Heliyon 5 (2019) e02121

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.heliyon.com

Seasonal quality variation and environmental risks associated with the consumption of surface water: implication from the Landzun Stream, Bida Nigeria

Japheth Daramola[a,**], Toriman M. Ekhwan[a], Ekundayo Joseph Adepehin[b,*], J. Mokhtar[a], Kuok Choy Lam[a], Ah Choy Er[a]

[a] Social, Environmental, Development, Sustainability Research Centre (SEEDS), Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Geology Program, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

ARTICLE INFO

Keywords:
Environmental hazard
Earth sciences
Earth-surface processes
Geography
Geochemistry
Geology
Hydrology
Lithology
Environmental risks
Surface water
Lead
Landzun stream
Bida Nigeria

ABSTRACT

Water constitutes a major environmental and public health concerns worldwide. A large proportion of global water consumption is sourced from surface water. The dependency level on surface water is higher in developing countries, especially in rural-to-semi-urban areas, where subsurface water is not accessible. Presented in this paper is a spatiotemporal and hydrochemical quality assessment of the spring-originated Landzun Stream in Bida, Nigeria; which is usually consumed in its untreated state. Water samples were systematically collected in eighteen locations along the stream channel in both rainy and dry seasons at an equidistance interval of 500m. On-site and laboratory measurement of important physical and hydrochemical parameters were carried out using standard procedures. Water temperature in the rainy season (34–37 °C) slightly exceeds measured values in the dry season (29–33 °C). 72.22% (rainy) and 83.33% (dry) of collected samples did not meet the odourless requirement for drinking water. Similarly, estimated percentages of 66.67 and 94.44 of collected samples in rainy and dry seasons respectively have a taste. Contrary to data in the rainy season, 89%, 11%, 67% and 56% of the dry season's samples were enriched in magnesium (Mg), lead (Pb), potassium (K) and iron (Fe) respectively above the 2018 World Health Organisation guidelines for drinking water. This study further established that seasonal variation plays a major role in altering the aesthetic surface water quality. The intake of untreated surface water is a vehicle for potential water-borne diseases and allergies, hence alternative sources of drinking water for the populace dependent on the Landzun Stream is recommended to reduce risks and possible dangers of consuming the stream water.

1. Introduction

Water is an essential life's necessity and it has constituted a major public health and environmental concern in the last two decades (Ayoade, 1988; Simeonov et al., 2003; Chandra et al., 2006; Wei and Gnauck, 2007; Bhutiani et al., 2016; Duan et al., 2016; Khan et al., 2016; Richards et al., 2016; Strady et al., 2016; Yang et al., 2016). The quest for unhindered access to safe and potable water for mankind takes priority on the agenda of many international organisations and developed countries. The United Nations Organisation during its' 2010 general assembly unequivocally reiterated that everyone is entitled to adequate, uninterrupted, safe, acceptable, physically accessible, and affordable water for personal and domestic purposes (United Nations General Assesmbly, 2010). This notwithstanding, reliable data published by the World Health Organisation (2018) established that an estimated 2 billion persons depend on water contaminated with faeces. Drinking contaminated water has been projected as a causative factor for an estimated 502, 000 deaths annually. Of the 7.7 billion global population, 844 million persons (~10.96%) reportedly lack access to potable water and 159 million of these (~2.1% of the global population) depend on surface water for drinking (World Health Organisation, 2018). According to the United States Geological Survey, (2015) about 80 % of all the water used

---

* Corresponding author.
** Corresponding author.
E-mail addresses: widespreadint@gmail.com (J. Daramola), jadepehin@gmail.com (E.J. Adepehin).

https://doi.org/10.1016/j.heliyon.2019.e02121
Received 30 March 2019; Received in revised form 11 July 2019; Accepted 17 July 2019

in the USA in 2015 were sourced from surface water. Similarly, surface water accounts for an estimated 82% of China total water supply in 2016 and 77% of South Africa's total water supply in 2005 (CWR, 2018; WWAP, 2006; FAO, 2016).

Although reasonable percentages of used water in developed countries are sourced from surface water, the situation is generally more critical in developing countries when it comes to the purpose of use and the pre-use treatments. Generally, dependence on untreated surface water for domestic use is more prevalent in the interiors and semi-urban areas than in cities. The availability of relatively uninterrupted good treatment facilities for surface water in the developed world, which is largely lacking or inefficient in developing countries makes those relying on surface water in developing countries to be high-risk candidates for waterborne breakouts. In Nigeria, treated surface water channelled to household and dispensed via taps constituted an average of 57% of total water supply between the years 1995 and 2000, unfortunately, this figure has dropped to a meagre 10% between 2006 and 2010 (Egbinola, 2017). Thus, making access to safe water supply difficult for the average income earners ($\geq$70 % of the population) who are unable to drill a private borehole to source subsurface water. Although intervention schemes by the World Health Organisations, the United Nations, USAID and other international agencies have made some contributions by sinking public boreholes, these efforts are still insufficient to serve the over 200 million population of the country. Expectedly, the effect of this is more felt in the non-urban, as such regions become water-stressed, and dwellers are forced to resort to untreated surface water.

Untreated surface water is often contaminated and sometimes polluted (Craun, 1988; Riva et al., 2019). Both anthropogenic activities and natural processes have been documented as culprits responsible for the contamination of streams and rivers (Kakulu et al., 1987; Okoye, 1989; Fufeyin, 1994; Udodo-Umeh, 2002; Scott et al., 2004; Marcus, 2011; Mompelat et al., 2011; Igwe et al., 2014, 2015; 2017; Izah and Angaye, 2016). Studies have established that sources of contamination include, mining (Adepehin, 2015; Igwe et al., 2014, 2015; 2017; Eludoyin et al., 2017), bedrock geology (Holloway et al., 1998; Yang et al., 2009), septic (Jamieson et al., 2004) and agriculture (Buerge et al., 2003; Carvalho, 2017) among others. This paper is the first to access the influence of seasonal fluctuation on, and the potential risks associated with the use of the Landzun Stream as a major water source for domestic activities in part of the north-central Nigeria from a hydrogeochemical point of view. The relatively low educational level and poor knowledge on potential harms inherent in this uncultured activities are conspicuous by mere traverse along the channel. One major way to achieve the stated objectives is to subject the stream water to field observation, laboratory analyses to ascertain if the quality conforms to set drinking water standards by the World Health Organisation (2018).

2. Study area

Bida Township resides in the heart of northern Nigeria (Fig. 1). It is located in the Niger valley within Latitudes 9^{o} 0` and $9^{o}$ 9` North of the Equator and Longitudes 5^{o} 56` and $6^{o}$ 04` East of Greenwich meridian. The town has a population of 118,181 (NPC, 2007) and occupying a total land area of 37.545346 km^2 (Daramola, 2013). The rainfall regimes of

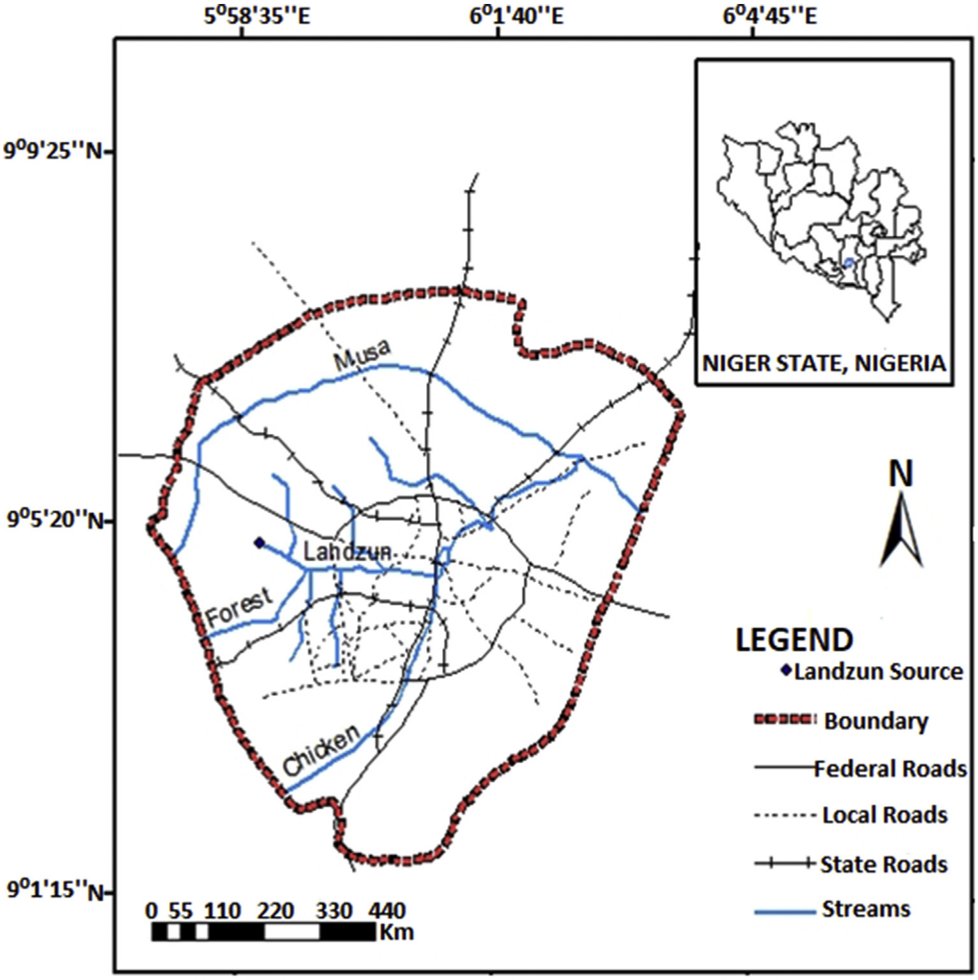

Fig. 1. Map of the study area showing Bida Township in Niger State, Nigeria.

the area are the result of the general atmospheric circulation of air masses over the earth modified by surface topography and elevation. Average rainfall between 1999 and 2019 in Bida is estimated to be 3.31mm, with the highest downpour recorded in between August and September annually, while average temperature ranged between 23.27 to 33.66 °C (PCA, 2019). Bida is well drained throughout the year by a number of streams. These include the Musa River, the Landzun River, the Chiken River etc. The Landzun stream is ~8.86 km long, and about 5km lies within the city of Bida, with an overall west to east flow pattern and estimated the flow rate of 22.21m^{3}s between 2010 and 2018 (PCA, 2019). The area is mainly residential, with little agricultural practice and trading. The town is also the main collection centre for the swamp rice cultivated in the floodplains of the Niger and Kaduna rivers. The discharge of household and automobile wash effluents into the Landzun stream is a common practice, alongside a host of untamed domestic and agricultural uses.

Geologically, the study location sits on the northern hemisphere of the Cretaceous Mid-Niger, Bida or Nupe Basin (Fig. 2), as it is locally referred to, among Nigerian geologist. Bida township falls on the northern section of the southern Mid-Niger Basin. This post-Santonian basin is an intracratonic downwarped clastic wedge with some occurrences of basement materials within it (Nwajide, 2013). It is an NW-SE trending embayment, which extends from Kotangora in Niger State, northern Nigeria to slightly beyond Lokoja in Kogi State in the south (Adeleye, 1973; Obaje, 2009; Nwajide, 2013; Areola et al., 2014). In the Nigeria geological context, the basin has been referred to with diverse names e.g. Bida Basin, Nupe Basin and NW extension of the Anambra Basin etc. Details of the academic discussion that resulted in these various names are definitely beyond the focus of hydrological/hydrogeological quality assessment manuscript, like this, and so is the theoretical details of the basin's origin. Some authors have proposed and explained that the basin was formed in connection with regional faulting that birthed the Benue Aulacogen; locally referred to as the Benue Trough (Kogbe, 1981; Ojo and Ajakaiye, 1989; Nwajide, 2013).

The basin is believed to be segmented into two sub-basins; the northern part called the Bida subbasin and the southern part known as the southern Lokaja subbasin. The Landzun stream occupies part of the Northern Bida sub-basin. This subbasin is stratigraphically made up of four geological units; Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone (Jones, 1958; Adeleye, 1974) listed incorrect stratigraphical order starting from the oldest. According to Jones (1958), the Bida Sandstone lies unconformably on the basement complex. Although the contact between the formation and the basement is not clear, its estimated thickness in the Bida area (where the Landzun stream drains) is put at 2000–3000m based on airborne magnetometry. Adeleye (1974) interpreted these variegated sediments to represent alluvial fan deposits that were deposited in braided paleochannels that sourced their detritus from basement rocks of the SW Nigeria. The Formation was subdivided into two members; the Doko Sandstone and Jima Sandstone members by Adeleye (1989). He described the former as the basal unit exposed in the Bida area and sedimentologically composed of arkoses, quartzose sandstones, sub-greywackes, sandy siltstones and intraformational breccia interpreted to be deposited in a braided stream environment and under low stream energy. It is generally reported to be ≥180m thick in the Bida area based on identified sequences in the geological survey of Nigeria's Borehole 1256. The Jima Sandstone member, which seats on the former has a maximum thickness of 95m and it is characterised with frequent change in facies. It is exposed in the Bida area and consists of brown cross-stratified quartzose sandstone, sub-greywackes, siltstones, claystones, and breccias (Adeleye, 1989).

The Sakpe Ironstone rests on the basal Bida Sandstone towards the Northern part. The formation is dominantly goethitic, oolitic, and pisolitic ironstones of about 5 m maximum thickness and it extends for an estimated area of 225 km^2 around Bida area (Adeleye, 1974). The oolitic ironstone range from 1 – 2mm size and become finer from the northern sub-basin to the southern sub-basin. The pisolitic types are restricted to the Bida area where they occur in the middle areas of the lower ironstones. Like the Bida Sandstone, the Sakpe Ironstone is subdivided into two members; the Baro ironstone and Wuya ironstone; which are both diachronous (Adeleye, 1973, 1989). Enagi Siltstone Formation overlies the Sakpe Formation. It is lithologically typified by argillaceous strata/beds, dominated by siltstones while subsidiary sandstone, sandstone-siltstone. Enagi Siltstone correlates with the southern Lokoja, Patti Formation (Jones, 1958) and the Mamu Formation to the east. The siltstone is thinly laminated and has been interpreted as a continental fluvial deposit under floodplain conditions (Adeleye, 1973). Recently in

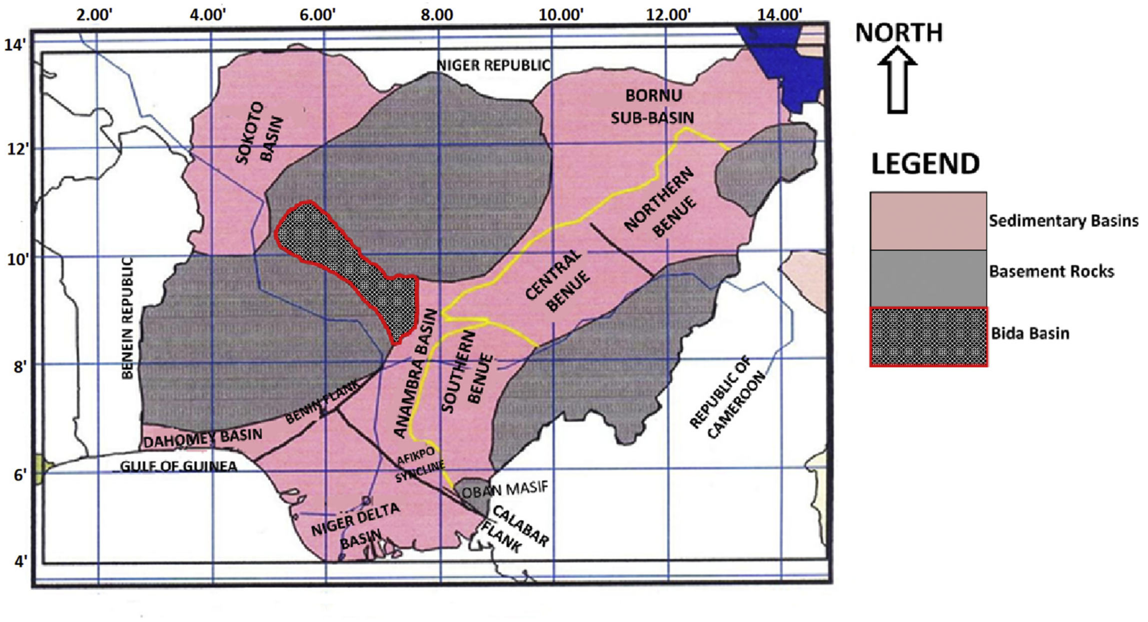

Fig. 2. Geologic elements of Nigeria. Note the Bida Basin marked round with red colour (modified from Ola and Adepehin, 2017).

the southern Bida Basin, Maastrichtian age had been allocated to the Patti Formation along the Lokoja- Abaji expressway, based on preserved pollen and spores of angiosperms, pteridophytes and gymnosperms (Akande et al., 2005; Ojo and Akande, 2006, 2008; Nwajide, 2013). It has a maximum thickness of about 65m and has been assigned a Maastrichtian age. The Batati Ironstone overlies the Enagi Formation. It is the lateral equivalent of the Agbaja Ironstone around Niger/Benue confluence. The beds are dominantly oolitic and show irregular lithologic changes. Subsidiary ferruginised claystones, sandstones and shelly beds occurred locally. It is assigned a Campano- Maastrichtian age (Nwajide, 2013).

3. Materials and methods

Materials used for this research include water containers, Global Positioning System (GPS), ice-crested coolers, combined portable pH and conductivity meter and mini thermometer. The adopted methodology for this research is in two main categories; (i) field studies and sampling, and (ii) laboratory analyses.

3.1. Field studies and sampling

Sampling was guided by our understanding of the Landzun Stream course. Water samples were collected midstream where possible, along the stream channel at equidistance interval of 500m, coordinates were taken with the aid of Global Positioning System (GPS). In all, a total of thirty-six samples were collected for this investigation; that is eighteen samples each in the rainy and dry season respectively (Fig. 3). Bowls and plastic storage jar were thoroughly rinsed with source water before sampling. The collected water samples were immediately poured into the pre-rinsed 1litre plastic jars and covered tightly. These were then kept in an ice-crested cooler to prevent possible reactions or microbial activities that could adversely impact laboratory outcomes.

Determination of colour, odour, taste, electrical conductivity and pH were done *insitu* at the point of sampling. Watercolour and odour were determined based on the appearance of the colour to the eyes, and the smell perception of the samples respectively. Observations were compared with standard colours and odours that are common to the senses of sight and smell. Water samples were felt with the tongue to determine whether samples were salty, tasteless, oily taste or metallic taste. Temperature measurement was done using a mini dipping thermometer (Model: MET540010, SciChem Co., Aberdeen, U.K). The PC200 combined portable pH and conductivity meter (Thomas Scientific., Swedesboro, New Jersey, USA) was used for the determination of the electrical conductivity (EC) and pH. The analytical atomic refractive index (R.I) was determined by placing two drops of the sample to be analysed on the pre-set refractometer sensitivity after which readings were taken from the lower knob viewer and documented.

3.2. Laboratory analysis

The Atomic Absorption Spectrometry (AAS) model 210 VGP was utilised for the determination of chemical parameters in the samples. An amount of 50ml of the filtered sample was dried to 5ml volume in dust-free environment and made up to 100ml in a standard volumetric flask with double distilled water, and labelled accordingly. Since each metal has a characteristic wavelength that will be absorbed, the specific hitch hollow cathode lamps were selected accordingly. The slit width for each element was also identified. Samples of interest were aspirated into the AAS flame; the metal present in the sample absorbed some of the light, thereby reducing its intensity. The computer data system converted the difference in intensity of the light into an absorbance value which was directly proportional to the concentrations of the metal ions present in each sample. Metals tested for in the samples are zinc (Zn), copper (Cu), magnesium (Mg), manganese (Mn), chromium (Cr), nickel (Ni), lead (Pb), sodium (Na), calcium (Ca), potassium (K), iron (Fe) and cadmium

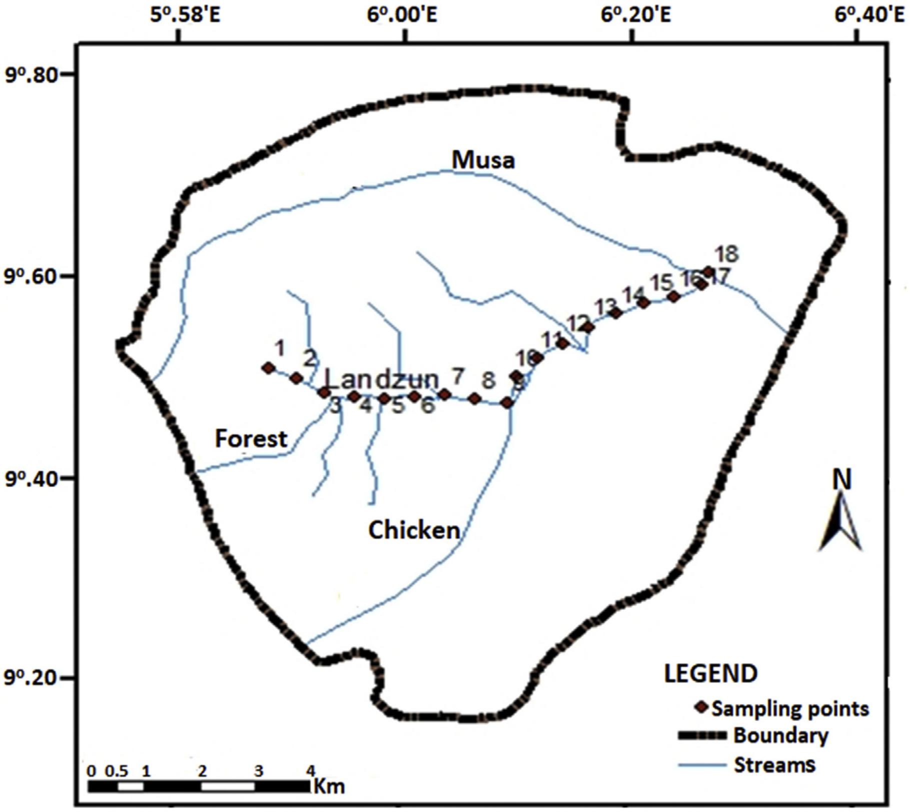

Fig. 3. Drainage map of the study area showing sampling points.

Fig. 4. Observed scenes along the Landzun Stream channel during field studies. (A) The spring source of Landzun Stream, (B & C) Inhabitants washing household utensils, (D) Children bathing in the channel.

(Cd). These Laboratory analyses were done immediately after sample collection for each season to avoid contamination of the samples. Care was however taken to ensure that samples collected in the two seasons were subject to the same conditions and analysed using the same set of laboratory equipment and procedures.

4. Results and discussion

The Landzun Stream is a spring originated surface water (Fig. 4A). Field studies revealed diverse ongoing agro-domestic activities in, and around the different sample points (Fig. 4). Notable among these include washing of household utensils (Figs. 4B & 4C) and bathing (Fig. 4D).

Fig. 5. Possible contamination linkages around the Landzun Stream (A) Discharge of automobile wash waste water to the Stream, (B) Animals grazing around the channel, (C) Palm tree plantation by river channel, (D) Millet farm flanking the channel.

Heaps of rice husk and evidence of indiscriminate waste channelling into the stream were observed (Fig. 5A). Agricultural activities including grazing (Fig. 5B & C), oil-palm plantations (Fig. 5C), millet farms (Fig. 5D) and vegetable gardens. These agricultural activities leverage on the stream for growth and survival.

4.1. Seasonal variation in organoleptic and physical parameters

Unobjectionable attributes of potable water include colourless, odourless and tasteless (Epundu et al., 2017; Kolawole et al., 2011; Panglisch et al., 2005; Majumdar and Sproul, 1974). In both the dry and rainy seasons, the water in the Landzun Stream is characterised with a wide array of colours, ranging from brownish to greenish (Table 1 and Fig. 4). Colour variation in water is an indicator of impurity possibly leached from earth materials as the stream moves over them, or introduced by surface runoff into the stream (Gupta, 2011; Hongve et al., 2004). Similarly, only six and three samples in the rainy and dry seasons respectively were odourless, thus indicating that some locations that were odourless in the rainy season were otherwise in the dry season (Table 1). Six of the samples obtained in the rainy season were tasteless, while seventeen of those collected in dry season have diverse taste ranging from rotten egg taste to muddy taste; thereby falling short of the WHO, 2018 standard (Fig. 3). These organoleptic parameters (Table 1) suggest that the physical qualities of the Landzun stream deteriorate as the water moves away from its spring source (LWS01) (compare Figs. 4A and 4C). Muddy odour and/or taste in the surface water is an indication of intense eutrophication (Persson, 1982). According to Hack (1981), the reduction of SO_4^{2-} to S^- by anaerobic bacteria is responsible for the rotten egg smell/taste observed dominantly between sample stations 10 to 14 in the Landzun Stream (Suffet et al., 1999).

As evidenced in Table 1, the Landzun Stream's water temperature patterns in both seasons generally increase downstream and fall below the WHO (2018) allowable limits of 37.5 °C. Water temperature exacts a major control on stream ecosystems (Letcher et al., 2016), pH, water density, water solubility (compound toxicity), conductivity and salinity, oxidation-reduction potential as well as dissolved oxygen and other dissolved gas concentrations (FEI, 2014). The documented spatiotemporal temperature in the rainy season (34 °C–37 °C) significantly exceeds the dry season values (29 °C–32 °C). The relatively higher temperature ranges in the rainy season than in the dry season suggests that solar energy is not the major controller of temperature in the stream. Prevailing Harmattan condition during field studies in the dry season is a probable cause of the relative decrease in stream temperature. Conversely, known emission of heat energy connected with the condensation of water vapour to form rain (Seinfeld and Pandis, 2016), and the subsequent release of warm air to the earth surface during precipitation possibly account for the relative rise in temperature in the wet season (Brewster, 2015). Anthropogenic contribution to stream temperature fluctuation via the discharge of cooling or industrial water as well as reduced shading owing to harvesting deforestation may also contribute to temperature variation. Stream temperature, according to Brown (1999) quantifies the mean dynamic energy (heat energy) of the atoms and molecules and this energy is transferable between substances. Potential sources of heat transfer to stream water as enumerated by FEI (2014) includes the sun, air, another water source or thermal pollution. Although measured stream temperature in the rainy season conforms with the World Health Organisation standard, marginal temperature value of 37 °C recorded in seven stations in the rainy season vis-à-vis the WHO (2018) threshold of 37.5 °C raises concern, hence the need for regular monitoring (Fig. 2).

Average pH and total dissolved solids (TDS) in the dry and rainy seasons are ~7.8, 60.613 mgL^{-1} and 9.61, 50.471 mgL^{-1} respectively. These data show that the Landzun Stream conforms to the Standard Organisation of Nigeria (2007) requirements for potable water in the dry season as regards pH and TDS (Tables 1 and 2). Similarly, the measure of the collective non-H_2O molecules present in the stream water (TDS) in the rainy season is far below the acceptable limit; thus suggesting that the total organic and inorganic substances e.g. minerals, salts, and organic matter in the water do not significantly affect the water quality of the stream. However, samples across the eighteen stations are characterised by pH values above the acceptable limit of 8.5 (Table 3). Although no limit was set for water pH by the WHO (2018), the US-EPA (2019) and the Standard Organisation of Nigeria (2007) had independently regulated that intake of water with pH values, not within the specified 6.5 to 8.5 range is dangerous to human health. High water pH (>8.0) may lead to corrosion of utensils, develop a slippery feeling and yield soda taste (US-EPA, 2019). Refractive Index (R.I.) is a measure of water turbidity (Tables 2 and 3). Refractive Index spatiotemporal values in the sampled water are low and below the allowable limits of 5NTUset standard for the two seasons, an indication that the water is less turbid. Careful analysis of the statistical data suggests that the spatiotemporal value in the sampled water is low and below the allowable limits of 1000 μS/cm standard for the two seasons.

4.2. Seasonal variation in hydro-elemental concentration

Concentrations of Cu, Cr, Ni and Cd in the rainy and dry seasons are generally below the equipment detection limit of 0.001 mg L^{-1} (Tables 2

Table 1

Organoleptic parameters of the analysed water samples for dry and wet seasons.

Sample Points	Temperature (°C)		Colour		Odour		Taste	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
LWS01	34	29	Greyish	Greyish	Odourless	Odourless	Tasteless	Tasteless
LWS 02	34	29	Brown	Light Brown	Odourless	Rotten egg	Tasteless	Pungent
LWS 03	35	30	Muddy Brown	Light Brown	Odourless	Muddy	Tasteless	Clay Taste
LWS 04	35	30	Light brown	Light Brown	Muddy	Muddy	Tasteless	Clay Taste
LWS 05	36	31	Light brown	Light Brown	Muddy	Odourless	Muddy	Clay Taste
LWS 06	35	32	Light Brown	Light Brown	Muddy	Odourless	Muddy	Clay Taste
LWS 07	36	30	Brown	Brown	Muddy	Muddy	Muddy	Clay Taste
LWS 08	35	31	Light Brown	Light Green	Muddy	Muddy	Muddy	Clay Taste
LWS 09	35	31	Brown	Light Green	Muddy	Muddy	Muddy	Clay Taste
LWS 10	37	33	Greyish	Light Green	Odourless	Rotten egg	Tasteless	Pungent
LWS 11	37	33	Light brown	Light Green	Muddy	Rotten egg	Muddy	pungent
LWS 12	37	33	Ash	Light Green	Rotten egg	Rotten egg	Rotten egg	Pungent
LWS 13	36	32	Brown	Brown	Muddy	Rotten egg	Muddy	Pungent
LWS 14	37	32	Ash	Dirty Green	Rotten egg	Rotten egg	Rotten egg	Pungent
LWS 15	37	33	Brown	Brown	Odourless	Muddy	Tasteless	Clay Taste
LWS 16	37	33	Brown	Brown	Muddy	Offensive	Muddy	Pungent
LWS 17	37	33	Brown	Brown	Muddy	Offensive	Muddy	Pungent
LWS 18	36	32	Ash	Brown	Rotten egg	Offensive	Rotten egg	Pungent
WHO, 2018	37.5		15 TCU*		Unobjectionable*		Unobjectionable*	

Table 2
Dry Season Inorganic Constituents in mgL^{-1}.

SP	Zinc (Zn)	Copper (Cu)	Magnesium (Mg)	Manganese (Mn)	Chromium (Cr)	Nickel (Ni)	Lead (Pb)	Sodium (Na)	Calcium (Ca)	Potassium (K)	Iron (Fe)	Cadmium (Cd)	pH	Refractive index	EC (μScm^{-1})	TDS (mgL^{-1})
LWS01	0.075	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.024	<0.001	<0.001	<0.001	7.7	1.333	10.2	6.79
LWS 02	0.075	<0.001	3.160	<0.001	<0.001	<0.001	<0.001	0.608	0.322	2.622	0.470	<0.001	8.0	1.332	38.0	25.31
LWS 03	<0.001	<0.001	1.000	<0.001	<0.001	<0.001	<0.001	0.229	0.250	4.378	0.235	<0.001	8.1	1.332	34.0	22.64
LWS 04	0.100	<0.001	1.580	<0.001	<0.001	<0.001	<0.001	0.163	0.250	4.378	0.412	<0.001	8.1	1.332	34.0	22.64
LWS 05	0.100	<0.001	3.161	<0.001	<0.001	<0.001	<0.001	0.163	0.250	4.919	0.529	<0.001	8.1	1.333	50.0	33.30
LWS 06	0.050	<0.001	6.066	<0.001	<0.001	<0.001	<0.001	1.215	0.250	7.135	0.294	<0.001	7.6	1.332	67.0	44.62
LWS 07	0.125	<0.001	7.775	<0.001	<0.001	<0.001	<0.001	1.936	0.803	11.811	0.176	<0.001	7.6	1.332	84.0	55.94
LWS 08	0.050	<0.001	9.743	<0.001	<0.001	<0.001	<0.001	0.357	0.803	15.865	0.529	<0.001	7.7	1.332	105.0	69.93
LWS 09	0.050	<0.001	11.581	<0.001	<0.001	<0.001	<0.001	2.627	1.659	15.865	0.353	<0.001	7.8	1.332	108.0	71.93
LWS 10	0.250	<0.001	11.581	<0.001	<0.001	<0.001	<0.001	2.732	1.490	15.676	0.588	<0.001	7.8	1.332	108.0	71.93
LWS 11	0.125	<0.001	16.360	<0.001	<0.001	<0.001	<0.001	4.162	3.120	46.189	0.118	<0.001	7.8	1.332	216.0	143.86
LWS 12	0.125	<0.001	12.114	<0.001	<0.001	<0.001	<0.001	2.572	1.442	12.054	0.470	<0.001	7.7	1.332	108.0	71.93
LWS 13	0.075	<0.001	10.515	<0.001	<0.001	<0.001	<0.001	3.238	1.649	22.702	0.235	<0.001	7.8	1.332	114.0	75.92
LWS 14	0.100	<0.001	10.349	0.024	<0.001	<0.001	<0.001	2.942	0.861	26.486	0.764	<0.001	7.8	1.332	97.0	64.60
LWS 15	0.025	<0.001	10.938	<0.001	<0.001	<0.001	0.009	3.249	1.659	15.891	0.235	<0.001	7.9	1.332	117.0	77.92
LWS 16	0.025	<0.001	10.735	<0.001	<0.001	<0.001	0.014	3.249	1.663	18.811	0.176	<0.001	7.9	1.332	114.0	75.92
LWS 17	0.125	<0.001	8.970	0.043	<0.001	<0.001	<0.001	3.014	1.553	23.243	0.823	<0.001	7.8	1.332	117.0	77.92
LWS 18	0.125	<0.001	8.970	0.043	<0.001	<0.001	<0.001	3.014	1.553	23.243	0.823	<0.001	7.8	1.332	117.0	77.92
Mean	0.089	<0.001	7.972	0.006	<0.001	<0.001	0.001	1.987	1.158	15.070	0.402	<0.001	7.8	1.332	91.011	60.613
STD	0.056	<0.001	4.495	0.015	<0.001	<0.001	0.004	1.364	0.777	11.123	0.243	<0.001	0.144	<0.001	47.249	31.469
CV	0.629	<0.001	0.564	2.5	<0.001	<0.001	4	0.686	0.671	0.738	0.604	<0.001	0.018	<0.001	0.519	5.192
WHO, 2018	<3	2	0.20*	0.4	0.05	0.07	0.01	200	75*	10*	0.2	0.003	6.5–8.5*	5*	1000*	500*

SP is sampling points, STD is standard deviation, CV is correct value, WHO, 2018 figures are guidance values from the World Health Organisation. * values not defined by the WHO, 2018 drinking water guidelines. They were obtained from the Standard Organization of Nigeria (2007). Maximum detection limit of the equipment is 0.001 mg L–1.

Table 3
Rainy Season Inorganic Constituents in mgL^{-1}.

SP	Zinc (Zn)	Copper (Cu)	Magnesium (Mg)	Manganese (Mn)	Chromium (Cr)	Nickel (Ni)	Lead (Pb)	Sodium (Na)	Calcium (Ca)	Potassium (K)	Iron (Fe)	Cadmium (Cd)	pH	Refractive index	EC (μScm^{-1})	TDS (mgL^{-1})
LWS01	<0.001	<0.001	0.018	<0.001	<0.001	<0.001	<0.001	0.149	0.007	0.133	<0.001	<0.001	11.0	1.331	8.1	5.39
LWS 02	<0.001	<0.001	0.486	<0.001	<0.001	<0.001	<0.001	0.466	0.024	0.127	<0.001	<0.001	10.0	1.332	12.0	7.99
LWS 03	<0.001	<0.001	0.402	<0.001	<0.001	<0.001	<0.001	0.259	0.041	0.182	<0.001	<0.001	10.3	1.332	30.0	19.98
LWS 04	<0.001	<0.001	0.125	<0.001	<0.001	<0.001	<0.001	0.160	0.022	0.165	<0.001	<0.001	9.9	1.332	41.0	27.31
LWS 05	<0.001	<0.001	0.232	<0.001	<0.001	<0.001	<0.001	0.309	0.045	0.171	<0.001	<0.001	9.2	1.331	56.0	37.30
LWS 06	<0.001	<0.001	0.322	<0.001	<0.001	<0.001	<0.001	0.434	0.027	0.213	<0.001	<0.001	9.1	1.331	114.0	75.92
LWS 07	<0.001	<0.001	0.380	<0.001	<0.001	<0.001	<0.001	0.545	0.04	0.245	<0.001	<0.001	9.4	1.331	42.0	27.97
LWS 08	<0.001	<0.001	0.516	<0.001	<0.001	<0.001	<0.001	1.369	0.159	0.353	<0.001	<0.001	10.3	1.332	53.0	35.30
LWS 09	<0.001	<0.001	0.510	<0.001	<0.001	<0.001	<0.001	0.761	0.082	0.308	<0.001	<0.001	8.9	1.331	75.0	49.95
LWS 10	<0.001	<0.001	0.588	<0.001	<0.001	<0.001	<0.001	0.808	0.166	0.397	<0.001	<0.001	9.6	1.331	54.0	35.96
LWS 11	<0.001	<0.001	0.992	<0.001	<0.001	<0.001	<0.001	2.344	0.169	1.135	<0.001	<0.001	8.6	1.331	280.0	186.48
LWS 12	<0.001	<0.001	0.429	<0.001	<0.001	<0.001	<0.001	0.670	0.063	0.409	<0.001	<0.001	9.4	1.332	52.0	34.63
LWS 13	<0.001	<0.001	0.481	<0.001	<0.001	<0.001	<0.001	0.728	0.09	0.393	<0.001	<0.001	9.0	1.331	129.0	85.91
LWS 14	<0.001	<0.001	0.411	<0.001	<0.001	<0.001	<0.001	0.615	0.086	0.334	<0.001	<0.001	10.1	1.331	51.0	33.97
LWS 15	<0.001	<0.001	0.809	<0.001	<0.001	<0.001	<0.001	0.615	0.182	0.321	<0.001	<0.001	9.5	1.333	48.0	31.97
LWS 16	<0.001	<0.001	0.789	<0.001	<0.001	<0.001	<0.001	0.597	0.186	0.646	<0.001	<0.001	9.4	1.331	49.0	32.63
LWS 17	<0.001	<0.001	0.481	<0.001	<0.001	<0.001	<0.001	0.678	0.094	0.334	<0.001	<0.001	9.2	1.331	150.0	99.90
LWS 18	<0.001	<0.001	0.355	<0.001	<0.001	<0.001	<0.001	0.581	0.052	0.263	<0.001	<0.001	10.0	1.331	120.0	79.92
Mean	<0.001	<0.001	0.463	<0.001	<0.001	<0.001	<0.001	0.672	0.084	0.341	<0.001	<0.001	9.606	1.331	75.783	50.471
STD	<0.001	<0.001	0.235	<0.001	<0.001	<0.001	<0.001	0.502	0.061	0.235	<0.001	<0.001	0.601	0.001	64.449	42.923
CV	<0.001	<0.001	0.508	<0.001	<0.001	<0.001	<0.001	0.747	0.726	0.689	<0.001	<0.001	0.063	7.5	0.850	0.850
WHO, 2018	<3	2	0.20*	0.4	0.05	0.07	0.01	200	75*	10*	0.2	0.003	6.5–8.5*	5*	1000*	500*

SP is sampling points, STD is standard deviation, CV is correct value, WHO, 2018 figures are guidance values from the World Health Organisation, * values not defined by the WHO, 2018 drinking water guidelines and was obtained from the Standard Organization of Nigeria, 2007). Maximum detection limit of the equipment is 0.001 mg L^{-1}.

and 3). Similarly, all samples collected in the rainy season recorded concentration below 0.001 mg L^{-1} for Zn, Mn, Pb, and Fe, even at those locations where reasonable concentrations were recorded in the dry season e.g. LWS01, LWS02, LWS14 etc. for Zn, LWS14, LWS17 and LWS 18 for Mn, LWS15 and LWS16 for Pb and LWS02 – LWS18 for Fe. This is suggestive of the influence of diffusion on the concentrations of these metals, and in consonance with the view that episodic rainfall mobilises aqueous metals from regions of higher concentrations to lower concentrations (Valencia-Avellan et al., 2017). This observation is in contrast with that of Yao et al. (2014), who documented unusually high metallic contents in rainy season over dry season in the Wusong and Taipu rivers, China.

The spatiotemporal value of Zn in the sampled water is extremely low during the rainy season (Table 3), and slightly different in the dry season, though the values are under the allowable limit of 3.00 mg L^{1} (Table 2). Comparative analysis shows that the Landzun Stream is quantitatively more enriched with Mg in the dry season than in the rainy season (Tables 2 and 3). Calcium in the sampled waterfall below 0.001 mg L^{-1} in rainy seasons and extremely low in dry season below the allowable limit of 75 mg L^{-1} (Tables 2 and 3). An estimated 89% and 94% of samples collected in the rainy and dry seasons respectively are characterised by elevated Mg concentration that exceeds the allowable limit of 0.20 mg L^{-1}, with sample point 11, having the highest concentrations in both the dry (16.360 mg L^{-1}) and rainy (0.992 mg L^{-1}) seasons (Tables 2 and 3). Concentration ranges from 0.018 to 0.992 mg L^{-1} (mean ~0.463 mg L^{-1}) and <0.001–16.360 mg L^{-1} (meañ 7.972). Magnesium ion alongside Ca^{2+} are known culprits responsible for hardness in water. Increased intake of Mg salts is a potential causative factor of diarrhoea (Chandra et al., 2013). Conversely, some authors have also advocated inverse relationship between risk of cardiovascular diseases and high magnesium intake (Pocock et al., 1980; Kubis, 1985; Yang, 1998; Sengupta, 2013), especially in men (Lacey and Shaper, 1984). Spatiotemporally, Mn in the sampled water falls below the detection limit in both rainy and dry seasons, except for sampled points LWS14, LWS17, and LWS18 in the dry season. That is slightly high, but still within the allowable limits of SON (2007) standard.

None of the acquired samples during the rainy season has Pb concentration that exceeds the detection limit of 0.001 mg L^{-1}. However, samples from two bordering stations; LWS15 and LWS16 located upstream recorded Pb concentrations above the allowable limit of 0.10 mg L^{-1} in the dry season (Tables 2 and 3). The elemental concentrations of Na, Fe and K in the Landzun Stream are mostly low and of no public health concern in the rainy season, except for LWS 08, LWS 10, LWS 11, LWS 12, LWS 13, LWS 14and LWS 16 where K exceeds the allowable limit (Table 3). Sodium is generally low in the dry season, below the allowable limit of 200 mg L^{-1} (Table 3). On the contrary, Fe contents were observed to be very high in most sampled points in the dry season above the allowable limit of 0.3 mg L^{-1}, except in sample points LWS 02, LWS 06, LWS 10, LWS 12, LWS 14 & LWS 15 (Table 2). Similarly, K concentration in the dry season is essentially high across the sample stations and well above the allowable limit of 10 mg L^{-1} (Table 3). Although the World Health Organisation opined that adverse health effects connected with high K intake from potable water are unlikely to happen in a healthy human, renal patients may be at risk owing to pre-existing kidney damage (Gosselin et al., 1984). Medical conditions such as heart failure chest tightness, diarrhoea, nausea and vomiting, hyperkalaemia and shortness of breath have been identified as probable health risk from the intake of excessive K. Potassium concentration $\geq$11 g (21 g of salt substitute) have been recorded to result in fatality owing to hyperkalaemia and its consequential asystole after ingestion (Restuccio, 1992). However, the World Health Organisation (2009) had stated that available datasets are not sufficient to establish an upper limit for K in drinking water.

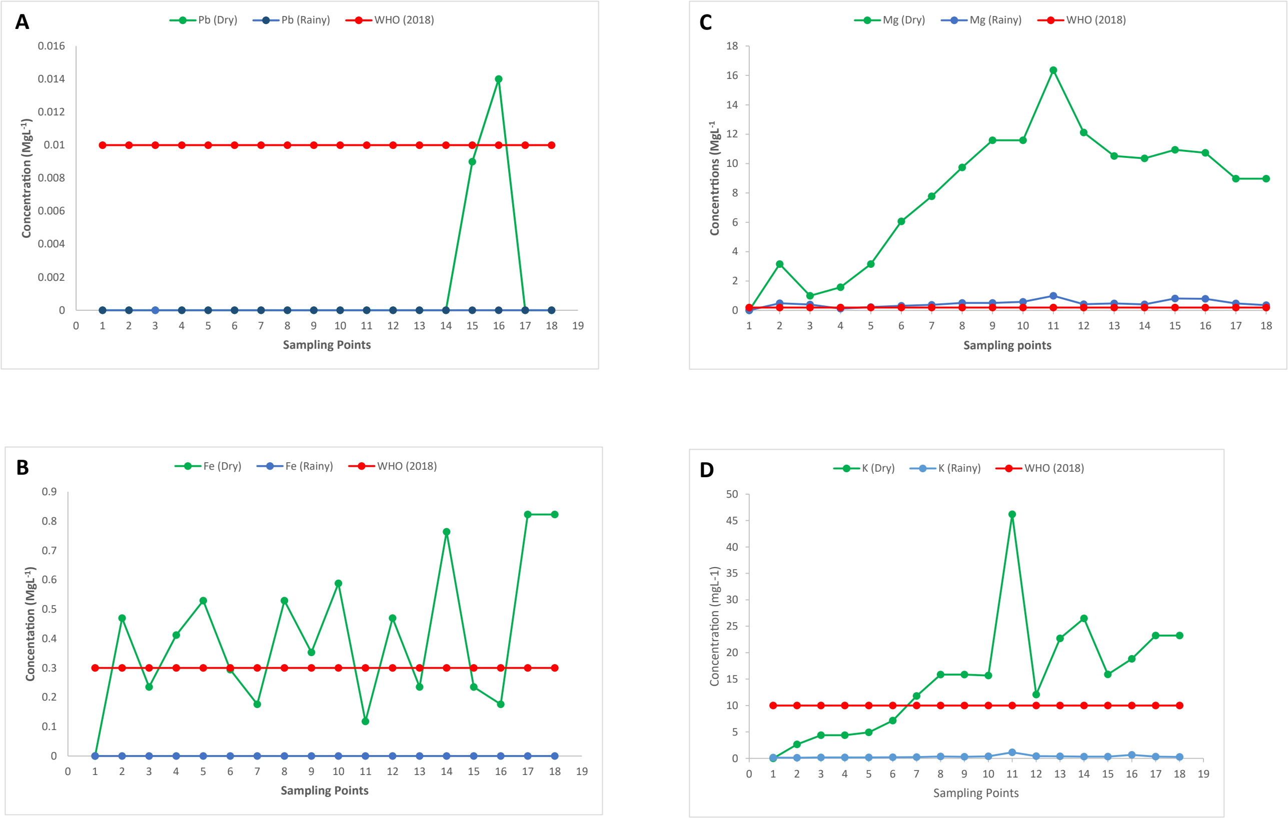

Fig. 6. Line graphs displaying metals with concentrations that exceed set threshold for drinking water in the Landzun stream (A) Lead, (B) Iron, (C) Magnesium and (D) Potassium.

4.3. Environmental risk implications

The relatively higher concentrations of Pb in LWS 15 and LWS 16 (Fig. 6A; Table 2) is of concern, especially noting that the concentration in the latter station exceeds the WHO (2018) allowable thresholds in drinking water (Fig. 5B). Pb is a known potentially toxic metal (PTM) in drinking water (Igwe et al., 2014; McCluggage, 1991). Its' possible impacts on human health, when ingested in any form is believed to be accumulative (Duruibe et al., 2007; Igwe et al., 2014). Based on the WHO (2018) thresholds for drinking water, the possible health risks associated with high Pb intake (i.e. $> 0.01 \text{mgL}^{-1}$) includes exposure to cancerous growth, interference with Vitamin D metabolism, affect mental development in infants, as well as the toxicity of the central and peripheral nervous systems. Lead poisoning can be either acute or chronic (Jaishankar et al., 2014). The former lead to appetite loss, headache, renal dysfunction, sleeplessness, hypertension, abdominal pain, fatigue (Martin and Griswold, 2009). Similarly, chronic exposure to Pb can result in mental retardation in children, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage and may even cause death (Martin and Griswold, 2009; Jaishankar et al., 2014). Although Pb contamination in the samples is generally low and inconsistent, continuous exposure and possible increment in Pb concentration may have accumulated effect(s), capable of constituting at least a chronic exposure to lead. The fact that Pb dispersion in water and stream sediments has been proven to be low compared to other metals (Igwe et al., 2015), probably accounts for the absence of Pb in other sample locations, except the contiguous locations LWS 15 and LWS 16, and the fact that the analytical equipment could not detect Pb in the rainy season is accounted for by higher volume of water in the stream during the season, thereby reducing its' concentration.

The relatively higher concentrations ($>10 \text{ mg L}^{-1}$) documented for Fe in >77% of the water samples in the dry season (Fig. 6B; Table 2) advocates secondary contamination, as Fe is a proven carrier of potentially harmful bacteria (Weinberg, 2000). Additionally, high intake of iron is a proven cause of iron overload, which is a causative factor for hemochromatosis that could degenerate to liver, heart and pancreatic damages, as well as diabetes (Turnberg, 1965; Adams et al., 2002). Intake of Fe-rich water beyond the acceptable threshold, hold the potential to lead to stomach problems, nausea and vomiting (Weinberg, 1999; Rimon et al., 2005), as well as skin wrinkles (Pouillot et al., 2013). The fact that inhabitants depend largely on this water for domestic purposes (Figs. 4 and 5) including drinking and bathing is a potential environmental risk concern.

Virtually all analysed samples exceeded the quoted acceptable limit for Mg in drinking water in both seasons (Fig. 6C). High magnesium is suggestive of water hardness. Although no significant adverse effect is documented for excessive magnesium intake by the WHO (2018) guideline for drinking water, it has been postulated that consumption of magnesium above the body requirement is particularly dangerous for persons with cancerous cells (Castiglioni and Maier, 2011). Although documented information on reported water-related diseases from local health centres was not available for this study, authors knowledge on the literacy level of the inhabitants, their exposures and access to medical facilities suggests that undiagnosed medical conditions connected with indiscriminate domestic use may not be uncommon among the populace. Even though no useful environmental risk is documented by the WHO (2018) for excessive intake of K, this study established that 66.7% of samples in the dry season significantly exceed the SON (2007) (Fig. 6D; Table 2). Though observed plantations contiguous to the channel (Figures 5C & D) were not analysed, Igwe et al. (2013) had reported that plant tissues from contaminated soil are significantly enriched with the same metals as the soils in which they grow. Hence the growth of millets and oil palm on land irrigated by the water of the Landzun Stream may serve as means for transporting excess metals to consumers of produce from such plantations.

According to Daramola (2013), three microbiological organisms characterised the Landzun Stream. These are *Bacillus subtilis, Klebsiella pneumonia* and *Proteus vulgaris.* The documented presence of these microbes justifies the muddy odour/taste, earlier arrogated to bacteria activity, thus buttressing Hack (1981) and Suffet et al. (1999) assertions. Although critical examination of the 2018 WHO drinking water guidelines revealed that none of the trios is listed to be potentially harmful to human, studies have established that some could be possibly risky. For example, Barati et al. (2016) reported that strains of *K. pneumoniae* isolated from the Matang mangrove estuary, Malaysia can be possibly virulent to humans being based on phenotypic and genotypic characterisation. Poor hygiene level of the inhabitants vis-à-vis the lack of processing (especially boiling) of the stream water before drinking and the unrestricted swimming/bathing in the channel all constitute environmental microbial risks to the users of the Landzun Stream.

4.4. Conclusion

The influence of seasonal variation on surface water quality and potential risks connected with the ingestion of untreated stream water in a semi-urban area was carried out. Findings show that most aesthetic physical qualities of the stream water are generally below the recommended guidelines for drinking water, and largely worse in the dry season. Hence, this study has shown that local seasonal variation plays a significant factor in altering the organoleptic, physical and hydrochemical qualities of surface water and that the quality of surface water is generally better in the rainy season than in the dry season based on the presented data. The concentrations of PTMs, such as Zn, Cu, Mn, Cr, Ni, Na, Ca, Cd are insignificant to constitute environmental risks. However, the higher concentrations of Pb, Fe, Mg and K in the dry season than their respective set-thresholds in drinking water by WHO (2018) calls for urgent check by relevant agencies, government representatives, public health practitioners and community leaders. Practices such as swimming, bathing and washing of household kitchen utensils in the Landzun Stream channel constitute significant environmental risks. Similarly, animal grazing and agricultural plantations flanking the stream bank may serve as potential means of extending potential risk in the water to consumers of the meat and farm products. The documented presence of *Bacillus subtilis, Klebsiella pneumonia* and *Proteus vulgaris* points to faecal contamination and may be potentially harmful to humans. A more detailed study of microbial risks associated with Landzun Stream is recommended alongside an alternative supply of drinking water to the Bida Central community and stern discouragement of inhabitants from using the Landzun Stream water for domestic purposes.

Declarations

Author contribution statement

Japhet Daramola: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Toriman Mohd Ekhwan: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Ekundayo Joseph Adepehin: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

J Mokhtar, Kuok-Choy Lam, Ah Choy Er: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by the Tertiary Education Trust Fund (TETFUND) Institution Based Research (IBR) 2015 grant (No: Batch 2 TETFUND/DESS/POLY/BIDA/RP/VOL.II/Sn10) to the first author through the Federal Polytechnic Bida, Niger State, Nigeria.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

Authors are grateful to the Federal Polytechnic Bida, Niger State Nigeria for the permission to publish this work. Mr. Isaac Okorie of the Centre for Genetic Engineering and Biotechnology, Federal University of Technology Minna. Niger State helped with laboratory analysis. We acknowledge his assistance with thanks. We are grateful to Heliyon editorial team and the two anonymous reviewers for their criticisms that improved the quality of the manuscript.

References

Adams, P.C., Acton, R., Barton, J., Dawkins, F., Eckfeldt, J., Gordeuk, V., Reboussin, D., 2002. Hemochromatosis and iron overload screening study (HEIRS): an interim analysis of 20,130 primary care persons. In: Gastroenterology, Vol. 122, No. 4. WB Saunders Co, Independence Square West Curtis Center, Ste 300, Philadelphia, Pa 19106-3399 USA pp. A634-A634.

Adeleye, D.R., 1973. Origin of ironstones, an example from the middle Niger Valley, Nigeria. J. Sediment. Res. 43 (3), 709–727.

Adeleye, D.R., 1974. Sedimentology of the fluvial bida sandstone (cretaceous), Nigeria. Sediment. Geol. 12 (1), 1–24.

Adeleye, D.R., 1989. The geology of the Middle Niger Basin. In: Kogbe, C.A. (Ed.), Geology of Nigeria. 2nd Rock View Nigeria Limited, Jos, pp. 335–339.

Adepehin, E.J., 2015. Preliminary risk assessment of lead-zinc mining in part of the Benue Trough, Nigeria. In: Paper presented at the 2015 AAAS Annual Meeting (12-16 February 2015). American Association for the Advancement of Science.

Akande, S.O., Ojo, O.J., Ladipo, K.O., 2005. Upper Creaceous Sequence in Te Soutern Bida basin, Nigeeia. A Field Guide Book. NAPE Geological Field Guide No. 1. Mosuro Publishers, Ibadan, Nigeria, 60 pp.

Areola, O., Ahmed, K., Leong, G.C., Irueghe, O.I., Ikwuyatum, G.O., Adeleke, B.O., 2014. Comprehensive Certificate Geography for Senior Secondary Schools (Physical, Human and Regional Geography with Map Reading). University Press PLC, Nigeria.

Ayoade, J.O., 1988. Tropical Hydrology and Water Resources. Macmillan Publishers Ltd, London, and Basingstoke, pp. 5–7. Siting Boreholes. Groundwater 26, 54-63.

Barati, A., Ghaderpour, A., Chew, L., Bong, C., Thong, K., Chong, V., Chai, L., 2016. Isolation and characterization of aquatic-borne *Klebsiella pneumoniae* from tropical estuaries in Malaysia. Int. J. Environ. Res. Public Health 13 (4), 426.

Bhutiani, R., Khanna, D.R., Kulkarni, D.B., Ruhela, M., 2016. Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices. Appl. Water Sci. 6 (2), 107–113.

Brewster, M.Q., 2015. Evaporation and condensation of water mist/cloud droplets with thermal radiation. Int. J. Heat Mass Transf. 88, 695–712.

Brown, W., 1999. Kinetic vs thermal energy. In: Ask A Scientist. Retrieved from. http://www.newton.dep.anl.gov/askasci/chem99/chem99045.htm.

Buerge, I.J., Poiger, T., Müller, M.D., Buser, H.R., 2003. Caffeine, an anthropogenic marker for wastewater contamination of surface waters. Environ. Sci. Technol. 37 (4), 691–700.

Carvalho, F.P., 2017. Pesticides, environment, and food safety. Food Energy Secur. 6 (2), 48–60.

Castiglioni, S., Maier, J.A., 2011. Magnesium and cancer: a dangerous liason. Magnes. Res. 24 (3), 92–100.

Chandra, R., Singh, S., Raj, A., 2006. Seasonal bacteriological analysis of Gola river water contaminated with pulp paper mill waste in Uttaranchal, India. Environ. Monit. Assess. 118 (1), 393–406.

Chandra, A.K., Sengupta, P., Goswami, H., Sarkar, M., 2013. Effects of dietary magnesium on testicular histology, steroidogenesis, spermatogenesis and oxidative stress markers in adult rats. Indian J Exp Biol. 51 (1), 37–47.

China Water Risk, 2018. No Water No Growth – does Asia Have Enough Water to Growth? Retrieved from. http://www.chinawaterrisk.org/the-big-picture/chinas-water-sources. on March 20th, 2019.

Craun, G.F., 1988. Surface water supplies and health. J. Am. Water Work. Assoc. 80 (2), 40–52.

Daramola, J., 2013. Spatiotemporal Variation in Hydrochemistry of Landzun Stream in Bida, Niger State of Nigeria. A dissertation submitted to the Department of Geography and Environmental Management, Faculty of business and social sciences. University of Ilorin, Ilorin Nigeria, 212 pp.

Duan, W., He, B., Nover, D., Yang, G., Chen, W., Meng, H., Liu, C., 2016. Water quality assessment and pollution source identification of the eastern Poyang Lake Basin using multivariate statistical methods. Sustainability 8 (2), 133.

Duruibe, J.O., Ogwuegbu, M.O.C., Egwurugwu, J.N., 2007. Heavy metal pollution and human biotoxic effects. Int. J. Phys. Sci. 2 (5), 112–118.

Egbinola, C.N., 2017. Trend in access to safe water supply in Nigeria. J. Environ. Earth Sci. 7 (8), 89–96.

Eludoyin, A.O., Ojo, A.T., Ojo, T.O., Awotoye, O.O., 2017. Effects of artisanal gold mining activities on soil properties in a part of southwestern Nigeria. Cogent Environ. Sci. 3 (1), 1305650.

Epundu, U.U., Adinma, E.D., Ezeama, N.N., Emelumadu, O.F., Ogbonna, B.O., 2017. A review on packaged drinking water, quality regulations and public health: exploring potability and safety gap implications for public health in Nigeria. Int. J. Trop. Dis. Health 25 (3), 1–10.

Fondriest Environmental, Inc, 7 Feb. 2014. "Water Temperature." Fundamentals of Environmental Measurements. https://www.fondriest.com/environmental-measurements/parameters/water-quality/water-temperature/.

Food and Agriculture Organisation, 2016. AQUASTAT Website. Food and Agriculture Organization of the United Nations (FAO). Website accessed on [2019/07/04].

Fufeyin, Y.P., 1994. Heavy Metals Concentration in Water, Sediment and Fish Species of Ikpoba Reservoir, Benin City. Ph.D. Thesis. University of Benin, Benin City, Nigeria, p. 167.

Gosselin, R.E., Smith, R.P., Hodge, H.C., 1984. Clinical Toxicology of Commercial Products, fifth ed. Williams & Wilkins, Baltimore, MD.

Gupta, S.K., 2011. Modern Hydrology and Sustainable Water Development. John Wiley & Sons.

Hack, D.J., 1981. Common customer complaint: my hot water stinks. Opflow 7 (9), 3.

Holloway, J.M., Dahlgren, R.A., Hansen, B., Casey, W.H., 1998. The contribution of bedrock nitrogen to high nitrate concentrations in stream water. Nature 395 (6704), 785–788.

Hongve, D., Riise, G., Kristiansen, J., 2004. Increased color and organic acid concentrations in Norwegian forest lakes and drinking water–a result of increased precipitation? Aquatic Sci.-Res. Across Bound. 66 (2), 231–238.

Igwe, O., Okechukwu, N., Adepehin, E.J., 2013. Assessment of asbestos waste dumpsite in Enugu meteropolis, Southeastern Nigeria. Implication for environmental concern. Nigeria J. Education Health Technol. Res. 4, 146–158.

Igwe, O., Adepehin, E.J., Iwuanyanwu, C., Una, C.O., 2014. Risks associated with the mining of Pb–Zn minerals in some parts of the Southern Benue trough, Nigeria. Environ. Monit. Assess.

Igwe, O., Adepehin, E.J., Adepehin, J.O., 2015. Integrated geochemical and microbiological approach to water quality assessment: case study of the Enyigba metallogenic province, South-eastern Nigeria. Environ. Earth Sci. 74 (4), 3251–3262.

Igwe, O., Una, C.O., Abu, E., Adepehin, E.J., 2017. Environmental risk assessment of lead–zinc mining: a case study of Adudu metallogenic province, middle Benue Trough, Nigeria. Environ. Monit. Assess. 189 (10), 492.

Izah, S.C., Angaye, T.C., 2016. Heavy metal concentration in fishes from surface water in Nigeria: potential sources of pollutants and mitigation measures. Sky J. Biochem. Res. 5 (4), 31–47.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N., 2014. Toxicity, mechanism and health effects of some heavy metals. Interdiscip. Toxicol. 7 (2), 60–72.

Jamieson, R., Gordon, R., Joy, D., Lee, H., 2004. Assessing microbial pollution of rural surface waters: a review of current watershed scale modeling approaches. Agric. Water Manag. 70 (1), 1–17.

Jones, H.A., 1958. The oolitic ironstone of Agbaja Plateau,Kabba province. Rec. Geol. Surv. Niger. 1955, 20–43.

Kakulu, S.E., Osibanjo, O., Ajayi, S.O., 1987. Trace metal content of fish and shellfishes of the Niger Delta area of Nigeria. Environ. Int. 13, 247–251.

Khan, M.Y.A., Gani, K.M., Chakrapani, G.J., 2016. Assessment of surface water quality and its spatial variation. A case study of Ramganga River, Ganga Basin, India. Arab. J. Geosci. 9 (1), 28.

Kogbe, C.A., 1981. Attempt to correlate the stratigraphic sequence in the middle Benue basin with those of the Anambra and upper Benue basins. Earth Evol. Sci. 2, 139–143.

Kolawole, O.M., Ajayi, K.T., Olayemi, A.B., Okoh, A.I., 2011. Assessment of water quality in Asa River (Nigeria) and its indigenous *Clarias gariepinus* fish. Int. J. Environ. Res. Public Health 8 (11), 4332–4352.

Kubis, M., 1985. Relation of water hardness to the occurrence of acute myocardial infarct. Acta Univ. Palacki. Olomuc. Fac. Med. 111, 321.

Lacey, R.F., Shaper, A.G., 1984. Changes in water hardness and cardiovascular death rates. Int. J. Epidemiol. 13 (1), 18–24.

Letcher, B.H., Hocking, D.J., O'Neil, K., Whiteley, A.R., Nislow, K.H., O'Donnell, M.J., 2016. A hierarchical model of daily stream temperature using air-water temperature synchronization, autocorrelation, and time lags. PeerJ 4, e1727.

Majumdar, S.B., Sproul, O.J., 1974. Technical and economic aspects of water and wastewater ozonation: a critical review. Water Res. 8 (5), 253–260.

Marcus, A.,C., 2011. Trace metals contents of bonny river and creeks around Okrika, Rivers State, Nigeria. A research thesis submitted in partial fulfillment of the requirement for the award of a doctor of philosophy (Ph.D.) Degree in Environmental/analytical Chemistry in the Department of Pure and Industrial Chemistry, Faculty of physical sciences. University of Nigeria, Nsukka, Nigeria.

Martin, S., Griswold, W., 2009. Human health effects of heavy metals. Environ. Sci. Technol. Brief Citizens 15, 1–6.

McCluggage, D., 1991. Heavy Metal Poisoning, NCS Magazine. Published by the Bird Hospital, CO, U.S.A. http://www.cockatiels.org/articles/Diseases/metals.html. (Accessed 4 August 2012).

Mompelat, S., Thomas, O., Le Bot, B., 2011. Contamination levels of human pharmaceutical compounds in French surface and drinking water. J. Environ. Monit. 13 (10), 2929–2939.

Nigeria Population Commission, 2007. National Census. Retrieved from. www.nigeriamasterweb.com/nigeria06c on 32/09/12.

Nwajide, C.S., 2013. Geology of Nigeria's Sedimentary Basin. CSS Bookshops Limited, 565pp.

Obaje, N.G., 2009. Geology and mineral Resources of Nigeria. Springer, Berlin, London, 221pp.

Ojo, S.B., Ajakaiye, D.E., 1989. Preliminary interpretation of gravity measurements in the mddle Niger basin area, Niger. In: Kogbe, C.A. (Ed.), Geology of Nigeria, second ed. Rock View Nigeria, Limited, Jos, pp. 347–358.

Ojo, O.J., Akande, S.O., 2006. Microflora biostratigraphy, paleoecology and paleoclimate of the upper cretaceous Patti Formation, SE Bida Basin. In: NAPE conference proceedings, August 2006, pp. 69–73.

Ojo, O.J., Akande, S.O., 2008. Microflora assemblage, age and paleoevironment of the upper cretaceous Patti Formation, SE Bida Basin. Nigerian J. Min. Geol. 44, 71–81.

Okoye, B.C.O., 1989. Heavy Metals in the Lagos Lagoon. Ph.D. Thesis. Department of Chemistry. Obafemi Awolowo University, Ile-Ife, Nigeria.

Ola, P.S., Adepehin, E.J., 2017. Sedimentological interpretation of coastal ditch cuttings: implications for subsurface geology and provenance in Dahomey Basin, Nigeria. Arab. J. Geosci. 10 (3), 65.

Panglisch, S., Holy, A., Urban, F., Dautzenberg, W., Sous, P., Ohligschläger, J., Gimbel, R., 2005. Transferring pilot experiments into the planning of Germany's largest two-stage ultrafiltration plant. Desalination 179 (1-3), 225–235.

Persson, P.E., 1982. Muddy odour: a problem associated with extreme eutrophication. Hydrobiologia 86 (1-2), 161–164.

Pocock, S.J., Shaper, A.G., Cook, D.G., Packham, R.F., Lacey, R.F., Powell, P., Russell, P.F., 1980. British Regional Heart Study: geographic variations in cardiovascular mortality, and the role of water quality. Br. Med. J. 280 (6226), 1243–1249.

Pouillot, A., Polla, A., Polla, B.S., 2013. Iron and iron chelators: a review on potential effects on skin aging. Curr. Aging Sci. 6 (3), 225–231.

Princeton Climate Analytics (PCA), 2019. African Flood and Drought Monitor. Website accessed on May 30th, 2019. https://platform.princetonclimate.com/AFDM/interface.php?locale=en.

Restuccio, A., 1992. Fatal hyperkalemia from a salt substitute. Am. J. Emerg. Med. 10 (2), 171–173.

Richards, S., Paterson, E., Withers, P.J., Stutter, M., 2016. Septic tank discharges as multi-pollutant hotspots in catchments. Sci. Total Environ. 542, 854–863.

Rimon, E., Kagansky, N., Kagansky, M., Mechnick, L., Mashiah, T., Namir, M., Levy, S., 2005. Are we giving too much iron? Low-dose iron therapy is effective in octogenarians. Am. J. Med. 118 (10), 1142–1147.

Riva, F., Zuccato, E., Davoli, E., Fattore, E., Castiglioni, S., 2019. Risk assessment of a mixture of emerging contaminants in surface water in a highly urbanized area in Italy. J. Hazard Mater. 361, 103–110.

Scott, T.L., Mike, R.S., Ton, H.S., Ned, J.N., Barry, J.F.B., 2004. Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. N. Z. J. Mar. Freshw. Res. 38, 347–366.

Seinfeld, J.H., Pandis, S.N., 2016. Atmospheric Chemistry and Physics: from Air Pollution to Climate Change. John Wiley & Sons.

Sengupta, P., 2013. Potential health impacts of hard water. Int. J. Prev. Med. 4 (8), 866.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Kouimtzis, T., 2003. Assessment of the surface water quality in Northern Greece. Water Res. 37 (17), 4119–4124.

Standard Organization of Nigeria, 2007. Nigeria Standard for Drinking Water Quality, pp. 15–17.

Strady, E., Dang, V.B.H., Némery, J., Guédron, S., Dinh, Q.T., Denis, H., Nguyen, P.D., 2016. Baseline seasonal investigation of nutrients and trace metals in surface waters and sediments along the Saigon River basin impacted by the megacity of Ho Chi Minh (Vietnam). Environ. Sci. Pollut. Control Ser. 1–18.

Suffet, I.M., Khiari, D., Bruchet, A., 1999. The drinking water taste and odor wheel for the millennium: beyond geosmin and 2-methylisoborneol. Water Sci. Technol. 40 (6), 1–13.

Turnberg, L.A., 1965. Excessive oral iron therapy causing haemochromatosis. Br. Med. J. 1 (5446), 1360.

Udodo-Umeh, G., 2002. Pollution Assessment of Olomoro Water Bodies Using Physical, Chemical and Biological Indices. Ph.D. Thesis. University of Benin, Benin City, Nigeria.

United Nations General Assembly, 2010. Resolution A/RES/64/292. General Comment No. 15. The Right to Water. UN Committee on Economic, Social and Cultural Rights, November 2002.

United States Geological Survey, 2015. Surface Water Use in the United States. Retrieved on March 19, 2019 from. https://water.usgs.gov/edu/wusw.html.

United States- Environmental Protection Agency - US-EPA, 2019. Ground Water and Drinking Water Regulations. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

Valencia-Avellan, M., Slack, R., Stockdale, A., Mortimer, R.J.G., 2017. Effect of episodic rainfall on aqueous metal mobility from historical mine sites. Environ. Chem. 14 (8), 469–475.

Wei, S., Gnauck, A., 2007. Simulating Water Conflicts Using Game Theoretical Models for Water Resources Management WIT Transactions on Ecology and the Environment, 106. WIT Press.

Weinberg, E.D., 1999. Iron loading and disease surveillance. Emerg. Infect. Dis. 5 (3), 346.

Weinberg, E.D., 2000. Microbial pathogens with impaired ability to acquire host iron. Biometals 13 (1), 85–89.

World Health Organisation, 2009. Potassium in Drinking-Water Background Document for Development of WHO Guidelines for Drinking-Water Quality, pp. 1–5.

World Health Organisation, 2018. A Global Overview of National Regulations and Standards for Drinking-Water Quality, 104pp.

World Water Assessment Program, 2006. Water: a Shared Responsibility; the United Nations World Water Development Report 2. UNESCO, 601pp.

Yang, C.Y., 1998. Calcium and magnesium in drinking water and risk of death from cerebrovascular disease. Stroke 29 (2), 411–414.

Yang, Q., Jung, H.B., Culbertson, C.W., Marvinney, R.G., Loiselle, M.C., Locke, D.B.,, et al., 2009. Spatial pattern of groundwater arsenic occurrence and association with bedrock geology in greater Augusta, Maine. Environ. Sci. Technol. 43 (8), 2714–2719.

Yang, X., Liu, Q., Fu, G., He, Y., Luo, X., Zheng, Z., 2016. Spatiotemporal patterns and source attribution of nitrogen load in a river basin with complex pollution sources. Water Res. 94, 187–199.

Yao, H., Qian, X., Gao, H., Wang, Y., Xia, B., 2014. Seasonal and spatial variations of heavy metals in two typical Chinese rivers: concentrations, environmental risks, and possible sources. Int. J. Environ. Res. Public Health 11 (11), 11860–11878.