Assessment of drinking water suitability in low income rural areas: a case study in Sixaola, Costa Rica

Leonardo Mena-Rivera and José Quirós-Vega

ABSTRACT

Vegas-Las Palmas is a rural settlement located in the southern Caribbean region of Costa Rica on the border with Panama. Its population does not have access to potable water, and inhabitants depend on water from wells at the water table level to meet their needs. These wells lack basic infrastructure to protect this water from contamination. In this study, water quality was evaluated at 12 wells from 2014 to 2016 ($n = 72$). The results revealed high concentrations of faecal coliforms and *Escherichia coli* with maximum values of 4.6×10^4 MPN/100 mL and 1.1×10^4 MPN/100 mL, respectively. In addition, maximum values of pH, conductivity, turbidity, Ca, Mg, K, Fe, Mn, Cd and Pb were found to be outside the standard limits (nationally and internationally) for potable water. Possible sources of water contamination are associated with the geomorphological characteristics of the area, as well as with hydrometeorological and anthropogenic factors such as the lack of sewerage, the presence of latrines, animals near the wells and the use of agrochemicals. The water quality was heterogeneous among wells, and all of them were found to have conditions that caused water to be unfit for human consumption.

Key words | drinking water, health, pollution, water quality

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INTRODUCTION

Access to safe and good quality drinking water is a human right (Montreal International Forum 1990). Everyone has the right to water in sufficient quantity to meet their needs because it is essential for human development, health, and well-being (Varol & Dravaz 2016). In 2015, the Millennium Development Goals target of 88% of the population having access to improved sources of drinking water was achieved (WHO 2017). However, approximately 663 million people around the world still lack basic access to safe drinking water (Fanucchi 2017). Water supply per person should be continuous and sufficient for personal and domestic use but must also be free of microorganisms, chemical substances and radiological hazards which pose a threat to human health (UN 2014). The lack of drinkable water, inadequate management of water resources, presence of pathogenic organisms, and lack of sanitation and hygiene eventually increase the presence of diseases that can affect human health (Sorline *et al.* 2013; Varol & Dravaz 2016).

Contamination of drinking water is caused by natural or anthropogenic factors, which can be present between the source and the distribution point, therefore increasing the possibility of transmitting diseases (Valiente & Mora 2002). Trevett *et al.* (2004) mention a wide number of critical points in the capture, transport, storage, distribution, and use of water during which contamination could be introduced – for example, hands, containers, ladles, filter cloths, dust, insects and animals are potential sources of contamination that could lead to the presence of bacteria or other pathogenic organisms in the water. In order to reduce the impacts of these sources of pollution, better management of the water supply is necessary, incorporating good practices

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from the source of supply to the consumer (Sorline *et al.* 2013). In addition, extreme hydrometeorological changes caused by climate change may affect water quality, especially surface water (Jovanelly *et al.* 2015), by altering physical and chemical variables including pH, alkalinity and temperature (Agudelo 2005; Moreira & Bondelind 2016).

Developing countries have made significant progress in access to and coverage of potable water. Particularly in Costa Rica, the percentage of the population with access to water in their homes was 99.5% in 2014, with a significant increase during the previous years; but only 93.4% of the population has access to safe drinking water (State of the Nation Program 2008, 2015). Thus, there are still marginal communities that do not have access to potable water, many of which are in areas of high vulnerability to natural disasters and with limited access to public services (Bower 2013). This information contrasts with Article 50 of the Constitution (1949), which states that access to a sanitary water supply is a fundamental right derived from the right to life and health, and should be seen as a public service that cannot be denied, through either inaction by the government or the actions of the provider.

One of this communities enduring difficult conditions is Vegas-Las Palmas parcels in Sixaola. There, the inhabitants obtain water of uncertain quality and quantity from different sources. These sources include wells in poor condition, river water and rainwater; none of this water undergoes treatment that guarantees its fitness for human consumption. The present study carried out a physical, chemical, and microbiological assessment of well water to define a baseline that would identify the possible risks which inhabitants are exposed to. This information is essential due to the prevailing conditions affecting water supply for human consumption in the community and for implementing mitigation measures to improve the health of inhabitants.

MATERIALS AND METHODS

Study area

Vegas-Las Palmas parcels are located in the Sixaola district of the canton of Talamanca, in the province of Limón, Costa Rica, between coordinates 9°33′0″ N and 82°36′0″ W and 9°30′0″ N and 82°38′0″ W (Figure 1). The study area is based in the southern Caribbean region of the country near its border with Panama. This region is characterized by two dry seasons (February–March and September–October) and two rainy seasons (November–January and April–August). During the study period, the average monthly precipitation varied at around 234 mm, with an average temperature of 26.5 °C, a maximum of 33.6 °C and a minimum of 19.0 °C (www.imn.ac.cr).

Vegas-Las Palmas parcels were established in 1984 as part of a rural settlement program of the government's Institute of Agrarian Development (IDA, by its acronym in Spanish). The settlement consists of 94 parcels within an area of approximately 300 hectares, intended for the cultivation of bananas, squash, maize, papayas, cocoa, rambutan, and Panamanian pepper. The community is bordered to the east by the Quiebra Caño (a primary canal that collects waters from the parcels and banana plantations and channels it into the Sixaola River), to the west by the town of Sixaola and the Finca Bananera Costa Rica, to the south by the river Sixaola, and to the north by the Finca Bananera Del Monte. The geology of the area consists of Quaternary alluvial formations, made up of clastic marine deposits, limestone, and clastic and volcanic rocks (Kapp 1989). The area is inhabited by 164 people in 43 households, of whom 56.4% are men and 43.6% are women.

Survey

A baseline study was carried out in the Vegas-Las Palmas parcels using a semi-structured instrument that gathered information about the basic services provided in the community, waste management, characteristics of wells, rainwater harvesting and farming activities. The instrument was applied to each of the 43 dwellings located within the parcels, and the results obtained served as input for the investigation of the well water quality used for human consumption.

Sampling and analysis

Water samples from 12 wells were collected during six sampling periods ($n = 72$): June and October of 2014; April, September and November of 2015; and May of 2016. The wells were selected based on (1) that they were

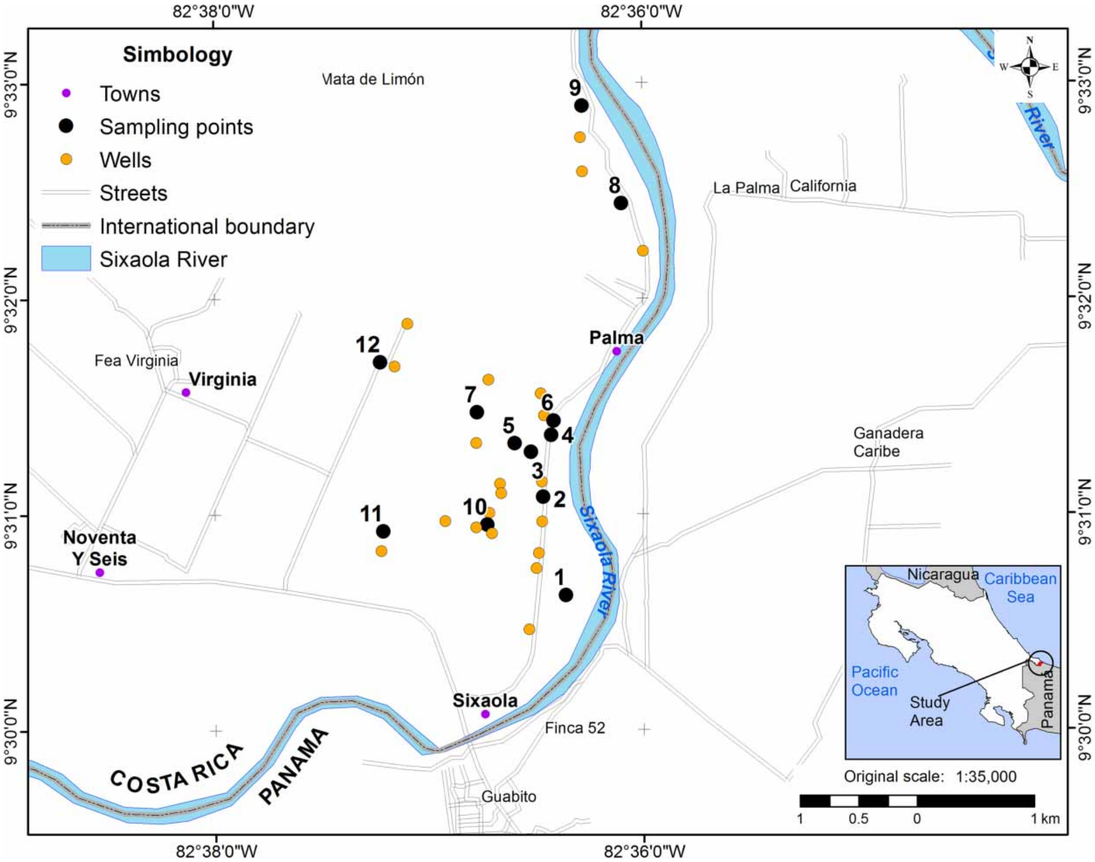

Figure 1 | Study area and sample sites.

being used for drinking purposes, (2) a higher number of inhabitants were supplied from the same well, and (3) the spatial distribution of houses in the parcels. The samples for physical and chemical analyses were collected in high density polyethylene (HDPE) bottles previously washed with 3% m/v HCl and deionized water. Microbiological samples were collected in 100 mL sterile non-reusable vessels and stored separately to avoid contamination. Samples were immediately stored at 4 °C and transported to the laboratory within 12 hours of collection. Physical, chemical and microbiological analyses were performed using the *Standard Methods for the Examination of Water and Wastewater* methodology (APHA/AWWA/WEF 2012). Temperature and pH were measured with an Oakton 300 multiparameter meter (IL, USA), and conductivity was measured with a Thermo Orion Star A222 meter (MA, USA); in both cases the measurements were *in situ*. Turbidity was measured with a Scientific Inc. Micro 100 turbidimeter (FL, USA) and water hardness was determined by titration with a EDTA standard solution. Gravimetric analysis at 180 °C allowed the determination of total dissolved solids (TDS) previous water filtration through 0.45 μm pore filter (Advantec® GC50). Atomic absorption spectroscopy (AAnalyst 800, Perkin Elmer, CT, USA) was used for the analysis of the most abundant cations and trace metals, where Ca, Na, K, Mg, Fe, Cu, Zn, Mn and Cd were analysed with an air-acetylene flame, while Pb, A, and Cr were analysed in a Zeeman-effect graphite furnace. F^-, Cl^-, NO_3^- and SO_4^{2-} were analysed by ion chromatography (ICS-90, Dionex, CA, USA). Finally, analyses of total coliforms, faecal coliforms and *Escherichia coli* were performed in the certified (INTE-ISO/IEC 17025:2005) San Martin Laboratory (San Jose, Costa Rica) using the multiple tube fermentation technique.

Data analysis

Data analysis was carried out using nonparametric survival procedures (Hensel 2012) with the NADA library of the R statistical package (Lopaka 2017). The maximum likelihood estimation (MLE) method was used to calculate the mean and standard deviation when the percentage of data below the detection limit (<QL) was less than 80%. The Kendall's tau correlation coefficient was calculated to evaluate the degree of association between water quality parameters. Subsequently, a multivariate analysis was performed using ordinal nonparametric methods assigning tied ranks to the data below the detection limit. Analysis of similarities (ANOSIM) was used to evaluate the degree of similarity in water composition among wells and between seasons (999 permutations); and the degree of clustering of the sites sampled was established using a hierarchical cluster analysis (CA) using Ward's method (Ward 1963) and squared Euclidian distance as a measure of similarity.

RESULTS AND DISCUSSION

Despite the advances achieved in Costa Rica in terms of the quality, quantity and accessibility of the water supply, there are still marginalized communities that do not have potable water. In the case of the Vegas-Las Palmas parcels in Sixaola, only 4.7% of the houses have piped-in water (Figure 2(a)), which is drawn from a deep well near a banana farm. Sierra (2011) reported Fe concentrations above the national standard (0.3 mg/L), which causes an unpleasant smell and taste in the water. Therefore, this source is not used for human consumption, but rather for domestic cleaning activities. Another source of supply is the Sixaola River, which is used by 7% of the people for consumption. The risk posed by this water is contamination by wastewater discharges and pesticides used in banana plantations located in the area. For instance, chlorpyrifos and terbufos have been detected in the Sixaola River near the parcels in concentrations up to 0.9 pg/L (Polidoro & Morra 2016).

The second-most frequent option as a source of water for the community is rainwater (55.8%). The inhabitants consider that this water is safe for consumption because it has not come into contact with any physical medium which can contaminate it. However, the practices used for its capture, transport and storage can affect its quality and therefore the consumers' health (Lee *et al.* 2017; Quirós 2017). In addition, the proximity of living areas to banana farms that use aerial fumigation must be considered, which can lead to an accumulation of toxic substances on the roofs of the houses as they settle out of the air (Barraza *et al.* 2011; Quirós 2017). It is also important to note that this source does not guarantee the quantity or accessibility of water for the entire population, since it is influenced by climatic factors and the financial investment for its collection cannot be made by all the householders.

Wells are the main source of local water supply (93.0%, Figure 2(a)). These shallow wells are dug by hand and provide access to water layers with depths ranging from 0.25 m to 5.12 m. Some of them do not have culverts or covers, which permits the entry of contaminants (Supplementary Figure S1, available with the online version of

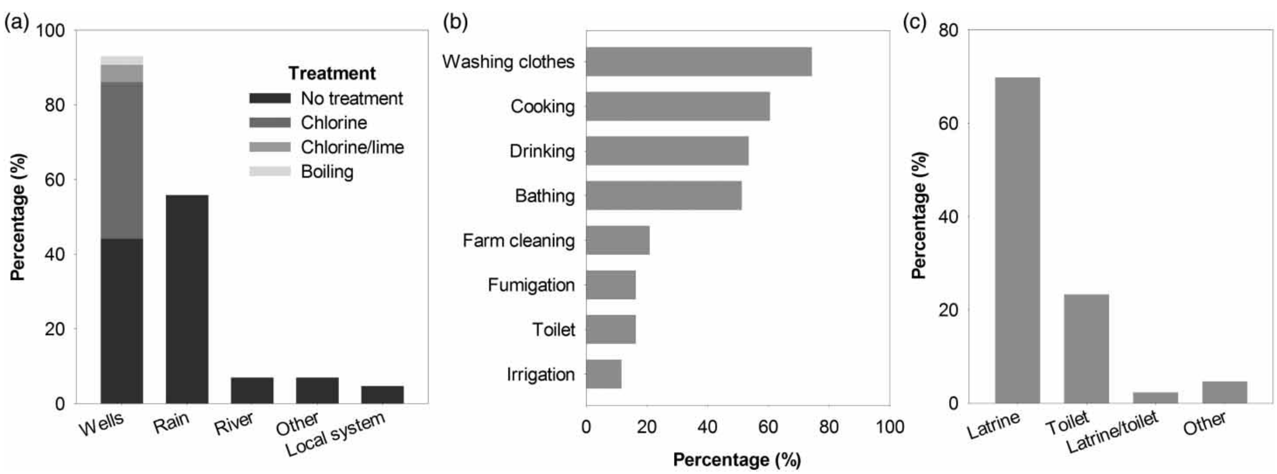

Figure 2 | Sources and treatment of water (a), well water use (b), and sewage disposal (c) in Vegas-Las Palmas parcels, Sixaola.

this paper). This water is used for several purposes (Figure 2(b)), including laundry, cooking, drinking and bathing, but it is not adequately disinfected. For instance, 41.9% of the consumers of this water use chlorine as a disinfectant and 44.2% do not disinfect it at all (Figure 2(a)). This disinfection practice does not ensure that the water is pathogen-free because chlorine is added directly into the well or inside the storage vessel without any control on the concentration applied.

Regarding sanitation, the parcels lack adequate wastewater management, where a latrine is the common system to treat human excreta (Figure 2(c)). These systems are approximately 6 m in depth, lack a drainage system, and are sometimes at a higher altitude than the well, so leaching of pathogens may occur. Untreated wastewater is discharged directly in the soil in areas close to the wells; this practice is common in rural areas in Costa Rica. In fact, only 37% of the total wastewater discharges in the country are adequately treated (Valverde 2010). In addition, farmers keep animals, such as pigs, cows, horses, goats and chicken, whose excreta is not deposited in appropriate areas. Solid waste management is also an issue, where 72.1% of the population burns solid waste and 2.3% buries it without any separation. Most of these potential sources of pollution are less than 40 m from the wells (Supplementary Table S1, available online), failing to comply with the protection radius established in the national regulation. These situations represent a clear issue that may influence water quality in the area.

The summary of physical, chemical and microbiological data of the water samples are shown in Table 1. Spatial and temporal variations in water quality are presented in Supplementary Tables S2–S5 (available online). These results were compared with the Costa Rican standards for drinking water (MINSA 2015) and with the international standards of the World Health Organization (WHO 2011). TDS, hardness, fluoride, chloride, nitrate, sulphate, sodium, Zn, Cu, Cr and As results met both regulations. High values of water temperature are mainly due to the high temperatures characteristic of the climate in the area, and the sun's rays directly affect some wells because of the shallowness and the lack of infrastructure (such as culverts and covers). pH values below the regulations were found (ranging from 5.50 to 7.29); however, the average was within an acceptable range. The maximum conductivity value was 670 μS/cm, reflecting a high concentration of dissolved ions in the water. The average turbidity was 4.67 NTU, but maximum values of up to 58.3 NTU were observed. Such high values can cause an increase in water temperature, the decrease of dissolved oxygen, stimulate the growth of certain thermotolerant organisms, and give it an unpleasing appearance (Chapman 1996).

Concentrations of fluoride, chloride, nitrate and sulphate were below the regulations, spatially and temporally. Nevertheless, there may be an exposure issue for some ions such as nitrate which can cause methaemoglobinemia in infants when it is ingested in high amounts (WHO 2011). The maximum nitrate concentration observed was 27.70 mg/L. In contrast, in the areas with the highest population density in Costa Rica, it does not exceed 5 mg/L (Reynolds-Vargas & Richter 1995). This situation shows the inequality related to access to good water quality that may also be present in other rural areas in the country.

Maximum values for Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in specific wells and samples also exceeded the regulations. The concentration of these ions is related to the lithology of the area and the rock–water interactions, but they can be increased by the dragging of materials in periods of extreme rainfall or floods. Moreover, some trace metals exceeded reference standards for drinking water. The maximum concentration of Cd and Pb exceeded the recommended values in four and three of the sampled wells, respectively. These metals are mostly related to industrial waste but may also be related to the mismanagement of materials such as plastics, PVC, paints, pesticides or even corroded materials stored near the wells (Chowdhury *et al.* 2016).

The maximum concentration of Mn exceeded the permitted limits in wells 1, 4, 6, 7, 8 and 12 (50% of wells sampled), reaching a maximum of 3.66 mg/L (Supplementary Table S4). Mora *et al.* (2014) reported a significant relationship between the concentration of Mn in well water and the concentration in human hair in an area close to the parcels. Their results indicate that the possible source of Mn could be residues from fumigation with fungicides. The excesses or deficiencies of this metal can negatively affect foetal growth or cause neurobehavioural deficits in children (Mora *et al.* 2014). The extensive use of pesticides in banana plantations is common to maintain

Table 1 | Summary of the physical, chemical and microbiological parameters of wells in Vegas-Las Palmas parcels, Sixaola

Parameter	Units	Average	SD	Min	Max	WHO	CR
Temperature	°C	25.5	2.6	19.9	33.9	–	30
pH	–	6.45	0.32	5.50	7.29	6.5–9.5	6–8
Conductivity	μS/cm	289	151	102	670	–	400
Turbidity	NTU	4.67	9.37	0.00	58.30	–	5
TDS	mg/L	205	92	80	460	1,200	1,000
Hardness	mg/L $CaCO_3$	133	81	12	380	–	400
Fluoride[a]	mg/L	0.123	0.061	<0.056	0.456	1.5	0.7
Chloride	mg/L	16.65	16.54	2.94	77.90	250	250
Nitrate[a]	mg/L	8.76	14.39	<0.402	27.70	50	50
Sulphate	mg/L	16.69	24.37	0.76	145.80	500	250
Ca^{2+}	mg/L	35.2	23.2	4.5	111.0	–	100
K^{+}	mg/L	1.98	2.17	0.20	14.00	–	10
Na^{+}	mg/L	14.7	7.3	0.7	38.4	200	200
Mg^{2+}	mg/L	8.8	8.7	0.1	61.0	–	50
Zn[a]	mg/L	0.061	0.085	<0.04	0.223	2	3
Fe[b]	mg/L	–	–	<0.3	4.82	–	0.3
Mn[b]	mg/L	–	–	<0.5	3.66	0.4	0.5
Cu[b]	mg/L	–	–	–	<0.3	2	2
Cd[b]	mg/L	–	–	<0.040	0.113	0.03	0.003
Pb[b]	μg/L	–	–	<4	17	10	10
Cr[b]	μg/L	–	–	–	<4	50	50
As[b]	μg/L	–	–	–	<0.5	10	10
Total coliform	MPN/100 mL	3.1×10^4	6.9×10^3	2	4.6×10^4	–	–
Faecal coliform	MPN/100 mL	3.0×10^4	7.0×10^3	2	4.6×10^4	0	0
Escherichia coli	MPN/100 mL	1.1×10^3	2.0×10^3	2	10^4	0	0

TDS, total dissolved solids; SD, standard deviation; WHO, World Health Organization; CR, Costa Rican legislation.
[a]Calculated using maximum likelihood estimation method.
[b] > 80% censored data.

high agricultural production. Some of the pesticides used in the area are mancozeb, bitertanol, chlorothalonil, propiconazole, difenoconazole, ethoprophos and fenamiphos (Quirós 2017). Consequently, there is a risk of drinking water pollution by these substances. In Sixaola, chlorpyrifos and ethoprofos have been detected in drinking water (Polidoro & Morra 2016), so their impact on people's health should be addressed.

Total coliform, faecal coliform and *Escherichia coli* were found in high concentrations (Table 1 and Supplementary Table S5). The latter is a common bacterium in the gut of humans and other warm-blooded animals (Edberg *et al.* 2000) and provides evidence of recent faecal contamination (Kostyla *et al.* 2015). The high concentrations of *E. coli* obtained are of particular concern due to the fact that other associated pathogens may also be present (e.g., virus, protozoa) (Wheeler *et al.* 2003) and can cause diseases such as diarrhoea (Chapman 1996). In other rural areas of Costa Rica, *E. coli* values (up to 218.5 MPN/100 mL) have been reported (Dobbin & Sarathy 2015). However, in those areas there are administrative committees responsible for water distribution and usually they provide adequate disinfection treatment. On the other hand, faecal coliform results were similar to the values reported by Mena-Rivera *et al.* (2017) in urban rivers in the Great Metropolitan Area in Costa Rica, and *E. coli* results were as high as in water that is not destined for human consumption (Scott *et al.* 2017). Microbiological data exceed figures established by the WHO and the Costa Rican regulation in 100% of cases (Supplementary Table S5). These results clearly indicate that water is not safe for human consumption.

Table 2 presents Kendall's tau correlation coefficients of the parameters analysed. Significant strong correlations (coefficient ≥ 0.7) were found for conductivity and TDS, conductivity and hardness, conductivity and Ca^{2+}, TDS and Ca^{2+}, total coliform and faecal coliform, and *E. coli* and faecal coliform. Correlation coefficients between 0.5 and 0.7 were found for conductivity and SO_4^{2-}, TDS and hardness, TDS and Cl^-, TDS and Mg^{2+}, Ca^{2+} and hardness, SO_4^{2-} and Cl^-, SO_4^{2-} and Ca^{2+}, and total coliform and *E. coli*. Low correlations with coefficients between 0.3 and 0.5 were found for conductivity and Cl^-, conductivity and Na^+, conductivity and Mg^{2+}, TDS and SO_4^{2-}, TDS and Na^+, hardness and Cl^-, hardness and SO_4^{2-}, hardness and Mg^{2+}, Cl^- and Ca^{2+}, Cl^- and Na^+, Cl^- and K^+, SO_4^{2-} and Na^+, SO_4^{2-} and Mg^{2+}; and Ca^{2+} and Na^+. Finally, significant weak correlations (coefficient < 0.3) were found for pH and Cl^-, pH and Fe, turbidity and Mn, TDS and K^+, TDS and Mn, TDS and faecal coliform, hardness and K^+, hardness and Na^+, hardness and Mn, F^- and Zn, F^- and Mn, F^- and Pb, F^- and Fe, Cl^- and Mn, Cl^- and Mg^{2+}, Cl^- and NO_3^-, NO_3^- and K^+, NO_3^- and Na^+, NO_3^- and Mn, Ca^{2+} and Na^+, Ca^{2+} and Mn, K^+ and Cd, K^+ and Na^+, Na^+ and Mn, Mg^{2+} and Pb, Zn and Fe, Zn and Mn, Zn and Pb, Zn and Cd, Fe and Mn, Fe and Cd, and Pb and faecal coliform. In general, conductivity, TDS and hardness showed positive correlations with the most abundant ions (Ca^{2+}, K^+, Na^+, Mg^{2+}, Cl^- and SO_4^{2-}), whereas trace metals such as Zn, Fe, Mn, Cd and Pb correlated with fluoride. The concentration of these latter species may be related to anthropogenic sources of pollution.

Water quality conditions were similar during the study period (Supplementary Table S2). No significant differences were found between seasons ($R = 0.015$, $p = 0.312$). However, no sample campaigns were carried out during the first months of each year or after flooding events. Inhabitants reported flooding events during certain months of the year, which carry high loads of contaminants and eventually affect water quality. These events are caused by the overflow of the Sixaola River and the irrigation channels, due to the heavy rainfall and the flat geomorphology of the terrain. After flooding events, wells cannot be used for long periods of time until they are cleaned and stabilized. In these periods, inhabitants use mainly rainwater for drinking purposes.

The water composition among wells is very heterogeneous. There is a high degree of dissimilarity ($R = 0.5988$, $p = 0.001$), even when they are located relatively close to each other. The high spatial variation of some parameters can be observed in Figure 3. These variations reflect the degree of vulnerability of some wells due to the influence of meteorological, geological and anthropogenic (such as disposal of excreta and well conditions) variables in water quality. For instance, data variability may reflect the difference in depth, infrastructure, maintenance and proximity of potential sources of pollution of each well. The well location in each dwelling is important due to their proximity to activities that could generate contamination, as previously mentioned. The daily productive and domestic activities can generate contaminants that can be transmitted by water and affect the health of the population. For example, the wide use of fertilizers could increase nitrate concentration in water. In the area, there is an open aquifer where the phreatic level is located a few metres below the surface, which together with the characteristics of a permeable soil, allow the percolation of liquids and dissolved substances to easily pass through soil strata, allowing their contact with groundwater (Dey *et al.* 2017).

Finally, cluster analysis allowed the identification of three main groups with a $D_{link}/D_{max} < 60$ (Figure 4). The first cluster consists of wells 7, 10 and 11, which are those with the worst water quality conditions. These wells were characterized by high concentrations of turbidity, NO_3^-, Cl^-, Fe, total coliforms and faecal coliforms. They are also more vulnerable to the impact generated by activities carried out in their surroundings due to deteriorating infrastructure. The second cluster consists of six wells (3, 4, 5, 6, 8 and 9), which have generally lower concentrations of major ions, faecal coliforms and *E. coli*. This group supplies most of the population, and some wells have infrastructure that can help to prevent contamination. Finally, wells 1, 2 and 12 make up cluster 3, which had the lower microbiological contamination, despite the fact that some values for these wells (such as Ca^{2+}, Mg^{2+}, K^+, conductivity and turbidity)

Table 2 | Kendall's tau correlation coefficients for the physical, chemical and microbiological parameters in Vegas-Las Palmas parcels, Sixaola

Parameter	pH	Conduct.	Turbidity	TDS	Hardness	F^-	Cl^-	NO_3^-	SO_4^{2-}	Ca^{2+}	K^+	Na^+	Mg^{2+}	Zn	Fe	Mn	Cd	Pb	TC	FC	*E. coli*
pH	1																				
Conduct.	0.034	1																			
Turbidity	0.086	−0.107	1																		
TDS	−0.024	**0.737**	−0.125	1																	
Hardness	0.071	**0.713**	−0.083	**0.629**	1																
F^-	0.111	0.045	0.072	−0.074	0.055	1															
Cl^-	− **0.170**	**0.464**	0.055	**0.514**	**0.343**	0.046	1														
NO_3^-	0.040	−0.019	0.079	0.049	−0.004	−0.116	**0.197**	1													
SO_4^{2-}	−0.023	**0.592**	−0.023	**0.486**	**0.496**	0.136	**0.522**	0.118	1												
Ca^{2+}	0.006	**0.732**	−0.091	**0.758**	**0.687**	−0.064	**0.438**	−0.002	**0.561**	1											
K^+	−0.089	**0.216**	0.036	**0.221**	**0.195**	−0.041	**0.355**	**0.192**	**0.226**	0.145	1										
Na^+	0.016	**0.371**	−0.046	**0.385**	**0.286**	0.122	**0.489**	**0.180**	**0.420**	**0.321**	**0.294**	1									
Mg^{2+}	−0.072	**0.494**	−0.150	**0.547**	**0.422**	−0.144	**0.267**	−0.033	**0.331**	0.512	0.072	0.154	1								
Zn	0.114	0.004	0.086	−0.005	0.090	**0.206**	0.010	−0.052	0.031	−0.028	−0.013	0.128	−0.078	1							
Fe	**0.122**	0.056	**0.237**	0.022	0.048	**0.140**	0.042	−0.002	0.065	0.027	−0.035	0.075	−0.076	**0.108**	1						
Mn	−0.027	0.057	**0.096**	**0.078**	**0.120**	**0.082**	**0.106**	−0.058	**0.100**	**0.083**	0.050	**0.090**	0.021	**0.081**	**0.052**	1					
Cd	0.021	0.016	0.014	0.016	0.013	0.025	0.007	− **0.044**	0.023	0.020	− **0.068**	0.006	0.028	**0.087**	**0.041**	0.018	1				
Pb	0.016	0.012	0.017	−0.008	0.026	**0.054**	0.007	− **0.038**	0.016	0.013	0.008	0.026	− **0.062**	**0.034**	0.011	0.045	−0.005	1			
TC	−0.041	−0.133	0.076	−0.164	−0.063	0.115	−0.024	0.108	−0.006	−0.142	0.121	0.055	−0.134	0.061	−0.048	−0.045	−0.003	−0.014	1		
FC	−0.069	−0.152	0.133	− **0.180**	−0.089	0.101	−0.030	0.098	0.006	−0.157	0.080	0.054	−0.142	0.078	−0.016	−0.029	0.011	− **0.042**	**0.875**	1	
E. coli	−0.006	−0.095	0.122	−0.102	−0.046	−0.020	−0.025	**0.195**	0.091	−0.042	0.006	0.065	−0.149	−0.050	−0.013	−0.032	0.024	−0.027	**0.635**	**0.725**	1

Bold values are significantly correlated ($p < 0.05$).

Conduct.: conductivity; TDS: total dissolved solids; TC: total coliform; FC: faecal coliform.

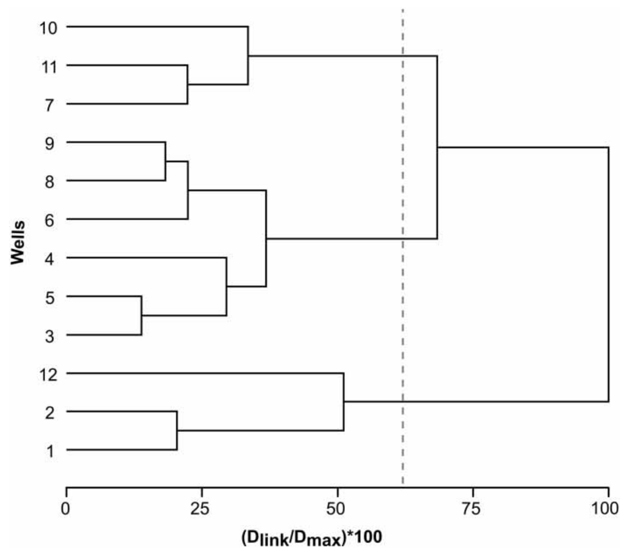

Figure 3 | Cluster dendrogram of the wells in Vegas-Las Palmas parcels, Sixaola.

were also found to be outside the standard limits considered fit for human consumption. This information may be useful for the implementation of remediation strategies in the short term. For instance, inhabitants that use wells of cluster 1 are in a more vulnerable condition. It is important to highlight that with such high concentrations of coliforms, nobody should be using water from those wells for drinking purposes without adequate previous treatment.

Regardless of all the data presented above, especially the microbiological data, Costa Rica is among the Latin American countries with fewer waterborne protozoa parasites studies reported (Rosado-García *et al.* 2017). Nevertheless, specific information about waterborne diseases in the area is not always available, so the number of cases reported in the literature may be underestimated. On the other hand, Costa Rica is among the countries with better water

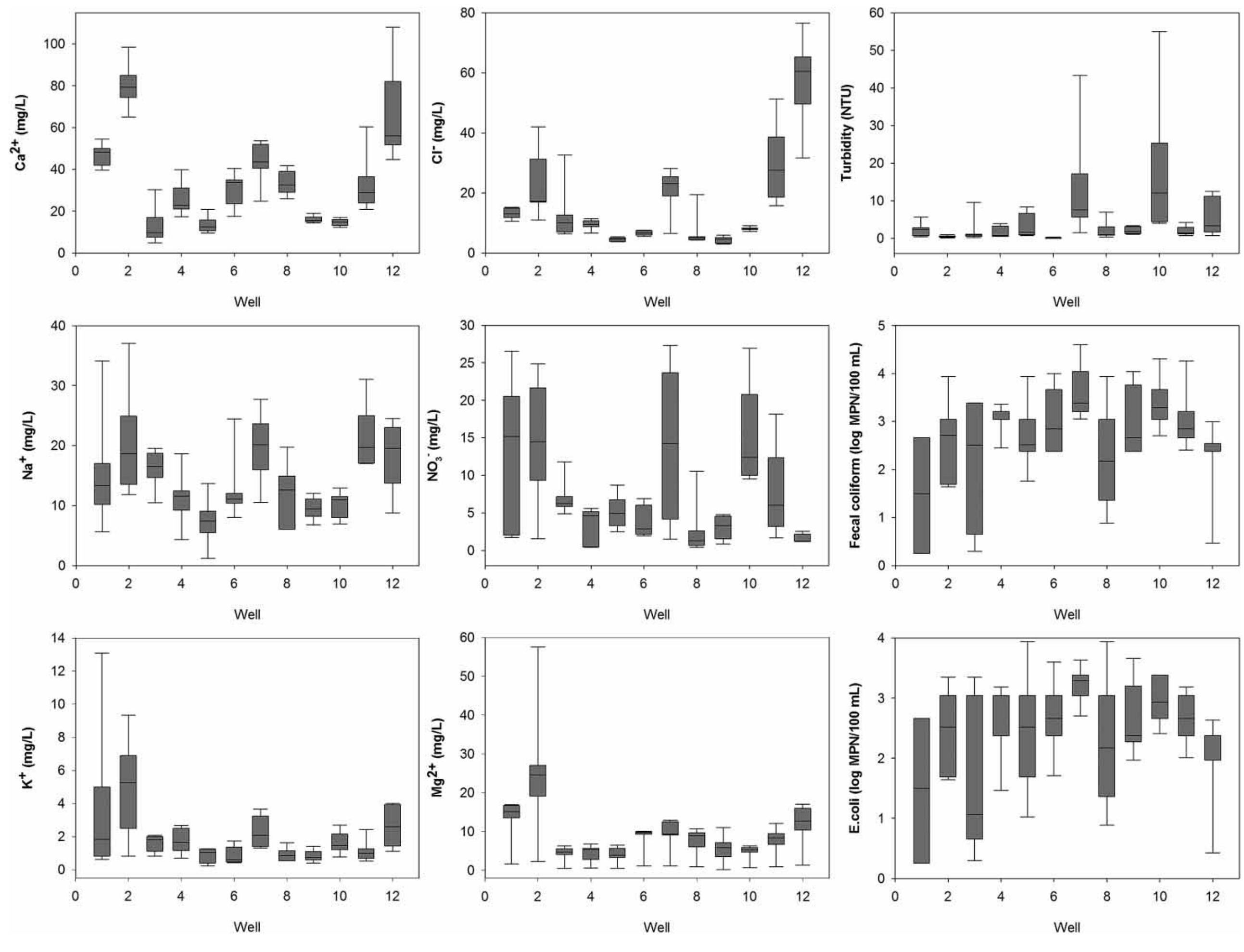

Figure 4 | Box-plots of water quality indicators in Vegas-Las Palmas parcels, Sixaola.

supply in the region. Only 0.5% of its population lack this service in comparison with the average of around 10% in Latin America and the Caribbean (Montgomery & Elimelech 2007). Our results indicate that special attention must be paid in rural areas, where data regarding water quality are scarce, but also that more extensive studies should be undertaken. This information can lead to a better coverage of safe and good quality drinking water in the country.

CONCLUSIONS

The importance of adequate water provision (quantity and quality) for public health cannot be overestimated. In the absence of adequate water provision for human consumption in the community of Vegas-Las Palmas parcels, its inhabitants are obliged to use other sources including wells, rainwater and river water. These sources do not ensure the quantity and quality of water needed to meet their basic needs. The data presented about well water were outside the standard regulations, which means it is not safe for human consumption. Attention should be paid to this situation since most of the population reported using this source.

The values of faecal coliforms and *E. coli* showed the absence of safe water in the area and may place the population at high risk of diseases caused by pathogenic microorganisms. The results obtained in this study show the importance of carrying out a more extensive study, including pesticides and risk assessments, to better estimate the impact of well water consumption on the health of the community. Further investigations have to be developed in these areas.

Finally, financial investment to improve the existing wells' condition and/or the construction of an adequate distribution system that complies with national and international standards should be evaluated to ensure safe drinking water for the whole population.

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