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Monitoring and Assessment of Mercury Pollution in the Vicinity of a Chloralkali Plant. IV. Bioconcentration of Mercury in *In Situ* Aquatic and Terrestrial Plants at Ganjam, India

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Abstract. *In situ* aquatic and terrestrial plants including a few vegetable and crop plants growing in and around a chloralkali plant at Ganjam, India were analyzed for concentrations of root and shoot mercury. The aquatic plants found to bioconcentrate mercury to different degrees included *Marsilea* spp., *Spirodela polyrhiza, Jussiea repens, Paspalum scrobiculatam, Pistia stratiotes, Eichhornia crassipes, Hygrophila schulli, Monochoria hastata* and *Bacopa monniera*. Among wild terrestrial plants *Chloris barbata, Cynodon dactylon, Cyperus rotundus* and *Croton bonplandianum* were found growing on heavily contaminated soil containing mercury as high as 557 mg/kg. Analysis of mercury in root and shoot of these plants in relation to the mercury levels in soil indicated a significant correlation between soil and plant mercury with the exception of *C. bonplandianum*. Furthermore, the tolerance to mercury toxicity was highest with *C. barbata* followed by *C. dactylon* and *C. rotundus*, in that order. The rice plants analyzed from the surrounding agricultural fields did not show any significant levels of bioconcentrated mercury. Of the different vegetables grown in a contaminated kitchen garden with mercury level at 8.91 mg/kg, the two leafy vegetables, namely cabbage (*Brassica oleracea*) and amaranthus (*Amaranthus oleraceous*), were found to bioconcentrate mercury at statistically significant levels. The overall study indicates that the mercury pollution is very much localized to the specific sites in the vicinity of the chloralkali plant.

Liquid effluent and solid waste discharged from the chloralkali plant at Ganjam, Orissa that has been in operation since 1967 represent the principal sources of mercury pollution at the region (Figure 1). Mercury from the effluent as well as the solid waste contaminate the adjacent land and water systems (Panda *et al.* 1989, 1990, 1991a, 1991b). Mercury being volatile is also air-borne. Plants growing in such a polluted environment uptake mercury from soil, water and air that eventually get bioconcentrated in the plant roots and aerial parts. The entry of mercury into food chains via the plant is of potential risk to human and environmental health. On the basis of bioconcentration of mercury, plants are useful indicators of localized high levels of mercury in the environment from various sources (Lindberg *et al.* 1979; Huckabee *et al.* 1983; Seigel *et al.* 1985; Shaw and Panigrahy 1986). Bioconcentration of mercury in crops and vegetables cultivated in polluted environments has been of serious concern (De Temmerman *et al.* 1986; Wiersma *et al.* 1986; Cappon 1987). It is estimated that under normal circumstances vegetables in particular contribute about 10% to the total mercury uptake by man (Fouassion and Fordu 1978). In this paper, an attempt has been made to monitor and assess mercury pollution on the basis of bioconcentration of mercury in *in situ* plants and vegetables at the chloralkali plant, Ganjam, Orissa.

Materials and Methods

Study Area and Collection of Samples

The experimental sites were selected around the chloralkali plant at Ganjam as indicated in Figure 1. Site 1 is the effluent channel that brings effluent from the chloralkali plant and discharges it into the Rushikulya estuary. Site 2 is an abandoned solid waste dump site. Adjacent to Site 2 lies the kitchen gardens where a variety of vegetables are grown by the plant workers residing in the adjoining staff quarters. Site 3 represents a low-lying wet area having a good vegetation cover of aquatic plants. Sites 4–8 represent private agricultural lands where rice is being cultivated. The characteristics (average values) of the agricultural soil of the region (Sites 4–8) are as follows: pH 5.2, conductivity 0.28 mΩ/cm, organic carbon 0.19%, available P_2O_5 0.9 g/sq m and available K_2O 18.9 g/sq m.

Top soil (upper 5 cm) samples were collected from all the sites in polythene bags, with the exception of Sites 1 and 3 from where surfacial sediments were collected, dried under natural sunlight, powdered, sieved and kept at room temperature (29 ± 1°C) until analyzed. The loss of mercury from soil or sediment samples over a period of two months was insignificant. Plants were selected based on their abundance at the contaminated site. At least six different plants for each species were collected on the same day from the sampling sites. A set of representative plants pressed dry at the time

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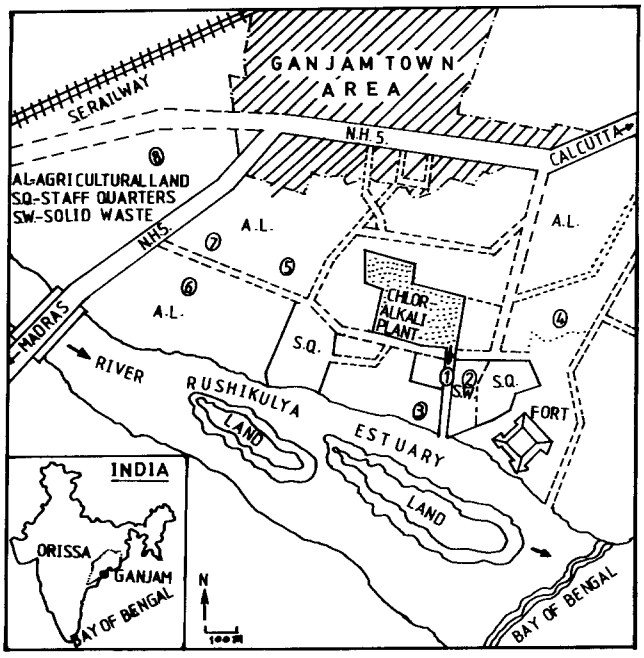

Fig. 1. Study area showing the location of the chloralkali plant at Ganjam, India. The sampling sites are numbered 1–8. Note that Site 1 is the effluent channel that brings liquid effluent from the chloralkali plant and discharges it into the Rushikulya estuary. Site 2 is an abandoned solid waste dump site. Site 3 is a low-lying wet area having aquatic plants. Sites 4–8 are agricultural lands where rice is cultivated seasonally

of collection were subsequently identified at the herbarium of the department or at Botanical Survey of India, Calcutta. Samples of whole plants or parts thereof after collection from different sites were thoroughly washed in running tap water and dried to constant weights at 60°C for analysis of mercury. Whenever necessary, soil and plant samples from a non-contaminated site near Berhampur University Campus about 30 km away from the chloralkali plant, Ganjam were collected on the same day as the plants from the contaminated site and handled alike to serve as the controls. At present, no attempt has been made to measure air mercury concentrations in the areas around the chloralkali plant nor the University campus, the control site.

Digestion and Analysis of Samples for Mercury

The dried soil/sediment samples were digested in BOD bottles at 95°C in a water bath with concentrated aqua regia, HCl:HNO_3 (3:1 v/v). The dried plant samples were wet digested at room temperature in concentrated perchloric acid:HNO_3 (1:4 v/v) for 24 h or more until dissolution followed by gentle heating in Betheges apparatus (Lenka *et al.* 1990). All the digests, in triplicate, were oxidized with potassium permanganate and potassium persulphate followed by reduction with hydroxylamine hydrochloride (Environmental Protection Agency 1976). Mercury in the digests were analyzed by cold vapor atomic absorption spectrophotometry after reduction with 20% $SnCl_2$ using a Mercury Analyser (MA 5800D, ECIL, India) with a detection limit of 0.02 μg. Prior to analysis, the instrument was tested for non-specific absorption. For standards ($HgCl_2$) taken at 0.02 and 0.04 mg/L, the analysis gave a standard deviation of ±8% and ±5%, respectively, when 12 subsamples from the same solution were analyzed for mercury. The precision of analysis, expressed as the coefficient of variance (CV) of replicate analysis was 1.9%.

Statistical Analysis

The data were statistically analyzed using analysis of variance, coefficient of correlation (r), F-test, and least significant difference test (Gomez and Gomez 1984).

Results

Distribution of Sediment and Soil Mercury Near the Chloralkali Plant

The concentration of mercury in the sediments of the effluent channel (Site 1) and the low-lying area (Site 3) were 192 and 41.3 mg/kg, respectively. The concentration of mercury in the solid waste deposits was 2,550 ± 339 mg/kg which remain almost barren, devoid of any vegetation (Site 2). However, as the mercury concentration decreased to 557 mg/kg or less in the peripheral regions encircling Site 2, a thin vegetation cover was found, represented by a few plant species viz., *Chloris barbata, Cynodon dactylon, Cyperus rotundus* and *Croton bonplandianum*. With a further increase of distance from the solid waste deposits at Site 2, the mercury concentration in soil was decreased from 50 to 20 mg/kg; marked by a gradual thickening of the vegetation and addition of a few more plant species. In the adjoining kitchen gardens, lying at about 100 m away from the Site 2, the levels of mercury in soil was found to be in the range of 8–10 mg/kg. The mercury levels in the top soils from the agricultural lands surrounding the chloralkali plant (Sites 4–8) ranged from 0.62 (Site 8) to 1.17 (Site 5) mg/kg (Table 3).

Bioconcentration of Mercury in Aquatic Plants

The results on bioconcentration of mercury in aquatic plants, root and shoot growing at Sites 1 and 3 are presented in Table 1. The levels of mercury in water from Sites 1 and 3 at the time of collection of plant samples were respectively 0.02 and 0.004 mg/L. Of the total ten aquatic plants analyzed from both the sites, *Cyperus rotundus* was found only in Site 1. *Eichhornia crassipes* was introduced at Site 3, about a year prior to experimentation. *Paspalum scrobiculatum* was common at either of the sites. The bioconcentration of mercury in root of *C. rotundus* and *P. scrobiculatum* growing at Site 1 were 140.66 and 200 μg/g and that in shoot were 17.83 and 29.67 μg/g, respectively. The rest of the eight plant species were from Site 3. The data indicated that the bioconcentration of mercury in roots ranged from 8.9 to 25.37 μg/g in roots and in shoots from 1.17 to 13 μg/g of aquatic plants which are common to Site 3 with a mercury level of 41.3 mg/kg sediment. Of these, *Baccopa monniera* exhibited the lowest level of root as well as shoot mercury. The highest levels of root and shoot mercury were recorded with *Marsilea* spp. and *Pistia stratiotes*, respectively. Invariably the bioconcentration of mercury in root was higher than that of shoot in all the aquatic plants irrespective of the sites. The shoot/root-mercury ratio ranged from 0.12 (*Cyperus rotundus*) to 0.65 (*Pistia stratiotes*).

Table 1. Bioconcentration of mercury in root and shoot of certain aquatic plants at Sites 1 and 3

Name of the plants from different sites	Hg in water mg/L ± SD	Hg in sediment mg/kg ± SD	Root Hg μg/g (dry wt) ± SD	Shoot Hg μg/g (dry wt) ± SD	Shoot/Root -Hg Ratio
Site 1					
Cyperus rotundus L.	0.02 ± 0.003	192.0 ± 3.74	140.66 ± 5.13	17.83 ± 2.56	0.12
Paspalum scrobiculatum L.			200.0 ± 17.37	29.67 ± 7.57	0.15
Site 3					
Bacopa monniera (L.) Penell	0.004 ± 0	41.3 ± 8.93	8.9 ± 0.56	1.17 ± 0.47	0.13
Eichhornia crassipes (Mart.) Solms[a]			15.66 ± 2.3	2.03 ± 0.25	0.13
Hygrophila schulli (Ham.) M.R. & S.A. Almcida			14.11 ± 2.27	4.06 ± 0.11	0.29
Jussiaea repens L.			25.22 ± 2.11	4.83 ± 1.08	0.19
Marsilea spp.			25.37 ± 4.5	3.2 ± 0.34	0.14
Monochoria hastata (L.) Solms			12.33 ± 2.3	1.58 ± 0.11	0.13
Paspalum scrobiculatum L.			25.00 ± 0	3.40 ± 0.72	0.14
Pistia stratiotes L.			20.00 ± 4.5	13.00 ± 4.36	0.65
Spirodela polyrhiza (L.) Scheid.			25.33 ± 2 (Frond)	—	—

[a] Introduced plant
Data are mean of three replications

Table 2. Bioconcentration of mercury in roots and shoots of terrestrial wild plants in relation to soil mercury near Sites 1 and 2

Name of the plants	Soil Hg mg/kg ± SD	Root Hg (dry wt) μg/g ± SD	Shoot Hg (dry wt) μg/g ± SD	Shoot/ root-Hg ratio	Mean shoot/ root-Hg ratio	Root/ soil-Hg ratio	Shoot/ soil-Hg ratio
Argemone mexicana L.	59.9 ± 7.1	1.97 ± 0.29	1.47 ± 0.25	0.74	0.74	0.03	0.02
Chloris barbata Sw.	6.55 ± 0.93	2.90 ± 0.60	0.67 ± 0.57	0.23		0.44	0.10
	108.5 ± 6.5	20.69 ± 2.47	5.68 ± 1.46	0.27	0.24	0.19	0.05
	327.53 ± 31.78	38.67 ± 9.8	9.0 ± 4.0	0.23		0.11	0.02
	523.6 ± 33.95	53.33 ± 4.0	11.33 ± 2.52	0.21		0.1	0.02
	(393.44**)	(48.18**)	(14.1*)				
Cynodon dactylon (L.) Pers.	22.04 ± 1.31	12.13 ± 1.84	4.83 ± 1.46	0.39		0.55	0.22
	108.5 ± 6.5	44.3 ± 10.6	10.35 ± 2.47	0.23	0.28	0.40	0.09
	327.53 ± 31.78	95.4 ± 9.85	29.93 ± 4.93	0.32		0.29	0.09
	557.33 ± 91.62	178.89 ± 41.38	37.33 ± 7.5	0.2		0.32	0.06
	(72.72**)	(125.97**)	(19.15**)				
Cyperus rotundus L.	10.27 ± 2.0	11.79 ± 1.92	3.43 ± 1.15	0.29		1.15	0.33
	59.16 ± 8.92	25.3 ± 2.46	6.36 ± 1.06	0.25	0.23	0.42	0.11
	557.33 ± 91.62	200.00 ± 40.9	35.49 ± 3.2	0.17		0.36	0.06
	(97.26**)	(48.53**)	(218.11**)				
Croton bonplandianum Baill.	7.75 ± 7.38	0.27 ± 0.08	0.38 ± 0.32	1.4		0.03	0.05
	10.27 ± 2.0	1.15 ± 0.13	2.1 ± 0.17	1.85	1.36	0.11	0.2
	18.24 ± 0	0.7 ± 0.27	1.3 ± 0.2	1.88		0.04	0.07
	59.16 ± 8.92	2.52 ± 0.32	2.5 ± 0.52	1.0		0.04	0.04
	557.33 ± 91.62	2.7 ± 2.3	2.8 ± 0.2	0.66		0.004	0.003
	(100.77**)	(88.18**)	(19.83**)				
Evolvulus alsinoides (L.) L.	18.24 ± 0	5.9 ± 2.0	4.0 ± 0.5	0.67		0.32	0.22
	22.04 ± 1.31	10.16 ± 5.0	8.56 ± 5.73	0.84	0.76	0.46	0.39
Justicia simplex D. Don	18.24 ± 0	3.3 ± 0.2	3.67 ± 0.57	1.1		0.18	0.2
	22.04 ± 1.31	6.67 ± 0.57	5.4 ± 0.6	0.81	0.96	0.24	0.24
Tribulus terrestris L.	22.04 ± 1.31	4.8 ± 1.57	8.0 ± 0.6	1.67	1.67	0.22	0.36

Data are mean of three replications; figures in parentheses represent F values; significant at $P \leq 0.05$ (*) and $P \leq 0.01$ (**)

Bioconcentration of Mercury in Terrestrial Plants

The data on bioconcentration of mercury with respect to eight select terrestrial plant species growing near Sites 1 (on either side of the effluent channel) and 2 are presented in Table 2. Of these, the four species namely, *Chloris barbata, Cynodon dactylon, Cyperus rotundus* and *Croton bonplandianum,* were found to grow on contaminated soils containing mercury as high as 523 or 557.33 mg/kg. With the former three plant species, the bioconcentration of mercury in root and shoot was found to increase with the increase of levels of mercury in the soil, that showed high degrees of correlation,

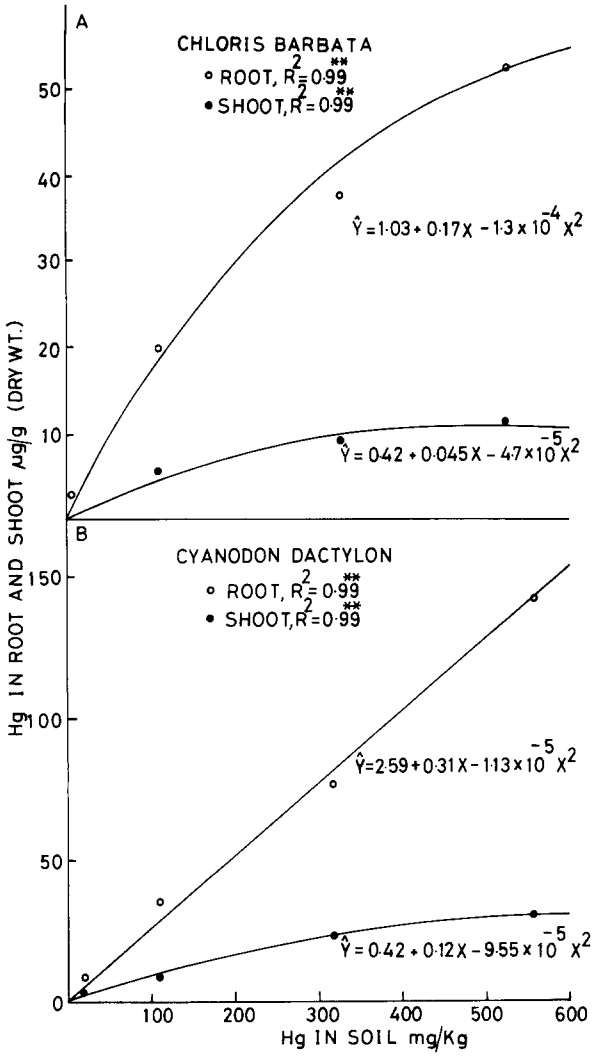

Fig. 2. Bioconcentration of Hg in root and shoot as a function of concentration of Hg in contaminated soil in (A) *C. barbata* and (B) *C. dactylon*. Significant at $P \leq 0.01$ (**)

$P \leq 0.01$ (Figures 2 and 3). Furthermore the said three plants accumulated mercury comparatively more in root than shoot resulting in a low shoot/root-mercury ratio in the range 0.17–0.39 (Table 2). The root-shoot mercury ratio, for that matter even the shoot/soil-mercury ratio for *C. barbata, C. dactylon* and *C. rotundus* declined with the increase of soil-mercury (Figures 4 and 5). Mercury uptake by *C. bonplandianum,* on the contrary, was found to be not only minimum but also showed little correlation with soil-mercury. With *C. bonplandianum,* the concentration of shoot-mercury was more than that of root mercury for most of the times that yielded an average shoot/root-mercury ratio of 1.36. Metal uptake by *Argemone mexicana* analyzed from a soil containing 59.9 mg/kg in the vicinity of Site 2 was also poor with a shoot/root-mercury ratio of 0.74. The remaining three plant species, namely *Evolvulus alsinoides, Justicia simplex,* and *Tribueus terrestris,* were found to grow on soil contaminated with relatively lower levels of mercury in the range 18–22 mg/kg. In spite of the limited data, a concentration-dependent increase of root- as well as shoot-mercury was apparent in *E. alsinoides* and *J. simplex* with shoot/root-mercury ratios at 0.76 and 0.96, respectively. With *T. terrestis* the bioconcentration of shoot mercury was more than that of root, resulting in a higher shoot/root-mercury ratio which was 1.67 (Table 2).

Bioconcentration of Mercury in Rice and Vegetables

The data with respect to bioconcentration of mercury in root, vegetative part (stem and leaf), inflorescence and grain of rice plant (*Oryza sativa*) cultivated at Sites 4–8 presented in Table 3. Of all the sites, the bioconcentration of mercury in root was significant only at Site 5 as compared to that of the control. The differences in root-mercury for the rest of the sites were insignificant. The bioconcentration of mercury in vegetative part, inflorescence and grain of rice cultivated at the sites near the chloralkali plant were insignificant. Interestingly, the bioconcentration of mercury was maximum in root but progressively decreased in vegetative parts and reached a minimum level in the grain of rice.

The bioconcentration of mercury in the vegetables grown in a kitchen garden located adjacent to Site 2 containing soil mercury at the level of 8.91 mg/kg was determined. The vegetables grown in a non-contaminated kitchen garden located near the University campus having soil mercury at 0.67 mg/kg was used as the controls. The data on bioconcentration of mercury in different vegetables are presented in Table 4. Compared to the controls, the bioconcentration of mercury in the leafy vegetables, namely cabbage (*Brassica oleracea*) and amaranthus (*Amaranthus oleraceous*), were significant ($P \leq 0.01$). Interestingly, none of the fruity vegetables had any significant levels of mercury as compared to the controls, although the vegetative parts in the case of chilli (*Capsicum annuum*), tomato (*Lycopercicon esculentum*) and lady's finger (*Abelmoschus esculentus*) were found to bioconcentrate mercury at significant levels ($P \leq 0.05$).

Discussion

Plants growing on metalliferous soil cannot prevent but may restrict metal uptake resulting in accumulation or bioconcentration of metals to varying degrees. The elevated concentration of metals in the soil will thus be reflected by the bioconcentration of metals in the plant body. This general assumption hold true for many species of plants and many situations despite numerous complications concerning the availability of the metal to plants and differences in uptake pattern within individual plant and between different species (Martin and Coughtrey 1982). On the basis of bioconcentration of metals three types of plant-soil relationship have been described (Baker 1981). (1) Plants in which uptake and translocation of heavy metals to aerial parts are regulated so that plant concentration reflect soil concentration, known as "indicators". (2) Plants in which metals are concentrated from low or high soil levels are known as "accumulators".

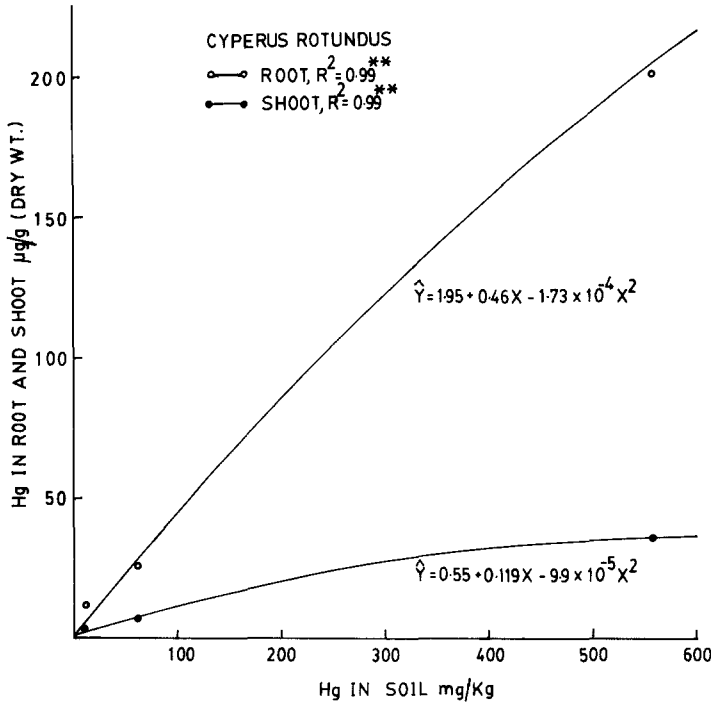

Fig. 3. Bioconcentration of Hg in root and shoot as a function of concentration of Hg in contaminated soil in *C. rotundus*. Significant at $P \leq 0.01$ (**)

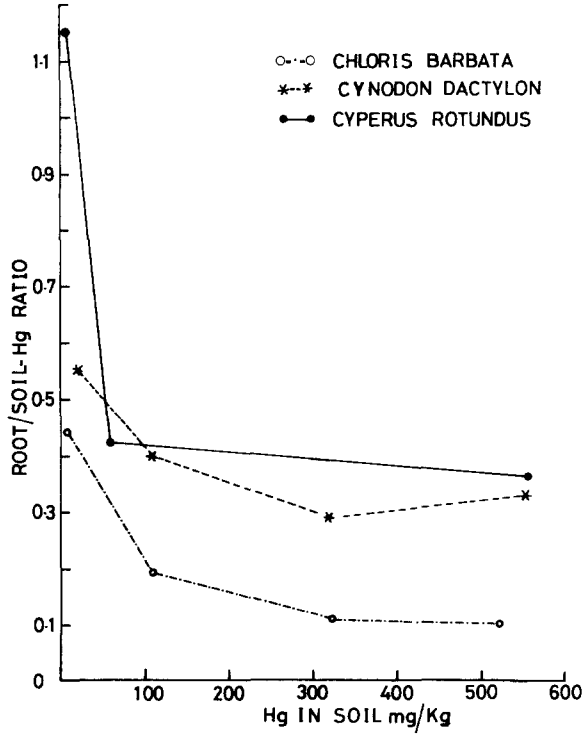

Fig. 4. Relative accumulation of mercury in root at different concentrations of soil-Hg in *C. barbata, C. dactylon,* and *C. rotundus*

(3) Plants in which concentration of heavy metals in the shoot remain low or constant over a wide range of soil concentrations, until the control mechanism breaks down and unrestricted transport occurs which is usually deleterious to the plant are known as "excluders." Excluder plants are otherwise termed as "non-indicators" (Siegel *et al.* 1985). Of these types the indicator and accumulator plants have attracted the attention of environmentalists because of their potential utility in biomonitoring (Martin and Coughtrey 1982; Burton 1986) as well as in pollution control (Wolverton and McDonald 1979; Banuelos and Schrale 1989; Brix and Schierup 1989).

Of the different sites surveyed for soil-plant-mercury around the chloralkali plant, Site 2 followed by 1 and 3 are highly contaminated with mercury. All the aquatic plants growing at Site 1 and 3 uptake mercury from the aquatic environments. The bioconcentration of mercury in the roots of *Marsilea* spp., *Jussiaea repens* and *Paspalum scrobiculatum* as well as in the fronds of *Spirodela polyrhiza* at Site 3 was 25 µg/g dry weight. In the rest of the plants at Site 3, the root-mercury concentration ranged between 8 and 20 µg/g. *Pistia stratiotes* concentrated relatively more mercury in the shoot compared to the rest of the aquatic plants studied. *C. rotundus* and *P. scrobiculatum* growing at Site 1, with sediment mercury level at 192 mg/kg had higher concentrations of root- and shoot-mercury, indicating that the bioconcentration of mercury in these aquatic plants may increase further with the increase of mercury levels in the sediment. Since none of these aquatic plants from the contaminated site are never consumed by humans, the risk of direct intake is likely to be minimum. At this conjuncture it may be recalled that *E. crassipes* known for its ability to bioconcentrate high levels of aquatic mercury (Lenka *et al.* 1990) was introduced into Site 3 about a year prior to the analysis of mercury. As a result, the relative efficiency of the aquatic plants for uptake of mercury could not be compared with *E. crassipes*. The low shoot/root-mercury ratio determined for aquatic plants at Sites 1 and 3 (Table 1) suggests that the plants accumulate mercury mostly in the root and

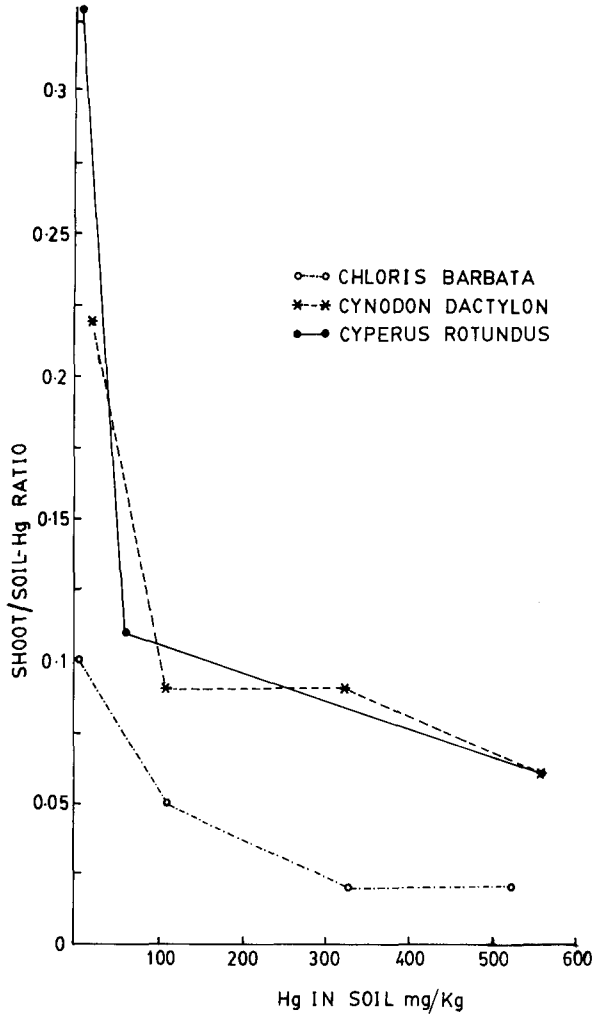

Fig. 5. Relative accumulation of mercury in shoot at different concentrations of soil-Hg in *C. barbata, C. dactylon,* and *C. rotundus*

the translocation of mercury from root to aerial parts is regulated. The natural occurrence of these plants at the mercury-contaminated Sites 1 and 3 by themselves indicate some degree of tolerance to aquatic mercury contamination and therefore should be useful in the control of aquatic mercury pollution in the lines as attempted with *E. crassipes* (Lenka *et al.* 1990) or with other aquatic plants as suggested by Brix and Schierup (1989).

From the results on bioconcentration of mercury in terrestrial plants (herbs) at Site 2 (Table 2), it was evident that the mercury-rich soil could not sustain vegetation above the contamination level of 557.33 mg/kg which may therefore be considered as the threshold concentration of mercury in soil for phytotoxicity at that site. Of the terrestrial plants data presented with respect to *C. barbata, C. dactylon, C. rotundus,* and *C. bonplandianum* that were found growing on soils with three or four contamination levels of mercury in the range 6.5–557 mg/kg were used to deduce a relationship between the plant- and soil-mercury under *in situ* conditions. For the three plants, viz., *C. barbata, C. dactylon,* and *C. rotundus* both root- and shoot-mercury were significantly correlated ($P \leq 0.01$) with soil-mercury and may serve as indicators of soil mercury. The low shoot/root-mercury ratios calculated for these plants that ranged between 0.23 and 0.28 (average values, Table 2) provided evidence that the translocation of mercury from root to shoot in these plants was highly restricted. The root/soil-mercury ratio as well as the shoot/soil-mercury ratio which were found to decline with the increase of concentration of soil-mercury further indicated the ability of these plants to avoid or restrict metal uptake from mercury enriched soil. This by itself perhaps explains the basis of tolerance of these plants to mercury toxicity which nevertheless warrents further investigation. The plant-soil relationship with respect to mercury further suggested that among the three plant species, tolerance to mercury was in the order *C. barbata* > *C. dactylon* > *C. rotundus* (Figures 4 and 5). With *C. bonplandianum* growing on contaminated soil with a wide-range of mercury concentrations from 7.75 to 557 mg/kg, the ranges of bioconcentration of mercury in its root and shoot were 0.27–2.7 and 0.38–2.5 μg/g, respectively (Table 2) which failed to show any significant correlation with the levels of soil mercury and therefore may be considered as a nonindicator plant. The data with respect to *Argemone mexicana* reported from a single contaminated soil seemed to be less or more similar to that of *C. bonplandianum.* The remaining plants *E. alsinoides, J. simplex,* and *T. terrestris* owing to their restricted distribution at the contaminated site found on soils containing mercury 22 mg/kg, were not very useful for biomonitoring mercury in the present study. Nonetheless, it may be borne in mind that such herbaceous plants may serve as efficient transporters of mercury in the terrestrial food chains which is of ecotoxicological concern.

The survey of soil mercury in the agricultural lands, Sites 4–8, indicated an elevated level of soil-mercury at Site 5 (Table 3) where the bioconcentration of mercury in root of rice was also found to be correspondingly increased compared to that of the control. The levels of contamination of rice plants as indicated by the bioconcentration of mercury in shoot, inflorescence and grain, were insignificant at all the Sites (4–8). Based on the analysis of the mercury in rice plants, the agricultural fields at the test sites appear to be free of mercury pollution. The bioconcentration of mercury in vegetables from one of the kitchen garden near Site 2 indicated elevated levels of mercury ($P \leq 0.01$) in the leafy vegetables namely amranthus and cabbage as compared to that from a control site (Table 4). This confirmed earlier reports showing elevated levels of mercury in leafy vegetables compared to other vegetables grown on the same contaminated soils (Wiersma *et al.* 1986; Cappon 1987). Among other vegetables analyzed for mercury in the present study, chilli followed by tomato and lady's finger exhibited significant levels of mercury in the leafy branches ($P \leq 0.05$) but not in the fruit. Similarly, the bioconcentration of mercury in none of the fruits from the contaminated sites was significant.

Attempts have been made to decide the permissible limits of mercury in soil, water, sediment, and fish (Hakanson *et al.* 1988; Revis *et al.* 1990; Panda *et al.* 1990, 1991a, 1991b). Information available with respect to limits of mercury in edible plants is sparse. Further investigation, particularly to assess the body burden of mercury in humans who ate the leafy vegetables grown in the contaminated kitchen garden at the chloralkali plant, Ganjam would therefore be worth-

Table 3. Bioconcentration of mercury in rice (*Oryza sativa*) cultivated at Sites 4–8 around the chloralkali plant at Ganjam

Site No.	Total soil Hg mg/kg ± SD	Hg in root (dry wt) μg/g ± SD	Hg in shoot (dry wt) μg/g ± SD	Hg in inflorescence (dry wt) μg/g ± SD	Hg in grain (dry wt) μg/g ± SD
Control	0.76 ± 0.11	5.83 ± 2.36	0.93 ± 0.11	1.20 ± 0.23	0.53 ± 0.13
4	0.66 ± 0.06	6.33 ± 1.15	1.46 ± 0.28	1.2 ± 0.52	0.52 ± 0.02
5	1.17 ± 0.30*	11.50 ± 1.29**	2.30 ± 0.46	1.53 ± 0.45	0.48 ± 0.07
6	0.87 ± 0.04	9.29 ± 2.89	1.8 ± 0.32	1.16 ± 0.11	0.47 ± 0.05
7	0.83 ± 0.15	7.50 ± 0.80	2.17 ± 0.73	0.97 ± 0.23	0.55 ± 0.08
8	0.62 ± 0.04	7.04 ± 1.08	1.53 ± 0.45	1.53 ± 0.45	0.51 ± 0.03
Computed F	5.45**	4.13*	2.53	0.7	0.26

Data are mean of three replication; significant at $P \leq 0.05$ (*) and $P \leq 0.01$ (**)

Table 4. Bioconcentration of mercury in vegetables grown in a mercury contaminated kitchen garden near Site 2 as compared with a control site

Name of the plants (common name)	Control site (0.67 mg Hg/kg soil)		Contaminated site (8.91 ± 0.71 mg Hg/kg soil)	
	Hg in plant μg/g Leafy branch	± SD (dry wt) Fruit	Hg in plant μg/g Leafy branch	± SD (dry wt) Fruit
Abelmoschus esculentus (L.) Moench. (Ladys' finger)	0.44 ± 0.11	0.62 ± 0.24	0.93 ± 0.6*	0.93 ± 0.05
Allium cepa L. (Onion)	0.1 ± 0 (Bulb)	—	0.8 ± 0 (Bulb)	—
Amaranthus oleraceous L. (Amaranthus)	0.96 ± 0.33	—	4.33 ± 0.57**	—
Brassica oleracea L. (Cabbage)	0.8 ± 0	—	9.33 ± 1.15**	—
Capsicum annuum L. (Chilli)	1.2 ± 0.35	0.81 ± 0.34	2.1 ± 0.23**	1.53 ± 0.25
Cyamopsis tetragonoloba (L.) Tanb. (Cluster bean)	ND	1.2 ± 0.69	1.7 ± 0.36	1.4 ± 0.52
Lycopersicon esculentum Mill. (Tomato)	1.32 ± 0.48	0.91 ± 0.51	2.36 ± 0.3*	1.13 ± 0.15
Momordica charantia L. (Bitter gourd)	1.2 ± 0.17	1.63 ± 0.57	1.4 ± 0.36	0.93 ± 0.11
Solanum melongena L. (Brinjal)	ND	1.4 ± 0.36	1.3 ± 0.2	0.87 ± 0.11

Data are mean of three replications; significantly different from control $P \leq 0.05$ (*) or $P \leq 0.01$ (**); ND = not done

while. The present study, based on bioconcentration of mercury in *in situ* plants and vegetables at the chloralkali plant, Ganjam, Orissa clearly demonstrated that mercury pollution is localized at Sites 1 and 2. To avoid any unwarranted human risk due to the mercury pollution it is suggested that Sites 1 and 2 in the vicinity of the chloralkali plant be prohibited from cattle grazing, human settlement, or kitchen gardening.

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