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ORIGINAL ARTICLE

Hydrochemistry of groundwater from Tocumen sector, Panamá city: an assessment of its possible usage during emergency events

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Abstract
In Panama City, the water supply sources for the population come mainly from surface waters, but in times of drought and extreme natural phenomena, the need to resort to underground sources is explored. This paper concerns an exploratory investigation with the aim of assessing the quality of groundwater in the southeastern part of the Province of Panama and to determine its possible use as drinking water during extreme natural phenomena. Monthly monitoring over a period of 15 months was carried out. The study included the sampling and analysis of groundwater by different physic-chemical, hydrochemical and biological parameters. The results showed that most of the parameters in the analysed groundwater conformed to the Panamanian drinking water norm and the water potability diagram, this is a convenient source of raw water for purification. As for other uses for this water source, it should be used with caution since it represents a medium risk of soil salinization for irrigation water; and it is a moderately hard water for industrial uses.

Keywords Groundwater · Rainwater · Hydrochemical study · Water security · Panama

Introduction

The achievement of universal water security and availability is one of the main agenda items of the UN Sustainable Development Goals (Savenije and Van der Zaag 2008). To achieve the goal of water security, particularly in rapidly expanding cities, the identification of safe and sustainable water resources is an absolute necessity (Saraswat et al. 2019).

Groundwater is the major source of water in most parts of the world. The presence certain ions at concentrations that are too high or too low is a major concern, as these ions make the groundwater unsuitable for various purposes (Brindha and Elango 2011). The volume of surface and groundwater in Panama is large due to its Tropical climate, but the quality must be studied to verify its potential use as resource.

In Panama, rivers and reservoirs are the main sources for drinking water. Although the water resource is abundant, there are problems with the distribution and the means of capture since the degree of deterioration of the surface waters is increasing due to the demographic pressure and the deficient wastewater sanitation systems. A viable way to alleviate this problem is water harvesting in those communities that have abundant rainfall – as in other tropical countries such as Australia and Africa (Nduka & Orisakwe 2010; Chubaka et al. 2018).

In Panama it is necessary to identify other sources of water, such as groundwater and rainwater harvesting, to ensure the supply of drinking water to the population, particularly in the face of extreme weather events. Also, as occurred in other parts of the world, the effect of climate change and the pressure on groundwater for irrigation produces significant reductions in this resource (Buvaneshwari et al. 2017; Niu et al. 2017). As a consequence, it is necessary to have a knowledge of water dynamics (El-Sayed et al.

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2018), to study water quality (Chidya et al. 2015; Tubau et al. 2017), to evaluate the possibilities for use and required treatment, and to identify possible risks related to its uncontrolled usage (Rojas Fabro et al. 2015).

The quality of groundwater is significantly influenced by the local and regional geological context (Ochoa-González et al. 2015; Taheri et al. 2017), by anthropogenic activities (Abiye et al. 2018; Niu et al. 2017; Vadiati et al. 2016; Zheng et al. 2017), due to the infiltration of domestic and industrial waste, and by atmospheric conditions and precipitation (AlSuhaimi et al. 2016; Appelo and Postma 2004). Therefore, water quality is subject to constant daily, seasonal and climatic changes, which makes it necessary to regularly monitor the physicochemical and microbiological parameters of groundwater (Vadiati et al. 2016; Zheng et al. 2017).

In this context, the main objective of this study was to characterize the physicochemical and microbiological quality of groundwater in the Panama area and its potential uses for irrigation and for domestic or human consumption, particularly for use in emergencies. Thus, this study was focused on providing valuable information on the quality of groundwater and rainwater in the southeastern area of Panama City because this resource may be important in future climate scenarios in the region. Currently this aspect is poorly studied and exploited. The results of this work can be applied to other regions that are affected by similar problems in a global change scenario.

Material and methods

Study area

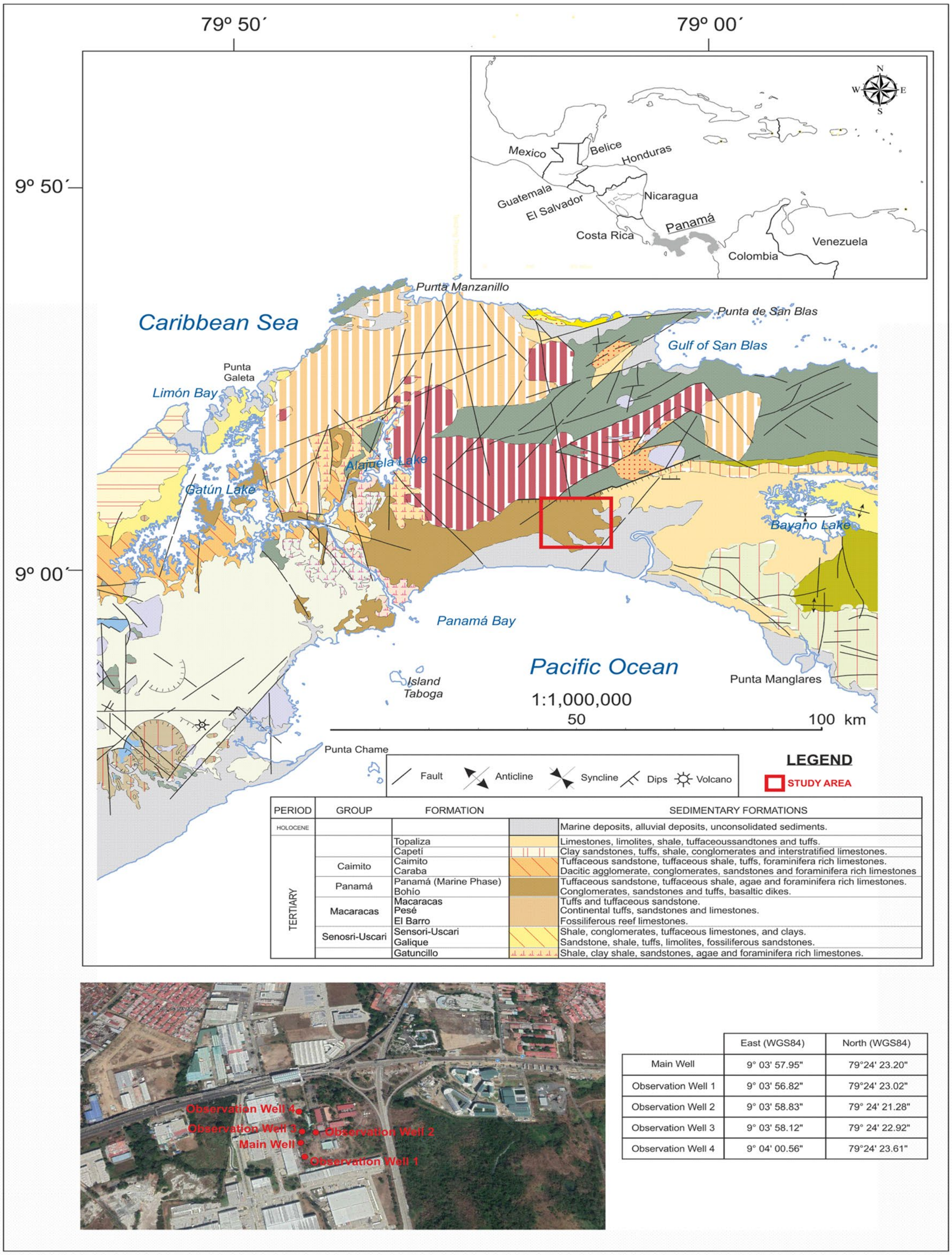
Panama is a narrow territorial belt in which the Central American Isthmus ends. It has a mountain range that divides the country into two very defined zones: to the north it extends the Caribbean slope and to the south the Pacific slope (Guardia 1988). The study area is located on the Pacific slope, in the southeastern part of Panama City, within the Tocumen Research Campus of the Technological University of Panama, and within an area of 14 067, 56 m^2, with geographic limits: 9° 04′ 01.20″ N, 79° 24′ 24.69″ W; 9° 03′ 56.34″ N, 79° 24′ 23.29″ W; 9° 03′ 57.09″ N, 79° 24′ 20.45″ W and 9° 04′ 01.92″ N, 79° 24′ 21.82″ W. The area belongs to the low regions and coastal plains, which correspond to depressed zones constituted by marine sedimentary rocks. The geological map of the study area is shown in Fig. 1. The area is located within the Group and Formation Panama (Marine Phase), of Tertiary age, and consists mainly of tuffaceous sandstone, tuffaceous shale, and algae- and foraminifera-rich limestones (Guardia 2018). According to a geotechnical study of an observation well in the study area, the soil corresponds to clayey gravel with sand and the substrate, to healthy sediments with discontinuities spaced at different angles that show the circulation of flows (Arrocha 2015). The aquifer is semi-confined (Vega 2004); in a pumping test at constant flow for 72 h carried out in October 2015, it was determined that with a flow of 20 gallons per minute, 100% efficiency is obtained and the well stabilizes at 6.15 m (Alpirez et. al 2015). The hydraulic gradient is relatively low, with a value of 6.10×10^{-4}; taking into consideration that the area is flat and with little slope, the flow direction goes from south to north (Alpirez 2015). The climate directly influences the recharge of the aquifer, since it recharges during the rainy season, and the static level decreases with the dry season, in the absence of rain (González 2016).

The weather is tropical rainy with an annual rainfall greater than 1000 mm and during the year there are several dry months with rains of less than 60 mm. The average monthly temperature during the year is greater than 18 °C, which corresponds to the aforementioned climate. The average annual relative humidity is 79.2% (ETESA 2019), which is high and is consistent with the type of climate and its proximity to the sea. The location is an area of high evapotranspiration, i.e., between 1326 and 1343 mm, as a consequence of the annual temperate temperatures. On this Pacific slope, there is an extended and unique rainy season that begins between April and May and persists until November. There is also a dry season that is established between December and the end of April, with an almost total absence of rain (IGNTG 1988). The area is coastal and is highly influenced by human and industrial residential activity.

Field sampling

The groundwater samples were taken from a single well, located at the geographical coordinates: 9°03′57.95″ N and 79°24′23.20″ W, which has an extraction pump; said sample was taken monthly from January 2014 to March 2015, it is the depth of the well is 24.00 m, with a water table of 2.40 m and an elevation of 18 m above sea level; on these basis, a total of 15 samples were taken. Two rainwater samples was taken near to the production well, in the months of October and December 2014, with a device to capture rainwater that was cleaned for this work. The sampling design, analytical procedures and quality controls for methods, such as blank, traceable reference materials to NIST and at least 10% analysis of duplicate samples, for duplicates the criteria is a difference of less than 5%, all based on the instructions of the Standard Methods for Examination of Water and Wastewater 22nd Edition 2012 (American Chemical Society 2012) and those established by the laboratory.

The samples were taken in polyethylene containers and preserved at 4 °C for physicochemical tests; the portion of the sample for metals was also preserved with 50% HNO_3



PERIOD	GROUP	FORMATION	SEDIMENTARY FORMATIONS
HOLOCENE			Marine deposits, alluvial deposits, unconsolidated sediments.
TERTIARY		Topaliza	Limestones, limolites, shale, tuffaceoussandtones and tuffs.
		Capetí	Clay sandstones, tuffs, shale, conglomerates and interstratified limestones.
	Caimito	Caimito	Tuffaceous sandstone, tuffaceous shale, tuffs, foraminifera rich limestones.
		Caraba	Dacitic agglomerate, conglomerates, sandstones and foraminifera rich limestones
	Panamá	Panamá (Marine Phase)	Tuffaceous sandstone, tuffaceous shale, agae and foraminifera rich limestones.
		Bohío	Conglomerates, sandstones and tuffs, basaltic dikes.
	Macaracas	Macaracas	Tuffs and tuffaceous sandstone.
		Pesé	Continental tuffs, sandstones and limestones.
		El Barro	Fossiliferous reef limestones.
	Senosri-Uscari	Sensori-Uscari	Shale, conglomerates, tuffaceous limestones, and clays.
		Galique	Sandstone, shale, tuffs, limolites, fossiliferous sandstones.
		Gatuncillo	Shale, clay shale, sandstones, agae and foraminifera rich limestones.

	East (WGS84)	North (WGS84)
Main Well	9° 03' 57.95"	79°24' 23.20"
Observation Well 1	9° 03' 56.82"	79°24' 23.02"
Observation Well 2	9° 03' 58.83"	79° 24' 21.28"
Observation Well 3	9° 03' 58.12"	79° 24' 22.92"
Observation Well 4	9° 04' 00.56"	79°24' 23.61"

Fig. 1 Geological map of the study area (adapted from IGNTG 2018)

and filtered; the sample for microbiology tests was taken in sterile containers and preserved at 4 °C. Determinations of nitrates (SM 4500 NO_3^- B), phosphates (SM 4500-P D), chlorides (4500-Cl^- B), sulfates (SM 4500-SO_4^{2-}E), bicarbonates (SM 2320 B), total suspended solids (SM 2540-D), total solids (SM 2540 B), total dissolved solids (SM 2540-C), turbidity (SM 2130 B), majority cations (iron, calcium, magnesium, manganese, sodium and potassium)

(SM 3111B); as well as the microbiological assays of total coliforms and E. coli (Colilert defined enzyme–substrate method, SM 9223 B), were carried out in the Laboratory of Industrial Analysis and Environmental Sciences (LABAICA) at the Experimental Center of Engineering (CEI), Technological University of Panama (UTP); the laboratory is accredited to the National Accreditation Council of Panama (CNA). As quality control for samples, the percentage (%) error in the ion balance of samples was calculated, and was lower than 5%, which confirms that the results obtained in the laboratory are very reliable (Dieng et al. 2017).

The field parameters, including reactivity (pH), contents in salts (estimated by electrical conductivity, EC) and temperature were determined with multiparameter probes (YSI 556 MPS and HANNA HI991301); the major cations iron, calcium, magnesium, manganese, sodium and potassium were determined by Atomic Absorption (Shimadzu AA-7000) in triplicate; the major anions nitrate, phosphate and sulfate were determined by visible ultraviolet spectrophotometry (Shimadzu UV-1800); chloride and bicarbonate were determined by titration; turbidity was evaluated with a turbidimeter in duplicate (HACH 2100AN) and suspended solids, total solids, and total dissolved solids were measured by gravimetry (JP Selecta 2,000,201 furnace). The microbiological assays of total coliforms and E. coli were carried out by the Colilert defined enzyme–substrate method, 9223 B Standard Methods for Examination of Water and Wastewater 22nd Edition 2012 (American Chemical Society 2012).

The results were interpreted by assessing diagrams (Ghesquière et al. 2015) such as Piper, Stiff, Schoeller–Berkaloff logarithmic diagram (Chihi et al. 2015), water classification diagram for irrigation, potability diagram and water chemistry. The results were compared with the Panama standard for water and drinking water and thus the water was classified to determine its possible uses.

Results

Hydrochemical characteristics

The results of the physicochemical parameters for groundwater and rainwater are presented in Table 1 and the major anions and cations are shown in Table 2.

The temperature of the groundwater remained constant throughout the year and it was in the range 28.1–30.1 °C. The pH varied between 6.64 and 7.70 in the dry season and from 6.50 to 7.36 during the rainy season. The slight decrease in the groundwater pH values during the rainy season is associated with the recharge of the aquifer with more acidic rainwater (pH range between 4.8 and 5.2) when compared with the stored groundwater. The electric conductivity (EC) values ranged from 686 to 760 µS/cm for the dry season and from 720 to 836 µS/cm in the rainy season; these values reflect the estimated contents of salts, which is also related with the total dissolved solids (TDS), ranging between 384 and 515 mg/L (Table 1). The slight increase in the conductivity during the rainy season is consistent with the pH behaviour, thus supporting the idea that the slight acidity of the rain solubilizes anions such as Cl^- and

Table 1 Results of the physicochemical analysis for samples of groundwater and rainwater in a single point

Month	T (°C)	EC (µS/cm)	pH	TDS (mg/L)	TSS (mg/L)	TS (mg/L)	Turb (NTU)
January 2014	29.1	686	6.64	391	< 1	428	0.14
February 2014	29.1	710	7.30	389	< 1	433	0.26
March 2014	30.1	730	7.40	446	< 1	464	0.18
April 2014	29.1	700	6.90	384	< 1	484	0.20
May 2014	29.1	750	6.90	465	< 1	552	< 0.10
June 2014	30.1	740	6.90	480	1	488	0.40
July 2014	29.1	836	7.00	444	< 1	434	0.20
August 2014	28.9	766	7.36	515	< 1	518	0.44
September 2014	30.0	720	6.50	410	2	435	< 0.10
October 2014	29.1	750	6.60	475	1	486	< 0.10
November 2014	28.1	760	6.70	473	1	480	0.16
December 2014	29.1	760	6.80	494	< 1	499	0.24
January 2015	28.1	729	7.50	445	< 1	477	0.25
February 2015	28.5	708	7.70	431	< 1	530	0.38
March 2015	30.0	720	6.70	474	< 1	472	0.28
October 2014 Rain	24.1	16.2	5.20	14	1	26	< 0.10
December 2014 Rain	25.1	16.5	4.80	16	3	27	< 0.10

EC Electric conductivity, *TDS* total dissolved solids/estimated content in salts, *TSS* total suspended solids, *TS* total solids, *Turb* turbidity

Table 2 Results for major anions and cations in groundwater and rainwater

Month	PO_4^{3-}-P (mg/L)	NO_3^- (mg/L) N-NO3	SO_4^{2-} (mg/L)	Cl^- (mg/L)	HCO_3^- (mg/L $CaCO_3$)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Fe^{2+} (mg/L)	Mn^{2+} (mg/L)
January 2014	< 0.03	0.12	68.31	15.60	NR	22.40	9.80	48.63	0.66	< 0.02	< 0.01
February 2014	< 0.03	< 0.01	64.85	13.90	NR	18.60	8.50	80.70	0.47	< 0.02	< 0.01
March 2014	< 0.03	0.02	77.15	11.20	NR	16.00	9.70	74.00	0.64	< 0.02	< 0.01
April 2014	< 0.03	0.06	77.87	14.45	232.57	16.40	11.70	74.00	0.57	< 0.02	< 0.01
May 2014	< 0.03	NR	127.30	18.42	225.00	NR					
June 2014	< 0.03	0.04	106.60	19.62	215.40						
July 2014	< 0.03	0.06	89.60	20.54	234.44						
August 2014	< 0.03	0.05	91.70	22.37	240.40						
September 2014	< 0.03	0.10	78.54	16.30	266.49	57.21	7.65	103.10	0.8	< 0.02	< 0.01
October 2014	< 0.03	0.17	89.30	21.03	268.50	55.94	7.04	85.08	0.79	< 0.02	< 0.01
November 2014	< 0.03	0.02	101.25	21.08	253.50	58.97	6.78	77.22	0.79	< 0.02	< 0.01
December 2014	< 0.03	0.04	94.58	21.67	256.04	47.83	5.03	97.74	0.73	< 0.02	< 0.01
January 2015	< 0.03	0.08	73.64	16.34	278.85	47.02	5.71	85.37	0.76	< 0.02	< 0.01
February 2015	< 0.03	0.02	72.73	15.65	270.61	43.04	5.40	88.88	0.82	< 0.02	< 0.01
March 2015	< 0.03	0.07	90.91	15.65	256.03	58.30	7.73	81.86	0.83	< 0.02	< 0.01
October 2014 Rain	< 0.03	0.06	< 1.00	6.40	0.20	< 0.03	< 0.0005	0.14	1.33	< 0.02	< 0.01
December 2014 Rain	< 0.03	0.25	1.38	3.47	1.70	< 0.03	< 0.0005	1.64	0.27	< 0.02	< 0.01

NR not recorded

SO_4^{2-} and leads to an increase in the conductivity of the waters. According to the World Health Organization (Who 2011), specific conductivity values of less than 900 µS/cm for groundwater correspond to fresh water.

Microbiological characteristics

The results of the microbiological analyses for groundwater are presented in Table 3.

The values for the groundwater are variable in total coliforms. In the dry season, the values range from 3 to 2,909 NMP/100 mL and in the rainy season from < 1 to 411 NMP/100 mL. The values for E. coli in the dry season range from < 1 to 12.4 MPN/100 mL and in the rainy season from < 1 to 19 MPN/100 mL. Comparison of the two sets of microbiological data shows that E. coli was much lower than total coliforms in the groundwater analysed.

Discussion

Evaluation of the physicochemical characteristics of groundwater using the relative order of abundance in meq/L (Dieng et al. 2017; Sako et al. 2016) shows that the major cations analysed are $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and for the anions $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$. This order was consistent throughout the sampling campaign in both the dry and rainy seasons.

In the case of rainwater, the values for the cations are below the limit of detection for Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{2+}, with $Na^+ > K^+$ detected in meq/L. For anions, the order of abundance in meq/L is $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$. As a general rule, turbidity in rainwater is caused by collected atmospheric solid substances that can be either inorganic or organic (Ratnoji and Singh 2014; Sillanpää et al. 2018). The turbidity values were less than 1 NTU and this shows that the rainwater and groundwater had not been physically polluted according to the technical regulation for drinking water of Panamá (Direccion General de Normas y Tecnología Industrial 1999). This finding also supports the low influence of anthropic sources on the atmosphere in the case of rainwater.

The diagrams proved to be very useful to interpret data, to classify the type of water and to identify possible uses (Custodio and Llamas 1976). The Piper diagram (Fig. 2) for groundwater during the sampling period corresponds to sodium bicarbonate-type, except in the month of November, when it corresponds to magnesium bicarbonate-type (Hernández-Antonio et al. 2017; Niu et al. 2017) but with close similarities to the sodium bicarbonate-type. Over the months, the major cations and anions varied in a parallel manner, thus indicating that simple exchange reactions occur in the water (Guo et al. 2017; Singh et al. 2017). The composition of the groundwater, in which the major anion is HCO_3^- and the major cations are Na^+ and Ca^{2+}, is explained by the composition of the local soils and rocks with calcium carbonate content (González, 2016), which has been reported in other carbonate rock areas (AlSuhaimi et al. 2016; Guo et al. 2017; Zhang et al. 2018; Zheng et al. 2017). In coastal areas with these characteristics, there have been reports that describe cation exchange phenomena (Sako et al. 2016; Taheri et al. 2017; Zheng et al. 2017), where the substrate has high concentrations of Na^+ and, being in a medium

Table 3 Results of the microbiological analyses for groundwater

No	Month	Total C. (NMP/100 mL)	E. coli (NMP/100 mL)
1	January 2014	> 2005	12
2	February 2014	5	< 1
3	March 2014	22	< 1
4	April 2014	10	< 1
5	May 2014	36	2
6	June 2014	411	12
7	July 2014	< 1	< 1
8	August 2014	10	< 10
9	September 2014	517	10
10	October 2014	15	1
11	November 2014	200	19
12	December 2014	48	5
13	January 2015	3	< 1
14	February 2015	64	< 1
15	March 2015	2909	5

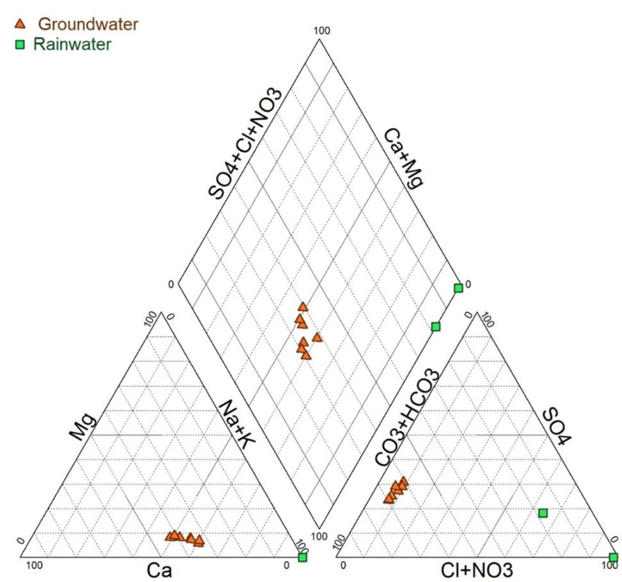


Fig. 2 Comparative Piper diagrams showing the relative compositions of groundwater and rainwater

saturated with Ca^{2+}, Na^{+} is released into the solution and Ca^{2+} is trapped by the ground. Therefore, the high content of HCO_3^- is associated with a high Na^+ content (Custodio and Llamas 1976; Niu et al. 2017; Ormachea Muñoz et al. 2016).

In the case of rainwater, the Piper diagram (Fig. 2) corresponds to a water with sodium and potassium chloride, which is consistent with the effect of marine aerosol, characteristic of coastal environment, as the main source of rainwater (Custodio and Llamas 1976).

On comparing the Piper diagrams for groundwater and rainwater (Fig. 1), it is evident that rainwater could be enriched in the cations Ca^{2+}, Mg^{2+} and Na^+, and anions Cl^-, SO_4^{2-} and HCO_3^-, due to its passage through the rocks for the infiltration effect. The order of filtration in clay-like membranes (Custodio and Llamas 1976) for anions from low to high delay is: $HCO_3^- > SO_4^{2-} > Cl^-$. This is the same order found in the groundwater under investigation and it is due to the nature of the local sedimentary rocks. The order of concentration for the cations is $Na^+ > Ca^{2+} > Mg^{2+}$ and this is also explained by the nature of the rocks being infiltrated and by their proximity to the coast.

The modified Stiff diagrams for both types of water (Fig. 3) allow one to appreciate month by month how the composition of the ions varies and that rainwater, which has very low concentration of ions, is enriched with Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-} and Cl^- when entering the aquifer.

The use of the diagram for the classification of water for irrigation, according to the U.S. Salinity Laboratory Staff for groundwater (Fig. 4) (Dhanasekarapandian et al. 2016; Selvakumar et al. 2017), is of great interest for assessing the possibility of agricultural use. All of the results are concentrated along the line for classifications C2 and C3, and they also fall within field S1. This implies that these waters are associated with a potential salinization risk for soils that is medium to high, with a risk of alkalization. These waters can be used for irrigation, but only on salt-tolerant crops with good drainage, and there is a need for soil washing processes to avoid changes in reactivity (Custodio and Llamas 1976). The low conductivity and ion concentrations of rainwater make it suitable for use for both agricultural and irrigation purposes according to the U.S. Salinity Laboratory Staff.

According to the water potability diagram (Zabala et al. 2016) (Fig. 5), groundwater appears to be suitable to obtain drinking water, i.e., it is acceptable as raw water for a purification process to bring it up to drinkable standards. For rainwater, the diagram (Fig. 5) indicates that it is appropriate for purification by pH adjustment alone, with an average value of 5 – a parameter that must be adjusted to neutrality (AlSuhaimi et al. 2016).

The average values for groundwater and rainwater (is referred for groundwater since September 2014 to March 2015, and for rainwater is referred the average value for

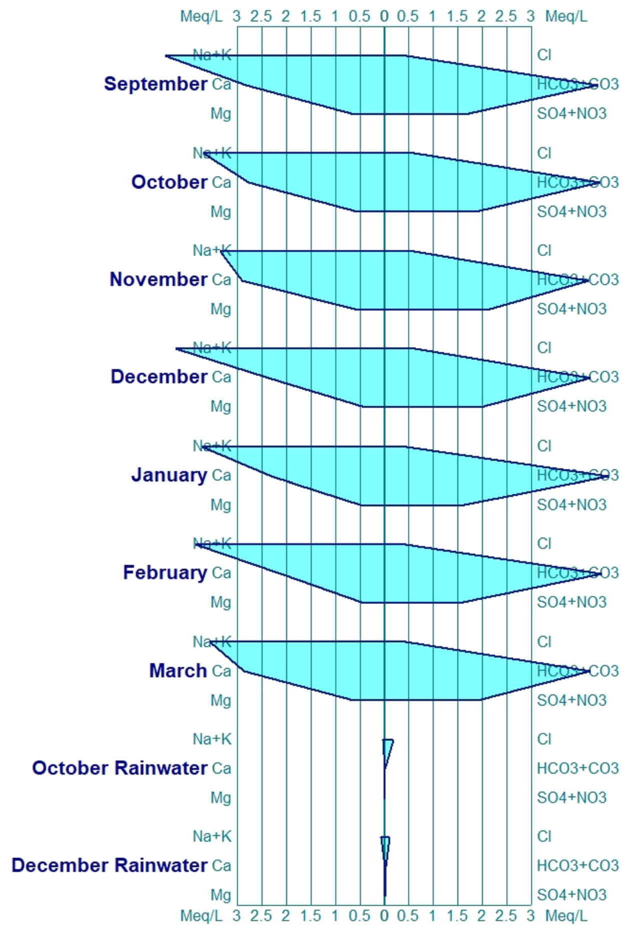


Fig. 3 Comparative Stiff diagrams showing the relative compositions of groundwater and rainwater

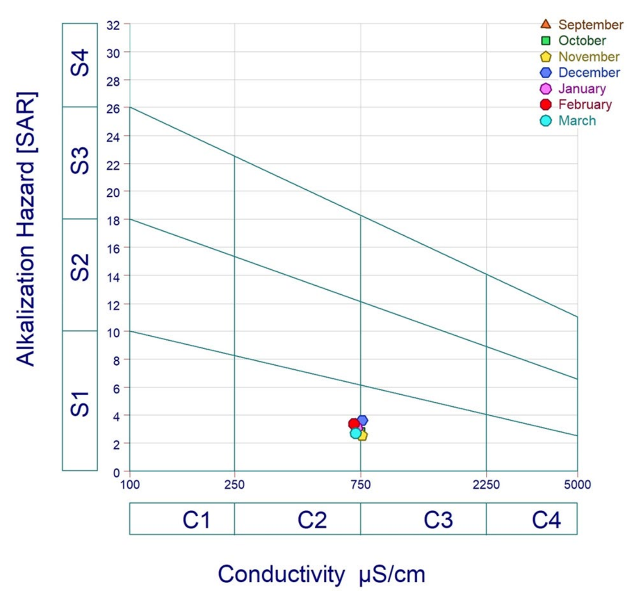


Fig. 4 Classification diagram for irrigation waters and for groundwater in dry and rainy seasons

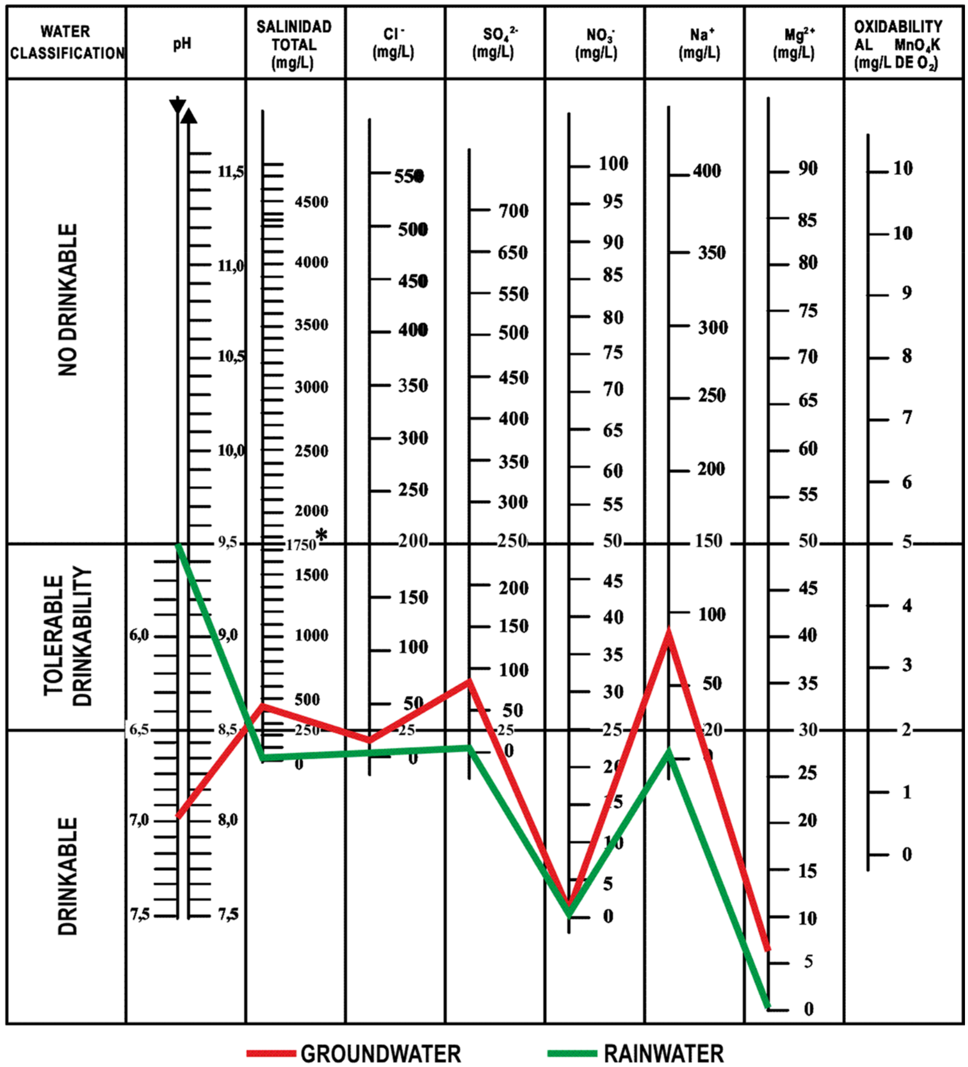


Fig. 5 Water potability diagram for groundwater and rainwater

the October and December 2014) were compared with the guide values of the national Norm DGNTI-COPANIT 23–395-99 for drinking waters not distributed by pipelines (Ministerio de Comercio e Industrias 1999), which is similar to the World Health Organization standards (WHO 2011) (Table 4), as well as with values for reused water for irrigation, Norm DGNTI-COPANIT 24–99 (Ministerio de Comercio e Industrias 2000) for reused water (Table 5). The results for total coliforms and E. coli, which were used for comparison with faecal coliforms, do not fulfil the requirements for water not distributed by pipelines either in groundwater. Groundwater meets most of the physicochemical parameters except for alkalinity and hardness. Rainwater complies with physicochemical parameters except for pH. In terms of hardness, the groundwater was very hard, with 158.19 mg/L total hardness as $CaCO_3$; while rainwater corresponds to soft water, in the month of October (month of greatest rainfall) and December (transition from rainy to dry season).

With respect to the regulations for reused water, for both waters the parameters tested meet the required standards for the purposes of crop irrigation, aquaculture in the culture of fish and aquatic plants, urban uses in the irrigation of green areas, and industrial use for boiler cooling. It would be necessary to adjust the pH of rainwater.

Conclusions

The results of this study concern the sustainability of groundwater and rainwater as a raw water supply for different purposes in relation to international standards. The quality of both groundwater and rainwater in Panama City seem to be suitable for use in different applications during periods of drought. The hydrogeochemical values and the microbiological quality of the water allow its direct use for large consumers such as for irrigation and aquaculture uses. However, for human supply both of these waters

Table 4 Comparison of values for groundwater and rainwater with standards for drinking water

Parameters	Norm DGNTI-COPANIT 23–395-99 Not distributed by pipes	Groundwater	Fulfilment	Rainwater	Fulfilment
Faecal coliform bacteria No. colonies/100 mL	0	< 1 to 19 (NMP/100 mL)	Not fulfil	–	–
Total coliform bacteria No. colonies/100 mL	10	3 to 2,909	Not fulfil	–	–
Turbidity NTU	1.0	0.23	Fulfil	0.8	Fulfil
pH	6.5–8.5	6.5–7.7	Fulfil	4.8–5.2	Not fulfil
Alkalinity as $CaCO_3$ mg/L	120.00	264.29	Not fulfil	0.95	Fulfil
Chloride mg/L	250.00	18.25	Fulfil	4.94	Fulfil
Iron mg/L	0.30	< 0.02	Fulfil	< 0.02	Fulfil
Manganese mg/L	0.1	< 0.01	Fulfil	< 0.01	Fulfil
Nitrate mg/L	10.00	0.07	Fulfil	0.16	Fulfil
Sodium mg/L	200.00	88.46	Fulfil	0.89	Fulfil
Total dissolved solids mg/L	500.00	457.43	Fulfil	15.00	Fulfil
Sulfates mg/L	250.00	85.85	Fulfil	1.38	Fulfil
Total hardness as $CaCO_3$ mg/L	100.00	158.19	Not fulfil	0	Fulfil

Table 5 Comparison of values for groundwater and rainwater with the norms for reuse of water treated for irrigation

Parameters	Norm DGNTI-COPANIT 24–99 Reused water	Groundwater	Fulfilment	Rainwater	Fulfilment
Chloride mg/L	200.00	18.25	Fulfil	4.94	Fulfil
Iron mg/L	5.000	< 0.02	Fulfil	< 0.02	Fulfil
Manganese mg/L	0.200	< 0.01	Fulfil	< 0.01	Fulfil
Sulfate mg/L	350.00	85.85	Fulfil	1.38	Fulfil
Electric conductivity EC dS/m	3.000	0.735	Fulfil	0.015	Fulfil

require simple treatments to achieve the necessary quality, which makes them a very interesting alternative resource during periods of drought.

This study provides a first approach to the potential uses of these waters in terms of their quality. Future studies should be aimed at gaining an in-depth knowledge of their characteristics if there are potential contaminants not evaluated in this work, such as heavy metals, and the volume of resources available to evaluate the potential of application of both types of water in this area.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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