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Trace Elements Assessments using Pollution Load Index and Spatial Maps Towards the Development of Environmental Policies Against the Impacts of the Natural Environment on Primary Health, Nadowli District-NW Ghana

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Abstract
Distributions and concentrations of trace elements at the surface environments are controlled by the natural environment and landuse. To identify the hazardous trace element areas in the study areas pollution load index (PLI) and spatial maps were used in the trace elements distributions and concentrations. Both the PLI and spatial maps used as assessment techniques both employ the contamination factors (CF) of the analysed trace elements at a sample station differently in establishing the degrees of pollution and contaminations. Twenty nine stations were sampled for trace elements contents. The PLI evaluation technique identified extreme arsenic (As) pollution of 5.39E+20 at the artisan mine and 5.62 fold-As pollution at the farmland areas. The spatial maps developed from the CF values recognized As, Co, Cr, Pb and Se to be contaminated at both artisan mine and farmland areas. Mercury (Hg) contaminations were found at some sampling stations at the artisan mine areas whilst Mo contaminations were recognized at some localities at the farmland areas. The source of Hg contaminations may be the use of Hg as a regent in extracting gold from the mine ore and Mo enrichment may be an attribute of fertilizers use to boost crop yields (particularly the use of ammonium molybdate fertilizer for crop growth). The combined assessment technique was effective in determining the overall polluted environments and also portrayed geographical contaminated areas for an environmental concern against public health.
Keywords: Artisan, farmland, trace elements, contamination, pollution

1. Introduction

The trace element concentrations have been identified by Arhin et al. (2015) to show pollution in some areas. Among the listed potentially toxic elements (PTEs) As, Cd, Hg, show strong to moderate pollutions whereas the essential elements (EEs) required for human and animal development display depletion in most areas. The main sources of trace metal contaminations to the surface environment will be from the weathering of the underlying rocks transforming primary minerals to secondary minerals in the natural environment and additional introduction of metal-ions from human activities. The underlying geology of the study areas consist of metavolcanic and metasedimentary rocks intruded at places by mafic and felsic granitoids (Kesse, 1985; Leube et al., 1990). These rocks under the influence of weathering processes release different trace metals into the surface environment. Their distributions, concentrations and residence at the surface environment depend on aquifer characteristics, groundwater regimes, infiltration rates and the regolith types. Human activities also impact on the metals ion concentrations through extractive mining activities, fertilizer and pesticide uses. Paradoxically one part of the study area showed evidence of artisan mine activities and the other area is characterized by farmlands and farm settlements. Trace elements distributions, concentrations and storage will be impacted upon via the artisan mine operations, farming techniques and any other human activities at the settlement areas. Although unequal trace elements may be introduced by the listed anthropogenically activities which when added to the natural contaminations from the geological resource base may trigger impacts on the environment and consequently affect human health and animal developments. This paper therefore seeks to establish the pollution indices at the study areas and also develop spatial maps to show PTEs and EEs that have deviated from universal baseline values. Impacts of the enriched and depleted of some specific trace elements on public health will be highlighted.

2. Materials and Methods Used

2.1 Location of study areas

The portion of the Nadowli District located on the Lawra Birimian Belt studied (Fig. 1) is in northern Ghana (Kesse, 1985), 700 km northwest of Accra, the national capital. The two study areas are the ancient artisan mine site (Fig. 2) situated in an abandoned township called Kunche, located about 15 km northwest of Nadowli by laterite road and Sabala a farming community, found close to the Black Volta River and is about 32 km west of Nadowli the district capital (Fig. 3).

2.2 Geology of Kunche and Sabala areas

Regional geology of Kunche and Sabala as well as the surrounding areas is presented in Fig. 1. Kunche area is underlain by metavolcanic rocks intruded by mafic granitoids and dolerites (Kesse, 1985; Leube et al. 1990) and metasedimentary rocks by felsic granitoids. The metavolcanic rocks contain basalts, andesite, rhyolites and some volcanoclastic rocks including tremolite schists, quartz feldspar schist and tuffs. The intrusive rock outcrops in terrains underlain by the volcanic rock units are mafic granitoids containing gabbros, dolerites, granodiorites and diorites. The composition of the mafic granitoids class comprise hornblende-rich varieties and are classified locally as 'Dixcove' or 'Belt' type granitoids (Leube et al., 1990). The belt granitoids are small discordant to semi-discordant, late or post-tectonic soda-rich hornblende-biotite granites or granodiorites that grade into quartz diorite and hornblende diorite (Hirde et al., 1996). The metasedimentary units consist of phyllite, sericite-schist, tuffaceous phyllite, shales and meta-greywacke and are intruded by felsic granitoids with occasional mafic dykes (Griffis et al. 2002; Baratoux et al. 2011). These felsic granitoids contain mica–rich varieties and are known as 'Basin' type (Leube et al., 1990).

Rocks at Sabala have similar make up like the metasedimentary units at Kunche. They contain phyllite, carbonaceous and graphitic schists, and shales. In the metasedimentary package are milky-white and smoky quartz veins and veinlets. In this area the felsic granitic intrusions are presented as large concordant and syntectonic batholithic granitoids commonly banded and exhibit black and white foliations. These intrusive granitic bodies are rich in potash and contain both biotite and muscovite, with the biotite dominating (Leube et al., 1990).

2.3 Climate

The climate of the area is Guinea savannah with annual rainfall range of 600-1200 mm (Webber, 1996a). Short single rainy season with long period of dryness characterizes the area (Dickson and Benneh, 1995). Monthly rainfall increase slowly from March and peaks in August after which there is a sharp decrease of rains after October (Kranjac-Bersaljevic et al. 1998). The average monthly rainfall estimate is 986 mm per month. But there is a consistently high monthly temperature that averages at 28.6^{o}C in the area that could influence the trace elements migrations and concentrations. The seasonal variation in climate in the area shows slight change in temperatures occurring during the peak seasons of the rains in August to be 26.4^{o}C and increasing to a maximum of 32.1^{o}C in April (Dickson and Benneh, 1995).

2.4 Regolith

The area is characterized by deep weathering profile with preserved-pre-existing and erosional surfaces. In association with these regolith-landforms are widespread lateritization that has a surface veneer of pisolith and extensive depositional cover of exotic origin. Regolith materials at lowland terrains are sheet wash deposits moved downslope during the flash floods. These regolith units originate from redistributed sediments that differ from the weathered materials from the underlying rocks. The regolith units occupying the upland areas contain degraded weathered rocks and materials that decreases in fragment size down-slope.

The topography is generally low with undulating landscapes interspersed with isolated hills at some places (Arhin and Nude, 2009). Some of the hills are capped by hardpans with gentle slopes marked by scree. The accumulated scree on hillslopes and the base of hills consist of small fragments of visibly mineralised and altered rock that decrease in fragment size down-slope.

2.5 Field sampling approach

Methods used in the study involved field and laboratory works. The fieldwork involved collection of 29 soil samples from different locations at a depth of 20 cm. Twenty of the samples were collected from the artisan mine area in Kunche and 9 taken from Sabala where land spaces in between houses are used by the inhabitants for agricultural purposes. A grid system of 500 m x 200 m and infilled to 500 m x 100 m were used at the artisan mine area whilst GPS-controlled traverses were used at Sabala area. Landuse-type and characteristics of topography and regolith-class guided the selection of sampling station, particularly at Sabala. Sampling intervals at Sabala ranged between 200-400 m and these were not on a regular grid pattern. Sample weight of 1 kg was collected from each 20 cm-diameter-hole dug to 20 cm depth. Sample and sampling environment information such as soil type, lithology, landuse, weathering and geomorphic histories were recorded to aid in the establishment of natural and human induced impacts on the environment.

2.6 Sample preparation and laboratory chemical analysis

The collected field samples were sun dried and later sieved to <2 mm particle size fractions. The sieved samples were then vaporized using laser cells. The vaporized samples were introduced into ICP-MS instrument that measures the trace elements contents (including the potentially toxic elements -PTEs). The introductions of vaporized samples into the ICP-MS equipment were done over a peristaltic pump, nebulizer and spray chamber. A torch in the ICP-MS instrument generates plasma which serves as the ion source that converts the atoms to be analyzed into individual ions in the samples. The sample ions are then detected after passing over the mass filter where the sample ions are either detected by direct current measurements on the ion collector or the ions generate secondary electrons that are propagated in the multiplier. The trace elements concentrations in the samples are then measured.

2.7 Data Analysis

The PLI of the stations were calculated by obtaining the n^{th} -root from the n- CFs obtained for all trace elements/metals at different sampling stations. Tomlinson et al (1980) method of calculating PLI was used in the study and the formula used is presented as follows:

$$CF = \frac{Concentration\ of\ metal}{Concentration\ of\ background\ value}$$

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \times CFn)}$$

Where,

CF = contamination factor, n = number of trace elements/metals, and explained PLI value of > 1 to represent polluted areas, whereas PLI<1 indicates no pollution (Harikumar et al., 2004).

2.7.1 Quality control and quality assurance of analytical data

Quality control certified reference materials (CRM) to monitor accuracy were inserted in batch of samples to ALS-Chemex. The CRM (GBM 398-4, GBM 900-10 and GBM 901-5) samples used were source from Geostats Pty Ltd., Australia. The precision of the analytical data were also evaluated from the field duplicate sample results. The average trace elements recovery from the CRM was in the range of 85–96 % and percentage precision was 9.3. The combined outcomes of CRM and field duplicate samples were considered acceptable for the analytical data.

3.0 Results and Discussions

3.1 Results

Results of samples collected at the artisan mine area in Kunche and farmlands in Sabala are presented in Tables 1 and 2. The tables show Contamination Factors (CF) and Pollution Load Indices (PLI) for the artisan mine and farmland areas. The CF is the quotient obtained by dividing the concentration of each trace element/metal with the concentration of the global accepted background value of that trace element in the continental crust. Spatial distributions and concentrations of some selected trace elements due to their impact on health are also shown in Figures 4 and 5 for the artisan mine area in Kunche and the farmland areas at Sabala. The red areas depicted in the spatial maps represent environments with high trace elements concentrations and thus grades down to low trace element concentrations terrains shown blue.

3.2 Discussions

Using single variable e.g. PLI values to assess impacts of exposed trace elements of the natural environment on human health may be underestimated if several variables are not considered in the evaluation processes. For example considering the analysis of polluted trace elements presented in Table 1, the PLI values showed the artisan mine area to be strongly polluted only in As and Se but there are some trace elements whose records in the collected samples are in excess of the background values. However elements such as Pb, Hg, Co, and Cr. could be hazardous. The PLI assessment was unable to highlight them relative to As and Se that had extreme high concentrations in the area. Despite their concentrations being lower than those of As and Se, they can influence human health in those communities dependant on the degree of exposure, bioavailability, pathways and bio-accumulation. The local contamination for Pb at KP021, contamination of Hg at KP010, Co contamination at KP014, KP016 and KP017, Cr contamination at KP017 and KP019 may appear low in concentrations but may be harmful. The contaminated trace elements identified in excess of the continental crustal averages in the samples are among the listed carcinogenic trace elements (ATSDR, 2003). Ignoring the local impact of Pb, Hg, Co and Cr whilst concentrating only on the health impact of As may present epidemiological challenges in the area from these trace elements due to their bioavailability and bio-accumulation. Similarly in Table 2, the PLI as an evaluation tool identified As, Cr, Mo and Se as the polluted trace elements at the farmland areas and placed Pb and Co as unpolluted trace elements for the area. Conversely the trace elements assessments on the basis of the geographical locations realized Pb and Co to show contaminations (Table 2). These trace elements can trigger localized health issues irrespective of their low concentration levels as they can bio-accumulate in the systems of the exposed human beings. The singular advantage of the spatial maps is that communities of environmental concerns requiring attention on the basis of enriched toxic trace element concentration levels and/or deficiencies of essential elements can be seen and directed for environmental attention.

As seen in Tables 1 and 2, the PLI for As at the artisan mine area is 5.39E+20 and that at farmland area is 5.62, which suggest an extreme As pollution at the artisan mine areas (Tomlinson et al., 1980). The PLI technique of evaluating the trace elements in terms of the pollution index was unable to indicate the degree or extent of the pollutions with respect to the landscape positons. On the contrary the geochemical patterns of As shown in Figs. 4 and 5 demonstrate uneven As distributions and concentrations in samples collected. In Fig. 4, the extreme As pollution is at the southwest with a patch of As pollution at the north. Any attempt to address or mitigate the impacts of As exposure to health will be directed first to communities or stations at the southwest assuming equal ingestion pathways. Additionally Tables 1 and 2 show high Se pollutions at the artisan mine and the farmland terrains. This trace element is considered as an essential element but can be toxic if the ingested amounts exceed certain concentration levels. PLI at the artisan mine area is 2.31+16 and that at the farmland area is 11.68. This implies that the Se pollution is extremely high at the artisan mine area compared to the farmland areas. An environmental policy to guide the affected communities not to cross the line where the essential trace element Se become toxic will depend on the use of a spatial map that provide guidance to the exact geographical locations depicting Se excesses. The prioritization of the exposed communities or environments having toxic trace elements and areas requiring essential trace elements monitoring needs the combined evaluation techniques of PLI values for the trace elements and spatial map creation for the hazardous trace elements.

4.0 Conclusion

The distributions and concentrations of trace elements in the environmental soils are influenced by natural environment and landuse or environmental conditions. At the artisan mine area in Kunche, As pollution was identified with some contaminations in Se, Pb, Hg, and Co. Almost the same set of trace elements but with different concentrations were identified at the farmland areas at Sabala. There was As pollution but the extent of pollution was lower than that at the artisan mine area. The overlapping trace elements contaminations at the artisan mine and farmland areas were As, Se, Pb, Cr, Co. The similar constitution of these trace elements As, Se, Pb, Cr, and Co contaminations at the artisan and the farmland suggests their sources are from the natural environment. The non-overlapping contaminated trace elements Hg at the artisan mine may be due to the mine and metal extraction operations whilst Mo at the farmland areas probably is emanating from fertilizer use. The polluted and contaminated trace elements at the two study areas present public health issues. Locations of polluted and contaminated hazardous trace elements and essential elements were detected using combined techniques of pollution load index and spatial maps and proposed their applications towards developing effective education on environmental policies against public health problems.

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Table 1 Contamination Factors (CF) and Pollution Load Indices (PLI) of some trace elements at an artisan mine area in Kunche

Sample ID	UTM-E	UTM-N	As	Cd	Co	Cr	Cu	Hg	Mo	Pb	Se	Zn
KP001	526650	1149550	5.4	0.1	0.8	1.2	0.7	0.1	0.2	0.5	9.0	0.9
KP003	527050	1149550	6.3	0.1	0.3	0.2	0.2	0.1	0.3	0.2	5.0	0.2
KP004	527250	1149550	7.0	0.1	0.6	0.3	0.3	0.0	0.3	0.3	4.0	0.3
KP005	527450	1149550	10.6	0.1	0.3	0.5	0.3	0.1	0.3	0.3	6.0	0.4
KP006	527650	1149550	44.7	0.3	0.6	0.7	0.6	0.1	0.5	0.5	10.0	0.5
KP007	527850	1149550	7.2	0.1	0.3	0.5	0.3	0.1	0.3	0.3	4.0	0.4
KP008	526900	1148600	9.6	0.2	0.4	0.5	0.3	1.1	0.4	0.4	3.0	0.3
KP009	527000	1148600	35.8	0.3	0.4	0.5	0.4	0.2	0.4	0.5	12.0	0.6
KP010	527100	1148600	56.1	0.3	0.1	0.5	0.4	2.0	0.8	0.2	24.0	0.3
KP011	527200	1148600	53.8	0.1	0.4	0.6	0.5	0.2	0.8	0.4	9.0	0.5
KP012	527300	1148600	11.6	0.1	0.3	0.5	0.3	0.2	0.4	0.4	10.0	0.3
KP013	527400	1148600	8.9	0.1	0.7	0.5	0.7	0.2	0.6	0.4	14.0	0.5
KP014	527500	1148600	15.6	0.1	1.7	0.7	0.8	0.4	0.6	0.5	16.0	0.9
KP015	527600	1148600	12.3	0.2	0.7	0.7	0.8	0.2	1.0	0.3	14.0	0.6
KP016	527700	1148600	15.5	0.1	1.0	0.6	0.6	0.2	0.4	0.4	14.0	0.5
KP017	527800	1148600	10.8	0.1	1.2	1.2	0.6	0.2	0.5	0.5	14.0	0.7
KP018	527900	1148600	7.3	0.1	0.3	0.4	0.3	0.1	0.2	0.2	7.0	0.2
KP019	528000	1148600	9.8	0.2	0.4	1.0	0.6	0.2	0.5	0.4	4.0	0.3
KP020	528100	1148600	9.4	0.1	0.4	0.3	0.4	0.1	0.4	0.3	2.0	0.4
KP021	528200	1148600	5.7	0.1	0.2	0.3	0.2	0.1	0.3	2.6	4.0	0.2
Product of CF			**1.08E+22**	**3.33E-18**	**1.52E-07**	**6.13E-06**	**3.98E-08**	**2.59E-15**	**1.57E-08**	**5.74E-09**	**4.63E+17**	**8.51E-09**
PLI			**5.39E+20**	**1.66E-19**	**7.62E-09**	**3.07E-07**	**1.99E-09**	**1.30E-16**	**7.87E-10**	**2.87E-10**	**2.31E+16**	**4.26E-10**

Table 2A Contamination Factors (CF) and Pollution Load Indices (PLI) of some trace elements in farmland soils at Sabala

Sample ID	UTM-E	UTM-N	As	Cd	Co	Cr	Cu	Hg	Mo	Pb	Zn	Se
SP001	519090	1143591	9.00	0.20	0.50	1.17	0.70	0.35	2.19	0.89	0.34	16.00
SP002	518995	1143689	3.89	0.13	0.49	1.11	0.40	0.24	0.86	0.65	0.27	6.00
SP003	518738	11434498	6.78	0.07	0.40	0.97	0.78	0.12	1.12	0.88	0.37	8.00
SP004	518642	1143498	4.00	0.13	0.35	0.99	0.31	0.24	0.93	0.61	0.24	14.00
SP005	518570	1143443	9.44	0.20	1.80	1.13	0.53	0.24	2.62	1.12	0.30	12.00
SP006	518443	1143096	7.56	0.07	1.42	0.84	0.46	0.35	1.53	1.10	0.23	10.00
SP007	518235	1143093	6.11	0.07	0.30	1.14	0.49	0.35	1.71	1.01	0.26	16.00
SP008	518539	1143097	3.56	0.13	0.60	1.05	0.32	0.12	0.76	0.51	0.26	14.00
SP009	518725	1143088	3.78	0.07	0.18	1.09	0.24	0.24	1.23	0.61	0.18	14.00
Product of CF			5558047.29	0.00	0.00	1.53	0.00	0.00	12.57	0.12	0.00	4046192640.00
PLI			5.62	0.11	0.52	1.05	0.44	0.23	1.32	0.79	0.27	11.68

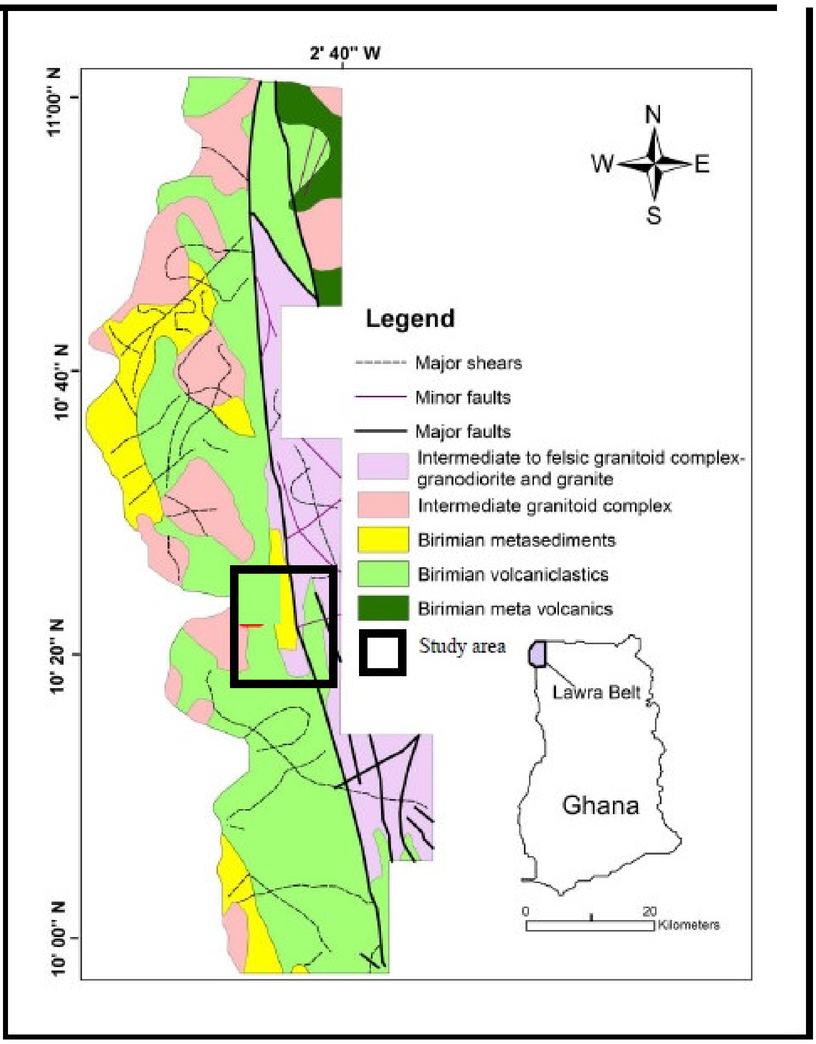

Figure 1: Geology and location of the study area (modified from Ghana Geological Survey regional geology map, 2010)

Figure 2: Scenes at the artisan mine site at Kunche

Figure 3: Scenes at the Farmland areas at Sabala

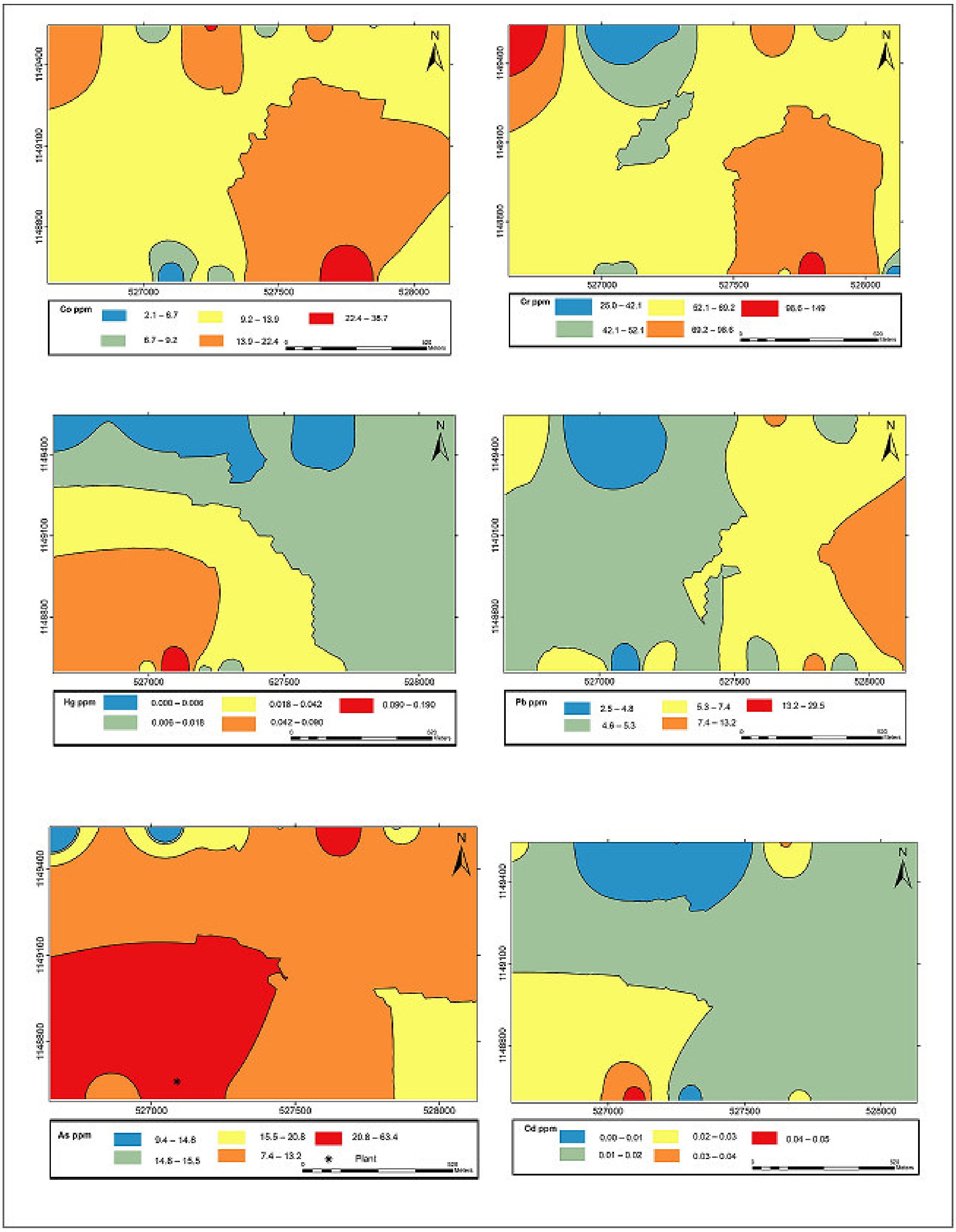

Figure 4: Trace element distribution and concentration at an artisan mine areas

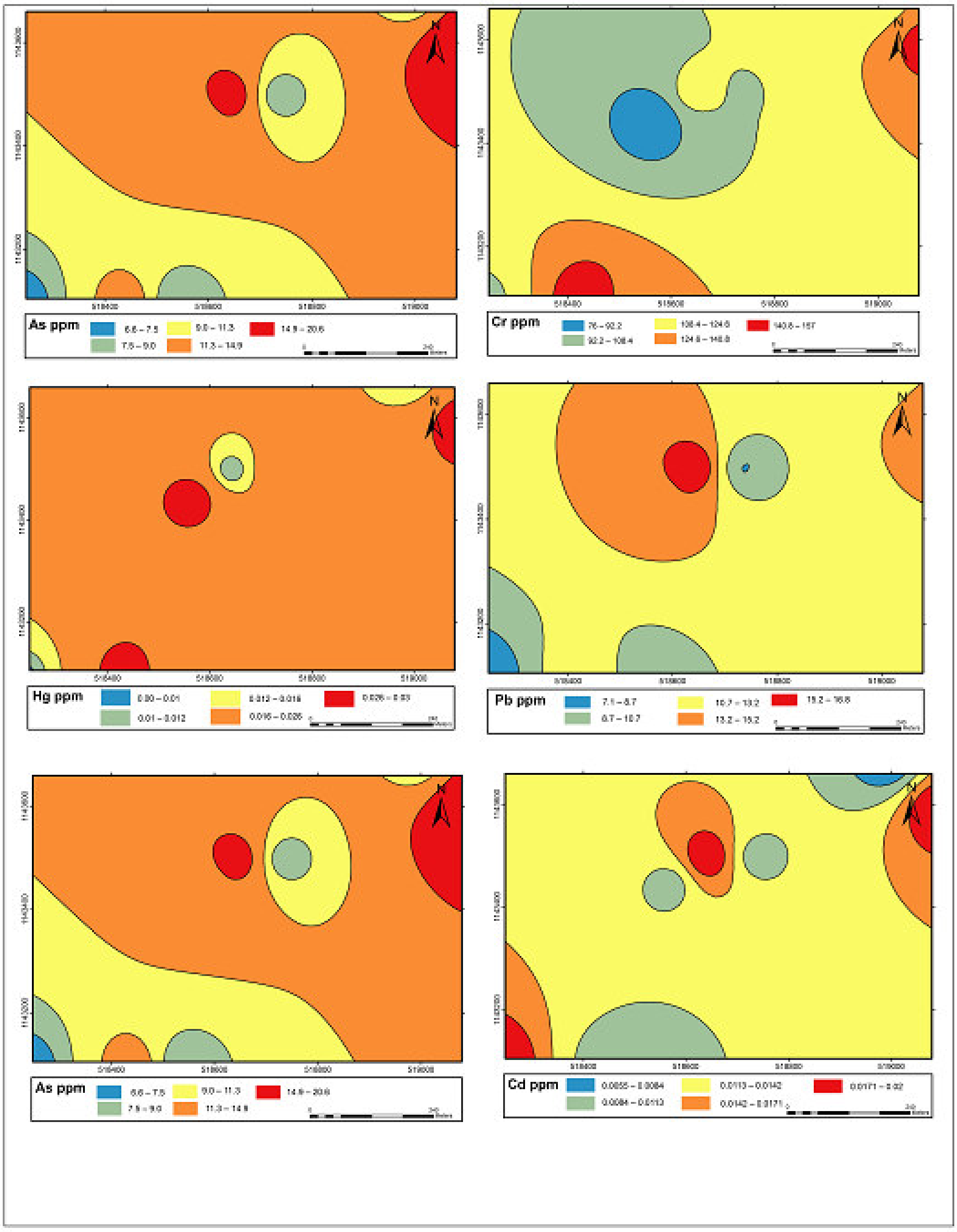

Figure 5: Trace element distribution and concentration at farmland areas