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RESEARCH ARTICLE

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Biological water contamination in some cattle production fields of Argentina subjected to runoff and erosion

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Abstract

Grain production has displaced livestock to marginal lands in most of the productive regions in Argentina since 1990. In the fertile Rolling Pampa region, extensive cattle production has been concentrated in lowlands subjected to flooding, salt excess, erosion and sedimentation processes but also in some feedlots recently located in sloping arable lands prone to soil erosion. We studied the concentration of microbiological contamination indicators in runoff water and sediments accumulated in depressions along the tributary network from these lands devoted to cattle production. The aims of this work were: (i) to gather a reliable set of data from different monitoring periods and scales, (ii) to search for simple and sensible variables to be used as indicators for surface water quality advising purposes and (iii) to corroborate previous biological contamination conceptual models for this region. Concentration of pollution indicators in these ponds was related to mean stocking rates from nearby fields and proved to depend significantly on the accumulated water and sediments. Viable mesophiles and total coliforms were found mainly attached to large sediments rather than in the runoff water phase. Seasonal sampling showed that the time period between the last significant runoff event and each sampling date regarding enterococci proved to be a sensible variable for predicting contamination. Enterococci concentration tended to increase gradually until the next extraordinary runoff event washed away contaminants. The mentioned relationship may be useful for designing early warning surface water contamination programs regarding enterococci dynamics and other related microbial pollutants as well.

Additional key words: watershed; runoff-sediment; bovine; biological pollution.

Introduction

The Pampa Region, located in the south cone of South America (33-35° S, 62-64° W), is one of the largest prairies in the world. The region is a large plain of fertile land suitable for agriculture and livestock. Livestock industry dominated absolutely the region for three centuries but after the mid XIX century and particularly nowadays annual cropping has become the dominant activity in arable lands and it continues displacing livestock (Kraemer *et al.,* 2013a). This process was dramatically incremented since 1990 being enhanced by many factors: the rise of the international price of grains, biotechnology improvement and the recent widespread adoption of conservation soil management practices like no tillage systems (Solbrig, 1997; SAGPyA, 2009). This fact raised the stocking rate pressure in marginal extensive grasslands, and also promoted the establishment of a few intensive cattle feeding farms (called feedlots or animal housing systems) in upland positions.

Several sub-units can be identified in the Pampa Region. The so-called Typical Rolling Pampa is recognized as the most productive subregion regarding crops and livestock production. This area is characterized by a very gently undulating relief. The upland arable soils occupy 80% of the area whereas river valleys occupy the rest. These uplands consist of deep, fertile silty loam Mollisols located in summits and back slope positions devoted to annual cropping like soybean, wheat, corn and to a lesser extent sunflower and sorghum. Rotation with pastures for cattle grazing, which was a usual management practice for recuperating soil

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organic matter during part of the last century, is no longer carried. Land degradation is a major concern. Official reports state than almost 36% of its $4 \cdot 10^6$ ha are already moderately to severely eroded in spite of the low gradient regional slopes, which are smaller than 3% (SAGYP-CFA, 1995). Sedimentation process is also widespread. Large concentrations of silt and very fine sand that are present in the regional topsoils (INTA, 1973) make them prone to slaking, dispersion through drop impact and erosion processes. A local report employing a ^{137}Cs detection technique showed that between 11.5 and 36 Mg ha^{-1} yr^{-1} were lost by water erosion since 1950 decade in lands devoted to agriculture under conventional tillage (Bujan *et al.,* 2003). Nowadays the adoption of no tillage management practices in these uplands subjected to annual crops, has improved soil conservation. However, monoculture with soybeans is widespread and rotations with cover crops and stubble mulch intended to protect soils and enhance water infiltration are still scarce (Chagas *et al.,* 2008; Cisneros *et al.,* 2012). That is why water erosion in the forms of sheet, rill and also gullies, are still regionally observed. Typical Runoff Curve Number for these arable lands is 82 under ordinary antecedent soil moisture conditions and larger than 90 under wet conditions for continuous conventional as well as for continuous no-tillage systems (Chagas *et al.*, 2008). This fact highlights their large surface runoff capacity.

A few animal housing systems (cattle feedlots) have been recently established in these uplands. Each farm usually feed between 10,000 and 20,000 animals. Stocking rate varies between 100 and 500 animals ha^{-1} with animal management yards of about 1.5 ha. Systematic manure management is seldom carried out because there is a lack of specific legislation and scientific research regarding chemical as well as biological contaminations risks is still scarce. Manure excess from the yards is sometimes disposed in specific sinks within the own feedlots. Runoff curve number estimated for these feedlots is nearly 100 due to their almost null final infiltration rate according to field experiments with simulated rainfall (Chagas *et al.*, 2007). Hence there is an important risk of runoff contamination from these farms.

On the other hand, lowlands within the Rolling Pampa occupy nearly 20% of the area. They consist of hydromorphic and often saline/sodic Alfisols and Mollisols soils devoted to graze cattle mainly for beef production. The overall stocking capacity of these bottomlands under low input extensive cattle management can be estimated in about $5 \cdot 10^5$ heads. However, no specifically official figures are yet available. Cattle consist of Aberdeen Angus, Hereford, Shorthorn, Holstein as well as other cattle races for beef production. Stocking rate usually varies between 0.5 to 1 animal units ha^{-1} yr^{-1}. Livestock fields are usually between 20 and 100 ha. Continuous grazing by cattle with no rotational management is the common practice. Due to the favorable climatic conditions, no stables are used so cattle graze in open fields throughout the year. Forage includes several natural and cultivated genuses like: *Lolium* spp, *Stypa* spp, *Cynodon* spp, *Paspalum* spp, *Festuca* spp, *Agropyrum* spp, *Bromus* spp, *Melilotus* spp, *Lotus* spp, *Trifolium* spp, etc. These grasslands surround the main water courses. Regional groundwater is usually deep enough to prevent capillary water rise to the soil surface. Runoff potential for these lowlands is larger than that for the well-drained arable lands. This is due to the topsoil´s aggregate instability as well as the incidence of a very slow permeable argilic/natric subsurface horizon (Chagas *et al.*, 2011). There are widespread signs of degradation like surface crusts, and water erosion processes like sheet erosion, rills and gullies, although local slope gradients are usually less than 1%.

Recently, concern has risen regarding the relationship between runoff, soil erosion and contamination in the Rolling Pampa. For example, small depressions along the river tributaries promoted by erosion and sedimentation can be found that are sinks of potential biological contamination due to the accumulation of cattle feces born microorganism (Chagas, 2007). These contaminants can reach freely the depressions by surface runoff, attached to soil/sediment particles (Kraemer *et al.*, 2011b, 2013b) or even directly by the own cattle. The grazing cattle often enter freely into gullies, streams and also rivers to drink and to get refreshed. No legislation forbids this practice yet. This fact has increased soil erosion and also water biological contamination which in turn can be a threat to the own farmers and to sensible animals too (WHO, 1995). For example, *Salmonella* spp has been detected in some of the accumulated water samples (Marta Paz, pers. observ.).

A recent local experiment in extensive as well as in intensive cattle feeding fields using a drop forming portable rainfall simulator (Chagas *et al.,* 2007) reported high amount of runoff volume as well as splash and wash erosion. Drops impact and runoff were able to detach and transport high concentration of fine soil particles, chemical contaminants as well as bacteria indicators of fecal contamination like total coliforms and enterococci. The bacteria sources were soil surface partially covered with cattle feces from both the intensive feedlots in the uplands as well as the extensive grasslands in the valleys. The concentration of fine sediments, the electric conductance, chloride, bicarbonates, and dissolved reactive phosphorus in runoff water was an order of magnitude larger in the feedlot compared to the extensive grazing grassland. The concentration of enterococci was almost two orders of magnitude larger. Also a tendency to larger total coliform load and pH was observed for the feedlot compared to that from the grassland runoff. The higher pH values and sediment concentration in the surface flow from the feedlot can enhance the bacteria survival in runoff water as well. The interrill erosion process has low sediment transport capacity due to the scarce velocity of the laminar surface flow (Nearing *et al.,* 1990). This fact may explain why fine and not large sediments were found in the runoff from the rainfall simulator field experiments. It follows that this degradation process which is regionally widespread in the study region could be responsible in part for the microbial transport from the soil surface and its further accumulation into the aforementioned depressions. However interrill erosion process cannot explain the transport, deposition and re-suspension of large aggregates that are also present at the bottom of the studied depressions, rather ascribable to high energy concentrated flows.

Efforts to study and model these complex dynamic processes in other countries were recently published (Tian *et al.,* 2002; Bai & Lung, 2005). Many reports about microbiological contaminants show close association with stream sediments (Sherer *et al.,* 1992; Chagas *et al.,* 2006). Other reports mention that biological contaminants concentration in streams and rivers can rise following flooding events that promote the resuspension of contaminated sediments (Nagels *et al.,* 2002). In a study regarding human but not cattle pollution in the Rolling Pampa a relationship was found between antecedent rainfall events and coliform concentration in shallow bathing waters from a river (Emiliani *et al.,* 1999). Recently Kraemer *et al.* (2011a,b; 2013b) studied regional soil and sediment properties that influenced microbial attachment to them in part of the Rolling Pampa and found that clay content and cation exchangeable capacity (CIC) had a significant incidence in this process. Also the size of the transported sediment aggregates conditioned bacteria transport by runoff. It should be remembered that sediments are considered as the main surface water contaminants generated by agriculture and livestock production at a global scale (Ongley, 1996).

Previous results from a monitoring program during 2004-2005 in the Tala River basin (Rolling Pampa) showed that concentration of biological contamination indicators in the aforementioned small ponds promoted by water erosion along the tributary network may be linked to surface runoff water events (Chagas *et al.,* 2010). That experiment included eight representative sites that were sampled once in each season (Fig. 1). The results showed that ordinary rainfall events which promoted small runoff volumes were fairly linked to total coliform concentration dynamics whereas large runoff events were significantly linked to fecal enterococci concentration dynamics. Large runoff events were considered the ones registered in the mid Tala River basin gauge (409 km^2). However this conceptual model still needs corroboration regarding the repeatability across different monitoring periods and different geographic scales. The optimal scale for the hydrological analysis in this new study was a primary watershed because it is at this level where runoff events are generated. That is why the runoff from a gauged 230 ha primary watershed belonging to the Tala River basin was considered. Thus, the aims of the present research were: (i) to gather a reliable set of data from different monitoring periods and scales regarding microbiological contamination indicators in runoff water and sediments from lands devoted to livestock production within a representative basin from the Rolling Pampa, Argentina; (ii) to search for simple and sensible variables to be used as indicators for surface water quality advising purposes in these cattle production fields; (iii) to corroborate previous biological contamination conceptual models for this region.

Material and methods

Location and general characteristics of the study area

The Rolling Pampa is located at the northeast of Buenos Aires province, South of Santa Fe province and East of Cordoba province (Fig. 1). It also limits with the Parana River and the La Plata River (INTA, 1973).

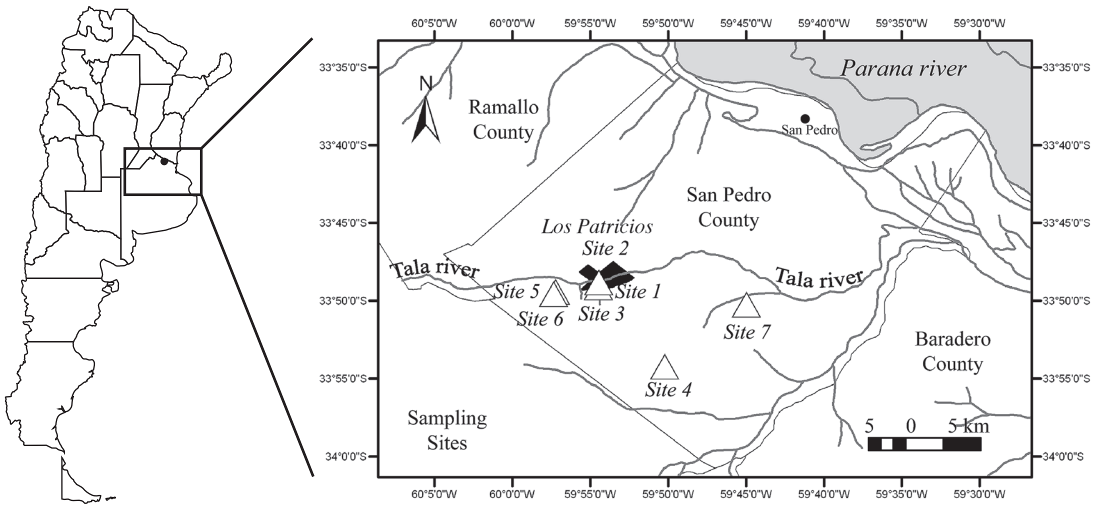

Figure 1. Location of the Tala River basin, at the NE of Buenos Aires Province, Argentina, within the Rolling Pampa. Sites 4 (intensive cattle production) and 7 (extensive cattle production) were monitored during 2008-2010 and also during 2004-2005 sampling periods. Sites 1, 2, 3, 5 and 6 were only sampled during the 2004-2005 period. Experimental field (shaded) belongs to the University of Buenos Aires.

The regional climate is temperate and humid. Its topography is gently undulated. The dominant arable soils are Argiudolls devoted to annual crops. Lowlands occupy c.a. 20% of the Rolling Pampa and consist of hydromorphic and saline/sodic Alfisols and Mollisols devoted mainly to cattle for beef production. The Tala River basin has 800 km^2, it flows into the Paraná River and is located mainly in San Pedro County, in the NE portion of Buenos Aires Province within the Rolling Pampa region, 180 km NW from Buenos Aires City. It represents the typical landscape features and land use from this region. Human population density is very low in this basin and the only industrial plant is a slaughterhouse located at the upper basin which has an effluent water treatment plant.

Top layer from dominant soils devoted to cattle production have the following properties: soil texture, silty loam; dominant clay mineral, illite; humified organic carbon, 2%; electric conductivity, 0.5 dS m^{-1} for grassland and 2.25 dS m^{-1} for the feedlot; pH, slightly acid for grassland and slightly alkaline for feedlot; extractable phosphorus, 5 mg kg^{-1} for grassland and 77 mg kg^{-1} for the feedlot.

Experiments using simulated rainfall under similar field conditions showed that runoff water had the following quality properties:

— Runoff from grasslands with animal feces on the surface: pH, 7,0; electric conductivity, 0.2 dS m^{-1}; Cl^-,40 mg L^{-1}; HCO_3^-, 61 mg L^{-1}; dissolved reactive phosphorus, 0.6 mg L^{-1}.

— Runoff from the feedlot: pH, 7.8; electric conductivity, 5.3 dS m^{-1}; Cl^-,721 mg L^{-1}; HCO_3^-, 427 mg L^{-1}; dissolved reactive phosphorus, 13.4 mg L^{-1} (Chagas *et al.,* 2007).

Sampling strategy performed during 2008-2010 period

Eight systematic water sampling events were performed seasonally during 2008-2010 in small depressions located along the intermittent waterway from two small primary watersheds devoted to livestock production (Sites 4 and 7, Fig. 1). The sites were selected regarding the results obtained from a former sampling period between 2004 and 2005 (Fig. 1; Chagas *et al.,* 2010). The primary watershed from Site 4 (33°50'15.07"S / 59°44'58.28"W) is located close to the Tala River and Arrecifes River basins divide. Land use consists of a 50 ha intensive feedlot with a stocking rate of about 15,000 living weight kg ha^{-1} throughout the year. Periodically, manure excess is partially removed from yards and disposed in sinks located in the same feedlot farm. The Site 7 (33°54'13.65"S/ 59°50'12.15"W) is a 50 ha grassland field in lowlands devoted to direct cattle grazing. The stocking rate is about 400 living weight kg ha^{-1} rather constant throughout the year (1 animal unit ha^{-1} yr^{-1}). This field also receives the runoff generated by a small gauged primary watershed of 230 ha located upstream and de-

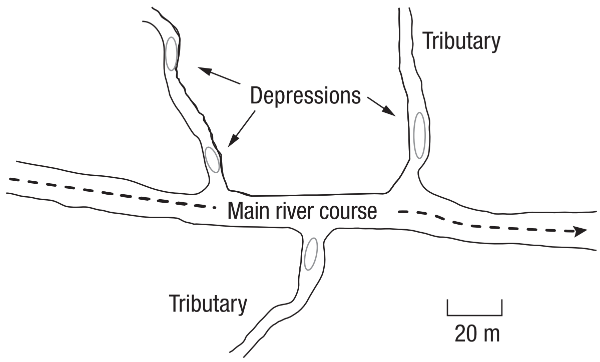

Figure 2. Exampling scheme showing a group of small depressions with less than 50 m^3 volume located within the tributary network at the mid studied basin. Note: the density of depressions and tributaries is unrealistically high.

voted to annual cropping. Thus, this field only receives fecal contaminants from the cattle grazing in it. Site 7 belonging to the former 2004-2005 sampling period is located 1000 m downstream from the Site 7 of the present 2008-2010 sampling period.

Water runoff and sediments samples were taken from small topographic depressions usually associated with water erosion and deposition processes located within the two studied primary watersheds aforementioned (Fig. 2). The size of these experimental sites is smaller than 300 m^2 and their volume occupied with water is often smaller than 50 m^3. These kind of depressions are widespread along the study area. Larger depressions were not included in this study because they are not commonly found. Two controls were also monitored: groundwater from a mill and surface water belonging to the Tala River.

Water samples were taken using 500 cm^3 sterile flasks by triplicate from each of both study sites during each of the sampling dates. Sampling was performed after the bottom of the depression was manually disturbed so as to simulate cattle trampling effects in order to obtain actual drinking water quality information. Water samples were kept refrigerated and taken to the laboratory within 24 h. Parallel samples from groundwater and from the Tala River mid-course were taken and used as subsurface and surface water controls respectively.

Climatic and hydrological measurements

Rainfall was registered by two automatic meteorological stations (34°48’25”S / 59°54’37”W and 33°50’36.75”S / 59°45’13.51”W), by the INTA meteorological gauges (33°41’S / 59°41’W) and also by some pluviometers located throughout the mid basin. Runoff measurements during 2008-2010 periods were preformed directly in the gauged watershed of 230 ha belonging to Site 7. As a hydrological control the runoff in the main river course close to sampling Site 3 in a place within the University of Buenos Aires field where the basin area is 409 km^2 was also measured. Discharge was continuously registered by an automatic water stage gauge. Water level records were then transformed into discharge rates through a height/discharge curve fitted specially for the study place. Mean peak runoff discharge for the 230 ha watershed and for the 409 km^2 basin were 2.5 m^3 s^{-1} and 7.7 m^3 s^{-1} for the study period respectively. The relatively small peak discharge from the 409 km^2 basin is due to the flat relief that dominates the headwaters of this basin (Chagas *et al.,* 2011).

Water and sediments analysis

The concentration of microbial indicators of animal fecal contamination in runoff water as well as in sediments was analyzed using the following procedure. Once in the laboratory the samples were left still for 10 minutes to let large sediments settle down. According to Stoke´s law no aggregates larger than 20 microns will be present on the supernatant. An aliquot from the upper supernatant water was then taken. Afterwards the large sediments were separated from the runoff water and were suspended in 300 cm^3 sterile distilled water. The suspension was then shaken for two hours and left still for 10 minutes to let large sediments settle down again. After that a new aliquot from the supernatant water was taken. This new sample contained bacteria formerly attached to large sediments and then detached by shaking action. The accuracy of this method to study bacteria attachment in large sediment was reported by Chagas *et al.* (2006). Samples were always kept refrigerated.

Both aliquots, the second one containing bacteria associated mainly with large sediments and the first one containing either free bacteria or associated with fine particles like small aggregates, clay or fine silt, were then inoculated into selective and differential mediums contained in plates or tubes in order to determinate the number of viable microorganism through the most adequate technique: either the plate count method or the most probable number method (APHA-AWWA-WEF, 2012). The cultivation media employed were: for mesophile microorganism, trypteine soy agar; for total coliforms, violet red bile dextrose agar; and for enterococci, Slanetz-Bartley agar (APHA-AWWA-WEF, 2012). The total concentration of each microorganism group was expressed as the sum of the concentrations in the first and second aliquots. In cases where large sediments were negligible like the groundwater and the main river course samples, the total concentration of microorganism corresponded to the first aliquot. All the bacteria concentrations were expressed in the original 500 cm^3 water sample volume base. The concentration of total solids was obtained by evaporating an aliquot of each of the analyzed water samples.

Climate and hydrological variables

In order to meet the objectives of this paper, simple relations were analyzed between the temporal variability of fecal indicators concentration and some rather easily measurable regional variables regarding the present 2008-2010 monitoring period to be compared to the ones obtained earlier (2004-2005; Chagas *et al.,* 2010). The selected variables for the analysis were: mean daily temperature (°C); time since the last rainfall event (days); volume and intensity of the last rainfall event (mm day^{-1}); time since the last runoff event recorded both in the Tala's river 409 km^2 basin and in a small primary 230 ha watershed that flows to this river and is directly linked to the study Sites 4 (intensive cattle management) and 7 (extensive cattle management) (days); rainfall that promoted the last runoff event in the basin and the watershed (mm); and peak discharge (m^3 s^{-1}) in the basin and in the watershed.

Statistics methods

Analysis of variance, linear regression and linear correlation analysis were performed following Snedecor & Cochran (1980).

Results and discussion

The results of the eight sampling dates (2008-2010) for the direct grazing and for the feedlot treatments showed significantly higher concentrations of viable mesophiles, fecal coliforms and enterococci in the depression's runoff water from this last treatment (Table 1). Surprisingly, enterococci were neither found in groundwater nor in the Tala River used as water quality controls. This result is remarkable because it shows lack of regional biological contamination in surface and groundwater.

Table 1. Concentration (in ln CFU mL^{-1}) of microorganisms in small depressions with accumulated water and sediments

Microorganisms	Extensive cattle production	Intensive cattle production
Viable mesophiles	11.1a	15.1b
Total coliforms	8.7a	11.8b
Enterococci	3.9a	9.1b

Data transformed to natural logarithms and then averaged. It corresponds to 8 successive sampling dates during 2008-2010. Means followed by the same letter do not differ significantly ($p > 0.01$)

The concentrations of these fecal contamination indicators were related to the mean stocking rate from the nearby grazing fields in which the depressions were located. The highest load corresponded to the intensive feedlot farm whereas the minimum load was associated with extensive cattle grazing farm. Particularly, enterococci concentration was at least two order of magnitude larger for the intensive compared to the extensive management. Hence, inputs can be ascribed mainly to the influence of the cattle grazing at or near these sinks. Wilcock *et al.* (1999) quoted that a bovine of 450 kg living weight can produce approximately 12.3 fecal pats per day each one containing $1.3 \cdot 10^9$ UFC of *Escherichia coli*. However, local specific microbiological analysis showed that some influence from wild fauna, particularly birds, cannot be discarded (Chagas, 2007). Surface runoff is able to transport part of these potential contaminants from feces located in the surrounding land to the study depressions according to field simulated rainfall experiments described by Chagas *et al.* (2007) and Kraemer *et al.* (2011b). The temporal variation coefficients of water microbial concentration found in the sinks from Table 1 using data not transformed varied between 150 and 250% throughout the study period 2008-2010. It must be considered that stocking rate was kept rather constant throughout the year in the studied farms. Thus, the large variation coefficients found can be related to climatic as well as hydrological variability. This result also show that even

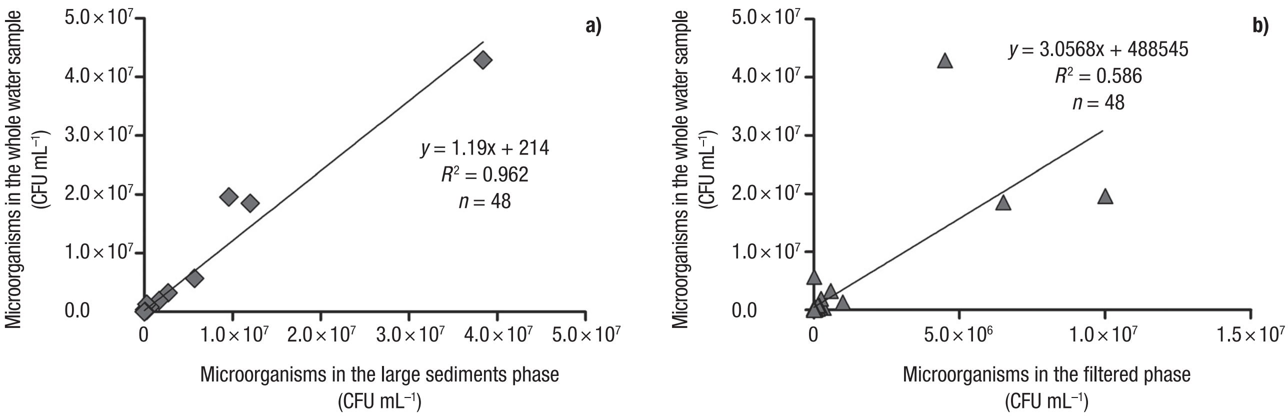

Figure 3. Total concentration of viable mesophiles, total coliforms and enterococci in water samples related to the same microorganism a) in the large sediments phase or b) in the filtered phase of each corresponding water sample for the 2008-2010 sampling period. Data not transformed

under extensive cattle production, risk of infections from pathogens can be expected along the year regarding the evidence of *Salmonella* spp in recent runoff water samples collected from the feedlot.

Pond runoff water samples taken to the laboratory also carried a noticeable concentration of solids, mainly large sediments with high settling velocity. This solid load was promoted by vigorous hand re-suspension of the sediments present at the bottom of the depressions during sampling operations in order to simulate the cattle disturbance while entering and drinking into them. The mean concentration of sediments larger than 20 microns measured in the sink water samples was 10 g L^{-1} with a variation coefficient of 100%. Local erosion studies showed that these sediments may be detached and transported from upland and surrounding fields and temporarily trapped in these small depressions (Bujan *et al.,* 2003). In the present work most of the bacteria colonies measured in water samples were related to large sediments accumulated in the bottom of the sampled depressions (Fig. 3). It can be seen that 96% of microbial concentration variability of the water samples was explained by the solid phase larger than 20 microns mainly consisting of viable mesophiles and total coliforms and to a lesser extent enterococci. However, no consistent relationship was found between bacterial concentration in water samples and the concentration of these solids in accordance with a former study by Chagas *et al.* (2006) (data not shown). This shows that microorganism concentration depends on the presence of a solid phase rather than on sediment concentration from this phase for the study conditions.

In order to search for simple and sensible variables to be used as indicators for surface water quality advising purposes selected climatic and hydrological variables were considered. The reason for selecting these variables is that temperature is a factor that regulates microbial activity in water (Cheremisinoff, 2002) and the rainfall intensity and volume are associated with runoff, soil erosion and microbial transport (Tian *et al.* 2002). Table 2 resumes the main results. The variable "time since the last measurable runoff event" proved to be highly correlated to enterococci concentrations. Similar responses were obtained in the former study aforementioned (2004-2005 period) (Chagas *et al.,* 2006). It must be stressed that for the mentioned experiment the measurable runoff events were registered on the main Tala river course (409 km^2 basin) whereas for the present experiment (2008-2010) the measurable runoff events were registered directly at the primary watershed's intermittent course (230 ha watershed), the same in which the small depression from the extensive grazing field is located. To extend the validity of the obtained results, Fig. 4 included data belonging both to the 2004-2005 period as well as to the present water sampling period (2008-2010). Although scientific reports show that bacterial concentration in runoff waters can raise shortly after flooding events, our results focused on pond waters did not show a consistent tendency for the first 20 days following each measurable runoff event (data not shown). In fact Fig. 4 shows subsequent bacteria concentration increments in the water samples from the study depressions.

According to the obtained results most of the ordinary (small) runoff event promoted by common rainfall events and hence undetectable by the runoff measuring devices located in the water courses, may transport

Table 2. Linear correlation coefficients between selected meteorological and hydrological variables measured for eight sampling dates during 2008-2010 on one hand, and the concentration of different microorganisms found in runoff water and sediments on the other hand (n = 8)

Selected climatic and hydrological variables	Microorganism concentration (CFU mL^{-1})					
	Viable mesophiles		Total coliforms		Enterococci	
	Direct grazing[1]	Feed-lot[2]	Direct grazing	Feed-lot	Direct grazing	Feed-lot
Mean daily temperature (°C)	–0.30	–0.30	+0.10	+0.04	+0.30	+0.25
Time since the last rainfall event (days)	–0.72	–0.60	–0.41	–0.60	–0.10	–0.10
Time since the last runoff event in the basin or the watershed (days)	–0.17	–0.22	–0.33	–0.14	**+0.87***	**+0.86***

[1] Direct grazing: extensive cattle production. [2] Feedlot: intensive cattle production. Data not transformed. * $p < 0.01$ in bold.

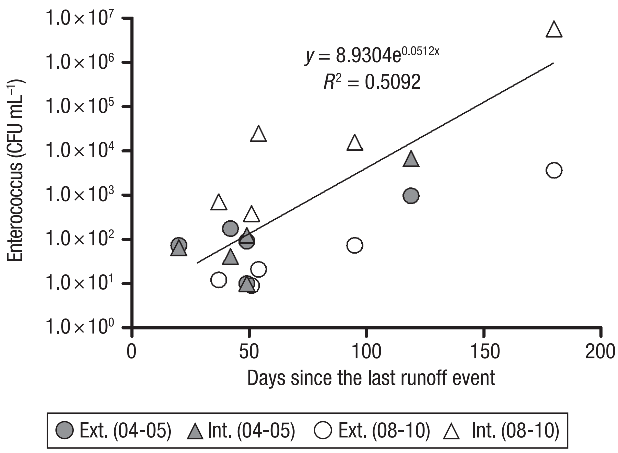

Figure 4. Relationship between enterococci concentration (CFU mL^{-1}) and number of days since the last runoff event in the 409 km^2 basin (2004-2005 sampling) or in the 230 ha watershed (2008-2010 sampling) for extensive (Ext.) and intensive (Int.) cattle production fields respectively. Data for periods smaller than 20 days were not included.

microbial contaminants from the fecal pats over the fields to the depressions. This fact is supported by the results from Chagas *et al.* (2007) and Kraemer *et al.* (2011b) using simulated rainfall. Once in the ponds, animal trampling may help to re-suspend sediments particularly the largest ones present in the bottom positions and put them in contact with microorganism promoting attachment according to Chagas *et al.* (2006), and Kraemer *et al.* (2011a, 2013b). Successive ordinary rainfalls may contribute to increase the microbial concentration progressively until a large runoff event (like those registered by hydrological probes) washes away these contaminated water and sediments bringing new unpolluted ones to the studied depressions.

The analyzed period (2008-2010) was characterized by a very dry year (2008) followed by a normal year (2009) and a wet year (2010). On the contrary the former study period (2004-2005) was slightly dry for the entire period (INTA,2014). As can be seen, similar relationships were obtained for different weather conditions. Pond water level varied throughout the study period, as a result of these changing conditions. However, rather than affecting the main observed tendency in the bacteria concentrations, evaporation and/or dilution may have increased the variability of the results being responsible for the rather low R^2 values in Fig. 4. It must be stressed that the mentioned tendency was observed for both periods (2004-2005 and 2008-2010), for the extensive as well as for the intensive farms and monitoring the discharge from the main river course (2004-2005) as well as from the primary watershed runoff (2008-2010). These facts give strength to the conceptual model of inputs and outputs of pollutants that is proposed here.

On the other hand, the lack of response to the hydrological variables regarding total coliforms compared to enterococci might be ascribed to differences in their affinity to the solid phase (larger for coliforms than for enterococci as observed by Chagas *et al.* (2006) but also to differences in their survival time out from the cattle intestine. According to WHO (1995) coliforms usually survive less time in the environment than enterococci do. These elements could help to explain why enterococci and not coliforms were sensible to the influence of runoff events that took place prior to sampling time. These results highlight the diagnostic value of the enterococci as a fecal contamination indicator as well as the significant effect of large runoff events on the microbial dynamics measured at different scales for the study area.

This conceptual model can be possibly adapted to predict the concentration dynamics of pathogens in water and sediments that show similar environmental response to the mentioned fecal indicator.

In conclusion, in the Rolling Pampa runoff water and sediments from cattle fields carried indicators of microbial pollution which accumulated in nearby sedimentation sites located within the tributary network, usually in small depressions generated by former concentrated water erosion processes. Pollutant concentration in these ponds was related to mean stocking rates. The studied microbial indicators were found mainly attached to large sediments rather than in the runoff water phase particularly for viable mesophiles and total coliforms. Sampling during several dates showed that the time period between the last significant runoff event and each sampling date regarding enterococci proved to be a sensible variable for predicting the level of fecal contamination in the studied depressions. These results highlight the relationships between runoff, soil erosion and water contamination in cattle production fields for the study area.

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