aluminum concentration has increased eleven times; total chrome, zinc and nickel concentrations increased three, one-half, and five times, respectively. Geochemical modeling using water chemistry from a nearby well shows that most of the metals are not mobile in this geologic environment.

KEY WORDS: Puebla, Chiltepec, sanitary landfill.

INTRODUCTION

In Mexico, more than two million hectares are used for agriculture and more than 60 million inhabitants and 75% of Mexican industry depend on ground water. In 1995, the Ley Federal de Aguas Nacionales was passed (Diario Oficial de la Federación). Ground water extraction is regulated by this law; and parties that contaminate ground water bodies are legally liable. The National Water Commission (C.N.A.) is the federal agency in charge of enforcing this law. The INE is responsible for establishing the norms for the construction, operation, monitoring, and closing of sanitary landfills.

The hydrogeology of the Valley of Puebla consists of volcanic rocks intercalated with carbonate rocks. The hydrogeological setting is complex. Beneath the surficial fresh water aquifer, which ranges in thickness from a few meters to at least 250 m, there is a confined aquifer (Marín *et al.,* 1994). This water flows to the surface in several localities, including the public baths at Agua Azul, it has a high H_2S content. The water may be found at different depths throughout the city, although the depth has not been mapped.

Marín *et al.* (1994) report for the City of Puebla highly variable spatial patterns in TDS content. Wells drilled within a few hundred meters from one another, and finished at approximately the same depths, show distinct variations in TDS content, which may range from less than 100 ppm to over 1000 ppm. The zones with high TDS concentrations are characterized by calcium carbonate deposits. Other
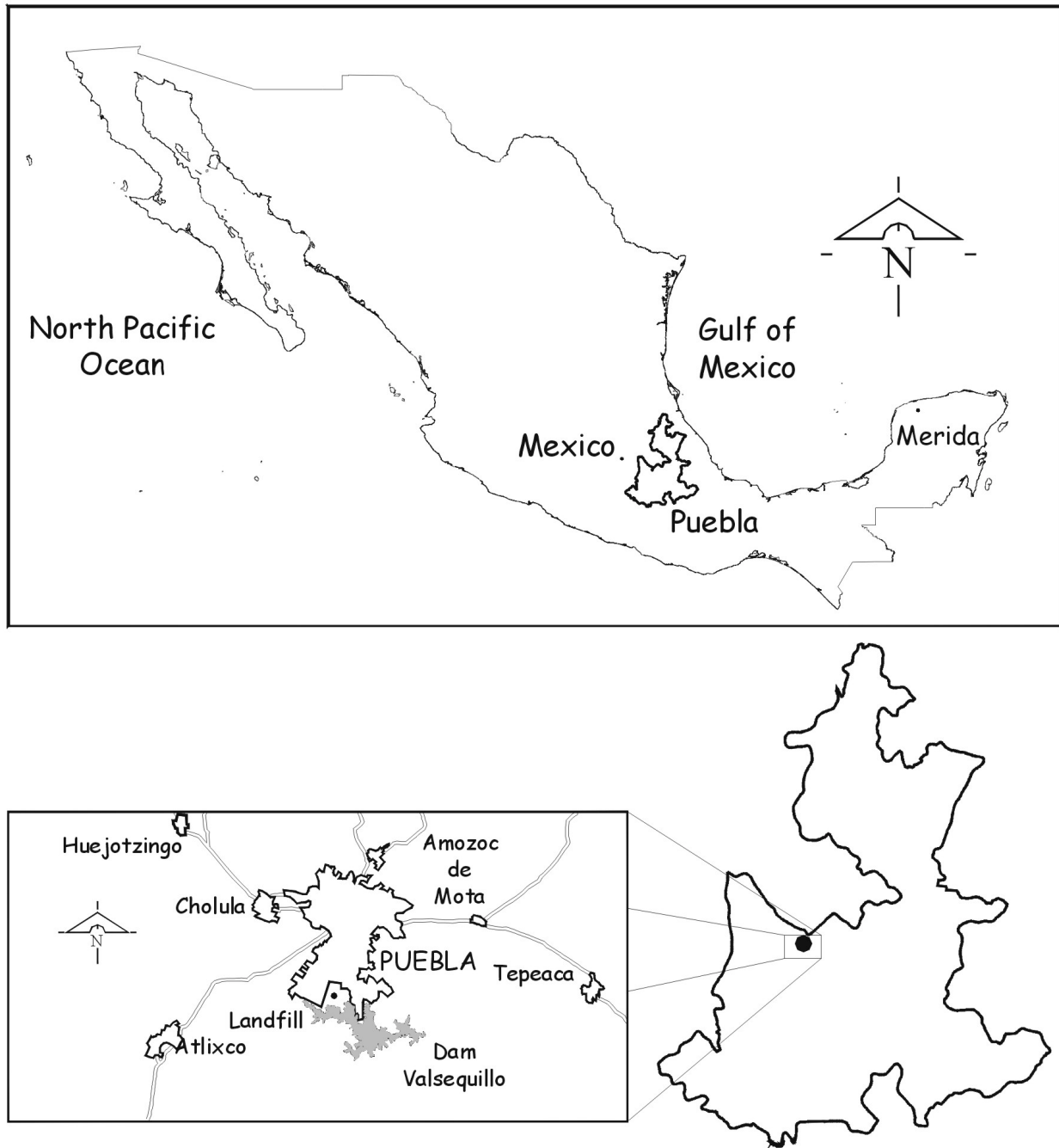
Fig. 1. Location of study site.

zones of the city, including the highway Cholula-Puebla (Figure 1), have extremely aggressive waters. Only one geochemical data set appears to be available for these wells (Velázquez Oliman, 2000). Saturation indices have not been determined for minerals such as calcium carbonate. The submersible pumps in this part of the Puebla well field must be replaced every six to nine months due to corrosion.

The Chiltepec sanitary landfill is located approximately 18 km southwest of the City of Puebla (population greater than 1 000 000 inhabitants). The landfill lies on the eastern flank of Chiltepec Creek within the municipal limits of Santo Tomás Chautla. Its location is 18°05N, 98°10W. The elevation is 2200 amsl. Within the creek both limestone and metamorphic rocks crop out; and, in some of these rocks, large fractures are clearly visible. It is likely that additional fractures have been created by blasting. No mapping of the regional fractures or of induced fractures has been conducted (Stirrat, 1993; Anonymous, 1993). According to the Instituto Nacional de Estadística, Geografía e Informática (INEGI)

Table 1

Mexican Standards for maximum concentrations allowed for leachates and results from the May and November, 1996 sampling dates (data from Kempe Laboratory, 1996a, 1996b).

Parameter	Units	NOM-031	May, 1996	November, 1996
pH		6.0 – 9.0	7.36	7.70
Sp. Conductance	Umho/cm	5000	5770	15 230
Temperature	°C		15.0	14.3
Solid settlement	ml/1000ml	5	0.5	0.5
Oils and greases	mg/l	60	4.76	49.2
Phenols	mg/l	5	0.20	0.25
Active substance to				
methyl blue	mg/l	30	9.5	nd
Aluminum	mg/l	10	0.94	11.0
Arsenic	mg/l	0.5	nd	nd
Total Chromium	mg/l	2.5	0.05	0.17
Zinc	mg/l	6.0	0.27	0.43
Nickel	mg/l	4.0	0.19	0.99
Lead	mg/l	1.0	nd	nd
Mercury	mg/l	0.01	nd	nd
Cadmium	mg/l	0.5	nd	0.01
Cianides	mg/l	1.0	nd	0.15
Silver	mg/l	1.0	nd	nd
Copper	mg/l	5.0	nd	nd
Total solids	mg/l		4680	11 134
Suspended solids	mg/l		98	934
Dissolved solids	mg/l		4582	12 200
DBO	mg/l		120	826
DQO	mg/l		600	12 400

(1987), the rocks underlying the site overlie basalt flows, which outcrop in the higher areas of the creek. The site lies within the Mesozoic of Central Oaxaca located within the Mexican Neovolcanic Belt.

The disposal site is located within CNA Hydrologic Region 18, which overlies the Aguaje sub-basin, fed by intermittent streams. Average overland flow is less than 10 mm per year, and the average base flow is on the order of nine cubic meters per second. The water table is approximately ten meters below the surface. The nearest surface water body, of regional importance is the Manuel Ávila Camacho Dam, located 10 km from the landfill (Escolero and Marín, 2000; Figure 1). Water from this dam is used primarily for irrigation. The landfill is located down-gradient from the city of Puebla and its associated well fields. Two small towns, Atlixco and Cholula, are located to the southeast and northeast of the site (Figure 1).

The Chiltepec landfill has an area of 67 hectares. It is divided into two sections, A and B. Section A is the largest and is subdivided into six active cells. The whole landfill is underlain by geotextiles. The leachate from the landfill is collected in two holding ponds where some evaporation occurs. It is likely that any VOC present are lost at this stage. When the evaporation ponds reach full capacity, the leachate is pumped back into the collection system. According to one of the landfill operators, the volume of the holding ponds remains constant. Thus, there are probably important volume losses, perhaps through leaks in the system, since the volume in the aeration ponds remains constant throughout the year.

To prevent overflow of the evaporation ponds on the rare days when it rains, the leachate is pumped back into the collection system. Major volumes of leachate are being lost every time that the leachate is re-circulated.

The Chiltepec landfill started to receive waste at the end of 1995 from the City of Puebla. Daily load is between 800-1100 metric tons. No recycling or separation of refuse was taking place when we visited the site in 1996. Thus, although Chiltepec is defined as a municipal landfill, which is permitted to receive only domestic wastes, it actually receives all kinds of wastes, including batteries, organic solvents, paints, etc., many of which are considered hazardous according to the USEPA.

Mexican law requires leachate samples as well as gas emissions to be collected and analyzed every three months. The chemical analyses for the Chiltepec landfill were conducted at the Kempe Laboratory in Mexico City according to NOM 031 (1993). The parameters that need to be monitored according to this norm are: pH, oils and greases, specific conductance, phenols, temperature, total suspended solids, total dissolved solids, BOD, COD, and the following trace elements: Al, Cr, Ni, Pb, Zn, Hg, Cd, As, Ag, and Cu.

Marín *et al.* (1998) suggest that an inexpensive water quality monitoring system might be used by comparing measured values of conductivity against the specific conductance vs. TDS type curves. They constructed a type curve for Mexico based on five different specific conductance vs. TDS type curves. One of these five curves is for the Valley of Puebla including the region where the Chiltepec sanitary landfill is located. The equation that describes this line for the Valley of Puebla is $y = 1.15x + 27$ ($r^2 = 0.91$). Although this monitoring system is only appropriate for inorganic species, it can be monitored on a more frequent basis than four times per year, as mandated by the Mexican norm. Marín *et al.,* (1998) also propose an alert system. If a specific conductance value from the system exceeds some threshold value, a complete chemical characterization would be performed in order to identify the source(s) of the high electrical conductivity.

Geochemical modeling allows one to determine the distribution of species based on equilibrium calculations. This information may be useful to evaluate the potential transport and toxicity of elements such as lead, which is more toxic as dissolved lead ($Pb^{2+}_{(aq)}$) than as a complex.

Input parameters for a geochemical model such as WATEQF are pH, temperature, alkalinity, redox conditions (if known), calcium, magnesium, sodium, potassium, chloride, sulfate and any trace elements of interest. Details of the geochemical modeling are presented in Trusdell and Jones (1974).

The objectives of this paper are (1) to propose a threshold value for the alert system based on specific conductance vs. TDS curve proposed by Marín *et al.*, (1998); (2) to evaluate the temporal evolution of the leachate coming from the Chiltepec sanitary landfill; (3) to evaluate the current parameters being used to characterize the geochemistry of the leachate; (4) to determine the speciation of selected elements coming from the landfill using the geochemical model WATEQF (Trusdell and Jones, 1974).

METHODOLOGY

The hydrogeologic setting of the Valley of Puebla was considered in order to set a threshold value for the alert system, based on the specific conductance vs. TDS curve. The temporal evolution for the leachate was examined on the basis of two sampling dates (May and November, 1996): since those were the only data available. Geochemical data from a nearby well was used with the leachate data to determine the

Table 2

Partial results of geochemical simulations using WATEQF

Species	Saturation Index for pH = 6.0	Saturation Index for pH = 7.0	Saturation Index for pH = 8.0
Magnesium calcite	-0.150	1.147	0.819
Calcite	0.173	0.821	1.082
Al(OH)$_3$	0.360	0.298	-0.014
AlHSO$_4$	-3.536	-1.597	-5.703
NiCO$_3$	-5.098	-5.223	-5.133
Ni(OH)$_2$	-1.062	-2.191	-0.023

saturation indices of the trace elements and to determine their speciation using the geochemical model WATEQF (Trusdell and Jones, 1974).

RESULTS AND DISCUSSION

Based on the type curve for the Valley of Puebla, the threshold value for the specific conductance was set at 1500 mho/cm. Any measurements above this proposed value would call for additional geochemical sampling, including determination of major elements.

Trace element geochemical data in conjunction with chemical analyses of a nearby well were used to determine the speciation of several metals reported in the two 1996 analyses of leachate from the Chiltepec sanitary landfill. The well is located 2.8 km from the landfill, and the water table lies less than nine meters from the surface. The geochemical data for the wells are from Quijano (1984). The reported values are in mg/l except as noted: Ca, 51.0; Mg, 11.0; Na, 54.0; K, 7.2; Cl, 220; SO_4, 50.0; SiO_2, 42.4; pH, 5.75, and HCO_3, 251. Obviously, the ideal would have been to run the simulation using the data from the leachate itself, and for the same sampling date, but these data were not available.

Table 2 shows the results for May and November 1996 from the Chiltepec sanitary landfill. The data come from the Kempe Laboratory in Mexico City (Kempe, 1996a, 1996b). The specific conductance values are 5770 and 15 230 mho/cm, respectively. According to Marín *et al.,* (1998), the extremely high specific conductance would have certainly triggered the alert system described by those authors. The temporal patterns are interesting. Between the two samplings there were important increases in concentrations. The specific conductance tripled, oils and greases increased more than ten times, the aluminum concentration increased 11 times, total chrome, zinc and nickel increased three, ten and five times, respectively. Total, suspended, and dissolved solids increased three, ten, and three times, respectively. The biological oxygen demand and the chemical oxygen demand increased seven and 20 times, respectively.

Only one sampled parameter exceeded the alert recommendation of Marín *et al.* (1998) in the first sampling. This parameter is conductivity. For the second sampling event, the aluminum concentration also exceeded the norm. In evaluating these results it should be taken into account that practically no organic pollutants were considered in the sampling protocol. Thus, the parameters sampled yield only a limited evaluation of the potential for contamination at this site. However, the percentage of organic matter available for biodegratadion is likely to lower eH, which may affect the solubility of arsenic, chromium, mercury, and possibly other elements.

The leachate from 1996 may be considered "young" according to McBean *et al.* (1995). However, it is important to follow the temporal evolution of the leachate, as it "matures", since known carcinogenic agents such as benzene and toluene are released.

The results of the geochemical modeling are presented in Table 2. Potential transport of many metals is very sensitive to changes in pH; small changes in pH may affect their mobility significantly (Stumm and Morgan, 1981). Although the pH of mature leachate tends to decrease with time, a strong buffering is probably occurring at this site due to the presence of carbonate rocks. The pH of water in equilibrium with calcium carbonate is on the order of 9.0 under specific conditions (Garrels and Christ, 1965). Thus, if there is enough solid calcium carbonate to buffer the leachate that may reach the ground water, one would expect to see basic pHs. As we wanted to see how species such as aluminum reacted to changes in pH, our simulations were for the measured pH´s, as well as one pH unit below and above. The results are presented in Table 2.

We only examined the saturation indices of a few species: $CaCO_3$, $Al(OH)_3$, $Al(HSO_4)$, $NiCO_3$, and $Ni(OH)_2$. Geochemical modeling suggests that for all three simulations the saturation indices with respect to calcium carbonate are supersaturated. For aluminum, the model predicts super-saturation in $Al(OH)_3$ at a pH of 6.0 and under-saturation at 7.0. This would suggest that under some circumstances aluminum might be transported in this hydrogeologic environment. Both species of nickel are under saturated, suggesting that nickel may also be mobile in this environment.

Thus geochemical modeling indicates that collecting major ion data (as well as the trace elements of direct interest) is essential, because the mobility of trace ions depends critically on major ion chemistry, and in order to illustrate how these models may help to understand the potential transport of metals. These studies may help to develop better remediation plans for similar sites.

The temporal evolution of the leachate from the Chiltepec sanitary landfill is of concern, due to the dramatic increases in concentrations within a six-month period. It is critical to continue monitoring this system and to have ready access to the geochemical data. For these types of sites, at least a basic ground water monitoring system should be implemented (one up-gradient, three down-gradient monitoring wells). Wells located down-gradient from the landfill should also be included in the quarterly monitoring plan. In addition to the parameters currently being monitored, the following sets of parameters should be added: (1) major ion chemistry to allow for geochemical modeling, and to provide a basic geochemical characterization, in case remediation

is called for, (2) A subset of organic contaminants such as the BTEX set to be monitored regularly. This, at the very least, would allow one to estimate a potential risk factor for the leachate from the Chiltepec sanitary landfill.

CONCLUSIONS

A threshold value of 1500 umho/cm for leachate from landfills in the Puebla area is proposed for the alert system suggested by Marín *et al.* (1998). If measured specific conductance values exceed this threshold, immediate geochemical sampling either by Comisión Nacional del Agua or Instituto Nacional de Ecología would be warranted to attempt to explain the anomalous specific conductance values.

The work presented here is a first step in the geochemical characterization of the Chiltepec landfill leachate. A much better approximation could be obtained by using a geochemical models such as PHREEQC (Parkhurst *et al.,* 1980), to model mixing of the leachate with waters from the aquifer to try to predict the composition of the final solutions. We strongly recommend that major ion chemistry be included in the parameters that are currently monitored under NOM 031.

The high variability of spatial patterns in ground water geochemistry observed in the City of Puebla suggests that the aquifer for the Valley of Puebla is geochemically complex. The presence of very aggressive waters in the Cholula-Puebla highway well field would facilitate transport of heavy metals, for example. Thus, it is important to continue with the hydrogeologic and geochemical characterization of the region.

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