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Artisanal Mining and Soil Quality in the Sudano-Sahelian Climate: Case of the Artisanal Mining Site of Yimiougou in Burkina Faso, West Africa

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Abstract

The majority of the population of Burkina Faso lives from agriculture and therefore depends on the land. The main objective of this study is to assess the quality of the soils in the area linked to artisanal mining activities. The methodology adopted consisted in sampling and characterizing the main types of soil. In order to assess the level of soil pollution by artisanal mining, parameters such as the geo-accumulation index (Igeo) and the contamination factor (CF) are calculated. A prediction of acid mine drainage (AMD) was also carried out on samples of mine tailings which are potential sources of pollution of these soils. The results obtained show that the soils in Yimiougou are of nil to low agronomic interest. The Igeo shows that for lead, copper, zinc and arsenic the levels found in the different morphological units are partly attributable to human action and specifically artisanal mining. The values of the contamination factor indicate contamination. Cobalt presents the lowest contamination. For cadmium, the different types of soil are moderately contaminated except for the FITLC type, which has a CF value of 0.50, therefore synonymous with low or absent contamination. The various morphological units studied are very heavily contaminated with zinc, copper, lead and arsenic. The pH and conductivity values indicate that the mine tailings samples are non-acidogenic, therefore not yet oxidized. As for the sulphide contents, they show that only samples S17, S22, S23 and S24 present values that are strictly above the threshold (0.3%) and therefore potentially acid-generating. The comparative study of the acid potential (AP) and the neutralization potential (NP) reveals that the neutralization potentials of the different samples are clearly higher than the acid potentials even for the samples which present a proven acidification potential (S17, S22, S23 and S24). These results show that the mine tailings have the natural capacity to neutralize any possible mine drainage, given the presence of acid-eating minerals such as the carbonates associated with the mineralization.

Keywords

Soil, Artisanal Mining, Environment, Heavy Metals, Potentially Harmful Elements, Burkina Faso

1. Introduction

In recent years, the economy of Burkina Faso has diversified with the exploitation of extractive resources including gold. Depending on the technology used in the exploitation of these resources, there are two main types of exploitation: industrial and artisanal mining. Started in the 1980s, artisanal mining was considered a survival activity due to the periods of drought that the country had experienced before. Thus, artisanal mining will experience rapid development, as evidenced by the number of artisanal mining sites on the national territory estimated today at more than 800 with approximately two million artisanal miners [1]. Indeed, more than 25% of the territory of Burkina Faso (approximately 70,000 km^2) is occupied by the Birimian volcano-sedimentary formations (lower Proterozoic) known for their richness in mineral resources. Each year, between 5 and 10 new artisanal mining sites are discovered with areas between 1 and 1.26 km^2.

This sector is experiencing an unprecedented expansion as it generates more than 232.22 billion CFA francs in revenue [1]. Thus, the artisanal mining sector is nowadays a very important pillar in the same way as agriculture and livestock in the country's economy because it helps to curb the rural exodus and generates foreign currency for the national economy.

However, artisanal mining has negative repercussions on the environment, mainly on the biophysical environment. Added to this are the many harmful effects of the chemicals (mercury, cyanide and acids) used during the extraction of gold. The damage caused by this activity on the soil, in particular the expropriation of agricultural areas, the storage of mining residues in areas originally intended for agricultural activities, the destruction of plant cover and the incessant deforestation of forests are difficult to assess from an economic point of view.

The village of Yimiougou, which falls administratively within the province of Sanmatenga ("land of gold", in the local language) was once a cotton-growing region. It ended up giving way, nowadays to subsistence farming and artisanal mining. Yimiougou is today characterized by the importance of artisanal mining in the upper part of the Nakanbe River (the second in terms of importance after the Mouhoun), which feeds the Ziga dam (source of drinking water supply for the city of Ouagadougou, the capital of Burkina Faso). The proximity of artisanal mining sites to the river and tributaries remains problematic. This situation has a corollary, an ecological fragility marked by strong soil erosion. These soils then have a massive and mediocre structure, a low retention capacity and a high acidity. In general, they are of almost zero agronomic interest with a pronounced lack of organic matter. As for the vegetation, it is weakly dense with a very weak wildlife in constant decline. However, the populations remain dependent on arable land and water resources and live mainly from agriculture and livestock. A reduction of these cultivable lands can only inevitably lead to land conflicts with its share of corollaries. It is therefore in this context that the present study is situated, the objective of which is to assess the quality of the soils of the artisanal mining site of Yimiougou.

2. Study Area

Yimiougou is located in the province of Sanmatenga (Centre-North Region), precisely in the commune of Korsimoro, 70 km northeast of Ouagadougou, the capital of Burkina Faso (Figure 1).

The relief is essentially characterized by more or less rugged lateritic hill chains, with tabular or rounded tops, and very marked by the phenomenon of bauxitic or ferruginous hardening. Climatically, the study area falls within the Sudano-Sahelian climatic zone, characterized by two main seasons. A long dry

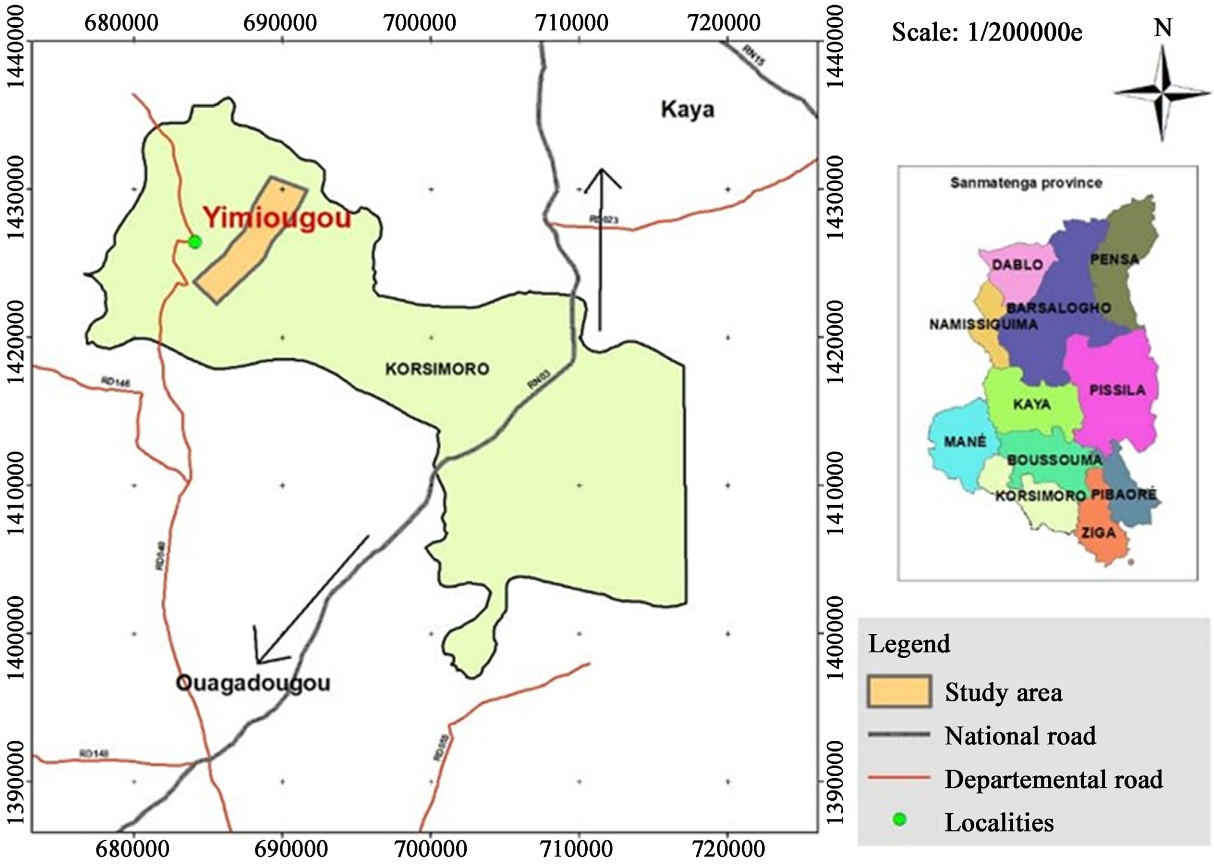

Figure 1. Location of the study area.

season that lasts from October to May. This season is marked by harmattan winds blowing from north to south, with periods of high heat in March and April, and extreme temperatures that can reach 42˚C in the shade. The shorter winter season, runs from June to September and is marked by thunderstorms with strong runoff.

Given that the spatial distribution of vegetation depends on the type of climate, in Yimiougou, we mainly encounter thorny trees, which constitute ligneous trees. There is also a carpet of grasses, which are becoming more and more persistent nowadays thanks to the control of bush fires and the many awareness campaigns made on the harmful effects of excessive woodcutting.

3. Methodology

Soil samples were collected, and then analyzed. This concerned the four units which are: tropical ferruginous soils, leached, indurated, shallow (FTLI), tropical ferruginous soils, leached, with concretions (FTLC), tropical ferruginous soils, leached, with stains and concretions (FILTC) and evolved soils, gravelly erosion (PEEG). The choice is made on these soils because they are the most represented. Several parameters were determined. These are particle size, total carbon, total nitrogen, total phosphorus, pH, conductivity, cation exchange capacity (CEC), exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), organic matter and potentially harmful elements (cadmium, lead, copper, zinc, iron, aluminum, cobalt, arsenic, mercury). In order to assess the level of soil pollution by artisanal mining, parameters such as the geo-accumulation index and the contamination factor are calculated.

4. Results and Discussions

4.1. Soils Characterization

The Yimiougou area is characterized by four soil units which are: tropical ferruginous soils, leached, indurated, shallow (FTLI), tropical ferruginous soils, leached, with concretions (FTLC), tropical ferruginous soils, leached, with stains and concretions (FILTC) and evolved soils, gravelly erosion (PEEG) whose different parameters are listed in Table 1.

4.1.1. Tropical Ferruginous Soils, Leached, Indurated, Shallow (FTLI)

The useful depth of these soils is limited by a ferruginous shell between 0 and 40 centimeters. In the dry state, they are light brown on the surface (0 - 75 cm), reddish yellow in the lower horizon (20 - 40 cm). Between these two layers, there is a rather gravelly horizon (7 - 20 cm).

The texture is coarse (sandy-loamy) on the surface and quite fine (silty-clayey) in depth. The soils are very porous. Fauna activity is average, but root activity is good on the surface and low below.

FTLIs have a grain size that varies with depth. For the three size fractions, the values are 26.98% to 49.12% for clay, 25.32% to 43.02% for silts and 25.03% to

Table 1. Physico-chemical parameters of soils.

Soil type	pH	Conductivity (µScm⁻¹)	Particle size proportion (%)			O.M (%)	N (%)	P (ppm)	C/N	Σbases	CEC	Exchangeable bases (meq/100)			
			Clay	Silt	Sand							Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
FTLC	4.62	338	31.26 - 35.32	25.42 - 35.61	33.19 - 39.36	0.86	0.05	576	11	1.46	2.25	1.36	0.24	0.06	0.17
FILTC	4.78	224	19.72 - 39.14	34.98 - 53.96	25.24	0.94	0.07	574	11	1.78	3.79	1.32	0.32	0.19	0.09
PEEG	5.54	278	-	49.00	-	0.88	0.054	480	11	2.98	6.51	1.78	0.99	0.06	0.22
FTLI	5.28	348	26.98 - 49.12	25.32 - 43.02	25.03 - 29.38	0.7	0.04	408	12	1.78	5.02	1.56	-	0.09	0.15

29.38% for sands. The soils are deficient in organic matter (0.86%) and total nitrogen (0.05%). Conversely, they have relatively high average levels of total phosphorus (408 ppm). The C/N ratio is average (C/N = 12), indicating good decomposition of organic matter. The sum of exchangeable bases and the cation exchange capacity are low (respectively 1.78 and 5.02 meq/100g). These are soils poor in exchangeable calcium (1.56 meq/100g), also poor in potassium and exchangeable sodium (respectively 0.15 and 0.09 meq/100g). The pH (5.28) is moderately acidic.

4.1.2. Tropical Ferruginous Soils, Leached, with Concretions (FTLC)

FTLCs are deep soils, with depths generally greater than 120 cm and comprising a variable rate of coarse elements (5% to 10% concretions) depending on the depth. They are clayey-silty to clayey and normally to moderately drain at depth. These soils are not very hard in the dry state on all horizons. In the dry state, these are porous soils with a dominant reddish-yellow to yellowish-red color at depth. They contain approximately 5% gravel and ferruginous to ferro-manganiferous concretions. The root presence is weak. It weakens more with depth. Faunal activity is well expressed throughout the profile with numerous pockets of coprolites on all horizons.

The grain size also varies with depth, ranging from 31.26% to 35.32% for clays, from 25.42% to 35.61% for silts and from 33.19% to 39.36% for sands. The soils are poor in organic matter (0.86%) and total nitrogen (0.05%). The contents are high in total phosphorus (576 ppm). The C/N ratio is average (11) and indicates good decomposition of organic matter. The sum of the exchangeable bases and the cation exchange capacity remain low (respectively 1.46 and 2.25 meq/100g). These are soils poor in exchangeable calcium (1.36 meq/100g), also poor in exchangeable magnesium, potassium and sodium (respectively 0.24; 0.17 and 0.06 meq/100g). Their pH is acidic (pH 4.62).

4.1.3. Tropical Ferruginous Soils, Leached, with Stains and Concretions (FILTC)

Like the FTLCs, these soils are deep with depths greater than 120 cm and include a variable rate of coarse elements (5% to 10% concretions) and some oxidation-reduction stains, which are present at average rates of 10%, depending on the depth. They are moderately porous with a dominant reddish-yellow to pink color when dry to depth. The structure is moderately developed in coarse or medium polyhedral sub-angular elements. The root presence is average on the surface and weakly developed in the lower horizons. Faunal activity decreases with depth. There are numerous pockets of coprolites on the 2nd and 3rd horizon.

The proportion of fine earth oscillates between 19.72% and 39.14% for clay, from 34.98% to 53.96% for total silt. On the other hand, the total sands remain constant (25.24%). The soils are deficient in organic matter (0.94%) and total nitrogen (0.07%). The total phosphorus contents are high (574 ppm). The C/N ratio is average (11) and indicates good decomposition of organic matter. The sum of exchangeable bases (1.78 meq/100g) and the cation exchange capacity (3.79 meq/100g) are unfavorable. These are soils poor in exchangeable calcium (1.32 meq/100g), also poor in exchangeable magnesium, potassium and sodium (respectively 0.32; 0.09 and 0.19 meq/100g). Their pH is acidic (pH 4.78).

4.1.4. Evolved Soils, Gravelly Erosion (PEEG)

These are soils with a poorly differentiated profile with essentially gravelly horizons (about 50% ferruginous gravel) on the 40 cm of useful depth. The humus horizon rests on a slightly altered parent material. The cuirass is outcropping in places and the ground surface is covered by a spreading of gravel. The surface texture is fine (silty) with normal drainage. The dominant color is very pale brown in the dry state. These are friable soils also in the dry state. The structure is weakly developed. The root presence is important as well as the pores. Fauna activity is well developed. The thickness is limited, the water reserve and the chemical fertility are very weak. These soils are of nil to low agronomic interest.

The fine part is essentially loamy with 49% total silt. The soils are deficient in organic matter (0.88%) and total nitrogen (0.054%). They have high total phosphorus contents (480 ppm). The C/N ratio is average (11) and indicates good decomposition of organic matter. The sum of exchangeable bases and the cation exchange capacity are low (respectively 2.98 and 6.51 meq/100g). These are soils poor in exchangeable calcium (1.78 meq/100g), also poor in magnesium, potassium and exchangeable sodium (respectively 0.99; 0.22 and 0.06 meq/100g). Their pH is moderately acidic (pH 5.54). These soils are of nil to low agronomic interest.

The textures of these four soil types are predominantly silty. The organic matter content is less than 1% while the nitrogen is below 0.06% (except soils FILTC = 0.06), which indicates a poverty in organic matter and nitrogen. Nevertheless, the organic matter content is higher than 0.6% considered as the threshold of non-response to mineral fertilizers [2]. These soils are also rich in total phosphorus with levels above 200 ppm. On the other hand, on all the soils studied, the sum of the bases and the CEC are low (low for the sum of the bases and very low for the CEC). pH values are less than or equal to 5.5 indicating that the soil is strongly acidic [3]. This acidity could have a negative effect on the assimilability by plants of certain nutrients such as phosphorus and promote the phyto-availability of heavy metals such as Cd. FTLCs and FILTCs with pH values of 4.62 and 4.78 respectively are lower than the standards (5.5 - 8) and therefore unsuitable for agricultural activities. The C/N ratio of the soil is between 11 and 12 indicating good mineralization of organic matter. The calculation of the saturation rate (Sum of exchangeable bases/CEC) shows that the soils studied are moderately saturated with exchangeable bases.

4.2. Content of Potentially Harmful Element (PHE) in Soil

The results (**Figure 2**) show that the main potentially harmful elements present in these different soils are essentially lead (Pb), copper (Cu), zinc (Zn), iron (Fe), aluminum (Al), cobalt (Co) and arsenic (As). Cadmium and mercury have almost zero content. Lead has levels lower than the standards that are 100 ppm. For copper, in the different types of soil, the contents are higher than the standards that are 20 ppm.

Regarding zinc, despite the high levels compared to the others, they are below the standards (200 ppm respectively) in these in these soil units.

Iron (Fe) expressed, as a percentage (5.24% - 8.52%) unlike the other elements, is present in all units regardless of the type of soil. This high content compared to the current standard (50 ppm) could be detrimental to the environment. However, the generally high concentration of iron, especially in West Africa, is due to leaching of lateritic soils.

The Al contents are above the limit value (20 ppm) for FTLI and FILTC type soils. This could be explained by the fact that the acidity of the environment contributes to increasing the solubility of aluminum because, at pH < 5.5, aluminum is very mobile in the form of Al^{3+}. Yimiougou soils are acidic with a pH between 4.62 and 5.54, which could explain the mobility of aluminum ions for

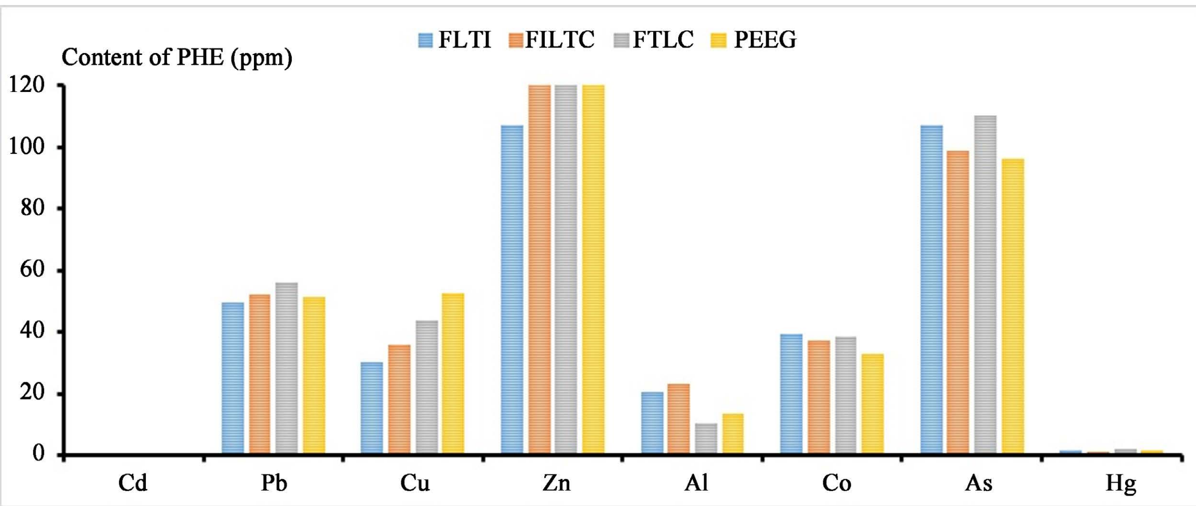

Figure 2. Distribution of PHE in different soils.

FLTI and FILTC soils that have the lowest pH. The same applies to the presence of clay in these soils, which could also more or less control the mobility of aluminum through adsorption or desorption reactions.

Cobalt has levels well above the standards of 25 ppm. The same is true of arsenic, the levels of which are much higher than the values, which are 20 ppm.

Apart from copper, which has increasing contents from FLTI to PEEG via FILTC and FTLC, the contents vary from one type of soil to another for the other elements.

In order to assess the level of soil contamination by potentially harmful elements (PHE) in the Yimiougou site, the geo-accumulation index (Igeo) and the accumulation factor were calculated.

4.2.1. Geo-Accumulation Index (Igeo)

It is an empirical parameter proposed by [4] [5] as a criterion for assessing metal contamination in sediments. The purpose of this index is to compare a datum with a value considered as a geochemical background, which makes it possible to assess the level of heavy metal contamination in the soil. This value is subject to a correction factor of 1.5, which makes it possible to reduce the consequences of variations in the values of the origin, which can be attributed to lithological variations in the sediments [6] [7].

Considering the variations caused by the effect of lithology [8], the average content of elements in the earth's crust replaced the geochemical background in the calculation [9]. So the formula is:

$$\text{Igeo} = \log 2\left(\text{Cx}/1.5 \times \text{Bgx}\right)$$

Cx = the measured content of a given element (metal) x,

Bgx = geochemical background for element x.

The levels of contamination can be distinguished according to the value of the geo-accumulation index (Igeo).

The values of the geo-accumulation index for PHE in the different morphopedological units in the Yimiougou area are recorded in the following **Table 2**.

The Igeo values for cadmium and cobalt of the different soil units are negative, reflecting an absence of pollution of these entities. The contents obtained for these elements would only represent the geochemical background, *i.e.* the concentration in the crust. With regard to zinc, the Igeo values belong to class I, therefore unpolluted to slightly polluted.

Table 2. Geo-accumulation index (Igeo).

Soil type	Cd	Pb	Cu	Zn	Co	As
FTLI	−0.18	1.30	1.30	0.55	−0.18	1.68
FILTC	−0.48	1.38	1.38	0.62	−0.21	1.64
FTLC	−0.18	1.47	1.47	0.61	−0.19	1.69
PEEG	−0.18	1.54	1.54	0.61	−0.26	1.63

The Igeo values for lead, copper and arsenic place them in class II, *i.e.* slightly to moderately be polluted. It therefore appears that for lead, copper, zinc and arsenic that the levels found in the different morphological units are partly attributable to anthropogenic action and specifically artisanal mining.

4.2.2. Contamination Factor (CF)

The introduction of the contamination factor was inspired by analogy to the weathering indices [10]. These indices use the comparison between the mobile elements and the conservative elements. The conservative element is used to quantify the gain of an element in a weathering product compared to the source rock and thus define an anthropogenic contribution [11]. Through this factor, it is possible to discriminate anthropogenic contributions from natural sources, and to assess the degree of contamination. The latter gives the number of times an element is enriched compared to the abundance of this element in the reference material [12].

The CF corresponds to the ratio of the measured content of an element x in the tested sediment and the background content of the same element.

$$CF = Cx/Bgx$$

Cx: Concentration measured for an element x,

Bgx: Background for an element x.

The values of the contamination factor for PHE in the different morpho-pedological units in the Yimiougou area are recorded in the following **Table 3**.

The contamination factor values obtained in the different morphological units for the PHEs studied indicate contamination according to the classification made by [13]. However, this contamination is of varying degrees according to the PHE. The weakest contamination is observed at the cobalt level. Indeed, the value of the CF with regard to cobalt places it in class I, namely that relating to the absence of contamination or low. For cadmium, the different types of soil are moderately contaminated (class II) with the exception of the FITLC type, which has a CF value of 0.50, therefore synonymous with low or absent contamination.

The various morphological units are very heavily contaminated (class VI) with zinc, copper, lead and arsenic.

This very high contamination of the different types of soil would be attributable to the highly developed artisanal mining in the study area. In addition, the presence in the study area of oxides of iron, aluminum or manganese (Mn),

Table 3. Contamination factor (CF) in different soil types.

Soil type	Cd	Pb	Cu	Zn	Co	As
FTLI	1.00	49.50	30.02	5.37	0.99	71.49
FILTC	0.50	52.10	35.65	6.27	0.93	65.85
FTLC	1.00	56.20	43.80	6.05	0.96	73.35
PEEG	1.00	51.08	52.40	6.11	0.82	63.99

organic matter constitute potential factors of immobilization of heavy metals in sediments or in soils [14] [15]. This could subsequently constitute a major source of local contamination in addition to the elements remobilized to the surface during the extraction of the ore.

Mining residues from artisanal mining activities represent significant potential sources of pollution through leaching and water infiltration [16]. These piled up mine tailings release PHE [17]. Given that soils and water are the sources of ingestion of arsenic, the latter could infiltrate and return to groundwater given the high permeability of the environment.

The distribution of heavy metals between the solid phase and the liquid phase of soil is strongly influenced by soil properties such as pH, organic matter content, ionic strength of soil solution, manganese and iron oxides. In other words, the distribution, the interactions between heavy metals as well as their transport in the different soil compartments are governed by these parameters and are carried out by very complex physico-chemical mechanisms such as adsorption, precipitation and complexation [18] [19].

If a soil contains too high levels of metals, it becomes toxic for the majority of plants [20] and consequently unsuitable for agriculture. In Yimiougou, in the different types of soil, the copper, iron, aluminum, cobalt and arsenic contents are clearly higher than the standards in force in Burkina Faso and could make them unsuitable for agricultural activities. If for cobalt, the Igeo calculation shows that it is of lithogenic origin, and not linked to gold panning activities, it is not the same for copper, iron, aluminum and arsenic. However, the contamination factor indicates that in the case of cobalt there is contamination, even if it is low. For the other metals, the contamination factors indicate high contamination except for cadmium for which this contamination is moderate. This state of affairs indicates that soil contamination in Yimiougou is attributable to artisanal mining activities.

4.3. Acid Mine Drainage (AMD)

Mine tailings can be a source of pollution, because when they contain sulphides, their contact with oxygen in the air, water and acidogenic bacteria can lead to their oxidation, resulting in the generation of AMD. The presence of pyrite which is one of the sulphides accompanying gold in mineralized zones in Burkina Faso [21] [22] is an important factor in the generation of DMA. The populations of Yimiougou live mainly from agriculture and livestock. For this reason, pollution by AMD is detrimental to the very life of this riverside community, which is highly dependent on these water resources. However, buffer reactions such as the dissolution of carbonates, aluminum silicates and aluminum hydroxides sometimes take place and have the effect of reducing the acidity of AMD and making the pH almost neutral. Hence, the need to estimate the total quantity of acidifying and neutralizing minerals contained in the mine tailings [23].

Geochemical tests (static and kinetic) are methods that predict acid mine drainage for better waste rock and tailings management.

Static geochemical tests are very simple to perform and inexpensive. They thus make it possible to estimate the variability of the acidification potential at the scale of the site (establish the balance between the acid generation potential (AP) and the neutralization potential (NP) for a given material). These are referred to as static conditions in that they do not take into account the relative rates of acid production and consumption. Their results therefore have above all an indicative and predictive value [24]. The static test is considered positive if the net neutralization potential (NNP) is less than 20 kg $CaCO_3$/tonne of material or the NP/AP neutralization ratio is less than 3. Static tests commonly called geochemical tests are based on analytical data and three main ones can be distinguished: measurement of pH and conductivity in saturated paste (EC), the aptitude test for the production of net acidity (ABA or NAPP) and the Net Acidity Generation (NAG) test.

25 samples of mine tailings from artisanal mining were collected for the prediction of acid mine drainage.

4.3.1. Measurement of pH and Conductivity in Saturated Paste (EC)

From physical parameters such as pH and conductivity, acid mine drainage (AMD) predictions can be made according to [25] who defines classes of DMA (**Table 4**).

The table below gives the predictions of AMD generation according to the pH and conductivity values measured in saturated paste of the samples of mine tailings from artisanal mining in Yimiougou.

The pH (6.7 to 8.5) and conductivity (70 to 468 $\mu S \cdot cm^{-1}$) values place the mine tailings samples in class IV of the [25] classification, therefore non-acidogenic (no risk of AMD). These values indicate that the analyzed samples are not yet oxidized. However, the risk of oxidation over time cannot be excluded because the possibility of acid generation from the oxidation of sulphide minerals depends on the primary factors, which are the presence of sulphides, their exposure to water and/or oxygen.

4.3.2. Sulphide Contents

The diagram of [26] allows from the threshold content of 0.3% distinguishing the range where the samples are not acidogenic from that where they are potentially

Table 4. AMD prediction classes from pH and conductivity [25].

pH	Conductivity ($\mu S \cdot cm^{-1}$)	AMD classes	Diagnostic
pH < 4	>1000	I	confirmed acid mine drainage
4 < pH < 5	>750	II	Acid mine drainage in development confirmed
5 < pH < 6	>500	III	Acid mine drainage in potential development
pH > 6	≤500	IV	No risk of acid mine drainage

acid generating according to the sulphide content (Figure 3).

Thus, only samples S17, S22, S23 and S24 present values, which are strictly above the threshold (0.3%) and therefore are potentially acid generators (Figure 3). However, the sulphide content is not synonymous with acid production, because the inhibiting or neutralizing minerals (carbonates) can produce neutralization reactions, *i.e.* play a buffer role [21] [22] [23].

Since carbonates are acid neutralizing minerals [21], a comparison of the acidification potential with that of the neutralization potential was made (Figure 4) in order to evaluate the neutralization capacity acid-consuming minerals.

The comparative study of the acid potential (AP) and the neutralization potential (NP) reveals that the neutralization potentials of the different samples are clearly higher than the acid potentials even for the samples presenting a proven acidification potential (S17, S22, S23 and S24).

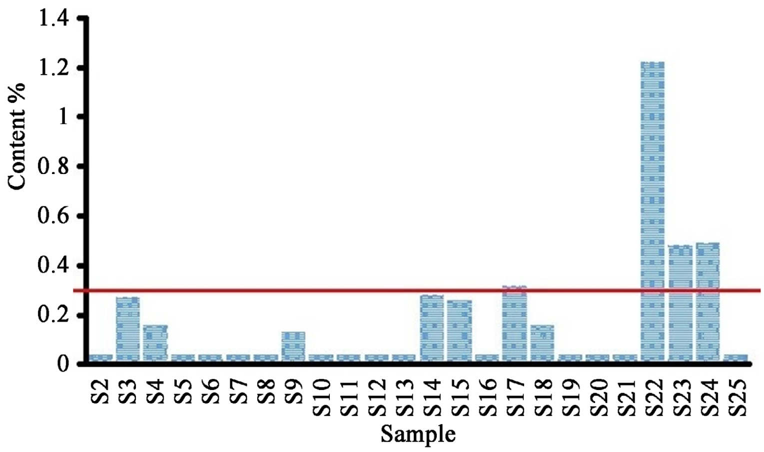

Figure 3. Sulphide content of Yimiougou mine tailings.

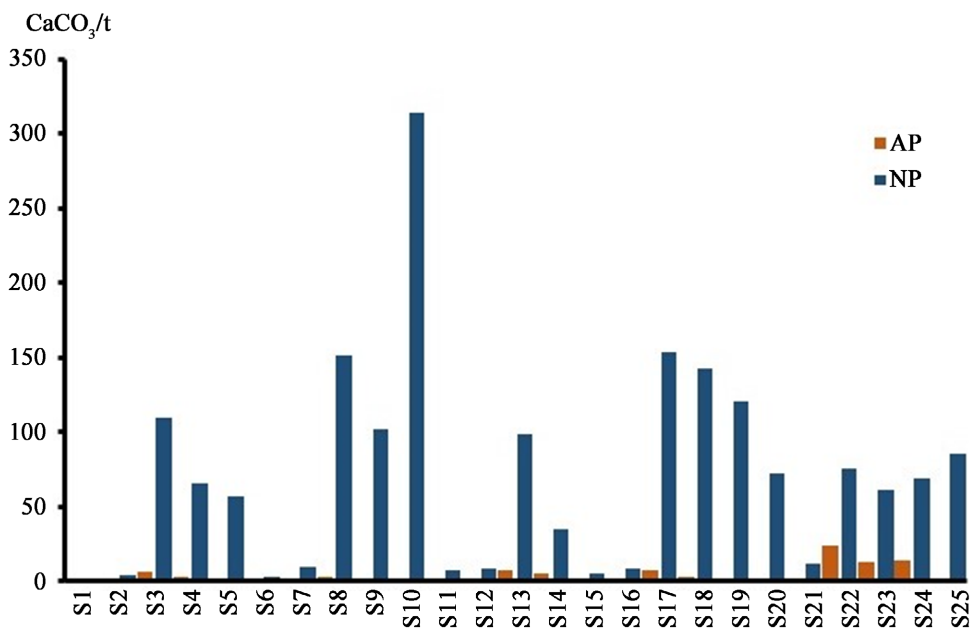

Figure 4. Comparative diagram of acid potential (AP) and neutralization potential (NP).

These results show that the mine tailings from the artisanal mining of Yimiougou have the natural capacity to neutralize any possible acid mine drainage. This is explained by the presence of neutralizing minerals such as carbonates associated with mineralization that is exploited by gold miners in the study area.

5. Conclusion

Soils in Yimiougou are mostly loamy, acidic and deficient in organic matter and total nitrogen. They are also poor in exchangeable calcium, magnesium and potassium. These soils are of nil to low agronomic interest. The various morphological units are very heavily contaminated with zinc, copper, lead and arsenic. The neutralization potentials of the different samples are clearly higher than the acid potentials indicating that the mine tailings have the natural capacity to neutralize any possible mine drainage, given the presence of acid-eating minerals such as carbonates associated with the mineralization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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