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Groundwater management in an agro-industrial school in Argentina

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ABSTRACT: Introduction: water management is of paramount importance in productive activities, such as agriculture, livestock and industry, due to its direct impact on both the quality and the availability of this valuable resource. However, groundwater management is usually addressed under a non-integrated approach which originates a high risk of pollution as well as water shortage for food and animal production in the agro-industrial systems. **Objective:** to analyze water quality for human consumption, hydrogeological features, water demand, and discharge of liquid effluents on soil and surface water. **Methods:** we carried out a diagnostics of water management in an agro-industrial school located in Buenos Aires province, Argentina. The production system includes a bovine dairy farm; calf, pork and rabbit breeding; beekeeping; poultry farming; dairy and cheese factory; agriculture and fodder area; processing of meat, and orchard. To perform the analysis, we calculated water requirements for six productive activities and evaluated the hydrological features of the area through water table measurements considering the groundwater flow sense. We analyzed the groundwater quality seasonally during a period of a year through five water samples. We considered microbiological and physicochemical parameters and they were compared with recommended level by law, and we carried out the monitoring of residual chlorine during a week. Also, we evaluated the generation and disposal of effluents. **Results:** water was suitable for human consumption, although we detected variations in its quality indicators. We determined that the main issues hindering an integrated water management were the diversified production developed with high volumes of water demanded, the water quality deterioration by the agro-industrial productions carried out, and the hydrogeological features of the area. In addition, we measured a high water demand which is in conflict with groundwater shortage and the complex hydrological conditions of extraction in the studied area. **Conclusion:** this study demonstrated the usefulness of applying effective strategies to act on environmental-priority subjects and to develop good practices regarding water management from an integrated approach.

Key words: water quality, groundwater, effluent, agriculture, industry.

RESUMEN: "Gestión del agua subterránea en una escuela agroindustrial en Argentina". **Introducción:** la gestión del agua es de gran importancia en las actividades productivas, debido a su impacto directo sobre la calidad y la disponibilidad de un recurso tan valioso. Sin embargo, el agua es en muchos casos utilizada sin un enfoque de gestión integrada, generando riesgo de contaminación, así como escasez de agua en los sistemas agroindustriales. **Objetivo:** analizar la calidad del agua para consumo humano, características hidrogeológicas, demanda de agua y descarga de efluentes líquidos en el suelo y aguas superficiales. **Métodos:** desarrollamos el diagnóstico de la gestión del agua subterránea en una escuela agroindustrial ubicada en la provincia de Buenos Aires, Argentina. El sistema productivo de esta escuela incluye un tambo bovino, cría de cerdos, terneros y conejos, avicultura y apicultura, fábricas de quesos y chacinados, área de forraje, sector de cultivos y huerta. Para realizar el análisis, calculamos los consumos de agua en seis sectores productivos y evaluamos las características hidrogeológicas del área de estudio mediante mediciones del nivel freático considerando el sentido de flujo subterráneo. Analizamos la calidad del agua subterránea estacionalmente durante un año a través de cinco muestras. Consideramos parámetros microbiológicos y físicoquímicos y los comparamos con lo recomendado en la legislación, y desarrollamos el monitoreo del cloro residual durante una semana. Además, evaluamos la generación y disposición de efluentes. **Resultados:** el agua resultó apta para consumo humano, aunque se encontraron variaciones en parámetros indicadores. Determinamos que los principales aspectos que dificultan la gestión integrada del agua fueron la diversidad de producciones desarrolladas con altas demandas de agua y el deterioro de la calidad del recurso que ocasionan, y las condiciones hidrogeológicas del área. Además, la gran demanda de agua entra en conflicto con la escasa disponibilidad del recurso subterráneo y la complejidad del medio geológico para la extracción del agua. **Conclusión:** este trabajo demostró la utilidad de aplicar estrategias efectivas para actuar en aspectos ambientales prioritarios y desarrollar buenas prácticas para el manejo del agua con un enfoque integrado.

Palabras clave: calidad del agua, aguas subterráneas, efluente, agricultura, industria.

Water management is of paramount importance for a wide range of productive activities such as agriculture, livestock, and industry due to its direct impact on quality and availability of the resource. It is expected that more water will have to be allocated to food production in the next 30-50 years (IWMI, 2007), which will demand higher production from smallholder farmers and the maintenance or increasing for other water users, including support of ecosystem services and society (Barron & Noel, 2011).

Sustainable water management has priority challenges to overcome, including water security for people and for food production, protection of ecosystems and groundwater quality, optimization of aquifer use while limiting environmental impacts, and the creation of popular awareness (Foster & Grey, 1997; GWP, 2000). In that sense, each agro-industrial activity should be carried out in the framework of an integrated approach. An integrated water resource management (IWRM) is defined as "IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000, p.22). Nevertheless, in many practical situations accomplishing an integrated approach is not straightforward because of different factors: the complexity of the organization, a broad variety of productions, the temporal and spatial variation of groundwater quality and availability.

Food and Agriculture Organization (FAO, 2006, 2014) analyzed the farmer field school approach and indicated that the participation of actors in the field promotes a better planning and a faster adoption of techniques or strategies to take care of water.

Recent investigations have been devoted to the research of water management. De Bruin, Mikhail, Noel and Barron (2010) considered that Agricultural Water Management (AWM) interventions need a "monitoring and evaluation framework that captures the holistic picture of its planned and unplanned effects on the watershed, or landscape, and livelihoods of people". Barron and Noel (2011) analyzed cases of AWM interventions in meso-scale watersheds in Asia, sub-Saharan Africa and Latin America. De Bruin et al. (2015) addressed AWM at basin level in study cases of South Africa. Douchamps et al. (2015) focused on water management in mixed crop-livestock systems in Burkina Faso and Ghana. However, researches following an integrated water management approach are scarce in Argentina.

With the aim of carrying out an environmental diagnosis of water and effluent management, this paper reports measurements in an agro-industrial school in Buenos Aires, Argentina. This school was selected because it constitutes an affordable minor-scale study case in which both, a detailed diagnostic and a further improvement of its environmental performance can be accomplished in a relatively short period of time respect to other big productions. Therefore, we assume that it is representative of the most of agro-industrial productions in the pampean region of Argentina.

In preliminary studies of our group that included extension and educational activities with the actors of the agro-industrial school (Rodríguez et al., 2014, 2015), some environmental and hydrological problems of the school were reported. Groundwater management was highlighted as the most critical concern, being limited in the area due to hydrogeological conditions. Other studies observed deficiencies on microbiological quality of groundwater (Mujica, Cirone, Vuksinic, & Provenzal, 2015; Vuksinic, Rodriguez, Tabera, & Ruiz de Galarreta, 2016).

The objective of this study was to analyze water quality for human consumption, hydrogeological features, water demand, and discharge of liquid effluents on soil and surface water.

The hypothesis is that groundwater management is not carried out with an integrated approach, situation that can affect water quality and availability and generates a high risk of pollution and water shortage for food and animal production in the agro-industrial system.

The information of this study will be useful to develop effective strategies to act accordingly to environmental priority subjects. Moreover, good practices regarding water management will positively inspire the students to acquire them for their future work.

MATERIALS AND METHODS

Study site: 'Ramón Santamarina' school, founded in 1916, is located near Tandil city (37°21'05"S & 59°12'09"W) at the southwest of Buenos Aires province (Argentina) on the head of Chapaleofú stream basin. The local hydrogeology features a sedimentary porous cover which gives place to a thin phreatic aquifer supported by crystalline basement rocks (Ruiz de Galarreta & Banda Noriega, 2005). This hydrogeological complexity determines low groundwater extraction volumes setting restrictions to its exploitation. Groundwater has low salinity, according to the position of the study area on the basin header (Pessolano, Ruiz de Galarreta, Varni,

Barranquero, & Larsen, 2012). All these features highlight the relevance of groundwater preservation in the area.

The school offers a specialized education about the agro-industrial production developed in its area of influence which is organized in two levels, high-school and tertiary careers. It has 60 teaching and technical staff, and approximately 500 undergraduate and graduate students. The school has eight main production sectors, namely bovine dairy farm; calf, pork, and rabbit breeding; beekeeping; poultry farming; dairy and cheese factory; agriculture and fodder area; factory of balanced food for animals; processing of meat and sausages; orchard; flour mill; factory of preserved food (Fig. 1). Additionally, there is an area of general maintenance and agriculture machines and a canteen. The production reaches 315kg of cheese and 2 300L of milk per day, and 400kg of meat per week. It is mainly destined for internal consumption except dairy products (e.g.: cheese and milk jam) which are commercialized. Regarding water requirements, human consumption, agro-industrial productions and sanitary use groundwater extracted from the phreatic aquifer. Consequently, an important effluent volume is generated.

Evaluations: Different measurements were made in order to address detailed diagnostics of water and

effluent management. Fieldwork was carried out during 2015 and 2016, beginning with observations in the study site and visits to each productive sector. The fieldwork included *in-situ* measurements of the hydrogeological features of the site and physicochemical parameters. Moreover, five groundwater samples were collected and transported to the laboratory for subsequent analysis to assess their microbiological quality for human consumption. Groundwater samples were taken during the seasons of the year, in order to evaluate water quality variations according to the temperatures and precipitation of the area. In addition, information about the water use and disposal of liquid effluents was recorded. Finally, it was necessary to integrate all the methodology steps to achieve the integral comprehension of water management.

Water demand: The water flow requirements ($m^3 \cdot s^{-1}$) were measured on each water supply device for six production sites of figure 1, selected as the main consumers (dairy farm, dairy and cheese factory, pork and calf breeding, orchard and canteen). The different activities taking place on each sector were registered in detail including its frequency, water sources employed, and effluent disposal modes. Then, the total daily and weekly demands were calculated for each process via the corresponding time of scheduled activities. In the case

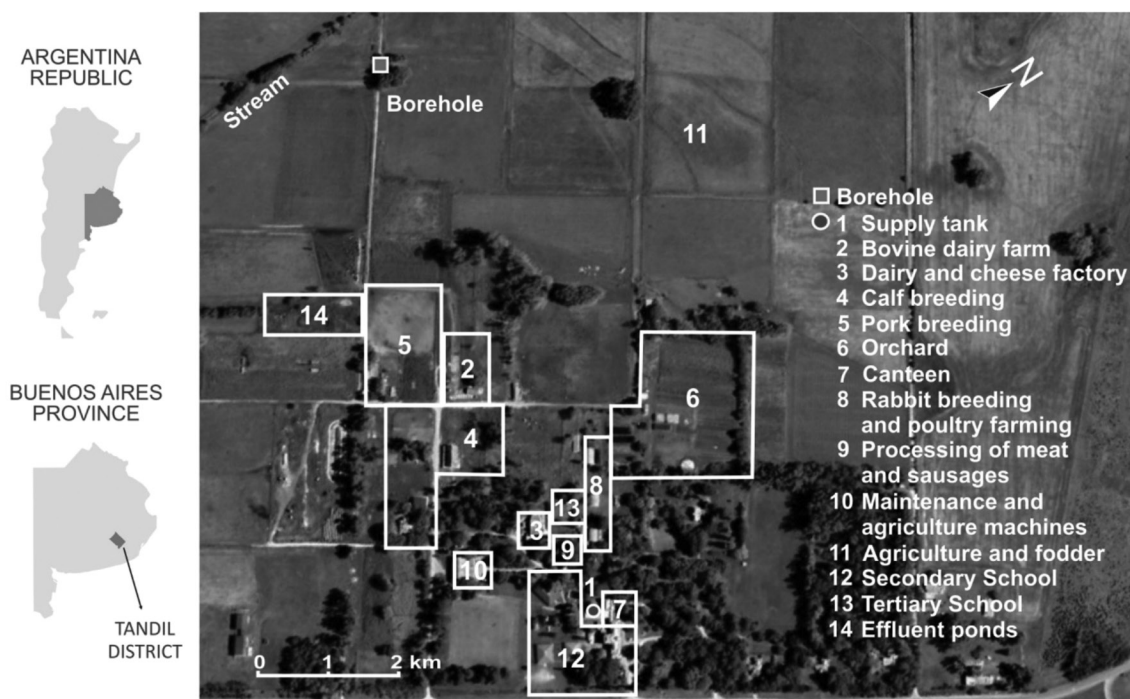


Fig. 1. Main productive sectors at the agro-industrial school studied.

of animal water consumption, data was obtained from previously reported data (Alarcón, Camacho, & Gallego, 2005; Almeyda, 2013).

Groundwater levels: The depth of groundwater level was measured in the fieldwork by using a level probe. Four boreholes located in the area were used to determine the local direction of groundwater flow and to assess the vulnerability of the aquifer to pollution. Also, the groundwater flow extracted from the supply borehole was quantified.

Physicochemical analysis: The electrical conductivity (EC) and pH were measured in the supply tank by using a multiparametric sensor (Hanna HI 9812). EC and pH constitute useful indicators of water salinity and degree of acidity/basicity, respectively. It is considered that these parameters do not vary along the network. In addition, nitrate and chloride concentrations were determined in the laboratory according to standard methodology (APHA, 2012) as indicators of organic and animal pollution. The results were compared with baseline values established by the Argentinean Alimentary Code.

Microbiological analysis: Five groundwater samples were collected from six selected sectors for laboratory determination of pathogen microorganisms. Four samples were collected from the water distribution network at the school, namely, supply tank, dairy-cheese factory, dairy farm and canteen. One additional sample was collected directly from the borehole supplying water to the whole network. The presence of pathogen agents regulated by the Argentinean Alimentary Code for human consumption: mesophilic aerobic bacteria, total coliformes, *Escherichia coli*, and *Pseudomonas aeruginosa*, was analyzed. These pathogens should be absent or below guide values in order to consider water suitable for human consumption and to avoid the transmission of waterborne diseases.

Residual chlorine: Consumption water flow through the distribution network is continually treated by an automatic chlorination device at the supply tank (34 000L of capacity) to prevent any possible contamination by organic compounds. Chlorine concentration was measured in the same four sites selected for the microbiological analysis along the distribution network, by colorimetric technique in order to determine the consumption of chlorine by organic matter. The monitoring of residual chlorine was carried out every day at the same

time during a week in order to analyze variations related to the different uses of water.

Water and effluent management: In order to achieve a deep insight of water management in the study site, the different measurements were correlated to visual inspections of each sector of interest and interviews conducted to the technical staff to further analyze the uses of water as well as the effluent disposal.

Ethical, conflict of interest and financial statements: the authors declare that they have fully complied with all pertinent ethical and legal requirements, both during the study and in the production of the manuscript; that there are no conflicts of interest of any kind; that all financial sources are fully and clearly stated in the acknowledgements section; and that they fully agree with the final edited version of the article. A signed document has been filed in the journal archives.

RESULTS

Water demands: Total monthly water consumption denoted a high consumption for the current facilities. Table 1 presents that the total monthly water consumption calculated for the overall normal functioning of the school reached 1 800m³.

The distribution per sectors is shown in figure 2. The highest amount of water was consumed at the area devoted to calf breeding (~54%), followed by the dairy-cheese factory (~22%). In the former, water is mainly used for the process of milk cooling through a hose system working 24 hours/day, while, in the latter, water is mainly employed in a boiler and in the cleaning of floors/allowances.

Hydrogeological features: The measurement of groundwater depth varied between 1,6 and 11,3m in all the boreholes: The lowest value corresponded to the supply borehole which is constantly working to bring water to the school. It has a depth of 18m. The groundwater flow currently extracted from this borehole reaches 12 000L*h⁻¹.

According to a geoelectrical study carried out in the site (IHLla, 2015), the depth of the aquifer basement varied from 6 to 19m. It indicates that the thickness of the unsaturated zone oscillated between 5 and 15m depending on the location in the area.

TABLE 1
Water consumption calculated for the different sectors of the school

Sector	Activities and facilities	Monthly consumption (L)	Percentage
Pork breeding	Cleaning of animal track. Drinking consumption.	154 280	8,6
Calf breeding	Cleaning of animal track. Drinking consumption. Cooling of milk for calf consumption.	965 490	53,6
Orchard	Cleaning of machinery. Irrigation.	90 177	5,0
Dairy farm	Cleaning of animal track. Cleaning of building and equipment.	146 100	8,1
Dairy and cheese factory	Salting pools. Cleaning of floors and allowances. Washing of molds, canvas and utensils. Boiler.	389 539	21,6
Canteen	Food preparation. Cleaning of the kitchen and building. Washing of utensils and enamelware. Staff and students drinking consumption.	55 150	3,1
Total		1800736	100

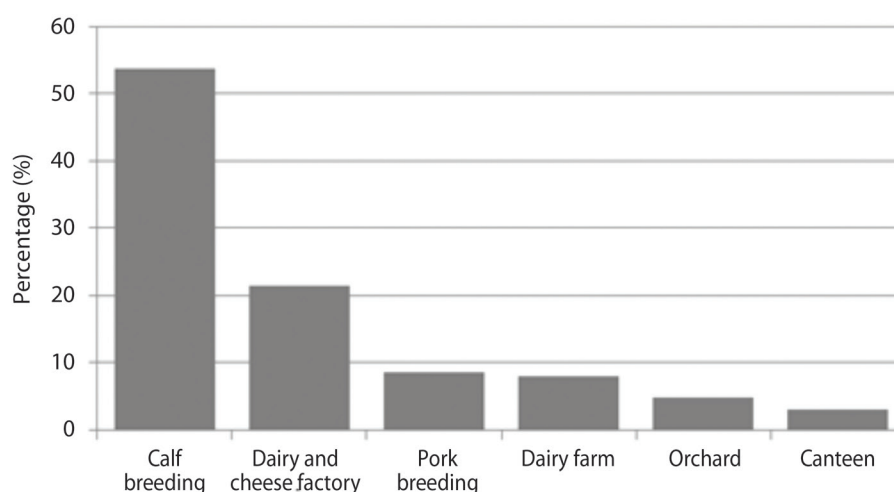


Fig. 2. Water consumption per sectors.

Water quality: The physicochemical quality of water was evaluated by measurement of EC, pH, chloride and nitrate concentrations in the supply tank (Table 2). For the seasons studied, all values are lower than the recommended by the Argentinean Alimentary Code, which indicates: a maximum of $45\text{mg}\cdot\text{L}^{-1}$ for nitrate, $350\text{mg}\cdot\text{L}^{-1}$ for chloride, pH between 6,5 and 8,5, and there is no regulation for EC.

Regarding its microbiological quality, water was suitable for human consumption in all the sectors analyzed during winter, with the exception of the supplying borehole in which *Escherichia coli* was detected (Table 3). Further analysis carried out at the borehole along spring and summer confirmed the presence of this bacterium and also detected a high level of total coliforms.

However, the quality at the supply tank is suitable for human consumption because of the effect of the

chlorination procedure, given that the residual chlorine concentration in the tank was $0,25\text{mg}\cdot\text{L}^{-1}$. In autumn, the results showed the absence of *E. coli* at the borehole.

It can be observed an important range of variation from the tank to the sectors during a day in winter for the sectors analyzed (Table 3). The highest concentrations were measured at the main tank, while lower values were measured at the rest of the network.

During summer, the values of residual chlorine measured along the distribution network showed variations during a day and also during the week (Table 4). All the values during this season are less than the recommended value for human consumption, i.e.: $0,2\text{mg}\cdot\text{L}^{-1}$ (Argentinean Alimentary Code, 2012).

Based on the residual chlorine measurements, it was deduced that the chlorine dosage process in the tank was working inadequately, allowing the proliferation of

TABLE 2
Physico-chemical quality of water

Sampling date	pH	Electrical conductivity ($\mu\text{S cm}^{-1}$)	Chloride (mg L^{-1})	Nitrate (mg L^{-1})
Winter 2015	7,2	710	10	12,78
Spring 2015	7	600	20	10,68
Summer 2016	8,3	690	14	18,8

TABLE 3
Microbiological quality of water during winter

Sample	Residual chlorine ($\text{mg} \cdot \text{L}^{-1}$)	Mesophilic aerobic bacteria (CFU mL^{-1}) †	Total coliforms ($\text{MPN}/100\text{mL}$) ¶	<i>P. aeruginosa</i> /100mL	<i>E. coli</i> /100mL
Borehole	NC	37	4	Absence	Presence
Supply tank	0,4	7	0	Absence	Absence
Dairy and cheese factory	0,2	1	0	Absence	Absence
Dairy farm	<0,02	200	0	Absence	Absence
Canteen	0,05	1	0	Absence	Absence
Guide levels §	0,20	500	3	Absence	Absence

† CFU: Colony Forming Units. ¶ MNP: Most Probable Number. § Argentinean Alimentary Code (2012). NC: No chlorination.

TABLE 4
Residual chlorine values during a week along summer ($\text{mg} \cdot \text{L}^{-1}$)

Sector	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Supply tank	0,15	0,10	0,10	0,03	0,03	Closed
Dairy farm	0,03	0,01	0,02	0,02	0,01	0,02
Dairy and cheese factory	0,05	0,10	0,10	0,03	0,10	0,03
Canteen	0,07	0,02	0,05	0,05	0,05	Closed

bacteria driven by favorable weather conditions of summer. In fact, the combined effects of high rainfall, temperatures and water demands (i.e.: for irrigation of crops and the orchard) taking place during this season contribute to organic pollution of the network. This fact can be correlated to the strong variations of residual chlorine concentration observed along the distribution network. This situation was explained by two main reasons: First, the chlorination device had an incorrect discontinuous functioning in time and did not receive the required maintenance. Second, the frequent disrepair, breaks, and deficient couplings of pipes (e.g.: old metallic and new plastic pipes) enabled water pollution through the ingress of organic matter into the network, hence, originating an extra consumption of chlorine. It should be noted that the staff of the school decided to check and adjust the chlorination system based on the information generated by this work.

Effluent management: Effluents originated from productive processes, such as dairy farms, cheese factories,

breeding sectors, and meat processing, content an important organic load and nutrients, reflected in high values of biochemical and chemical oxygen demand, as well as pathogen microorganism, solids, and cleaning products (Vassallo, 2008).

Even though in this study the total volume of effluent was not quantitatively determined, an order of magnitude was estimated with the approximation that the major part of water consumption was turned into effluent after being used on each productive process. Hence, given the total monthly water used, the volume of effluents reached an average of $60\,000\text{L} \cdot \text{day}^{-1}$.

Those from the dairy farm and cheese factory were the most relevant for the environment given their volumes and chemical composition. At the dairy farm, effluents with a high organic load are mainly generated by cleaning of the building and animal track. Water employed for these cleaning activities comes from the reuse of water from the milk refrigeration system. In turn, the effluents from the dairy and cheese factory have different components depending of the step of the productive process.

The major volume is originated in the separation of buttermilk and is disposed as food for the pigs. Another kind of effluents is composed by a mixture of milk, buttermilk, and rests of cheese coming from the cleaning of the building and equipment. Furthermore, liquid waste from salting pools with a high salinity is drained once a year. The effluents are collected through pipes and drains, which are affected by breaks and losses, conducted toward a first artificial pond and, then, to a second pond by overflow. These two stabilization ponds lack of any treatment or depuration, which could compromise water quality. No data exist about their functioning. Finally, the liquid effluents are conducted by gravity through a channel to a nearby stream. From the reasons discussed, it was evidenced that the effluent treatment system resulted inadequate and deficient. We did not observe a hydraulic linking between the ponds and the supply borehole, but if groundwater extraction rate is not diminished, the cone of depression of the phreatic aquifer will affect by interception the effluent discharged area, thus causing severe drinking water pollution.

DISCUSSION

We concluded that the main causes hindering an integrated water resource management in the school are the diversified production developed with high volumes of water demanded, the water quality deterioration by the agro-industrial productions, and the hydrogeological features of the area.

The hydrogeological conditions showed that the phreatic level is quite shallow in the study site which entails a high vulnerability of the aquifer to pollution effects due to the thinness of the unsaturated zone. On this regard, a deeper study will be necessary to achieve a more detailed evaluation of its pollution vulnerability (Foster, Hirata, Gomes, D'Elia, & Paris, 2002). The high water demand for the different productive sectors was in sharp conflict with groundwater shortage given the particular hydrological conditions of the area.

These results of physicochemical quality of water agreed with previously reported regional values by Hernández, Giaconi, and González (2002), Ruiz de Galarreta and Banda Noriega (2005) and Pessolano et al. (2012). They are a natural consequence of the location of the school in the basin header, which originates low water salinity due to its recent infiltration to the aquifer. Consequently, our measurements determined that water from the tank has a proper physicochemical quality, being suitable for human consumption. However, groundwater evidenced a high risk of microbiological pollution mainly

at summer season where temperature, rainfall, and water requirements were increased. Chlorination process and conditions of pipes are two key factors that affect water quality, mainly on microbiological parameters.

Even though some positive actions were developed by the staff of the school, more actions are mandatory to improve water and effluent management.

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