

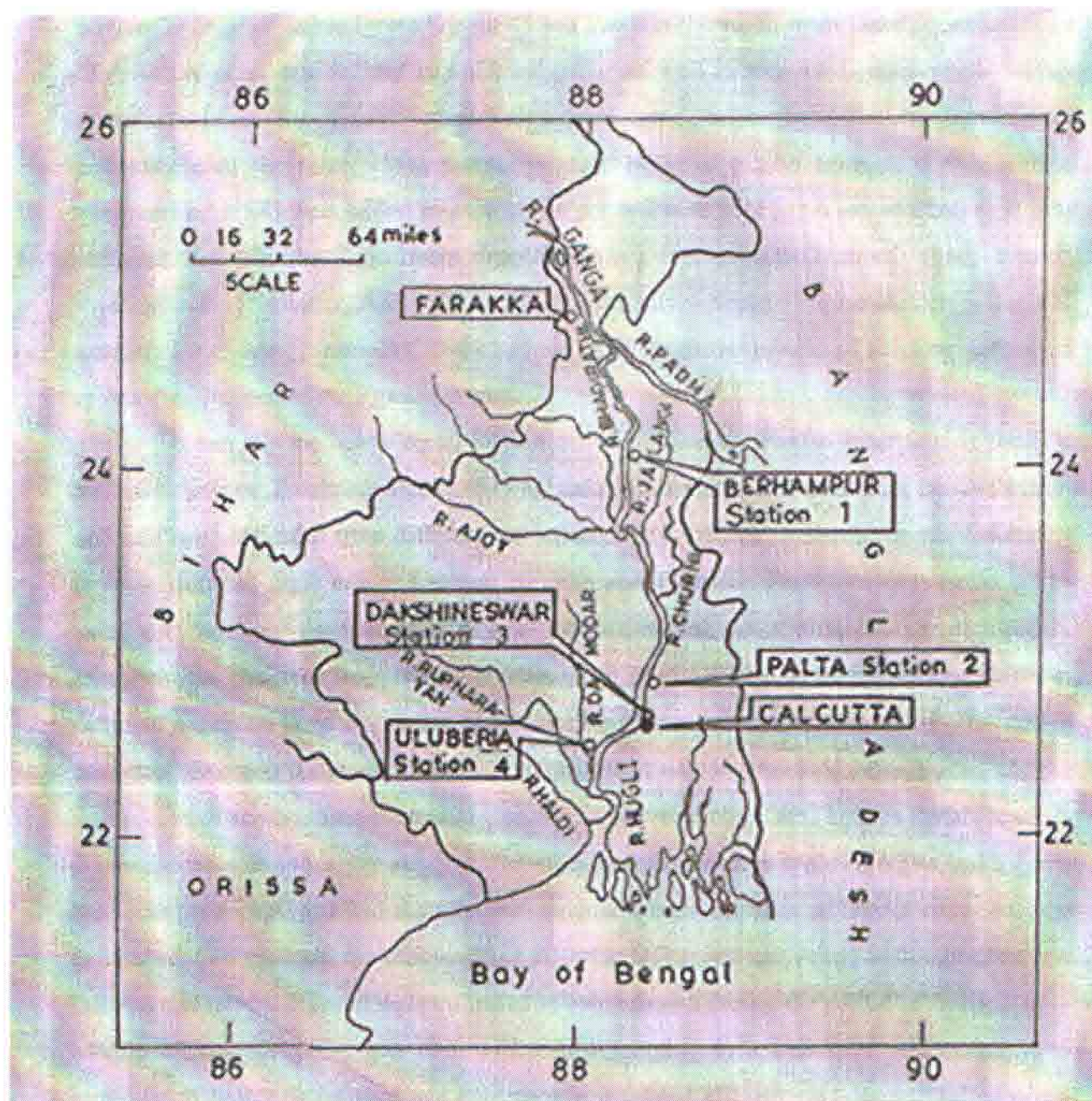
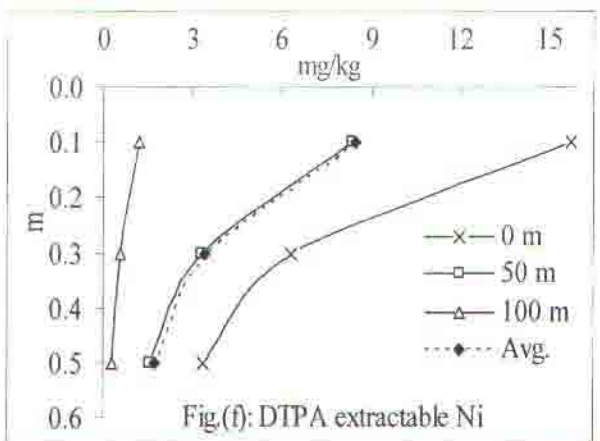
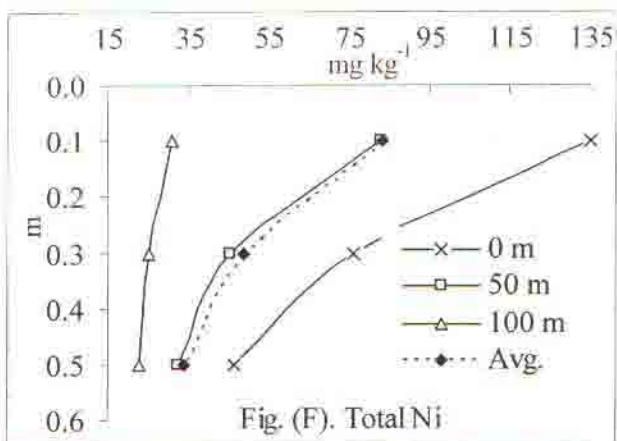
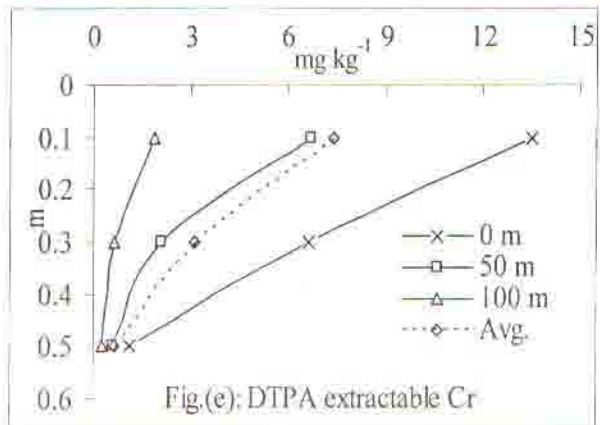
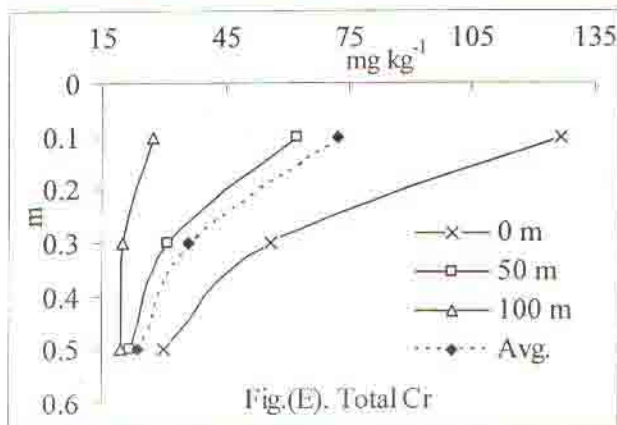
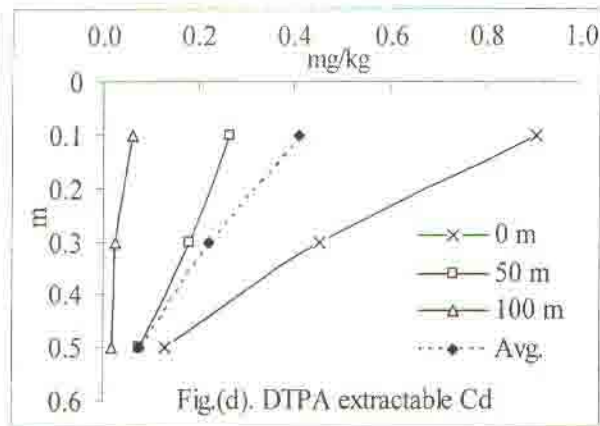
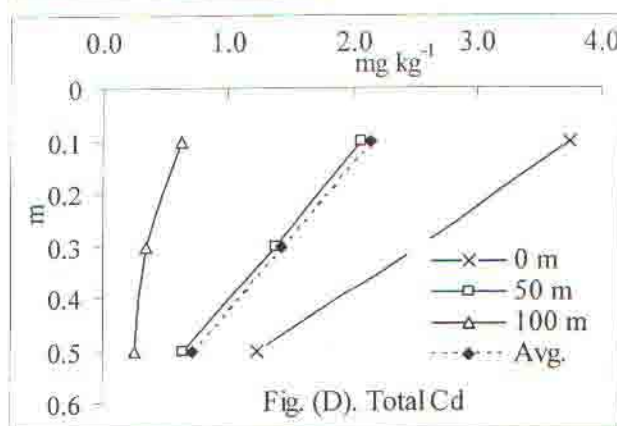
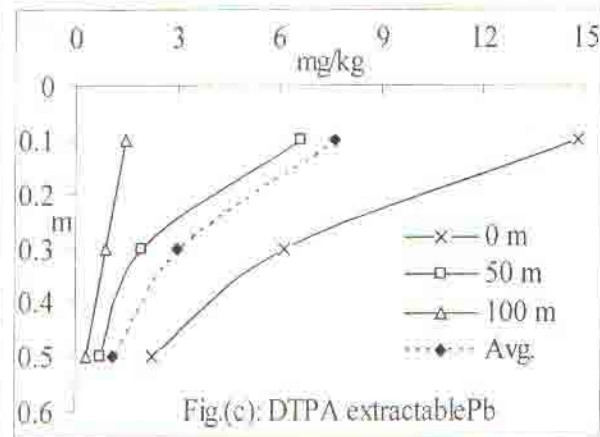
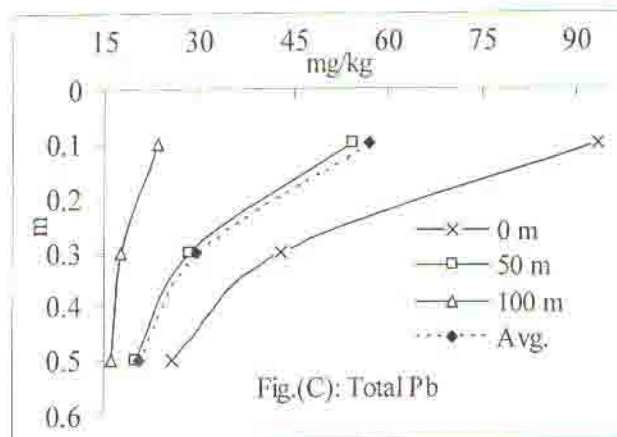


Fig. 3.2 Sampling locations on the river Ganga

To study the temporal and spatial variations of heavy metal load in surface water and sediment of the river Ganga at different discharge points, surface water samples were collected from about 300 km stretch of the river Ganga in West Bengal starts from Berhampore, Dist. Murshidabad in the north and extends up to Uluberia, Dist. Howrah in the South. Therefore, our study stretch of the river takes the name Hooghly (Fig. 3.2). Four sampling stations were selected, namely Berhampore (BH) which is situated about 115 km away in the South from Farakka barrage where the river mainly receives agricultural run off and sewage water, Palta (PA) centre is located about 220 km south from Berhampore. The river receives here the discharges from small & large industries, municipal sewage and agricultural run-off. The Centre Dakshineswar (DK) (about 25 km south from Palta) is situated in front of the famous Kali Temple. Fourth and the last sampling centre in the down



Heavy metal accumulation in crops is a function of complex interaction among soil, plant and environmental factors. It has been well documented that the contents of heavy metals in crop plants are closely associated with their levels in soil. Moreover, the uptake and accumulation of heavy metal by plants are largely dependent on the available rather than total level of a metal in soil (Norvell, 1971; More, 1997). Results showed there was an increase in the concentration of all the six heavy metals in rice plant with increase in the concentration of DTPA extractable metals. The concentration of Zn, Cu, Pb and Cd were highest in root followed by straw and grain.

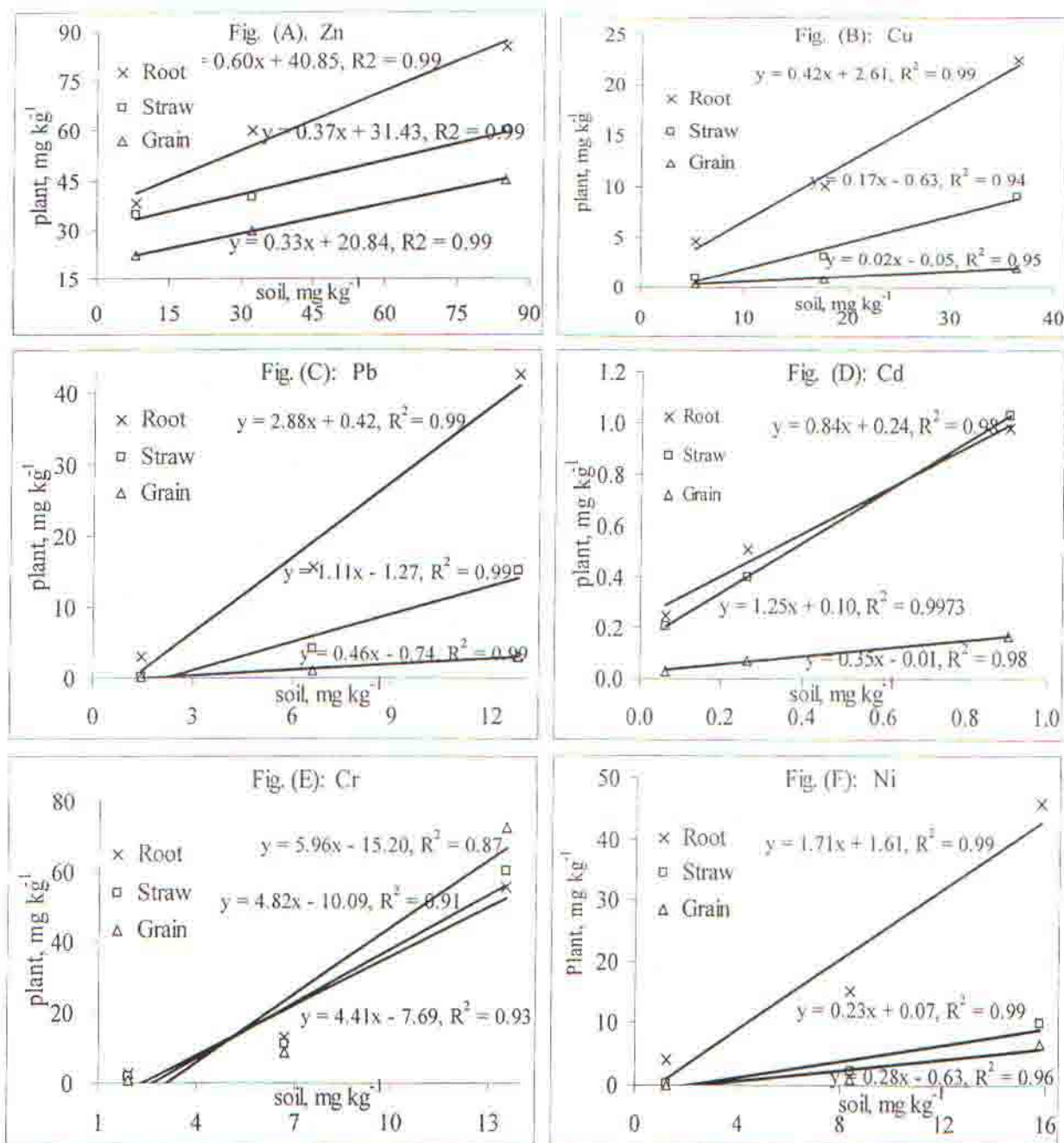
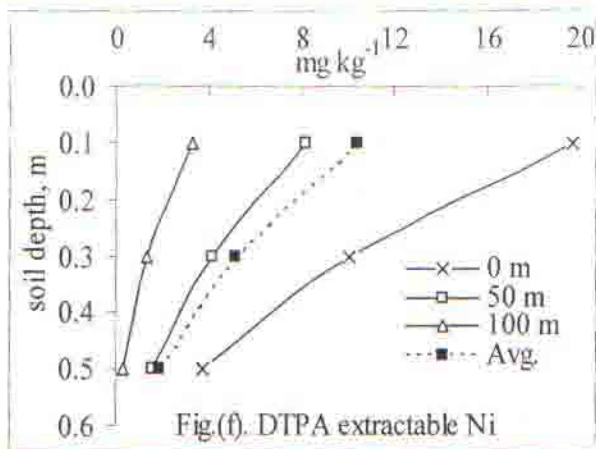
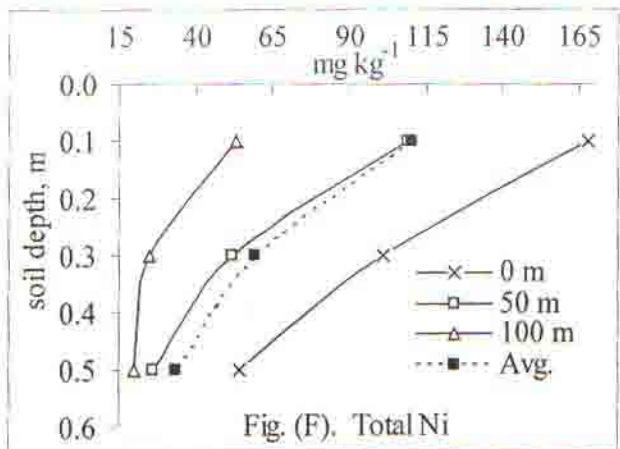
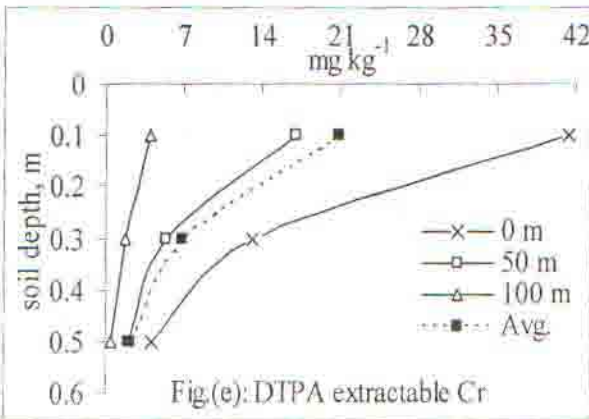
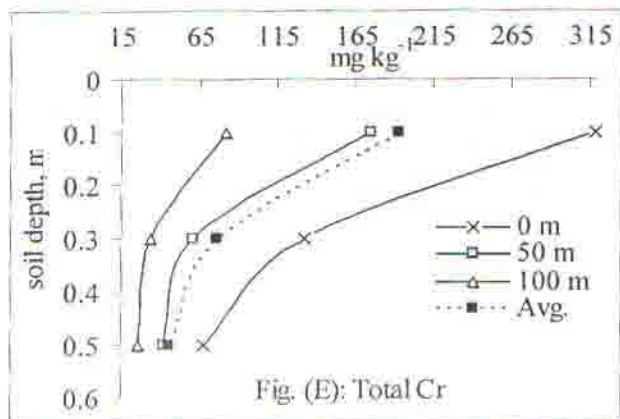
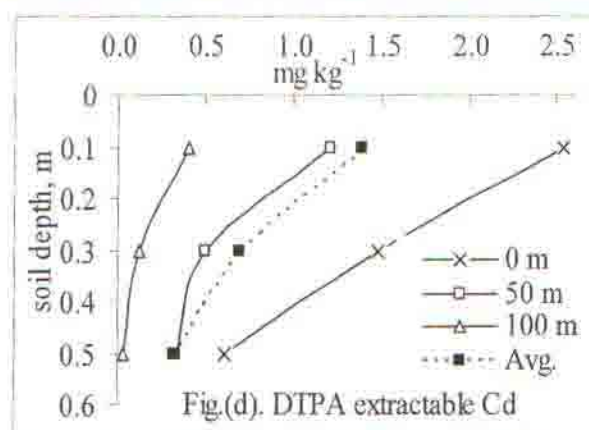
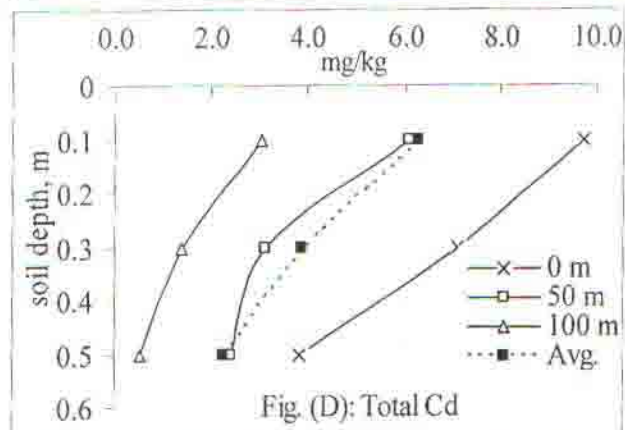
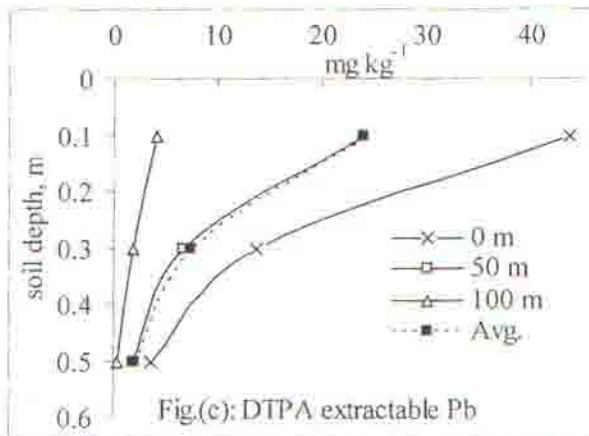
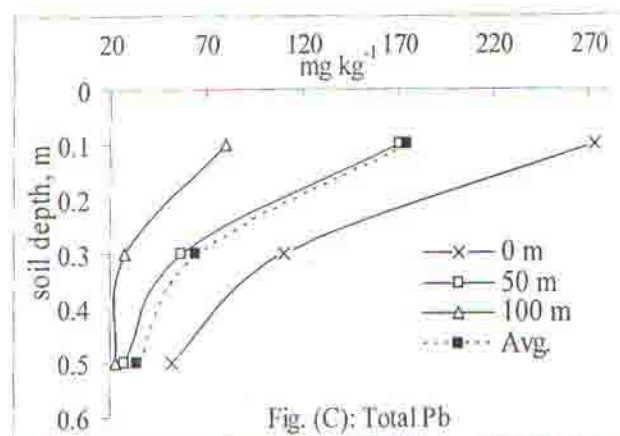
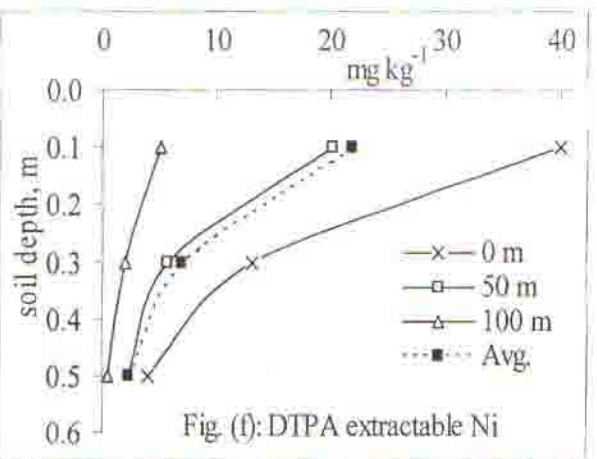
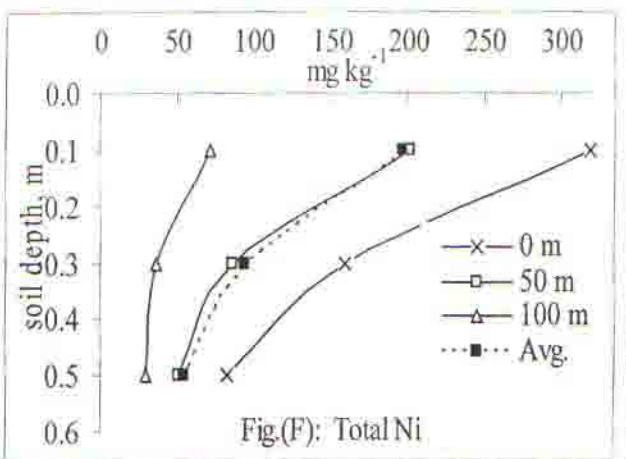
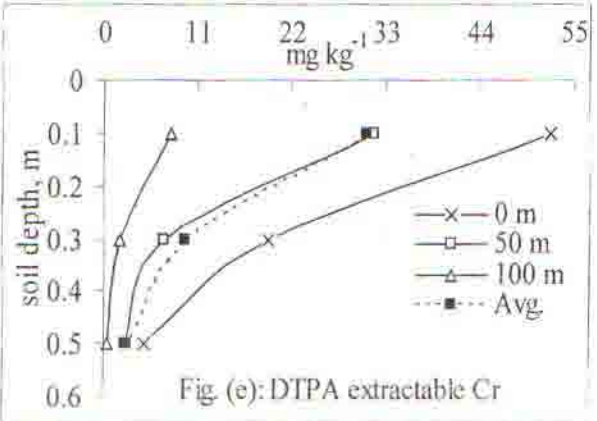
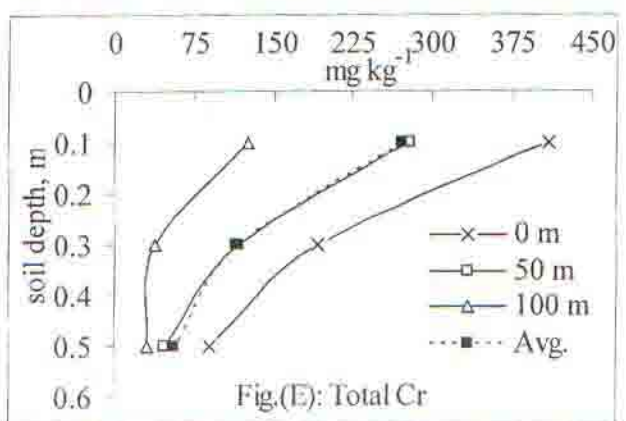
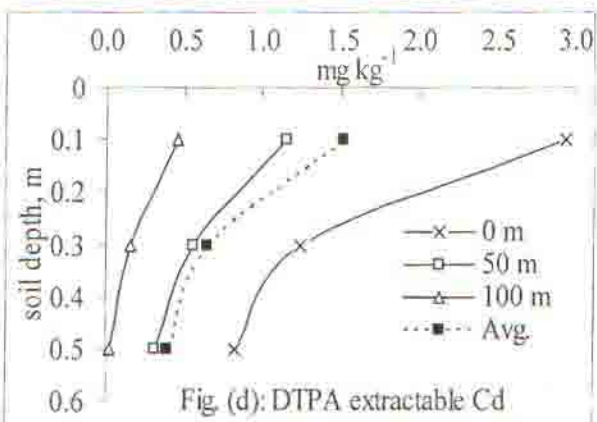
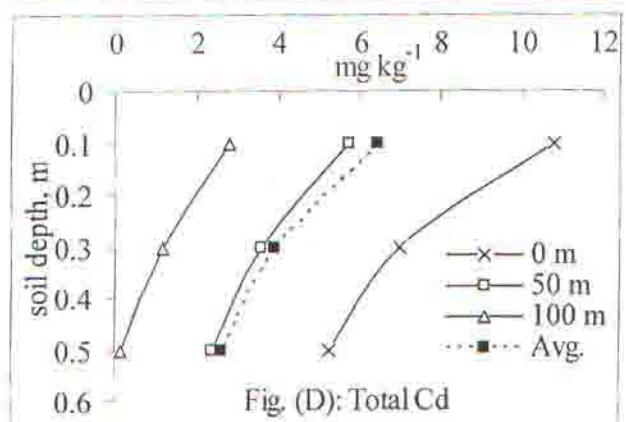
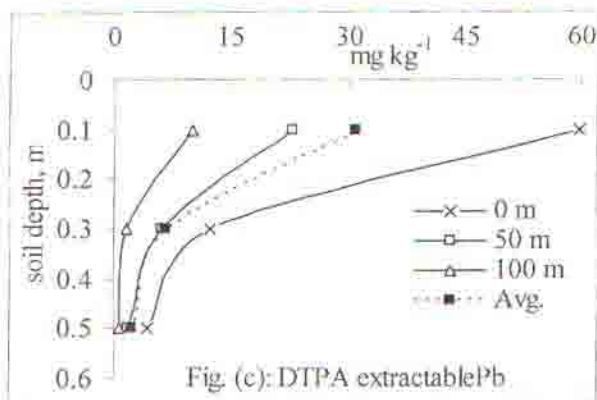
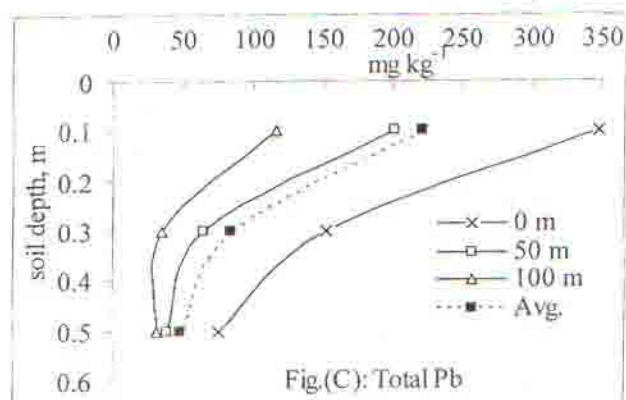


Fig. 4.1.3 Relationships of DTPA extractable heavy metals and plant concentration





from shoots and reproductive tissue by retaining metals in the root either in cell wall or cell vacuoles or else where (Baker, 1981). Lombi *et al.* (2001) also reported higher concentration of heavy metals in root that shoot of maize plant grown in contaminated soils. Pečiulytė (2006) also demonstrate an enhanced potential of maize and vetch plants in accumulation of Zn, Cu and Pb.

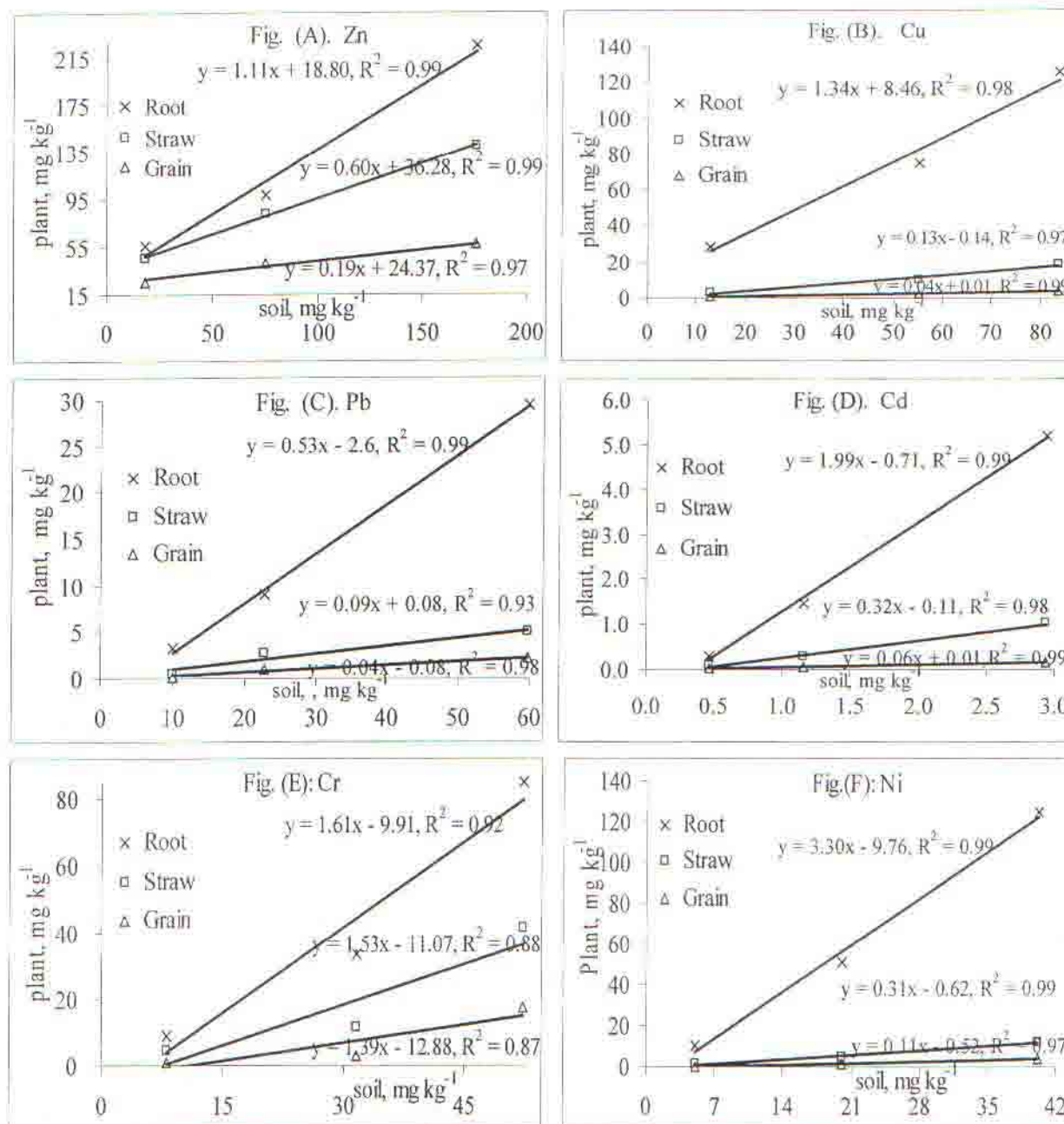
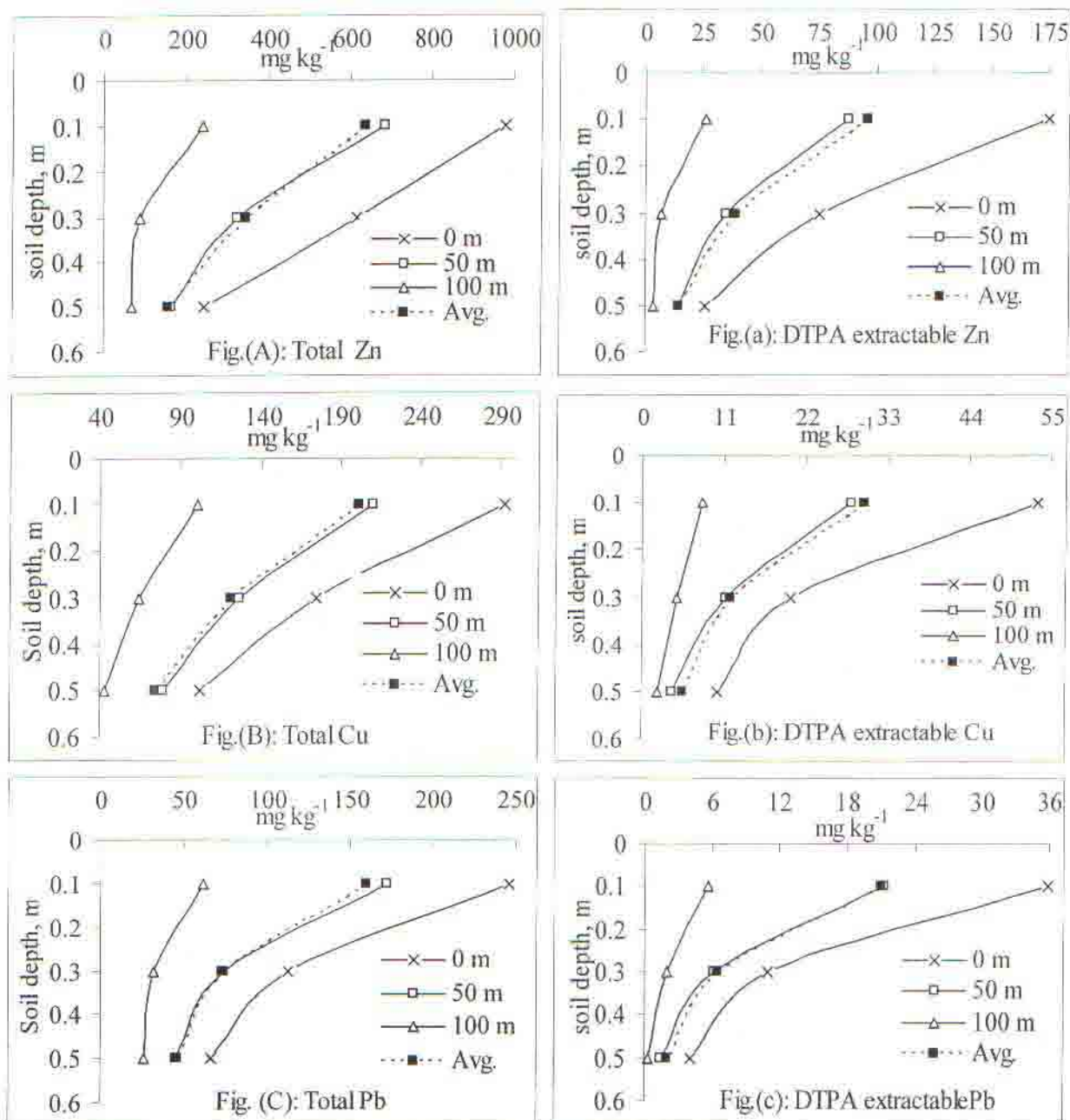


Fig. 4.1.8 Relationship of DTPA extractable heavy metals and their concentration in plants

Vertical and horizontal distribution of total and DTPA extractable heavy metals in the surrounding area of Nezo-strips, basically an electro plating industry produces different machinery parts are presented in the Figs 4.1.9. Results showed that the degree of Zn, Cu, Pb,

Cd, Cr and Ni contamination was decreased with increase in distance from the distance from the industry and with increase of depth. The degree of contamination, in terms of average concentration (mg kg^{-1}) of total metal up to the 0.6 m soil depth of 100 m surrounding area of the plant was in the order of : Zn (378.57) > Cr (153.11) > Cu (132.24) > Pb (92.81) $\approx$ Ni (90.55) > Cd (2.25). The concentration of total Zn, Cu, Pb, Cd, Cr and Ni in vicinity of the plant from surface (0.0 – 0.2 m) to sub – surface (0.4 – 0.6 m) soil, ranged from 243.98-981.34, 101.77-291.94, 66.65-246.43, 1.68-5.40, 138.49-377.33 and 77.40-275.45 mg/ kg (Fig. 4.1.9(A) to Fig. 4.1.9(F)) with mean values of 613.48, 189.36, 141.77, 3.31, 248.72 and 154.99 mg kg^{-1} soil, respectively.



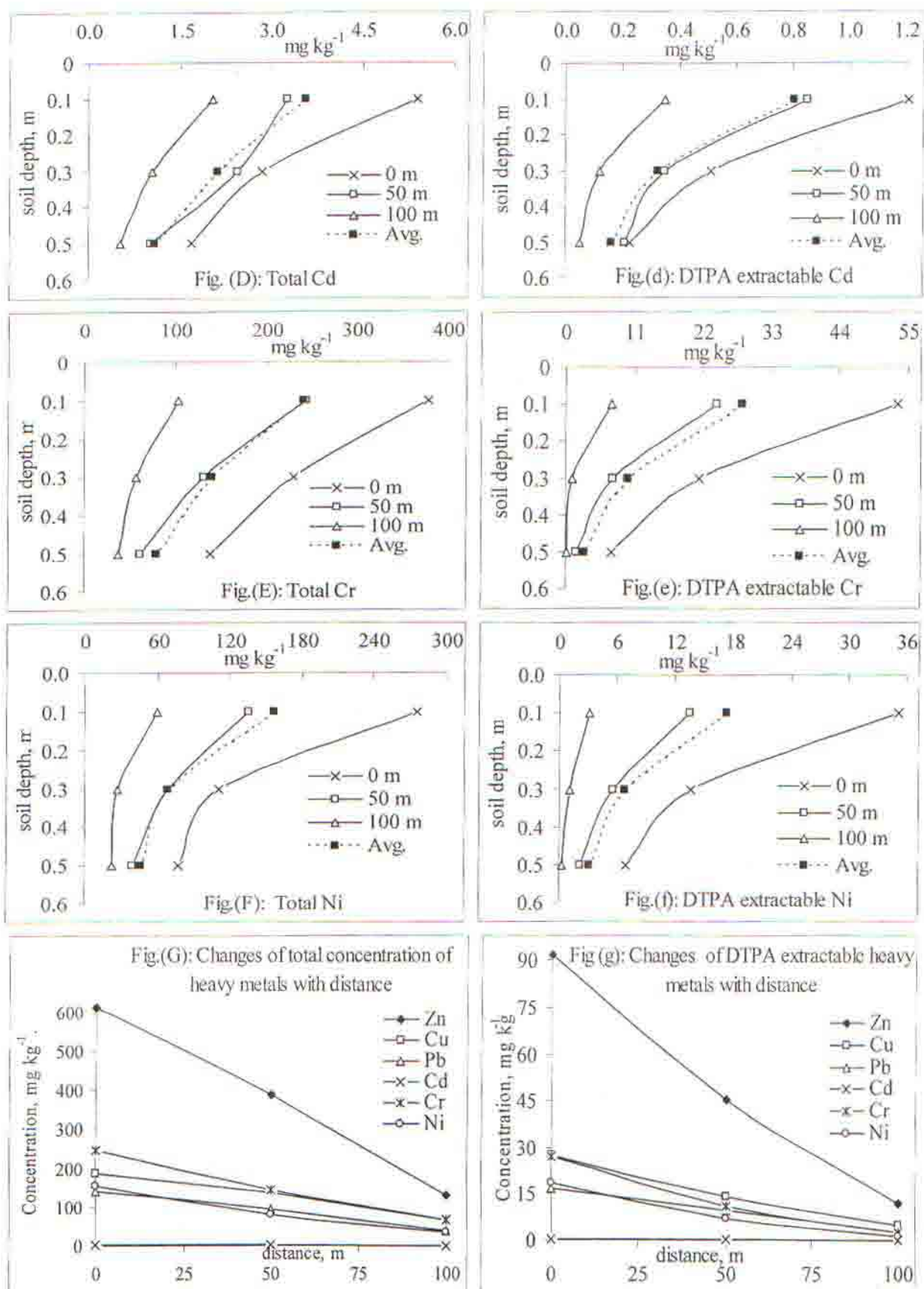
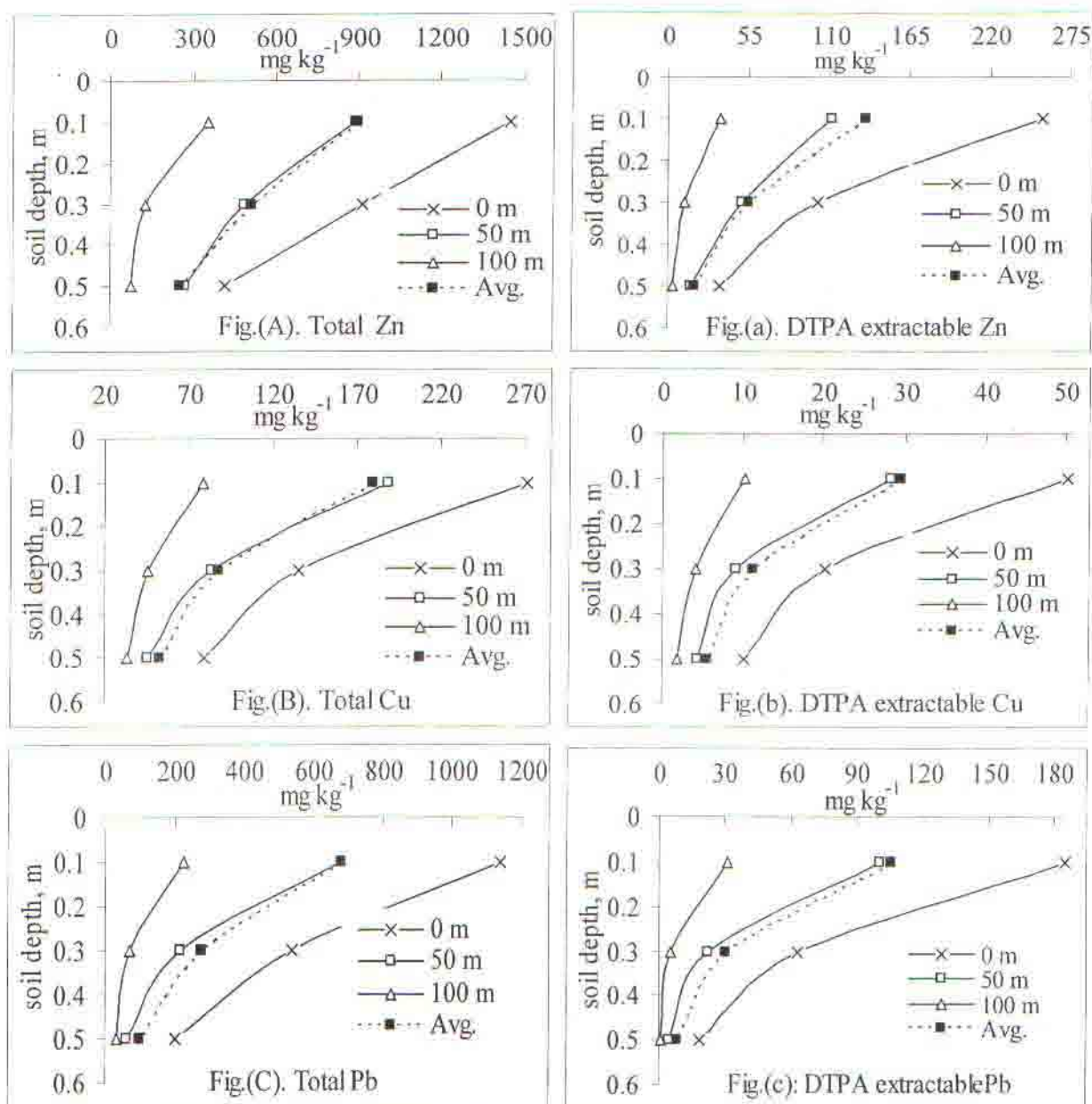


Fig. 4.1.9 Spatial and vertical distribution of total and DTPA extractable heavy metals surrounding Nezo strips

contamination i.e. 50 m away from the plant. Results showed that degree of contamination. In that case the sequence was as follows Pb (68.2%) > Ni (64.2%) $\approx$ Cr (63.8%) $\approx$ Zn (63.4%) > Cu (58.2%) > Cd (53.2%), Fig. 4.1.10 (B).

Vertical and horizontal distribution of total and DTPA extractable heavy metals in the surrounding area of Star Battery, produces different batteries are presented in the Figures 4.1.11.(A) to 4.1.11.(g). Results showed that the degree of Zn, Cu, Pb, Cd, Cr and Ni contamination was decreased along the distance from the industry and with depth of soil profile in terms of average concentration (mg kg^{-1}) of total metal up to the 0.6 m soil depth of 100 m surrounding area of the plant was in the order of: Zn (552.36) > Pb (352.00) > Cu (106.50) > Ni (79.29) > Cr (63.09) > Cd (1.64).



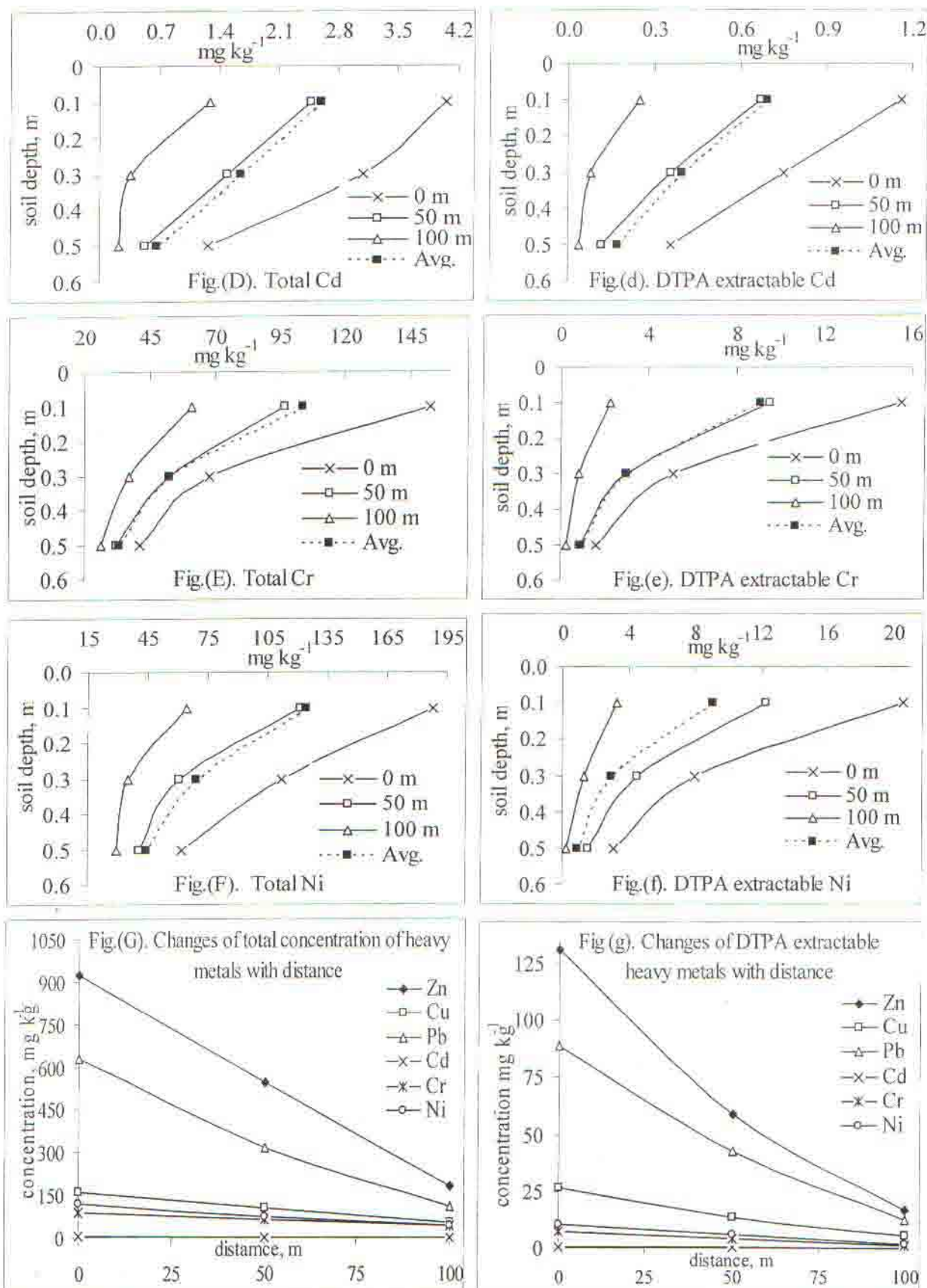
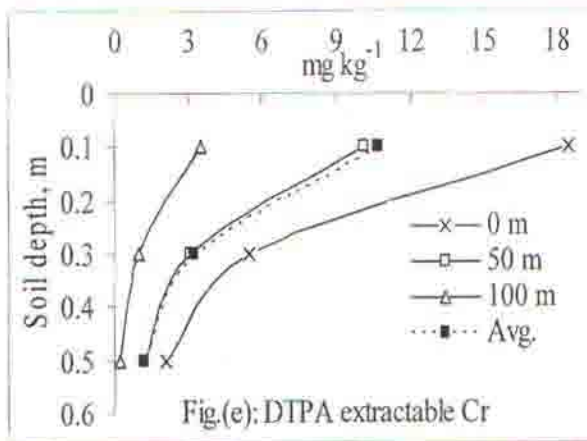
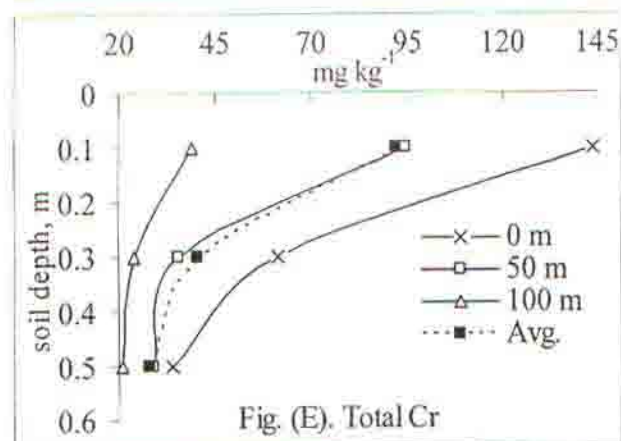
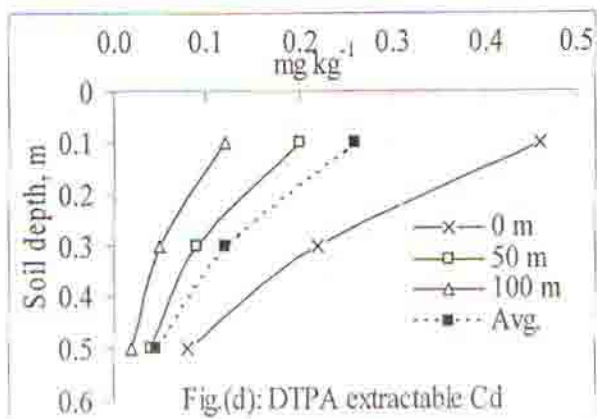
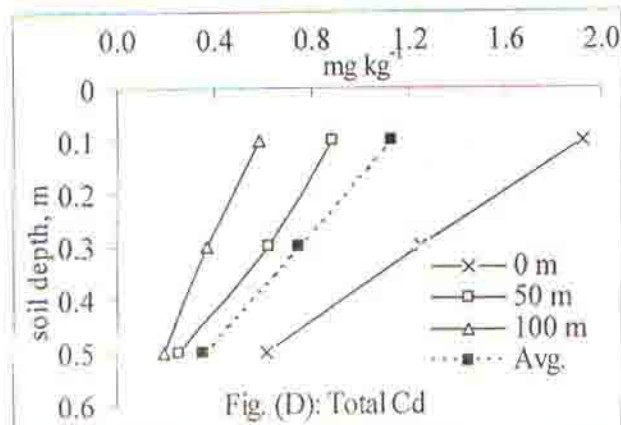
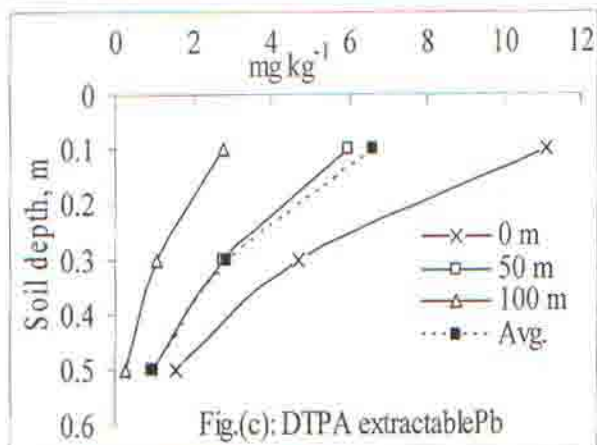
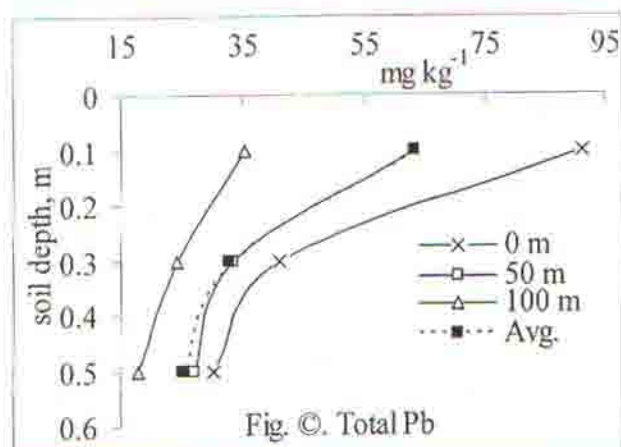
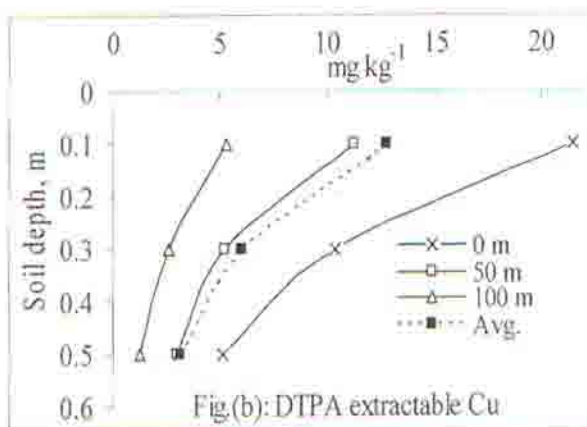
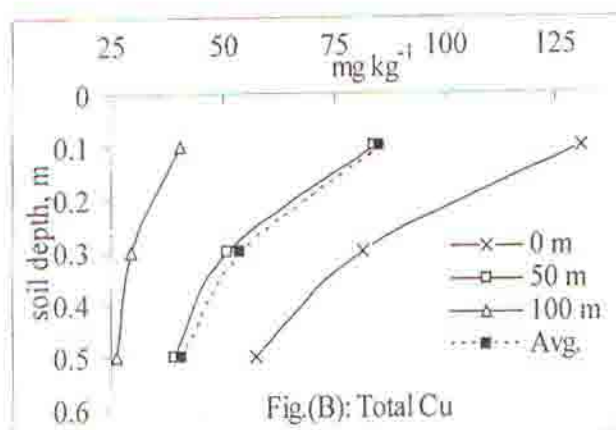


Fig. 4.1.11 Spatial and vertical distribution of total and DTPA extractable heavy metals surrounding star battery



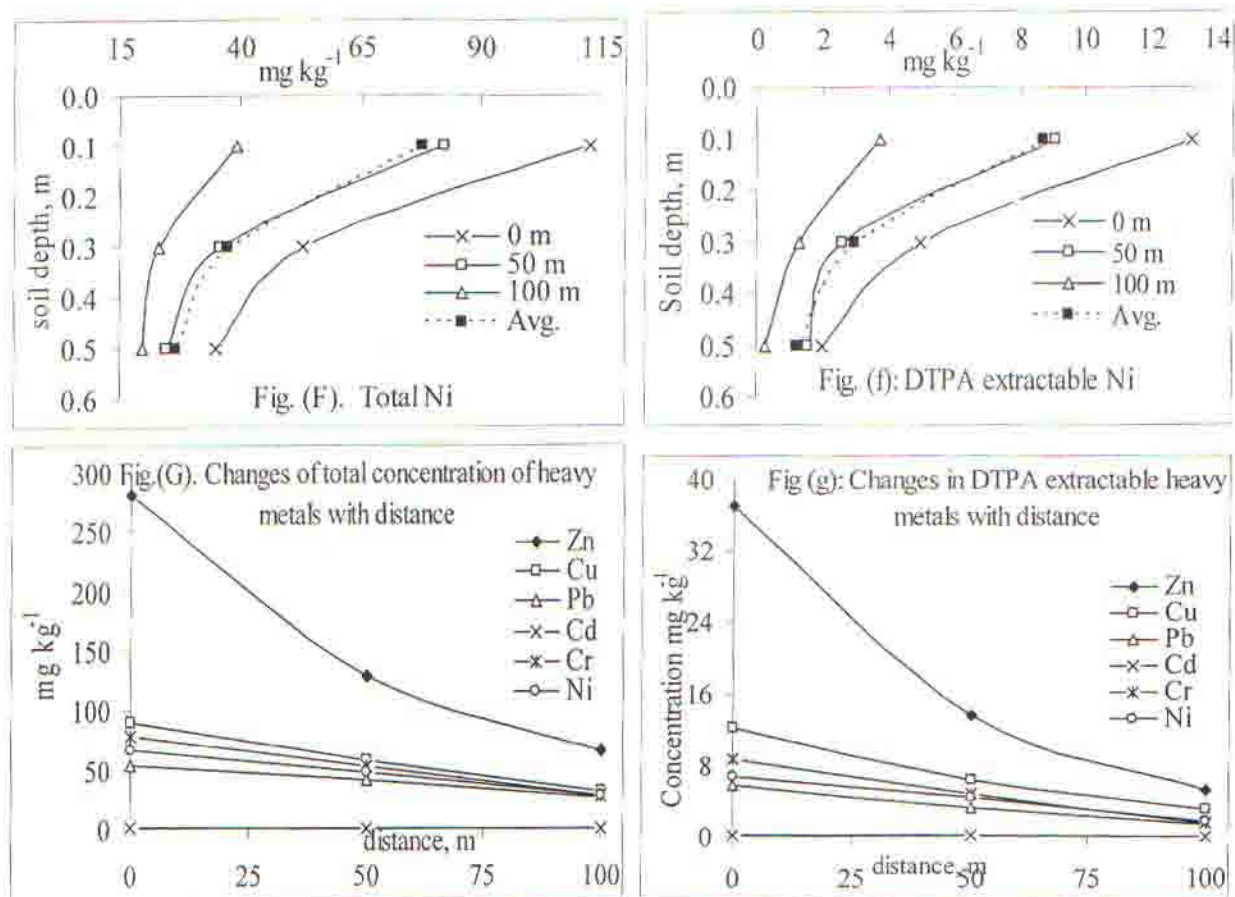


Fig. 4.1.13 Spatial and vertical distribution of total and DTPA extractable heavy metals surrounding the Mother Dairy

The concentration of total Zn, Cu, Pb, Cd, Cr and Ni in the vicinity of the plant from surface (0.0 – 0.2 m) to sub – surface (0.4 – 0.6 m) soil ranged from 145.59-414.49, 57.43-130.91, 30.26-91.26, 0.61-1.93, 34.12-143.91 and 34.88-112.66 mg kg^{-1} [Fig. 4.1.13 (A) to Fig. 4.1.13 (F)] with a corresponding mean values of 281.40, 89.90, 54.21, 1.26, 79.75 and 66.89 mg kg^{-1} soil respectively. The concentrations of heavy metals was decreased with increase distance from the vicinity of source industry in the order as follows: Zn (54.0%) $\approx$ Cd (53.8) > Cu (35.6) > Cr (33.6%) > Ni (28.9%) > Pb (23.9%) at 50 m and at 100 m it was Zn (76.6%) > Cd (69.8) > Cr (64.9) $\approx$ Cu (64.4%) > Ni (59.2) > Pb (52.4%) [Fig. 4.1.13(G)]. Similar trend was also observed in case of DTPA extractable metals. The depth-wise concentration of DTPA extractable Zn, Cu, Pb, Cd, Cr and Ni in soils at the adjacent area of the plant ranges from 12.11-69.12, 5.12-21.56, 1.58-11.12, 0.08-0.46, 2.10-18.49 and 2.01-13.27 mg kg^{-1} soil [Fig. 4.1.13 (a) to Fig. 4.1.13 (f)] with a corresponding mean values of 37.12, 12.34, 5.80, 0.25, 8.70 and 6.75 mg kg^{-1} soil respectively with increase in distance from the source of pollution, there was a decrease in the mean concentration of these metals in the order as follows: Zn (63.4%) > Cd (56.6%) > Cu (47.4%) > Cr (44.7%) > Pb (43.9%) > Ni (34.6%) at 50 m and at 100 m it

4.1.2 Relationship of total and DTPA extractable heavy metals:

The relationship of DTPA extractable heavy metals with their total concentration are presented in Fig. 4.1.15 (a) to Fig.4.1.15 (F). Results showed that for each metal, there was an increase in the bio-available or DTPA extractable metal with increase of their total concentration.

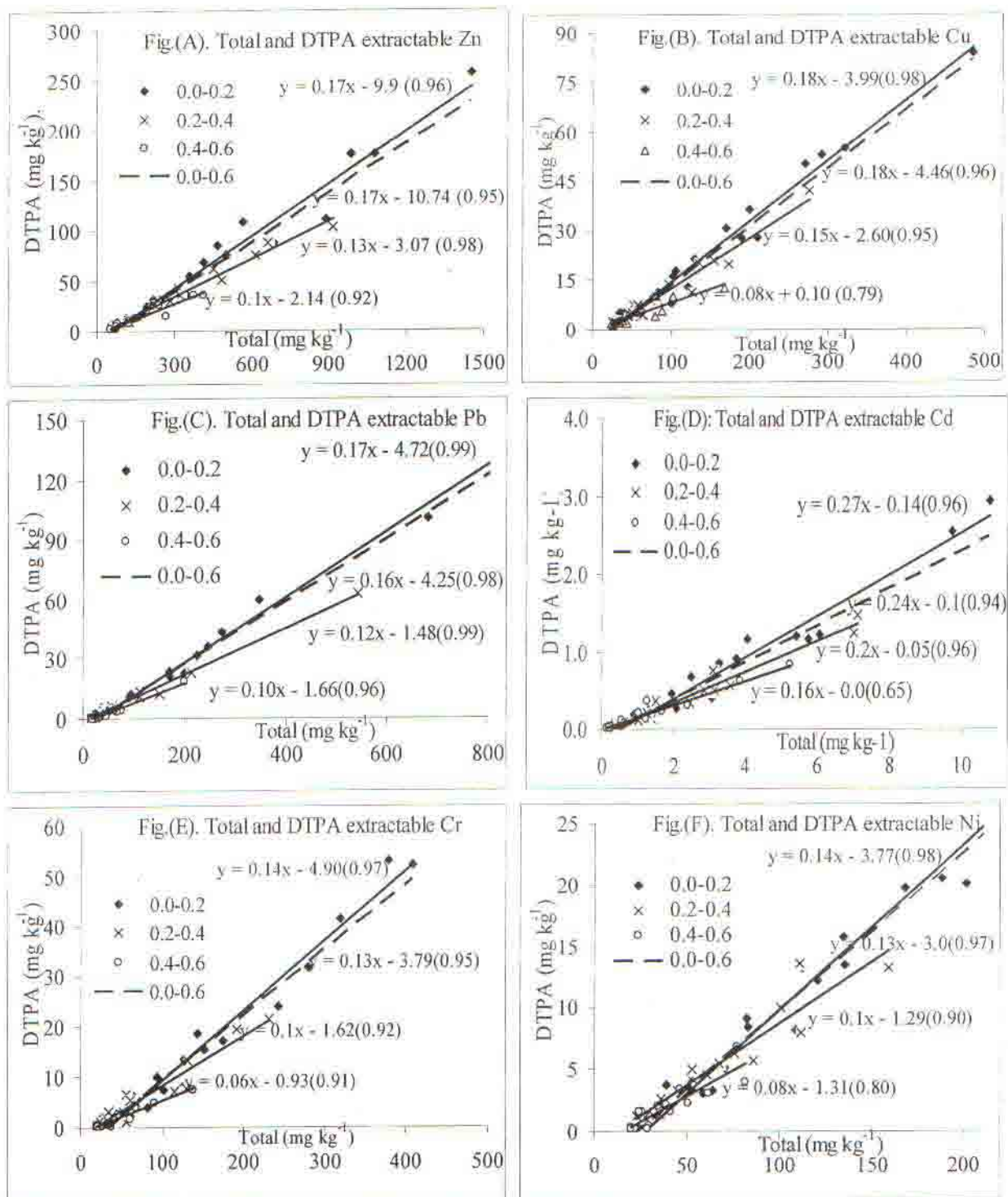


Fig. 4.1.15 Relationship of Total and DTPA extractable heavy metals at different soil depth

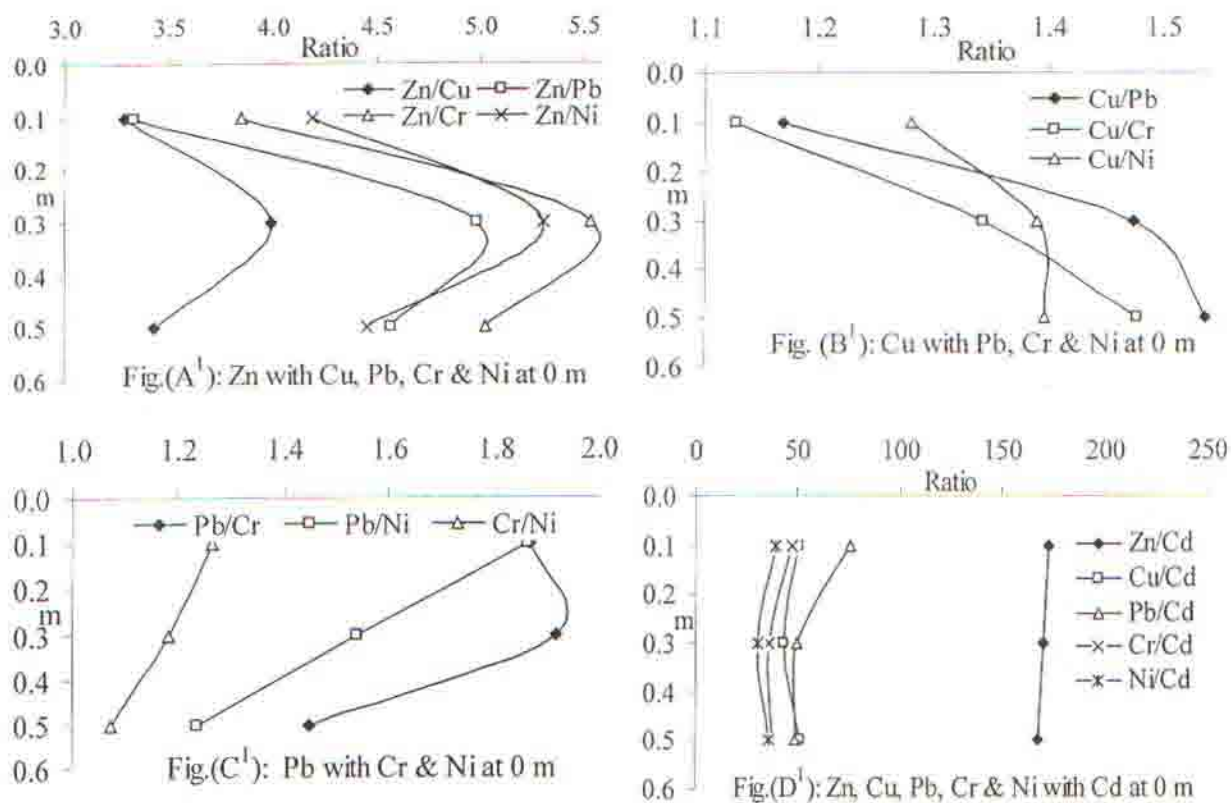


Fig. 4.1.16 Relative distribution of different heavy metals at 0 m distance from the source

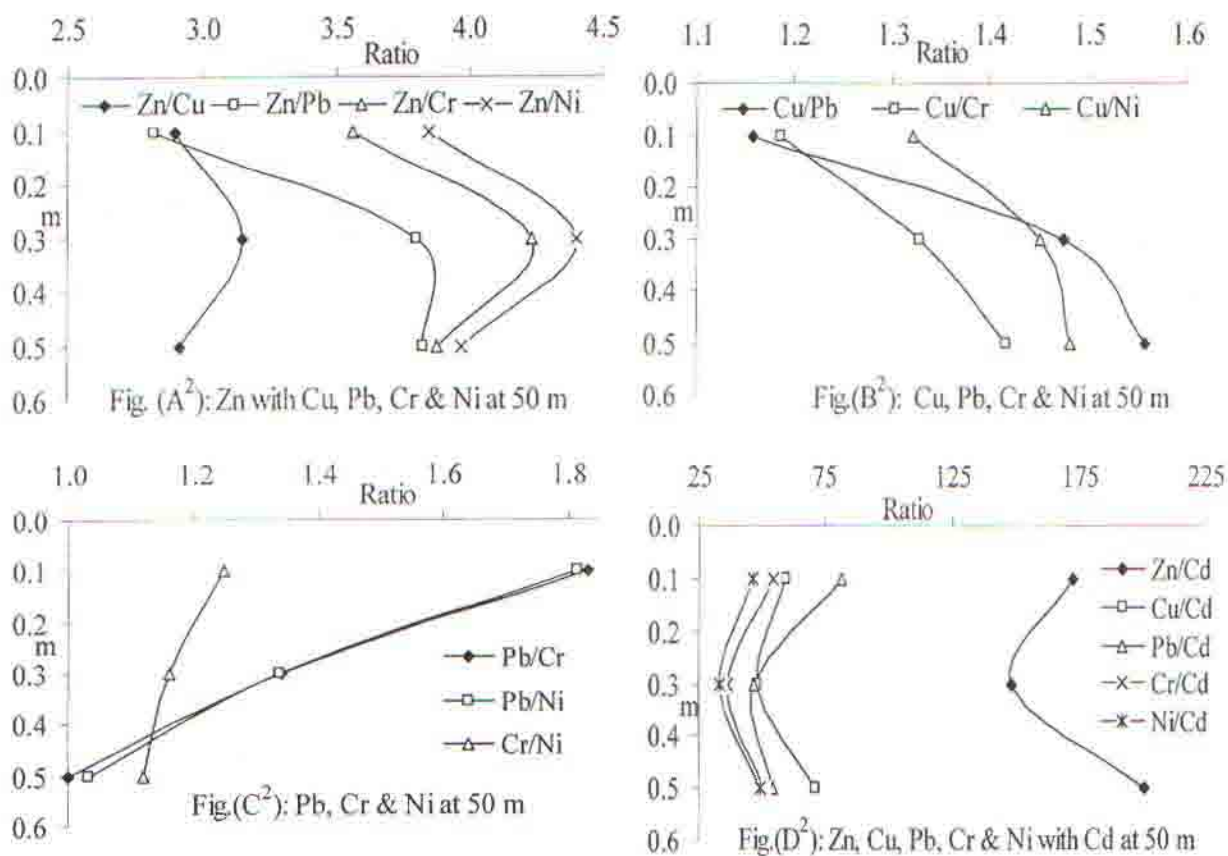


Fig. 4.1.17 Relative distribution of different heavy metals at 50 m distance from the source

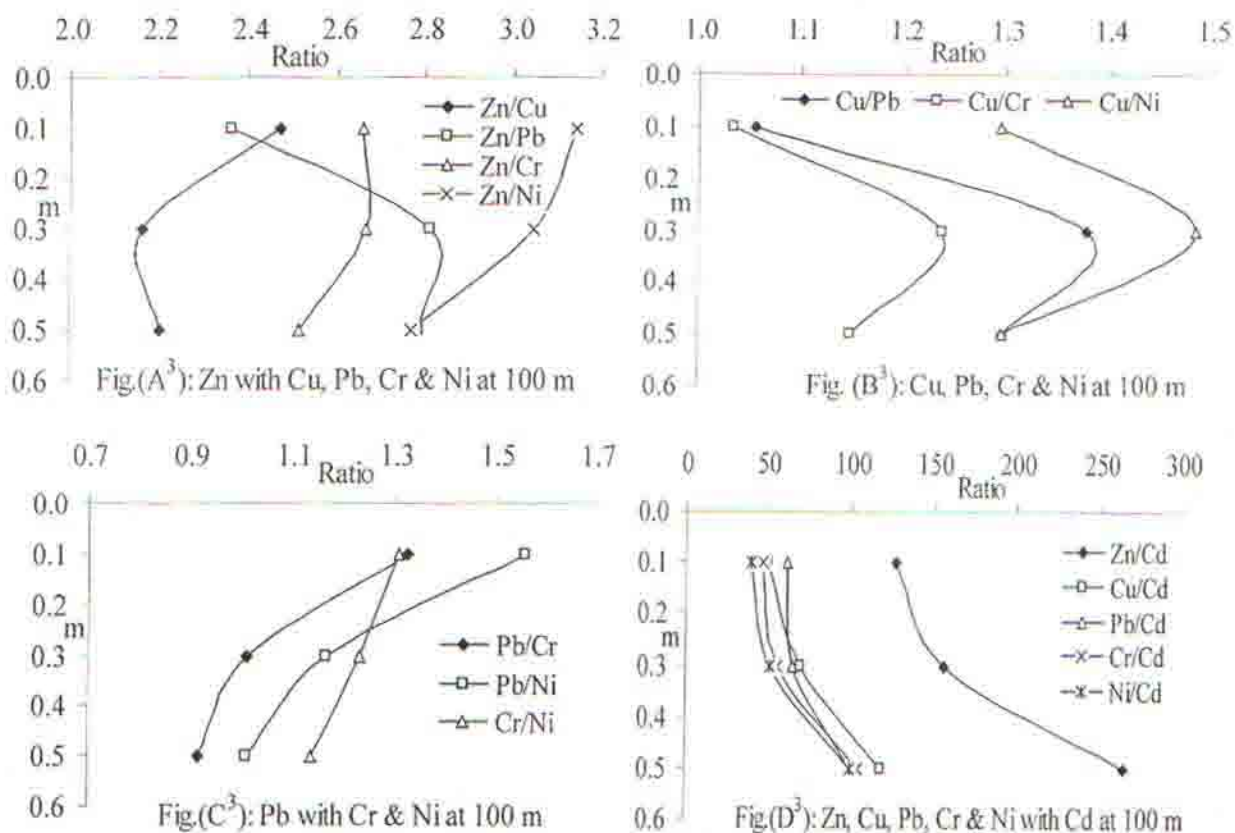


Fig. 4.1.18 Relative distribution of different heavy metals at 100 m distance from the

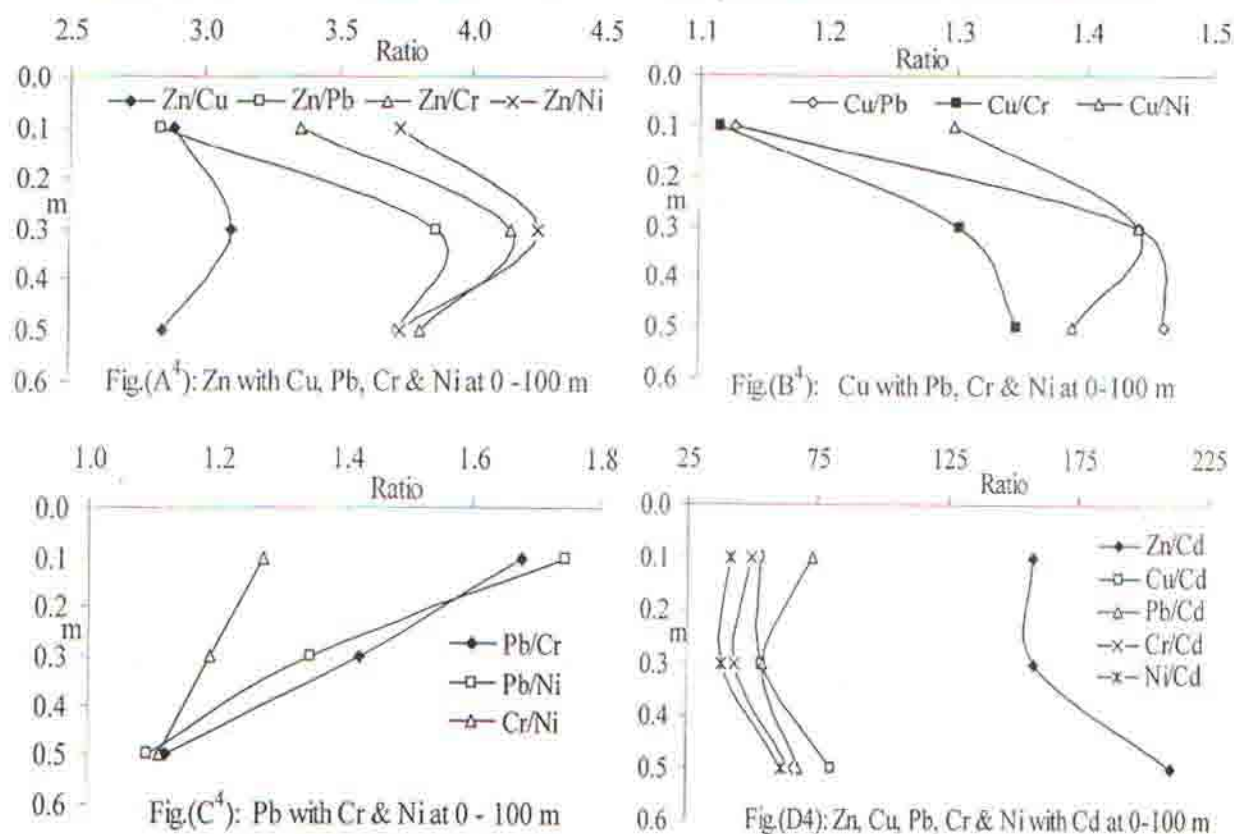
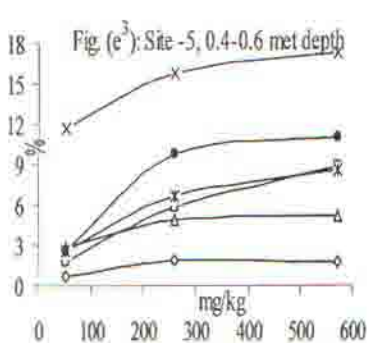
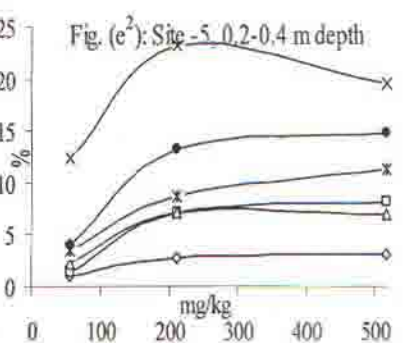
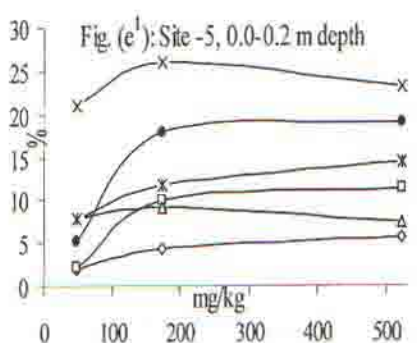
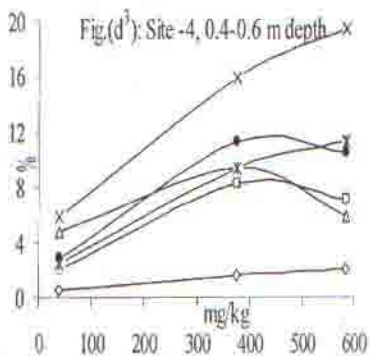
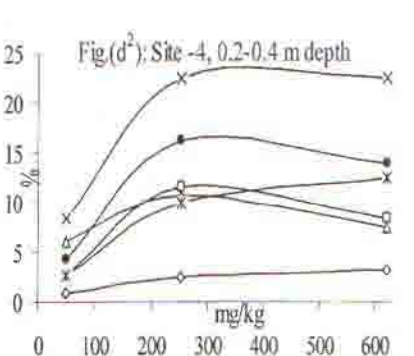
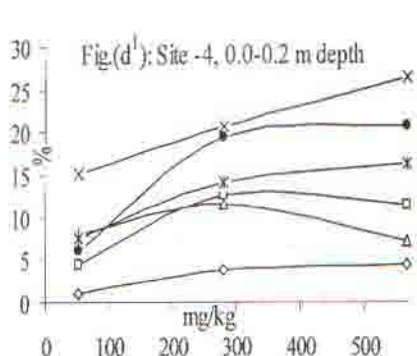
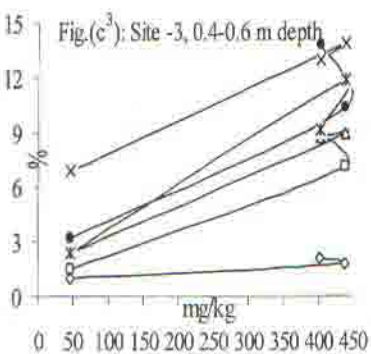
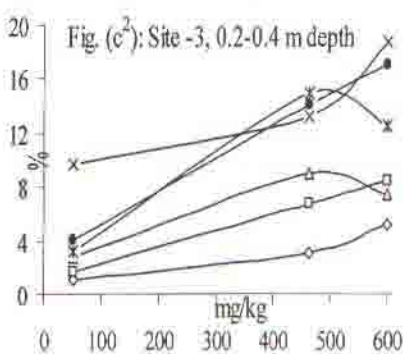
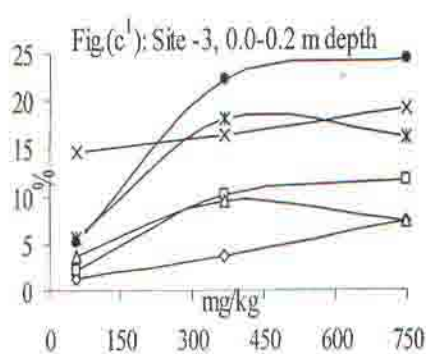
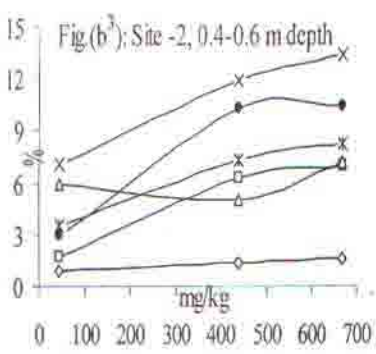
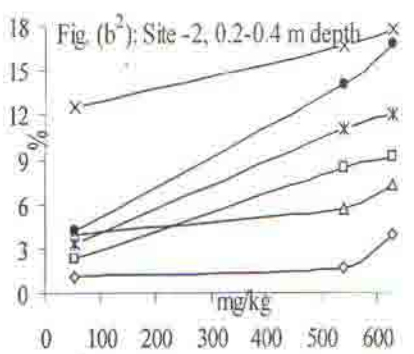
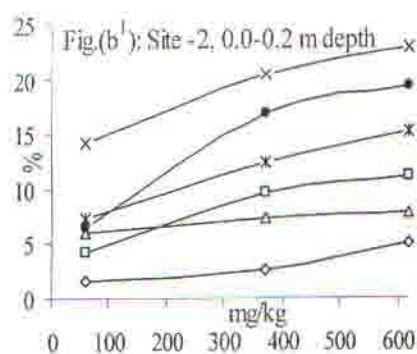
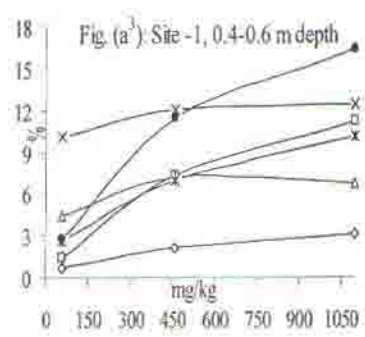
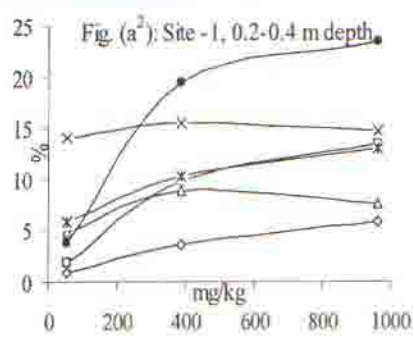
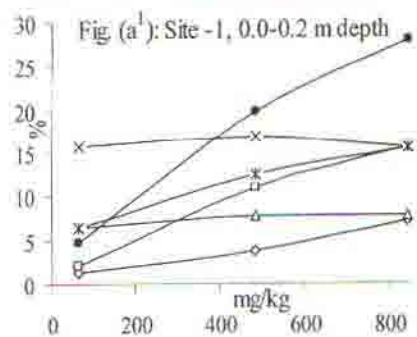
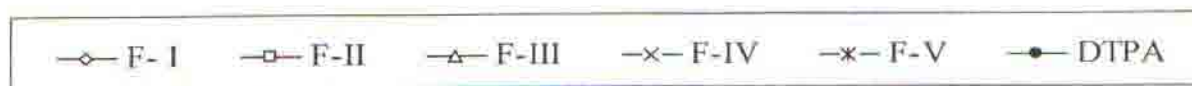


Fig. 4.1.19 Relative distribution of heavy metals at 0-100 m distances from the source



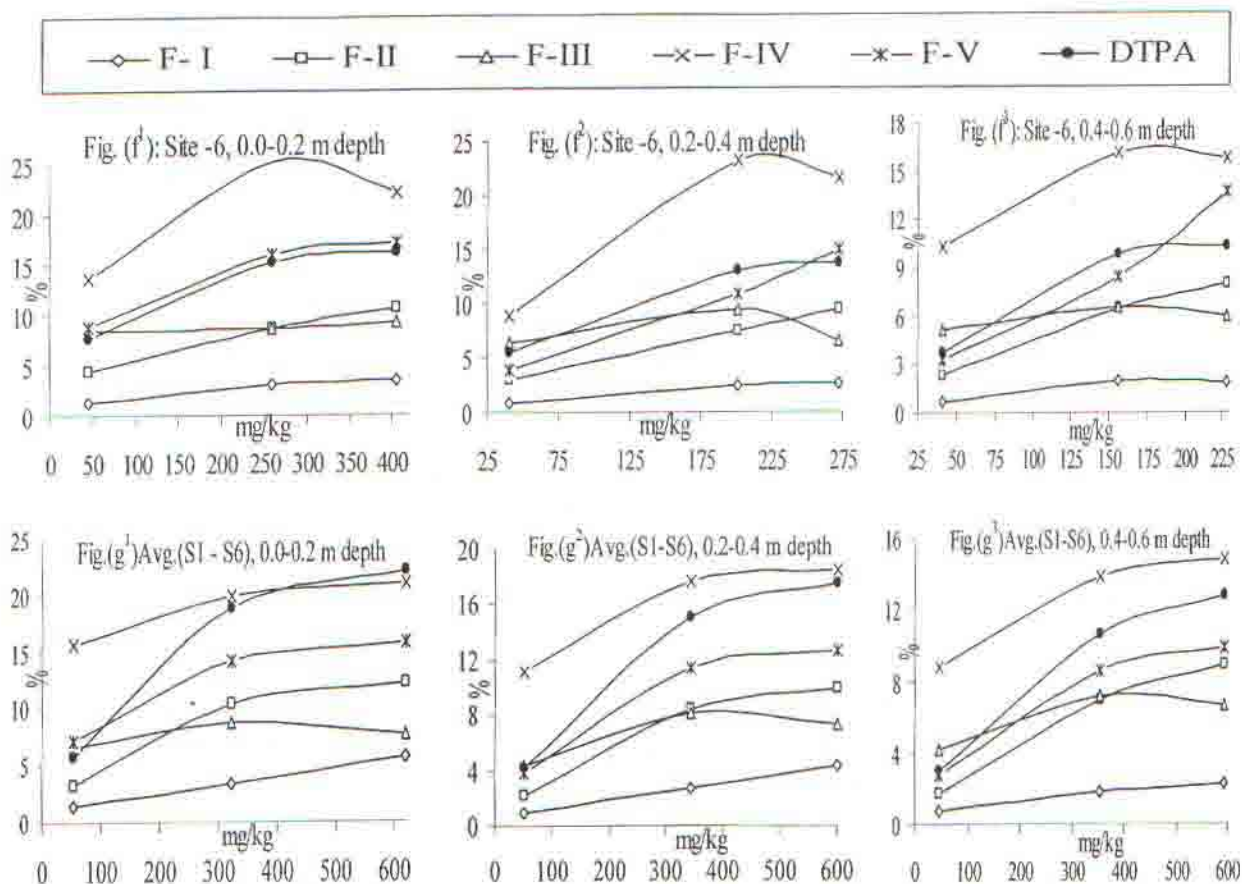
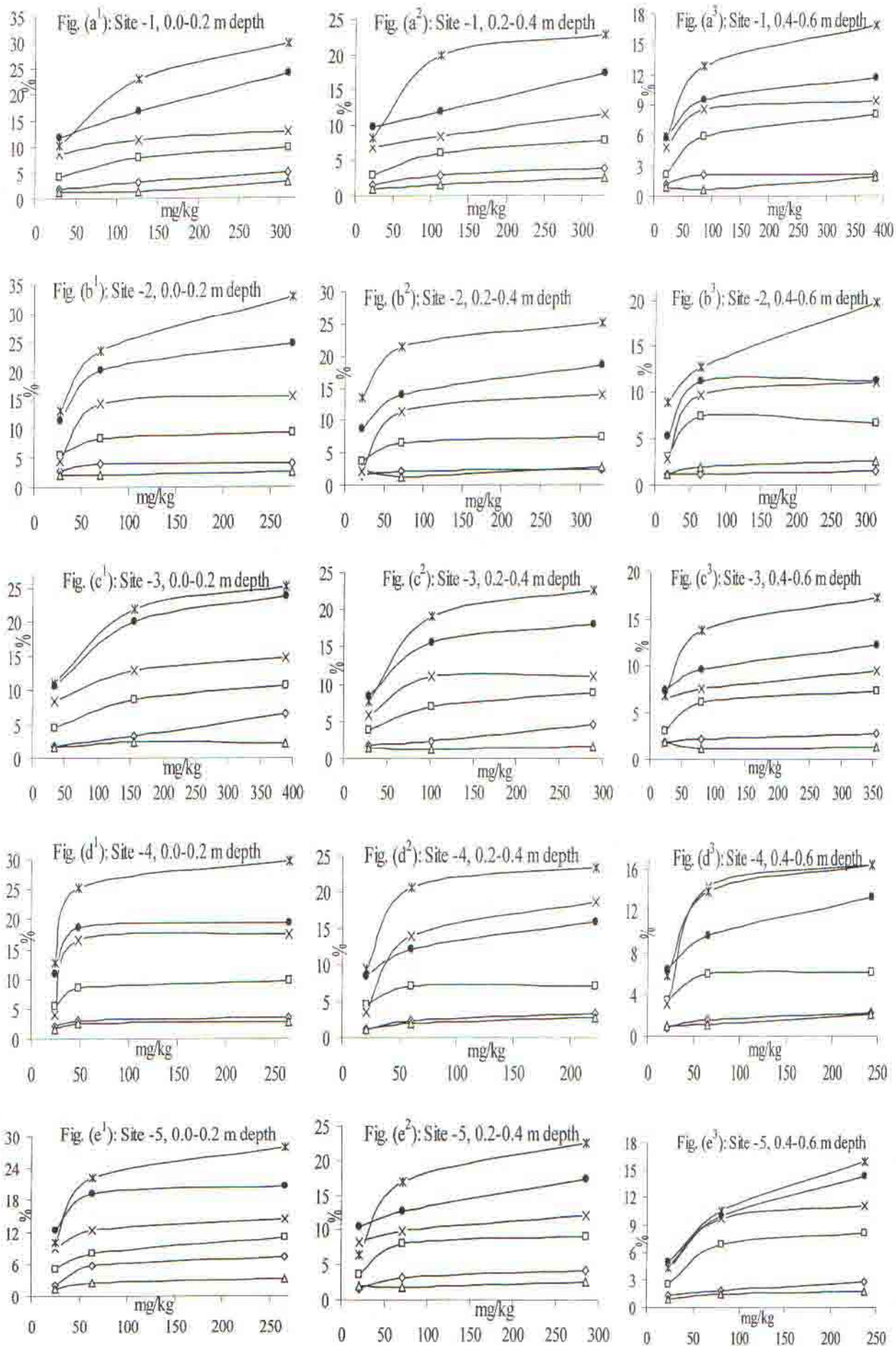


Fig. 4.2.1 Changes in contributions of different forms of zinc to total Zn as influenced by level of loading (Where F - I, exchangeable; F-II , carbonate; F - III, manganese oxides bound; F - IV, sesquioxides bound; F - V, organic)

However, there were 2-3 times higher Zn in exchangeable (F-I), carbonate (F-II) and organic forms (F-III) in moderately and heavily contaminated soils than non-contaminated ones. In fact on an average, less than 6% of total Zn in the non-contaminated soil occurred in F-I and F - II forms; these values in moderate and heavily contaminated soil were 11 to 23%. The F-I and F-II fractions may be readily available for plant uptake or leaching (McLaren and Crawford, 1973). Monday *et al.* (2001) observed that less than 7% of total Zn in control soil was in exchangeable and carbonate bound forms whereas it was 26 -36 % in sludge amended soil. A constant increase in percent contribution of exchangeable, carbonate, organic and DTPA extractable fractions of zinc with increasing levels of contamination indicated that as contamination loading increased there would be more bioavailable forms of Zn that might prove to be toxic.

4.2.2 Forms of Cu

On average, the total Cu content of the soil profile was highest for highly contaminated sites followed by medium and low contaminated ones. Its content, in general, was also higher in the surface followed by the mid-and sub-surface layers (Table 4.2.7). This was true for all the three level of loading. Without any exception, the DTPA extractable



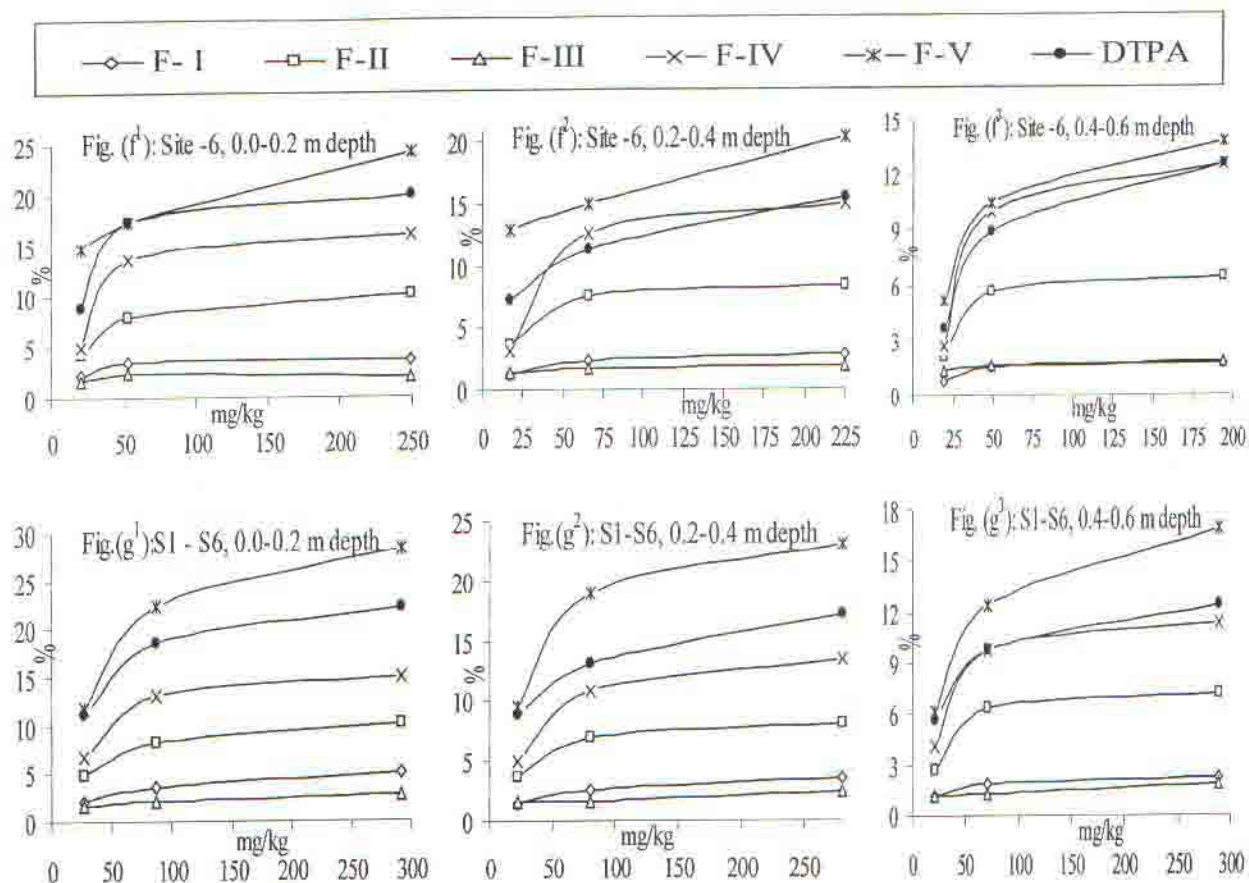
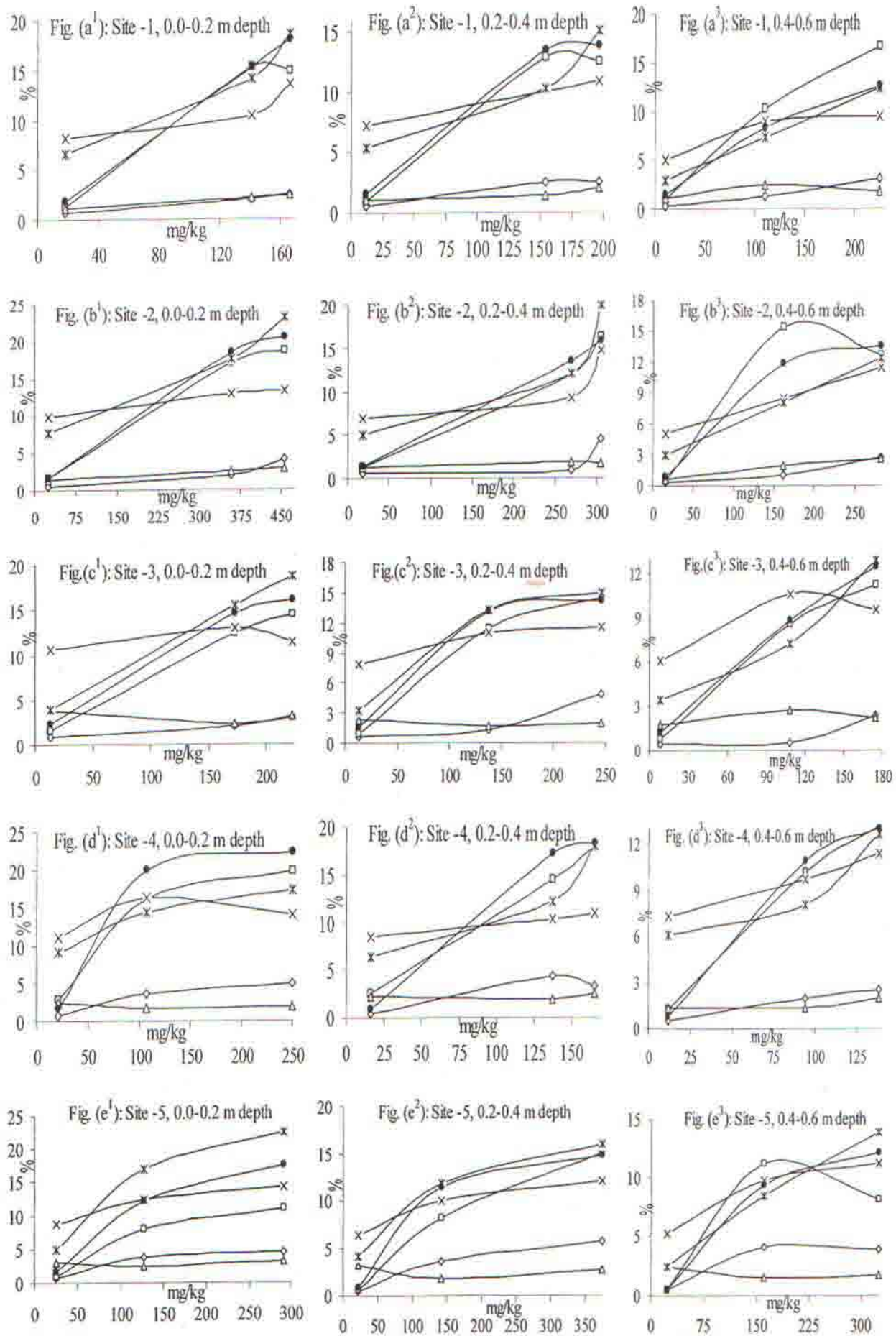
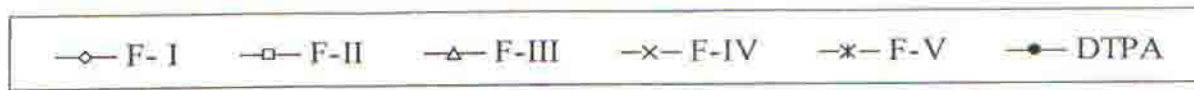


Fig. 4.2.2 Changes in contributions of different forms of copper to total Cu as influenced by level of loading (Where F - I, exchangeable; F-II, carbonate; F - III, manganese oxides bound; F - IV, sesquioxides bound; F - V, organic)

The contributions (%) of different forms of Cu to total Cu varied with the levels of heavy metals loading and depth of soil profile (Fig. 4.2.2). Irrespective of locations, in soils with no external loading the contribution of F-I, F-II, F-III, F-IV, F-V, F-VI and DTPA extractable forms to total Cu ranged from 1.9-2.9, 1.2-5.5, 1.4-2.1, 4.0-8.8, 10.0-14.9, 71.8-74.2, 9.0-12.4% ; 1.1-1.9, 2.9-4.6, 1.0-2.3, 2.1-8.3, 6.4-13.6, 76.5-80.0, 7.2-10.5% and 0.8-1.9, 2.2-3.4, 0.9-2.0, 2.7-6.5, 4.4-9.0, 79.7-87.8 and 3.7-7.4% in surface, mid-surface and sub-surface layers, respectively. These values for contaminated soils (mean for medium and high levels), however, varied from 3.0-7.4, 7.8-11.0, 1.2-3.2, 11.3-17.5, 17.5-32.9, 35.7-55.0, 16.6-24.6% ; 2.2-4.6, 6.1-9.0, 1.2-2.9, 8.4-18.7, 15.0-25.1, 44.9-61.2, 11.4-18.6% and 1.3-2.8, 5.7-8.1, 0.7-2.6, 8.6-16.4, 10.5-19.8, 56.6-70.6 and 8.9-14.3%, respectively. In comparison with the non contaminated profile there was less Cu in residual fraction of the sludge amended soil, whereas exchangeable (F-I), carbonate (F-II) and organic forms (F-III) were two to three times higher in moderate and heavily contaminated soils. Less than 9% of the total Cu in the non-contaminated soil was as exchangeable and carbonate form, whereas in moderate and heavily contaminated soil it was about 11 to 22%. The F-I and F-II fractions may be readily available for plant uptake or leaching (McLaren and Crawford, 1973). Monday *et al.* (2001) observed that less than 7% of total Cu in control soil was in



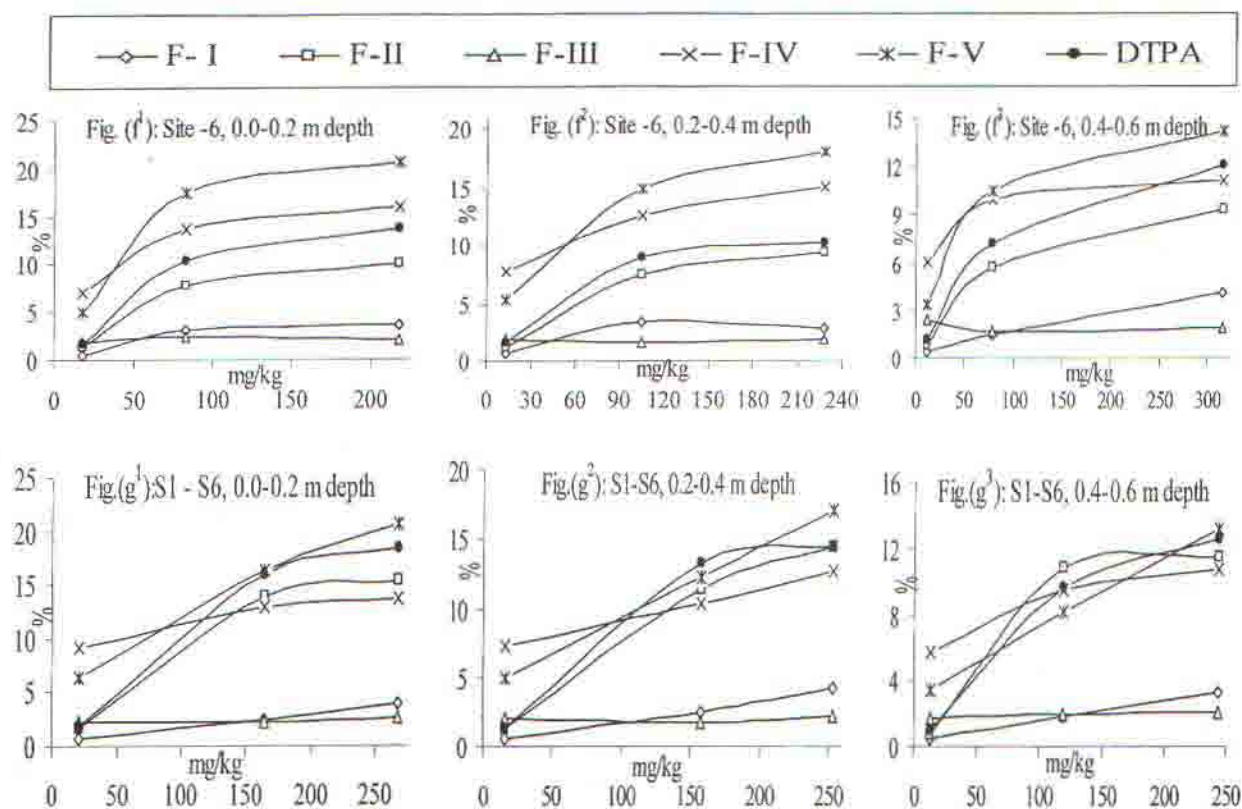
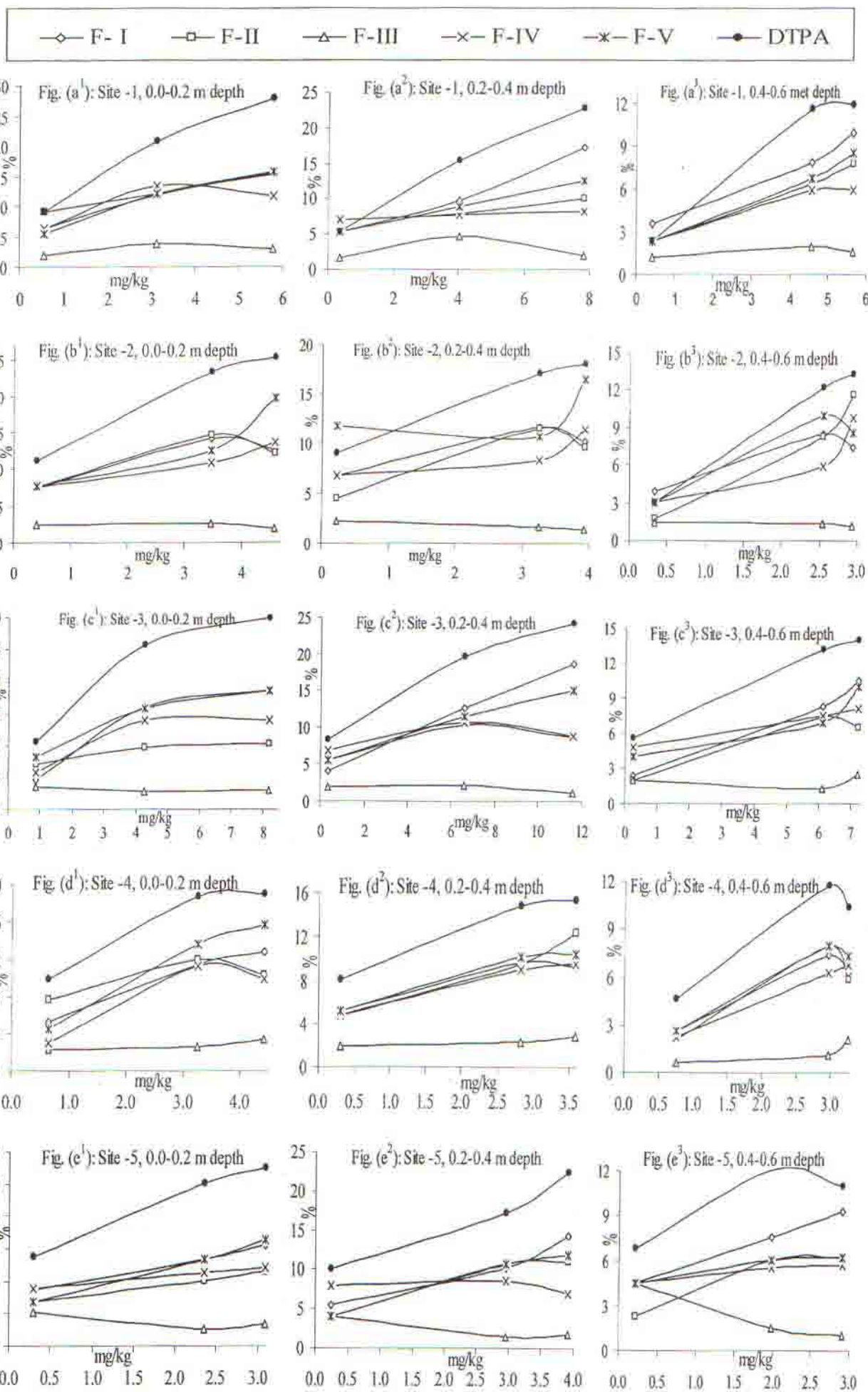


Fig. 4.2.3 Changes in contributions of different forms of Lead to total Pb as influenced by level of loading (Where F - I, exchangeable; F-II, carbonate; F - III, manganese oxide bound; F - IV, sesqui-oxide bound; F - V, organic)

The contributions (%) of different forms of Pb to total Pb varied with the levels of heavy metals loading and depth of soil profile (Fig. 4.2.3). Irrespective of locations, in soils with no external loading the contribution of F-I, F-II, F-III, F-IV, F-V, F-VI and DTPA extractable forms to total Pb ranged from 0.6-0.9, 0.9-2.9, 1.1-3.9, 7.1-11.2, 3.9-9.3, 73.4-84.0, 1.7-2.3 %; 0.5-0.7, 0.7-2.6, 1.1-3.2, 6.4-8.5, 3.2-6.4, 79.8-85.0 and 0.9-1.7%; 0.3-0.5, 0.5-1.3, 0.7-2.4, 5.1-7.3, 2.4-6.2, 83.3-90.4 and 0.6-1.4% in surface, mid-surface and sub-surface layers, respectively. These values for contaminated soils (mean for medium and high levels), however, varied from 2.0-5.1, 7.9-19.9, 1.8-3.2, 10.3-16.4, 14.1-23.1, 37.8-56.5, 10.4-22.3; 1.0-5.7, 7.6-18.0, 1.5-2.7, 9.3-15.1, 10.3-20.1, 42.5-64.5, 9.1-18.4% and 0.5-4.2, 5.7-16.6, 1.4-2.8, 8.5-11.5, 7.3-14.3, 56.8-70.6 and 7.2-13.5%, respectively. In comparison with the non contaminated profile there was less Pb in residual fraction of the sludge amended soil, whereas exchangeable (F-I), carbonate (F-II) forms were seven to eight times and organic form (F-III) was about four to five times higher in moderate and heavily contaminated soils. Less than 4% of the total Pb in the non-contaminated soil was as exchangeable and carbonate form, whereas in moderate and heavily contaminated soil it was about 5 to 25%. Kabala and Singh (2001) reported less than 10% of total Pb in exchangeable and specifically adsorbed form in non- contaminated soil. A similar result was



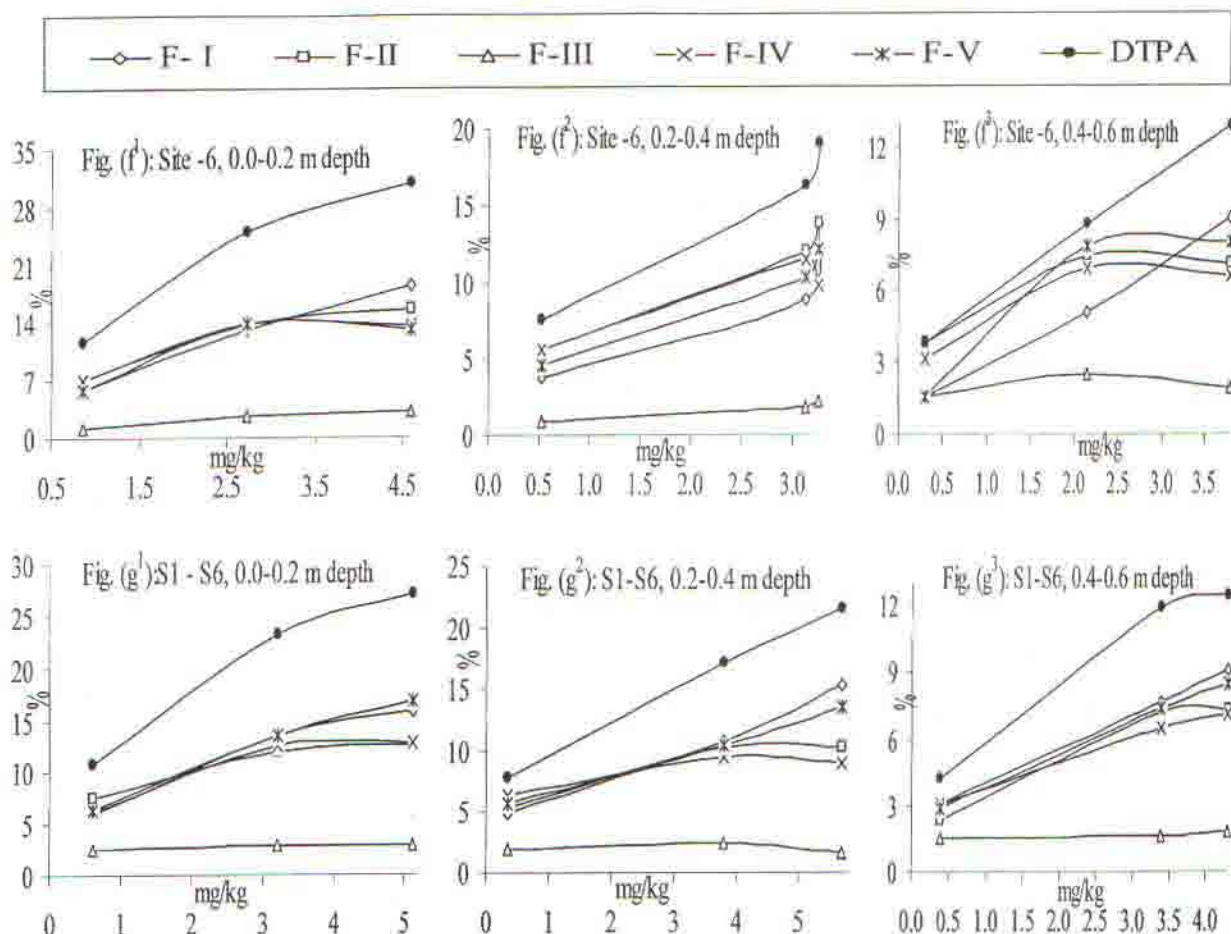


Fig. 4.2.4 Changes in contributions of different forms of cadmium to total Cd as influenced by level of loading (Where F - I, exchangeable; F-II , carbonate; F - III, manganese oxide bound; F - IV, sesqui-oxide bound; F - V, organic)

The contributions (%) of different forms of Cd to total Cd varied with the levels of heavy metals loading and depth of soil profile (Fig. 4.2.4). Irrespective of locations, in soils with no external loading the contribution of F-I, F-II, F-III, F-IV, F-V, F-VI and DTPA extractable forms to total Cd ranged from 4.7-8.6, 6.9-9.1, 1.2-5.2, 5.8-9.0, 4.6-8.1, 63.5-76.9, 9.1-13.8 %; 3.8-6.8, 4.0-7.0, 0.9-4.0, 4.8-8.0, 4.0-11.8, 67.7-79.4, 5.4-10.0% and 1.6-4.6, 1.8-3.9, 0.7-4.6, 2.3-4.8, 1.6-4.6, 79.6-89.6, 2.4-6.8 % in surface, mid-surface and sub-surface layers, respectively. These values for contaminated soils (mean for medium and high levels), however, varied from 11.5-18.5, 9.6-15.6, 2.0-3.9, 10.0-13.9, 12.2-19.8, 38.7-49.1, 18.8-30.8%, 8.9-18.6, 8.0-13.8, 1.2-4.7, 7.0-11.5, 10.2-16.5, 47.7-61.0, 14.8-24.3% and 5.1-10.5, 5.9-11.6, 1.0-2.5, 5.6-9.82, 6.1-10.0, 61.4-73.2, 8.8-14.0%, respectively. In comparison with the non contaminated profile there was less Cd in residual fraction of the sludge amended soil, whereas exchangeable (F-I), carbonate (F-II) and organic forms (F-III) were two to three times higher in moderate and heavily contaminated soils. Less than 17% of the total Cd in the non-contaminated soil was as exchangeable and carbonate form, whereas in moderate and heavily contaminated soil it was about 11 to 45%. The F-I and F-II fractions may be readily available for plant uptake or leaching (McLaren and Crawford,

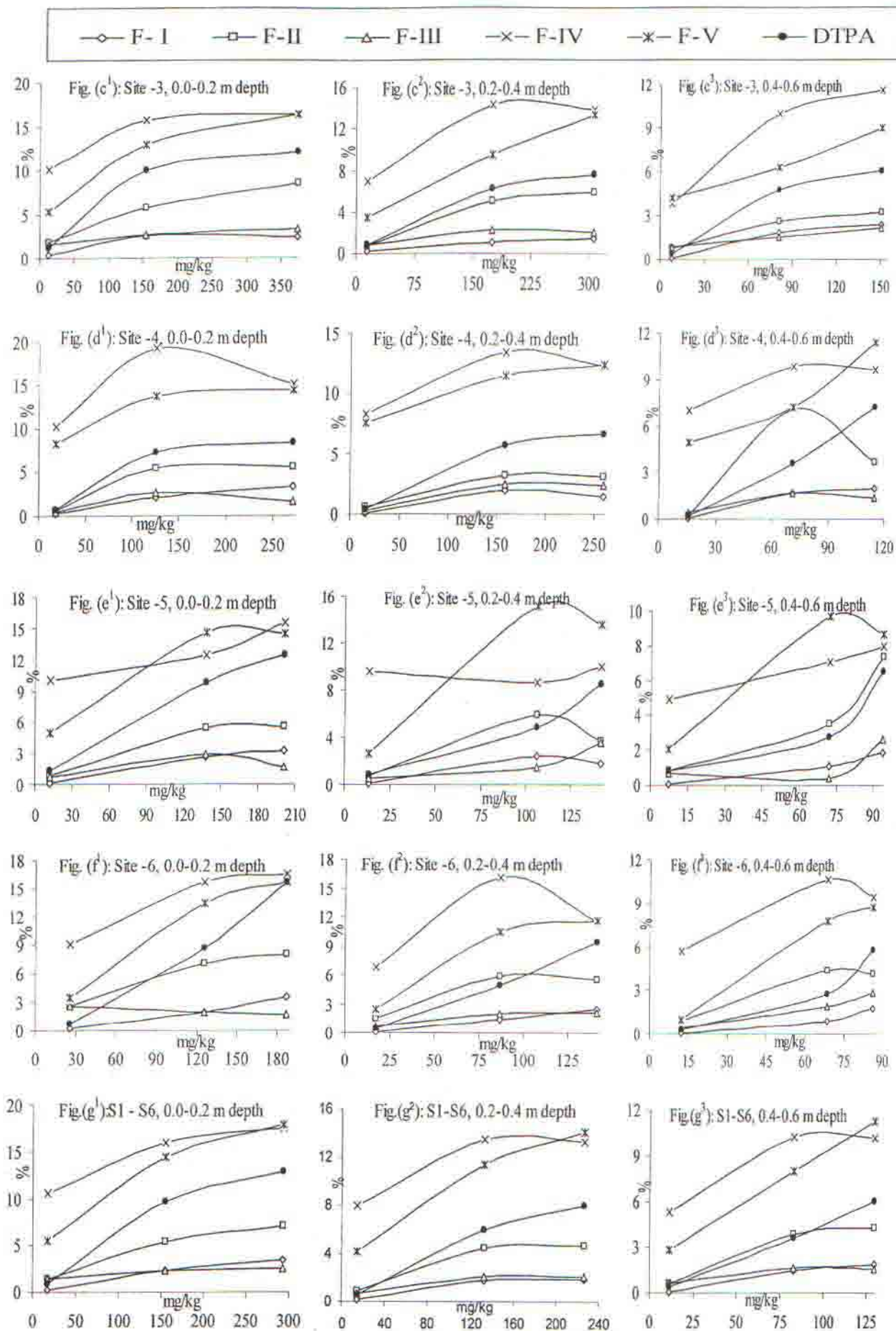
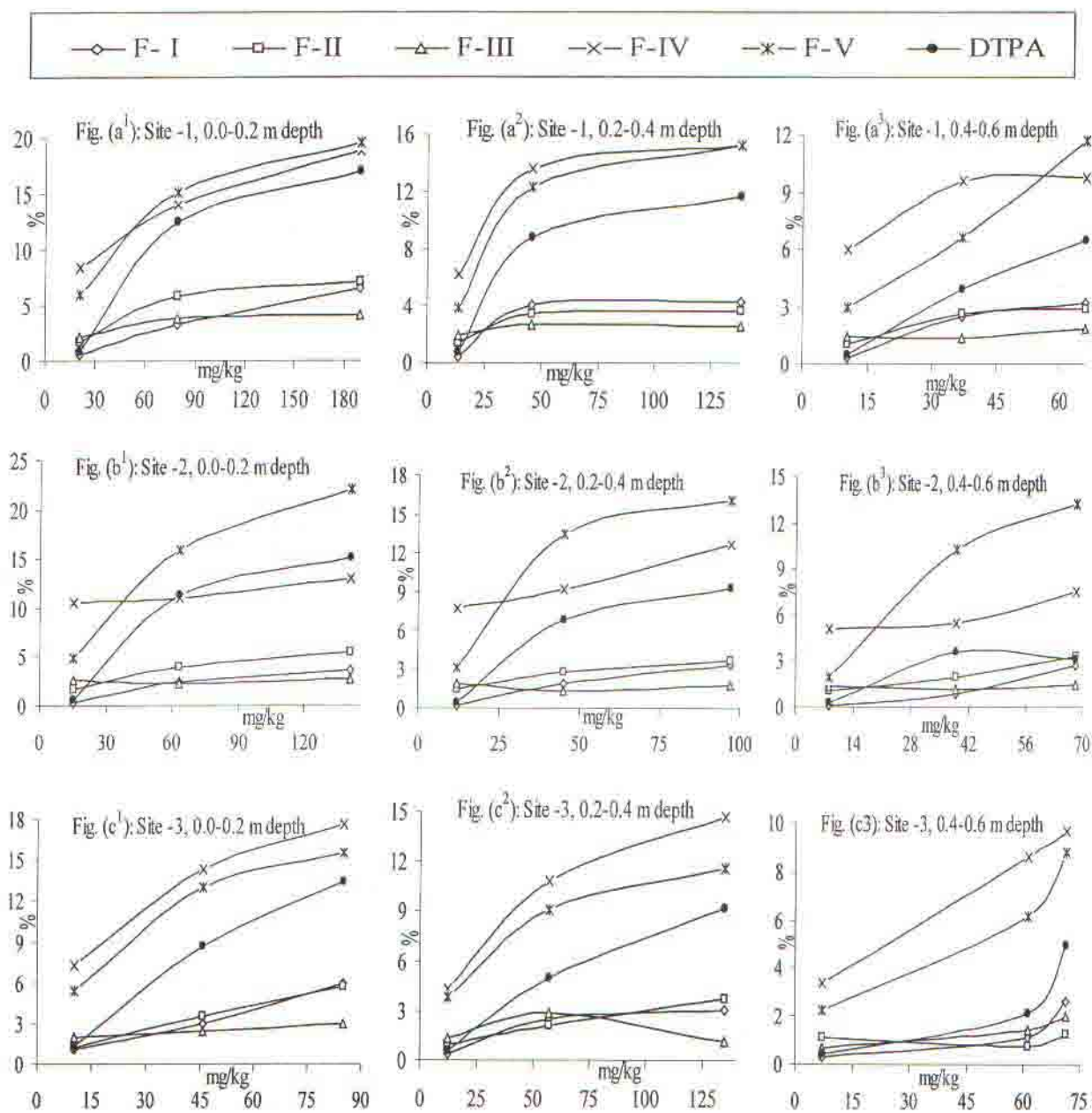


Fig. 4.2.5 Changes in contributions of different forms of Chromium to total Cr as influenced by level of loading (where F – I, exchangeable; F-II, carbonate; F – III, manganese oxide bound; F – IV, sesquioxides bound; F – V, organically bound)

levels), however, varied from 2.3-6.5, 3.5-7.6, 2.3-4.2, 11.1-18.9, 13.0-22.1, 43.8-65.7, 7.2-17.0%; 1.9-4.3, 2.2-6.7, 1.2-2.9, 9.2-15.5, 8.8-16.1, 58.9-72.5, 5.1-11.8% and 0.9-3.2, 0.7-4.3, 1.4-2.2, 8.6-13.4, 6.0-13.2, 70.5-81.9, 2.1-6.5%, respectively. In comparison with the non contaminated profile there was less Ni in residual fraction of the sludge amended soil, whereas sesquioxides bound (IV) and organic forms (F-III) were two to three times higher in moderate and heavily contaminated soils. Less than 3% of the total Ni in the non-contaminated soil was as exchangeable and carbonate form, whereas in moderate and heavily contaminated soil it was about 6 to 14%. The F-I and F-II fractions may be readily available for plant uptake or leaching (McLaren and Crawford, 1973). Olajire *et al.* (2003) reported the carbonate and residual fraction contained on an average 13 and 50%, respectively.



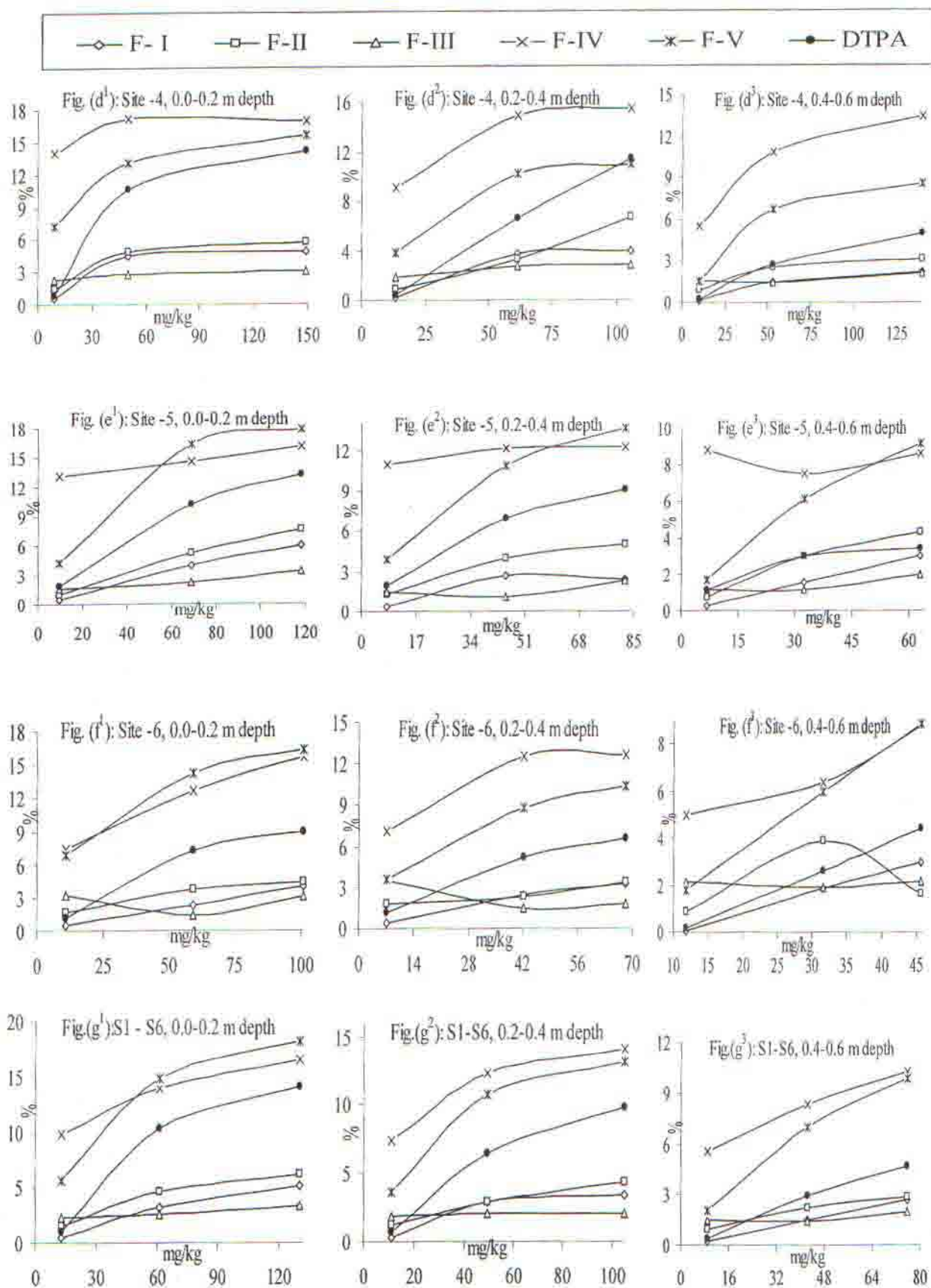


Fig. 4.2.6 Changes in contributions of different forms of Nickle to total Ni as influenced by level of loading (Where F - I, exchangeable; F-II, carbonate; F - III, manganese oxides bound; F - IV, sesquioxides bound; F - V, organic)

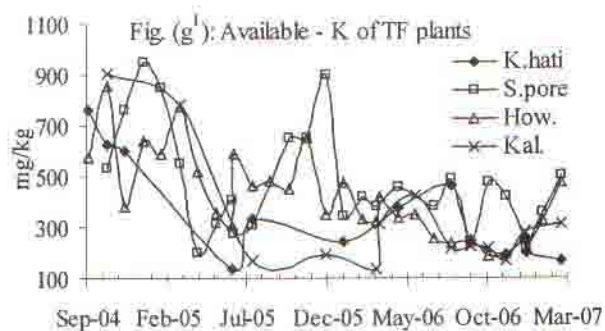
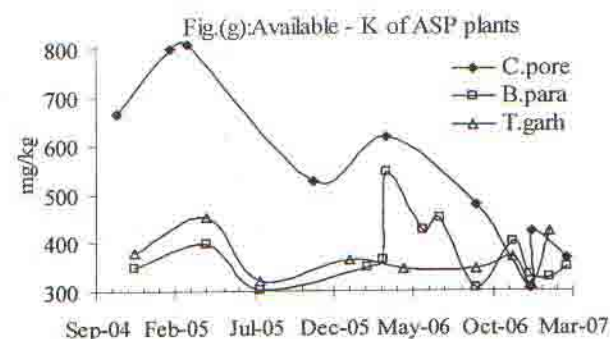
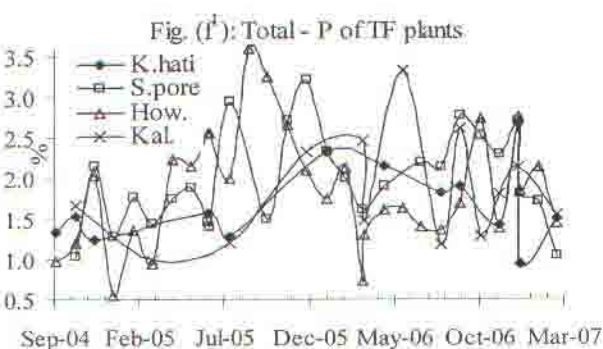
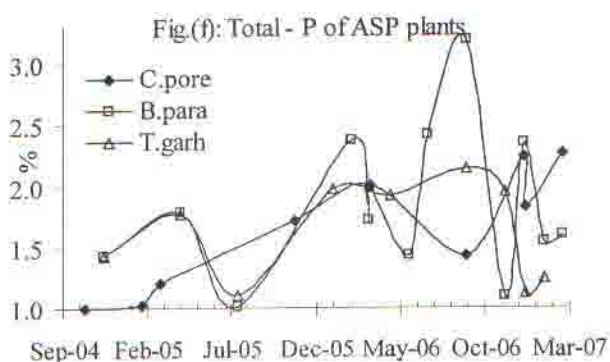
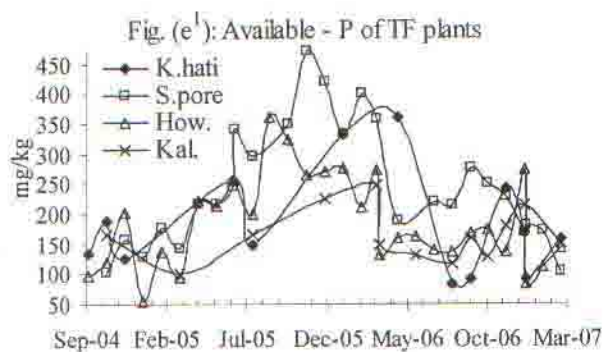
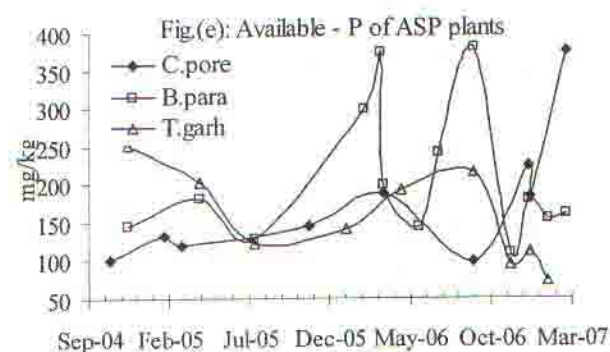
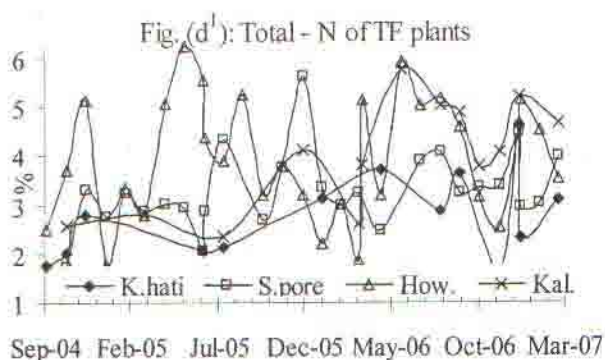
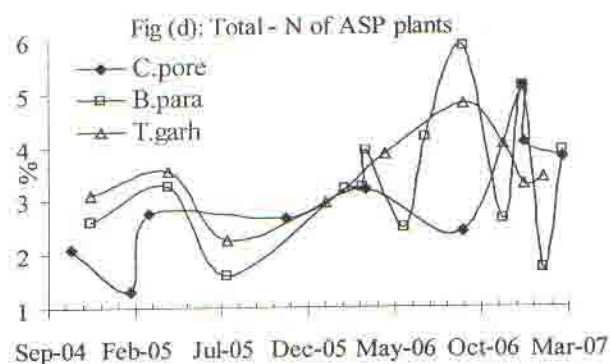
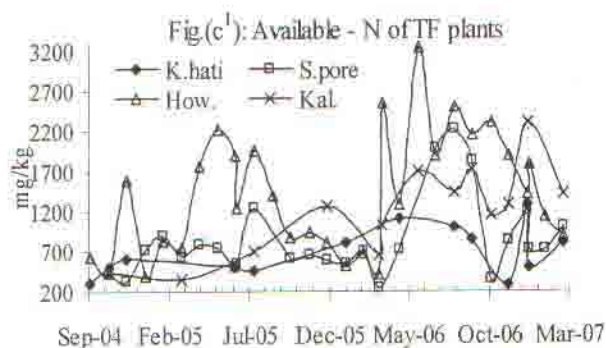
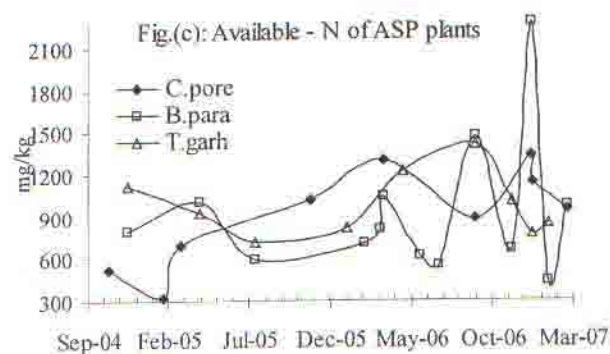


Fig. 4.3.1 Physico-chemical properties and essential plant nutrient content of sludge produced by different types of STPs

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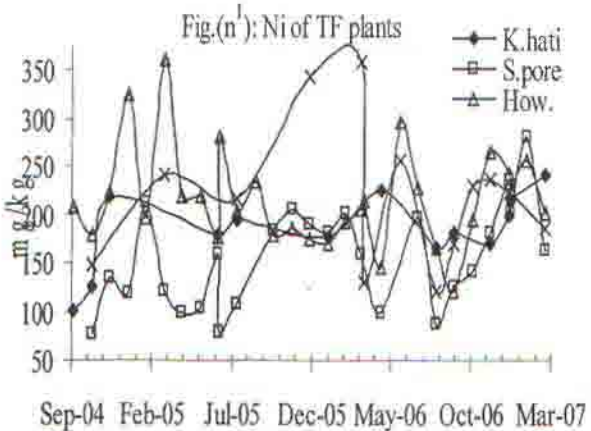
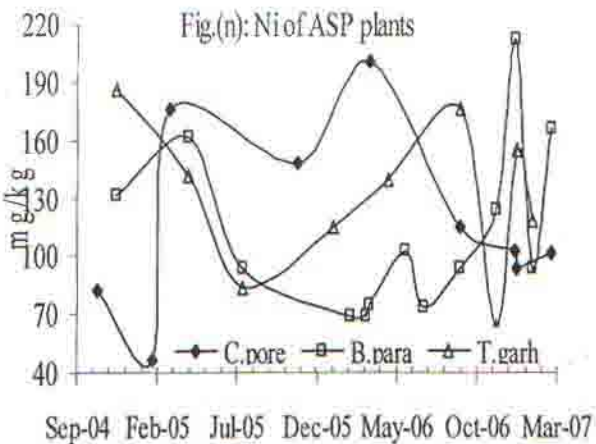
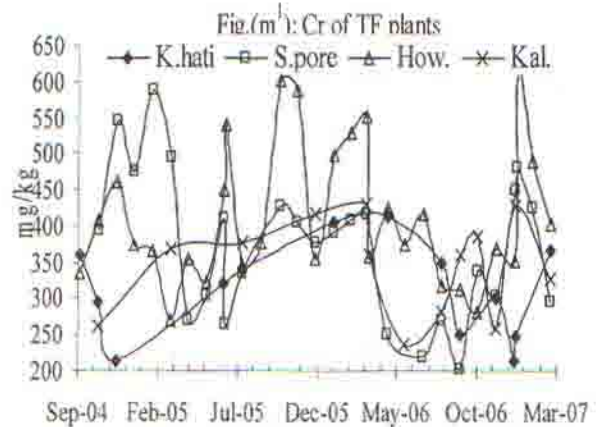
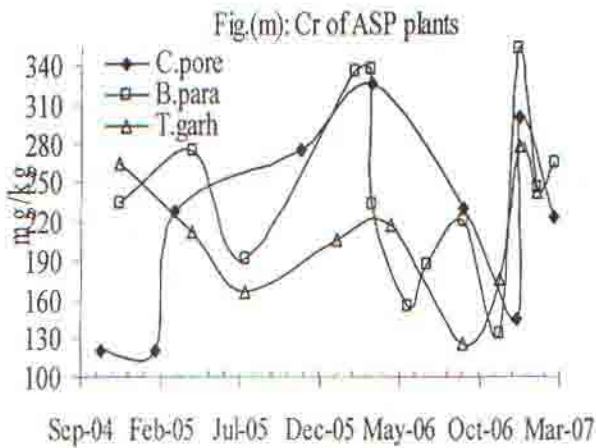
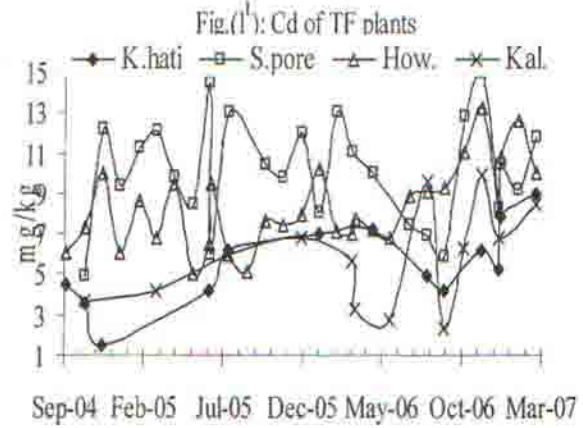
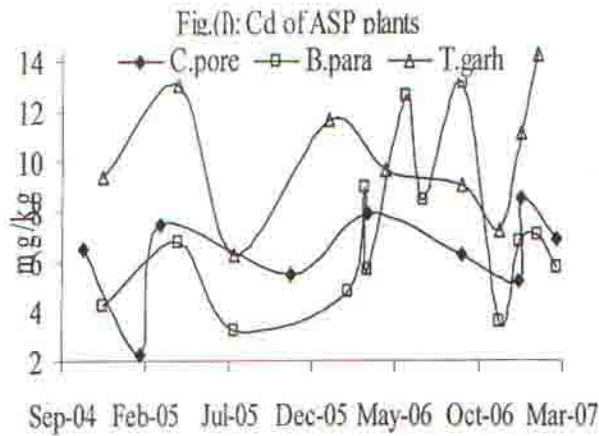
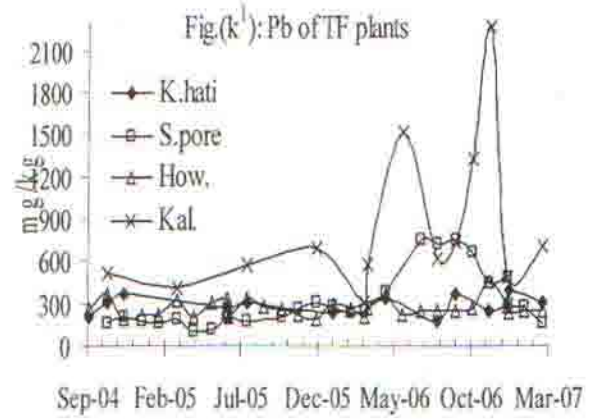
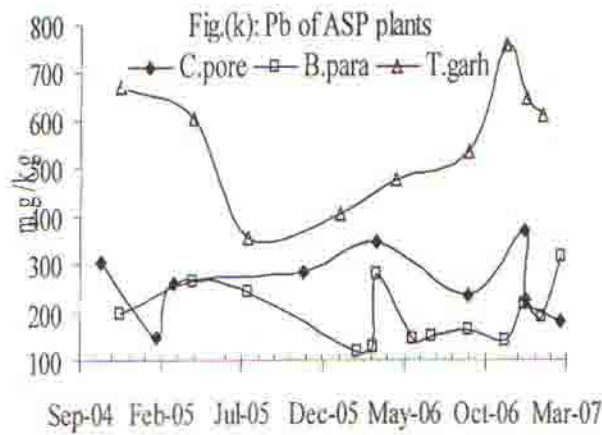


Figure 4.3.2 Heavy metal content of sludge produced by different types of STPs

of Zn as complexes with organic matter and significant amounts in the residual fraction. Brummer et al. (1986) reported a relatively higher percentage of total Zn in amorphous and crystalline iron oxides bound form which might be related to their lower solubility and higher stability at increased pH. This was supported by the findings of Kabta – pendias (1993). Where they reported high fixation of Zn by Fe-oxides in soil environment.

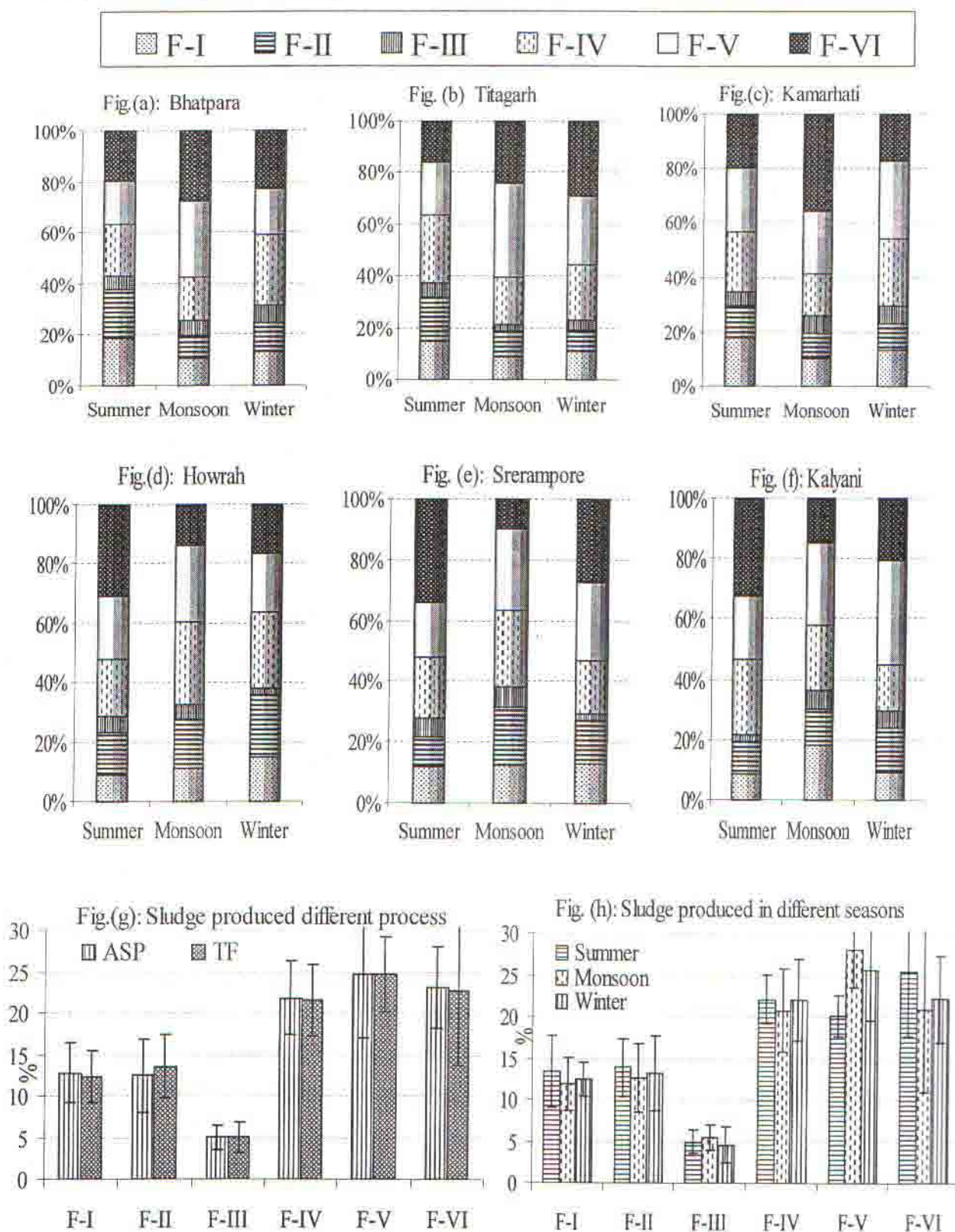


Fig. 4.3.5 Relative contribution of different chemical forms to total Zn of sludge collected from different locations in different seasons (Bar indicates $\pm$ S. E.)

corroborated by Solís *et al.*, 2002 and Zufiaurre *et al.*, 1998. Jakubus and Czekala (2001) reported the following relative order of contribution of different fractions of Cu in sludge (%): residual (34-90) > sesquioxide bound (3-28) > organic bound (2-34) > exchangeable (1-3) $\approx$ manganese oxide bound (1-3) $\approx$ carbonate bound (1-3).

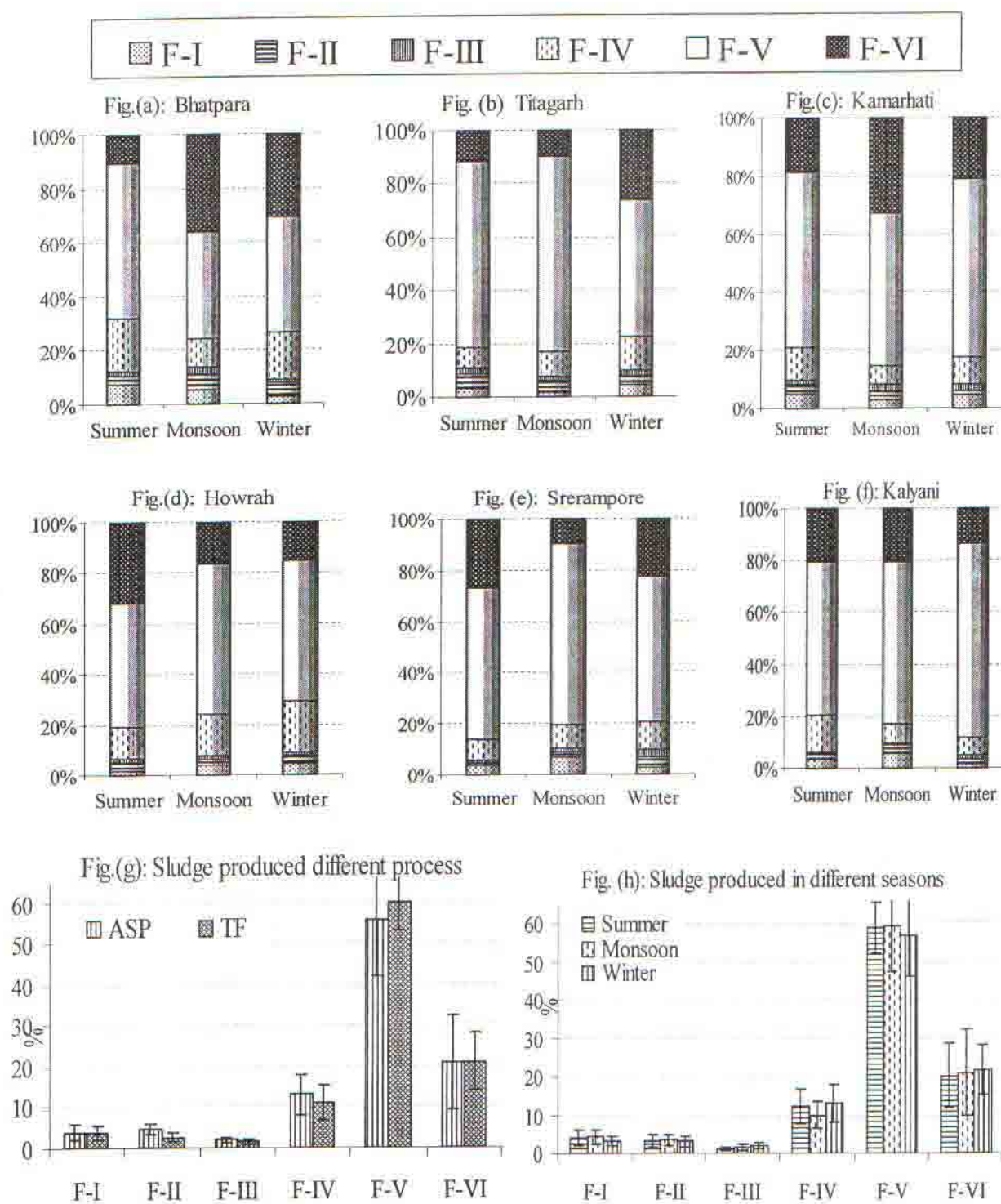


Fig. 4.3.6 Relative contribution of different chemical forms to total Cu of sludge collected from different locations in different seasons. Bar indicates $\pm$ S. E.

The speciation of copper obtained through the study corroborated the results obtained by different authors (Marschner, 1995; Carlson and Morrison, 1992), who showed the lowest mobility of Cu. As per their opinion it was manifested by the firm binding of Cu with the

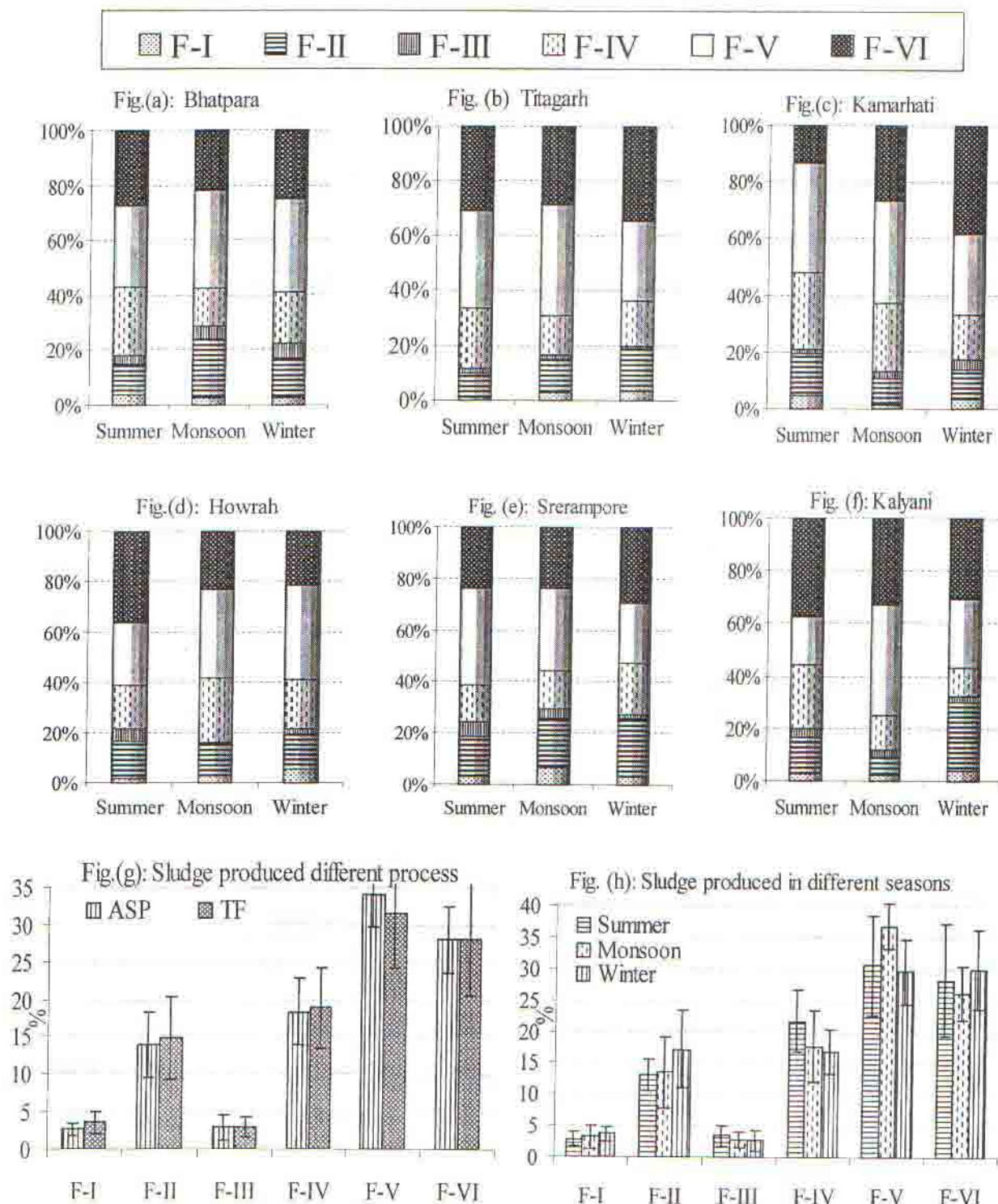


Fig. 4.3.7 Relative contribution of different chemical forms to total Pb of sludge collected from different locations in different seasons (Bar indicates $\pm$ S.E.)

A lion share of the total Pb was contributed by organic bound fraction. Presence of a reasonable portion of Pb in carbonate bound form indicated its tendency to be precipitate out from the system as carbonate. Zufiaurre *et al.* (1998) reported that about 60 % of Pb was extracted in the residual fraction of a sewage sludge sample. Mbila *et al.* (2001) observed about 21, 52 and 25% of total Pb (47 mg kg^{-1}) in sludge collected from University of Nigeria, Nsukka was contributed by sesquioxide bound, organically bound and residual form, respectively. Excepting organically bound fraction, there was no any considerable difference

contribution of total Pb with the mode of their production i.e. ASP of TF. On the other hand the contribution of organically bound Cd was highest in monsoon but sesqui-oxide and carbonate bound fractions were maximum in summer and winter respectively.

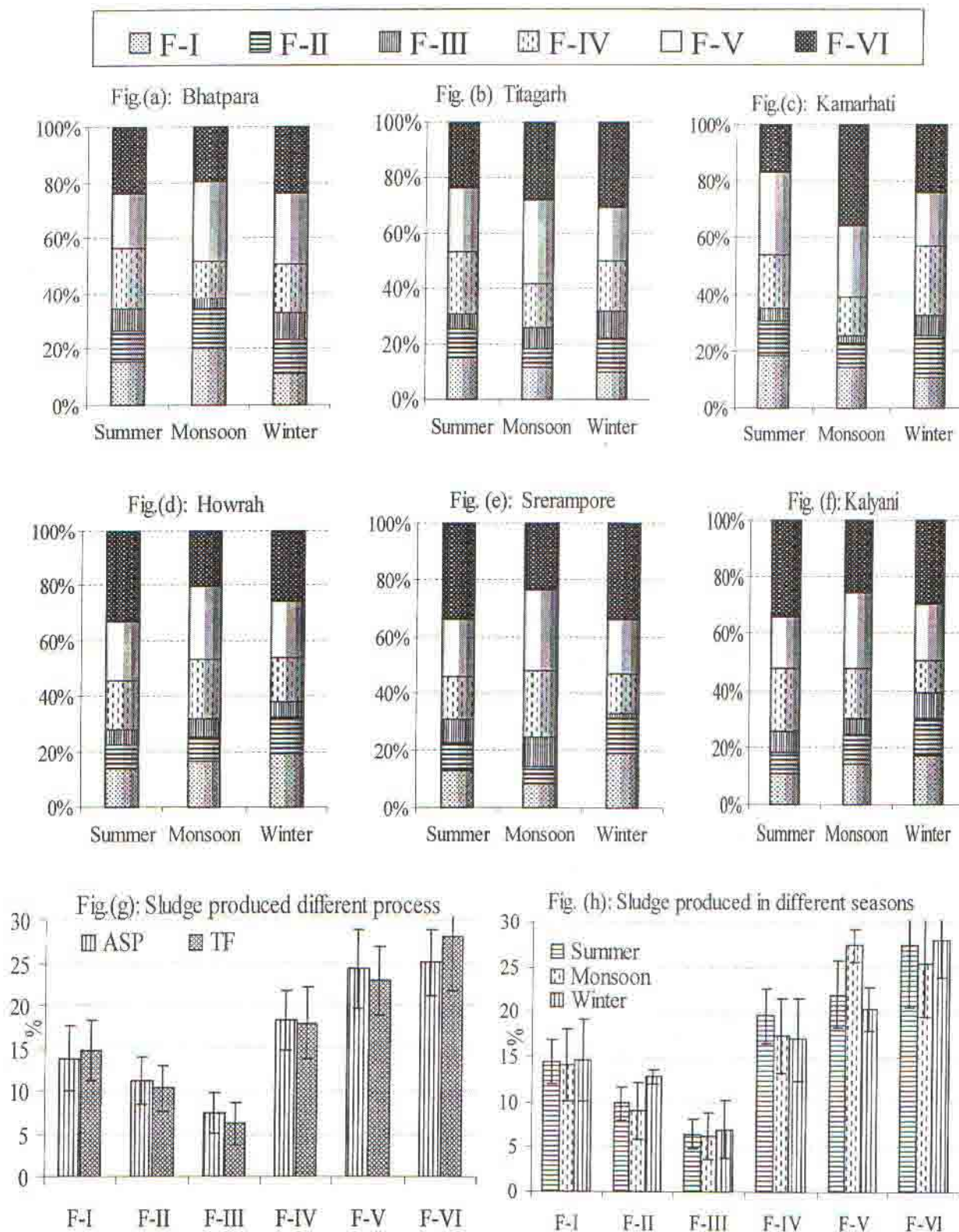


Fig. 4.3.8 Relative contribution of different chemical forms to total Cd of sludge collected from different locations in different seasons. Bar indicates $\pm$ S.E.

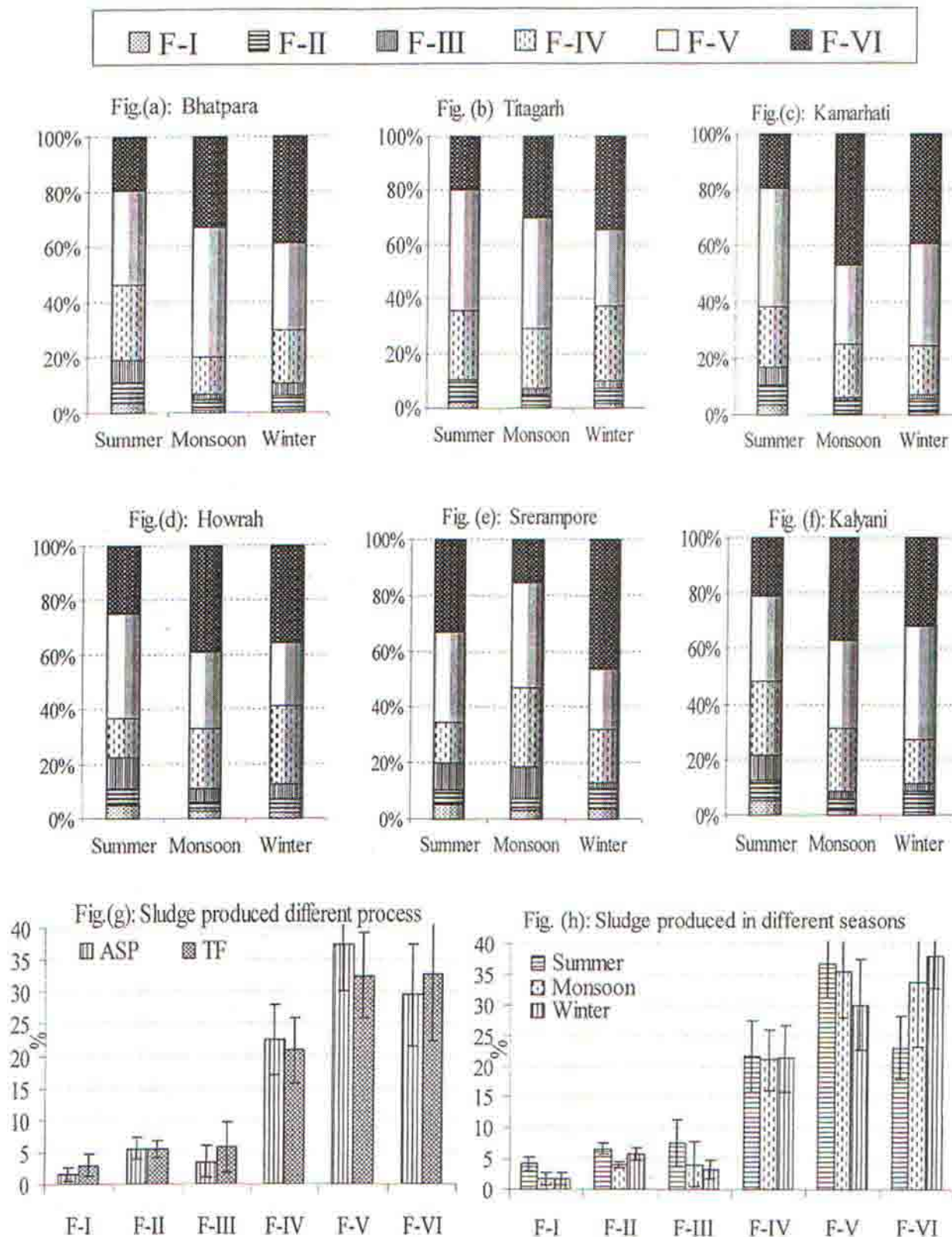


Fig. 4.3.9 Relative contribution of different chemical forms to total Cr of sludge collected from different locations in different seasons. Bar indicates $\pm$ S.E.

The predominance of Cr in the organic matter fraction of the sewage sludge was in conformity with Qiao and Ho (1996), who found about 62 % of Cr in this fraction, Zufiaurre *et al.* (1998) concluded that about 40 % of Cr was present in the organic and sulfide fractions of a sewage sludge sample. Experimental results, of this study also confirmed that the highest percentage (%) of it was observed in organically bound, residual and sesquioxides

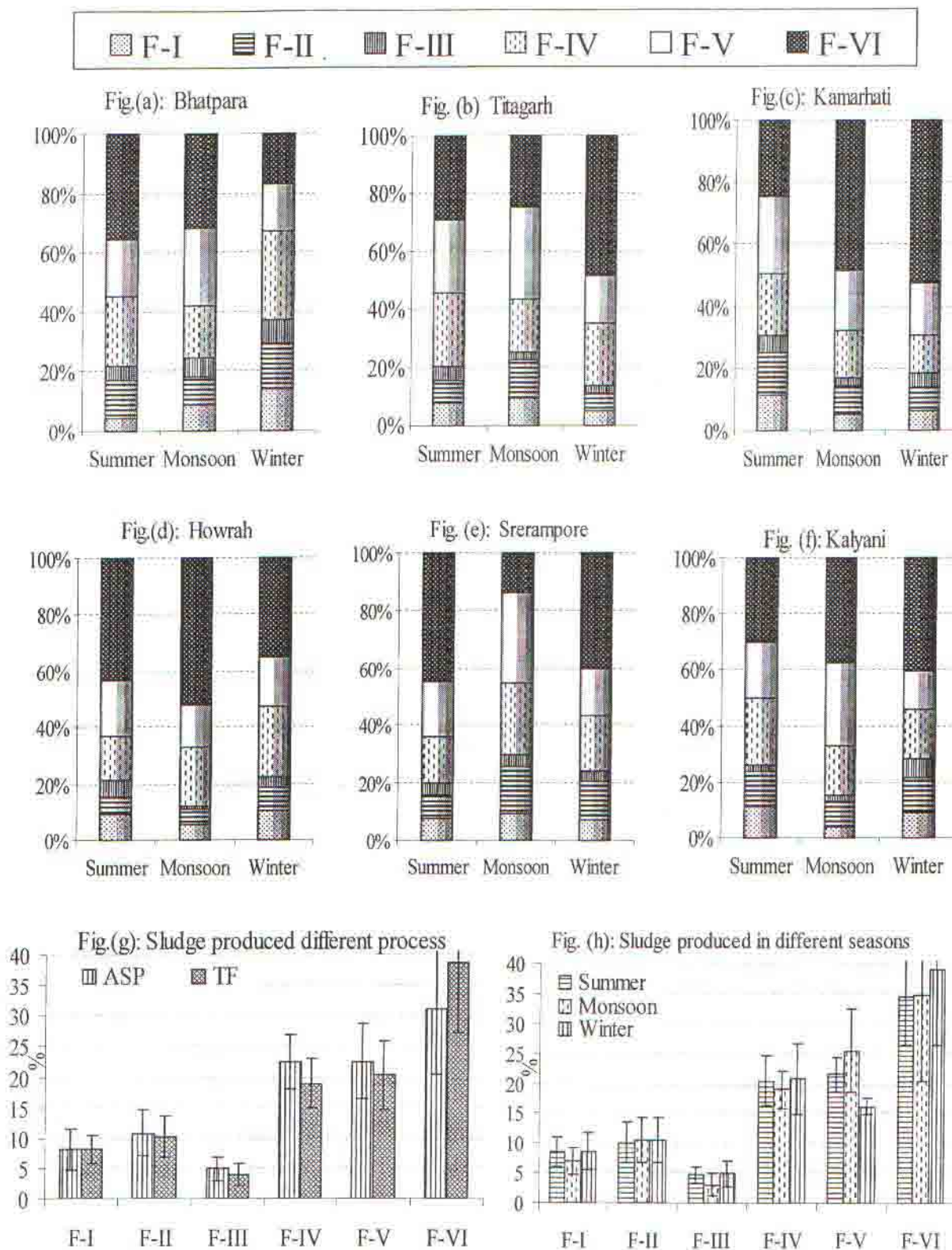


Fig. 4.3.10 Relative contribution of different chemical forms to total Ni of sludge collected from different locations in different seasons (Bar indicates $\pm$ S.E.)

Jakubus and Czekala (2001) reported the relative contribution of different fractions of Ni in sludge (%); residual (15-77) > sesquioxide bound (11-36) > organic bound (4-23) > carbonate bound (3-16) > exchangeable (1-25) > manganese oxide bound (3-16). Results, therefore, revealed that Cadmium and nickel exhibited an almost identical distribution of their fractions, with very similar percentages in individual fractions of sludge. The results

4.4.2 Heavy metal concentration of water in the river Ganga at different locations

4.4.2.1 Heavy metal concentration at Berhampore

Temporal changes in heavy metals contamination of water in river Ganga at Berhampore are presented in the Fig. 4.4.1. Concentration of Zn, Cu, Pb, Cd, Cr and Ni at impact point

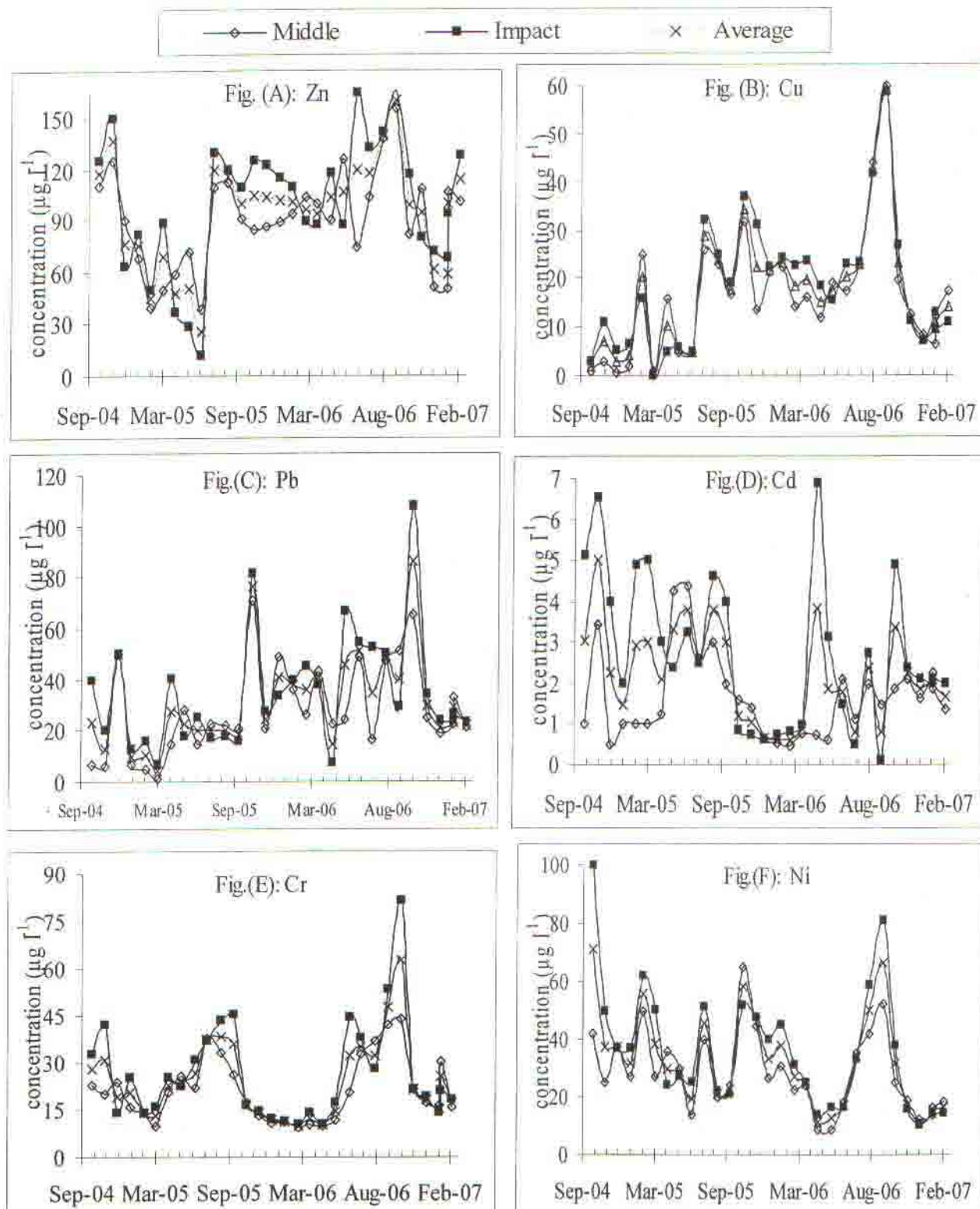


Fig. 4.4.1 Heavy metal concentration of water in the river Ganga at Berhampore

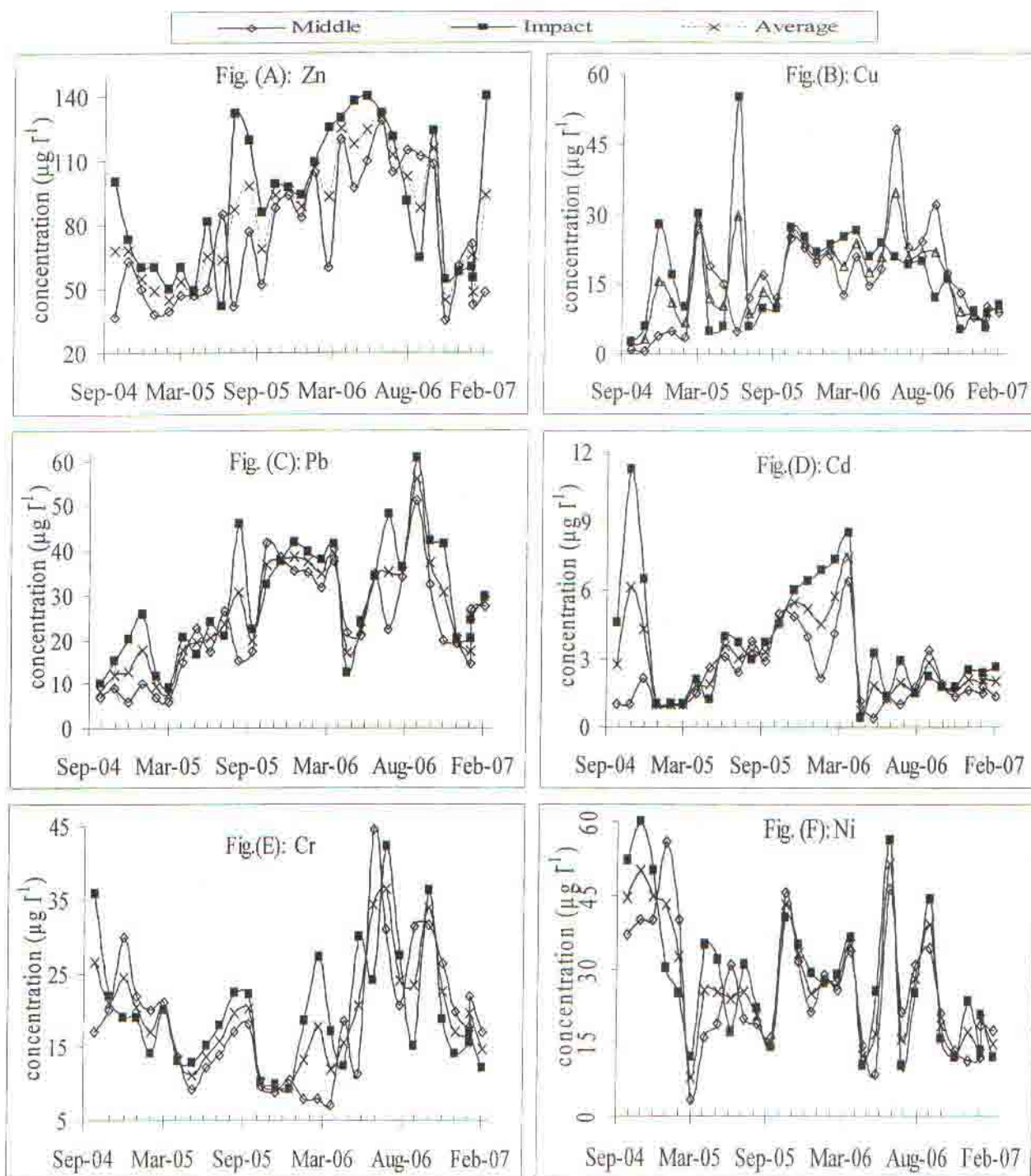


Fig. 4.4.2: Heavy metal concentration of water in the river Ganga at Palta

73.81, 15.63, 23.48, 2.28, 18.61 and 25.77 $\mu\text{g l}^{-1}$. On average (middle and impact), the preponderance of the metals ($\mu\text{g l}^{-1}$) was: Zn (82.60) > Ni (26.98) $\approx$ Pb (26.19) > Cr (19.16) > Cu (16.28) > Cd (2.93). There were no significant seasonal changes in the concentration of all the heavy metals at impact point at Palta, excepting Cr (Table 4.4.3). Such concentration of Cr at impact point was significantly higher in monsoon than in summer and winter seasons. Of the two locations, concentration of Zn, Pb and Cd was higher at impact point than at middle stream of the river with insignificant variations for Cu, Cr and Ni.

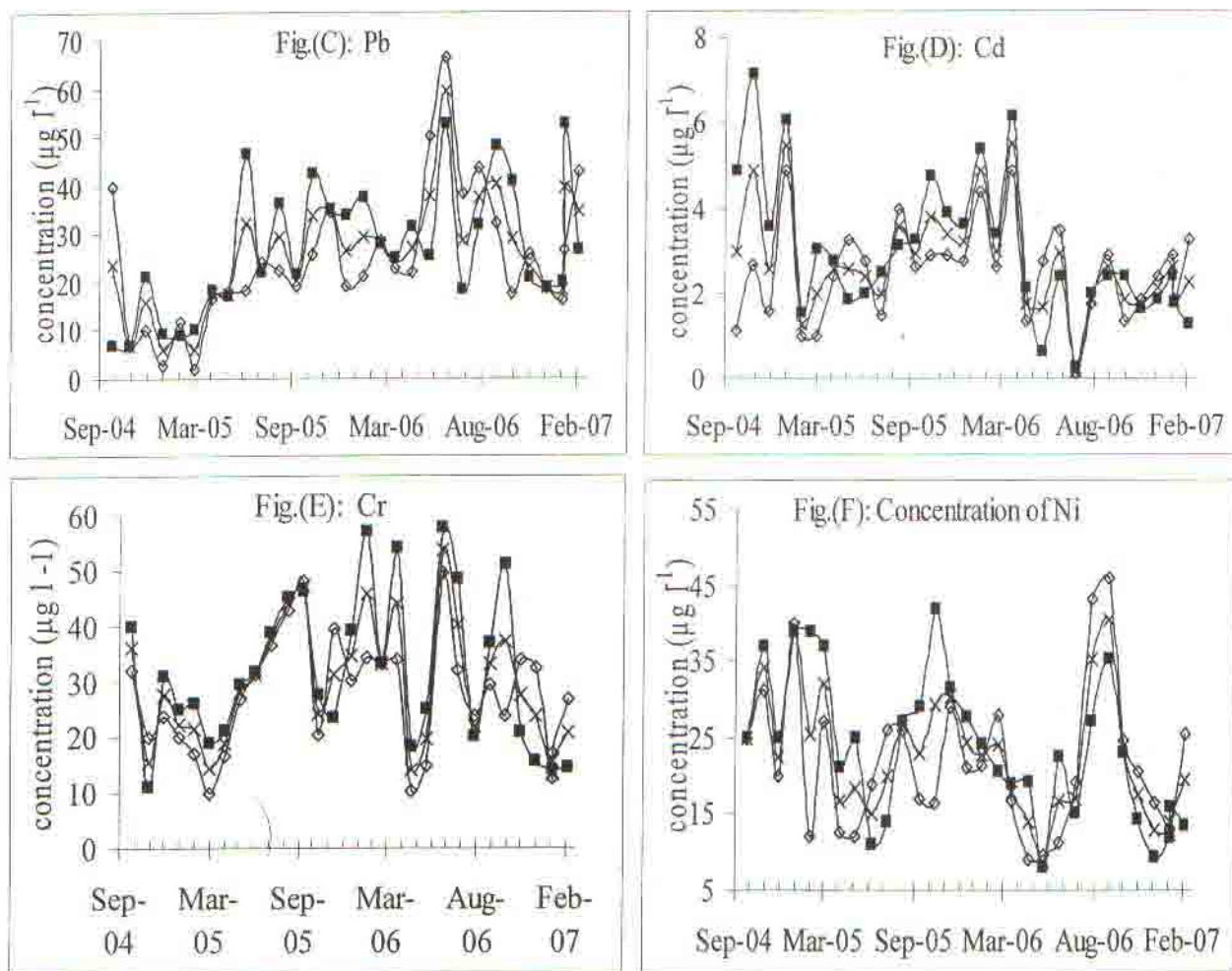


Fig. 4.4.3 Heavy metal concentration of water in the river Ganga at Dakshineswar

Table 4.4.4 Seasonal changes in heavy metal concentration ($\mu\text{g l}^{-1}$) of river Ganga, Dakshineswar

Position	Season	Zn	Cu	Pb	Cd	Cr	Ni
Middle stream	Summer	70.56 ^a	16.31 ^a	28.82 ^a	2.79 ^a	24.48 ^a	15.85 ^a
	Monsoon	87.43 ^a	17.22 ^a	29.26 ^a	2.03 ^a	32.19 ^a	27.11 ^b
	Winter	58.52 ^a	11.38 ^a	18.56 ^a	2.64 ^a	26.18 ^a	22.00 ^{a,b}
	Mean	70.81	14.61	24.85	2.50	27.47	21.72
	Sem $\pm$	10.62	2.64	4.51	0.38	3.43	2.93
Impact point	Summer	86.64 ^{a,b}	24.69 ^a	28.08 ^a	2.46 ^a	30.10 ^{a,b}	19.51 ^a
	Monsoon	109.22 ^a	20.68 ^{a,b}	29.74 ^a	2.84 ^a	39.39 ^a	26.39 ^a
	Winter	68.92 ^b	12.56 ^b	24.40 ^a	3.51 ^a	25.84 ^b	24.63 ^a
	Mean	86.33	18.64	27.11	2.99	31.18	23.62
	Sem $\pm$	13.60	3.72	4.55	0.55	4.36	3.17
Grand mean		78.57	16.62	25.98	2.75	29.33	22.67
CD(P = 0.05)		14.09	3.77	5.03	0.52	4.51	3.53

Similar alphabet within a column indicates absence of any significant difference; DMRT test

The seasonal changes in the concentration of the metals in middle and impact point of the river stream at Dakshineswar are presented in Table 4.4.4. At the middle of the river stream, excepting Ni there was no significant seasonal changes in the concentration of the metals. The Ni concentration was highest in monsoon season ($27.11 \mu\text{g l}^{-1}$). At impact point,

there was however, a significant seasonal change in Zn, Cu and Cr, with the highest values being recorded at monsoon season. Of the two positions of sampling, significant variation was observed only for Zn and Cu, with their values being higher at impact point than those at middle of the stream.

4.4.2.4 Heavy metal contamination at Uluberia

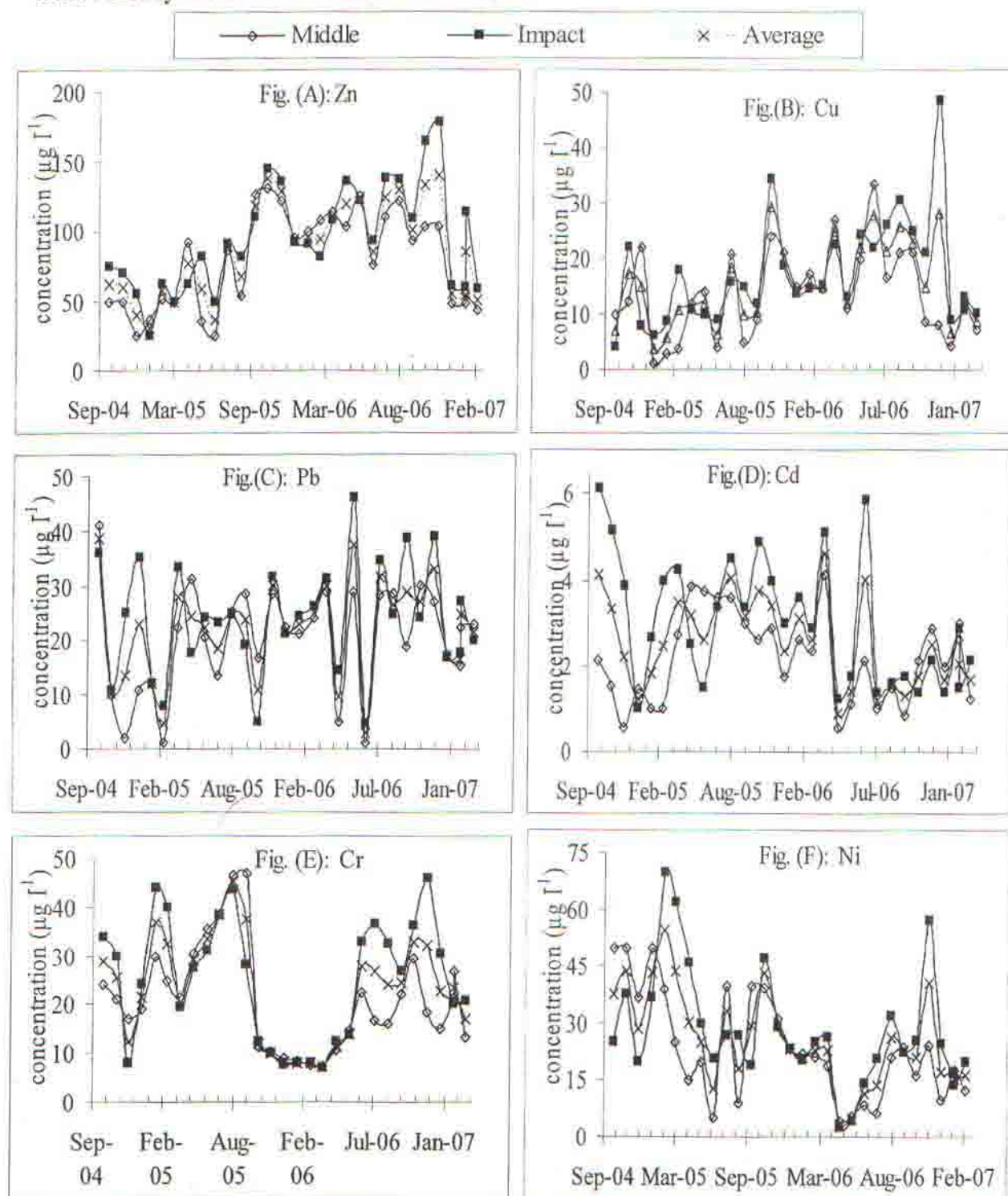


Fig. 4.4.4: Heavy metal concentration of water in the river Ganga at Uluberia

> Berhampore $\approx$ Uluberia > Palta. There was almost no spatial variation in the concentration of Cu and Cd.

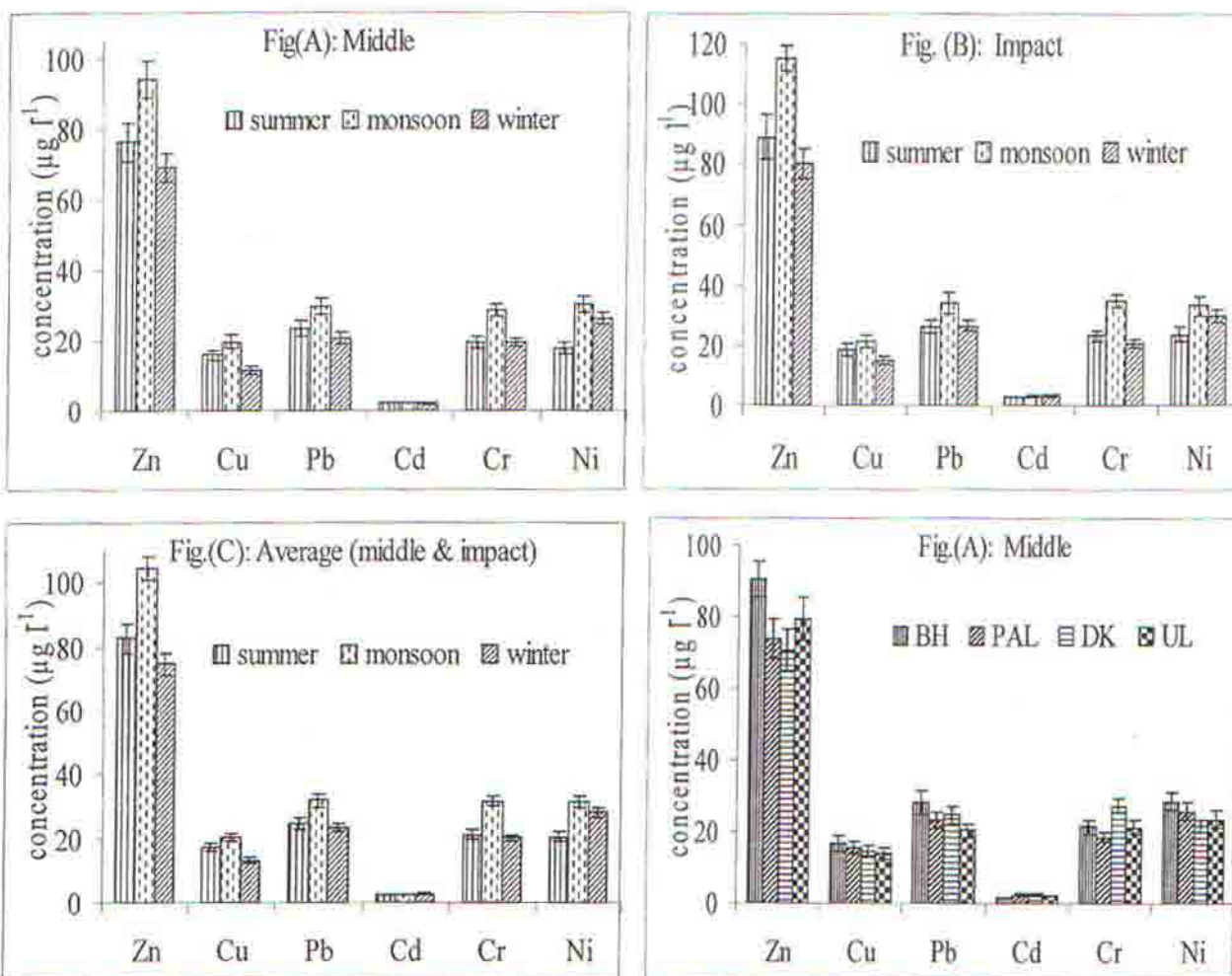


Fig. 4.4.5 Seasonal changes of heavy metals at different position of the river stream

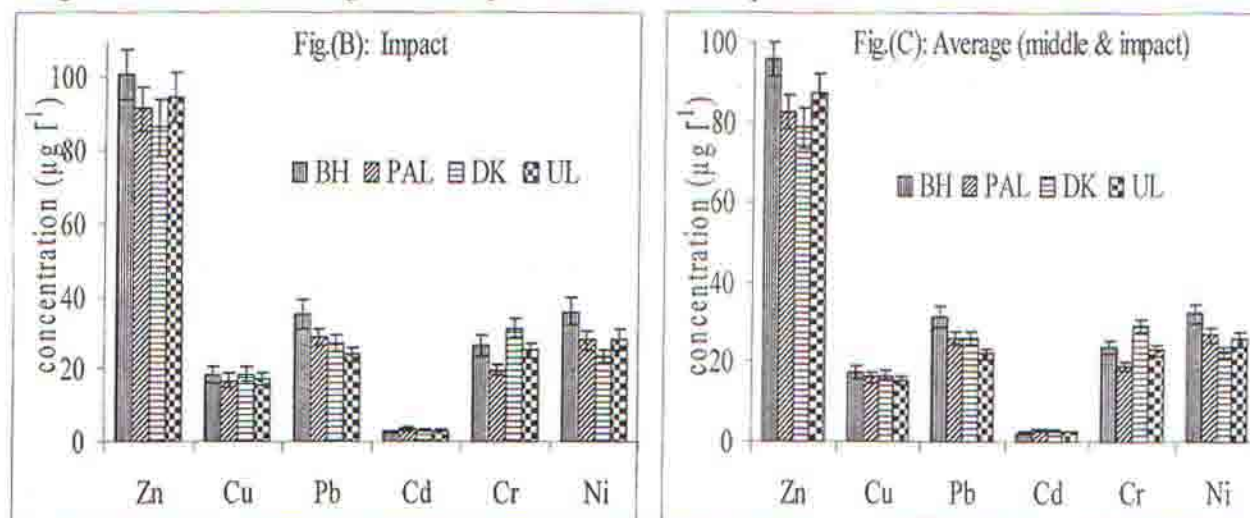


Fig. 4.4.6 Spatial changes of heavy metals at different position of the river stream

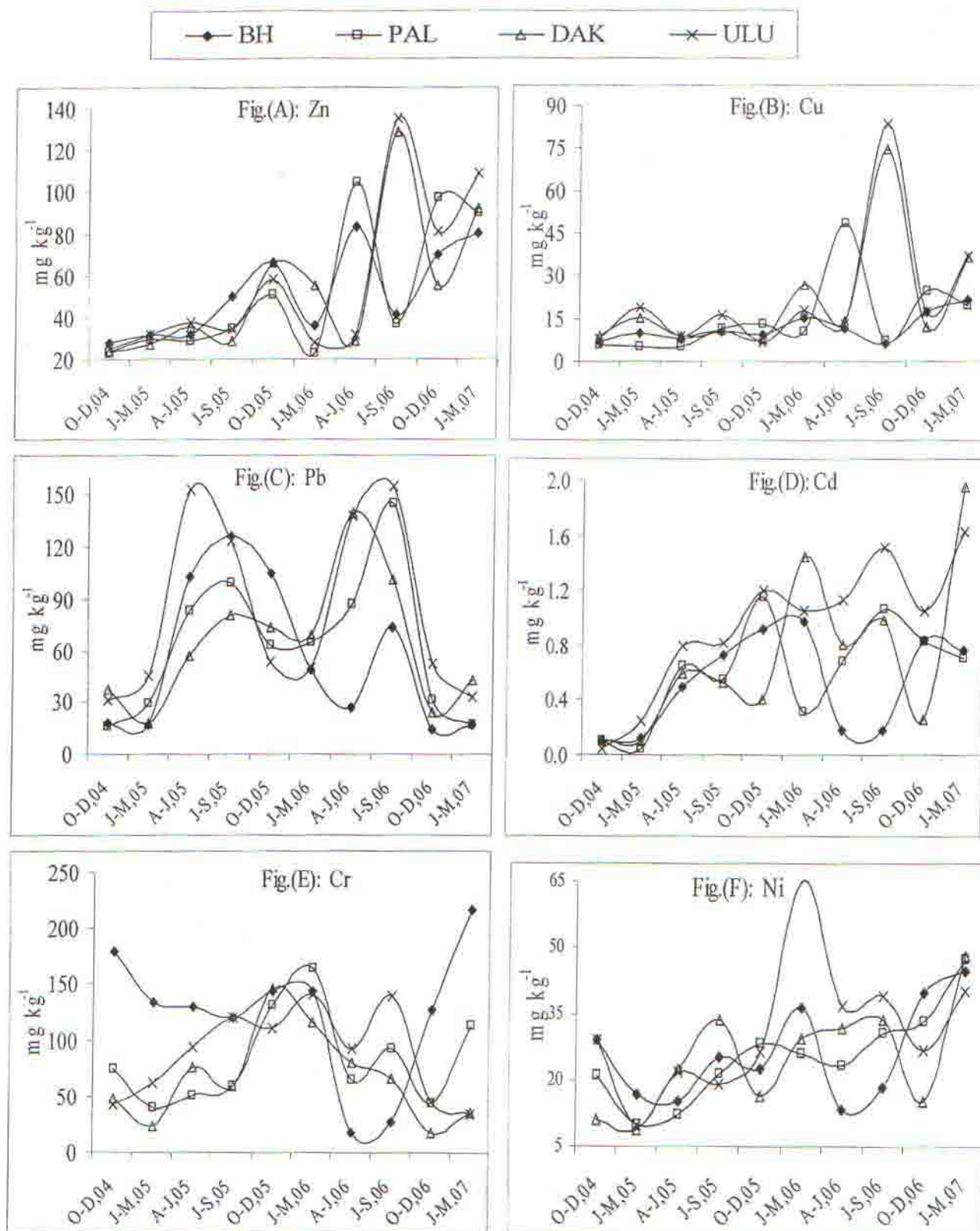


Fig. 4.4.7 Heavy metals contents in sediments of river Ganga at four locations during October, 2004 to March, 2007

Irrespective of the locations, average concentration of Zn, Cu, Pb, Cd, Cr and Ni in four quarter ranged from 47.93 - 61.49, 11.64 - 27.72, 37.64 - 113.24, 0.59 - 0.80, 75.86 - 102.33 and 22.23 - 31.99 mg kg⁻¹, respectively (Fig. 4.4.8). Of the four quarters of sampling compared, the

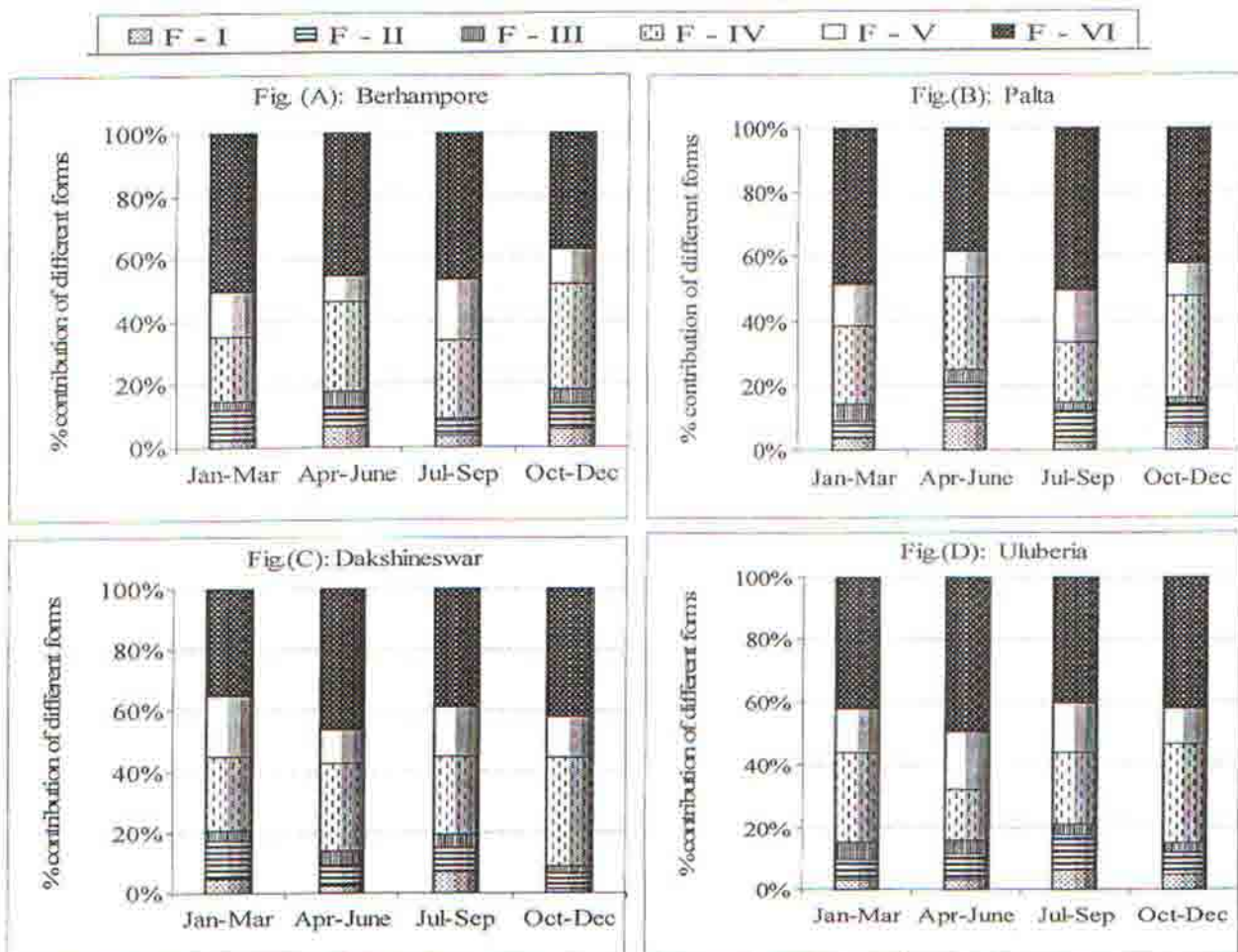


Fig. 4.4.10 Forms of Zn in sediments collected periodically from sampling sites of the river Ganga

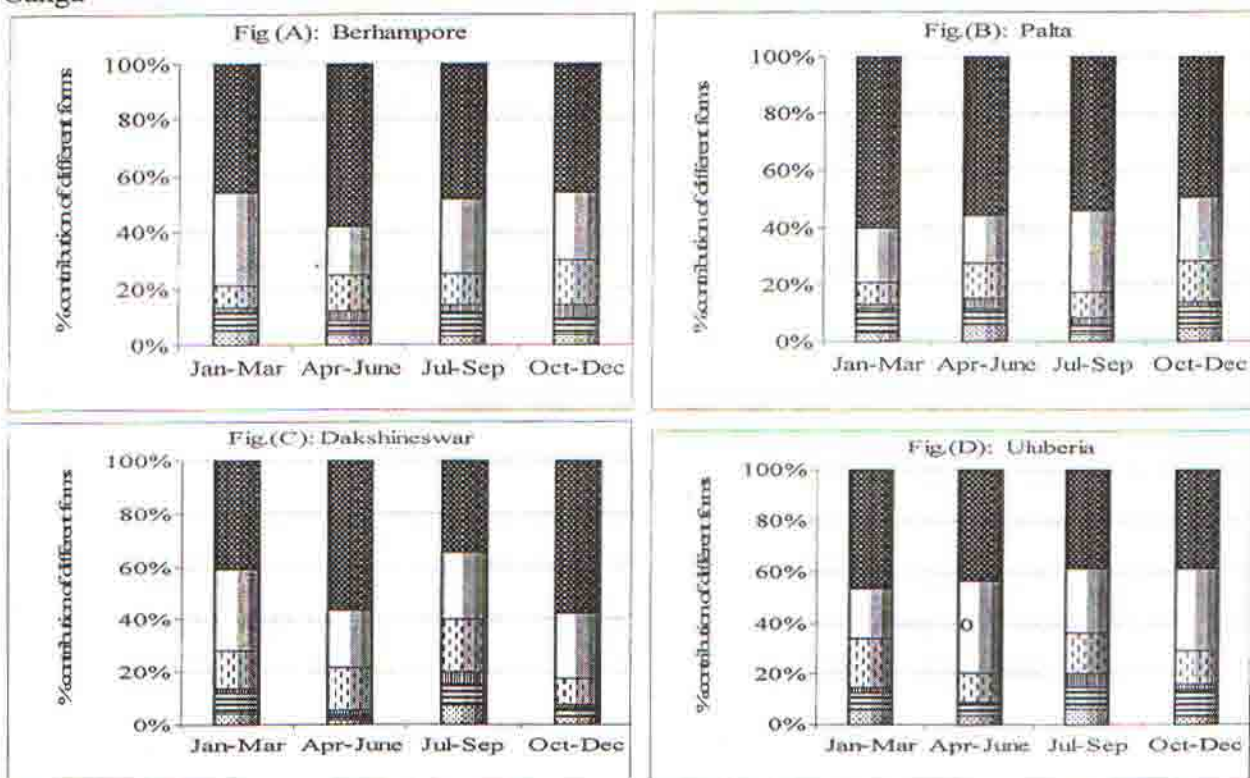


Fig.4.4.11 Forms of Cu in sediments collected periodically from sampling sites of the river Ganga

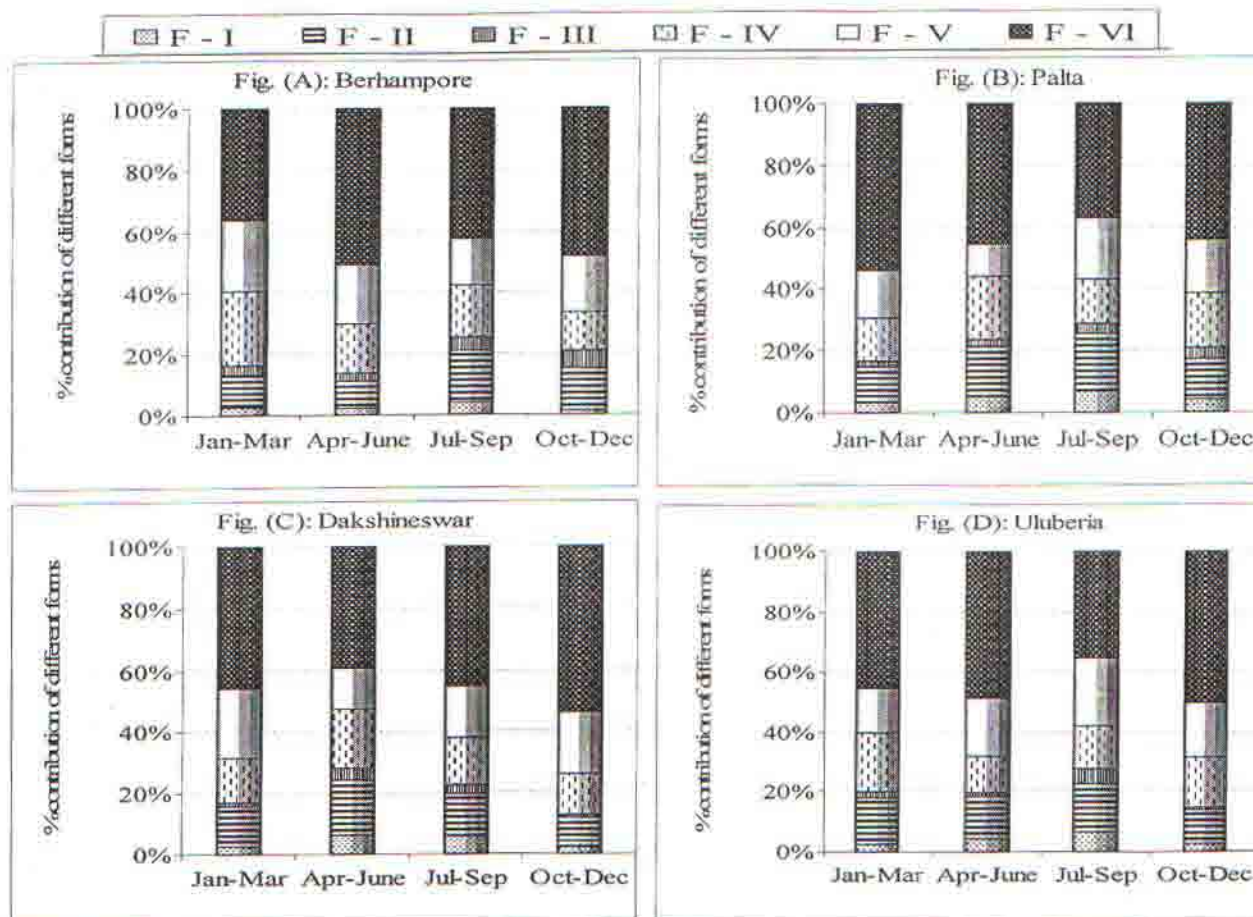


Fig. 4.4.12 Forms of Pb in sediments collected periodically from sampling sites of the river Ganga

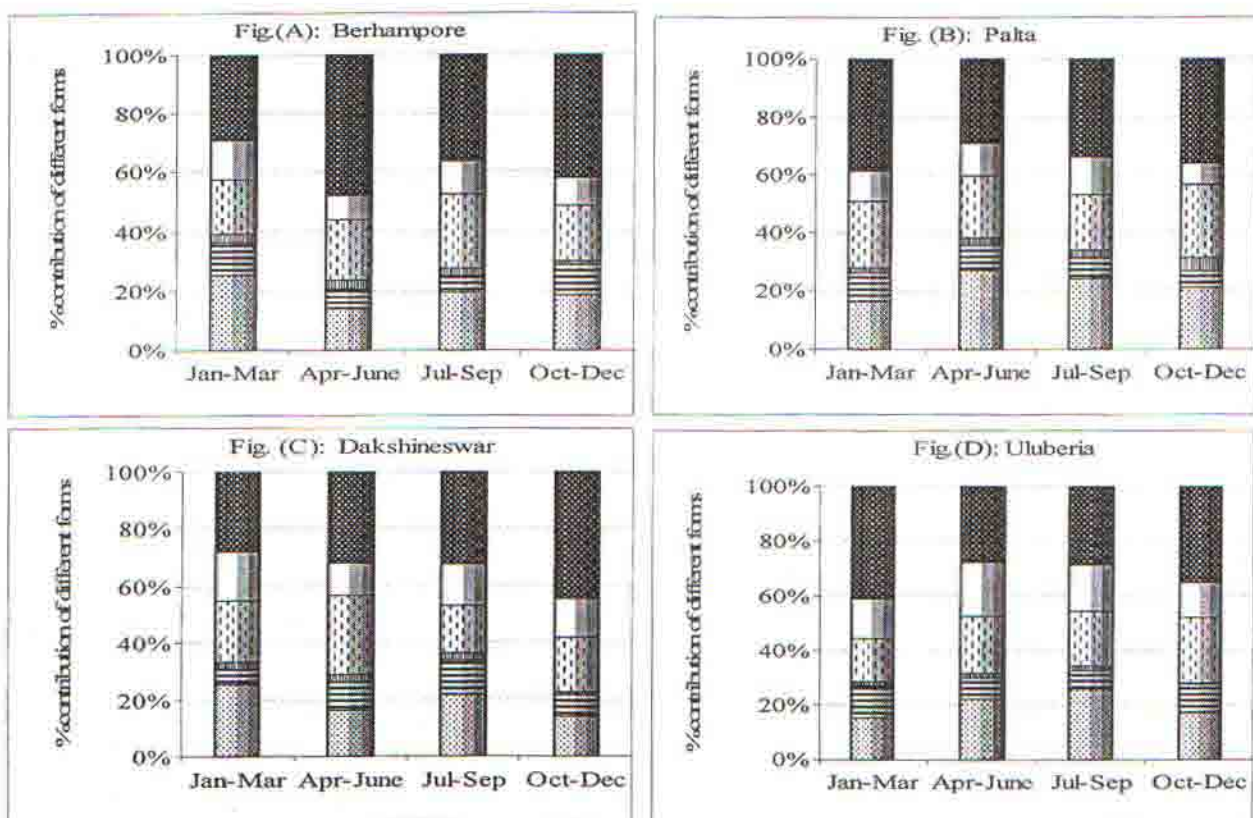


Fig.4.4.13 Forms of Cd in sediments collected periodically from sampling sites of the river Ganga

4.4.5.3. Cadmium

The contribution of exchangeable (F - I), carbonate bound (F - II), manganese oxides bound (F - III), sesquioxides bound (F - IV), organic (F - V) and residual (F - VI) forms of Cd to total sediment Cd ranged from 13.9 - 27.1, 5.2 - 12.1, 0.6 - 4.8, 15.6 - 27.8, 8.3 - 19.5 and 27.9 - 47.8% with mean values of 20.3, 6.5, 2.3, 20.9, 12.7 and 35.2%, respectively (Fig. 4.4.13). The relative abundance of different forms of Cd thus had the following sequence: residual > sesquioxides bound > exchangeable > organic bound > carbonate bound > manganese oxides bound. Studies of lake and fluvial sediment indicated that most cadmium is bound to exchangeable site, carbonate fraction, and iron-manganese oxide minerals, which can be exposed to chemical changes at the sediment-water interface, and are susceptible to remobilization in water (Schintu *et al.*, 1991). In oxidized, near neutral water, CdCO_3 limits the solubility by precipitation (Kersten, 1988) or by adsorption (McBride, 1980) of Cd^{2+} . Results thus indicated a good portion of total Cd in sediment remained in bioavailable form potential for causing harm to different organisms.

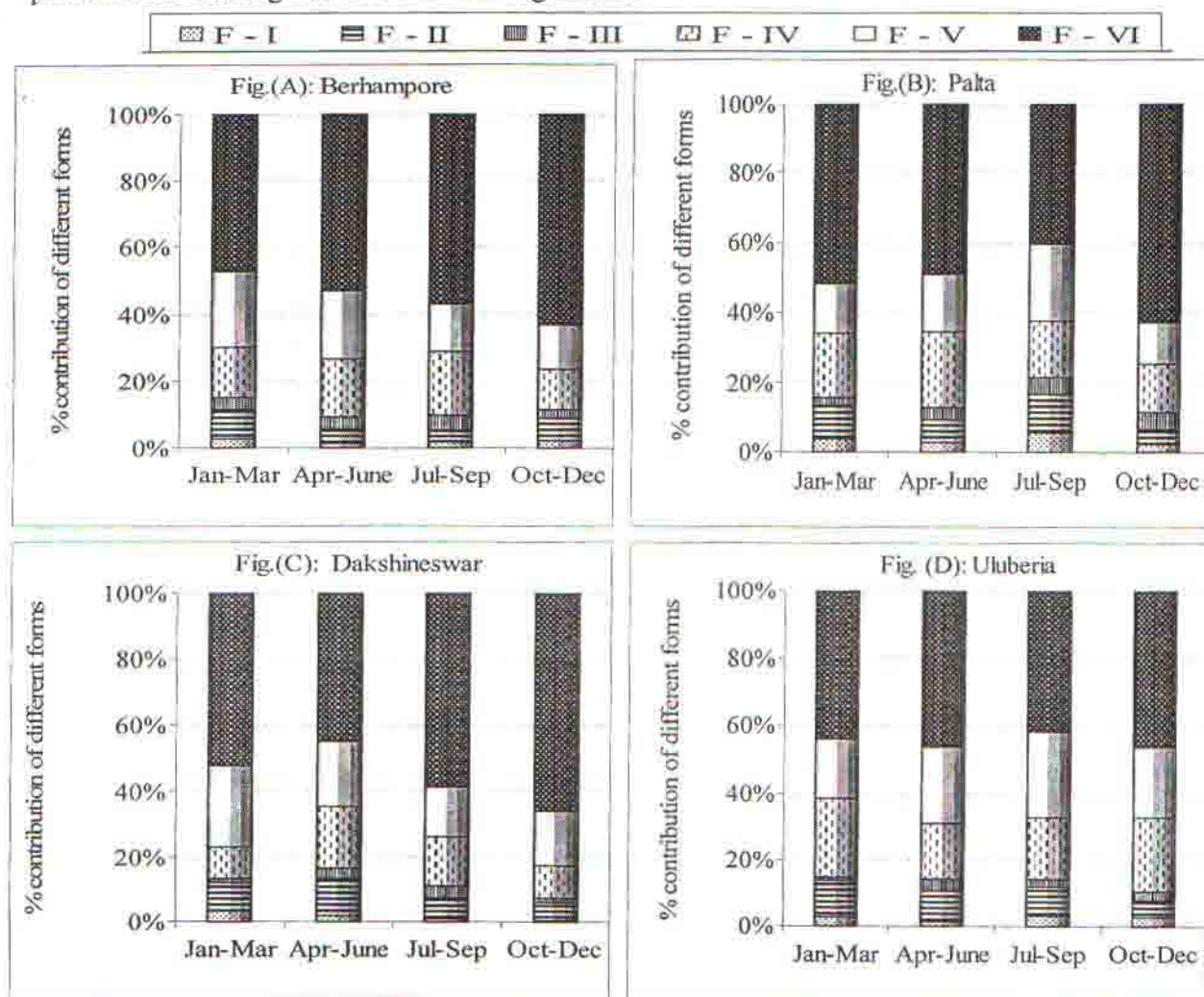


Fig.4.4.14 Forms of Cr in sediments collected periodically from sampling sites of the river Ganga

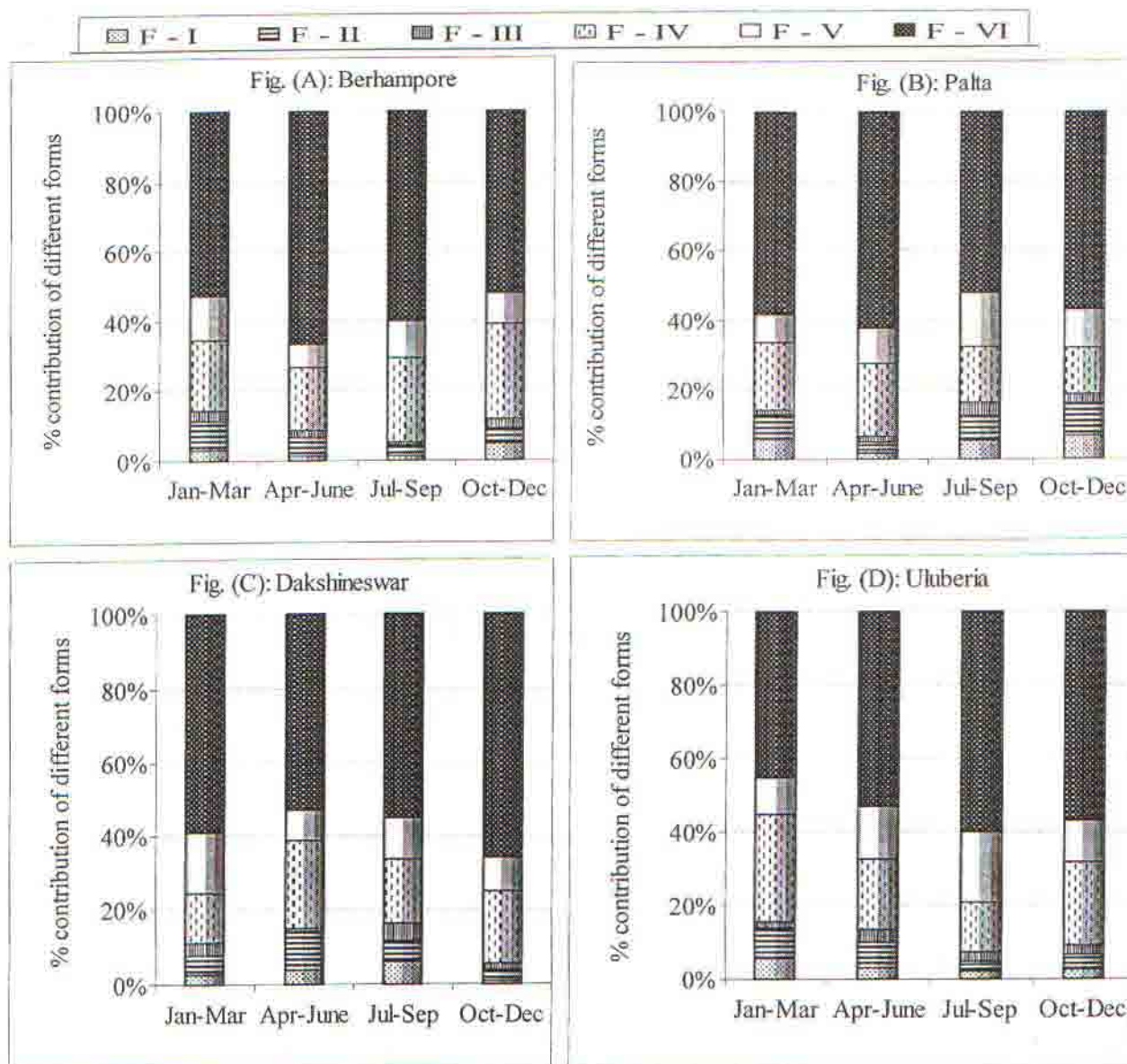


Fig.4.4.15 Forms of Ni in sediments collected periodically from sampling sites of the river Ganga

4.4.5.3. Chromium and nickel

The contribution of exchangeable (F - I), carbonate bound (F - II), manganese oxides bound (F - III), sesquioxides bound (F - IV), organic (F - V) and residual (F - VI) forms of Cr to total sediment Cr ranged from 0.7 - 5.6, 3.6 - 11.3, 1.2 - 5.0, 9.7 - 23.6, 14.3 - 35.6 and 40.6 - 66.1% with mean values of 2.5, 7.5, 3.1, 16.7, 18.6 and 51.6%, respectively (Fig. 4.4.14). The average share of different chemical forms of Cr in its total amount present in the sediment followed the sequence: residual > organic bound $\approx$ sesquioxides bound > carbonate bound > manganese oxides bound > exchangeable. Organic bound form of Cr thus contributed maximum portion of total Cr, followed by sesquioxides bound form.

Contribution of exchangeable (F - I), carbonate bound (F - II), manganese oxides bound (F - III), sesquioxides bound (F - IV), organic (F - V) and residual (F - VI) form of Ni to total sediment Ni varied from 0.5 - 6.7, 2.6 - 10.2, 1.0 - 4.6, 12.9 - 29.1, 6.6 - 19.0 and 52.1 - 66.8% with mean values of 3.6, 5.8, 2.5, 19.8, 11.4 and 56.9%, respectively

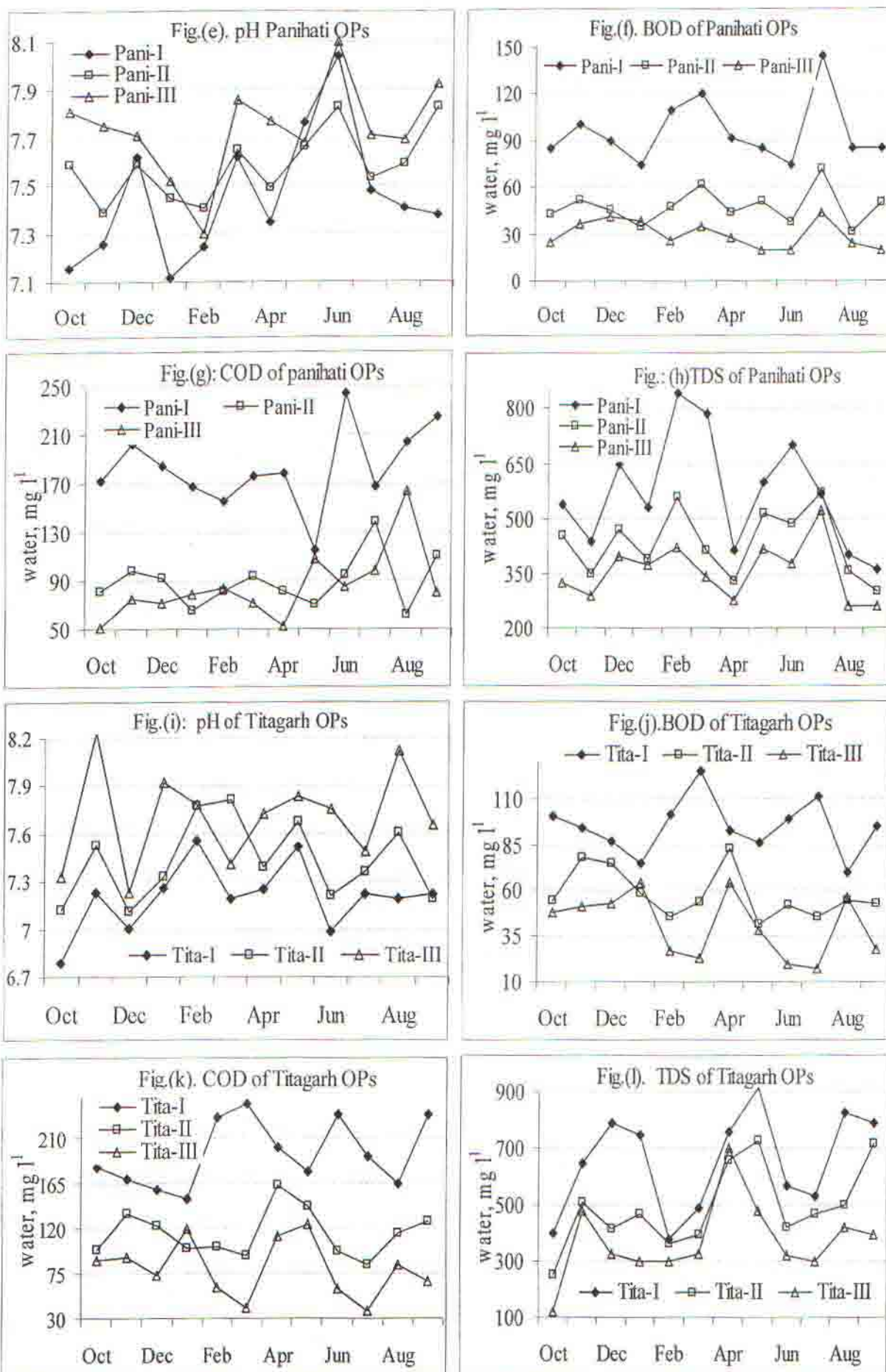


Fig. 4.5.1 Physico chemical properties of water of oxidation ponds at different locations
(I, II, III and IV denote OP-I, OP-II, OP-III and OP-IV)

possible bioavailability to the invertebrates. This can be assumed by fractionating different forms of nutrients in sediments. Keeping this in view changes in different forms of Zn in sediments as a function of contamination load in different OPs of the three locations are studied and presented in Table 4.5.9.

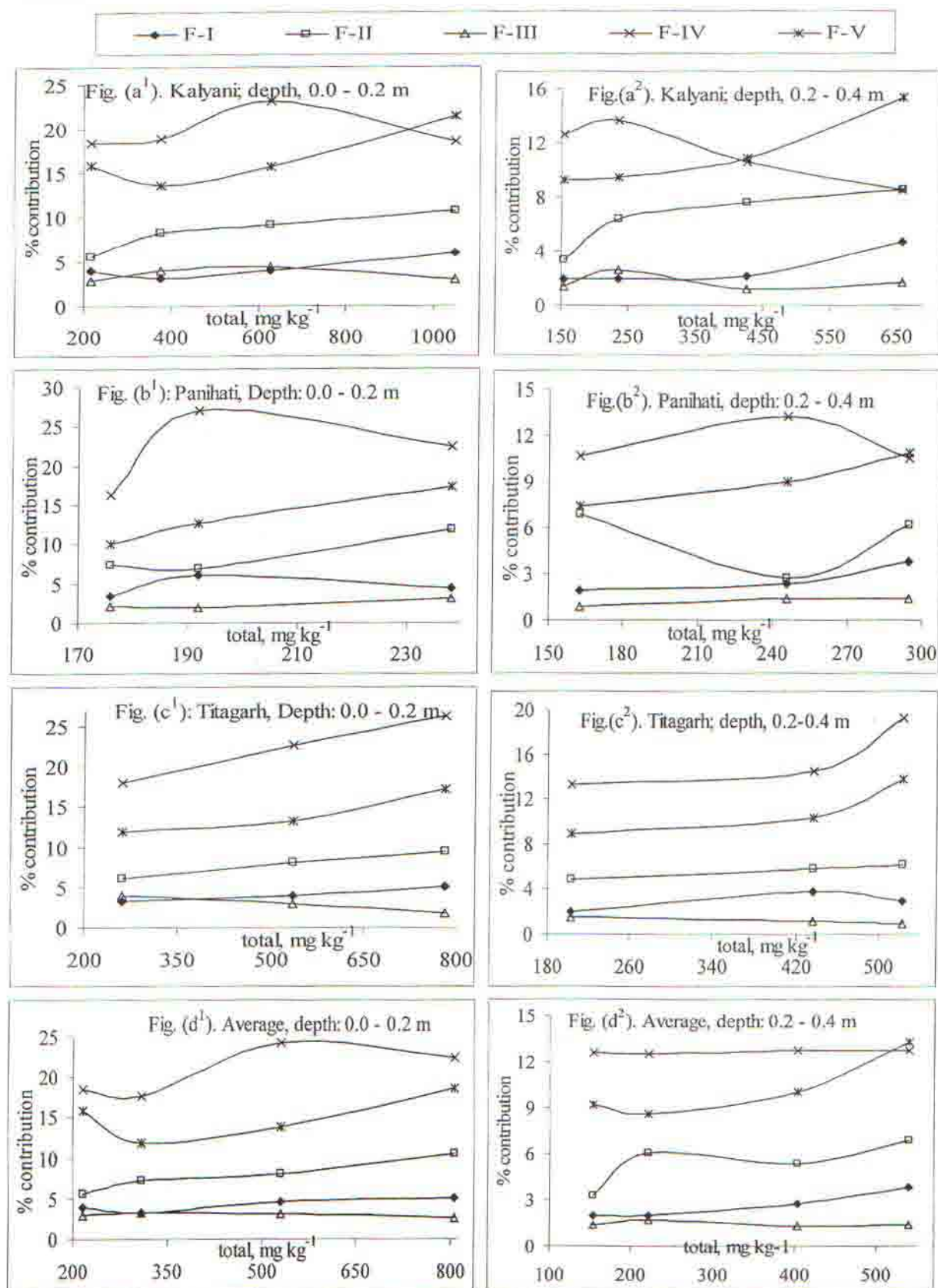


Fig. 4.5.4 Changes in the contribution of different forms in total Zn with its load in sediment

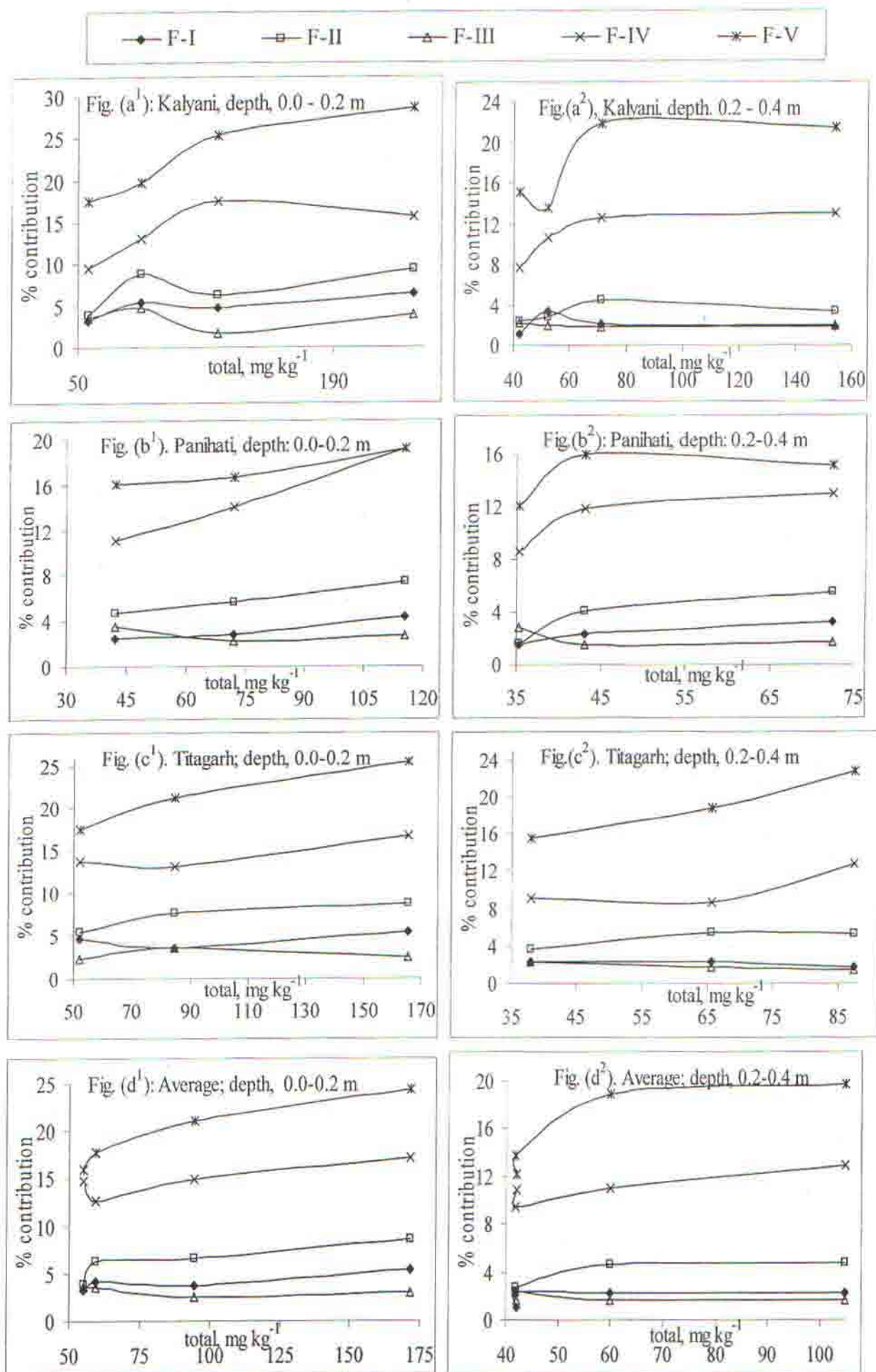


Fig. 4.5.8 Changes in the contribution of different forms in total Cu with its load in sediment

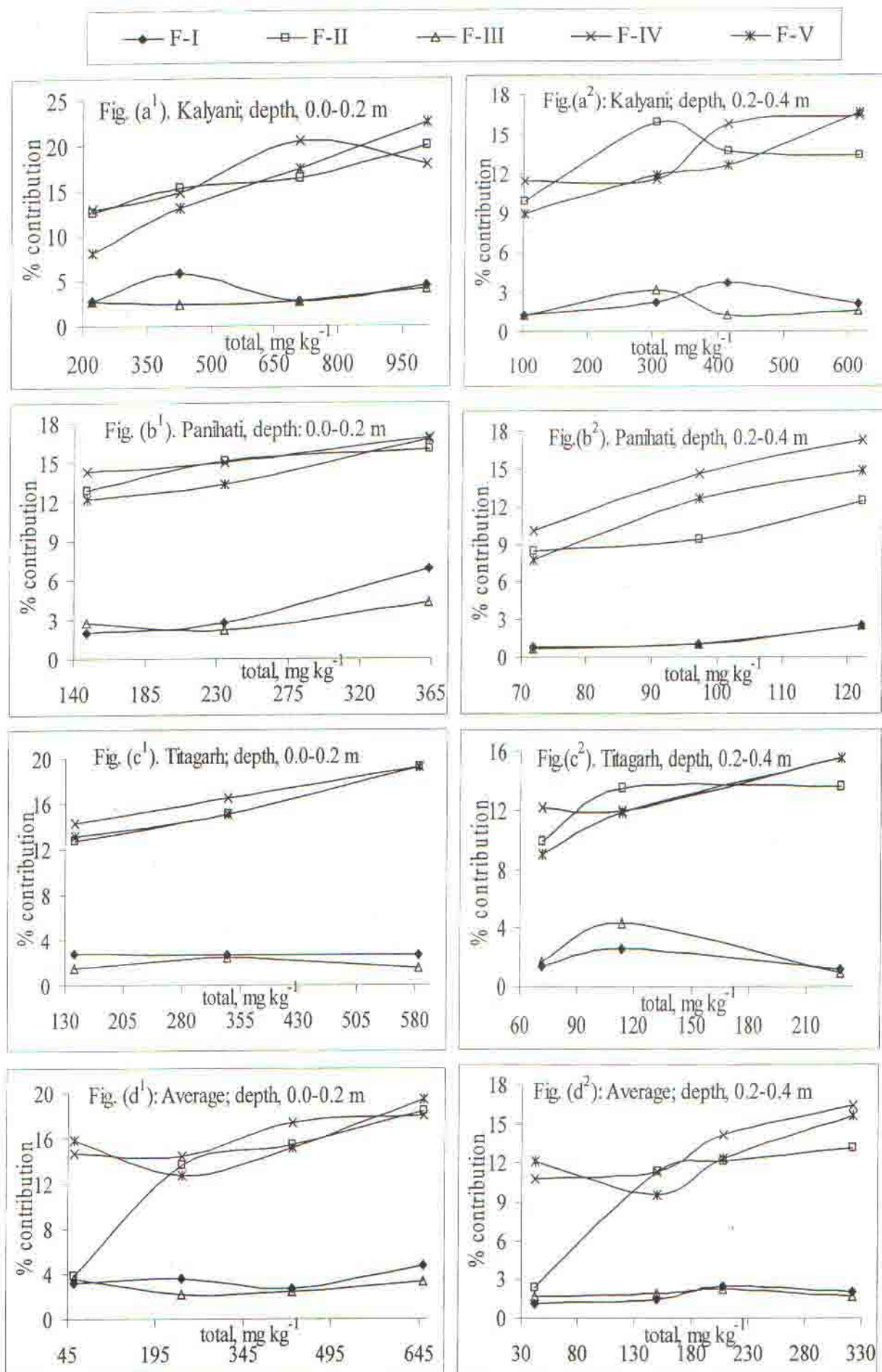


Fig. 4.5.12 Changes in the contribution of different forms in total Pb with its load in sediment

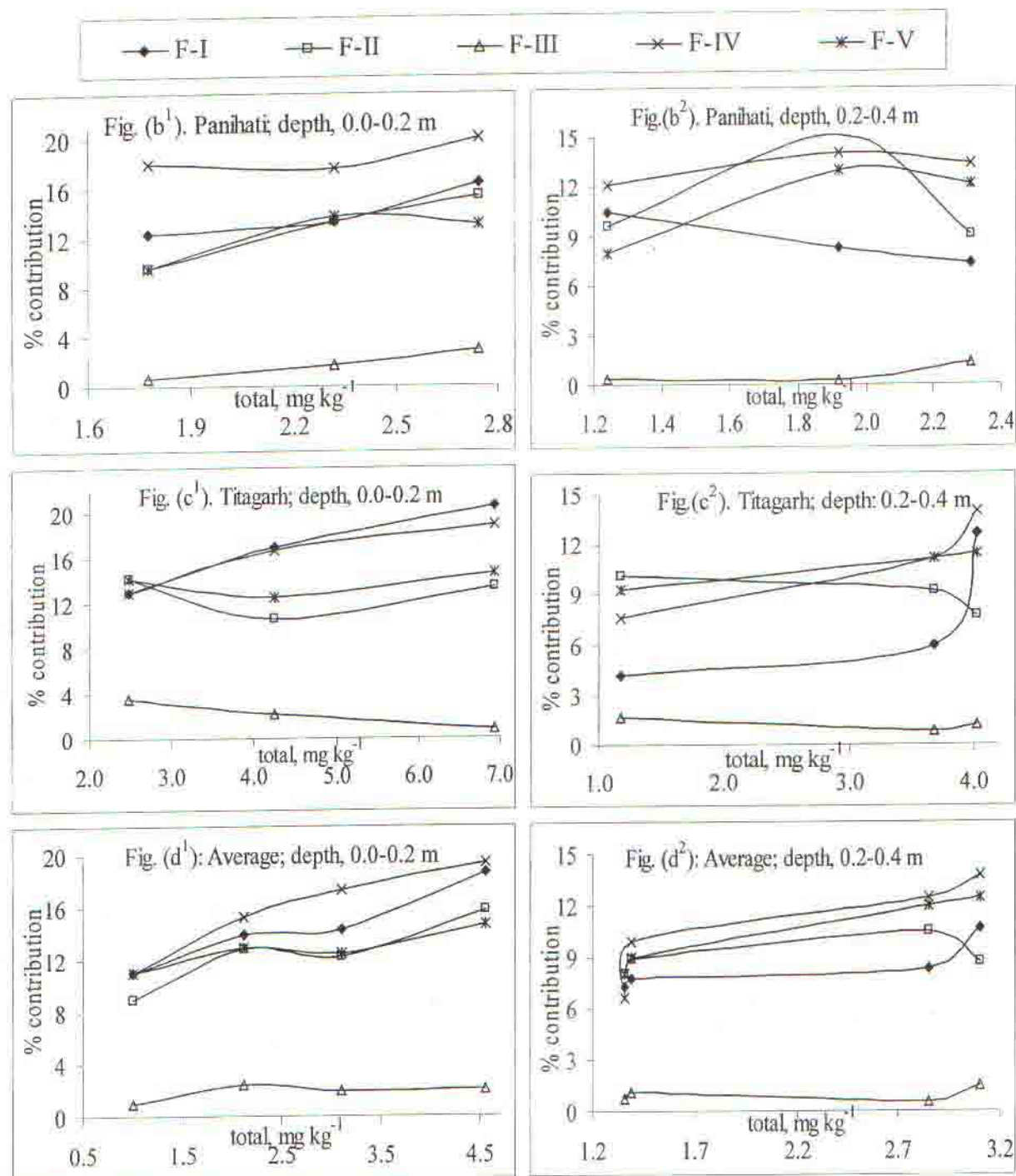


Fig. 4.5.16 Changes in the contribution of different forms in total Cd with its load in sediment

The contribution of exchangeable, carbonate and organic matter bound Cd, on the other hand, always increased with the levels of contamination i.e. from OP-IV to OP-I (Fig. 4.5.17). The higher slope of the regression equation between Cd concentration in water and its content in carbonate bound form indicated higher tendency of Cd to precipitate out from the over lying water column as carbonate or settling down as adsorbed ion on clay colloids or solid particles (exchangeable) from the heavily contaminated water.

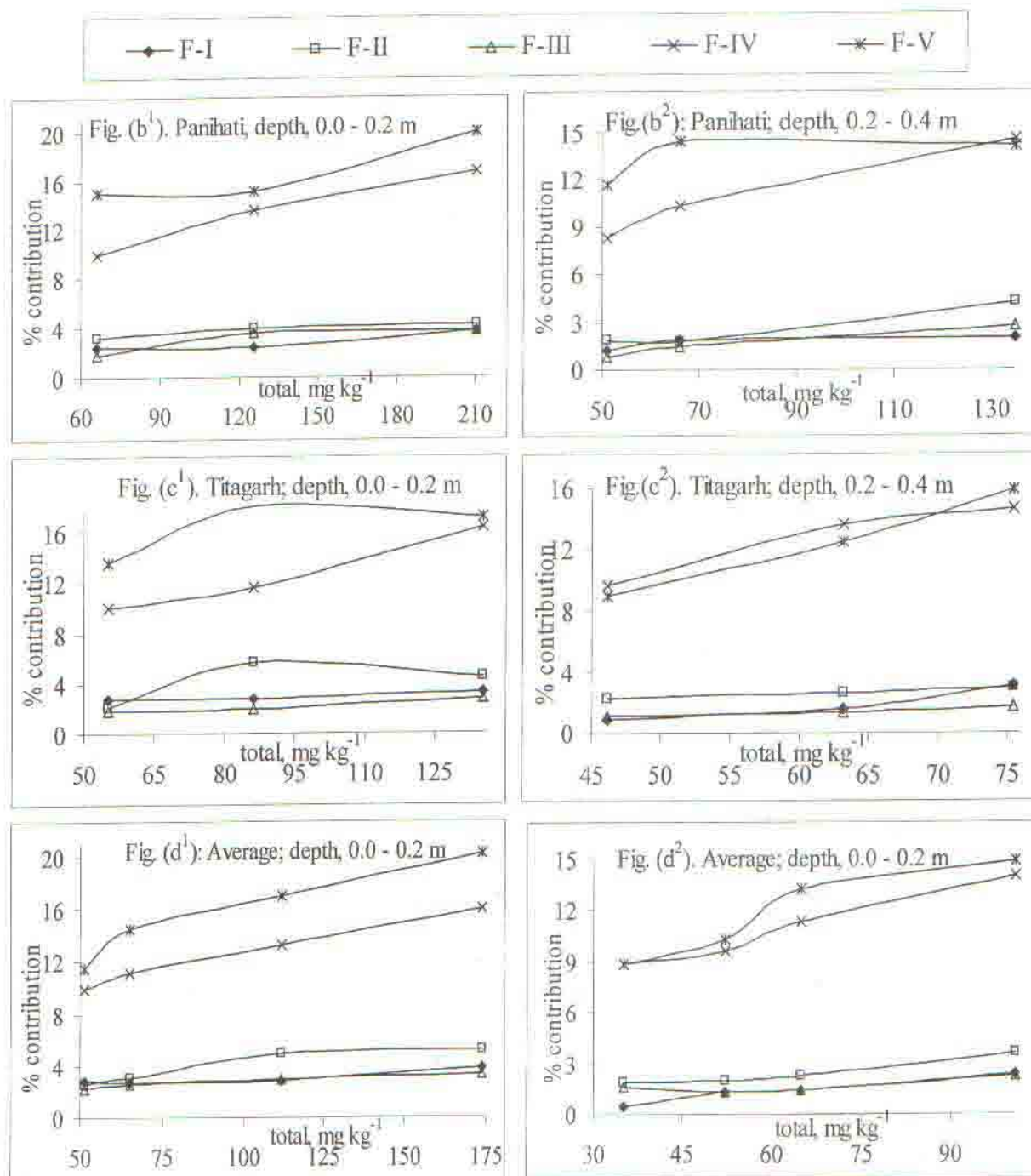


Fig. 4.5.20 Changes in the contribution of different forms in total Cr with its load in sediment

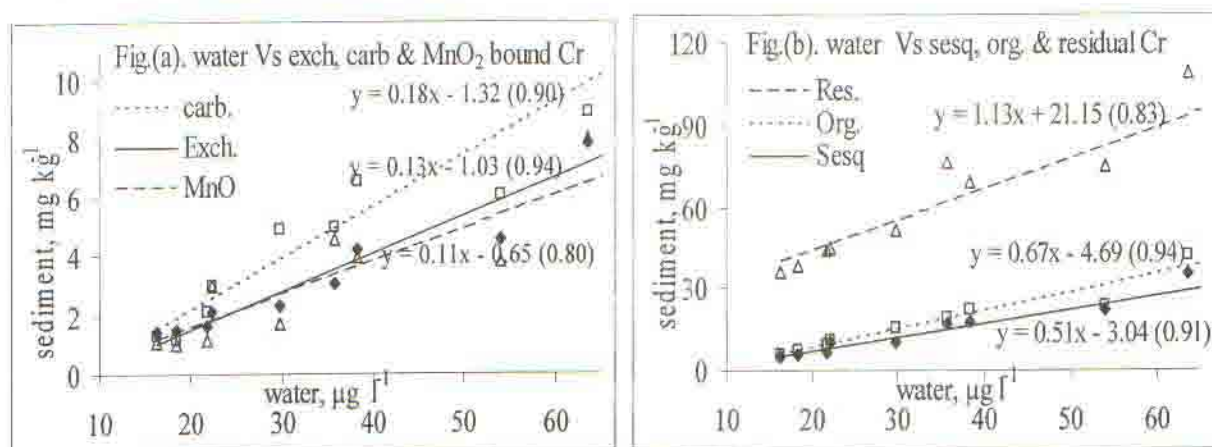


Fig. 4.5.21 Influence of concentration of Cr in water on Cr concentration in different forms in sediments

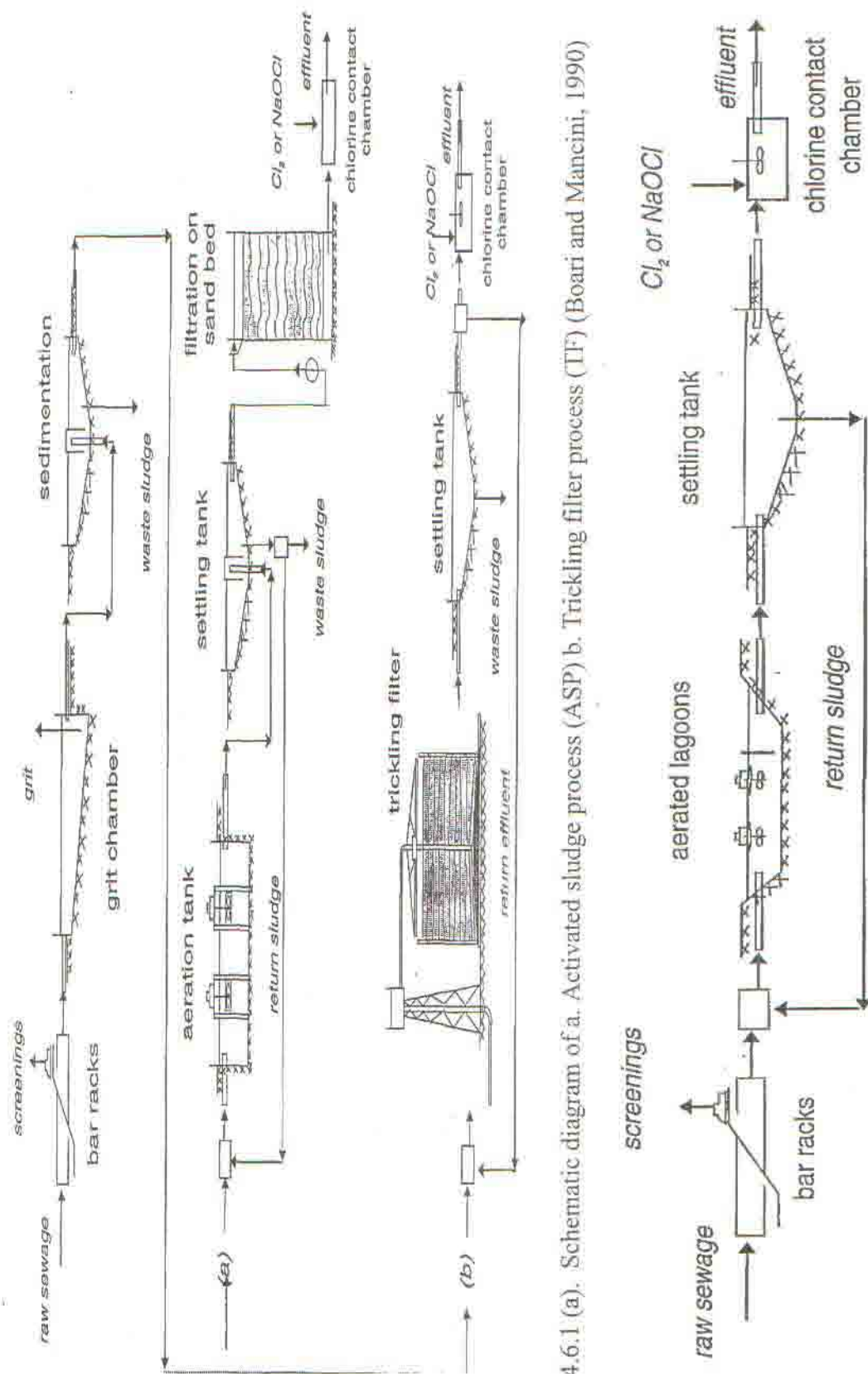


Fig. 4.6.1 (a). Schematic diagram of a. Activated sludge process (ASP) b. Trickling filter process (TF) (Boari and Mancini, 1990)

Figure 4.6.1(b) Schematic diagram of Oxidation Pond

Table 4.6.9 Average pollutant removal efficiency of different (%) different types of STPs

	ASP		TF		OP	
	Min	Max	Min	Max	Min	Max
Zn	41.6	87.2	17.0	83.0	50.7	90.6
Cu	42.6	87.2	36.2	85.1	26.9	96.3
Pb	44.7	89.9	39.4	88.1	54.3	96.4
Cd	41.9	87.9	20.6	86.9	31.2	93.5
Cr	31.6	92.3	52.1	90.3	45.6	94.7
Ni	29.5	84.5	28.6	76.9	30.7	94.4
BOD	41.5	86.7	35.3	84.7	54.0	91.3
COD	20.5	80.4	7.7	77.6	4.0	88.2
TDS	15.6	67.3	12.5	70.5	4.0	80.5
TSS	20.0	87.5	20.0	83.3	33.3	95.0
PO ₄	16.6	93.9	14.2	86.0	3.7	99.5

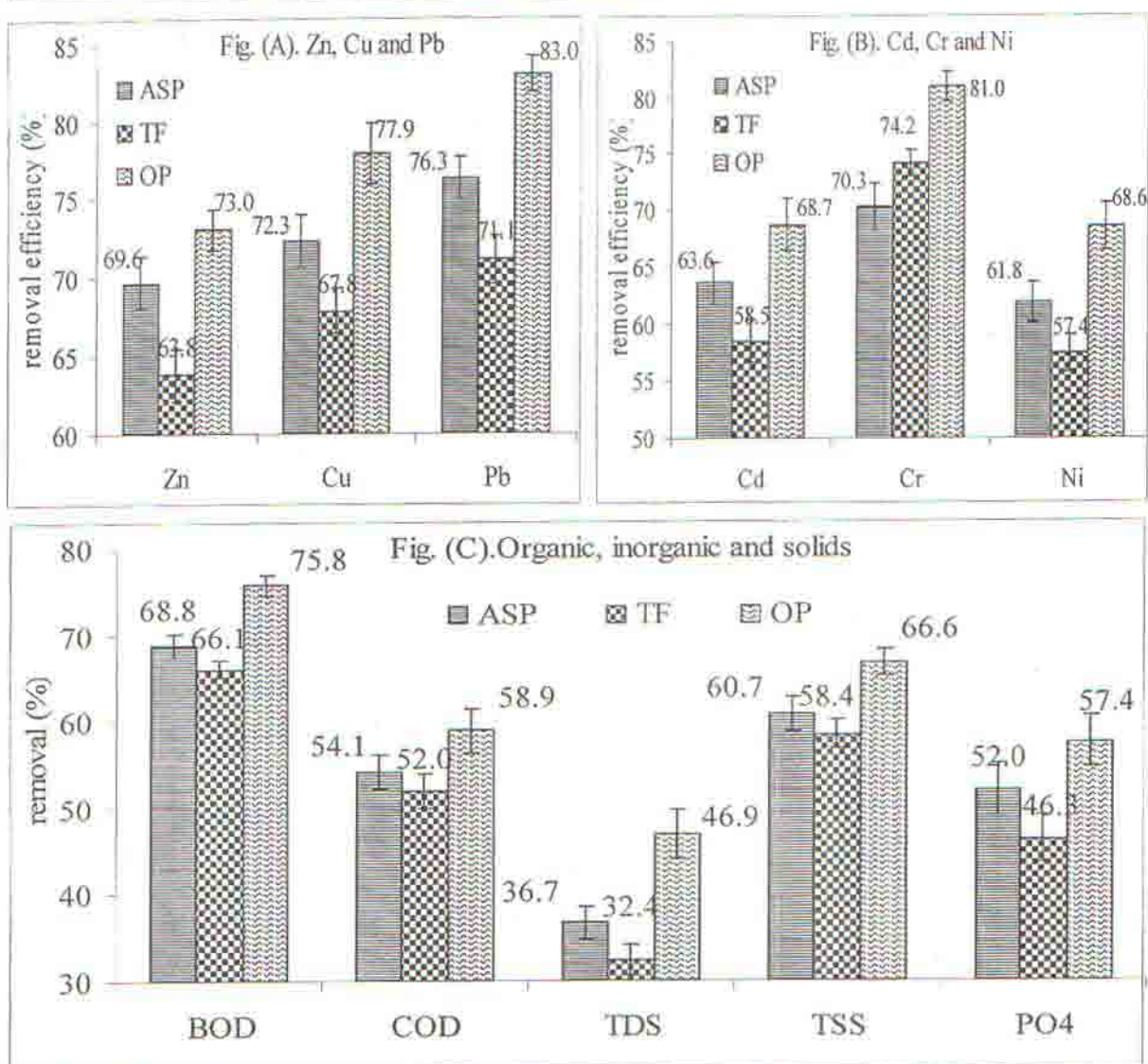


Fig. 4.6.2 Average pollutant removal efficiency of different types of sewage treatment plants

Existence of significant positive correlations between the removal efficiencies of different heavy metals indicated their more or less similar chemical behavior, especially in aqueous system (Table 4.6.10). Significant positive correlations of removal efficiency of

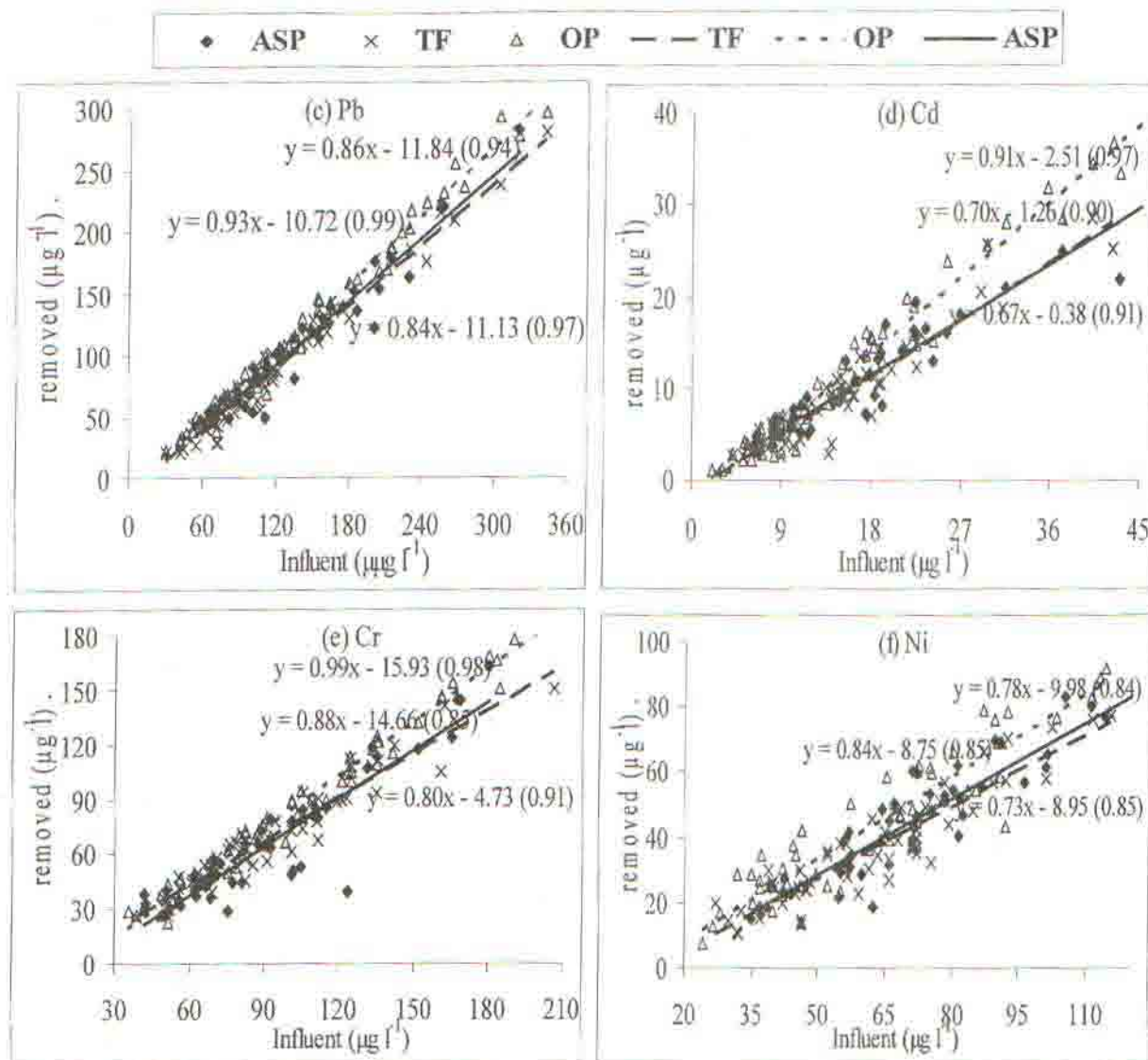
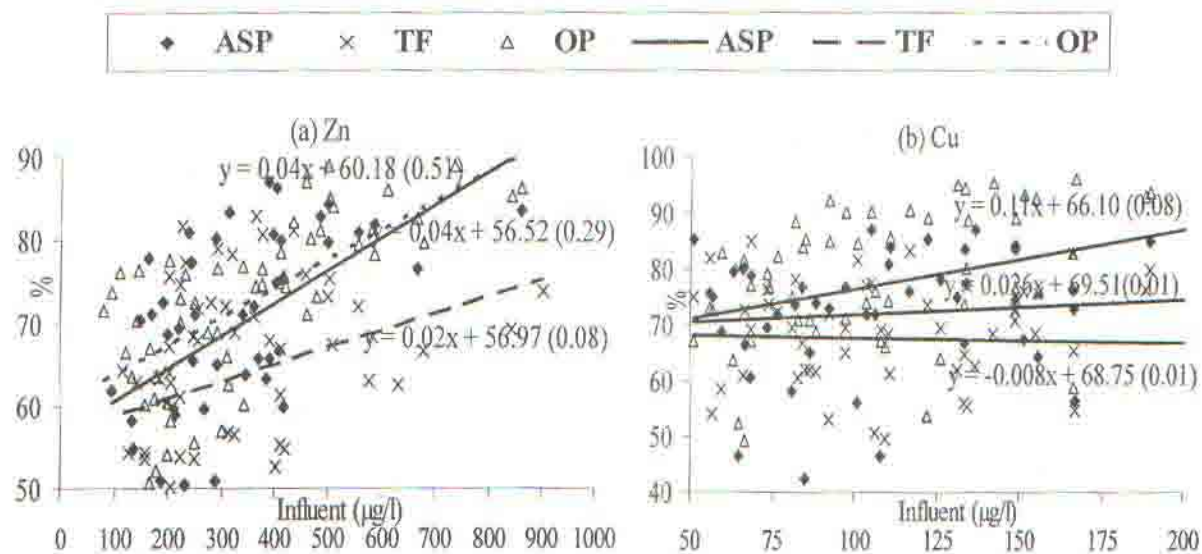


Fig. 4.6.3 Changes in quantitative removal of heavy metal with their load in influent ($\mu\text{g l}^{-1}$)



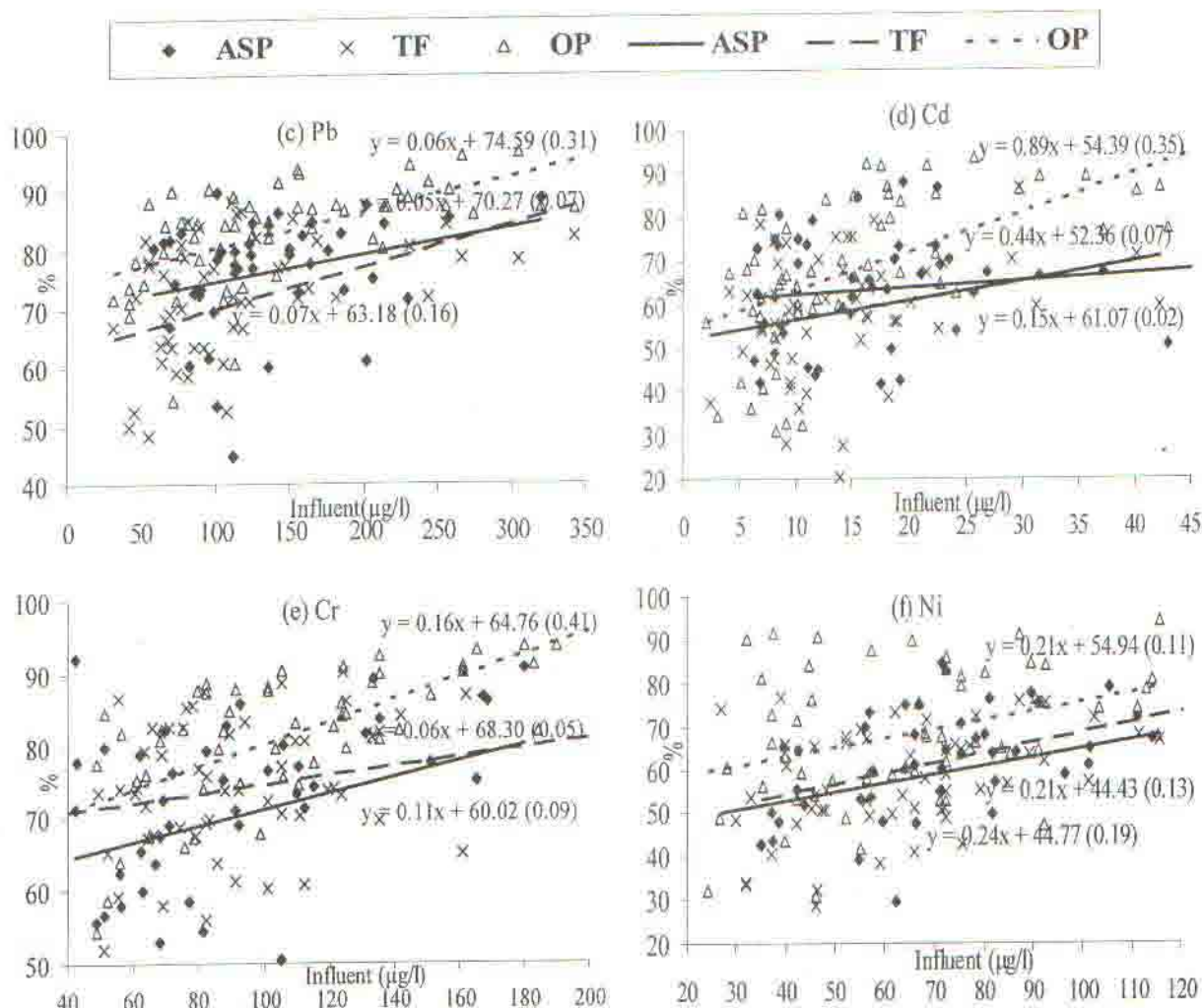


Figure 4.6.4 Changes in removal efficiency of heavy metals with increasing load in influent

4.6.2 Phyto-remediation of water

Phytoremediation is an emerging technology widely considered for the remediation of contaminated sites because of its cost effectiveness, aesthetic advantages and long term applicability. At present, the number of metal – accumulating taxa identified has grown to 397. Presently at least 45 plant families are known to contain metal – accumulating species (Salt *et al.*, 1998). Binding to the cell wall is not the only plant mechanism responsible for metal immobilization into roots and subsequent inhibition of ion translocation to the shoot. Metals can also be complexed and sequestered in cellular structures (e.g. vacuole), becoming unavailable for translocation to the shoot (Lasat *et al.*, 1998). In addition, some plants, coined excluders, possess specialized mechanisms to restrict metal uptake into roots. However, the concept of metal exclusion is not well understood (Peterson, 1983). Rhizofiltration can be defined as the use of plant roots to absorb, concentrate and/or precipitate hazardous compounds particularly heavy metals or radionuclides, from aqueous solutions (Salt *et al.*, 1995; Dushenkov *et al.*, 1995). Hyper accumulation ability of Pb, Cu,

decreased at all the levels of liming. The concentration of Zn dropped down to 60.9 mg kg^{-1} with 0.5% level of liming as compared to 89.9 mg kg^{-1} with no liming control. Concentration of Cu, Pb, Cd, Cr and Ni at 0.25 and 0.5% levels of liming in spinach was almost, however similar. This indicated that liming @ 0.25% level might be economically profitable for curbing Cu, Pb, Cd, Cr and Ni loading in spinach. A higher decrease in root concentration of Cd (50.4%) and Ni (43.1%) might be due to their presence in soluble form (Fig. 4.6.5). Higher tendency to get precipitated as PbCO_3 was the causes for Pb and Zn repetitively as ZnCO_3 . But the lowest decrease in the concentration of Cu (22.9%) and Cr (24.0%) might be due to the presence of these two metals maximum in organic matter bound form which is less affected by the pH of the environment. John and Van Laerhoven (1972) showed that higher pH resulted in lower Cd uptake. Peles *et al.* (1998) concluded that the addition of lime to contaminated soils (essentially increasing the pH) decreased the uptake of heavy metals. In unlimed soils *Ambrosia trifida* accumulated $13.6 \mu\text{g Cd g}^{-1}$ of tissue and in limed soils *A. trifida* accumulated $2.5 \mu\text{g Cd g}^{-1}$ of tissue.

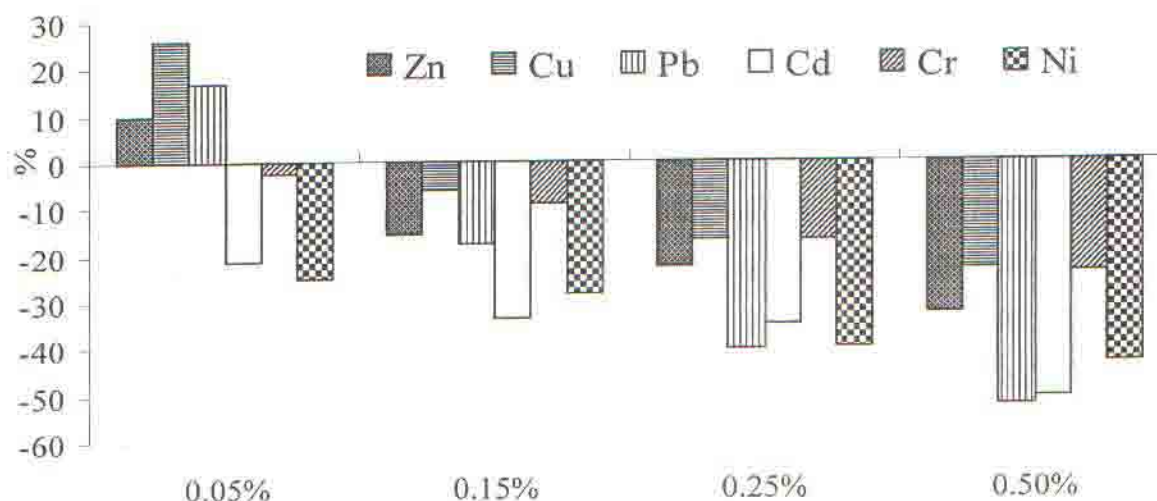


Figure 4.6.5 Effect of liming on the changes (%) in concentration of heavy metals in spinach over the no lime control

Table 4.6.26 Effect of liming on the heavy metal content of Mustard (mg kg^{-1})

Lime (%)	Parameters							
	Dry Matter (g.)	Soil pH	Zn	Cu	Pb	Cd	Cr	Ni
0.00	6.40 ^a	6.74 ^a	131.12 ^a	17.66 ^a	19.31 ^a	1.68 ^a	13.06 ^a	20.54 ^a
0.05	6.80 ^{a,b}	6.95 ^a	122.46 ^b	17.35 ^{a,b}	19.23 ^a	1.43 ^a	12.22 ^{a,b}	18.55 ^b
0.15	6.91 ^{a,b}	7.22 ^b	117.00 ^a	15.21 ^b	17.24 ^b	1.50 ^a	11.46 ^b	17.16 ^{b,c}
0.25	7.33 ^b	7.32 ^{b,c}	105.14 ^c	14.67 ^{c,d}	14.31 ^c	0.94 ^b	9.62 ^c	15.54 ^c
0.50	7.43 ^b	7.46 ^c	92.11 ^d	13.83 ^d	12.72 ^d	0.67 ^c	9.37 ^c	13.65 ^d
Sem ±	0.24	0.07	3.46	0.88	0.52	0.08	0.56	0.63

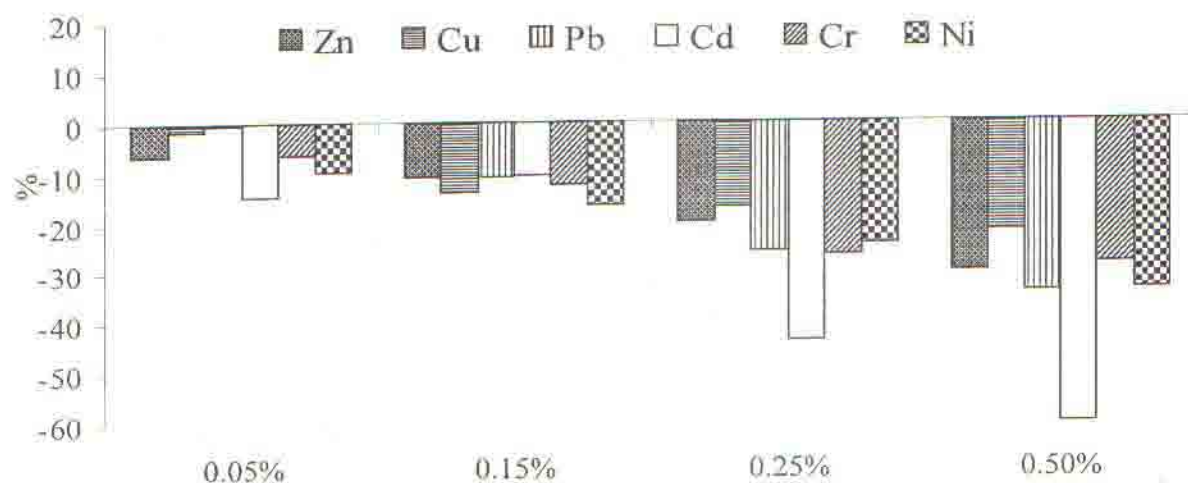


Fig. 4.6.6 Effect of liming on the changes (%) in concentration of heavy metals in mustard over the no lime control

There was almost similar changes in dry matter yield of mustard like spinach, upon application of lime at different levels (Table 4.6.26). The shoot concentration of all the six heavy metals, however, decreased upon liming. The magnitude of decrease in heavy metals concentration upon 0.5% level of liming as follows: Cd (60.0%) > Pb (34.1%) > Ni (33.6%) > Zn (29.8%) > Cr (28.3%) > Cu (21.7%) (Fig. 4.6.6). Chen and Liu (1999) observed the application of organic composts along with CaCO_3 significantly reduced the concentration of Cd and Pb in cabbage. Applying amendments of calcium carbonate transformed the exchangeable forms of Cd and Pb into unavailable sulfide and residual fractions (Chen *et al.*, 1997). Bolan and Duraisamy (2003) also reported that lime was effective in reducing the phyto availability of Cd and Cr.

