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# Assessment of the environmental impact of artificial effluent lagoon in Jiayuguan City of China

PEI Yuan-sheng[1,2], LUAN Zhao-kun[1*], BARBER C[3]., WILLIAMSON D[3].

(1. Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: pys_1@263.net; 2. Institue of Environmental Sciences and Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China; 3. Center for Groundwater Studies, CSIRO Land and Water, Perth, Australia)

**Abstract**: An artificial effluent lagoon for storing wastewater were excavated in Jiayuguan City since 1994. As a part of a demonstration project of Sino-Australia cooperation, an assessment of the environmental impact of the lagoon was carried out. The assessment was based on field and laboratory tests and predictive model. The main impacts from the lagoon site are likely to be on the groundwater system, and, to a lesser extent, on ambient air quality in the vicinity. Currently it is expected that groundwater is being polluted with effluent from the effluent lagoon. Air pollution(odor nuisance) is mainly caused by untreated effluent in the irrigation channel. The impact of high total dissolved salt(TDS) on groundwater is likely to be significant in the long run if the lagoon is continuously used. There is, consequently, no likelihood of contamination of surface water system, particularly of the city water supply system, from infiltration of effluent at the lagoon.

**Keywords**: assessment; environmental impact; groundwater contamination; lagoon

## Introduction

Jiayuguan City is located in the northwest of Gansu Province, China, to the north of the Qilian Mountains and within the Hexi Corridor along the Silk Road(Fig. 1). The city sits on a flat, bare, intermontane gravel plain within the Gobi Desert. The elevation of the city is between 1500 and 1800 m above sea level. The area is characterized by typical inland desert climate, with hot summers and very cold winters, strong winds and sandstorms, little rainfall( < 100 mm/a) and high evaporation. Annual average temperature is around 7.68℃.

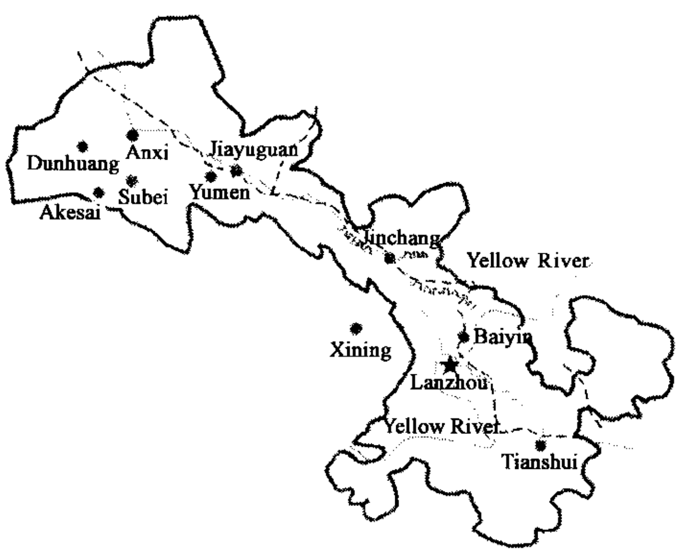


Fig.1 Location of Jiayuguan City, Gansu Province, China

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In Jiayuguan region, groundwater occurs in Quaternary and older mixed alluvial and colluvial sediments which have accumulated within the graben structure. The sediments form two basins, separated by a fault zone(Fig. 2). The aquifer is much deeper in the east of the fault, and the hydraulic head may be found as deep as 100 m below ground surface (Barber, 1999). Groundwater for the industrial and domestic needs of the city is pumped from the west basin from bore fields in the shallowest water level zones near the fault. Groundwater is also extracted at the eastern parts for irrigation and domestic use. The groundwater flow is generally from south to north towards the fault zone. Groundwater contours are shown in Fig. 2.

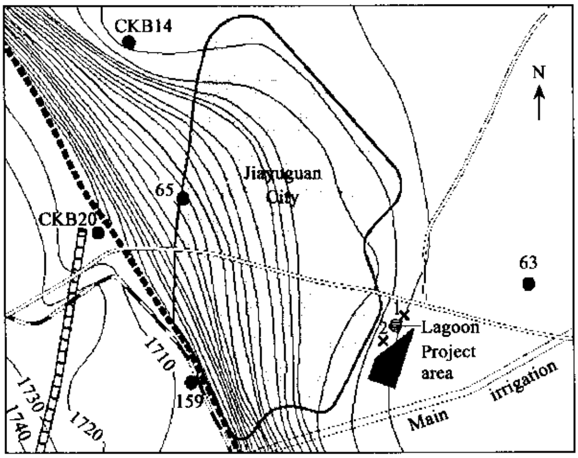


Fig. 2 Groundwater level contours and location of the lagoon with monitoring well 1# and 2#

A lagoon has been excavated by the City Council and filled with untreated urban sewage effluent since 1994 (Fig. 2). At present, the infiltration has been greatly decreased since a thick layer of sludge accumulated in the bottom of the lagoon. A current estimation of the average effluent volume of the city is given, as $13 \times 10^3$ $m^3/d$. Flow directly to the effluent lagoon is $3.9 \times 10^3$ $m^3/d$. The rest flows into a channel, which takes untreated effluent to the Jiayuguan airport road as well as directly allocates effluent to irrigation. Untreated wastewaters in the lagoon as well as in the channel may cause water contamination, soil salinity and air contamination, and even appear as a risk of environment and human health.

As part of the Sino-Australia Links Program, this paper assesses the environmental impacts of the artificial effluent lagoon. The considered impacts include impacts of salinity on the groundwater system, surface water contamination, extent of regional impacts on groundwater, air contamination, and impact on the landscape.

## 1 Materials and methods

Since not much information was available on the geology and hydrogeology around the lagoon, two boreholes(Bore 1 and Bore 2 in Fig. 2) were drilled near the existing effluent lagoon to determine soil conditions and the hydrogeology of the infiltration site. Groundwater level measurements were recorded from Bore 1 (96-C52), 250 m northwest to the effluent lagoon. Jiayuguan Environmental Protection Bureau (EPB) has also taken groundwater samples for analysis. Water levels in this well have stably remained around 146 m. Water quality of groundwater was also analyzed in this study. An experiment of infiltration was carried out in a filter that was filled with original soil taken from locale(Fig. 3). Soil samples were repacked to field bulk densities in 1.8 m long Plexiglas columns with diameter of 300 mm. Saturated hydraulic conductivity measurements, based on Darcy's Law, were measured, using both clean and effluent water. Besides treating organic wastes, the removal of nitrogen within the filter was tested, which provided main parameters for simulation of the processes of nitrate leakage under the lagoon.

To evaluate the effect of the lagoon on groundwater, it was essential to model water movement and chemicals transport, particularly nitrogen transport, in soil and aquifer. Pei (Pei, 2001) had developed a two-dimensional model for the saturated-unsaturated flow and the chemicals transport based on Richards' equation. The model has unified the unsaturated and saturated zones in its entirety. In the water flow model, the interface between the unsaturated zone and the saturated zone was smoothed for carrying out the correct simulation (Pei, 2001).

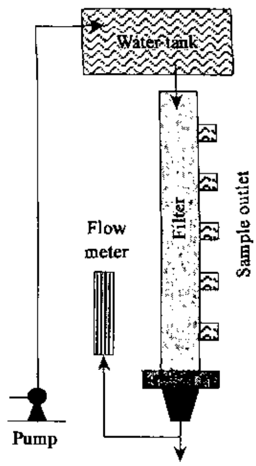


Fig.3 Experimental set

In the transport model, nitrogen transport and transformation involved mineralization, immobilization, leaching, adsorption, nitrification and denitrification(Johnsson, 1987). Carbon source, oxygen concentration and soil temperature primarily controlled the processes for nitrogen migration in soil. Sorption of positively charged ammonium ions onto the porous medium was modeled by assuming the process to be at equilibrium at all times. Both ammonium and nitrate were considered to be wholly in solution. Nitrate was calculated as the product of ammonia in water flow. Oxygen concentrations and temperature affected both nitrification and denitrification. The process ratio of denitrification was revised by the half-saturation constant. The model used soil water content as an indirect expression of soil oxygen status so as to achieve a dynamic process modeling.

# 2 Results and discussion

## 2.1 Field tests and experiments

Beneath the lagoon there is a thick accumulation of intermontane and river-lake sediments of Quaternary age overlying tertiary red clays. The upper 60 m thick layer of the vadose zone has a high, hydraulic conductivity estimated to be around 20 m/d on average. Infiltration testing at the Jiayuguan site in 1997 gave short-term rates of around 6 m/d. However, the amount of clay increases with depth, and permeability probably decreases also with depth. The quality of groundwater sampled in 1997 is listed in Table 1. A flow weir was installed in the upper reaches of the irrigation channel close to the effluent lagoon. Jiayuguan EPB has taken samples of sewage effluent from the channel for analysis. Results of analyses of these are given in Table 2 for sampling periods in 1997.

**Table 1 Quality of water samples from Bore No.1 (96-C52) in 1997 (unit: mg/L)**

| Water quality | 24 Feb. | 4 Mar. | 20 Mar. | 9 April | 23 April |
|---|---|---|---|---|---|
| pH | 9.09 | 8.94 | 8.79 | 8.69 | 8.72 |
| *EC*, mS/cm | 0.31 | 0.32 | 0.325 | 0.28 | 0.34 |
| $NO_3$-N | 0.73 | 0.59 | 0.75 | 0.74 | 0.73 |
| $NH_4$-N | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| TKN | 0.62 | 1.68 | 1.22 | 0.85 | 0.98 |
| COD | 6.5 | 6.1 | 8.5 | 6.5 | 3.5 |
| Total P | 0.12 | 0.12 | 0.1 | 0.14 | 0.02 |
| Hardness | 1.78 | 1.72 | 1.66 | 1.72 | 1.78 |

**Table 2 Results of analyses of sewage effluent samples taken from the lagoon (unit: mg/L)**

| Water quality | 24 Feb. | 4 Mar. | 20 Mar. | 9 April | 23 April |
|---|---|---|---|---|---|
| pH | 8.11 | 7.84 | 7.49 | 7.63 | 7.56 |
| *EC*, mS/cm | 0.71 | 0.78 | 0.72 | 0.64 | 0.70 |
| $NH_4$-N | 2.5 | 3.4 | 2.6 | 2.5 | 2.7 |
| TKN | 18 | 16 | 18 | 18 | 17 |
| COD | 157 | 208 | 177 | 175 | 172 |
| BOD | 37 | 103 | 72 | 99 | 85 |
| Total P | 3.33 | 4.24 | 3.38 | 3.41 | 4.28 |
| Hardness | 2.55 | 2.73 | 2.69 | 2.21 | 2.73 |

In order to measure the upper layer infiltration capability, laboratory and field water infiltration experiments were carried out. Field tests showed that *in situ* infiltration rate was an average of 5.6 m/d. Laboratory tests were also carried out using soil columns to determine infiltration rates. Soil conductivity for repacked soil columns of Jiayuguan soil was averagely 25.8 m/d. Hydraulic conductivities were also found to decrease with time. This was thought to be due to clay particle expansion. Conductivities from columns receiving wastewater also decreased slowly with time, presumably because of biofilm formation.

## 2.2 Model predictions

Due to the demands from assessment of environmental impacts as well as from evaluation of groundwater contamination, there is a need to forecast the presentation of the lagoon in the field. In this work, nitrogen transport and transformation were considered as the focal problem of groundwater contamination and assessment. Parameters to define these processes were partially obtained from the field tests and laboratory experiments, as well as from literature. Table 3 shows the parameters used in the model, in which the data with the denoted asterisk were taken from literature (Hutson, 1991; Johnsson, 1987).

**Table 3 Parameters used in the model (data with the denoted asterisk were taken from literature (Hutson, 1991; Johnsson, 1987))**

| Water flow model | | Nitrogen transport and transformation model | |
|---|---|---|---|
| Porosity | 0.426 | Total nitrogen in the lagoon, mg/L | 17 |
| Bulk density, g/L | 1.45 | Total nitrogen decomposition rate, day$^{-1}$ | 0.35 |
| Evaporation rate, mm/d | 8 | C-N rate micro and humified products, day$^{-1}$ | 0.2* |
| Transverse dispersivity, m | 0.2 | Adsorption capacity of ammonia, mg/kg | 0.143 |
| Longitude dispersivity, m | 0.05 | Nitrate-ammonia ratio | 8* |
| Storativity | 0.2 | Nitrification coefficient, μgN/(g·d) | 9.23 |
| Special storage coefficient | 0.4 | Denitrification coefficient, μgN/(g·d) | 8.88 |
| Saturated aquifer depth, m | 30 | | |
| Effluent volume, m$^3$/d | 300 | | |
| Square infiltration areas, m$^2$ | 1800 | | |

Fig.4 shows the predictive nitrogen distribution below the lagoon after 30 days infiltration. The key control factor for nitrogen in soil was determined as adsorption. Ammonia concentration quickly decreases from 2.3 mg/L in the lagoon to 0.42 mg/L below the surface of 40 m. With the increase of depth, ammonia is almost not the pollutant. It may be relatively possible to produce the pollutant of nitrate in groundwater.

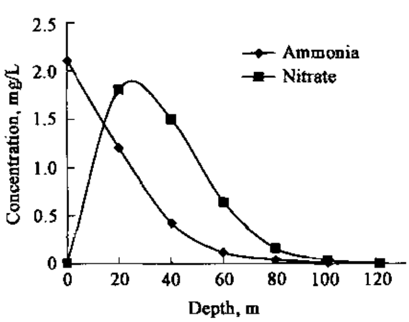


Fig.4 Predictive nitrogen distribution below the lagoon after 30 days infiltration

## 2.3 Assessment of the environmental impact

### 2.3.1 Impacts on groundwater salinity

The electrical conductivity (*EC*) of untreated effluent is approximately twice that of *EC* in groundwater (Bore 1) near the lagoon. Concentration of total dissolved salts (TDS) or salinity will consequently be the same ratio in effluent and groundwater. TDS in groundwater has been shown to be approximately 300 mg/L; therefore TDS in effluent will be approximately 600 mg/L.

Salinity is likely to increase substantially during the lagoon infiltration in the vadose zone; consequently TDS close to the water table would increase as a result of infiltration, and at worst would double within a zone close to the water table. The impact of high TDS on groundwater is likely to be significant in the long run if the lagoon is continuously used.

### 2.3.2 Surface water impacts

Jiayuguan City is situated within the Taolei catchments, which is a branch of the Hei River. The total catchments area is 6883 $km^2$. The maximum flow of water in flood season (June to September) through the catchments can be as many as 140 $m^3/s$. The average annual flow is $5 \times 10^8$ $m^3$. The closest river to the lagoon is the Beida River, which flows from west to east. The site is 3.8 km from the river, and the site elevation is 60 m below that of the river. Groundwater flow from the site is from the southwest to the northeast, approximately parallel to the river direction. The river itself recharges the groundwater system (water table depth below the river is thought to be over 100 m below surface). There is, consequently, no likelihood of contamination of surface water system from infiltration of effluent at the lagoon.

### 2.3.3 Regional groundwater impacts

Nitrogen transport and transformation have been modeled to provide preliminary estimates. Nitrate is possibly the pollutant in soil and groundwater. However, the travel time for nitrogen to reach the nearest known water supply well, at less than 3 km from the site, was estimated to be from four to eight years. Thus it is possible that the lagoon has already polluted this well and other wells around the lagoon. The lagoon is more than 5 km distance, and hydraulically down gradient from the aquifers of the Western Basin provides water supply to the people of Jiayuguan. The hydraulic head of the groundwater in the Western Basin is approximately 70 m above the hydraulic head in the native groundwater aquifer at the effluent infiltration site. This virtually guarantees that the city water supply system would be completely insulated from the groundwater mound at the lagoon site.

### 2.3.4 Air pollution

Air pollution from the lagoon is considered to be mainly odor nuisance from volatile organic compounds typical of sewage, and from ammonia which has volatilized from sewage. In additional, odor nuisance may also produce from hydrogen sulphide developing under anaerobic conditions in lagoons and impoundments containing effluent and sludge.

At Jiayuguan City, the predominant wind direction is westerly. In summer, the area is affected by a southern warm, humid airflow, and the main wind direction during that period is easterly. The northwesterly wind has the highest frequency in December(21.5%), and the lowest in August(11.9%). The easterly wind frequency is the highest in August(17.5%) and the lowest in December(9.3%). Therefore, though the lagoon is located 1.5 km to the southeast of the city area, the current irrigation channel carrying unsettled, untreated effluent does produce odor nuisances locally during the summer.

### 2.3.5 Impact on the landscape

Land around the lagoon is currently undeveloped, and consists mainly of a low relief plain at the edge of the Gobi Desert. The stone desert plain has few natural features. The main surface relief is dominated by elevated roads and railway tracks and by buildings alongside some of the roads. The artificial effluent lagoon, therefore, does not appear as a risk to the landscape at present. However, there will be a potential risk that the lagoon and the channel obstruct the development of the city in the long run.

## 3 Conclusions

The main impacts from the lagoon site are likely to be on the groundwater system, and, to a lesser extent, on ambient air quality in the vicinity of the site. Currently it is expected that groundwater is being polluted with effluent from the effluent lagoon, as well as from the irrigation channel carrying untreated effluent. Likewise, air pollution(odor nuisance) mainly is caused, at present, by untreated effluent in the irrigation channel. The impact of high TDS on groundwater is likely to be significant in the long run if the lagoon is continuously used. In addition, there is, consequently, no likelihood of contamination of surface water system, particularly of the water supply system for the city, from infiltration of effluent at the lagoon.

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