Journal of Urban and Environmental Engineering
E-ISSN: 1982-3932
celso@ct.ufpb.br
Universidade Federal da Paraíba
Brasil

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Journal of Urban and Environmental Engineering, vol. 1, núm. 1, enero-marzo, 2007, pp. 18-25
Universidade Federal da Paraíba
Paraíba, Brasil

Journal of Urban and Environmental Engineering, v.1, n.1 (2007) 18–25

ISSN 1982-3932
doi: 10.4090/juee.2007.v1n1.018025

Journal of Urban and Environmental Engineering

www.journal-uee.org

WATER QUALITY INDEX AS AN TOOL FOR RIVER ASSESSMENT IN AGRICULTURAL AREAS IN THE PAMPEAN PLAINS OF ARGENTINA

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Received 03 Mar 2007; received in revised form 20 Abr 2007; accepted 10 May 2007

Abstract: The contributions of nutrients and xenobiotics by anthropogenic activities developed in riverside deteriorate water quality. In this context, the impact of different agroindustry effluents on the water quality of Salado River in Buenos Aires Province (Argentina) was analyzed applying water quality indexes (WQI). Water quality index is an efficient a simple monitoring tool to instrument corrective and remediation policies. Winter and summer samplings were performed. A minimal water quality index (WQImin) was calculated using only two parameters which can be easy determined in situ. The use of WQImin may be a useful methodology for river management. Meat industry appears as the most pollutant source. Since it is considered as point pollution source, effluents should be treated previous to its disposal with the available technologies.

Keywords: Salado River; effluent; agroindustry; nutrients, organic matter

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INTRODUCTION

Rivers are continuous ecosystems with longitudinal organization, characterized by a space-temporal heterogeneity and influenced by a great number of factors, which impedes its study (Townsed, 1996). The heterogeneous both spatial and temporal variations of these water bodies have direct influence on the dynamic of nutrients (Hildrew, 1996). The physical and biological properties of the lotic systems reflect the climate and geology features, the basin particularities, the surrounding vegetation and the anthropogenic activities (Santos & Rocha, 1998).

Human emplacements have been settled and agroindustry activities have been generally developed in the riverside of template great plains. The contributions of nutrients and xenobiotics by anthropogenic activities developed in riverside have deteriorated water quality. In addition, water courses have been modified in its flow due to wetlands drainage and canalizations (Van Dijk *et al*., 1996) and hydrological dynamic modifications, reducing significantly the retention capacity and accelerating the nutrients transport (Kronvang *et al*., 1999). As consequence of the considerable nutrients input, eutrophication of water bodies constitutes one of the main global problems that affects water quality and biodiversity of aquatic ecosystems (Kronvang *et al*., 1999).

The Salado River, main river of Buenos Aires Province, is the most austral tributary of the Plate Basin. This river is approximately 700 km long and its drainage basin represents 55.3 % of the Buenos Aires Province surface, the main agricultural province of Argentina. The Salado River drainage system is poorly developed due to the scarce slope (0.3 m/km, Sala, 1975). Seasonality is one of the river's features, which is demonstrated in temperature and rainfall variations. The average annual temperature is 15°C and the average annual rainfall is 870 mm, with an increasing gradient North-South (SMN, 1998; 1999).

Different aspects of water bodies from low basin of the Salado River were studied by Conzonno and Cirelli (1987; 1988; 1995; 1997) and Cirelli *et al.* (2006).

Land use evolution in the Salado River Basin, first involved a change from grazing cattle systems to a mixed crop-cattle production, and more recently, to intensive and technological agrarian development. The human impact increase in this basin is determined by the population growth, the spilt of urban and industrial effluents, the infrastructure constructions (riverbed modifications, canalizations, and drainage changes) and other associated constructions (road systems). These impacts alter the dynamic, biodiversity and uses of the river, its associated ecosystems (flood plains, wetlands) and the marine coastal ecosystem where the river flows (Conzonno *et al*., 2001, 2002; Volpedo *et al*., 2005).

The management of these systems, especially of its water quality, needs efficient and simple tools to instrument corrective and remediation policies. In this respect, water quality indexes, proposed by diverse authors (Brown *et al*., 1970; Conesa Fdez-Vitora, 1995; Pesce and Wunderlin, 2000), are a proper way to obtain a numerical expression of water quality that allows trend determinations (Chapman, 1992). Most water quality indexes were frequently applied to mountain rivers (Tyson & House, 1989; Pesce & Wunderling, 2000, Jonnalagadda *et al*., 2001) and references of water quality indexes applied to plain rivers is scarce (Bordalo *et al*., 2001; 2006). Dynamic and behavior are different between plain and mountain rivers. In this context, the development of water quality indexes applied to plain rivers is relevant.

In this context, the impact of different agroindustry effluents on water quality of a plain river will be analyzed applying water quality indexes.

MATERIALS AND METHODS

In a section of the Salado River middle basin, 8 sampling stations were selected in correspondence with Lobos and Roque Pérez localities. Each river water sampling station was selected in correspondence to the area where effluents from different agricultural activities are discharged: intensive porcine productions, intensive bovine productions, meat industry (bovine and poultry) and urban core. Samples were taken in relation to channels that discharge effluents into the river or sloping zones that favor the runoffs. Zones of natural grasslands without effluent discharges were considered as depuration points (**Table 1** and **Fig. 1**).

Samplings were taken in winter and summer of 2006. The winter sampling (July) was concordant with the minimal rainfalls period (5.9 mm in June and 9.0 mm in July) and the summer sampling (December) in correspondence with the maximum rainfalls period (27.9 mm in October and 28.6 in November). Data of monthly rainfall average from the zone considered mean values from the period 1998 to 2005 (SAGPyA, 2007). The annual average river flow is 390 m^3/seg (Lasta *et al*., 2003). In the winter sampling, river water level was lower than the river-bed while in the summer was higher, acceding to the flooding plain.

Electric conductivity (E.C) (µS cm^{-1}), pH, temperature (°C) and dissolved oxygen (mg/L) were determined *in situ* using Hanna Instruments field equipments (HI 9033, HI 9025 and HI 9142, respectively).

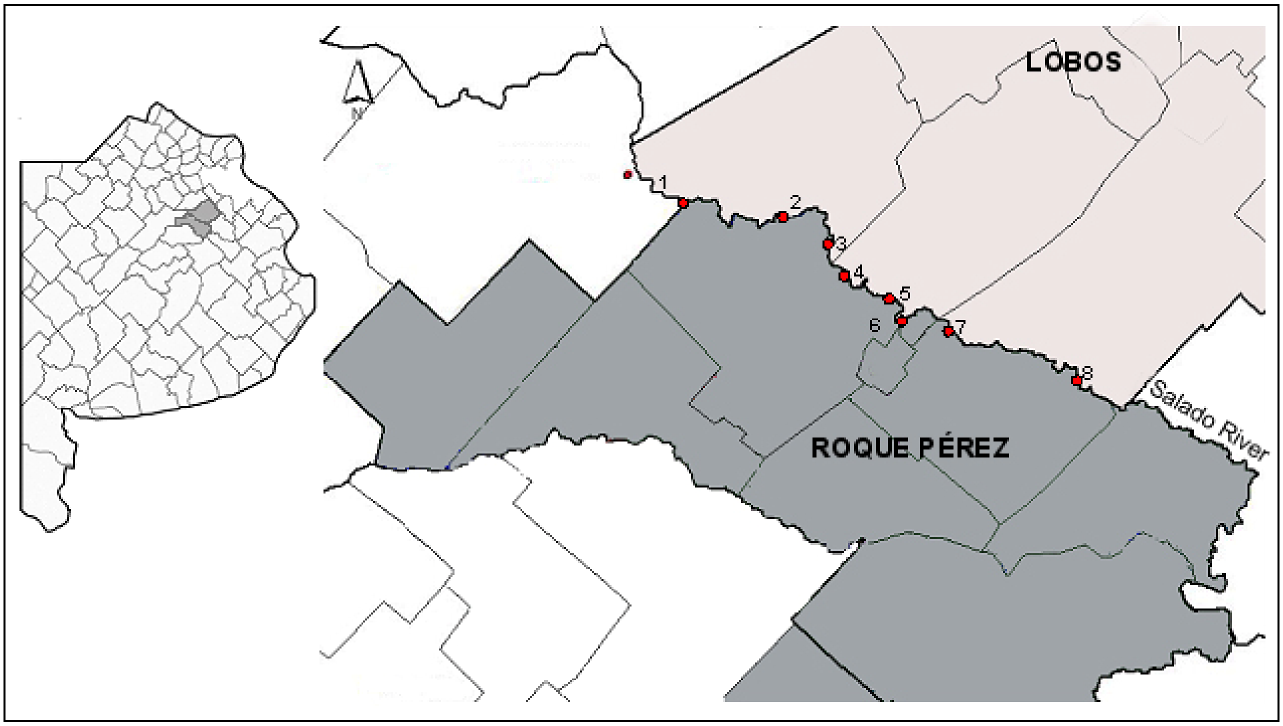


Fig. 1 Sampling stations in selected study zone of the Salado River, in correspondence with Lobos and Roque Pérez localities-Argentine.

On each station, two water samples were collected in 500 mL plastic bottles, and maintained at 4 ºC (Brown *et al*. 1970; Rodier, 1981). Once in the laboratory, samples were filtered through a cellulose acetate membrane Micro Separations Inc. (MSI) with a 0.45 **µm** pore size.

The content of total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), total Kjeldahl-nitrogen (N-TKN) and total phosphorus (TP) were analyzed by triplicate using normalized analysis techniques (APHA, 1998).

Table 1. Sampling stations in selected study zone of the Salado River, in correspondence with Lobos and Roque Pérez localities - Argentine.

Sampling station	Georeference	Points in Fig.1
Locality limit	35º16'03.2''S 59º33'01.9''W	1
Porcine prod.	35º21'27.8''S 59º19'39.7''W	2
Depuration 1	35º21'31.1''S 59º19'26.9''W	3
Bovina prod.	35º21'36.3''S 59º19'20.7''W	4
Depuration 2	35º21'36.1''S 59º19'18.6''W	5
Meat industry	35º21'31.1''S 59º19'27.3''W	6
Urban core	35º23'27.4''S 59º15'43.0''W	7
Depuration 3	35º21'31.1''S 59º19'27.3''W	8

Salado River trophic conditions were determined in relation to N and P concentrations (Forsberg and Riding, 1980) and the limiting nutrient (LN) by the N/P molar relation.

Average values of physicochemical parameters and nutrient (N and P) contents from low (winter) and high (summer) waters periods were compared. In each period, Principal Components Analysis (PCA) was applied to explore sample grouping using PRIMER 5 statistical package.

An objective water quality index (WQIobj), a subjective water quality index (WQIsubj) and a minimal water quality index (WQImin), were calculated for each sampling stations in both sampling periods.

The parameters normalization was realized using **Table 2**. The weight values and the normalization factors were adapted to local conditions, using our previous knowledge of the zone and the available literature (Pesce & Wunderlin, 2000; Debels *et al*., 2005, Boyacioglu, 2007). The quality indexes values contemplate the best water quality (100 %) as the ideal situation.

The objective water quality index (WQIobj) was developed based on the proposed by Rodríguez de Bascarán (Conesa Fdez-Vitora, 1995):

$$WQIobj= (\sum Ci\ Wi)/ (\sum Wi) \qquad (1)$$

Table 2. Parameters used in water quality indexes calculation, normalization values and relative weights (Wi).

Parameter	Wi	Ci										
		100	90	80	70	60	50	40	30	20	10	0
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
COD (mg/L)	3	<5	<10	<20	<30	<40	<50	<60	<80	<100	≤150	>150
DO (mg/L)	4	≥ 7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	≥ 1	<1
TDS (mg/L)	2	<100	<500	<750	$<1^3$	<1500	<2000	<3000	<5000	$<10^3$	$\leq 20^3$	$>20^3$
E.C (µS/cm)	4	<750	$<1^3$	<1250	<1500	<2000	<2500	<3000	<5000	$<8^3$	$\leq 12^3$	$>12^3$
N-KTN(mg/L)	2	<0.4	<0.7	<1	<1.5	<5	<10	<15	<20	<30	≤35	>35
PT (mg/L)	1	<0.005	<0.01	<0.02	<0.03	<0.05	<0.1	<0.25	<0.5	<0.75	<1	>1

Ci = is the assigned value (in %) to each parameter after the normalization (**Table 2**).
Wi = is the assigned weight to each parameter (**Table 2**). The parameter relative weight ranged from 1 to 4, where 4 represents the major importance for aquatic life conservation and 1 the minor relative importance for aquatic life.

The subjective water quality index (WOIsubj) was calculated using the equation (2), considering k=0.75 in all cases (except in “Meat industry” sampling station, k=0.50).

$$WQIsubj= k\ [(\sum Ci\ Wi)/ (\sum Wi)] \quad (2)$$

k represents the perception of the river deterioration evaluated by a person without training in environmental problematic. K is a constant that can take the following values in relation to the river condition. (1: water without apparent pollution, clear or with natural presence of suspended solids; 0.75: water lightly contaminated, with light color, foam, light not apparently natural turbidity; 0.50: water with appearance of being contaminated and strong odor; 0.25: black water that presents fermentation and odor).

Seven parameters were considered for the WQIobj and the WQIsubj calculation (**Table 2**).

The minimal water quality index (WQImin) was calculated using only two parameters (dissolved oxygen and electric conductivity) by the following equation:

$$WQImin= \sum Ci\ Wi/ (\sum Wi) \quad (3)$$

The values of the three calculated indexes were correlated applying Pearson's correlation (Sokal & Rohlf, 1995; Zar, 1999).

RESULTS AND DISCUSSION

The registered values of the physicochemical parameters and the nutrient contents are described in **Tables 3** and **4**.

In the winter sampling, pH values ranged from 7.05 to 8.20, the lowest value was observed on the “Meat Industry" sampling station (7.05). The range of COD values was from 21.5 to 27.2 mg/L, except for “Meat Industry" sampling point, which value was 102.7 mg/L. The dissolved oxygen content presented a range from 8.1 to 8.6 mg/L, except in “Meat Industry" sampling station (1.9 mg/L). The highest suspended solids values were observed on the “Porcine Prod." and “Depuration 2" sampling stations and the lowest value is in the “Meat Industry" sampling point. The observed electric conductivity ranged from 6510 to 6730 µS/cm.

In the summer sampling, pH was in the range from 8.03 to 8.42, the lower value was observed in the "Urban core" sampling station (8.03) and the higher in the "Locality Limit” (8.42). The dissolved oxygen ranged between 2.7 and 11.1 mg/L, presenting the lower value in “Meat Industry" sampling point. In all the stations, the dissolved oxygen in the high waters period (summer) was higher than in the low (winter) waters period, due to the increase of the river flow. This also would influence in the TDS decrease. The suspended solids ranged between 51.2 and 90 mg/L and the TDS from 4530 to 5610 mg/L, being the higher TSS value in the “Meat Industry" sampling point and the higher TDS in the "Urban core" sampling station. COD values presented great heterogeneity from 25.6 to 45 mg /L, being the highest value on in the “Meat Industry" sampling point. The conductivity ranged between 6860 and 7180 µS/cm.

The N and P contents were different in the high and low waters periods in the different sampling stations (**Tables 3** and **4**).

In the summer sampling, total phosphorus and nitrogen concentrations were lower than in the winter sampling. This could be attributed to the dilution effect generated by the river flow increase, consequence of rainfalls. This also was observed by Schenone *et al.*, (2007, 2008) in the Salado River lower section that flows in the Samborombón Bay.

The results of the PCA, performed on the physicochemical parameters during the low waters period, are showed in **Fig. 2.**

Table 3. Parameters determined in winter sampling-Salado River-Argentine.

Sampling station	pH	COD (mg/L)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	Electric conduc. (µS/cm)	N-TKN (mg/L)	Total P (mg/L)	N/P	Trophic State	LN
Locality limit	8.20	21.5	8.6	60	4630	6730	2.029	1.088	4.1	hypertrophic	N
Porcine prod.	7.85	23.9	8.1	114	4420	6620	1.816	0.659	6.1	hypertrophic	N
Depuration 1	7.63	24.4	8.4	42	4370	6580	2.873	0.818	7.8	hypertrophic	N
Bovina prod.	7.45	26.7	8.3	34	4280	6510	2.932	0.869	3.7	hypertrophic	N
Depuration 2	7.82	25.1	8.1	156	4320	6610	3.327	1.098	6.7	hypertrophic	N
Meat industry	7.05	102.7	1.9	18	4290	6340	15.361	2.399	27.9	hypertrophic	P
Urban core	7.63	25.8	8.5	50	4460	6600	2.922	1.108	5.8	hypertrophic	N
Depuration 3	7.68	27.2	8.3	60	4510	6630	2.863	1.320	4.8	hypertrophic	N

Table 4. Parameters determined in summer sampling -Salado River-Argentine.

Sampling station	pH	COD (mg/L)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	Electric conduc. (µS/cm)	N-TKN (mg/L)	Total P (mg/L)	N/P	Trophic state	LN
Locality limit	8.42	26.5	8.4	53.0	5170	7180	1.771	0.539	7.3	hypertrophic	N
Porcine prod.	8.16	25.6	10.2	51.2	5000	6860	1.583	0.723	4.8	hypertrophic	N
Depuration 1	8.33	26.5	10.4	52.9	4880	6960	1.735	0.493	7.8	hypertrophic	N
Bovina prod.	8.32	27.8	10.8	55.5	4840	7000	1.485	0.692	4.7	hypertrophic	N
Depuration 2	8.14	29.0	10.4	58.0	4820	6950	1.717	0.618	6.1	hypertrophic	N
Meat industry	8.08	45.0	2.7	90.0	4580	6900	1.610	1.769	2.0	hypertrophic	N
Urban core	8.03	28.5	11.1	57.0	5610	6890	1.592	0.664	5.3	hypertrophic	N
Depuration 3	8.31	27.5	10.8	55.0	4530	6910	1.216	0.593	4.5	eutrophic	N

The second axis (17.4 % of the variance), represents total P concentration and its eigenvalue is 0.917. The **Fig. 2** shows a difference between the “Meat Industry" sampling point with the remaining ones due to its highest P value (2.399 mg/L). The remaining sampling stations present P values between 0.659 and 1.320 mg/L.

The results of the PCA, performed on the physicochemical parameters during the high waters period, are showed in **Fig. 3**. The first two components (1 and 2) explained 82.02 % of the total variability. The first axis (54.18 % of the variance), mainly represents dissolved oxygen, COD and P with eigenvalues of -0.474, 0.533 and 0.540 respectively.

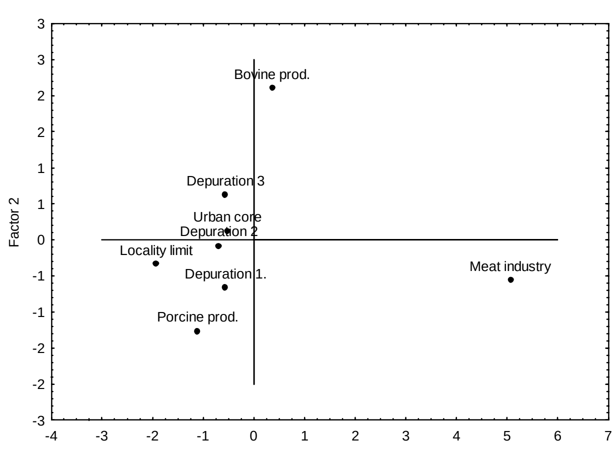


Fig. 2 Results of the Principal Components Analysis (PCA) based on values of physic-chemical variables and nutrients measured in winter

The second axis (27.82 % of the variance), represents pH, electric conductivity and total N content which eigenvalues are 0.387, 0.654 and 0.507 respectively. Considering the PCA, the “Meat Industry" sampling point is again the separated station from the remaining ones, in relation with nutrients and physicochemical parameters (**Fig. 3**).

In both samplings (winter and summer), the majority of sampling stations were in hypertrophic state and, in general, N was the limiting nutrient. In the winter sampling, P was the limiting nutrient in the “Meat Industry" sampling station. Historically, P was considered the limiting nutrient in the freshwater ecosystems (Hecky & Kilhom, 1988; Dzialowski *et al.*, 2005) and N in the marine coastal ecosystems (Guildford & Hecky, 2000). Nevertheless, there has been demonstrated that many water bodies present N as limiting nutrient, specially those of the great plains that receive high P concentrations by runoff, between other factors (Guildford & Hecky, 2000; Dzialowski *et al.*, 2005).

The water quality indexes calculated for each station and period are described in **Fig. 4a** and **4b.** There are no significant differences in the indexes values between

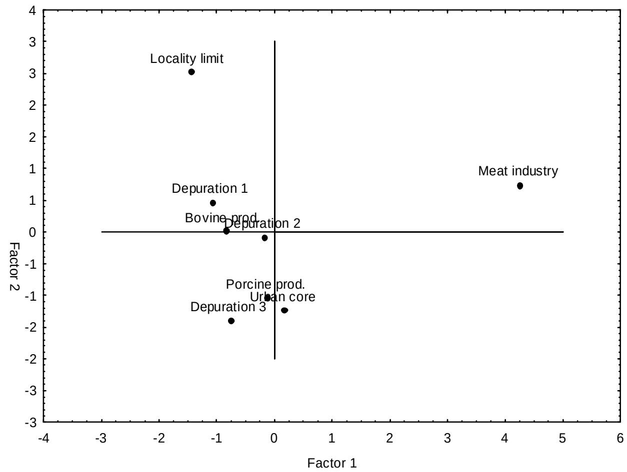


Fig. 3 Results of the Principal Components Analysis (PCA) based on values of physic-chemical variables and nutrients measured in summer sampling -Salado River-Argentine.

is registered in the “Meat Industry" sampling station, for both low and high waters periods. This evidence that urban, bovine and porcine systems effluents have a low impact on Salado River water quality compared to water quality deterioration produced by in the “Meat Industry" effluents. Besides, nutrients and organic matter contribution of this point pollution source is so high that water quality indexes maintain the same values even in the summer sampling (high waters period) when the river flow increases and dilution effects are normally observed.

Water quality indexes of the "Porcine Production" station sampling were constant in both periods. The "Bovine Production" sampling station indexes diminished in the summer sampling (high waters period), mainly related with the dilution effect. Nevertheless, this decrease was not significant.

Confined porcine and bovine production effluents located in the zone are considered as potential pollution sources of the river due to its high organic matter and nutrients contents. Intensive pig production systems are located a distance of approximately 5 km from the riverside, and constructed canalizations communicate these systems with the river course.

The highest WQIobj value was observed in "Urban core" sampling station (in correspondence with Roque Perez's city). Water quality did not show deterioration because it is a small city (10,902 inhabitants) and posses a wastewater treatment plant.

Water quality index values remained approximately constant in the intermediate stations (depuration 1, 2 and 3), demonstrating a relatively high autodepuration capacity of the river between the discharging effluent stations. The autodepuration capacity could be explained by the high river flow (annual average 390 m^3/seg, Lasta *et al.*, 2003) and nutrients retention processes realized by riparian plants. Nevertheless, new agroindustry emplacements and/or urban effluent the nutrients load in the water body, naturally eutrophic, intensifying this process and compromising the autodepuration river capacity.

Figures 4a and **4b** shows a similar trend in the calculated indexes, nevertheless, the WQIsubj possesses lower values in relation to the WQIobj in all sampling stations, due to the K constant incorporation that overestimates the water quality deterioration determined by the visual perception.

The Pearson's correlation results were highly significant between the indexes value obtained in each sampling station, being high correlation coefficients ($r>0.99$, $P<0.0001$). The high correlation obtained between water quality indexes, indicate that the proposed WQImin with only two parameters (dissolved oxygen and electric conductivity) is a useful and effective tool for water quality determination in Salado River. This result also is been valued even if without the “meat industry” sampling point. Correlation results observed in water quality indexes (WQIobj, WQIsubj and WQImin) could be related to the similar behavior among parameters studied in the different sampling points.

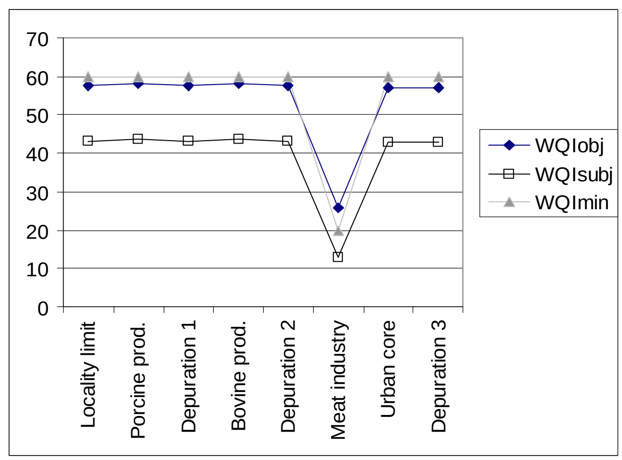
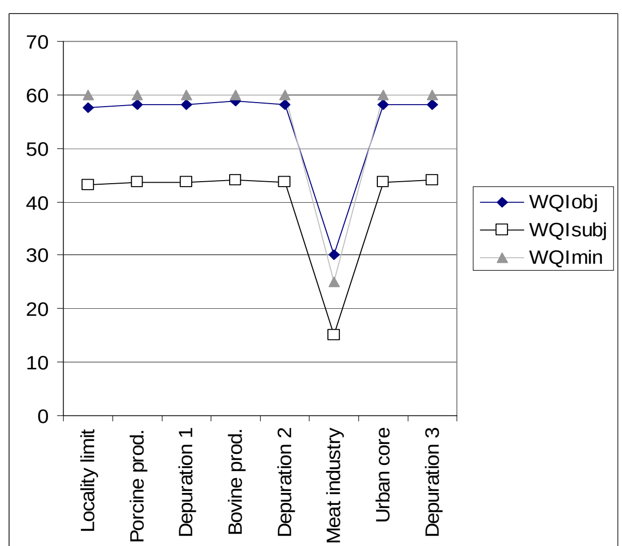


Fig. 4a Water quality indexes in winter sampling in Salado River.



CONCLUSIONS

The assessment of the effect of different agroindustry activities on the water quality of Salado River showed that only meat industry effluents had a differential impact. Since it is a point pollution effluents should be treated previous to its disposal with the available technologies.

The developed WQImin using only two parameters of quick determination resulted useful for the evaluation of the water quality of Salado River. It may be a suitable methodology to be applied for plan river management.

ACKNOWLEDGEMENTS: The authors would like to thank Gamaliel Martínez de Bascarán for his comments and the University of Buenos Aires and CONICET for the financial support.

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