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Hydrogeology and groundwater pollution of Yaqui Valley, Sonora, Mexico

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Hydrogeology of Yaqui Valley
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RESUMEN

El uso del sistema G.O.D. fue empleado en la evaluación de la vulnerabilidad del acuífero del Valle del Yaqui, partiendo de datos de pozos perforados y de planos de niveles freáticos. Las descargas de contaminantes fueron ident ificadas y cuantificadas y el riesgo de contaminación fue calculado analizando la vulnerabilidad del acuífero y las descargas de contaminantes. La zona más vulnerable está en el Oeste y las principales fuentes contaminantes so n de origen industrial, agrícola, ganadería y de centros de población. Las áreas de más alto riesgo de contaminación est n en la Central, Oeste y Este.

PALABRAS CLAVE: vulnerabilidad de acuíferos, calidad del agua, contaminación de aguas subterráneas, riesgo de contaminación, descargas de contaminantes.

ABSTRACT

We use the G.O.D. criteria to evaluate the vulnerability of the Yaqui Valley aquifer from drill hole data and water table maps. The pollutant loads are identified and quantified and the aquifer pollution risk was calculated from the aquifer vulnerabili ty and the pollution load. The most vulnerable zones are in the West, and the most important contributions of pollutants are from industrial, agricultural, livestock and population centers. The highest aquifer pollution risk areas are Central, West and East

KEY WORDS: aquifer vulnerability, water quality, groundwater contamination, pollution risk, pollution load.

INTRODUCTION

The Yaqui Valley produces 1'500,000 tons/yr of crops, mainly wheat, corn, soya bean and cotton, plus 35,600 tons/yr of pork, chicken and beef (González and Córdova, 1992). The population is 311,443 habitants (INEGI, 1990). The weather is arid with a rainfall of 300 mm/yr. Up to 1,600 million m3/yr of runoff is stored in three dams on the Yaqui River. About 340 million m3/yr of groundwater are produced by 350 wells drilled into the alluvial aquifer. This water is used to 95% in irrigation of 360,000 hectares of land (González, 1993).

The study area is located between 108ø53'W to 110ø 37'W and 26ø53'N to 28ø37'N (Figure 1). The aquifer consists of alluvial deposits, in lenses and layers of a mixture of clays and sands to gravels and boulders. The water table level is high in alm ost all the valley.

AQUIFER VULNERABILITY ASSESSMENT

The aquifer vulnerability was determined using the G.O.D. (Groundwater-Overall lithology-Depth to water table) system for the evaluation of the vulnerability index (Foster and Hirata, 1988). This criterion is based on the evaluation of three input index parameters: groundwater occurrence (confined, unconfined and leaky), overall lithology (consolidation potential and structure as a function of fissuring and permeability) and depth to the water table. Based on the stratigraphic study, five different zones have been identified. These zones were mainly defined by groundwater occurrence and lithology. Thus we have the North subaquifer unit, the South subaquifer unit, and so on (Figure 1). The G.O.D. scale has been used to classify the aquifer subunits. The vulnerability index was computed for all subaquifer units as the arithmetic product (GxOxD) of Groundwater occurrence (G), Overall lithology (O), and Depth to water table (D). See Table 1.

north subaquifer unit

This unit is unconfined covered (Foster and Hirata, 1988). The input index for this type of aquifer is 0.8, using the G.O.D. scale. The upper layers lie on thin highlands, while the lower parts have significant thickness. Underneath the upper layer, a gravel-boulder conglomerate is found with a low clay content (Figure 2). For this lithology type, the input index is 0.5 according to the G.O.D. scale. The water table is found from 5 to 20 m below the surface, and the input index for this depth is 0.8 using the G.O.D. scale. The results are shown in Table 1.

South subaquifer unit

This unit is leaky, and the input index for groundwater occurrence ("G") is 0.6 using the G.O.D. scale. The upper layer is found 20 m below the surface. It consists of a mixture of clay-gravel to a clay-gravel-sand conglomerate. The basement is reached at a depth of 150 m. The unconfined part is close to the sea with deeper layers of sand and little clay (Figure 2). The input index is 0.5 for lithology. The water table is found between 1.5 to 3.0 m; thus the input index for depth is 1.0. The results are shown in Table 1.

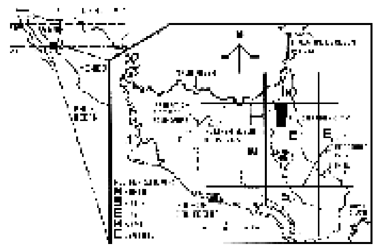

Fig. 1. Study area.

East subaquifer unit

This unit is unconfined, and the input index for this type of aquifer is 1.0. The upper layer consists primarily of a gravel conglomerate associated with clay lenses. The deeper layers contain boulders until the basement. Across the Cocoraque River near the right side of Canal Alto, the lithology consists of clay and sand (Figure 3). For this lithology the input index is 0.6. The water table is found between 10 to 30 m but is 1.5 to 3.0 m near the Cocoraque River; thus the input index for depth is 0.7 (Table 1).

West subaquifer unit

This unit is also unconfined, and the input index for this type of aquifer is 1.0 using the G.O.D. scale. The layer below the surface consists mainly of a sand-gravel conglomerate underlain by clay-gravel in the highlands. A thin clay layer (less than 20 m) is found in the lower part below conglomerate layers of sand with gravel size clasts. This bed has a thickness of 150 m, and is followed by alternating layers of boulders and clay (Figure 3). For lithology the input index is 0.5. The water table is found less than 2.0 m from the surface, and the input index for depth is 1.0 using the G.O.D. scale (Table 1).

Central subaquifer unit

This unit is confined, and the input index for this type of aquifer is 0.4 using the G.O.D. scale. In this area the upper layer consists of 14.0 m of clay with large sand lenses in some areas. The lower layers consist of a conglomerate of clay-sand and clay-gravel to a depth of 150 m. Below this depth boulders are found (Figure 2 and 3). The input index is 0.5 for lithology according to the G.O.D. scale. The water table is found between 1.5 to 3.0 m of the surface; thus the input index for depth is 0.9 (Table 1).

Table 1

Aquifer vulnerability index for the Yaqui Valley aquifer subunits

Parameters	North	South	East	West	Central
Groundwater occurrence	0.8	0.6	1.0	1.0	0.4
Overall lithology	0.5	0.5	0.6	0.5	0.5
Depth to water table	0.8	1.0	0.7	1.0	0.9
Vulnerability index	0.32	0.3	0.42	0.5	0.18
Vulnerability class	Moderate	Moderate-Low	Moderate	Moderate-High	Low

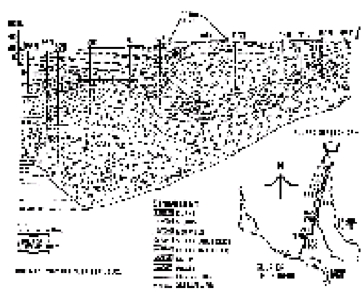

Fig. 2. Geologic section J-J'.

POLLUTION LOAD ASSESSMENT

The economic activities in the study area were compiled from Federal and State Government sources as well as private sources. The components of the subsurface pollution load were estimated from these activities.

Urban and suburban pollution

The liquid and solid pollution load was estimated from Genez and Gervois (1983) at an average of 150 l/person/day of sewage. Genez and Gervois (1983) and Rapoport et al. (1983) estimated 0.7 kg/person/day of solid waste. The sewage is collected by a sewer system which discharges into an open ditch also used for collecting the surplus irrigation water. Most small communities do not have sewerage, and the sewage flows into cesspools. Using data by Genez and Gervois (1983), for a population of 311,443 settled in the valley (INEGI, 1990), we compute 46,716 m3/day of sewage. Sewage often infiltrates the aquifers. Using data by Genez and Gervois (1983), Rapoport et al. (1983) and INEGI (1990), the total solid garbage computed is 218 tons/day. The garbage of Obregón City is disposed in a 4.0 m deep landfill. The water table in this area is found at 6.0 m below the surface, which means that the aquifer is highly vulnerable at this point of the valley. The amount and geographic distribution of these pollutant sources (human settlement and garbage disposal) are shown in Table 2, and the polutant load is shown in Table 3.

Industrial pollution

The data for industrial activities and for the pollution load were compiled. 399 industries are found in this valley; 247 are small, 96 are medium and 56 are large (Cajeme, 1992). The industrial park outside Obregón City contains large industries (Cajeme, 1992), and the smaller industries are located within the city limits. We counted 101 industries that produce garbage and sewage, which probably reaches the aquifer since the sewage flows into the Gulf of California. González and Córdova (1992) report 39,000 m3/day from industrial sewage and 300 tons/day from collection of domestic and industrial garbage in Obregón City (Cajeme, 1992). The difference between the average human waste and the city record is 82 tons/day, corresponding to industrial and commercial activities. The amounts and geographic distribution of these pollutant sources are shown in Table 2, and the pollutant load is shown in Table 3.

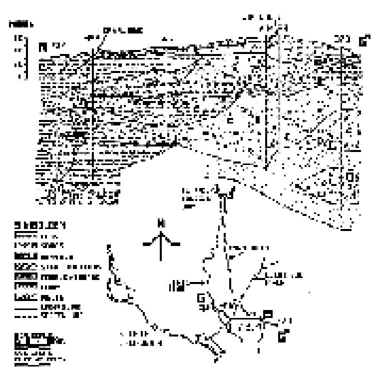

Fig. 3. Geologic section G-G'.

Among others, pork and beef are raised in this valley as part of the farming activities. The amount of livestock and farms was compiled by INEGI (1990). The pollution load from this source includes manure and urine, amounting to around 3,200 m3/day from pork, 850 m3/day from beef and 650 m3/day from poultry (González and Córdova, 1992). Thus we compute 4,700 m3/day of pollutant load from this activity. Some of this amount goes into the ground and the rest is drained into the sewer. The amount and geographic distribution of these sources are shown in Table 2, and the pollutant load is shown in Table 3.

Agricultural pollution

The pollution load from fertilizers and pesticides was compiled. According to González and Córdova (1992) about 233 m3/day of fertilizer are used. The most common fertilizers are ammonia, urea and combined N-P-K (Nitrogen, Phosphorus and Potassium). The use of large amounts of pesticides is common in the area. It is estimated that about 0.92 l/hectare of pesticide is applied (González, 1991). For 3 crops/yr at 360,000 hectares/crop, the total amount of pesticide used is in the order

of 0.3 m3/day. Pesticides in low concentrations have been found in five wells located in the Central subaquifer, in two wells in the East subaquifer and in one in the North subaquifer in moderate concentrations (González, 1993). García and Meza (1991) found pesticides in food and biologic extracts. The Table 3 show the estimated volume dumped in this valley.
The pollution load index is computed by the product of the potential hazard input index for each pollutant source (Foster and Hirata, 1988), times the number of sources per subaquifer (Table 2). The output index of pollutant load for each subaquife r is shown in Table 4.

Table 2

Amount of point pollutant sources for Yaqui Valley

Source	North	South	East	West	Central	Total
Human settlement	4	1	5	17	13	40
Garbage disposal	0	0	0	0	1	1
Industry	4	1	3	4	89	101
Livestock	24	2	38	10	35	109
Total	32	4	46	31	138	251

Table 3

Pollutant load emitted by economic activities in Yaqui Valley

Activity	Source	Partial Pollutant (m^3/day)	Pollutant Load Per Activity (m^3/day)
Urban	Sewage	46,716	46,934
	Solid waste	218	
Industry	Sewage	39,000	39,082
	Solid waste	82	
Livestock	Porcine	3,200	4,700
	Bovine	850	
	Aviculture	650	
Agricultural	Fertilizers	233	233
	Pesticides	0.3	
Total			90,949

Table 4

Pollution load index and potential hazard per pollutant source and subaquifer

Source	Potential Hazard Index	North	South	East	West	Central
Industry	0.38	1.52	0. 38	1.1	1.52	33.82
Farming	0.35	8.40	0. 70	13.3	3. 50	12.25
Garbage disposal	0.09	0	0	0	0	0.09
Human settlement	0.23	2.60	0.65	3.2	11.05	8.45
Total		12.52	1.73	17.7	16.07	52.71

AQUIFER POLLUTION RISK

The criteria proposed by Foster and Hirata (1988) were used to estimate the risk of contamination from the interaction between components of aquifer vulnerability and the surface pollution load. We computed the pollution risk of the aquifer as the arithmetic product of the indexes of the aquifer vulnerability times the pollution load. Table 5 summarizes the risk evaluation as follows.

North subaquifer unit

Medium risk as a result of cattle raising activity, and medium vulnerability index for the aquifer.

Southern subaquifer unit

Here the risk is low because of the medium vulnerability index and the low pollutant load.

Eastern subaquifer unit

High risk index as a result of livestock activity and high pollutant load near the Irrigation District, just across Cocoraque River, even though this s ubaquifer unit has a moderate vulnerabilty index.

Western subaquifer unit

Rates a high risk of contamination due to the pollutant load and the high vulnerability index.

Central subaquifer unit

Has a low vulnerability index but a high pollutant load. This is because most activities are concentrated in this area.

Table 5

Pollutant hazard index for each of the subaquifer units

Subaquifer	North	South	East	West	Central
Vulnerability Index	0.32	0.30	0.42	0.50	0.18
Pollutant Load Index	12.52	1.73	17.69	16.07	52.71
Pollutant Risk Index	4.01	0.52	7.43	8.03	9,49
Potential Danger Class	Medium	Low	High	High	High

CONCLUSIONS

The Yaqui Valley aquifer is more vulnerable in the West and less in the Central subaquifer units. The main pollutant sources for this aquifer are livestock, industry and agriculture. We find that the pollution risk is high in the Central, West and East, and low in the South subaquifer units. This is a consequence of the concentration of economic activities as well as of the population. A medium pollution risk is proposed for the North subaquifer unit. These results suggest that priorities in terms of research and regulation should be given to the Central, West and East subaquifer units.

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