Geochemical Variations of Groundwater Quality in Coastal and Karstic Aquifers in Jaffna Peninsula, Sri Lanka

K. Gunaalan, H.B. Asanthi, T.P.D. Gamage, M. Thushyanthy, and S. Saravanan

Introduction

Chemical constituents of ground water evolve due to the interaction with aquifer minerals and mixing of different groundwater reservoirs along the flow path in the subsurface. Consequently, geochemical properties of ground water depends on chemistry of water in the recharge area as well as on the different geochemical processes that take place in the subsurface of the locality, including the presence of possible contamination sources. The increasing contamination of ground water by nitrate is primarily from the widespread use of commercial fertilizers which is an evolving public health concern factor in many agricultural regions of the world (Gulis et al., 2002; Raju et al., 2009).

A five-year study on the geographical pathology of malignant tumours in Sri Lanka from 1973–1977 had confirmed that the incidence of cancer is relatively higher in Jaffna district and one of the reasons for the esophagus cancer incidences could be due to NO_3^--N in groundwater (Panabokke, 1984). Later on, Gunaalan et al. (2011) have observed a relative risk factor for esophagus and stomach cancers associated with the consumption of NO_3^--N concentration higher than the recommended level (which is >10 mg/L for WHO standards) at the three areas in Jaffna peninsula. In many countries nitrate levels of ground water have increased significantly due to extreme use of nitrogenous fertilizers (Kross et al., 1992;

K. Gunaalan • H.B. Asanthi (✉) • T.P.D. Gamage
Department of Limnology, Sciences & Technology, University of Ruhuna, Sri Lanka
e-mail: asanthi@fish.ruh.ac.lk

M. Thushyanthy
Department of Agricultural Engineering, University of Jaffna, Jaffna, Sri Lanka

S. Saravanan
Regional office, National Water Supply & Drainage Board, Jaffna, Sri Lanka

N.J. Raju et al. (eds.), *Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges*,
DOI 10.1007/978-3-319-05969-3_5

Raju et al., 2011) and it is becoming major factor for polluting ground water. Therefore, consumption of well water rich in nitrogenous compounds has been considered as a possible risk factor for esophageal cancer (Zhang et al. 1996). Nitrates which could be converted into carcinogenic substances such as nitrosamines within the body are of importance in the carcinogenesis of esophageal and stomach cancers (Dissanayake, 1988).

Inhabitants in Jaffna peninsula mainly depend on groundwater sources because other freshwater sources are not available (Rajasooriyar et al., 1999). This is especially true in the regions of arid to semiarid climate where average annual rainfall is less than 1000 mm and the recharge of aquifer is limited (Udayalaxmi et al., 2010). It has been reported that the Jaffna peninsula has the highest levels of total hardness in ground water in Sri Lanka and there are cumulative effects of the carbonate factors, such as Cl^-, NO_3^--N, and SO_4^{2-} (Rajasooriyar et al., 1999).

The whole Jaffna peninsula is underlined by Miocene limestone formations, which are generally 100 m to 150 m thick and this layer is distinctly bedded and well jointed while highly karstified. The shallow aquifer of the peninsula occurs in the channels and cavities (karsts) of this Miocene limestone. All the shallow groundwater found within the karstic cavities originates from the infiltration of rainfall, and this shallow groundwater forms mounds or lenses floating over the saline water. These water mounds or lenses reach their peak during the monsoon rains which falls in between November and December. However, monitoring studies have confirmed a significant imbalance between the draw-off and recharge rates of groundwater (Balendran, 1969). The variations in the amount of precipitation, the timing of precipitation events, and the form of precipitation are the key factors in determining the amount and timing of recharge to aquifers and ultimately change the groundwater quality.

Approximately 80 percent of ground water is being used for high-value agriculture and the remaining 20 percent is for domestic uses including flushing of toilets in urban areas of Jaffna. Water quality studies have shown that the enhanced levels of nitrate pollution in domestic wells have been situated in more densely settled municipal areas of Jaffna peninsula (Nagarajah et al., 1988). Jaffna Feasibility Report (2006) disclosed that the thin cover (0 to 3 m) over the groundwater table consisting mainly of sandy soils with an infiltration capacity of 50,000 $Lm^{-2}.day^{-1}$ can provide no protection against pollution of the groundwater infiltrate from the surface.

Although the karstic aquifers are providing more favourable conditions for groundwater recharge compared to other aquifer types, karstic systems are more vulnerable to land surface-originated contamination due to fast transport ($>$100 m/day) and limited attenuation of contaminants (Alper and Rahime, 2011). For these reasons, it is important to assess the groundwater quality particularly in karstic aquifer functions as a primary water source in Jaffna peninsula. Therefore the prime objective of this study is to provide a statistical evaluation of groundwater quality in the selected areas in Jaffna peninsula using principle component matrix to select what are the most suitable parameters to explain selected aquifer types and to evaluate the water quality using the Sri Lankan standards for drinking water. This study is important as a step of continuous monitoring programme conducted by National Water Supply and Drainage Board (NWSDB) of Sri Lanka to draw attention towards the most vulnerable wells in Jaffna Peninsula.

Materials and Methods

Study Area

Three divisional secretaries in Jaffna peninsula, Vadamaradchi, Chunnakam and Jaffna, were selected for this study. Chunnakam area can be considered as an intensive agricultural area, Jaffna is a densely populated urban area and Vadamaradchi is considered as no relevant survey was found in literature on groundwater quality variations for the last few years. Vadamaradchi and Jaffna areas are located in close proximity to the coastline other than Chnunnakam area. Data obtained from Meteorological Department of Sri Lanka indicated that Jaffna peninsula has received mean annual precipitation of 1350 mm during the period of 2000 to 2011. The highest monthly average precipitations were observed in December, January and April owing to 532, 112 and 108 mm respectively in Jaffna peninsula. Typically, February and March were dry months during the period of study and the mean monthly rainfalls were lower than 3 mm. The entire drinking water is supplied from nearly 80,000 shallow wells in the Jaffna peninsula, in close proximity to sanitation facilities. Sivarajah (2003) has reported that the underground water is being continuously polluted as a result of human activities in the form of biological and chemical sources of pollutants in Jaffna peninsula. Also, with more and more refugees returning to their homes after thirty years long turbulent period the population is likely to increase rapidly, putting additional pressure on the already vulnerable groundwater resources.

Water Sampling and Analysis

Twenty wells were selected randomly from Chunnakam area (karstic aquifer), Vadamaradchi (coastal aquifer) and Jaffna area (coastal aquifer) and mapped their respective locations using Global Position System (GPS), as given in Fig. 1. The distance between the wells were not less than 100 m and each water sample was collected at 20 cm below the water surface using a depth sampler on monthly basis during the period of December 2010 to April 2011. Characteristics of the wells such as well depth, well diameter and height of the protection wall from the ground level were measured. Chemical parameters such as pH (Jenway CE 370 pH/mV meter, with an accuracy of 0.01 pH/$\pm$0.02 Jenway CE470) and conductivity (Meter with an accuracy of 0.01–0.1 mS/cm) were measured in the field using portable meters.

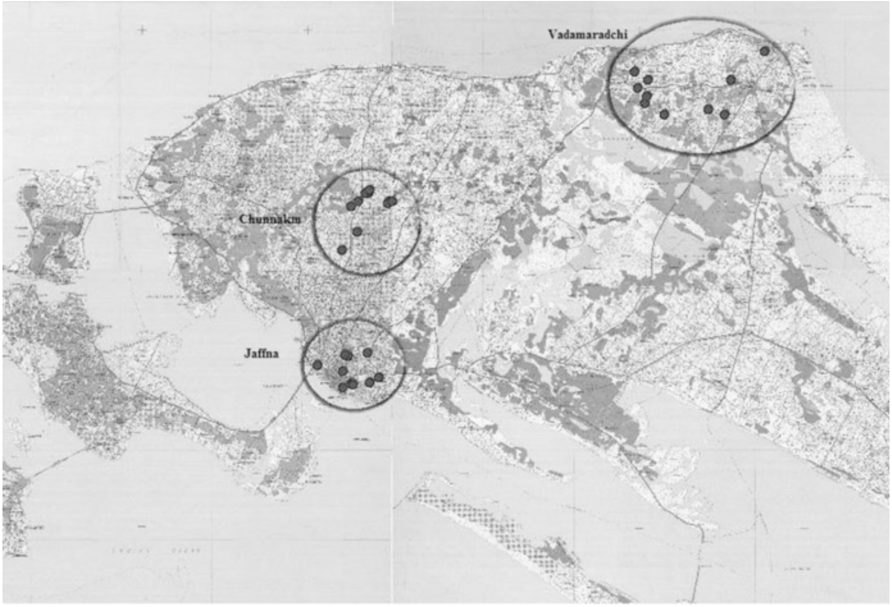

Fig. 1 Locations of wells at the three selected areas in Jaffna peninsula

Groundwater samples were collected into cleaned polyethylene bottles and were transported to the laboratory and filtered using 0.45 μm Millipore filter papers for further analysis. The chemical and biological parameters of NO_3^--N (photometry method using DR/2000 spectrophotometer (at an λ accuracy ±2 nm for 400–700 nm and ±3 nm for 700–900 nm), NO_2^--N (by diazotization method), ammonia (by Nessler's Reagent), phosphate (by PhosVer3 (ascorbic acid) method), sulphate (Turbidity meter 2100P), total hardness (EDTA titration), total alkalinity (acid-base titration) and chloride (Mohr's titration method) were analyzed excluding cations within 48 hrs after collection based on Sri Lankan standard 614 (1983). Since, the rainfall is the major factor of groundwater recharge in the areas the rainfall data were collected from meteorological department, Jaffna.

One-way ANOVA test and multiple comparison tests were used to study the variations of physico-chemical characteristics between the areas and correlations were studied between the parameters and between parameters and rainfall in Jaffna peninsula. Meanwhile, Principal Component Analysis (PCA) was conducted for explaining the large variance of the analytical data into single matrix. The matrices were used to find out the sets of parameters most related with the type of aquifers. Two components were separated based on the presenting variance from the total variance of the data. All statistical analysis was performed in SPSS (version 16.0).

Results

The minimum and maximum values of general characteristics of the selected wells are displayed in Table 1. Mean values of the well depth from ground level to bottom at Vadamaradchi area was significantly different from Chunnakam and Jaffna areas ($p < 0.05$). Relatively lower well depth and higher well depths were observed in Jaffna and Vadamaradchi areas respectively (Table 1).

The minimum and maximum values of physical characteristics of ground water in the three areas are given in Table 2. The pH concentration of well water samples in the three areas was generally alkaline in nature especially at Jaffna area. EC of the water samples has reached the highest value of 9700 μS/cm at Vadamaradchi area due to the salt water intrusion in January just after the high rainfall in December. Also, according to Tukey HSD the EC value in the wells at Chunnakam area of karstic aquifer was significantly different from other two areas ($p < 0.05$). Turbidity of the ground water was significantly different in Jaffna area from other two areas and the highest turbidity was observed at Jaffna area of mostly coastal aquifer. However, turbidity of all the wells did not exceed the maximum permissible level (SLS 614, 1983).

The minimum and maximum concentrations of chemical parameters in ground water at the three areas are given in Table 3. The maximum value of alkalinity,

Table 1 The minimum and maximum values of some important properties of wells located in the three study sites

Important properties of wells	Chunnakam	Vadamarachchi	Jaffna
Height of the protection wall from the ground level (m)	0.25–0.75	0.1–0.8	0.1–0.8
Well depth from ground level to bottom (m)	2.4–12.5	2.8–15	2.1–5.7
Depth from ground level to water level (m)	1.8–10.7	1.0–13	1.3–4.2
Water level (m)	0.6–2.2	0.3–3.5	0.6–2.8

Table 2 Minimum and maximum values of physical characteristics in ground water at the three areas (min-max)

Area	pH	EC (μS/cm)	Turbidity (NTU)
Chunnakam	6.84–7.74[a]	589–2880[a]	0.24–2.55[a]
Vadamaradchi	6.62–7.88[a]	260–9700[b]	0.12–3.12[a]
Jaffna	7.04–8.20[b]	669–6930[b]	0.19–3.86[b]
Drinking water quality standards (SLS 614, 1983)			
Highest desirable level	7.0–8.5	750	2
Maximum permissible level	6.5–9.0	3500	8

Note: a and b indicate the significant difference along rows

Table 3 The minimum and maximum values of chemical parameters recorded in ground water at the three areas

Area	Total alkalinity (mg/L)	Total hardness (mg/L)	Chloride (mg/L)	NO_3^--N (mg/L)	NO_2^--N (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)
Chunnakam	136–880[b]	80–414[b]	46–946[b]	0.0–19.0[b]	ND–0.114[b]	0.00–2.56[ab]	42–347[b]
Vadamaradchi	80–504[b]	72–862[a]	51–1725[a]	0.0–10.1[a]	ND–0.019[a]	0.00–1.72[a]	4–500[a]
Jaffna	320–776[a]	96–691[c]	70–1527[a]	0.0–11.3[a]	ND–0.330[b]	0.00–2.38[b]	48–532[c]
Drinking water quality standards (SLS 614, 1983)							
Highest desirable level	200	250	200	–	–		200
Maximum permissible level	400	600	1200	10	0.01	2	400

Note: a and b indicate significant difference of the detected parameter at the three locations while ND is for not detected values

NO_3^--N and PO_4^{3-} were observed at Chunnakam area and the maximum value of total hardness and chloride were observed at Vadamaradchi area. Similarly, the maximum value of NO_2^--N and SO_4^{2-} were observed at Jaffna area during the study period. The range of minimum and maximum concentrations of chloride and SO_4^{2-} have been recorded as 0–355 mg/l and 1–405 mg/l respectively in ground water of Nalgonda district, Andhra Pradesh, India and these concentrations were comparatively lower than the observed values in present study (Rajesh et al., 2011).

The both ions of chloride and SO_4^{2-} were relatively higher at Vadamaradchi and Jaffna areas than at Chunnakam area due to salt water intrusion of those coastal aquifers. Total alkalinity, NO_3^--N and NO_2^--N in some wells at the three areas exceeded the maximum permissible levels of SLS 614 (1983). Also, total hardness, chloride and SO_4^{2-} in some wells exceeded the maximum permissible level of SLS 614 (1983) only at Vadamaradchi and Jaffna areas of coastal aquifers. Table 3 explains the significant difference of each chemical parameter in the three studied areas according to Tukeys HSD ($p < 0.05$). Total hardness and SO_4^{2-} concentrations were the only parameters varied significantly among the three areas. However, total hardness, total alkalinity and SO_4^{2-} concentrations varied significantly in the coastal aquifer of Jaffna area from other two areas. The intensive agricultural area of Chunnakam area is significant due to chloride and NO_3^--N concentrations in ground water during the study period.

Three components were extracted from the total variance of all data and the component 1 explains 44.34 %, 38.49 %, and 50.54 % of the total variance in Jaffna, Chunnakam and Vadamaradchi areas respectively. The component 2 explains 20.15 %, 24.42 % and 18.24 % of the total variance in Jaffna, Chunnakam and Vadamaradchi areas respectively. Therefore, Table 4 gives the component matrix for all parameters in the three studied areas under the above two components. According to the component matrix the contribution were higher than 0.8 for EC, SO_4^{2-}, total alkalinity and chloride concentrations and those can be considered as major parameters for explaining the water quality in karstic and coastal aquifers in Jaffna peninsula. Meantime, the component matrix shows the contribution of 0.963 for total hardness and it is also an important parameter for the water quality in coastal aquifer of Vadamaradchi area. Similarly, NO_3^--N concentration is an important parameter especially at Chunnakam and Vadamaradchi areas presenting the contribution higher than 0.8 in the matrix due to the effects of agricultural runoff on ground water in the areas.

Some of the authors have explained the relationships between the groundwater level and physico-chemical characteristics in the water (Rajesh et al., 2011). However, there were no significant correlations between the general characteristics of the wells (Table 1) and physico-chemical characteristics in water (Tables 2 and 3) at the studied areas.

Table 4 Component matrix for the water quality parameters in the studied areas

	Chunnakam area		Vadamardchi area		Jaffna area	
Parameter	Component 1	Component 2	Component 1	Component 2	Component 1	Component 2
pH	0.321	−0.482	−0.518	0.346	−0.016	0.935
EC	0.922	0.277	0.926	−0.180	0.965	−0.121
Turbidity	−0.016	0.477	−0.616	−0.179	0.535	0.475
Sulphate	0.912	0.233	0.961	0.040	0.889	−0.019
Alkalinity	0.904	−0.312	0.861	−0.075	0.822	0.472
Hardness	0.434	0.674	0.963	−0.044	0.585	−0.708
Chloride	0.934	0.157	0.890	−0.212	0.936	−0.251
NO_3-N	−0.370	0.825	0.221	0.843	0.315	0.188
NO_2-N	−0.231	0.581	0.148	0.627	0.658	0.141
PO_4^{-3}	0.042	−0.507	0.308	0.695	0.025	0.256

Discussion

The depth range of the dug wells has been recorded from 1.45 m to 20 m below the ground level in Andhra Pradesh, India (Rajesh et al., 2011). Since the maximum depth did not exceed 15 m in the present study the groundwater level fluctuation was varied within a very narrow range and the maximum groundwater level was 3.5 m at Vadamaradchi area. Narrow range of variation of groundwater level during the study period explains no significant correlation between important physical properties of the wells and physico-chemical characteristics in water.

Rajesh et al. (2011) has also recorded the range of EC value of ground water from 375 to 2500 μS/cm in Andhra Pradesh, India and another study in Madras aquifer, India has reported EC value of groundwater from 400 to 4200 μS/cm (Elango and Manickam, 1987). However, EC value in some wells of Vadamaradchi and Jaffna areas of coastal aquifers exceeded the maximum permissible level of 3500 μS/cm (SLS 614, 1983). Ramkumar et al. (2010) have noticed that the overexploitation of coastal aquifers for agricultural and drinking purposes, along with structural interventions and climatic conditions increases the possibility of seawater intrusion into the groundwater reservoirs. In fact, the maximum values of total hardness, chloride and SO_4^{2-} at Vadamaradchi and Jaffna areas of coastal aquifers were comparatively higher than the maximum values that have been observed in ground water of a karstic aquifer system near Izmir, Turkey (Alper and Rahime, 2011). In areas of limestone geology (Karst topography), sinkholes provide a direct link between the surface-applied nitrogen fertilizers and subsurface water. Thus, areas with a shallow water table or sinkholes are more vulnerable to nitrate contamination. Since, Chunnakam aquifer is a shallow limestone aquifer; it could be one of the reasons for high nitrate-N in the ground water.

Rainfall is one of the important climatic variables responsible for qualitative and quantitative changes of ground water. After the rainfall, 10–15 % of rain water runs off and about 40–48 % is lost by evaporation, only 30–32 % of rainfall is left over for groundwater recharge in Jaffna area (Navaratnarajah, 1994). The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels and saline intrusion in coastal aquifers due to sea level rise and resource reduction in Jaffna peninsula that have been observed by Navaratnarajah (1994) and Rajasooriyar et al. (2002). However, no significant correlations were observed between physico-chemical characteristics and rainfall in the studied areas except for PO_4^{3-} concentration ($p < 0.05$) and those physico-chemical characteristics did not change significantly with the water level in the wells.

Conclusion

Since, there were no significant temporal variations of physico-chemical characteristics during the study period a long-term study on dependence of climatic variables on groundwater quality is recommended especially at water scarcity areas as Jaffna peninsula. Also, further studies should be focused on chemical nature of ground water specially with respect to EC, SO_4^{2-}, total alkalinity and chloride concentrations because those parameters were identified in the principal component matrix as the most specific water quality parameters in the studied areas of karstic and coastal aquifers in Jaffna peninsula.

Acknowledgement The authors wish to thank Research and Development section of National Water Supply & Drainage Board (NWS&DB) for providing financial assistance to conduct this research and for providing laboratory facilities in the regional office of NWS&DB in Jaffna.

References

Alper, E. and Rahime, P. (2010). Assessment of the statistical significance of seasonal groundwater quality change in a karstic aquifer system near Izmir-Turkey. *Environment Monitoring Assessment*, **172:** 445-462.

Balendran, V.S., Sirimanne, C.H.I. and Arumugam, S. (1968). Groundwater resources of Jaffna Peninsula. Water Resource Board, Colombo.

Balendran, V.S. (1969). Salt water fresh water interface studies in the Jaffna Peninsula. Report III. Geological survey department, Colombo, Sri Lanka.

Dissanayake, C.B. (1988). Nitrate in the groundwater in Sri Lanka – Implication for community health. *Journal of the Geological Society of Sri Lanka*, **1:** 80-84.

Elango, L. and Manickam, S. (1987). Hydrogeochemistry of the Madras aquifer, India: Spatial and temporal variation in chemical quality of groundwater, The role of Geology in Urban development. *Geological Society of Hong Kong Bulletin*, **3:** 525-534.

Feasibility report (2006). A feasibility study for water supply and sanitation system for the Jaffna Peninsula. ADP project. Project No: 5068020. National Water Supply and Drainage Board, Jaffna, Sri Lanka.

Gulis, G., Czompolyova, M. and Cerhan, J.R. (2002). An ecologic study of nitrate in municipal drinking water and cancer incidence in Trnava District, Slovakia. *Environ Res*, **88:** 182-187.

Gunaalan, K., Asanthi, H.B., Gamage, T.P.D., Thyshyanthy, M., Saravanan S. and Jayakumaran, N. (2011). Incidence of oesophageal and stomach cancer related to Nitrate-N concentration in groundwater in Jaffna peninsula. *In:* The water resources research in Sri Lanka. Dayawansa N.D.K. and Ranjith Premalal De Silva (eds). Symposium proceedings of the Water Professionals' Day, 95-103.

Kross, B.C., Hallberg, G.R., Bruner, D.R., Cherryholmes, K. and Johnson, J.K. (1993). The nitrate contamination of private well water in Iowa. *Am J Public Health*, **83:** 270-272.

Nagarajah, S., Emerson, B.N., Abeykoon, V. and Yogalingam, S. (1988). Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution. *Tropical Agriculture*, **44:** 61-73.

Navaratnarajah, V. (1994). Water problems in the Jaffna peninsula. 20th WEDC International Conference in Affordable water supply and sanitation. 1994, Colombo, Sri Lanka.

Panabokke, R.G. (1984). The geographical pathology of malignant tumors in Sri Lanka—A 5-year study. *Ceylon Medical Journal*, **29**.

Rajasooriyar, L., Mathavan, V., Dharmagunawardhane, H.A. and Nandakumar, V. (2002). Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka. *In:* Sustainable groundwater management. Hiscock, K.M., Rivett, M.O. and Davison, R.M. (eds). Geological Society, London, **193:** 181-197.

Rajesh, R., Brindha, K., Murugan, R. and Elango, L. (2011). Influence of hydrogeochemical processes on temporal changes in groundwater quality in a part of Nalgonda district, Andhra Pradesh, India. *Environment Earth Science*, DOI 10.1007/s12665-011-1368-2.

Raju, N.J., Ram, P. and Dey, S. (2009). Groundwater Quality in the Lower Varuna River Basin, Varanasi District, Uttar Pradesh. *Jour. Geol. Soc. India*, **73:** 178-192.

Raju, N.J., Shukla, U.K. and Ram, P. (2011). Hydrochemistry for the assessment of groundwater quality in Varanasi: A fast urbanizing center in Uttar Pradesh, India. *Environ. Mont. Assess.*, **173:** 279-300.

Ramkumar, T., Venkatramanan, S., Anitha Mary, I., Tamilselvi, M. and Ramesh, G. (2010). Hydrogeochemical Quality of Groundwater in Vedaraniyam Town, Tamil Nadu, India. *Research Journal of Environmental and Earth Sciences*, **2(1):** 44-48.

Sivarajah, N. (2003). Health related problems of water pollution in Jaffna. International workshop on environmental management in north-east Sri Lanka. 1st- 4th December, 2003. Jaffna, Sri Lanka.

Sri Lanka standard 614: Part 1, 1983. Specification for potable water physical and chemical requirements.

Udayalaxmi, G., Himabindu, D. and Ramadass, G. (2010). Geochemical evaluation of groundwater quality in selected areas of Hyderabad, A.P., India. *Indian journal of Science and Technology*, **3(5):** 546-553.

Zhang, W.L., Tian, Z.X., Zhang, N. and Li, X.Q. (1996). Nitrate pollution of groundwater in northern China. *Agric. Ecosyst. Environ.*, **59:** 223-231.