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Dynamics of land cover changes and condition of soil and surface water quality in a Mining–Altered landscape, Ghana

Samuel Kumi [a,*], David Adu-Poku [b], Francis Attiogbe [c]

[a] Department of Environmental Management, University of Energy and Natural Resources, Sunyani, Ghana
[b] Department of Chemical Sciences, University of Energy and Natural Resources, Sunyani, Ghana
[c] Department of Civil and Environmental Engineering, University of Energy and Natural Resources, Sunyani, Ghana

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ABSTRACT

This study investigated the dynamics of mining effects on land use land cover changes and the chemical and physical characteristics of soil and surface water in the Ahafo mining area in Ghana. Landsat imagery was used to analyze land use-land cover changes (LULC) using a supervised classification technique. Soil samples were collected within 600 m from active mining operations and at depths of up to 75 cm, as well as surface water samples from upstream and downstream of the mine. Atomic Absorption Spectrometry was used to determine the concentration of heavy metals in the soil and water samples. The results demonstrated a significant loss of forest and other vegetation covers, which decreased from 44% to 31% to 8% and 20%, respectively, with corresponding increases in the mining site, mine water, settlement/bare surface, cropland and plantation. Organic matter, organic carbon, exchangeable bases, cation exchange capacity, available phosphorus, and pH were all moderate in the soil surrounding the mine. Except for As (4.027 mg/kg) and Hg (1 mg/kg), all heavy metals found in the soil were within FAO/WHO guidelines. Total Dissolved Solids (TDS) (416.18 mg/L), Total Suspended Solids (55.08 mg/L), Turbidity (54.49 NTU), Ca (84.49 mg/L), Mg (31.97 mg/L), nitrate (10.23 mg/L), and sulphate (606.83 mg/L) in the downstream water were higher than those in the upstream and USEPA/WHO limits for drinking water except for TDS. Because of the geology of the area, there were high concentrations of iron, manganese, and aluminum in the surface water. The results show that mining induced severe land cover changes and impaired surface water and soil quality in the mine's vicinity. The findings have implications for stakeholder education, appropriate community water interventions, and company-community-regulator participatory monitoring to avoid health risk exposure and further water and soil quality and vegetation degradation.

1. Introduction

The mining industry contributes significantly to the global economy and modern societies, especially in developing nations with mineral resources [1,2]. Mining continues to attract the most foreign direct investment in resource-dependent developing countries, mainly in Africa and Asia and accounts for between 2 and 20% of total revenues [3,2]. When measured by the Human Development Index, resource-dependent countries in Sub-Saharan Africa once experienced annual economic growth of 1.3%, which was higher than that of non-resource-dependent nations [4]. For instance, Ghana's mining sector attracts over 50% of all Foreign Direct Investments,

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* Corresponding author.
E-mail address: Samuel.kumi@uenr.edu.gh (S. Kumi).

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accounts for approximately 33% of all revenues and 43% of total merchandise exports, and contributes considerably to tax, GDP, and employment [5].

However, because sustainable development entails more than just financial flows, the role of mining in economic development remains debatable. Mining is linked to several economic, environmental, and social issues that raise concerns about its sustainability [6,7]. The degradation and depletion of forest resources, the decline in soil nutrients, wildlife habitat destruction, and an increasing threat to human health have all been associated with mining activities [8]. Water and soil have been identified as the primary environmental resources in Ghana that mining has degraded [9,10,11]. Mining physically disturbs topsoil and impacts soil and water quality chemically [12]. Surface mining, the most common mining practice, removes topsoil and depletes soil nutrients, rendering land infertile and useless for agricultural purposes [8,13,14]. Soils of many mining communities have a lot of metal contaminants because of metal ores mining and milling [15,16]. Heavy metal (lead, mercury, arsenic, cadmium, chromium, zinc and nickel) pollution exists in the soil surrounding mines, posing persistent risks to public health [15,17].

Similarly, mining affects water quality via erosion and sedimentation, processing chemical pollution, heavy metal contamination and leaching, and acid mine drainage. Mining-related erosion and sediment loading cause elevated particulate matter concentrations in water [18]. Water has been mining's most frequent casualty [19].

Mining-related water contamination exists in Ghana [8,20]. Obuasi and its environs were among the first mining areas in Ghana and on the African continent, that continue to face mining-induced groundwater pollution as well as other environmental and health issues relating to heavy metal contamination [20,21]. Communities in other well-established mining areas, like Ahafo, which had never dealt with mining-related environmental and health issues, now face them frequently.

Despite the plethora of evidence that suggests mining is polluting the soil and water in mining regions, the effects on these resources have not been examined frequently or early enough. Considering the adversative implications of land use/cover changes and water and soil quality degradation on water availability and livelihood, assessing their trends is crucial in guiding future development management. Evaluating the dynamics of land cover, water, and soil in mining would produce data with significance for integrated water resource management and planning in the mining setting. In spite of the numerous mining-induced land disturbance, there is little focus on assessing the influence of mining on land use land and cover changes and the consequent impairment of surface water and soil quality. Few studies have looked at the impact of mining on LULC changes, surface water and soil quality independently. However, there is a dearth of information on an integrated study of the mining-induced land use/cover changes and the resultant surface water and soil quality degradation with implications for proper integrated water resources management measures in mining landscapes. This study, therefore, evaluates the influence of mining on land use/cover changes and consequential impacts on surface water and soil quality in a mining landscape within the Ahafo region, Ghana. As the intense global demand for mineral resources continues to extend mineral exploitation, relevant data and a good appreciation of land use/cover changes and connected implications on water and soil resources are required to design integrated monitoring, management, and policy interventions to mitigate adverse effects and guarantee sustainable mining and water resource management. Such data would enable comprehensive planning, management and conservation of forest, surface water and soil resources at the landscape level. Monitoring the soil and water conditions in mining regions, particularly in farming communities near recent mining activities, as the investigated area, is critical to assist in early identification, prevention, and mitigation of the adverse effects.

2. Materials and methods

2.1. Study area

The study's geographic scope covers the surroundings of Newmont Ghana Gold Limited - Ahafo Mine, located between 7° 5′ 59.7″ N and 2°25′ 33.9″ W to 6° 56′ 43.3″ N and 2° 17′ 19.3″ W. The region is part of the early Proterozoic Birimian Formation, which is made up of broad, parallel, and evenly spaced volcanic belts (Upper Birimian) and sedimentary basins. The area is near the boundary of the Sefwi Belt of meta-volcanic and the fine-grained metasedimentary rocks of the Sunyani Basin to the northwest [22]. Intruded into the metavolcanics are granitoid plutons and dikes of granitic to dioritic composition. The contact between the Upper and Lower Birimian is marked by a major shear zone that was the avenue for the intrusion of gold-bearing hydrothermal fluids. The Sefwi volcanic belt consists primarily of mafic volcanics and granitoid; whereas, the Sunyani sedimentary basin is dominated by argillites and wackes, with subordinate graphite zones and volcaniclastics. The Birimian-age rocks have been subjected to regional metamorphism, resulting in meta-volcano-sedimentary rocks in the study area. Bedrock has been subjected to long periods of tropical weathering, resulting in duricrust and laterite soil, underlain by saprolite, which consists of decomposed bedrock weathered in situ to sand-silt-clayey soil. Deep lateritic weathering is present on and in between the mountain ranges of the Sefwi Belt.

Weathering generally extends to depths of 50 m or more. Duricrust or ferricrete, is often present at the ground surface and consists of sand/gravel cemented into a hard mass by iron oxide. This weathered zone consists of red lateritic clay and saprolite, which are commonly covered at the ground surface by duricrust, consisting of alluvial fragments and iron pisoliths cemented with iron oxide. Saprock is generally considered the uppermost aquifer in the study area, except areas where alluvium (silt, sand and gravel) along the stream and river channels contains groundwater. The saprolite generally is considered an aquitard due to its clay content but does contain weathered quartz veins that can serve as conduits for infiltration and groundwater flow. Beneath the saprock is competent bedrock where the unit is sufficiently fractured to store and transmit groundwater. In the study area, this bedrock consists primarily of granitoid, mafic volcanics and metasediments. The primary structural zone in this area is the shear zone with associated tectonic breccias [22].

The research area is drained by the Tano River and its ephemeral and perennial tributaries, which include the Amama, Subika, Atensu, and Subri. The Tano River Basin is the primary watershed. This basin is close to Ghana's southwest corner. The river drains into the Gulf of Guinea and is close to the border between Ghana and Cote d'Ivoire. The Tano River is Ghana's third biggest river, with a length of 512 km and a drainage area of approximately 16,060 km^2 (1,600,000 ha) [23]. The river enters the study area from the north and runs along the eastern boundary.

2.2. *Determination of land use and land cover changes of the studied area*

This investigation employed Landsat imageries with limited or cloud-free cover from the US Geological Survey to determine the land use and land cover changes in the studied area. To enhance the Landsat images, a radiometric correction was performed. The study area was sub-set from a broader image. Totaling 120 field points were utilized as training data for the supervised imagery classification. Four multi-temporal imageries of the area under study were classified using the maximum likelihood algorithm. The image classification accuracy was evaluated. The validation data utilized to measure the classification accuracy were produced from the field and were distinct from the training samples. The confusion matrix obtained from the accuracy evaluation was used to generate the producer's and user's accuracies, overall accuracy, and kappa statistic. Erdas Imagine 2016's "matrix union" feature was used for change detections in the final generated maps of the identified land uses and land covers.

2.3. *Soil sampling*

The study looked at the heavy metal concentration and physicochemical properties of soils around operational mining facilities such as gold mine tailings dam, mining pits, and waste dumps. Mining has had an impact on the sampling location for over a decade. The area has the same soil parent materials. Thus, we attribute differences in soil quality over the location to mining. A total of thirty-six (36) sampling points were located, twelve (12) around each of the three selected facility sites (Fig. 1). Soil samples were collected from a distance of 200 m, 400 m up to 600 m radius from the active mining facilities, and at a depth of up to 75 cm (ranging from 0 to 25, 25–50 and 50–75 cm), using soil augur, a clean bucket and a plastic scoop. The samples were well-labeled in zip-lock sample bags and delivered to Soil Research Institute-managed laboratory at Kwadaso in Kumasi.

2.4. *Physicochemical analysis of soil*

The particle sizes of the air-dried samples of soil were determined by the hydrometer method. The conductivity meter Cond 7110 was used to measure Exchangeable Cations Exchanges Capacity. Through an electrometric process, the pH of the soil was determined using a glass electrode pH meter, the Sartorius Basic Meter PB-11. The modified Kjeldahl method was used to calculate the total N, while the available P was computed using Bray's No. 1 method. Total soil organic matter and carbon were estimated using the modified Walkley and Black techniques [24]. Exchangeable bases – Calcium, Magnesium, Sodium and Potassium in the soil were extracted through leaching using 1 M solution of ammonium acetate. The leachate was then examined using an atomic absorption

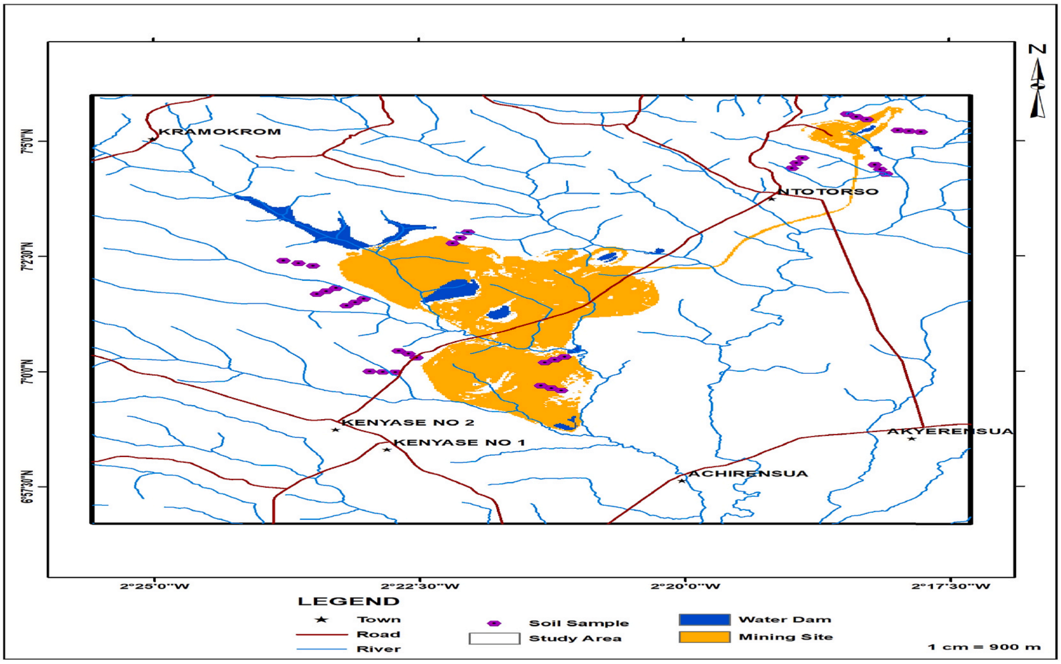

Fig. 1. A Map of soil sample locations within the Ahafo south Mining Area.

spectrophotometer to identify the individual cations [25]. To determine the total concentrations of As, Pb, Cd, Hg, Cu, and Zn in the soil, pulverized dried samples were 'filtered' through a 0.2 mm sieve and digested in accordance with EPA Procedure 6010 [26]. Thirty-six (36) samples were digested independently, with replicate results obtained for the individual sample. Each batch of digestion followed the same process, including a blank and reference to the industry-standard substance (Montana Soil Moderately Elevated Traces). The studied heavy metals in the soil were analyzed with the Flame Atomic Absorption Spectroscopy (AAnalyst 100, PerkinElmer, USA). For each metal analysis, five standard solutions of their respective salts were prepared whilst deionized water was used as a blank. The method detection limit for the metals analyzed were: Pb: 0.0100 mg/kg, As: 0.0030 mg/kg, Cd: 0.0020 mg/kg, Hg: 0.0020 mg/kg, Cu: 0.0030 mg/kg and Zn: 0.0010 mg/kg. The calibration lines were linear with a correlation coefficient between 0.994 and 0.998.

2.5. *Water sampling*

The surface water sampling was undertaken in July (rainy season) and December (drying season). Sampling points were designed to assess surface water quality upstream and downstream of the mining activities/facilities across the project area (Fig. 2). The downstream area has been under the direct and indirect the influence of mining for over a decade. The water samples were prepared according to the protocols summarized in Ref. [27] and expanded upon by Ref. [28] in determining trace elements and major ions. Before taking the samples, polyethylene bottles were thoroughly rinsed with water to be sampled. Single-grab samples were collected because baseline samples were similarly collected. In-stream measurements of upstream and downstream waterbodies' physicochemical properties - pH, turbidity, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) were conducted. Thus, a fraction of each sample was used to measure those parameters with previously calibrated equipment.

2.6. *Physicochemical analysis of water*

To preserve the sample for dissolved metal analyses, 10 mL of the sampled solution was mixed with one drop of redistilled, concentrated HNO_3. The samples were stored in clearly labeled brown plastic bottles, placed in an ice chest with ice and brought to the lab for analysis. The atomic absorption spectrophotometer was used to examine the eight heavy metals (Pb, Hg, As, Cd, Cu, Fe, Mn, and Al) for presence and concentration.

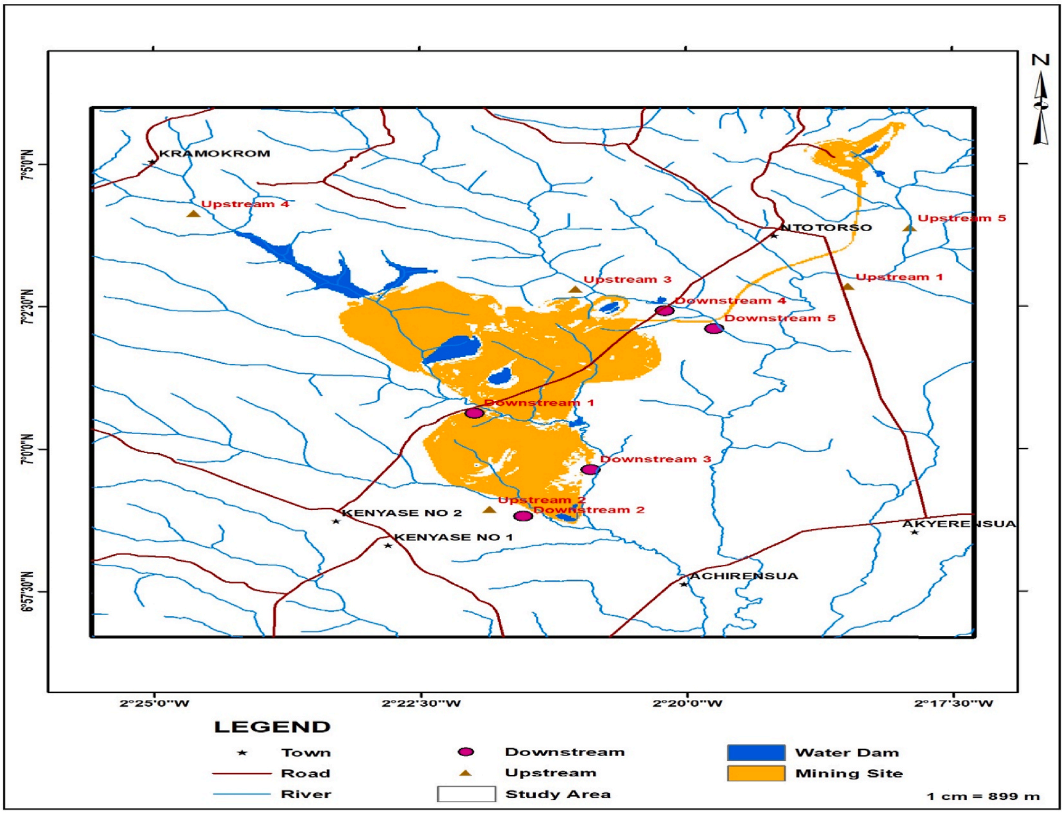

Fig. 2. Water sampling locations within the Ahafo south Mining Area.

2.7. Data analysis

The mean plus standard deviation was used to express the levels of the investigated soil parameters. Comparing the mean between distances and depths, one-way ANOVA was adopted, and differences with a significance level of $p < 0.05$ were regarded as statistically significant. The ANOVA calculation was done using the statistical programme R. The studied water parameters' levels were expressed as mean plus standard deviation. The upstream and downstream water quality were compared using a sample *t*-test.

3. Results

3.1. Trends of mining-induced land use land cover changes

Except for the 2003 land use-land cover map, which depicted five land use/cover classes (excluding mine site and mine water), the other two maps showed seven categories involving forest area, cropland, plantation, mining site, mine water, and settlement/bare surface (Fig. 3). Forest cover, other vegetation, cropland, and plantation represented the main types of land uses or covers (Tables 1–3; Figs. 3 and 4). The forest cover and other vegetation declined consistently from 44% to 31% to approximately 8% and 20% in 2020, respectively. Actually, within the seventeen (17) year investigation period (i.e., 2003 to 2020), on a continual basis, the forest cover saw high conversion to other land uses or land cover categories (Table 2). Thus, in all, 9,845.28 out of 11,622.87 ha of forest cover was transitioned to other forms of land use.

On the contrary, between 2011 and 2020, settlement/bare surface and mining site increased. Correspondingly, among the other land cover forms, the combined contribution of other vegetation and plantation to the settlement and mining site equaled 91% and 67%, respectively (Table 3). The most significant contributors to the mining site were forest cover, followed by other vegetation and cropland. Mining site and mine water experienced limited conversion into other land use types. Plantation and mine water increased considerably in 2011 and decreased marginally in 2020. Relative to other land use/covers, the forest made the highest and most consistent contribution to the plantation, totaling 8862.57 ha and 7983.72 representing 78% and 70% for 2011 and 2020, respectively. Cropland declined sharply in 2011 and increased significantly in 2020 (Fig. 4). Out of 531758 ha cropland area, 4362.39 ha was a conversion from other vegetation and plantation, representing 82% of the cropland (Table 3). Mine water – waterbody created mainly from water impoundments for mining activities experienced a marginal transition to other land use types, including mining sites, of which it made the highest conversion, which accounted for 28.62 ha in 2020 (Table 3).

In general, forest and other vegetation cover recorded a net loss, while the areas of cropland, plantation, mining site, and mine water settlement/bare surface saw significant gains (Fig. 5). Over 9,000 ha of forest cover were lost in the 26,000 ha area investigated.

3.2. Levels of agronomic properties of soils around the mine

Generally, all the agronomic properties of the soil except exchangeable acidity and base saturation showed no significant variations

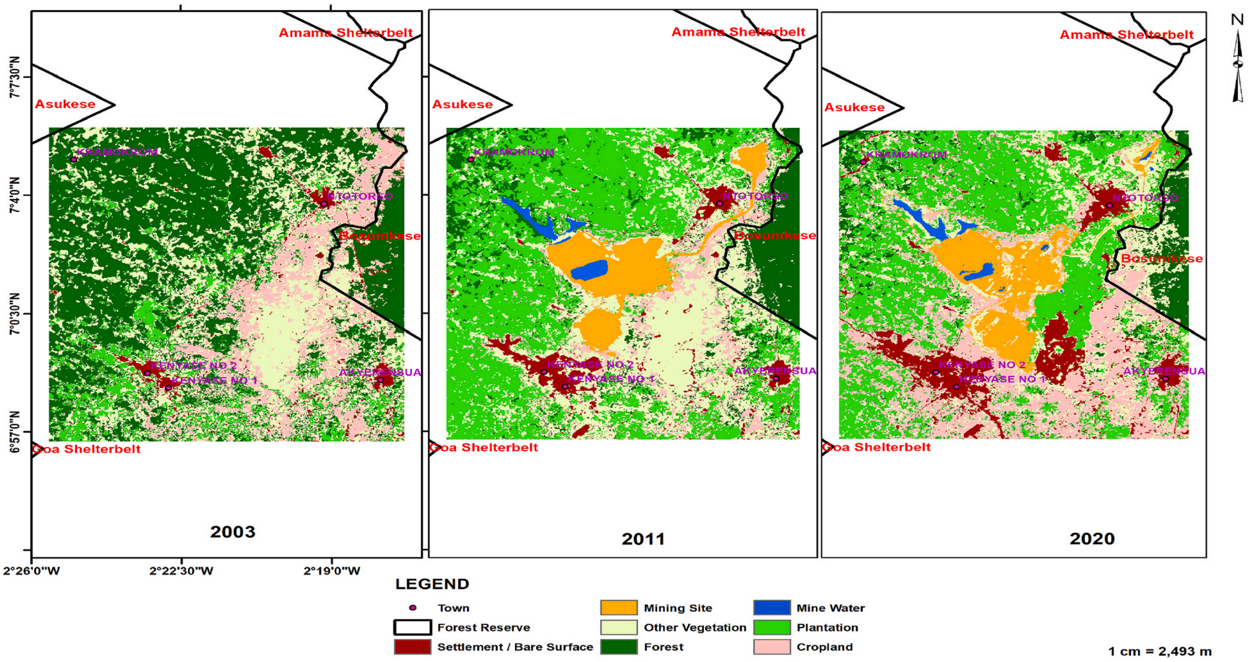

Fig. 3. Land use/cover Maps for 2003–2020 in a mining landscape, Ghana.

Table 1
Land use land cover (LULC) change matrix between 2003 and 2011.

2011 LULC (ha)									
	Land use	Settlement	Mine Water	Other Vegetation	Forest	Mining Site	Plantation	Cropland	**Total**
2003 LULC (ha)	Settlement/bare surface	574.02	1.53	31.14	51.75	36.81	7.56	0.45	703.26
	Other Vegetation	277.47	112.68	5,139.54	144.27	630.36	1,633.68	90.72	8,028.72
	Forest	113.49	139.86	660.87	2,675.16	745.38	6,873.48	414.63	11,622.87
	Plantation	86.49	33.66	656.82	5.58	185.31	1,480.05	35.19	2,483.10
	Cropland	86.04	0.90	847.17	408.87	267.21	347.85	1,264.41	3,222.45
	Total	**1,137.51**	**288.63**	**7,335.54**	**3,285.63**	**1,865.07**	**10,342.62**	**1,805.40**	**26,060.40**

Table 2
Land use land cover (LULC) change matrix between 2003 and 2011.

	Land use	2020 LULC (ha)							Total
		Settlement	Mine Water	Other Vegetation	Forest	Mining Site	Plantation	Cropland	
2003 LULC (ha)	Settlement/bare surf	549.81	1.08	62.10	18.27	32.40	11.79	27.81	703.26
	Other Vegetation	1,031.58	87.84	2,484.36	94.95	711.36	1,649.34	1,969.29	8,028.72
	Forest	290.61	121.23	1,507.23	1,777.59	862.20	5,558.22	1,505.79	11,622.87
	Plantation	230.67	28.89	339.66	23.22	210.42	874.44	775.80	2,483.10
	Cropland	204.03	4.86	745.11	160.83	304.56	764.37	1,038.69	3,222.45
	Total	**2,306.70**	**243.90**	**5,138.46**	**2,074.86**	**2,120.94**	**8,858.16**	**5,317.38**	**26,060.40**

Table 3
Land use land cover (LULC) change matrix between 2011 and 2020.

	2020 LULC (ha)								**Total**
	Land use	Settlement	Mine Water	Other Vegetation	Forest	Mining Site	Plantation	Cropland	
2011 LULC(ha)	Settlement	1,082.70	–	4.41	0.18	28.98	5.13	16.11	1,137.51
	Mine Water	–	213.66	0.18		74.79	–	–	288.63
	Other Vegetation	944.55	1.17	2,939.85	4.59	400.14	843.93	2,201.31	7,335.54
	Forest	14.31	0.27	1,081.80	1,961.64	37.71	131.58	58.32	3,285.63
	Mining Site	2.61	28.62	442.71	–	1,387.35	2.07	1.71	1,865.07
	Plantation	168.75	0.09	424.08	92.70	94.23	7,401.69	2,161.08	10,342.62
	Cropland	93.78	0.09	245.43	15.75	97.74	473.76	878.85	1,805.40
	Total	**2,306.70**	**243.90**	**5,138.46**	**2,074.86**	**2,120.94**	**8,858.16**	**5,317.38**	**26,060.40**

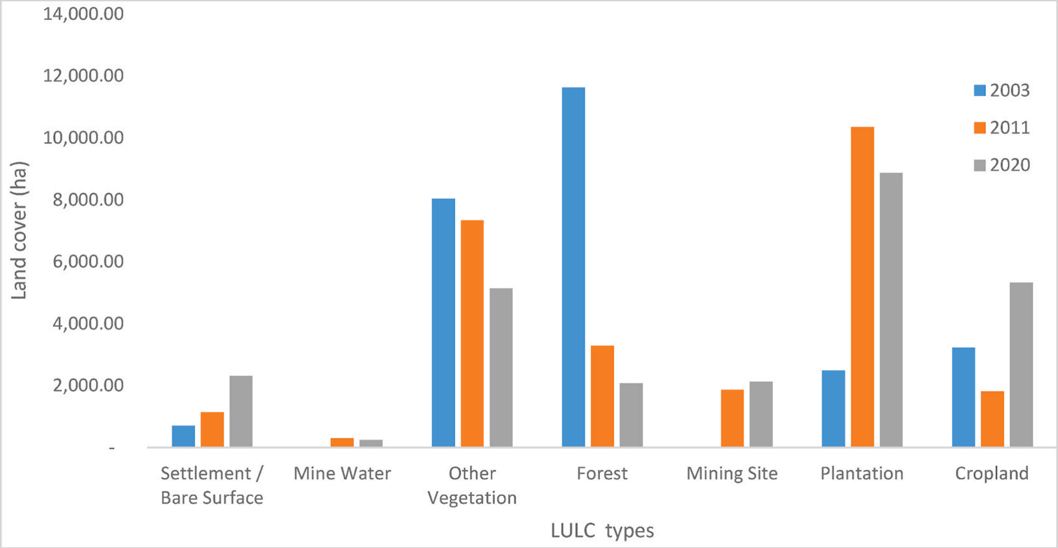

Fig. 4. Changes in the various land use/cover types for each year (2003, 2011 and 2020.

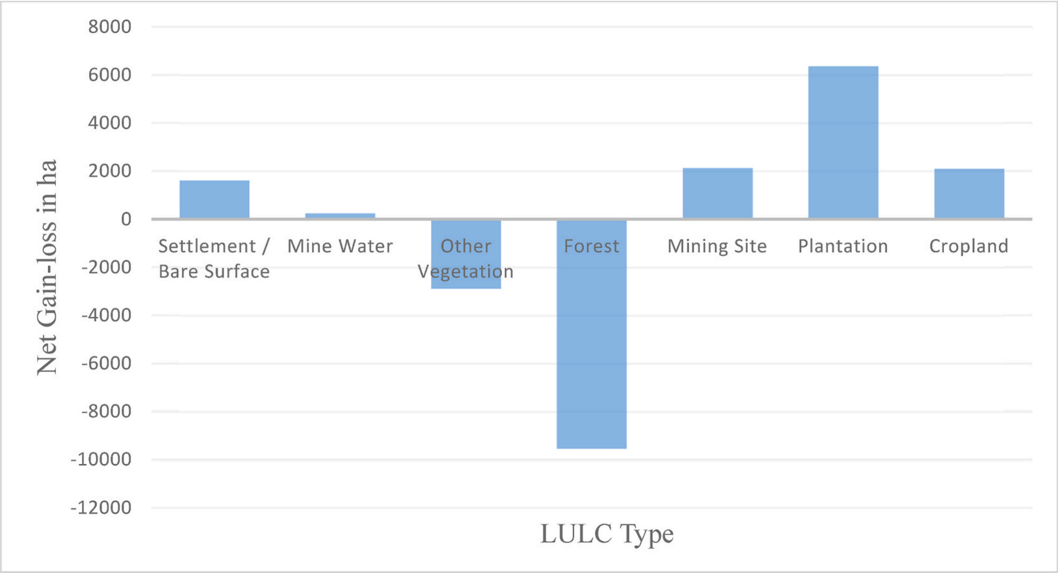

Fig. 5. Net changes (Gains–losses) for the various land use/cover categories for 2003–2020.

among the three sites/distances (Table 4). The soil at 400 m had significantly higher exchangeable acidity than that of 600 m, which in turn had higher exchangeable acidity levels compared to the 200 m site. The base saturation level at the 200 m site was significantly higher than the rest of the sites. However, the base saturation at sites 400 m and 600 m showed no significant variation.

3.3. Concentration of heavy metals in soils around the mine

At distances of 200 m, 400 m, and 600 m from mine facilities, the concentrations of six heavy metals in the soil samples investigated generally did not change (Table 5). However, the concentrations of each metal varied with depth (Table 6). All the studied metals decreased with depth, except copper concentration, which increased and then decreased with depth. Except for As and Hg, all the heavy metals were within WHO and FAO limits.

3.4. Levels of surface water quality parameters

The levels of all the physicochemical parameters (physical, ions, and nutrients) examined were significantly higher in the downstream samples compared to the upstream of the mine except for color and chloride (Table 7).

Except for iron, the concentrations of heavy metals in the downstream surface water were comparable to those in the upstream.

Table 4

Levels of soil properties over distance from the mining facilities.

Soil property	Distance from mining facilities			*P*-value
	200 m (n = 36)	400 m (n = 36)	600 m (n = 36)	
pH	$6.383^{a}\pm0.43$	$5.971^{a}\pm0.96$	$5.835^{a}\pm.87$	0.226
Organic carbon (%)	$1.363^{a}.\pm0.48$	$1.384^{a}\pm0.40$	$1.33^{a}\pm0.46$	0.953
Total nitrogen (%)	$0.138^{a}\pm0.04$	$0.138^{a}\pm0.04$	$0.135^{a}\pm.04$	0.97
Organic matter (%)	$2.349^{a}\pm0.82$	$2.385^{a}\pm0.79$	$2.288^{a}\pm0.70$	0.951
Ca (cmol/kg)	$4.897^{a}\pm3.23$	$6.465^{a}\pm4.29$	$4.817^{a}\pm1.976$	0.397
Mg (cmol/kg)	$1.992^{a}\pm1.00$	$2.492^{a}\pm1.84$	$2.047^{a}\pm0.95$	0.603
K (cmol/kg)	$1.105^{a}\pm0.91$	$1.297^{a}\pm0.96$	$1.468^{a}\pm.69$	0.594
Na (cmol/kg)	$0.687^{a}\pm0.24$	$0.805^{a}\pm0.41$	$0.818^{a}\pm0.33$	0.571
TEB (cmol/kg)	$8.680^{a}\pm4.38$	$11.058^{a}\pm6.88$	$9.148^{a}\pm3.36$	0.488
Acidity (cmol/kg)	$0.129^{a}\pm0.19$	$2\ .513^{b} \pm 0.48$	$0.608^{c}\pm0.37$	0.008
ECEC (cmol/kg)	$8.810^{a}\pm4.37$	$11.570^{a}\pm6.66$	$9.756^{a}\pm3.42$	0.4
Base saturation cmol/kg	$98.339^{a}\pm2.18$	$93.841^{b} \pm 6.41$	$93.070^{b} \pm 4.89$	0.004
Available P (ppm)	$4.548^{a}\pm2.48$	$4.852^{a}\pm5.13$	$3.978^{a}\pm4.83$	0.881
Sand (%)	$56.000^{a}\pm9.87$	$50.333^{a}\pm13.29$	$49.000^{a}\pm15.00$	0.38
Clay (%)	$10.167^{a}\pm3.76$	$13.667^{a}\pm6.43$	$13.500^{a}\pm7.14$	0.281
SILT (%)	$33.833^{a}\pm6.69$	$36.000^{a}\pm8.57$	$33.833^{a}\pm9.34$	0.557

Values with the same superscript in a row are not significantly different ($P > 0.05$).

Table 5
Mean concentration (±SD) of heavy metals in soil over distance from mining.

Heavy metals	Mean concentration (mg/kg) over distance from mine facility			P-value
	200 m (n = 36)	400 m (n = 36)	600 m (n = 36)	
Pb	10.429^{a}±4.19	10.397^{a}3.12	10.223^{a}2±.10	0.545
As	4.014^{a}±2.11	4.0136^{a}±1.19	4.013^{a}±1.00	0.952
Cd	0.495^{a}±0.19	0.848^{a}±0.42	0.567^{a}±0.21	0.574
Hg	0.353^{a}±0.19	0.325^{a}0.14	0.342^{a}±0.12	0.970
Cu	17.487^{a}±8.13	16.855^{a}±7.13	17.545^{a}±8.43	0.530
Zn	21.977^{a}±10.00	22.871^{a}±10.55	20.500^{a} ±10.55	0.271

Facility. Values with the same superscript in a row are not significantly different(P > 0.05).

Table 6
Mean concentration (±SD) of heavy metals in different depths around the mining facilities
Values with the different superscripts in a row are significantly different (P < 0.05).

Heavy metals	Mean concentration ((mg/kg)) over different depths around the Mine			P-value	WHO/FAO
	25 cm (n = 36)	50 cm (n = 36)	75 cm (n = 36)		
Pb	10.106^{b} ± 5.17	10.722^{a}±5.22	10.221^{b} ± 5.17	0.00398	300
As	4.027^{a}±2.02	3.00^{b} ± 1.35	3.00^{b} ± 1.37	2.96e-06	3
Cd	1.545^{a}±0.75	0.213^{b} ± 0.11	0.151^{b} ± 0.01	1.79e-05	3
Hg	1.014^{a}±0.22	0.003^{b} ± 0.00	0.002^{b} ± 0.00	2e-16	0.18/0.92
Cu	10.305^{b} ± 4.45	13.136^{a}±5.49	10.446^{b} ± 4.47	4.47e-06	140
Zn	33.520^{a}±15.4	8.935^{b} ± 3.69	6.972^{b} ± 3.55	1.28e-15	99.40

WHO-World Health Organization; FAO –Food and Agricultural Organization.

Downstream had a lower mean iron concentration than upstream. The water samples taken upstream and downstream did not contain any cadmium. Except for total iron (0.200 mg/L), manganese (0.050 mg/L), and aluminum (0.087 mg/L), all of the metal concentrations under examination were within WHO and USEPA permissible limits.

4. Discussion

4.1. Mining-induced land use and cover dynamics

The results demonstrate a considerable change in land use and land cover of the studied landscape over the 17-year study time (i.e.,

Table 7
Mean values (±SD) of surface water quality parameters in the study area.

Parameters	Upstream	Downstream	EPA	WHO
Physical				
pH	7.3^{a}±0.38	7.6^{b} ± 0.57	6.5–8.5	6.5–8.5
Colour (TCU)	56.5^{a} ± 36.33	29.5^{b} ± 30.51	15	UD
Turbidity (N.T.U)	33.2^{a} ± 23.35	54.49^{b} ± 37.51	75	5
TSS (mg/L)	39.64^{a} ± 38.25	55.08^{b} ± 130.29	50	UD
TDS (mg/L)	142.28^{a} ± 69.48	416.18^{b} ± 279.92	1000	1200
Ion and nutrients				
Ca (mg/L)	29.46^{a}±27.14	84.49^{b} ± 271.7	30	UD
Mg (mg/L)	13.83^{a}±17.86	31.97^{b} ± 28.16	30	UD
Chloride (mg/L)	16.12^{a} ± 6.95	15.97^{a}± 20.89	250	UD
Nitrate (mg/L)	3.83^{a} ± 7.05	10.23^{b} ± 20.89	10	50
Sulphate (mg/L)	3.01^{a} ± 5.28	606.83^{b} ± 219.14	250	500
Total Cyanide (mg/L)	0.003 ± 0.001	0.004 ± .002	1	UD
Heavy metals				
Fe (mg/L)	3.710^{a} ± 2.900	2.39^{b} ± 4.590	3.5	0.3
Mn (mg/L)	0.360^{a} ± 0.660	0.26^{a}± 0.880	0	0.4
Cu (mg/L)	0.002^{a}±.001	0.003^{a}±0.004	0.5	2
Pb (mg/L)	0.001^{a}±0.002	0.001^{a}±.0.003	0.1	0.01
Hg (mg/L)	0.023^{a} ±.2.140	0.0002^{a}±0.000	0.005	0,006
As (mg/L)	0.003^{a}±0.004	0.003^{a} ±.002	0.1	0,01
Cd (mg/L)	0.000^{a}±0.000	0.000^{a}±0.000	0.1	0.01
Al (mg/L)	1.240^{a} ±1.250	1.590^{a} ±4.180	UD	0.1-0.2

EPA -Environmental Protect Agency, WHO - World Health Organization, UD -undefined.
Values with the different superscripts in a row are significantly different (P < 0.05).

2003–2020). Forest area (82%) and other vegetation transformed into mining site, mine water, settlement/bare surface, cropland and plantations. Forest cover and other vegetation substantially and steadily declined, while the adjoining land use/cover forms generally increased continuously within the studied years. Other studies [29,30,31] found a similar trend in land use/cover dynamics, with forest cover decreasing as other land uses increased. The remarkable forest cover decline is attributable to mining and other disturbance resulting from the mining-induced influx of people and high mining-land-compensation expectations by the surrounding communities.

The mining site increased by 13% between 2011 and 2020, compared to a 20% increase in another study [5] of the same area between 2013 and 2018. Analysis of the current LULC matrix shows that out of 478 ha of mining site area converted between 2011 and 2020, approximately 443 ha representing 93% of the conversion, went into other vegetation. Thus, the percentage reduction in 2011–2020 may have resulted from increased vegetation cover because of natural regeneration and mine reclamation of abandoned mining areas. Settlement/bare surface expanded steadily between 2003 and 2020, with a percentage increase of 228% accounted for by the combined contribution of other vegetation and plantation. Settlement/bare surface expansion along with mining growth in the studied landscape concurs well with reports of other studies in Ghana and India [5,32,32]. This settlement growth is ascribable to mining-induced socioeconomic drivers such as building to meet the housing demand for the large influx of individuals into the area, community development infrastructure built by the mining company, increased numbers and size of resettlement communities established by the mine for project-displaced people and capital injection into the local economy due to the mining business, making it affordable for individuals to build more improved houses. Increased settlement and mining expansion raise environmental concerns as such development increases pollution levels and degrades soil and surface water quality [32,33].

The mine water also showed an increase from 2011 to 2020. The expansion occurred with the greatest contribution from the mining site, meanwhile, the area of mine water experienced marginal conversion with the highest conversion to the mining site. The mining site-mine water contribution and conversion matrix are not surprising since mine water is mainly water impoundments created for mining activities and the mining environmental controls, so they are within designated and approved mining areas. Mine water, which includes water impoundments, dams, and lake-like waterbodies, was created or extended from original streams and rivers within the catchment basin. Mine water dams off and breaks the continuity of the network of streams in the area, yet overflows and discharges make it into the downstream surface water. Thus, mine water quantity and quality communicate with and affect downstream surface water.

Plantation expanded mainly from the conversions of forest area compared to other land uses/covers, indicating forest transformation and degradation. The establishment and expansion of plantations at the pre-mining stage (2003) and during the operation in the landscape could be explained by the community practice of strategically planting crops in the mining area to attract higher compensation from the mining company [5,34]. Cropland which was predominantly converted from other vegetation and plantation increased significantly in 2020. Cropland expansion was a response to the food demand for the increased population size in the community mainly due to the mining-induced influx of people [5]. Extensive and intensive cropland cultivation has implications for soil and water quality in the catchment area, as agriculture affects soil quality through erosion, compaction, salinization, organic matter reduction, and non-point source pollution, which consequentially affects water quality through pesticide and excess nutrient leaching [35]. The massive transformation of forest and other vegetation, resulted in a large increase in settlement/bare surface, mining site, mine water. Plantation and cropland. The dynamics of land use/cover of the landscape reflect deforestation and land degradation. Adding to the reports of land use change such as land development and agriculture uses that come along with consequent effects of creating impervious surfaces contributing to nonpoint source water pollution, accelerating stormwater runoff to deliver more pollutants, sediments, nutrients, and pesticides to degrade water quality [35,36].

4.2. Comparative analysis of physicochemical properties of soils around the mine

Generally, the results showed no significant difference in the soil's physical and chemical qualities over the study area. The soil could be described as moderately acidic [37] and within an optimal range for plants' nutrient availability for normal growth of many plants. The slightly acidic nature of the soil could be related to the considerable deforestation due to mining and persistent crop cultivation with fertilizer. Deforestation, intensive cultivation with the application of ammonium-base fertilizers, erosion loss and leaching compromise the cation exchanges capacity (CEC) of soil and increase soil acidity [38,39]. Organic matter content of <2.0% is low, 2.1–3.0% medium and >3.1% high [39,40,41]. From this classification, the studied soil organic matter is moderate. The level of CEC within the soil corresponds with organic matter content – thus suggesting moderate CEC. Exchangeable CEC provides a buffering effect that limits leaching in the soil [42]. Therefore, its level in the studied soil reveals a moderate leaching potential. Lower and declined soil nutrients in mined soil compared to the unmined were attributed to ecosystem disturbance and loss of vegetation and litter layer during mineral mining [9]. Even though, in this study, the soil properties were not compared with an unmined site, it reasonable to infer that the landscape changes may have influenced the soil quality.

Elevated levels of heavy metals in agricultural soil and plants from industrial pollution may degrade soil quality and raise human health risks [9]. The concentrations of six heavy metals in the soil samples investigated showed no variation at 200 m, 400 m, and 600 m away from the mining facilities. This suggests there was no particular point source of metal introduction in the area. However, except for copper, which increased in concentration at 50 cm depth and decreased at 75 cm, all the studied metals decreased down to 75 cm. This is attributable to the moderate acidic condition and the organic matter content of the topsoil. pH and soil organic matter influence metal mobilization [43,44]. A strongly acidic medium facilitates greater metal mobilization [45,46]. The pH for the sampled topsoil (0–25 cm) analyzed in this study is classified as moderate acidic, suggesting there might be a decrease in metal leaching from the topsoil. Soil organic matter is typically rich in humic materials with several functional groups, which can form complex metals, allowing them to be retained in soil [44]. The bulk of soil organic matter is concentrated in or near the surface of the soil and A horizons; thus, organic matter lessens at depth of soils [47,48]. Therefore, the soil pH range and SOM content near the surface may have enabled the soil to retain metals within it or restrain the mobility of the metals. This explains the decrease in heavy metal concentration with increasing depth.

Except for As and Hg, the concentrations of heavy metal investigated were generally within WHO/FAO permissible bounds. Perhaps, this indicates that metal mobilization from the mining processes was checked or minimal due to the geological makeup of the area. However, given the ability of these heavy metals to bioaccumulate and biomagnify, the levels detected in this study should still be a source of concern. In particular, the elevated levels of As and Hg in soils around the mine raise serious health risks due to the potential impact on drinking water and food production. Continuous monitoring and control of the large-scale mining and small-scale mining or 'galamsey' activities in the area are required to check the content of the metals in the soil as the mining operation continues.

4.3. Comparative analysis of physicochemical properties of waterbodies around the mine

Apart from the colour that was high in the upstream, the physicochemical parameters of the waterbodies downstream of the mining operations showed higher values. This could generally be attributed to the impacts emanating from the mining operation in the vicinity. The downstream colour, turbidity, and TSS were all above the EPA/WHO allowable bounds for drinking water. The colour of natural water usually results from the leaching of organic debris and intensely coloured water occurs in many environments where vegetation is plentiful [49]. Water-colour changes can also result as consequent to a waste drain, suspension of particulate matter, or when organic matter forms complexes with metal ions in an acidic medium. In this study, the downstream waterbodies were more in an alkaline state (pH of 7.6) with consequent less metal mobilization. The mean colour value was higher at the upstream relative to the downstream surface water. Therefore, barring the occurrence of acidic complexes, the higher colour value downstream is attributable to the deposition of organic debris from vegetation or particulate matter carried by runoffs into the streams from the mine. High water colour downstream of the mine presents two critical issues to the mine – regulatory concerns and social license implications. The latter generates company-community conflict because the key noticeable water pollution indicators to the local people are colour changes and turbidity of a waterbody. The higher TSS and turbidity in the downstream waterbodies may be explained by erosion and sediment transport due to large areas disturbed by the mine [49]. The higher TDS in the downstream waterbodies could be a consequence of disturbance of the land surface in the mining area that placed unweathered rocks at or near the surface [28]. These exposed and unweathered rocks may have increased the rate of chemical erosion in the mining areas resulting in higher concentrations and loads of chemical constituents in runoffs from the mine to the downstream surface water.

The presence of significant quantities of Mg, Ca, and SO4 in samples collected downstream of the mine is notable. The high levels of Mg and SO_4 in water samples from downstream of the mine align with recent research reports from the area [31]. High concentration of Mg and Ca in drinking water raises public health concerns, as studies have shown positive correlations between these substances and blood pressure [50], though recent studies give a counter version of the effect the ions have on cardiovascular health [50]. High nitrate and sulphate concentrations are similarly released into the water from geological disturbance through excavations and mining [51,52]. The high prevalence of these inorganic salts downstream compared to upstream may be due to the mining in the vicinity. Because pit water, nitrogen-based chemicals used in blasting rock, and leaching from large rock dumps can trigger greater nitrate levels in water bodies in the mining area [53]. These features are predominant in the mining vicinity under study. High nitrate levels in water than recommended might lead to methemoglobinemia (infant cyanosis or "blue baby disease") in infants who drink or use such water [54]. and other serious health effects [53]. The elevated sulphate may have resulted from the oxidation of iron sulfide present in dark claystone or siltstone. Perhaps, from surface disturbance, iron sulfide was exposed to the atmosphere and got oxidized to produce iron sulphate that got washed into waterbodies downstream of the mining facilities.

Except for iron, manganese, and aluminum which were also high upstream, the rest of the studied heavy metals were below EPA/WHO permissible limits. The relatively high levels of iron, manganese, and aluminum are attributable to the nature of the geology of the area. It is not unexpected that the Fe and Mn levels exceed the permissible drinking limits. These two metals are typical water contaminants in mining localities [55,56] because they are associated with gold-bearing rocks in mining regions in Ghana. Thus, the weathered rocks and their exposure to air due to mining disturbance may be discharging the metals into the surface water [57]. The general levels of the metal concentration in the water can be explained in part by the geology of the area which is much more basic and limits metal mobilization, and perhaps environmental management that ensured geochemical containments from the various waste sources. This corroborates the observation that concentrations of heavy metals found much lower than those in acid solution occurred naturally by cause of geological setting [58].

5. Conclusions

The study examined the influence of mining on land use/cover changes and consequential effects on surface water and soil quality in a mining landscape within the Ahafo region of Ghana. The results demonstrate a significant loss of forest and other vegetation covers, which decreased from 44% to 31% to 8% and 20% respectively, with corresponding increases in the mining site, mine water, settlement/bare surface, cropland, and plantation in the Ahafo mining landscape. Mining activity was the primary driver of the intensive land use and cover changes.

The data again showed that pH, organic matter, organic carbon, cation exchange capacity, exchangeable bases, and available phosphorus were moderate in the soil around the mine. All the studied heavy metals in the soil, except As and Hg were within WHO/FAO limits. The results further demonstrated comparatively high levels of physicochemical parameters (turbidity, TDS, and TSS) and some ions and nutrients (Mg, Ca, Nitrate and Sulphate) in the downstream water bodies within the mining region during the sampling period. High levels of iron, manganese, and aluminum reflect the nature of geological setting.

The findings suggest that mining influenced the intense land cover changes and impaired surface water and soil quality around the mine. The condition of the mining landscape requires education, appropriate community water interventions, and company-community-regulator participatory monitoring to avoid health risk exposure and further water and soil quality and vegetation degradation.

Author contribution statement

Samuel Kumi - Conceived and designed the experiments; performed the experiments;analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; and wrote the paper.

David Adu-Poku and Francis Attiogbe - Analyzed and interpreted the data; and wrote the paper

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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