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Influence of urbanization and tourist activities on the water quality of the Potrero de los Funes River (San Luis – Argentina)

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Abstract A study of the water quality of the Potrero de los Funes River (San Luis – Argentina) was carried out in order to evaluate the possible effect of the anthropogenic activities on the river developed in the homonymous town. Samples were collected during the period March 2000–November 2005 at three selected sampling sites (RP_1, RP_2 and RP_3). Different physicochemical and bacteriological parameters (turbidity, pH, conductivity, suspended solids, alkalinity, potassium, sodium, calcium, magnesium, chlorides, nitrates, phosphates, sulphates, chemical oxygen demand (COD), 5-day biological oxygen demand (BOD_5), dissolved oxygen, total coliforms, *Escherichia coli* and total heterotrophic bacteria) were analysed according to the Standard Method for the Examination of Water and Wastewater. When comparing the values of total coliforms, *E. coli*, total heterotrophic bacteria, COD, BOD_5 and phosphates from the zone without anthropogenic influence (RP_1) and the urban zones (RP_2 and RP_3) an important variation in the parameters was observed. These results indicate that the urban activity produces a serious and negative effect on the water quality, thus constituting a sanitary risk and may have a major impact on the trophic status of the Potrero de los Funes dam. As case study, we report on the use of General Quality Index (GQI) to evaluate spatial and seasonal changes in the water quality of Potrero de los Funes River. Results revealed a significant degradation of the water quality at RP_2 and RP_3.

Keywords Water quality · Quality index · Pollution · Environmental monitoring · River

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Introduction

The economic development, the industrialization and the urbanization, together with the demographic advance, lead to a significant growth in water consumption and contaminating wastage in water bodies. A great number of rivers and streams are highly contaminated due to the anthropogenic activities such as industrial and sewerage wastage (Jonnalagadda et al. 1991; Jonnalagadda and Mhere 2001; Koukal et al. 2004; Pesce and Wunderlin 2000).

The problem increases when the depurating capacities of these aquatic systems are greatly reduced in relation to the contaminating wastage received. Thus, contamination, a highly increasing phenomenon, seriously affects water quality and endangers water reserves. Therefore, every problem related with lack of water and the deterioration of its quality constitutes an important issue for the twenty-first century.

The development of monitoring programs of aquatic systems plays a significant role in water quality control since it is necessary to know the contamination degree so as not to fail in the attempt to regulate its impact (Feijóo et al. 1999). The aim of these monitoring programs is to keep the aquatic systems free from deterioration so that the water can still be used for consumption and recreation and to avoid downstream contamination produced by the upstream contaminating agents.

The use of water for tourist purposes is one of the most important ones. Even though the use of water for recreation activities can be beneficial for an individual's health, it can also be damaging if it is contaminated or unsafe.

The water quality is sometimes difficult to evaluate from a large number of samples, each containing concentrations for many parameters (Chapman 1992; León Vizcaino 1991). Water quality indices are intended to provide a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water body. Basically, a water quality index attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Del Río 1992; Miller et al. 1986; Shiow-Mey et al. 2004; Smith 1989; Tyson and House 1989).

To show the water quality independently from human use, that is to say its conservation state, the General Quality Index (Mingo Magro 1983) is used.

San Luis, located in the centre of Argentina, is a highly Mediterranean province with a semi-arid climate predominantly temperate, with summer rains from October to March, with an annual rainfall average of 500–600 mm (Ceci and Cruz Coronado 1981). The system chosen for this study is the Potrero de los Funes River.

Potrero de los Funes is a hilly village located at 17 km from San Luis city (Argentina) on the margins of the homonymous river and has a population of approximately 2,500 inhabitants. Its urbanization has extended along the river, and its population has increased a 100% for the last 10 years. In summer, it has an important tourist activity. Since this village does not have sewerage or effluents treatment, and due to the fact that the river is mainly used for recreational activities and as the main drinking water source, a systematic study about the river water quality is of great importance in order to evaluate its pollution and self-depuration capacity.

There are few studies about the quality of superficial waters in the province of San Luis. Among them, we can mention the use of biotic indices, with benthic macroinvertebrates (Gil et al. 1998; Medina et al. 1997; Tripole 2003; Vallania et al. 1996, 1998), the physico-chemical characterization and determination of the environmental background (Garbagnati et al. 2005) and studies of contamination by mining activities (Tripole et al. 2006).

In this paper, we report a 5-year monitoring in order to evaluate the influence of urbanization and tourist activities on the water quality of Potrero de los Funes River.

Materials and methods

Location and description of the study area

Potrero de los Funes River originates in the Sierras Pampeanas is located between the 33° and 34° parallels of South latitude and the 66° and 65° meridians of East longitude. Its tributaries are Los Molles and La Bolsa streams, whose flows depend on the local rains. The river is 2,700 m long and flows into the Potrero de los Funes dam. Its flow average is 0.304 $m^3 s^{-1}$, and its maximum flow is 33 $m^3 s^{-1}$, constituting the dam's main source (Fig. 1).

Three sampling sites at the river were chosen for the study: RP_1, representing the background values, i.e. without interference from anthropogenic activities; this station is located in the main intake of the water potabilization plant of the Potrero de los Funes town. RP_2 located at 1,112 m from RP1; this river section flows through a city district where a wastage discharge from residential houses and hotels occur. RP_3 is located at 747 m from RP_2, at the end of the urban area and at the entrance to the Potrero de los Funes dam. The distance between RP_3 and the dam's entrance is 782 m.

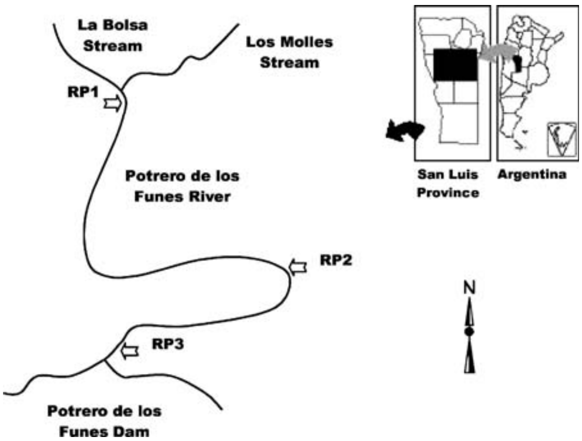

Fig. 1 Map of San Luis Province (Argentina) with indication of the sampling sites on the Potrero de los Funes River

Sampling and analytical methods

The study was carried out from March 2000 to November 2005. Collection receptacles, sample stabilization and transportation to the laboratory as well as sample storage were done according to the Standard Methods for the Examination of Water and Wastewater (APHA 1992). Samples were taken at least 40 cm under the water surface and whenever it was possible, at the middle of the stream. Samples were never taken while raining but at least 72 h after the rain had stopped, so that the river returned to its regular flow condition. Water samples were transported within 2 h after collection and they were kept at ±5°C until analysis.

Water pH and electrical conductivity were measured using a portable meter. All water samples were analysed according to the Standard Methods for the Examination of Water and Wastewater (APHA 1992), method numbers are cited: turbidity (NTU)-S.M. 2130-B; pH -S.M. 4500-B; conductivity (μS cm^{-1})- S.M. 2510-B; suspended solids (mg l^{-1})- S.M.2540-D; alkalinity – (mg l^{-1}) $CaCO_3$- S.M. 2320-B; potassium (mg l^{-1})- S.M. 3500-K-B; sodium (mg l^{-1})- S.M. 3500-Na-B; calcium (mg l^{-1}) – S.M. 3500-Ca-B; magnesium (mg l^{-1}) - S.M. 3500-Mg-B; chlorides (mg l^{-1}) -S.M. 4500-Cl^- B; nitrates (mg l^{-1}) -S.M- $4500 - NO_3^- - E$; phosphates (μg l^{-1}) -S.M.- $4500 - PO_4^{3-} - E$; sulphates (mg l^{-1}) -S.M.- $4500 - SO_4^{2-} - E$; chemical oxygen demand – COD (mg l^{-1}) S.M. 5220-B; 5-day biological oxygen demand-BOD_5 (mg l^{-1}) S.M. 5210-B; dissolved oxygen (mg l^{-1}) S.M. – 4500-O-B; total coliforms (CFU.100 ml^{-1}) S.M. 9221-B; *Escherichia coli* (CFU.100 ml^{-1}) S.M. 9221-c; total heterotrophic bacteria. (CFU.100 ml^{-1}) S.M. 9215-B.

Water quality index

The General Quality Index (GQI; Mingo Magro 1983) was adopted since it is useful to obtain information of ecological state of the river in the different studied zones. The General Quality Index was calculated with nine basic and two complementary parameters. Each parameter (λ_i) corresponded with weighting factors (F_1 and F_2) which permitted to determine the quality index through the following mathematical equation:

$$I = \sum_{i=1}^{n} F_1(\lambda) F_2(\lambda, n) = \sum_{i=1,n} Q_i x P_i$$

Q_i water score quality of parameter i
P_i weighting factors ($\Sigma\ P_i$=1)

Function F_1 transforms the analytical value of each parameter in a non-dimensional value or quality level (Q_i) through a mathematical equation or its corresponding graphic representation. Function F_2 attempts to weight the influence of each parameter in the total value of the index, which can be considered as their individual weight (P_i):

$$P_i = \frac{1/a_i}{\sum 1/a_i}$$

The coefficient values a vary from 1 (very important parameter) to 4 (less significant parameter) according to the importance assigned to each parameter involved in the index. The nine basic parameters chosen for the calculation of this index were: total coliforms, COD, nitrates, conductivity, phosphates, dissolved oxygen, BOD_5, suspended solids, pH and calcium and sodium as the complementary parameters. This index is defined as the degree of contamination in the water of the sample expressed as a percentage of pure water. Thus, for completely contaminated water the quality index will be close to or similar to 0 whereas for excellent quality water the index will be 100.

Results and discussion

We explored the river behaviour by measuring 19 parameters. All these parameters were measured at three stations (RP_1, RP_2 and RP_3) as described in the experimental section. Table 1 summarises the mean values of the parameters monitored at dry and wet seasons, measured every 2 months from March 2000 to November 2005. Data show that water pollution increases as the river flows through the town of Potrero de los Funes.

pH results did not show spatial or seasonal differences. The values obtained in the three sampling sites are comparable with the values found in most of the natural systems studied in the province of San Luis (Gil et al. 1998; Medina et al. 1997; Tripole 2003; Vallania et al. 1998).

Conductivity qualitatively reflects the status of inorganic pollution and is a measure of total dissolved solids and ionized species in the waters. Conductivity was low in samples collected upstream (RP_1) throughout the study period. RP_2 and RP_3, samples collected in areas with high population densities, recorded an increase in the values. The higher conductivity values recorded at RP_2 and RP_3 in relation to RP_1 are due to the wastewater discharges on the water river.

The total dissolved solid values (TDS) correlated well with the conductivity values. In agreement with the high conductivity values, TDS levels were high at RP_2 and RP_3. Conductivity and concentrations of dissolved substances exhibit seasonal variation caused by the annual hydrological cycle. Most of the physicochemical variables decreased in wet season by the dilution effect.

The waters at RP_1 were well oxygenated with the highest level of dissolved oxygen (DO) and with a decrease in DO value at RP_2. The oxygen depletion observed at RP_2 reveals occurrence of a high content of organic matter in waters resulting from discharges coming from the urban area of Potrero de los Funes. In RP_3 a little increase was observed in the value of DO, attributed to the water turbulence in this river that permits its aeration and self-purification.

Table 1 Physical, chemical and bacteriological parameters of the Potrero de los Funes River

Parameter	Dry season[a]			Wet season[b]		
	RP_1	RP_2	RP_3	RP_1	RP_2	RP_3
pH	7.92±0.15	7.75±0.15	7.8±0.17	7.68±0.16	7.47±0.12	7.59±0.17
Turbidity (FTU)	1.7±0.2	1.4±0.3	1.5±0.4	1.9±0.2	2.3±0.3	1.8±0.4
Conductivity ($\mu S\ cm^{-1}$)	149.6±11.7	210.3±25.8	211.6±23.1	121.9±8.74	185±4.62	188±5.23
Suspended solids ($mg\ l^{-1}$)	ND	ND	ND	ND	ND	ND
Calcium ($mg\ l^{-1}Ca^{2+}$)	25.7±3.1	33.7±4.4	33.3±4.0	19.8±3.1	26.7±3.9	32.7±4.1
Magnesium ($mg.L^{-1}Mg^{2+}$)	3.8±1.4	4.9±0.9	4.5±0.9	3.2±1.1	4.1±0.90	4.3±0.9
Sulphates ($mg\,L^{-1}SO_4^{=}$)	6.8±1.7	11.6±5.4	11.6±5.3	4.8±1.8	9.8±3.2	9.9±2.9
Sodium ($mg\ l^{-1}L\ Na^{+}$)	5.9±1.3	17.9±1.9	16.2±1.9	4.9±1.2	9.9±1.3	10.2±1.2
Potassium ($mg\ l^{-1}\ K^{+}$)	2.3±0.1	2.9±0.1	3.0±0.2	2.0±0.9	2.5±0.2	2.6±0.1
Phosphates ($\mu g\ l^{-1}\ P$)	7.8±1.5	26.3±2.1	22.0±2.1	3.4±1.5	21.3±2.6	19.2±2.3
Nitrates ($mgL^{-1}NO_3^{-}$)	0.19±0.10	0.43±0.08	0.39±0.09	0.11±0.20	0.39±0.08	0.36±0.09
BOD_5 ($mg\ l^{-1}O_2$)	1.82±0.54	7.63±0.86	7.27±0.87	1.34±0.54	4.64±0.86	4.22±0.87
COD ($mg\ l^{-1}O_2$)	3.01±0.65	9.32±0.78	9.2±0.98	2±0.51	7.2±0.73	7.0±0.91
Alkalinity ($mg\ l^{-1}CaCO_3$)	46.3±15.8	68.3±22.4	64.4±22.0	34.3±11.8	56.3±15.4	54.4±12.0
Chlorides ($mg\ l^{-1}Cl^{-}$)	6.7±3.7	14.6±4.2	12.9±4.1	4.8±1.1	10.6±2.8	10.9±2.1
Dissolved oxygen ($mg\ l^{-1}O_2$)	8.22±0.65	5.44 ±0.57	7.01±0.58	7.11±0.32	3.80±0.56	6.02±0.81
Total coliforms ($CFU.100\ ml^{-1}$)	18±4	456±120	287±75	30±4	936±122	643±105
E. coli ($CFU.100\ ml^{-1}$)	18±34	227±87	127±39	9±4	534±93	350±43
T.heterotrophic bacteria ($CFU.100\ ml^{-1}$)	252±127	957±686	629±485	198±146	1025±654	745±385

[a] Wet season: November, December, January, February, March, April.

[b] Dry season: May, June, July, August, September, October.

ND indicates that the analyte was not detected.

Photosynthesis and respiration play an important role in the self-purification of natural water. The disturbance of the stationary state between photosynthesis and respiration leads to chemical and biological changes reflecting pollution. High levels of phosphorous increase the growth of vegetation in water systems and increase the oxygen demand. Concentration of reactive phosphorous in the RP_1 waters was low. High levels were observed at RP_2 and RP_3, which indicate that wastewater discharges from the town of Potrero de los Funes were the most likely source of phosphorous in the waters, as this species is an important constituent of domestic detergents. The enrichment of nutrients in this sites suggests that the river can affect significantly the primary productivity and trophic status of Potrero de los Funes Dam.

BOD values, which measure the concentration of labile organic matter, and COD values, that are a measure of total oxidable organic matter, showed spatial and seasonal variation, in clear agreement with the depletion of dissolved oxygen in the waters. This condition was very critical during dry season and downstream, denoting the effect of contamination with organic waste.

Coliform bacteria are common indicators of overall water quality and although they are ubiquitous in the environment and are generally not considered harmful to humans, their presence in high concentrations often coincides with more dangerous bacteria (WHO 1996). RP_2 and RP_3 show high levels of coliform bacteria in dry and wet season. Although coliform bacteria come from many diverse sources (soil, water or animal digestive systems), *E. coli* is a subset of bacteria that originates in the intestines of human and other warm-blooded animals. Obviously, the high *E. coli* and total coliform values obtained at RP_2 and RP_3 sites indicate severe microbiological contamination, originated due to the wastewater discharges on the river. The analysis of the bacteriological parameters shows a great difference between RP_1 and RP_2–RP_3 with a greater variation of total coliforms in RP_2 typical of sewage contamination. The constant presence of total coliforms and *E. coli* through all the study period clearly indicates a pathogenic risk caused by the accidental consumption of water during recreation (WHO 1996). An important fact to be taken into account is that two strains of *Vibrio cholerae* were isolated during the dry season months.

The evaluation of overall water quality is not an easy task particularly when different criteria for different uses are applied. Moreover, the classification of water quality follows various definitions with respect to the contents of different water parameters and dozens of variant have been developed (Smith 1989). In this report, the application of the General Quality Index to the Potrero de los Funes River waters had the purpose of providing a simple, valid method for expressing the results of several parameters in order to asses the water quality. Assembling different parameters into one single number, leads to an easy interpretation of index, thus providing an important tool for management purposes.

The parameters used in the calculation of the GQI for the different sampling sites were: pH, conductivity, COD, BOD_5, suspended solids, phosphates, calcium, DO, sodium, nitrate and total coliforms.

The GQI values were 91.9 for RP_1, 73.6 for RP_2 and 78.4 for RP_3 during dry season; the values were 94.1 for RP_1, 67.3 for RP_2 and 77.9 for RP_3 during wet season over studied period.

The GQI values ranged from 67.3 to 94.1. Following the GQI values classification of 0–25=very bad, 26–50=bad, 51–70=medium, 71–90=good, and 91–100=excellent. The waters samples at RP_2 and RP_3 fall in the medium quality range and at RP_1 was excellent. The decline of water quality at RP_2 and RP_3 is due to the wastewater discharges on the water river coming from the urban area of Potrero de los Funes. In wet season, the values of the GQI increased at RP_1 by dilution effect upon the analysed parameters, but in RP_2 a decrease in the quality is observed due to the increase of the bacteriological parameters generated by the combination of urban wastewater and the higher tourist affluence.

The extent of the pollution at the Potrero de los Funes River may not appear severe. Considering that the river is a source of drinking water and of tourist activity, the pollution potential gains significance, showing the need of urgent measures in order to increase water quality.

Conclusions

The substantial difference in the parameters analysed between the RP_1 and RP_2–RP_3 stations revealed a significant degradation of the water quality in a stretch of the Potrero de los Funes River located downstream of the town. This state result from discharges coming from the urban area of Potrero de los Funes, thus constituting a sanitary risk that can adversely affect the public health of the community.

The increasing bacteriological contamination during the wet season in relation to the dry season indicates that, despite the dilution, there is a notable contamination produced by the tourist affluence.

The average values of *E. coli* through all the studied period exceed the reference values established by the international organisms for recreational waters (Leeden et al. 1991); thus suggesting that this water body might be out of use for recreational purposes in a short time.

Surface waters of the Potrero de los Funes River were enriched with nutrients, suggesting that the river can seriously disturb the functioning of this aquatic ecosystem. Studies on the trophic status of the Potrero de los Funes dam were never performed, but signs of eutrophication were evident in recent years, due to the large amount of vegetation that periodically develops in the waters. Therefore, further research should complement the present study and be centred on the dam nutrient dynamics and productivity.

The conclusions obtained from this work, reported by the GQI values, can be transferred to different social sectors and appropriate authorities in order to revert the present situation that may affect the socio-economic development of the region since its principal activity is tourism.

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