Original Research Article

Assessment of the Soils and Tailings Multi-element Pollution from the Koma Bangou (Niger) Artisanal Gold Mining Area

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ABSTRACT

Artisanal gold mining in Niger began in Koma Bangou following the 1984's drought, followed by poor harvests and famine in Niger. Gold panning had been going on at Koma Bangou since 1984, with the introduction of ore leaching in 2009. The aim of this work was to assess the multi-element pollution generated by ore processing at Koma Bangou. Geochemical data acquired with portable XRF analyzer, corrected with ICP-MS data, were used to assess the global pollution level in As, Cr, Cu, Mn, Pb and Zn using the pollution load index and the local soil-geochemical background data from Koma Bangou. Multi-element pollution generated by the ore processing was identified at the ore processing sites. It was extremely high in the acidification waste (PLI_{Mean} = 5.35), and moderately high in the cyanidation waste (PLI_{Mean} = 1.98) and the cyanidation area soils (PLI_{Mean} = 1.66). The perimeter soils (PLI_{Mean} = 0.47), located far from the cyanidation sites were not polluted. Multi-element pollution at the Koma Bangou cyanidation sites is anthropogenic, due to the use of chemicals in hydrometallurgical processing and the discharge of tailings into the environment.

Keywords: Koma Bangou, Gold panning, Cyanidation, Waste, Pollution

1. INTRODUCTION

Artisanal gold mining is the main employer in the artisanal mining sector and is practiced in over 80 countries worldwide [1]. Gold panning began in Niger at the Koma Bangou site in the Tillabéri region [2], following the drought and poor harvests of 1984 [3-6]. It's the most widely practiced non-agricultural subsistence activity in Niger [3,5]. The hydrometallurgical ore processing with cyanide was introduced since 2009 at Koma Bangou [7]. From 1984 to the present day, the gold panning at Koma Bangou had produced large quantities of tailings [8]. These tailings have a negative impact by causing environmental pollution [7-12].

Pollution is any process that causes toxicity, disrupts ecological processes, damages infrastructure or poses a risk to human health [13]. For the purposes of this work, As, Cr, Cu, Mn, Pb and Zn were selected for their adverse effects on human health. Arsenic (As) can cause dermatitis, nervous system disorders, gastrointestinal diseases, kidney and bladder diseases, cardiovascular and respiratory diseases, bone marrow and blood diseases [14]. Chromium (Cr) can be carcinogenic in the Cr (VI) form. It can cause skin rashes, gastrointestinal disorders, respiratory problems, weakening of the immune system, liver and kidney damage, alteration of genetic material, lung cancer [15-17]. Copper (Cu) can cause Wilson's disease, gastroenteritis, nausea, vomiting, diarrhea, hemolytic anemia, infantile cirrhosis and jaundice [16,18,19]. High concentrations of manganese (Mn) can cause cirrhosis of the liver, pneumonia, neurological problems, headaches, insomnia, memory loss, emotional instability, hyperreflexia, tremors, speech and walking disorders [19]. Lead (Pb) is highly toxic, carcinogenic and causes nephropathy, nervous system disorders, cardiovascular and intestinal damage and infertility [19-21]. Zinc (Zn) in high doses can

cause a drop in plant biomass production, physiological and gastrointestinal disorders in humans, complications in the respiratory system and skin disorders [22,23].
Soils, particularly those in or near mining sites, were polluted by several metals [24]. Geochemical indices, such as the pollution load index (PLI), can be used to assess the multi-element pollution of sites [25,26]. The pollution load index (PLI), as introduced by Tomlinson et al [26], can be used to assess the extent of the global pollution [27-31]. Several authors had used the pollution load index (PLI) to assess global pollution in mining area [32-42].
The aim of this work is to assess the multi-element pollution of As, Cr, Cu, Mn, Pb and Zn in soils and tailings from the artisanal and small-scale gold mining site of Koma Bangou.

2. MATERIAL AND METHODS

2.1 Study Area

The Koma Bangou artisanal gold mining area belongs to the Téra department, in the Tillabéri region, which constitutes the south-western part of the Republic of Niger (Fig. 1a). Koma Bangou is located between latitudes 14°01'41''and 14°07'56'' N and longitudes 01°02'12''and 01°10'00'' E, and covers 150 km^2 [8]. It lies within hydrographic network comprising the main Niger River and several small rivers (Fig. 1b) [8].

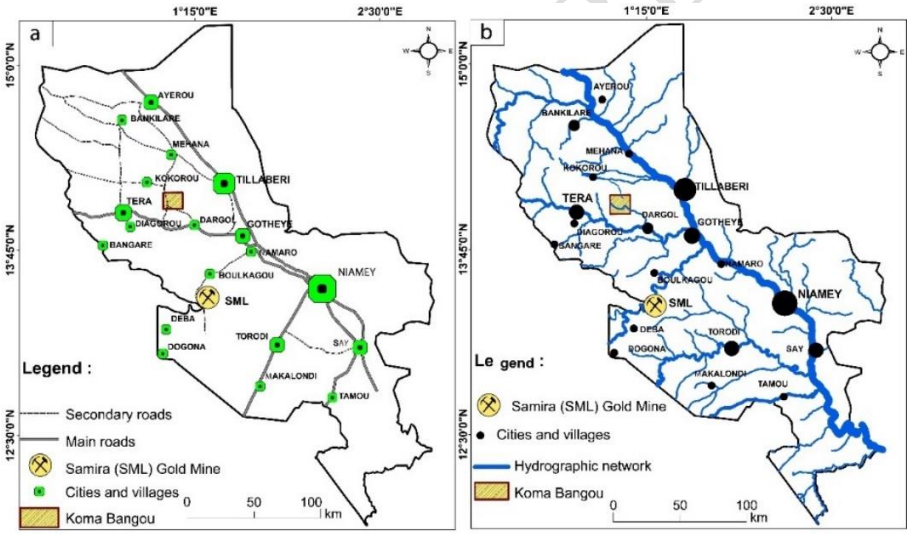

Fig. 1. Location of the Koma Bangou area.

Geologically, Koma Bangou is located on the Diagorou-Darbani greenstone belt in Niger's Liptako (Fig. 2b) [43]. The Liptako forms the northeastern end of the Léo-Man Ridge (Fig. 2a), on the West African craton [44]. The geological formations of Koma Bangou (Fig. 2c) consist of meta-basalt and meta-sediment [44-46] with small outcrop of gabbro, quartz diorite, granite, syenite, rhyolite, andesite and dacite [46]. The hard rock is locally overlain by lateritic cuirass and sandy-clayey eolian deposits [46]. The gold mineralization at Koma Bangou is quartz-vein type, controlled by faults and fractures [46-48]. It is also related to gabbro, quartz diorite and rhyolite dyke [48]. The sulfide minerals associated with the gold-bearing quartz include pyrite, chalcopyrite, chalcocite, sphalerite and galena [8].

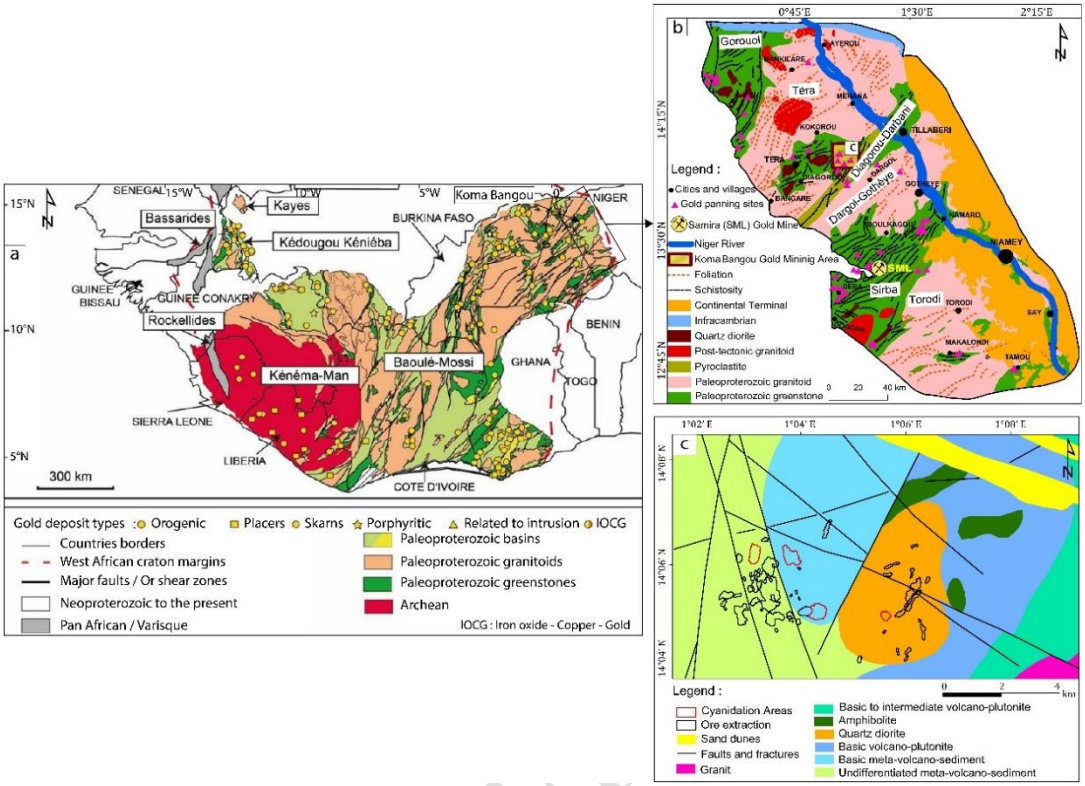

Fig. 2. Geological map of the Léo-Man ridge [49] and location of gold deposits [50]; b) Geological map of Liptako [51]; c) Koma Bangou geological features map [45].

2.2 Artisanal gold Mining at Koma Bangou

Artisanal gold mining at Koma Bangou was manual [4]. It involves digging vertical shafts (Fig. 3a) to extract the ore. The extracted ore was brought to the surface and was sorted. The mineralized quartz undergone to crushing (Fig. 3c), grinding (Fig. 3d), sluicing (Fig. 3e) and cyanide leaching (Fig. 3f) to recover the gold. The gold contained in the cyanide juice was recovered by cementation with zinc plates using the Merill-Crowe process [52]. Zinc plates loaded with gold were dissolved with sulfuric and nitric acids to obtain residues containing gold. These residues were then burned with water and sulfuric and nitric acids to obtain the gold concentrate.

Fig. 3. Stages of artisanal gold mining at Koma Bangou. a) Ore extraction shaft fitted with winch; b) Gold-bearing quartz; c) Manual ore crushing; d) Manual ore grinding; e) Gravity gold concentration with sluice; f) Cyanide leach tanks.

2.3 Sampling

Soil and tailings samples were collected from Koma Bangou. Systematic grid sampling was used for soils (perimeter soils and cyanidation areas soils), and stratified random sampling was used for tailings (cyanidation waste and acidification waste). Soil samples were taken with a hand auger at depths ranging from 0 to 40 cm. Tailings samples were taken from piles using a metal shovel. 400 samples were collected: acidification waste (27), cyanidation waste (181), cyanidation area soils (122) and perimeter soils (70). The cyanidation waste consists of fine particles of crushed ore that have first undergone to gravity sluicing and then cyanide leaching (Fig. 4a). The acidification waste come from the final stage in the chemical ore treatment chain, corresponding to acidification of the gold-bearing zinc plates (Fig. 4b). The cyanidation area soils are the soils of the sites where ore leaching operations are carried out. The perimeter soils are soils located outside chemical ore processing sites. Fig. 5 shows the sampling plans from Koma Bangou gold mining area.

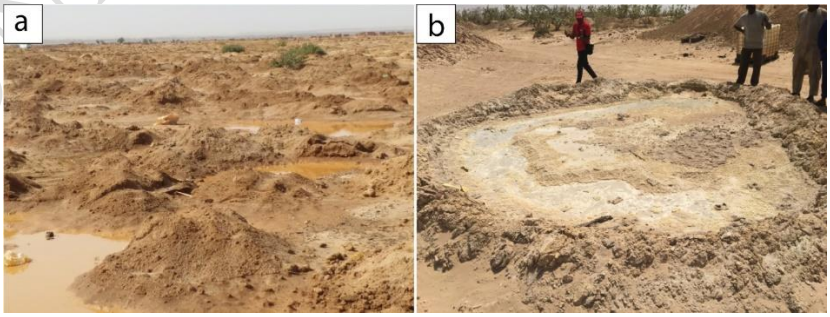

Fig. 4. Tailings from Koma Bangou. a) cyanidation waste; b) acidification waste.

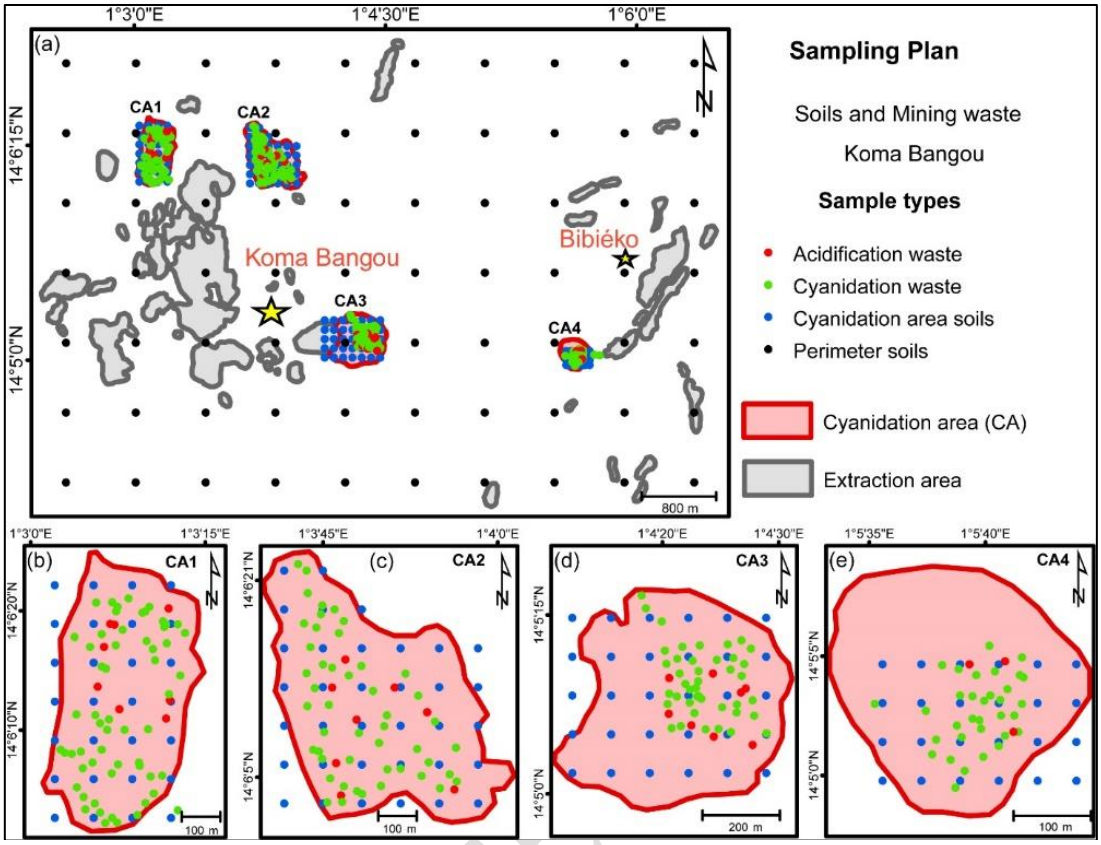

Fig. 5. Sampling plans on the Koma Bangou area. a) Ground-plan showing sampling groups; b, c, d, e) Sampling plan on the cyanidation areas (systematic by grid and stratified random).

2.3 Chemical analysis

All the 400 samples were first air-dried, then sieved. The < 2 mm fraction was ground to 75 µm and analyzed with a Thermo Niton XL3t XRF analyzer. 55 representative samples were analyzed by inductively coupled plasma mass spectrometry ICP-MS (iCAP TQ, Thermo Scientific®). XRF data were calibrated and corrected with the ICP-MS data according to Eq. 1 [8].

$$[X]_{ICP\text{-}MS} = \exp(b \pm db)\left([X]_{pXRF}\right)^{(b \pm db)} \quad (1)$$

$[X]_{ICP\text{-}MS}$ is the ICP-MS X element concentration; $[X]_{pXRF}$ is the pXRF X element concentration; a, b; da, db are the regression coefficients and their related errors.

2.4 Multi-element pollution assessment

The pollution load index (PLI), as suggested by Tomlinson et al [26] (Eq. 2), is the root n of the n number of the multiplied contamination factor (CF) [29,31,53-57].

$$\mathrm{PLI} = \sqrt[n]{(\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \cdots \times \mathrm{CF}_n)} \quad (2)$$

where n is the number of studied metals; CF is the factor used to assess the level of contamination for each metal in a sample [28,55,58]. It is the quotient of the concentration of each element in the soil sample (Cm) over the concentration of the same element in the reference soil (Cb) (Eq. 3) [29,31,59]:

$$CF = \frac{Cm}{Cb} \qquad (3)$$

There is no pollution when PLI < 1. Sample is polluted by several metals when its PLI > 1 [31].

The soil-geochemical baseline values corresponding to the local soil-geochemical background of As (58.05 mg/kg), Cr (172.89 mg/kg), Cu (76.25 mg/kg), Mn (1478.31 mg/kg), Pb (18.95 mg/kg) and Zn (133.29 mg/Kg) [8] in the Koma Bangou perimeter soils were used to calculate the pollution load index (PLI).

To better represent the spatial distribution of the PLI values, a cartographic approach using GIS, consisting of representing the PLI index classes according to the sampling points coordinates and the sample groups, was implemented.

3. RESULTS

Table 1 gives the statistical values of the pollution load index by sample group. The distribution of the average PLI shows different pollution degrees. Acidification waste, cyanidation waste and cyanidation area soils were polluted (PLI > 1). Perimeter soils were unpolluted (PLI < 1).

Table 1. PLI statistical values of the sample groups.

Sample group	Number	Minimum	Mean	Maximum
Cyanidation area soils	122	0.41	1.66	3.54
Cyanidation waste	181	0.47	1.98	5.54
Acidification waste	27	2.24	5.35	10.39
Perimeter soils	70	0.16	0.47	1.33

Fig. 6 shows the spatial distribution of the PLI in the soils and waste from Koma Bangou. The polluted samples represented by large points (PLI >1) were mainly located in the cyanidation areas: acidification waste, cyanidation waste, cyanidation area soils. Very few perimeter soil samples were polluted.

Fig. 7 shows the PLI classification for the sample groups. All the acidification waste samples were polluted (PLI > 1). 170 out of 181 (93.92%) cyanidation waste samples were polluted (PLI > 1). 11 cyanidation waste samples (6 from CA1 and 5 from CA2) were unpolluted (PLI < 1). 96 samples out of 122 (78.69%) of cyanidation area soils were polluted (PLI > 1). 26 cyanidation area soil samples (8 from CA1, 4 from CA2, 7 from CA3 and 7 from CA4) were unpolluted. 67 out of 70 (95.71%) perimeter soil samples were unpolluted (PLI < 1). 2 samples of from the perimeter soils were intermediate (PLI ≈ 1), i.e. they had the soil-geochemical background value. Only one perimeter soil sample was polluted (PLI > 1).

The evolution of the global pollution degree in the sample groups from Koma Bangou (Fig. 8) was as follows: acidification waste > cyanidation waste > cyanidation areas soils > perimeter soils.

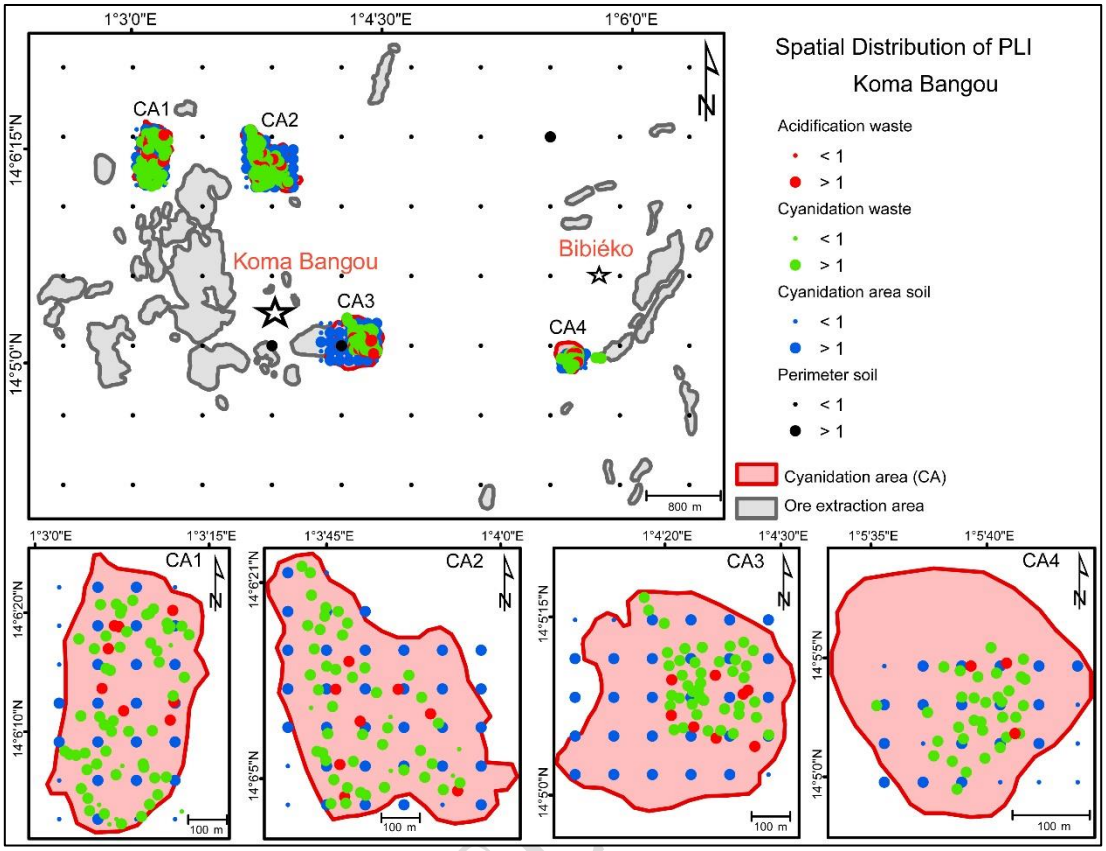

Fig. 6. Spatial distribution of the PLI in the Koma Bangou's soils and tailings.

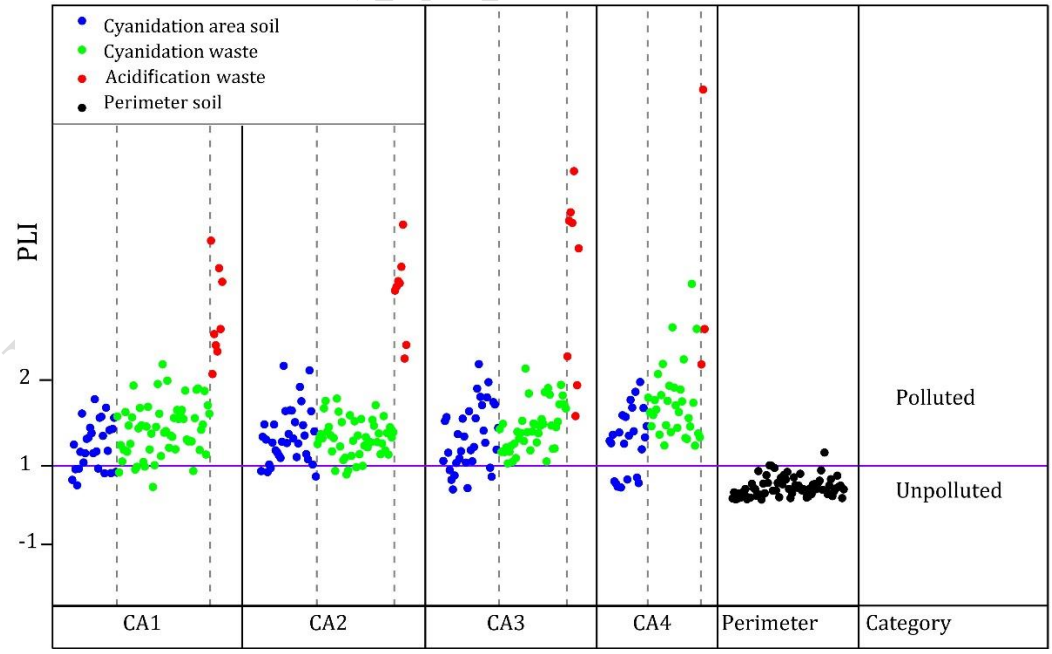

Fig. 7. Classification of the PLI in the Koma Bangou sample groups.

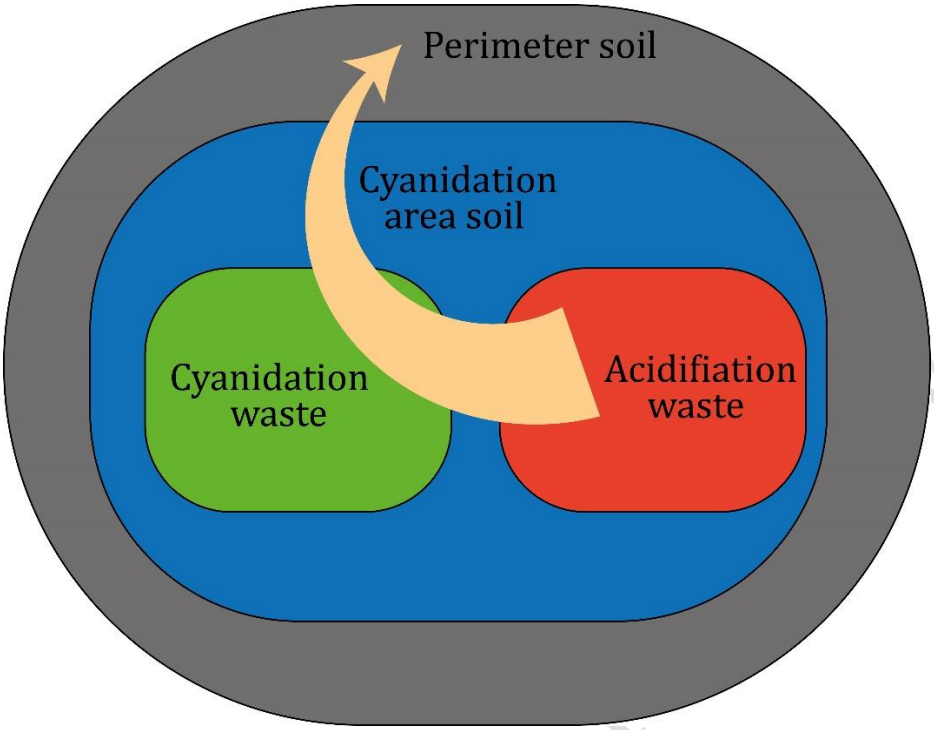

Fig. 8. Multi-element pollution trends in the Koma Bangou samples.

4. DISCUSSION

The multi-element pollution (As, Cr, Cu, Mn, Pb and Zn) was well localized on the cyanidation areas (acidification waste, cyanidation waste, cyanidation area soils) at Koma Bangou. This metallic pollution stems from hydrometallurgical processing at the cyanidation sites: the use of chemicals and their discharge onto the sites [8]. Depending on the degree of pollution, the acidification waste group was the most polluted, followed by the cyanidation waste group and finally the cyanidation areas soils group. The perimeter soils, localized outside the cyanidation sites were not polluted. The same results were obtained by Alassane-Boukari et al [60]; Tankari-Dan-Badjo et al [9], [10] and Zakaria-Ibrahim et al [12] in the Koma Bangou gold mining area.

The Koma Bangou ore contains some sulfides such as pyrite, chalcopyrite, chalcocite, galena, sphalerite which were rich in metals (As, Cd, Cr, Cu, Hg, Pb, Zn) [8]. These metals were released and concentrated in the tailings during the hydrometallurgical extraction [8,10,60]. The multi-element pollution linked to the artisanal gold mining activities on the Koma Bangou area had affected not only the soil, but also vegetation and water resources [9-11]. Zakaria-Ibrahim et al [11] and Tankari-Dan-Badjo et al [10] found very high concentrations of Co, Cu, Ni, Pb and Zn in plants and grasses in the Koma Bangou area. Tankari-Dan-Badjo et al [9] showed that average concentrations of As, Cd, Co, Cu, Hg, Ni, Pb and Zn in Koma Bangou water exceeded Niger's limit values for wastewater discharge into the natural environment [61]. All studies concluded that the multi-element pollution at Koma Bangou was localized in the cyanidation sites. It decreases with distance from the cyanidation sites and becomes absent in the areas outside the cyanidation sites. They suggest a direct impact of gold mining on soil, water and plant pollution by metals.

5. CONCLUSION

The soil geochemical baseline data were used to assess the multi-element pollution (As, Cr, Cu, Mn, Pb, Zn) in the Koma Bangou artisanal gold mining area soils and tailings. The pollution load index showed that multi-element pollution was associated with cyanidation sites. The multi-element pollution was highlighted at the cyanidation sites. The acidification waste was extremely polluted; the cyanidation waste and the cyanidation areas soils were moderately polluted. The perimeter soils were not polluted. Multi-element pollution at the Koma Bangou cyanidation sites was anthropogenic, due to the use of chemicals in the ore processing and the discharge of the tailings into the environment.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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