Impact of Mining Operations on the Ecology of River Offin in Ghana

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Abstract

Five sites in the Offin river basin were studied with respect to the quality of water and bottom sediment, as well as the community structure of both fish and phytoplankton along the river course to assess the effects of gold mining operations on the aquatic ecosystem. Turbidity, conductivity and concentrations of lead and cadmium in the water column showed a decreasing trend from the dredging area. Sediments upstream of and around the dredging area were sandy with low concentrations of organic (0.01-0.02% DW) and inorganic (e.g. $CaCO_3$ 1.1-1.2 mg g^{-1} DW; PO_4, 1.2-3.5 mg g^{-1} DW) materials, including trace metals (e.g. Hg < 0.05 mg g^{-1} DW, Pb < 0.20 mg g^{-1} DW, As < 0.50 mg g^{-1} DW). Fish in the dredging area had accumulated higher mean concentrations of trace metals in their tissues compared to those from the non-impacted sites. Higher diversities of phytoplankton were recorded at sites where turbidity was lower. Autotrophs (blue-green and green algae) were virtually absent from sites with high turbidities. The structure of the fish community in the dredging area was different from other adjacent areas. However, the diversity and richness indices (0.56–0.67 and 1.12-1.67, respectively) of the fish communities along the river course were similar except for the most polluted site, which had the lowest indices.

Introduction

Mining and its associated activities can be responsible for considerable environmental damage. Pollution of water, damage to land and habitat destruction are some of the impacts that have been recorded in the past (UNEP, 1991). For example, mercury used in gold mining in the Amazon Basin in Brazil contaminated vast areas of the Amazon river with about 200 tons being deposited per year in the basin (Malm *et al.*, 1990). Grösser *et al.* (1994) also reported mercury contamination in a gold-mining area in Southern Colombia.

Contamination of water bodies has degraded aquatic ecosystems especially in most of the industrialized world, resulting in altered fish populations and, in some cases, complete loss of fish (Down & Stocks, 1978; Welcomme, 1992). Chemicals used in mining operations may, consequently, affect man through the food chain such as occurred in Minamata Bay in southern Kyushu, Japan, due to discharge of mercury-laden effluents (Fujiki, 1980). Apart from chemicals, large quantities of solids are suspended in the water column due to mining operation, especially in alluvial dredging. Suspended solids may affect biological resources in various ways (Chansang, 1988). In Ghana, gold is currently the leading export commodity, and mining occurs within the catchment of such rivers as Birim, Pra, Offin and Ankobra. Alluvial dredging practiced in certain parts of the River Offin could result in the release of residual chemicals, not only in the dredging area but also further downstream. This study assessed the effect of mining operations on the ecology of the River Offin in the Western

Region of Ghana.

Materials ans methods

Study area

The study area, which was around Dunkwa, extended from Kaniago, located south of latitude 6° 22' N on the River Offin, to Twifu-Praso, downstream of the confluence between River Pra and River Offin (Fig. 1). Within this stretch, five stations were sampled between 20 and 26 Aug 1994. The stations were Kaniago, Buabuasin, Kubi, Baadoa and Twifu-Praso (Fig. 1). Buabuasin was an active dredging area. Kaniago, which was considered as a control area, was situated 55 km upstream of Buabuasin and was outside the influence of dredging activities. Kubi was located 35 km immediately downstream of Buabuasin on River Jimi, a small tributary of River Offin, which also received effluents from a gold mining company upstream. River Offin had no influence on River Jimi with respect to sediment load. Baadoa and Twifu-Praso were situated 47 km and 107 km, respectively, downstream of Buabuasin. While Baadoa was influenced by dredging activities as evidenced by a high sediment load, Twifo-Praso was unaffected.

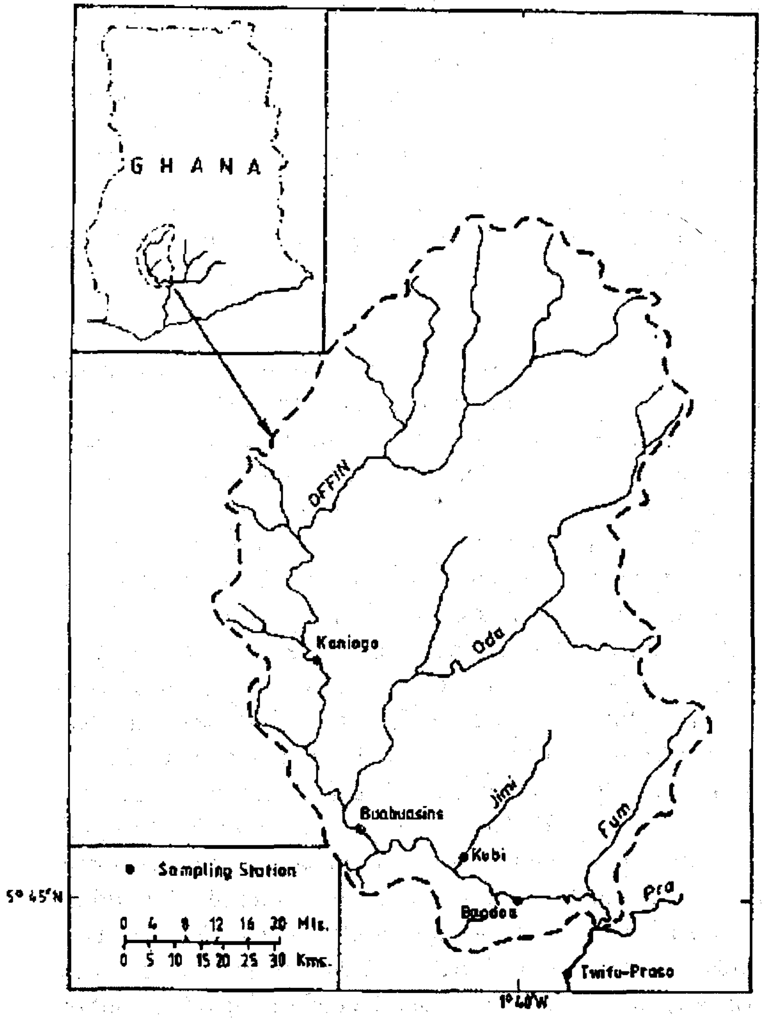

Fig. 1. River Offin basin showing sampling sites

Water quality

Surface-water samples were collected with a plastic container from all the sites in the morning between 09:30 and 10:00 h. Samples were stored on ice in 1-*l* opaque plastic bottles, except those to be tested for chloride, which were stored in transparent glass bottles. All laboratory analyses were done within a week for the following variables; dissolved oxygen (DO), ammonia nitrogen (NH_3-N), metals (Cd, Pb and Fe) and chloride, according to the methods described in the *Standard Methods for the Examination of Water and Wastewater* (APHA-AWWA-WEF, 1992).

Hydrogen ion concentration (*p*H), conductivity and turbidity were measured in the field using a portable Griffin *p*H meter, conductivity meter and Hatch turbidity meter, respectively.

Sediment quality

Sediment samples from Kaniago and Buabuasin were collected with an Ekman grab into clean plastic bags and kept at ambient temperature in the field. Samples could not be collected from the other sites because of the rocky nature of the riverbed. In the laboratory, the samples were dried at 30 °C, sieved through a 100 µm mesh and stored in polyethylene bags at -10 °C. They were analyzed for organic matter/carbon, Kjeldahl nitrogen, available phosphorus, total phosphates, calcium carbonate and the following metals: Hg, Cd, Pb, As, Cu, Zn, Mn and Fe (APHA-AWWA-WEF, 1992).

Phytoplankton

Water samples were collected from each site in a 250-ml plastic container and topped up with 10 ml 40% formalin. After thorough mixing, a 10-ml sub-sample was taken into a counting chamber for identification and counts of cells under an inverted compound microscope. The concentration of cells per 100 ml was calculated for each genus at each site.

Fish fauna

Fish samples were collected in the morning between 08:00 and 10:00 h from Kaniago, Buabuasin, Baadoa and Twifu-Praso using a cast net with a mesh size (bar mesh) and length of 15 mm and 3 m, respectively. All fish samples were stored in plastic bags on ice in the field. In the laboratory, each fish was identified with keys (Lévéque *et al.*, 1992), measured and weighed to the nearest mm and g, respectively. Samples for muscle analysis were stored at -10 °C in the laboratory. Muscle tissues were digested under pressure with nitric acid, after which metals were determined by flame and cold vapour AAS (UNEP *et al.*, 1984a, 1984b, 1984c).

The catch per unit of effort (CPUE) was calculated as the number and weight of fish caught per cast at each site. The diversity of the fish community at each site was calculated with the CPUE data for number using the Shannon-Weaver diversity index (H') expressed as:

$$H' = -\Sigma Pi \log Pi$$

where Pi is the proportion of individuals in the ith species (Dahlberg & Odum, 1970).

The species richness (D) was computed using the formula:

$$D = (S-1) / \log N$$

where S is the number of species in the sample and N the total number of individuals.

Results

Water quality

Water quality parameters are summarized in Table 1. Turbidity ranged from 11 NTU at Kaniago, the control area, to 1110 NTU at Buabuasin, the dredging area. The concentrations of Cl and NH_3-N were also highest at Buabuasin. However, Pb and Fe levels were higher at Baadoa but reduced considerably at Twifu-Praso. The *p*H values recorded at all the sites ranged from 6.8 at Kubi to 7.5 at Twifu-Praso. With the exception of Twifu-Praso, where the dissolved oxygen (DO) was 8 mg l^{-1}, the DO levels at the other sites were below 5

TABLE 1

Summary of water quality parameters

River location (km from dredging area)	pH	COND	Turb	mg l^{-1}					
		$\mu S/cm^{-1}$	NTU	DO	Cl	NH_3-N	Pb	Fe	Cd
Offin-Kaniago (+55)	7.4	164	11	4.0	26	< 0.01	0.23	1.20	< 0.01
Offin-Buabuasin (0)	7.1	239	1110	3.7	66	3.94	0.24	1.08	< 0.01
Jimi-Kubi (-35)	6.8	649	22	4.3	35	0.99	0.19	1.08	< 0.01
Offin-Baadoa (-47)	7.0	348	100	4.8	44	0.18	0.47	2.09	< 0.01
Pra-Twifu Praso (-107)	7.5	152	34	8.0	19	0.25	0.29	0.82	< 0.01

mg l^{-1}.

Sediment quality

Sediments from both Kaniago and Buabuasin were mainly sandy and devoid of organic materials. They contained low concentrations of nitrogen and phosphates (Table 2). Concentrations of trace metals in sediments except Cd (Table 3) in both the dredging area and upstream fell below the limits expected in uncontaminated sediments (Salomons & Forstner, 1984).

Phytoplankton

Twenty-two genera of phytoplankton were identified (Table 4). The number of genera recorded for all the areas sampled was low, ranging from six at Buabuasin to a maximum of 15 at Kaniago. Similarly, counts of individuals were generally low for all the areas sampled. Green and blue-green algae were either virtually or

TABLE 2

Physico-chemical parameters of sediment

Location	% DW				mg g^{-1}	DW	
	Organic carbon	Organic matter	KjN	$CaCO_3$	PO_4	K	T-PO_4
Kaniago	0.01	0.02	0.01	1.1	3.5	10.0	3.8
Buabuasin	0.01	0.02	0.01	1.2	1.2	10.0	1.0

TABLE 3

Metal concentration in sediment (mg g^{-1} DW)

Location	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe ($\times 10^3$)
Kaniago	< 0.05	< 0.20	< 0.20	< 0.50	< 0.20	12.9	1.45	12.9
Buabuasin	< 0.05	< 0.20	< 0.20	< 0.50	< 0.20	12.9	2.15	18.6
WHO limits	0.05-0.3	0.11	19.0	5.0	33.0	95.0	770.0	41.0

TABLE 4

Occurrence of phytoplankton genera at the various sites

Genus/Site	Counts of individuals per 100 ml				
	Kaniago	*Buabuasin*	*Kubi (R. Jimi)*	*Baadoa*	*Twifu Praso*
CHILOROPHYTA					
(Green algae)					
Pediastrum	40	-	-	-	-
Closterium	-	-	12	8	8
Coelastrum	-	-	-	-	64
Phacus	344	-	32	-	-
Scenedesmus	96	160	32	32	80
Peridinium	64	-	-	-	-
Euglena	32	-	-	-	-
Staurastrum	-	-	4	-	-
CYANOPHYTA					
(Blue-green algae)					
Agmenellum	-	-	-	-	288
Anabaena	40	-	-	-	152
Anacystis	-	-	-	-	72
Stichosiphon	8	-	-	-	12
Oscillatoria	104	-	424	-	-
BACILLARIOPHYTA					
(Diatoms)					
Diatoma	12	-	-	4	20
Denticula	8	-	-	8	24
Melosira	4	-	-	16	-
Navicula	70	160	16	16	68
Nitzschia	8	120	288	-	24
Pinnularia	-	-	-	8	4
Pleurosigma	4	80	-	8	16
Surirella	-	80	-	12	-
Synedra	28	40	12	-	28
Total number of genera	15	6	9	9	14

completely absent from Buabuasin and Baadoa, while the latter was virtually absent from Kubi.

Fish fauna

The fish fauna comprised 15 species, belonging to 10 genera and 7 families (Table 5). The highest number of species (seven species) was recorded at Kaniago and Buabuasin and the lowest (three species) at Baadoa. Of all the species, only the characid *Brycinus nurse* (R) occurred at all the sites, while the claroteid *Chrysichthys nigrodigitatus* (L) occurred at three of the

TABLE 5

List of fish species and their distribution at various sites

Species/Site	*Kaniago*	*Buabuasin*	*Baadoa*	*Twifo-Praso*
MORMYRIDAE				
Petrocephalus bovei V.	-	+	-	-
Marcusenius senegalensis S.	-	+	-	-
CHARACIDAE				
Brycinus nurse R.	+	+	+	+
Brycinus macrolepidotus V.	-	-	+	+
SCHILBEIDAE				
Schilbe mystus L.	-	+	-	-
CLAROTEIDAE				
Chrysichthys nigrodigitatus	+	+	+	-
CYPRINIDAE				
Labeo senegalensis V.	-	+	-	-
Labeo coubie R.	+	-	-	-
MOCHOKIDAE				
Synodontis vellifer N.	-	+	-	-
Synodontis sp.	+	-	-	-
CICHLIDAE				
Tilapia discolour G.	+	-	-	+
Tilapia guineensis B.	-	-	-	+
Tilapia zillii G.	-	-	-	+
Sarotherodon galilaeus L.	+	-	-	-
Hemichromis fasciatus G.	+	-	-	-
Total number of species	7	7	3	5

+ Present, - Absent

four sites. Seventy-nine per cent of *B. nurse* caught from all the sites occurred at Kaniago, 9% each at Buabuasin and Twifu-Praso and 3% at Baadoa. Similarly, 93% of *C. nigrodigitatus* that were caught from the three sites occurred at Kaniago, 4.3% at Buabuasin and 2.8% at Baadoa (Table 6).

Four out of the seven species caught at Buabuasin were found only at that site, with the mormyrids *Petrocephalus bovei* (V) and *Marcusenius senegalensis* (S) forming about 43% of the total number. The cichlids *Tilapia discolour* (G), *Hemichromis fasciatus* (G), *Tilapia guineensis* (B), *Tilapia zillii* (G) and *Sarotherodon galileus* (L) occurred at Kaniago and Twifu-Praso only, areas which had relatively low turbidities, 11 and 34 NTU, respectively. The cichlids were completely absent from Buabuasin and Baadoa, where turbidities were high (1110 and 100 NTU, respectively). Kaniago recorded the highest CPUE both in terms of number and weight followed by Buabuasin and Twifu-Praso, while Baadoa recorded the lowest for both weight and number (Table 6). With the exception of Baadoa the diversity and richness indices at Kaniago, Buabuasin and Twifu-Praso were

TABLE 6

Catch per unit of effort (CPUE) of fishing at the various sites

Species	Kaniago		Buabuasin		Baadoa		Twifo-Praso	
	No.	Wt	No.	Wt	No.	Wt	No.	Wt
MORMYRIDAE								
Petrocephalus bovei			0.85	8.35				
Marcusenius senegalensis			0.55	6.25				
CHARACIDAE								
Brycinus nurse	2.64	48.71	0.3	6.04	0.10	1.60	0.30	6.24
Brycinus macrolepidotus					0.10	1.03	0.20	13.78
SCHILBEIDAE								
Schilbe mystus			1.15	19.10				
CLAROTEIDAE								
Chrysichthys nigrodigitatus	3.27	5.175	0.15	7.60	0.10	1.78		
CYPRINIDAE								
Labeo senegalensis			0.05	0.65				
Labeo coubie	0.09	0.95						
MOCHOKIDAE								
Synodontis vellifer			0.20	4.70				
Synodontis sp.	0.09	0.26						
CICHLIDAE								
Tilapia discolour	1.82	23.38					0.10	4.17
Hemichromis fasciatus	0.09	9.11						
Tilapia guineensis							0.30	5.10
Tilapia zillii							0.20	7.75
Sarotherodon galilaeus	0.18	10.98						
Total CPUE	8.18	145.14	3.25	55.69	0.30	4.41	1.10	37.04

quite similar (Table 7).

Fish quality

The mean concentrations of eight trace metals in three fish species, *Brycinus nurse*, *Chrysichthys nigrodigitatus* and *Tilapia zillii*, are shown in Table 8. The concentrations of Pb, Mn, Cu and Fe in *B. nurse*, which occurred at all four sampling locations, were highest at Buabuasin in the dredging area. Comparing the immediate sites upstream (Kaniago) and downstream (Baadoa) of the dredging area, Pb, Cu, Zn and Fe were higher downstream, while Hg

TABLE 7

Species diversity and richness of fish communities at the various sites

Site/Index	Diversity (H')	Richness (D)
Kaniago	0.56	1.33
Buabuasin	0.64	1.44
Baadoa	0.48	1.12
Twifu-Praso	0.67	1.67

TABLE 8

Mean concentrations of metals in fish (mg g[1] fresh weight)

Species/Location	Hg	Cd	Pb	As	Cu	Zn	Mn	Fe
Brycinus nurse R.								
Kaniago	0.33	< 0.10	0.26	< 0.30	0.23	2.08	0.44	1.66
Buabuasin	0.13	0.11	0.31	< 0.30	0.39	1.27	0.63	8.32
Baadoa	0.13	< 0.10	0.27	< 0.30	0.25	6.22	0.39	4.49
Twifu-Praso	0.70	< 0.10	0.14	< 0.30	0.33	0.67	0.53	0.56
Mean values	0.32	<0.10	0.25	<0.30	0.30	2.56	0.50	3.76
Chrysichthys nigrodigitatus L.								
Kaniago	0.22	< 0.10	0.43	< 0.30	0.31	1.81	< 0.2	2.51
Buabuasin	0.29	≤ 0.10	0.42	< 0.30	0.36	2.86	1.41	5.31
Baadoa	0.17	< 0.10	0.46	< 0.30	0.31	2.84	0.21	2.12
Mean values	0.23	< 0.10	0.44	< 0.30	2.50	0.57	0.57	3.31
Tilapia zillii G.								
Twifu-Praso	0.06	< 0.10	0.17	< 0.30	0.22	1.82	1.35	2.66
WHO limits	0.50	2.00	2.00	-	10.0	1000	-	-

and Mn were higher upstream.

Discussion

Water quality

Suspension of large quantities of solids in the water column is one of the immediate physical effects resulting from alluvial dredging. The high turbidity recorded at Buabuasin was expected because of the continuous dredging and washing of sediments in that area. This influenced the turbidity at Baadoa, the site immediately downstream on the Offin. Suspended solids may affect biological resources in various ways (Chansang, 1988), including physical harm to fish, interference with self-purification of water by diminishing light penetration and, hence, photosynthetic reactions, and, subsequently, elimination of phytophagous species.

The deterioration of water quality at Baadoa, located 47 km and 12 km downstream of Buabuasin and Kubi, respectively, was due partly to input of mine wastes from River Jimi, which discharges into the Offin between Buabuasin and Baadoa. Thus, instead of an expected recovery in water quality at Baadoa, conditions worsened as a result of discharges from River Jimi. The considerable recovery in the water quality at Twifu-Praso was mostly due to the absence of further mine discharges and the distance (60 km) from Baadoa, which was sufficient to allow self-purification to take place, including settlement of particulates from the water column.

The *p*H values recorded at all the sites were within the recommended range of 6.5-9.0 for optimum fish growth (Boyd, 1984). Dissolved oxygen concentration of below 5 mg l^{-1} recorded at all the sites, except Twifo-Praso, was not the optimum for fish growth (Boyd, 1984) even though some fish can survive at such low dissolved oxygen concentrations.

Sediment quality

In the dredging area at Buabuasin, it was likely that metals were adsorbed onto fine suspended materials, which could stay in the water column for a long period because of continuous agitation of the water by dredging. Such materials could be dispersed further downstream, resulting in the low concentrations of trace metals in sediment in the dredging area. Grösser *et al.* (1994), investigating heavy metal concentration in stream sediment in a gold mining area in southern Columbia, reported higher concentrations in downstream areas and attributed this to mechanical transport of the sediment

Phytoplankton

Phytoplankton in the tropics are made up of fewer species than in temperate communities (Lewis, 1978). Lotic environments also do not favour the proliferation of phytoplankton (Prowse & Talling, 1958). The low numbers of individuals, as well as counts recorded at all the sites, confirm the findings of Prowse & Talling (1958).

The lowest diversity recorded at Buabuasin was a reflection of the disturbed nature of its environs resulting from dredging activities which may have prevented the occurrence of green and blue-green algae. The diatoms, which utilize siliceous materials for building their cells, dominated in the turbid areas. In contrast, Kaniago located 55 km upstream and Twifu-Praso, located 107 km downstream, which were less turbid, had higher diversities of 15 and 14 genera, respectively. These results confirm that of Down & Stocks (1978), who reported that silted conditions caused by discharge of china-clay wastes, which were neither toxic nor deoxygenating, prevented survival of algal life in Cornish rivers.

Fish fauna

Turbidity mainly caused by suspended soil particles adversely affects fish populations (Duchrow & Everhart, 1971). High concentration of suspended materials restricts light penetration and limits photosynthesis. This negatively affects phytophagous fishes by depriving them of algae, which serve as source of food. Sedimentation of soil particles may smother fish eggs and destroy communities of benthic organisms (Boyd, 1984). Species such as cichlids, which depend on nests on the riverbed for spawning, and those that feed on benthic organisms, may not find such environments suitable. This may partially explain the absence of cichlids from Buabuasin and Baadoa, where turbidity was high. The mormyrids which contributed about 43% and 31% by number and weight, respectively, of fish caught in the dredging area, are known to be adapted to living in muddy rivers and lakes and contribute greatly to their fisheries resource (Moyle & Cech, 1988).

Introduction of heavy metals or other contaminants in a river system, even at sub-lethal levels, may effect changes in the longitudinal distribution of fauna along the river course (Down & Stocks, 1978; Kantsky, 1992). Some fish species may move out of affected areas but movement of species into 'new' areas of a river usually affects the ecological balance of local fish communities. The chain-effect of this, with particular reference to competition for space and food resources, may eventually lead to the elimination of some species. Introduction of contaminants from mining activities may also adversely affect the abundance of fish by reducing their reproductive ability, preventing breeding or reducing survival of fry (Welcomme, 1992). Aquatic ecosystems in most of the industrialized world have been degraded due to contamination, and this has either altered fish populations or resulted in complete loss of fish (Down & Stocks, 1978; Welcomme, 1992).

The relative abundance, measured as CPUE, can be compared from place to place provided the same fishing gear is used. The high catch from Kaniago, which was considered as a control area, was largely due to better water quality at that site compared to Baadoa and Buabuasin. The lowest CPUE was, however, recorded at Baadoa even though it had less suspended materials than Buabuasin. This can be attributed to further deterioration of water quality as a result of additional inputs of mine effluents from River Jimi.

Diversity indices summarize the numerical associations of organisms and allow populations to be compared; they are generally more reliable indicator of environmental health or stress than are individual indicator species (Cain & Dean, 1976). Pollutants can lower both the diversity and resistance of the ecosystem (Down & Stocks, 1978). Bechtel & Copeland (1970) found that in the Galveston Bay, diversity was inversely proportional to the amount of effluents and toxic material an area received; the most polluted areas exhibiting the lowest mean annual diversity. The low diversity and richness indices at Baadoa confirm the poor water quality at that site due to the additional inputs of mine wastes from River Jimi.

Chemicals used in mining operations accumulate not only in sediments and particulate matter but also in the flesh of fish through the food chain and may consequently affect man (Fujiki, 1980). The concentrations of Pb, Mn, Cu and Fe in *B. nurse*, which occurred at all four sampling stations, were highest at Buabuasin in the dredging area. Dredging tends to release metals such as Cu and Fe, associated with gold mining, into the aquatic system. Since *B. nurse* is a pelagic omnivore it could accumulate metals from the water column either directly through the gills or indirectly through the food chain, hence, the high concentration of metals recorded in the species at Buabuasin. On the contrary, a higher concentration of Hg was recorded in *B. nurse* upstream at Kaniago. Samples of *B. nurse* analysed from Kaniago were, on the average, larger than those from Buabuasin (97 and 90 mm SL, respectively) and might have concentrated more Hg, since Hg concentration is related to age and size of fish (Bouquegneau & Joiris, 1988). The trend shown by Mn is, however, not clear and cannot be explained by the present data.

Concentrations of metals in *C. nigrodigitatus* at the three sites also showed a similar trend. With the exception of Hg, fairly low concentrations of metals occurred in fish at Twifu-Praso, an indication that most metals might have become unavailable through adsorption by the time they reached that site. With the exception of Hg concentration in *B. nurse* at Twifu-Praso, the concentrations of the other metals in the fishes were below the permissible levels recommended by WHO (Nauen, 1983).

Thus, mining activities can negatively affect the abundance and community structure of both micro flora and fauna as well as the quality of water along a river course. It is, therefore, recommended that such mining activities should be accompanied by restoration efforts such as reforestation and temporary closure of certain stretches of rivers and streams to human activities. Restoration measures should also be monitored.

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