Groundwater Quality Monitoring on Northeast Yucatan Peninsula, Mexico

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ABSTRACT
The aims of the study are to determine groundwater flow direction, to detect ground and surface water quality and to identify contaminations in the aquifer of the Northeast Yucatan Peninsula, Mexico. As a synthesis of this investigation potential zones for drinking water supply in future have to be determined.

INTRODUCTION
The easterly part of the Yucatan Peninsula is formed a by Tertiary - Pleistocene limestone plain that is underlying by porous and fissured limestone. Along the coastline Pleistocene reef limestone are exposed in quarries from the Northern Cape to Tulum. An important geomorphologic characteristic at the westerly border of the investigation area is the Holbox Fracture System. It consists of a series of fractures running NNE-SSW from Cabo Catoche to Playa del Carmen. The length of the system is about 100 km and about 50 km wide running parallel to the coast.

The karstic aquifer is unconfined where a fresh water lens floats above denser saline water. The aquifer transmissivity is very high combined with a very low hydraulic gradient ranging from 7-10 mm/km through most of the northern part of the peninsula (Marin, 1990; Gonzalez-Herrera *et al.*, 2002). Beddows *et al.* (2007) determined the hydraulic gradient in the range of $5 – 10 \times 10^{-5}$ in the centre of Yucatan peninsula and along the Caribbean coast and Gonzalez-Herrera (1984) reported the porosity in the range of 7 – 41 %. The average porosity of Pleistocene deposits along the Caribbean is determined by Harris in the range of 14 -23 % (Harris, 1984).

METHODS
The following representation of the hydrochemical results is focussed on the most important parameters for characterizing the water quality due to potential contamination sources (Fetter, 2001) in the investigation area. One of the most important impacts on ground water related to the increase of salinity is seawater. Electrical conductance of seawater at the Mexican Caribbean coast is represented by a value greater than 54,400 µS/cm (Matthes *et al.*, 2006, Wurl & Giese, 2005).

Physicochemical parameters
The dominant ions of seawater and of freshwater affected by seawater are chloride and sodium. The values of EC range between 102 - 53,300 µS/cm. The highest value is detected in Cenote Chemuyil in a depth of 29 m and is close to seawater conductance. Increased values of 10,000 - 30,000 µS/cm were detected on the island Isla Mujeres and in a sinkhole in Cancun. Groundwater samples with EC values up to 5000 µS/cm are located nearby the coastline in the southerly part of Solidaridad The bulk of ground and surface water, like e.g. samples of the capture zones for drinking water supply of Cancun and Playa del Carmen, shows EC values in the range of 1,000 - 1,500 µS/cm .

The concentration of nitrate shows a range from not detectable to 111 mg/l. The amount of samples represents values less than 5 mg/l. These very low concentrations are dominant in the capture zones of Playa del Carmen and Cancun. Increased values were found in the urban areas of Cancun, Playa del Carmen, Tulum and Cobá.

Ammonia concentrations range from not detectable to 72 mg/l. Very high ammonia concentrations ranging between 30 to 72 mg/l were detected in the Cenote Chemuyil and in Tulum.

Iron and manganese were analyzed in very low concentrations. The range of concentrations of iron is 0.018 – 0.736 mg/l and of manganese 0.001 – 0.185 mg/l. The dominant concentration of iron is in the range of 0.08 – 0.16 mg/l and of manganese less than 0.04 mg/l.

PH was measured in the range of 6.8 – 9. The bulk of samples shows a pH value in the range of 7 – 7.5 that is due to the buffer of limestone. Zinc was measured in 47 samples in the range from not detectable to 0.130 mg/l. Twelve samples show values above the detectable value of 0.001 mg/l.

Groundwater flow direction

Groundwater levels related to ground surface were measured during the field campaign between March 2007 and September 2007. Contour lines of equal groundwater levels were constructed by the use of groundwater elevation. The calculation of groundwater levels in the northerly part of Isla Mujeres was done by the assumption that groundwater levels at the coastline are equal to the sea level. The highest water level of more than 3 m above the mean sea level was found in the westerly part of Solidaridad. The general flow direction is from west - east directed to the coastline. A variation of this direction is identified in the area northwesterly of Cancun, where the flow direction turns to north showing a parallel orientation to the coastline. Along the coast between Tulum and Playa del Carmen the water level of 1 m contour line was detected near to the coast indicating a high gradient to the sea. Northerly of Playa del Carmen the 1 m contour line tends more in direction to the inland.

Contaminations and sources of pollution

The groundwater in the investigation area is high vulnerable caused by structural fractures and high solubility of the limestone aquifer represented by caves and conduit systems with high hydraulic conductivity (INEGI 2005). Because of the absence of rivers the runoff of surface water will infiltrate rapidly into the aquifer along sinkholes, fissures and fractures. Hence, contaminated surface runoff from urban area represents an extremely hazard of groundwater contamination. Typical urban sources of pollution are leakages from landfills (industrial and household waste) producing an impact of organic material. By the lowering of pH and redoxpotential heavy metals become mobile and will be dissolved and transported in groundwater. Gas stations and scrap yards are locations for potential oil, grease and gas pollution.

Water quality related to Mexican drinking water supply standard

The assessment of water quality is evaluated by the comparison of the collected samples to the Mexican drinking water standard (Tab. 1).

Potential areas of inundation and seawater intrusion

The northern part of Yucatan peninsula is plain and shallow related to the distance of surface to groundwater. It contains solution depressions locally known as sabanas (Ihl, et al. 2007). This geomorphologic setting is due to temporary floods represented by polje-like depressions that seasonally filled with water creating swamps. Along the coastline a stripe of increased electrical conductance was detected, representing the influence of seawater. It was discussed before that the thickness of the freshwater lens will grow related to increasing distance to the coastline. Hence, the locations of potential wellfields in future should be located far away from the coastline.

Table 1. Percentages of exceeding values of dominant Mexican drinking water standards

Dominant Parameters of exceeding values of Mexican drinking water standard	Samples [%]
TDS	23 %
Cl	19 %
NO3-N	16 %
NH3-N	73 %
SO4	3 %
Total hardness	23 %
Na	22 %

DISCUSSION AND CONCLUSIONS

In the inland at the westerly border of the investigation area the results show low salinity at shallow water depth represented by electrical conductance (EC) of 102 µS/cm. Increasing salinity with a maximum EC value of about 4900 µS/cm was found at shallow water depth near to the coastline building up a sequence of stripes parallel to the coastline. The comparison of EC to chloride and sodium concentration shows that the increase of salinity is due to the rise of the fresh-saltwater interface at the shoreline following the general build up of a freshwater lens that is floating on denser saline groundwater.

The comparison of the chemical results to the Mexican standard of drinking water shows exceeding values of total dissolved solids (TDS), chloride and sodium. Ammonia concentrations exceeding the Mexican standard of drinking water were found in 137 samples showing a widespread distribution.

Anthropogenic sources of nitrogen compounds were established by the distribution of maximum concentrations of nitrate combined with very low oxygen contents in shallow water depth. A second source of ammonia impact to groundwater was identified at the urban waste disposal site in Cancun, where increased ammonia concentrations were identified in direct vicinity to the landfill site indicating most likely a leakage. Another source of pollution was identified in the urban area of Cancun by the detection of gasoline. An oil film combined with the smell of gasoline was found in a household well in the quarter Bonfil. The location of the contamination source could not be detected. In the investigation area the general groundwater flow is determined to the east in direction to the coastline. A variation of this direction is identified in the district Isla Mujeres, where the flow direction tends to north.

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