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Evaluation of Surface Water Contamination Using Heavy Metal Pollution Indices in the Mgoua Watershed, Southwestern Cameroon

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An integrated pollution assessment index approach was used to assess the application of heavy metal pollution indices in the Ngoua watershed in southwestern (SW) Cameroon. The concentrations of Pb, Cr, Cu, Ni, Zn, Mo, Fe and Al in most of the water samples exceeded the maximum allowable concentration recommended by the World Health Organization (WHO). The Heavy Metal Evaluation Index (HEI) shows strong correlations with the Heavy Metal Pollution Index (HPI), Metal Index (MI) and the degree of contamination (C_d), and gives a better assessment of the pollution levels. Selected samples from the 10 sampling stations were classified as high polluted in C_d, MI and HPI in relation to the respective critical values. These values show comparable results to those of the HEI and indicate that about 88% of the samples with above average values were classified as highly contaminated and the remaining samples (12%) with below average values were classified as moderately contaminated. The Enrichment Factor (EF) analysis and the pollution indices reveal that the water quality is mainly controlled by natural and geogenic processes with major anthropogenic input. The current level of heavy metal distribution in the water of the Ngoua catchment is an environmental and health concern and requires special attention.

Introduction

The Mgoua river catchment, that harbours an active industrial area, is one of the principal catchments in south western Cameroon because its water is used for a wide range of purposes that include among many others, domestic, irrigation, fisheries, navigation, and industrial uses (Ndjama *et al.*, 2008; Noa Tang *et al.*, 2021). However, the quality of the water, that is very important for human health and for the environment, has been undermined by anthropogenic factors such as agriculture, urbanization, industrialization and rapid population growth. These activities are culminating in the indiscriminate discharge of warm waste/effluent water, laden with heavy metals into the surface waters of the catchment. This is similar to what has been observed elsewhere in the world where various kinds of pollutants, like heavy metals and inorganic ions have been introduced into surface waters through different mechanisms (Bhardwaj *et al.,* 2017; Pandey and Singh, 2017; Ekoa Bessa *et al.,* 2018a).

In spite of their contaminant potential, not all heavy metals are toxic. Antoine *et al.,* (2012) and Myvizhi and Devi (2020), have categorized heavy metals into two main groups: one as biologically essential and the other as nonessential. Heavy metals such as cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni),vanadium (V) and zinc (Zn) are characterized as essential because they play an indispensable role in the functioning of living beings (animals and human). For example, they play a very important role in different metabolic functions and enzymatic activities and in protein transport. However, when their concentrations exceed a certain threshold, they become toxic (Jaishankar *et al.,* 2014; Binam Mandeng *et al.,* 2019; Armstrong-Atrin *et al.,* 2021). On the other hand, non-essential heavy metals such as aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), lead (Pb), strontium (Sr), titanium (Ti), rubidium (Rb), zirconium (Zr), lithium (Li), yttrium (Y) and uranium (U) are toxic even at very low levels. Assessment of heavy metal contamination in basins and even rivers is therefore important due to the threat they may pose by way of their bio magnifications and their toxicity to aquatic life, human health and to the environment (Ahmed *et al.,* 2015; Ali *et al.,* 2016; Ekoa Bessa *et al.,* 2018b;EkoaBessa *et al.,* 2021; Tchatchouang Chougong *et al.,* 2021). Heavy metal indices have been computed to assess the suitability level of water resources for drinking and non-drinking and also determine how the quality of these waters impact on the environment (Ndam Ngoupayou *et al.,* 2007; Noa Tang *et al.,* 2021).

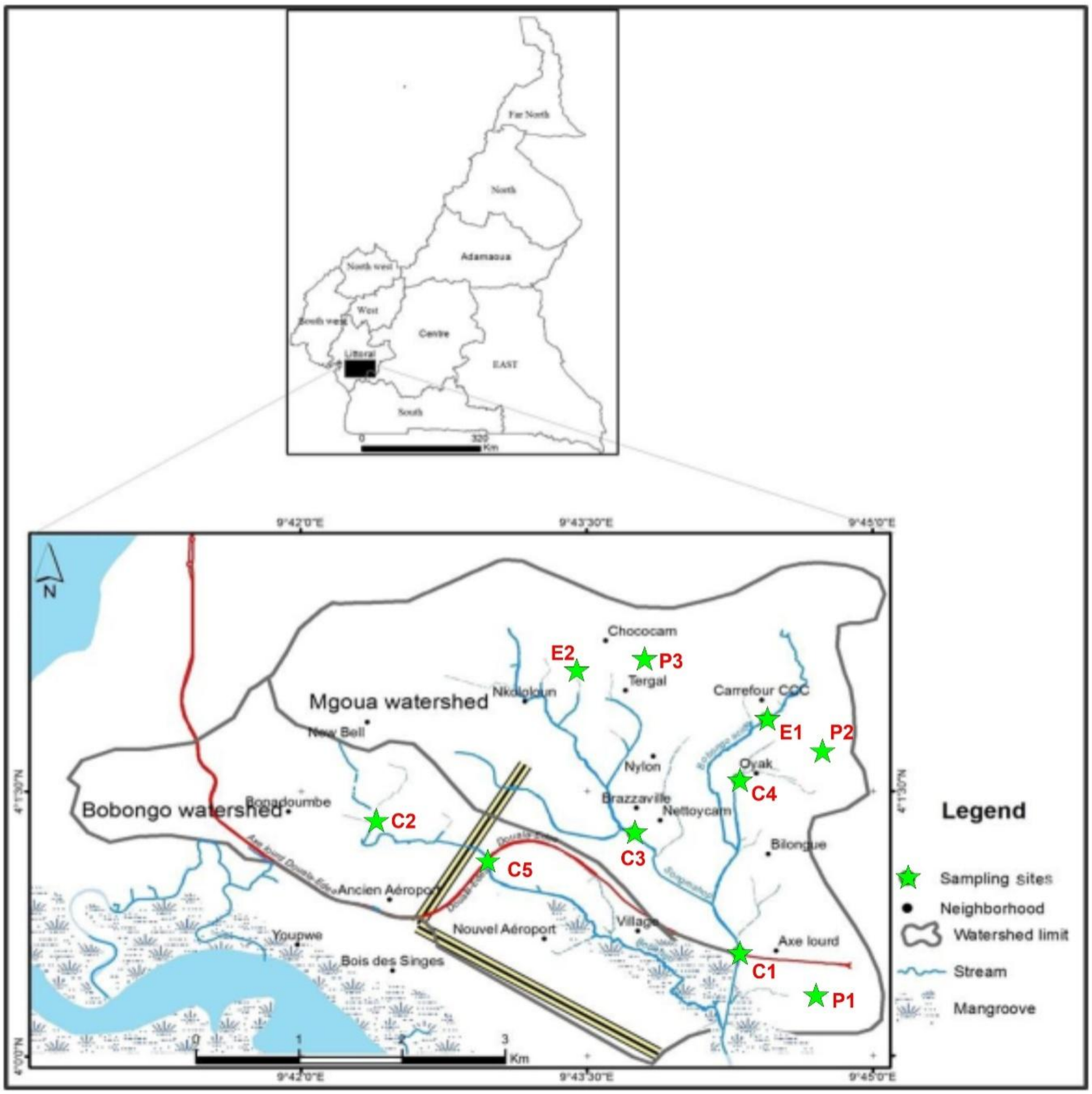
In the Mgoua catchment, prevailing factors such as increasing industrialization, spreading urbanization and increasing population without an accompanying adequate waste disposal scheme have increased the vulnerability of the surface water to contamination. This makes it imperative for the heavy metal load, a most likely contaminant, to be evaluated. This will help determine the potability of the water and its impact in the environment. In this study, an attempt has been made, for the first time, to determine the heavy metal content (Pb, Cr, Cu, Cd, Co, Ni, As, Zn, U, Mo, Fe, Al, Mn, Ba, Ti, Sr,Rb, Zr, Y, V, Li,) of surface water in the catchment and then deploy different pollution indices (HPI, HEI, MI, C_d and EF) to establish the suitability of the water for drinking and other purposes. This has been done against a backdrop of the WHO standards.

Materials and Methods

Study area

The Mgoua watershed is one of the seven watersheds of the Douala sedimentary basin, extending between 4°00' and 4°02' of latitude North and between 9°42' and 9°45' of longitude East (Fig.1). This 780 ha catchment is the site of many industrial activities that range from soap manufacturing, through paint production to brewery. Its more or less flat topography with altitudes of no more than 100m, characteristic of coastal lowlands, leads to poor drainage of the wastewater which in turn promotes water pollution. The climate is typically equatorial, characterized by two seasons: a long rainy season of about 9 months (March to November) and a short dry season of about 3 months (December to February). Meteorological data from the locality's national archives show that the average annual rainfall in the study area is 4000 mm/year. The temperature varies from 23 to 30°C, with an average value of 27°C (Belmonte, 1966). Winds are rarely violent, with an average speed of 1 m/s and the maximum speed does not exceed 14 m/s (Ketchemen, 2011).

Fig.1 Location of Ngoua basin and different sampling stations



The lithology of the Douala sedimentary basin shows several formations grouped according to their ages of deposition: Quaternary, Tertiary and Secondary (Njike, 1984; Regnoult, 1986; and Ngueutchoua *et al.*, 2019). The Wouri formation makes up the Quaternary sediments that are typified by limestones and clays such as kaolinite, smectite and illite. Tertiary sediments occur in Nkapa, Souellaba and Matanda formations. They of consists of black or brown clays with a few small sandy banks, clayey sands as well as fine sands and gravels alternating with plastic clays, arkosic sandstones showing layers of quartz with clay-limestone intercalations which become predominant towards the surface. The Logbaba and Mundeck formation make up the Secondary sediments. They consist of fossiliferous sandstone, sands and sandy clays (Dumort, 1968; Njike, 1984). The pedology of the study area is characterized by ferrallitic soils, hydromorphic soils, poorly evolved soils and rough mineral soils derived from sandstone and sandy-clay sediments (Ngueutchoua, 1996; Hieng, 2003).

Sampling and sample analysis

Sampling was done between March 2015 and February 2017. Ten samples were collected at different sites in the study area (Fig.1). Of the ten, five were from rivers (C1 to C5), three from shallow hand-dug wells (P1 to P3) and two (E1 and E2) from industrial effluents indiscriminately discharged from soap, brewery and paint producing plants into the riparian settlement.

All samples were filtered (Whatman no.45µm) and collected in 1000 ml polyethylene bottles which were acidified with nitric acid (HNO_3) to a pH of 2 to prevent the precipitation of metal. They were all transferred to laboratory in iceboxes and refrigerated at 4 °C until the day of analysis (Edet *et al.*, 2002). Samples were analyzed using Inductively Coupled Plasma Mass spectrometry (ICP-MS) with a Perkin-Elmer 5100 ZL equipment at the Geosciences and Environmental Laboratory at Toulouse (GET), in France.

Evaluation methods

Different methods were used for the evaluation pollution assessment in this study. They include Heavy Metal Pollution Index (HPI), Heavy metal Evaluation Index (HEI), Metal Index (MI), Degree of Contamination (C_d) and Enrichment Factor (EF).

These indices have been widely used to characterize the degree of pollution of each metal in the water (Brraich *et al.*, 2015; Panigrahy *et al.*, 2015; Tiwari *et al.*, 2014; Ndjama *et al.*, 2021). The methods are described below in detail.

Heavy metal pollution index (HPI)

HPI is a method that assesses the cumulative effects of individual heavy metals on the overall water quality (Mohan *et al.*, 1996) and is calculated as shown:

$$HPI = \frac{\sum_{i=1}^{n} Wi\, Qi}{\sum_{i=1}^{n} Wi} \quad (1)$$

where W_i is the unit weighting of the i^{th} heavy metal, Q_i is the sub-index for the i^{th} heavy metal, and n is the number of heavy metals which equals 14 (Pb, Cr, Cu, Cd, Co, Ni, As, Zn, U, Mo, Fe, Al, Mn and Ba) for this study. The sub-index (Q_i) is computed as:

$$Qi = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \quad (2)$$

where Mi (µg/L) is the examined value of the i^{th} heavy metal. Ii and Si are the ideal and standards values, respectively, for drinking water taken from WHO (2017) for the heavy metals (µg/L). A value of HPI below 100 represents low pollution of heavy metals, while 100 is the threshold value at which harmful health consequences are probable. An HPI value greater than 100 indicates the water is unsuitable for consumption.

Heavy metal evaluation index (HEI)

The Heavy metal evaluation index **(**HEI) gives an overall quality of the water regarding heavy metal content. It is computed from the following equation (Edet and Offiong, 2002) as follows:

$$HEI = \sum_{i=1}^{n} \frac{H_C}{H_{mac}} \qquad (3)$$

where, H_c indicates monitored value of the i^{th} parameter and H_{mac} indicates maximum admissible concentration (MAC) of the i^{th} parameter (Sobhanardakani, 2016).

According to Edet and Offiong (2002), the water quality is classified into three categories as follows: HEI< 10 for low, 10 <HEI<20 for moderate and HEI>20 is high pollution. This index was used for a better understanding of the pollution indices and was calculated for Pb, Cr, Cu, Cd, Co, Ni, As, Zn, U, Mo, Fe, Al, Mn and Ba among the selected trace metals.

Metal Index (MI)

The metal index (MI) is another index generally used for estimating the quality of water for different utilizations (Tamasi *et al.*, 2004). This assessment method addresses the effects of heavy metals on human health and helps to quickly appraise the overall quality of drinking waters (Mambenga *et al.*, 2017). Metal index is determined by the equation of Tamasi *et al.*, (2004):

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i} \qquad (4)$$

where $(MAC)_i$ is maximum allowable concentration for i and C_i is the mean concentration of each metal element. MI values greater than 1 is a threshold of warning (Addey *et al.*, 2018, Zahra Khoshnam *et al.*, 2017). Boateng *et al.*, (2019) have used MI values to establish six classes of water quality: very pure (<0.3), pure (0.3 – 1.0), slightly affected (1.0 – 2.0), moderately affected (20 – 4.0), strongly affected (4.0 – 6.0) and seriously affected.

Degree of Contamination (C_d)

The C_d method gives an estimate of the quality of water with respect to the degree of contamination using contamination factor. Therefore, the C_d recapitulates the combined effects of a number of quality parameters regarded as unsafe to domestic water (Nasrabadi, 2015).

C_d also known as contamination index, was developed by Backman *et al.*, (1997) and is also used as reference for estimating the extent for metal pollution (Rubio *et al.*, 2000). Degree of contamination is a sum of the contamination factors of the individual parameters that exceed the upper respective permissible values and is calculated as follows:

$$C_d = \sum_{i=0}^{n} Cfi \qquad (5)$$

$$C_{fi} = \frac{Ci}{Cn} - 1 \qquad (6)$$

where, C_{fi} is contamination factor for a single component, C_i is analytical value for the component and C_n is upper permissible concentration of the component. C_d has been used in previous research to assess the degree of metal pollution. It was calculated for Pb, Cr, Cu, Cd, Co, Ni, As, Zn, U, Mo, Fe, Al, Mn and Ba among the selected trace metals.

According to Nasrabadi (2015), C_d values are regrouped into three categories as follows: $C_d<1$ (low), $C_d= 1–3$ (medium) and $C_d>3$(high).

Enrichment Factor (EF)

Enrichment factor (EF) is commonly used to determine whether the sources of the metals are geogenic and/or anthropogenic as well as to assess the degree of metal contamination (Surindra *et al.*, 2019; Olivares-Rieumont *et al.*, 2005). EF values lower than 1.5 indicate geogenic sources (natural source), while those greater than 1.5 indicate anthropogenic sources (Wang *et al.*, 2008). Andrews and Sutherland (2004) suggested five contamination categories of enrichment factor and they are presented in Table 1.

Table.1 Enrichment factor according to Andrews and Sutherland (2004)

EF Value	Quality
< 2	Minimal enrichment
2-5	Moderate enrichment
5-20	Significant enrichment
20-40	Very highly enriched
> 40	Extremely highly enriched

Originally proposed by Buat-Menard and Chesselet (1979) to assess the metal enrichment in the water, it is expressed as:

$$EF= [(M_n/M_{ref})sample]/(B_n/B_{ref}) \qquad (7)$$

where, $M_{n\,(sample)}$ is the content of the examined element, $M_{ref(sample)}$ is the content of the reference element, B_n is the background value of the reference element. For this study, Fe was used as the reference at the average trace element content of rivers worldwide value (Gaillardet *et al.*, 1999).

Results and Discussion

Heavy metal concentrations

The statistics of the concentration of twenty-one heavy metals analyzed for the ten water samples, WHO (2017) guidelines and the average trace element content of rivers worldwide (Gaillardet *et al.*, 1999) is provided in Table 2. The average concentration values of all heavy metals in the water samples of this study range from 0.07 to 8151.60 µg/l with an average of 788.41 µg/l. Among all the analyzed heavy metals, the highest mean values detected are for Fe (8151.60 µg/l) followed by Ni (4355.84 µg/l) and Cr (3089.03 µg/l), while the lowest average concentration is observed for U (0.07 µg/l) followed by Cd (0.12 µg/l), Mn (0.42 µg/l) and Zr (0.48µg/l). Based on the mean concentration level and value for the twenty-one heavy metals analyzed in the stream water of the Mgoua catchment, the heavy metals are relatively ranked from the smallest to the highest value as follows: U< Cd< Mn< Zr< As< Y< V<Pb< Rb< Li< Mo< Ba< Co< Cu<Ti<Sr< Al< Zn< Cr< Ni <Fe.

A comparison of the mean concentration values of heavy metals in the study area with WHO standard values, shows that more than 50% of the heavy metals (Pb, Cr, Cu, Ni, Zn, Mo, Fe and Al) are above the permissible standard values of WHO (2017) while the rest (Cd, As, U, Mo, Mn, Ba and V)fall below (Table 2). But for U, Mn and Ti, all selected heavy metals in the Mgoua catchment are higher than the allowable limit for the Worldwide River average set by Gaillard *et al.*, (1999). From the foregoing, Cd, Cr, Cu, Ni, Zn and Al are the heavy metals from the samples in the study area that have the potential to deteriorate human health because their values are higher than WHO (2017) standards and Worldwide River average (Gaillard *et al.*, 1999). This corroborates

Domingo (1994) and Goorzadi *et al.*, (2009) assertion that although some elements are essential for humans, they can be dangerous at relatively high exposure levels.

Pollution evaluation indices

Five main tools were used to assess the risk level of metal contamination in the samples, notably HPI, MI, HEI, C_d and EF.

The HPI of the Mgoua surface waters ranges from 55.57 (E2) to 17468.08 (P1) with a mean of 1990.64 (Table 3). Their pollution status is illustrated in Figure.2 that shows that the concentration of all but one of the samples (E2) exceeds the threshold value of the pollution index which is 100. These values are higher than those reported by Dolma *et al.*, (2015) in the Sirsa Bassin in India (HPI ~ 16.78), while they are lower than those obtained by Enaam and Abdullah (2013) in Delta River (HPI ~ 2097). Measured against the work of Prasad and Bose (2001), the Mgoua values indicate that there is heavy metal pollution of the surface waters in the area and the source could be attributed mainly to domestic sewage and industrial discharge.

Table 4 shows that MI varies from 14.70 to 2977.38 with a mean value of 337.20. The highest value is observed in site P1 (2977.38) and the lowest value in site E2 (14.70) with the rest falling within that bracket in the following increasing sequence: E2< P3 < C5 < C1 < P2 < E1 < C3 < C2 < C4 < P1. Against a backdrop of the work of Boateng *et al.*, (2019), the Mgoua waters are seriously polluted with Pb, Cr, Ni and Fe, moderately polluted with Mo and slightly polluted with Al. This is due to the big number of industries including thermal power plant, fertilizer, chemical and mineral processing plants, textile mills, match factories and nearly 200 small scale industries that are located the area.

The HEI values range from 14.702 to 2977.39 with an average of 337.201 (Table 5). The highest value is observed in site P1 (2977.39) and the lowest in site E2 (14.702). The order for mean values of HEI is as follows: E2 < P3 <C5 <C1 <P2 <E1 <C3 <C2 <C4 <P1. According to the classification proposed by Edet and Offiong (2002), sampling sites C1, C5, P2, P3 and E2 have low pollution (HEI < 27), sites C2, C3 and E1 have medium pollution (27 < HEI < 54), while sites C4 and P1 have high pollution (HEI> 54). This observation can be explained by the downstream position of C4 and P1 which favors the accumulation of heavy metal. Similar observations have been made in the waters of Nile Delta in Egypt (Hegazy *et al.*, 2020).

The C_d of the studied water ranges from 34.27 (E2) to 13783.91 (P1), with a mean value of 1557.36 (Table 6). These values exceed 36 in 9of the 10samples with only 1 (sample E2 with value of 37.27) falling in the medium zone ($18 < C_d < 36$) of pollution. They are far above those obtained by Dolma *et al.*, (2015) and underscore water of very poor drinking quality.

Enrichment Factor of the heavy metals

The values obtained in this study are presented in Table 7. They vary from 0.00092 for Mn to 491.24 for Ni, with an average of 26.88. EF values from Mgoua watershed follow the descending other of Ni>Y>Cr>Cu>Zn>Pb> Rb>Fe>Mo>Li>Ti>V>Sr>Co>Zr>Al>Ba>As >U>Cd>Mn.

Table.2 Evaluation of heavy metals concentration of waters in Mgoua catchment and comparison with guidelines (μg/L)

Heavy metal	Min.	Max.	Avg.	World Rivers avg.	WHO 2017(μg/l)
Pb	0.003	156.13	18.83	0.08	10
Cr	12.15	29092.38	3089.03	0.7	50
Cu	4.3	283.57	40.1	0.15	10
Cd	0.01	0.79	0.12	0.8	20
Co	1.78	314.38	37.04	1.48	2000
Ni	118.47	38190.07	4355.84	0.08	10
As	0.22	4.07	1.02	0.62	10
Zn	21.21	2235.15	275.9	0.6	50
U	0.01	0.23	0.07	0.37	30
Mo	1.91	239.15	28.85	0.42	70
Fe	352.35	69681.95	8151.6	66	3
Al	11.68	1638.77	237.8	32	200
Mn	0.04	1.4	0.42	34	200
Ba	12.69	46.58	30.18	23	300
Ti	0.66	592.19	64.68	0.489	-
Sr	4.55	510.24	162.91	60	-
V	0.3	94.84	11.64	0.71	50
Li	2.02	197.75	27.85	1.84	-
Rb	7.88	39.44	19.3	1.63	-
Y	0.02	26.87	2.95	0.04	-
Zr	0.02	3.84	0.48	0.039	-

Table.3 HPI recorded at the different sampling stations

Station	C1	C2	C3	C4	C5	P1	P2	P3	E1	E2
HPI	161.02	355.51	233.47	958.59	199.32	17468.08	186.87	168.40	119.60	55.57
Average	1990.64									

Table.4 Metal Index (MI) of studied samples of Mgoua watershed

Heavy metal	Si	Wi	I	MAC	Sample	MI	Class
Pb	100	0.01	10	1.5	C1	23.53	VI
Cr	50	0.02	50	50	C2	50.07	VI
Cu	1000	0.001	2000	1000	C3	41.01	VI
Cd	3	0.33	3	3	C4	164.09	VI
Co	10	0.1	-	1000	C5	23.49	VI
Ni	20	0.05	20	20	P1	2977.39	VI
As	50	0.02	10	50	P2	25.00	VI
Zn	5000	0.0002	5000	5000	P3	22.72	VI
U	30	0.033	-	3	E1	30.01	VI
Mo	70	0.014	-	10	E2	14.70	VI
Fe	300	0.0033	200	200	Mean	337.20	-
Al	200	0.005	-	200			
Mn	300	0.0033	50	50			
Ba	300	0.0033	-	1300			

Table.5 HEI recorded at different sampling stations

Station	C1	C2	C3	C4	C5	P1	P2	P3	E1	E2
HPI	23.527	50.066	41.008	164.086	23.491	2977.391	25.004	22.724	30.012	14.702
Average	337.201									

Table.6 Recorded values of contaminant index (C_d)

Heavy metal	C1	C2	C3	C4	C5	P1	P2	P3	E1	E2
Pb	-0.54	-1	0.15	5.6	-0.63	103.09	-0.77	-0.68	9.87	0.42
Cr	-0.24	0.8	2.72	25.34	-0.02	580.85	-0.22	-0.4	-0.25	-0.76
Cu	-0.99	-0.98	-0.99	-0.98	-0.99	-0.72	-0.99	-0.99	-0.98	-1
Cd	-1	-0.99	-0.99	-0.97	-0.99	-0.74	-1	-0.98	-0.97	-0.99
Co	-1	-0.99	-0.99	-0.98	-0.99	-0.69	-1	-1	-1	-1
Ni	107.68	278.23	170.3	701.85	129.91	12729.02	139.25	125.16	89.57	38.49
As	-0.98	-0.99	-0.98	-0.98	-0.99	-0.92	-0.99	-0.99	-0.98	-1
Zn	-1	-0.99	-0.99	-0.96	-0.99	-0.55	-0.99	-0.99	-0.99	-0.98
U	-0.98	-0.99	-0.98	-0.98	-0.98	-0.98	-0.92	-0.98	-0.98	-1
Mo	-0.67	-0.04	-0.45	0.33	-0.53	22.91	-0.63	-0.58	-0.68	-0.81
Fe	4.5	4.08	8.71	22.89	0.76	347.41	1.23	1.22	1.36	5.42
Al	-0.94	-0.75	-0.92	-0.68	-0.81	7.19	-0.78	-0.86	1	-0.56
Mn	-0.98	-1	-0.99	-1	-0.99	-1	-1	-1	-0.99	-0.97
Ba	-0.97	-0.98	-0.97	-0.97	-0.97	-0.98	-0.96	-0.98	-0.99	-0.99
Cd	101.91	273.41	172.61	747.51	120.76	13783.91	130.21	115.96	93	34.27
Mean	1557.36									

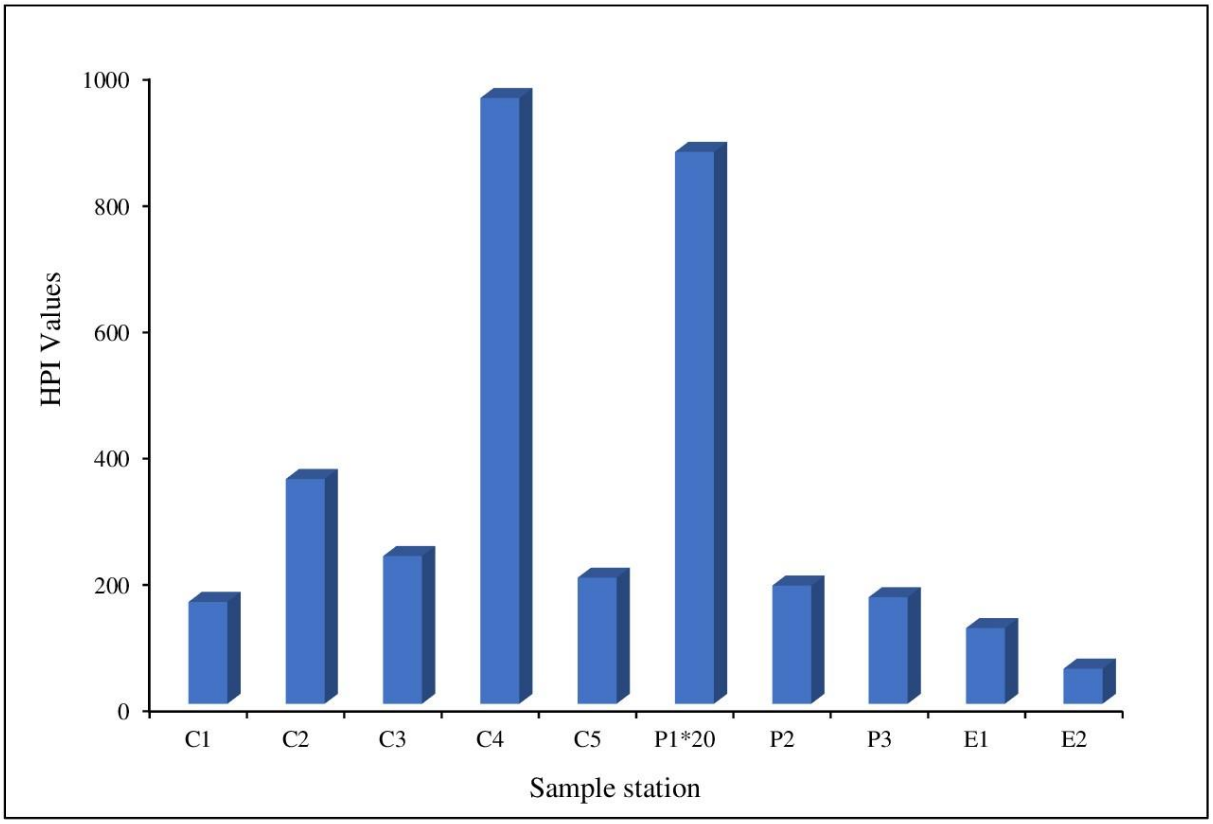
Table.7 Enrichment factor in water of the Ngoua watershed

Heavy metal	C1	C2	C3	C4	C5	P1	P2	P3	E1	E2	Min.	Max.	Mean
Pb	0.51	0	0.73	1.71	1.3	1.85	0.63	0.9	28.52	1.37	0	28.52	3.75
Cr	3.24	8.34	9.02	25.98	13.05	39.36	8.27	6.36	7.5	0.89	0.89	39.36	12.2
Cu	4.47	8.35	2.43	2.18	12.88	1.79	10.58	6.91	18.92	1.48	1.48	18.92	7
Cd	0	0	0	0	0	0	0	0.01	0.02	0	0	0.02	0
Co	0.2	0.39	0.12	0.18	0.71	0.2	0.36	0.39	0.33	0.06	0.06	0.71	0.29
Ni	244.35	680.69	218.28	364.02	919.54	452.15	779.35	702.55	475.25	76.18	76.18	919.54	491.24
As	0.09	0.06	0.05	0.02	0.15	0.01	0.08	0.17	0.25	0.02	0.01	0.25	0.09
Zn	2.12	6.32	2.31	4.21	9.08	3.53	12.75	7.26	7.79	6.62	2.12	12.75	6.2
U	0.01	0	0.01	0	0.03	0	0.09	0.03	0.02	0	0	0.09	0.02
Mo	0.47	1.49	0.45	0.44	2.08	0.54	1.29	1.49	1.06	0.23	0.23	2.08	0.95
Al	0.02	0.1	0.02	0.03	0.22	0.05	0.2	0.13	1.75	0.14	0.02	1.75	0.27
Mn	0	0	0	0	0	0	0	0	0	0	0	0	0
Ba	0.11	0.08	0.05	0.02	0.31	0	0.3	0.14	0.1	0.03	0	0.31	0.11
Ti	0.14	0.09	0.35	1.2	0.43	1.15	0.22	0.28	0.49	0.08	0.08	1.2	0.44
Sr	0.33	0.07	0.07	0.03	1.59	0	0.48	0.36	0.01	0.03	0	1.59	0.3
V	0.04	0.07	0.05	0.11	0.17	0.13	0.06	0.96	1.43	0.05	0.04	1.43	0.31
Li	0.58	0.07	0.04	0.04	2.51	0.1	0.34	0.17	1.53	0.06	0.04	2.51	0.55
Rb	0.92	0.47	0.66	0.23	2.02	0.01	1.07	3.59	0.68	0.38	0.01	3.59	1
Y	0.03	0.06	0.02	0.02	125.82	0.05	0.65	0.25	0.51	0.15	0.02	125.82	12.75
Zr	0.07	0.03	0.04	0.06	0.25	0.09	0.68	1.05	0.46	0.05	0.03	1.05	0.28
Min.	0	0	0	0	0	0	0	0	0	0			
Max.	244.35	680.69	218.28	364.02	919.54	452.15	779.35	702.55	475.25	76.18			
Mean	12.89	35.33	11.74	20.02	54.61	25.05	40.87	36.65	27.33	4.39			

Table.8 Classification of water quality based on modified categories of HPI, C_d and HEI

Index method	Class	Extent of pollution	No of samples	Percentage	Samples
HPI	< 15	Low	0	0	-
	15-30	Medium	0	0	-
	> 30	High	10	100	C1, C2, C3, C4, C5, P1, P2, P3, E1 and E2
Cd	< 18	Low	0	0	-
	18-36	Medium	1	10	E2
	> 36	High	9	90	C1, C2, C3, C4, C5, P1, P2, P3, E1 and E2
HEI	< 27	Low	5	50	C1, C5, P2, P3 and E2
	27-54	Medium	3	30	C2, C3 and E1
	> 54	High	2	20	C4 and P1

Fig.2 HPI representation at different samplings stations



According to the classification proposed by Andrews and Sutherland (2004), stations C1, C2, C3, C4, P1, P2, P3 and E2 are minimally enriched (EF <2) with elements such as Pb, Cd, Co, As, U, Mo, Al, Mn, Ba, Ti, Sr, V, Li, Rb, Y and Zr. Moderate enrichment (2 < EF <5) is observed for Cu, Cr and Zn instation C2, Cu and Zn in stations C3 and P4 respectively, Mo, Li and Rb instation C5, Zn instation P1 and Rb instation P2. A very high enrichment is seen at stations C4 and P1 in Cr and station E1 in Pb. A significant enrichment (5 <EF <20) is obtained at stationsC2 and E1 in Cr, Cu and Zn, station C3 in Cr, at station C5 in Zn, station P2 in Cr, Cu and Zn; at station P3 in Cr and Cu and station E1 in Cr and Zn. The last category (extremely highly enriched; EF>40) is represented by Ni at all sampling stations and Y in station C5. According to Wang *et al.*, (2008), Pb, Cr, Cu, Ni, Zn and Y have EF > 1.5 signify that the sources of contamination are due by anthropogenic activities, while the lower values for the other heavy metals appoint to a geogenic origin (a natural source).

Evaluation of water quality

Pollution evaluation indices (HPI, HEI and C_d) were made individually using the international recommendations and are indicated in Table 8. The HPI assessment method shows that all sample sites are heavily polluted. The pollution level drops with the Cd method that shows that 90% of samplings sites are high polluted. The drop is even greater with the HEI method which reveals that only 20% of samples sites high polluted while 30% and 50% show medium polluted and low polluted respectively. The high mean values of HPI, HEI and C_d for all the sampling sites indicate hence polltuion. These averages show very alarming pollution compared to those obtained by Dolma *et al.,* (2015) with low polluted samples, although the contexts are not very similar.

Heavy metals pollution evaluation indices by have been used to assess the intensity of pollution in the water of Mgoua watershed. The HPI and MI indices show that this watershed is critically polluted with heavy metals. The HPI index has revealed the importance of pressure areas like station P1, which show the highest level of metals pollution. HEI and C_d indices reveal a strong contamination of the water by the trace metals. Enrichment factors indicate that the study area is very highly enriched in Ni, Cu, Cr and Pb. Enrichment is low for the other elements in relation to the geochemical background values. Industrial discharge and anthropogenic activities are the main sources of heavy metal pollution in the Mgoua watershed. It is expected that the results of this study will serve as a basis for policy makers, water resource management authorities and other stakeholders in the water and environment sector to curb heavy metal pollution in the Mgoua watershed.

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