Long Term Effects of Municipal Sewage on Soils and Pastures

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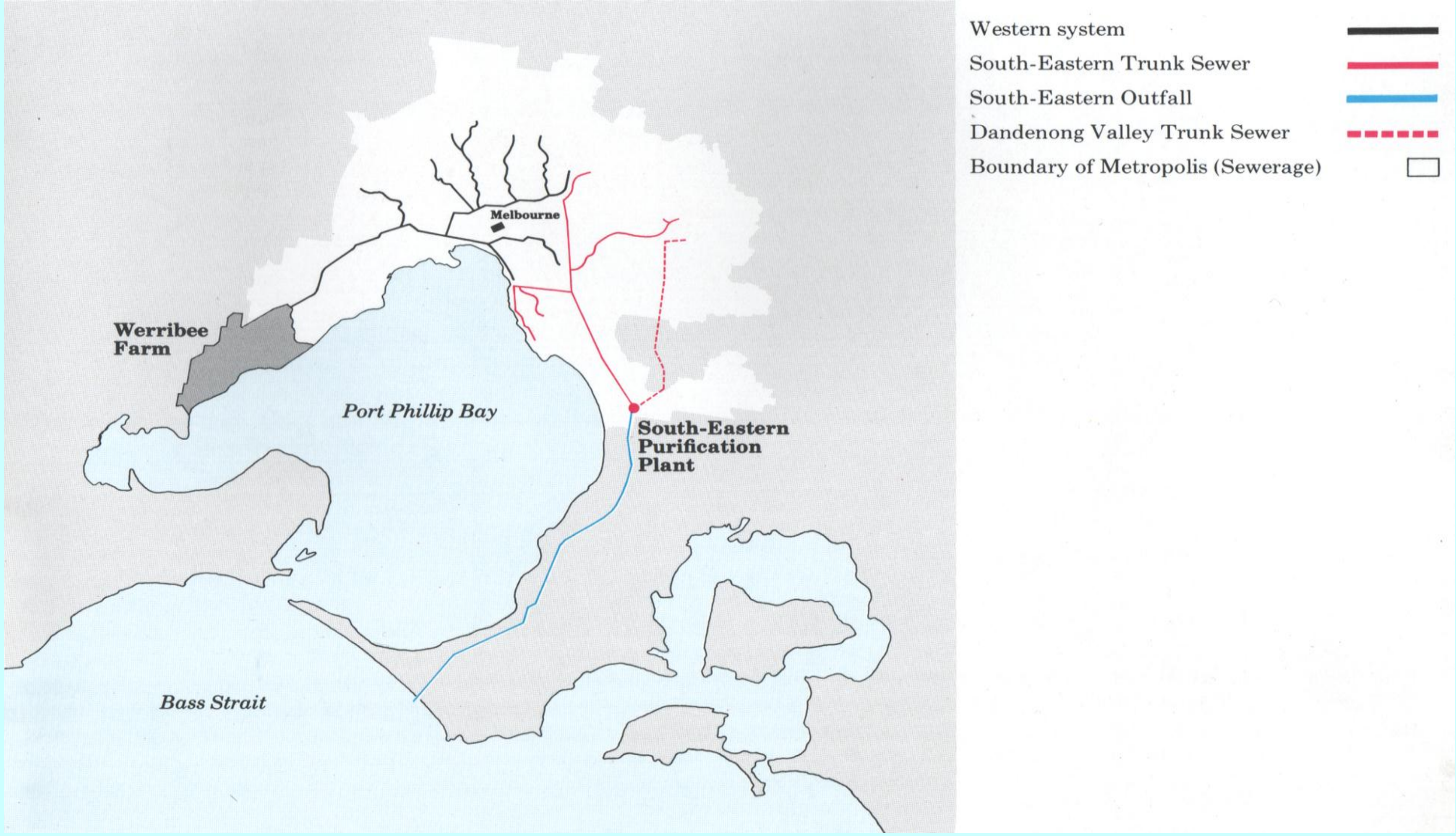
Werribee Sewerage Farm

- 

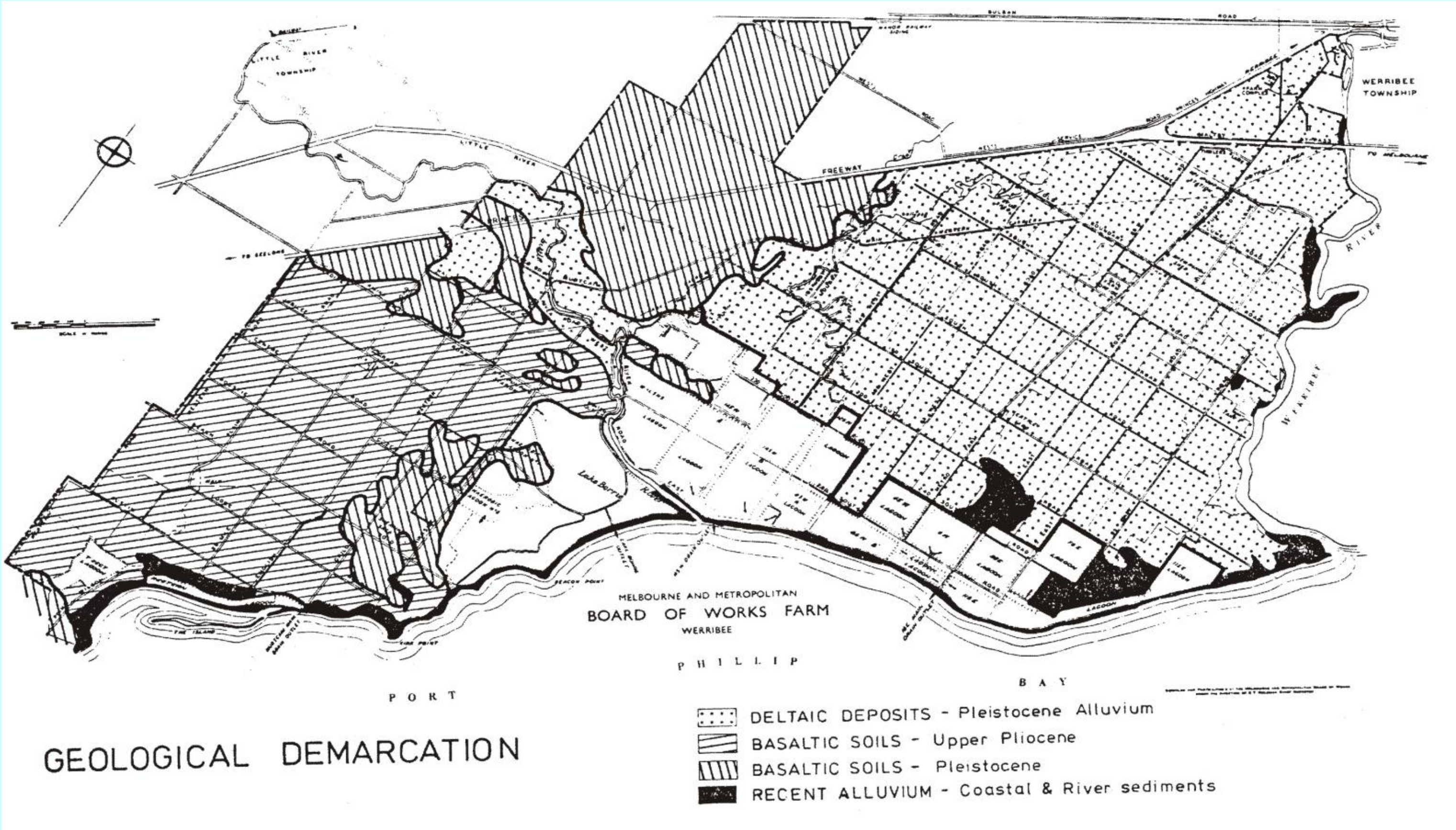
Site Information

- Commenced 1897
- Size 10,900 ha
- Annual Rainfall 500-550 mm
- Annual Evaporation 1,400 mm
- Weekly Irrigation Flow 1,743 ML
- Average Irrigation Application 11.2 ML/ha.year

Soils of the Werribee Farm

- Basalt and alluvial basaltic and sedimentary parent material
- Texture contrast soils
  - Medium to heavy clay subsoils, high shrink swell
- Free $CaCO_3$ at 30 cm depth
- pH 5-7 (surface) to 8-9 (subsoil)

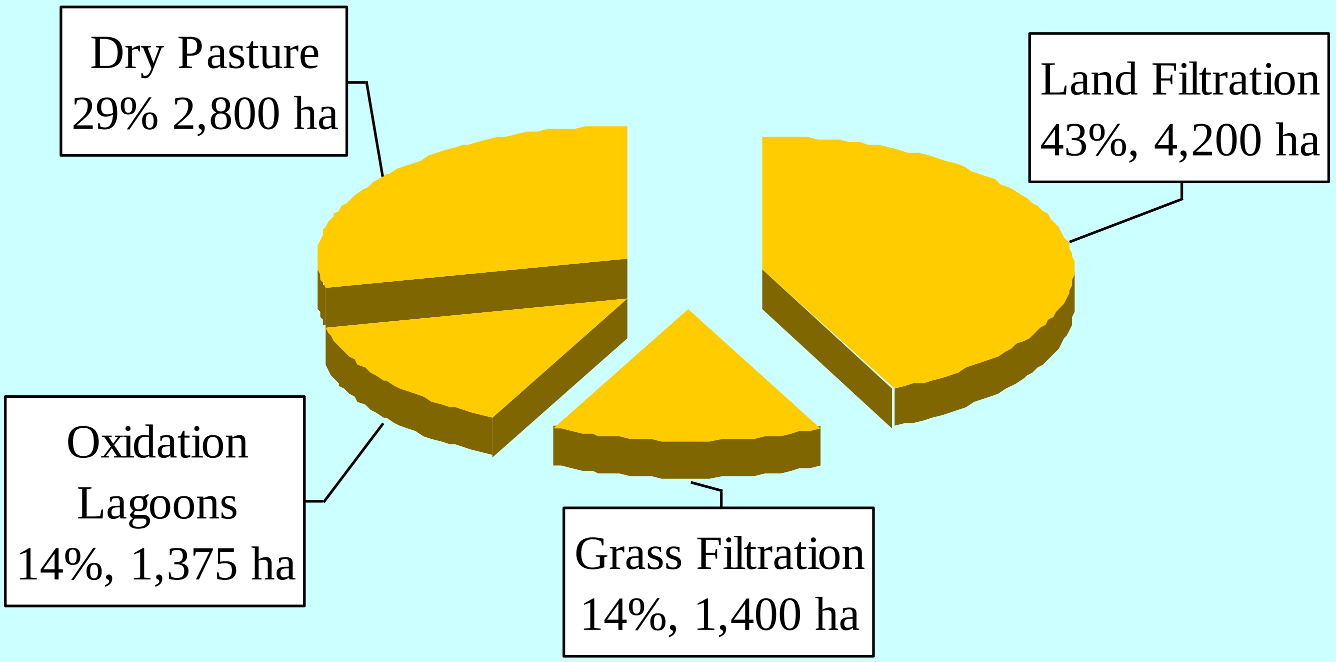
Geology and Soils



Disposal of Sewage

- Treatment in Lagoons and Discharge to Bay 46%
- No Treatment and Irrigation 54%

Activities carried out at Werribee (total area 10,900 ha)



Soils in Irrigation Regions at Werribee (total area 10,900 ha)

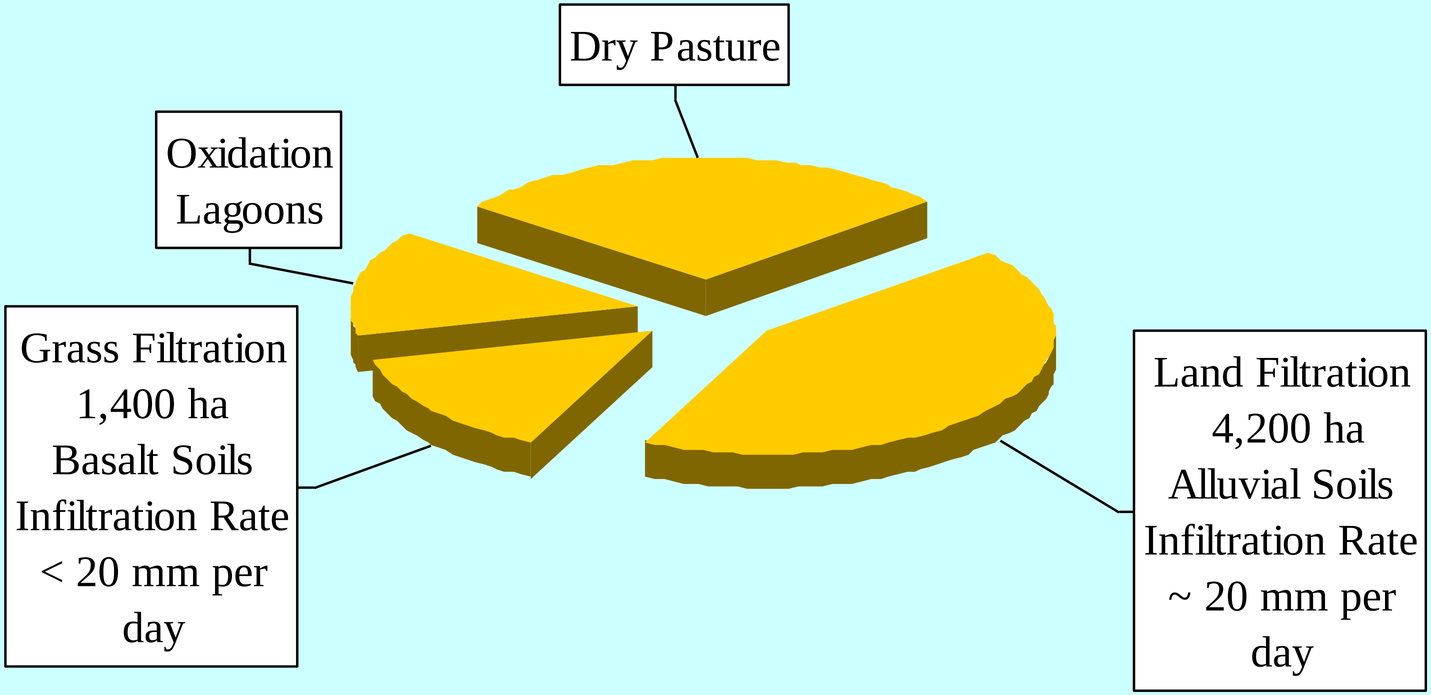
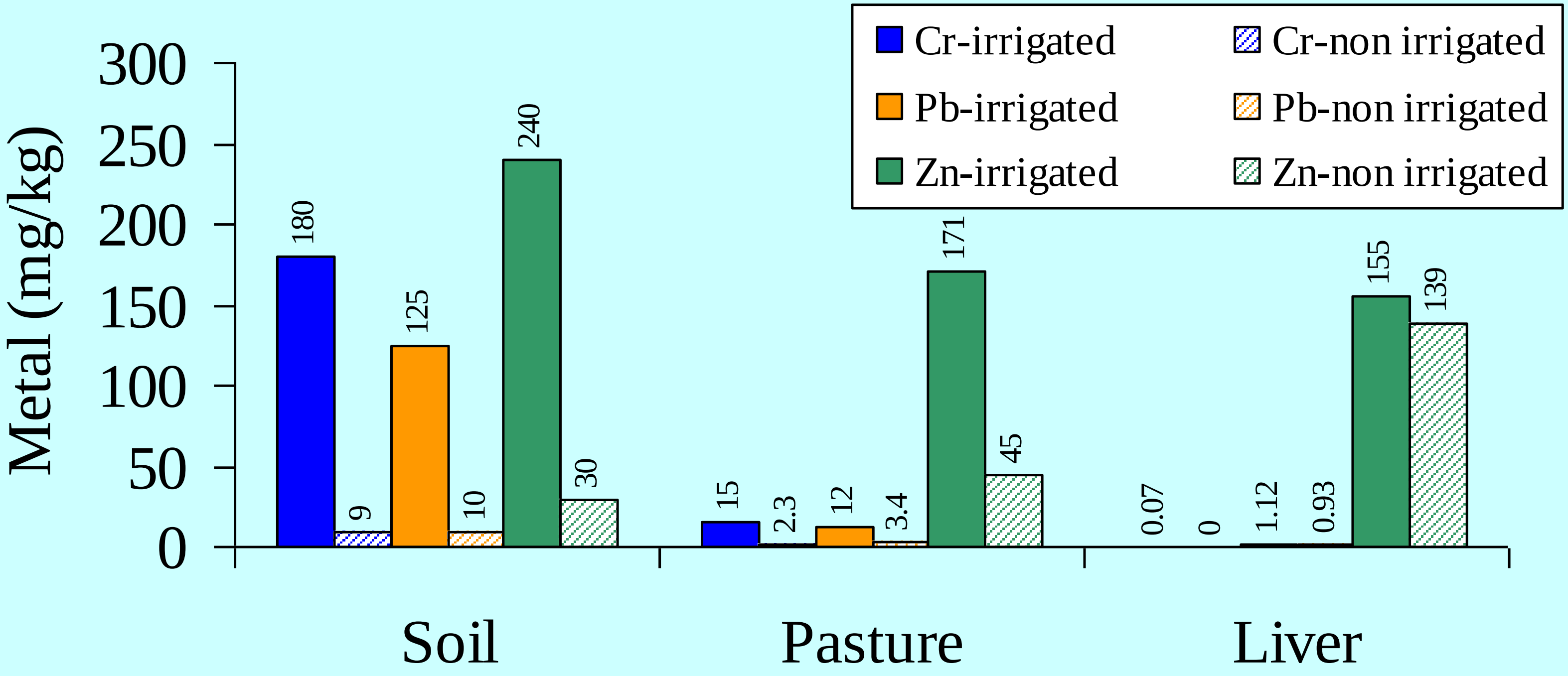


Table 1. Mean Heavy Metal and Total P content (mg/L) in raw sewage and annual loading to soil by irrigation (kg/ha (1) and moles/ha (2))

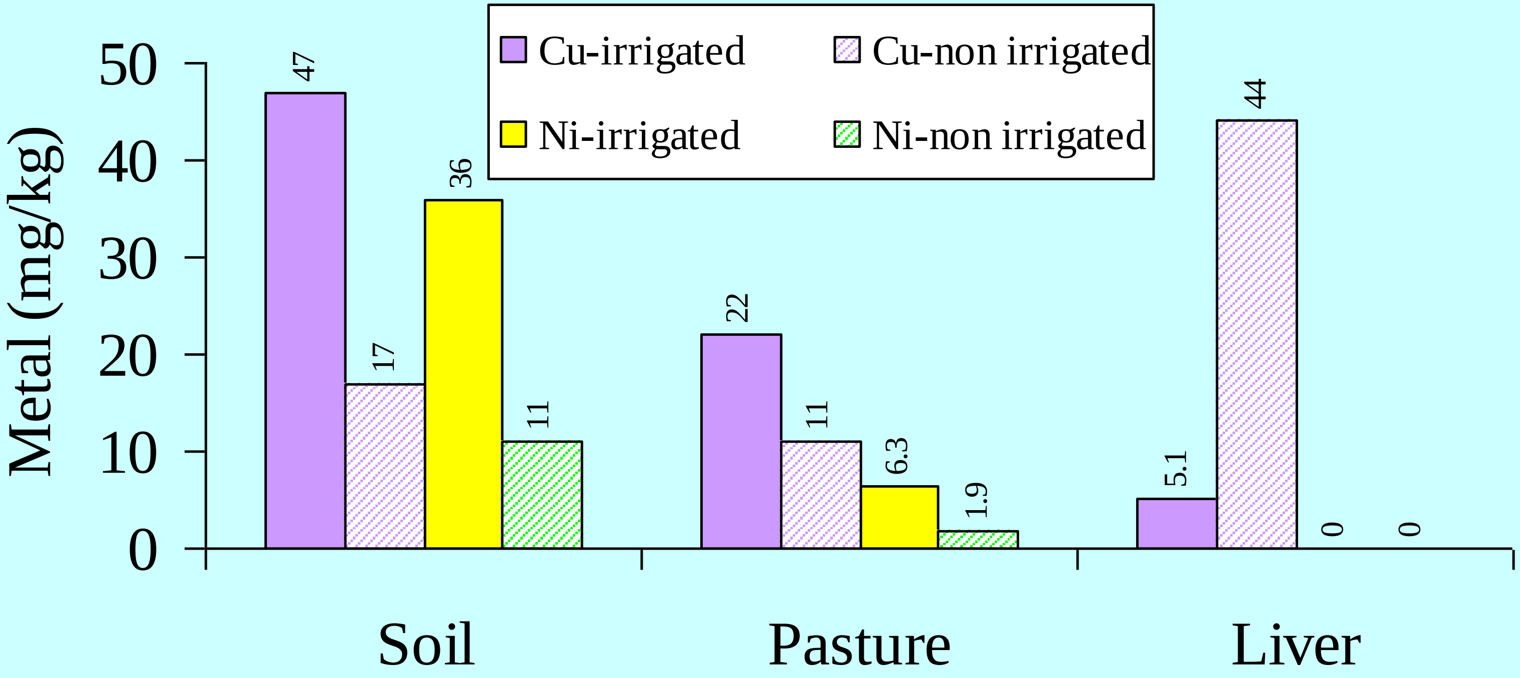
	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn	Total P
Raw sewage	0.11	0.59	0.25	2.28	0.002	0.09	0.22	0.77	10.8
Annual Loading (1)	1.77	9.45	4.07	36.71	0.32	1.45	3.51	12.40	174
Annual loading (2)	15.8	181.7	64.1	657.3	1.6	24.7	16.9	189.7	5615

Heavy Metal Transfer; Soil to pasture to animal tissue



Data taken from Evans et al. (1978) *Heavy Metal Accumulation in Soil Irrigated by Sewage and Effect in Plant-Animal Systems* (Figure 3).

Heavy Metal Transfer; Soil to pasture to animal tissue



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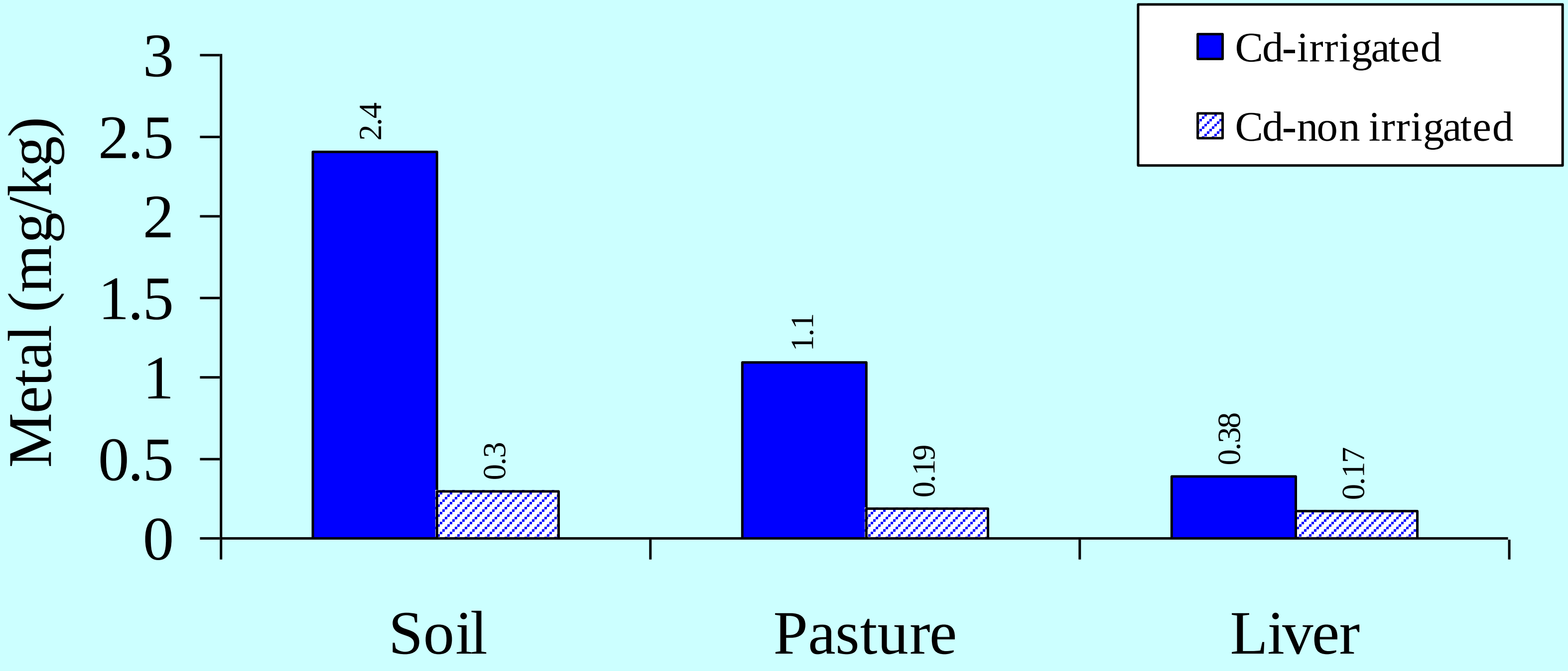
Heavy Metal Transfer; Soil to pasture to animal tissue



Data taken from Evans et al. (1978) *Heavy Metal Accumulation in Soil Irrigated by Sewage and Effect in Plant-Animal Systems* (Figure 3).

Monitoring of site

- Land and Grass Filtration sites
  - Soil sampling 0-10, 10-20 cm
  - Herbage twice per year
- Wastewater
  - Flow every 2 weeks
  - Composition monthly

Outcome of monitoring

- Years 1976 to 1993
- Heavy metals -Soil
  - Accumulation of all metals except Fe and topsoil Zn
  - Greater concentration of all metals except Fe in topsoil compared to subsoil, in both treatments
  - Greater concentration of all metals except Fe in topsoil under grass filtration compared to land filtration

Outcome of monitoring

- Heavy metals –Soil
  - Greater rate of accumulation in subsoil than topsoil
  - Greater rate of accumulation from grass filtration than from land filtration in subsoil for all metals except Zn
  - Little difference in accumulation rate in topsoil between treatments

Outcome of monitoring

- Heavy metals –Herbage
  - Decline in all metals except Fe
  - Decline in Cd, Cr and Zn greater in land filtration
  - Decline in Cu, Pb, Ni similar under both treatments
  - Increase in Fe greatest in land filtration

Table 2. Slope of Metal versus Time charts

	METAL						
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Herbage-grass	*-0.00005*	*-0.005*	*-0.030*	6.16	*-0.022*	*-0.019*	*-0.354*
Herbage-land	*-0.001*	*-0.013*	*-0.033*	9.86	*-0.027*	*-0.017*	*-0.461*
Soil-grass (0-10 cm)	0.032	0.077	0.073	*-0.044*	0.067	0.046	*-0.008*
Soil-grass (10-20 cm)	0.040	0.328	0.128	*-0.017*	0.063	0.273	0.610
Soil-land (0-10 cm)	0.032	1.102	0.773	*-0.058*	0.072	0.067	*-0.025*
Soil-land (10-20 cm)	0.056	2.166	1.111	*-0.070*	0.178	0.849	0.430

(negative slopes in italics)

Table 3. Intercept of Metal versus Time charts

	METAL						
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Herbage-grass	0.167	1.106	7.07	88.34	4.05	2.269	64.06
Herbage-land	0.345	3.361	12.56	152.26	4.16	3.173	93.30
Soil-grass (0-10 cm)	0.682	157.41	42.59	2.642	31.29	81.69	177.42
Soil-grass (10-20 cm)	*-0.497*	58.42	20.03	2.382	24.58	24.16	69.31
Soil-land (0-10 cm)	2.621	274.28	105.2	2.894	49.82	126.81	196.68
Soil-land (10-20 cm)	0.377	76.30	24.59	3.225	32.67	42.34	125.66

(negative intercepts in italics)

Figure 1 Cadmium in topsoil (0-10 cm) under land filtration and grass filtration

Grass Filtration, Cd = 0.032 x + 2.621
Land Filtration, Cd = 0.032 x + 0.682

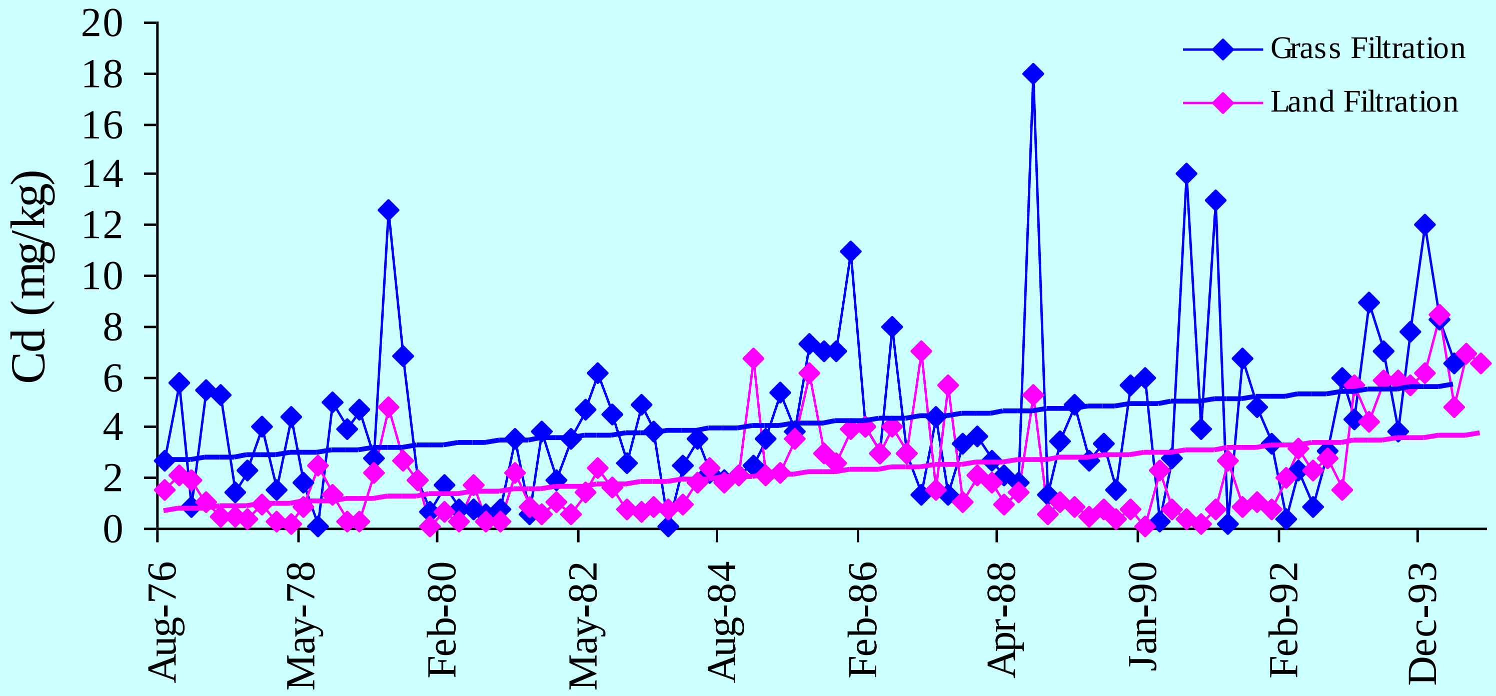


Figure 2 Cadmium in subsoil (10-20 cm) under land filtration and grass filtration

Grass Filtration, Cd = 0.056 x + 0.3774

Land Filtration, Cd = 0.040 x – 0.497

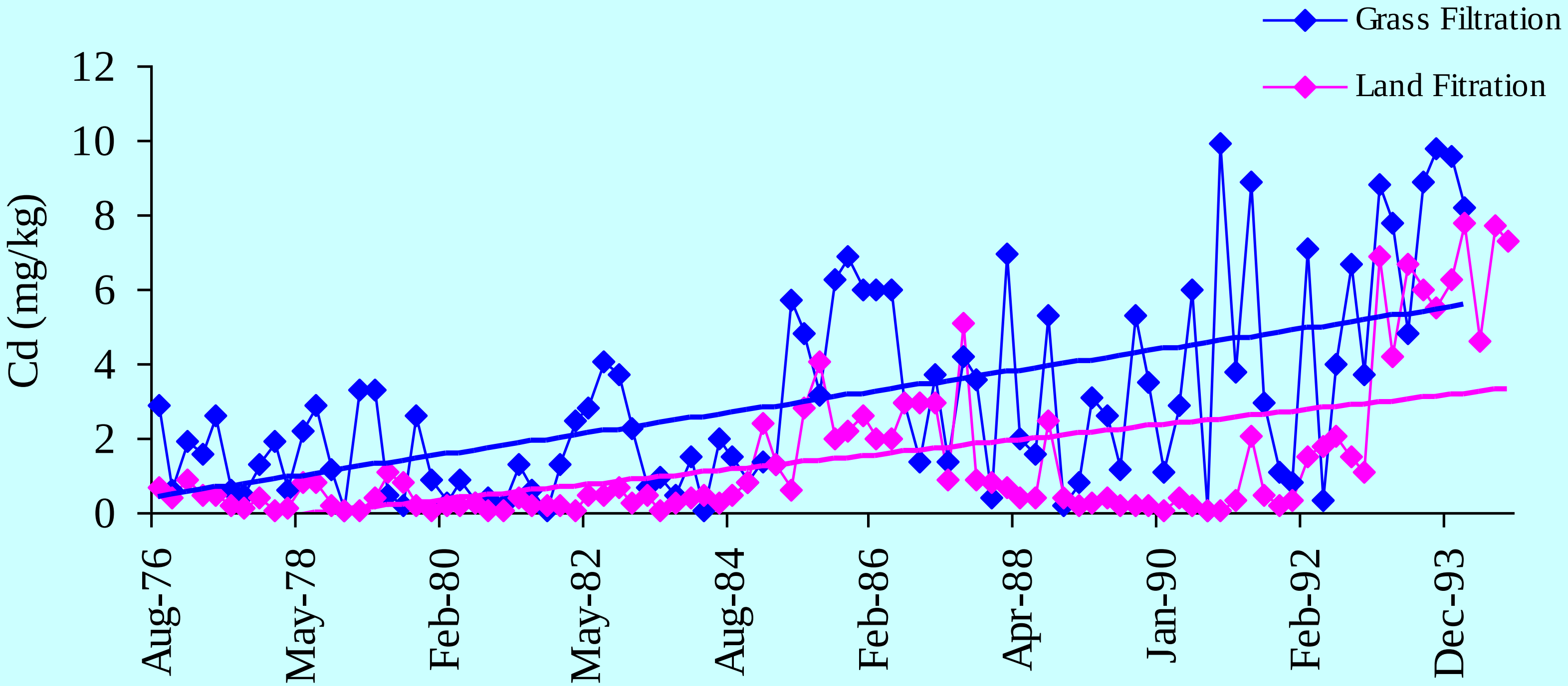


Figure 3 Cadmium in soil under grass filtration

0-10 cm,   Cd = 0.032 x + 2.621

10-20 cm, Cd = 0.056 x + 0.377

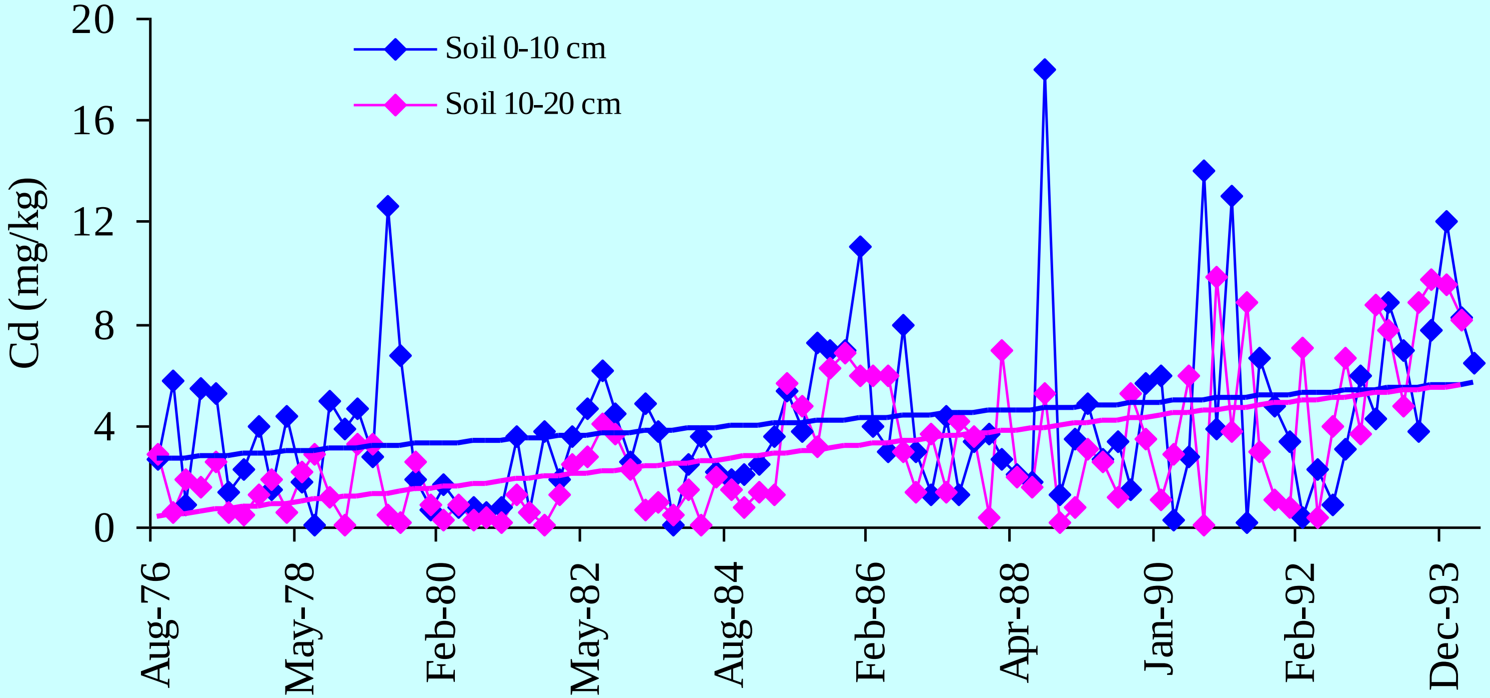


Figure 4 Lead in soil under land filtration

0-10 cm, Pb = 0.046 x + 81.694
10-20 cm, Pb = 0.273 x + 24.162

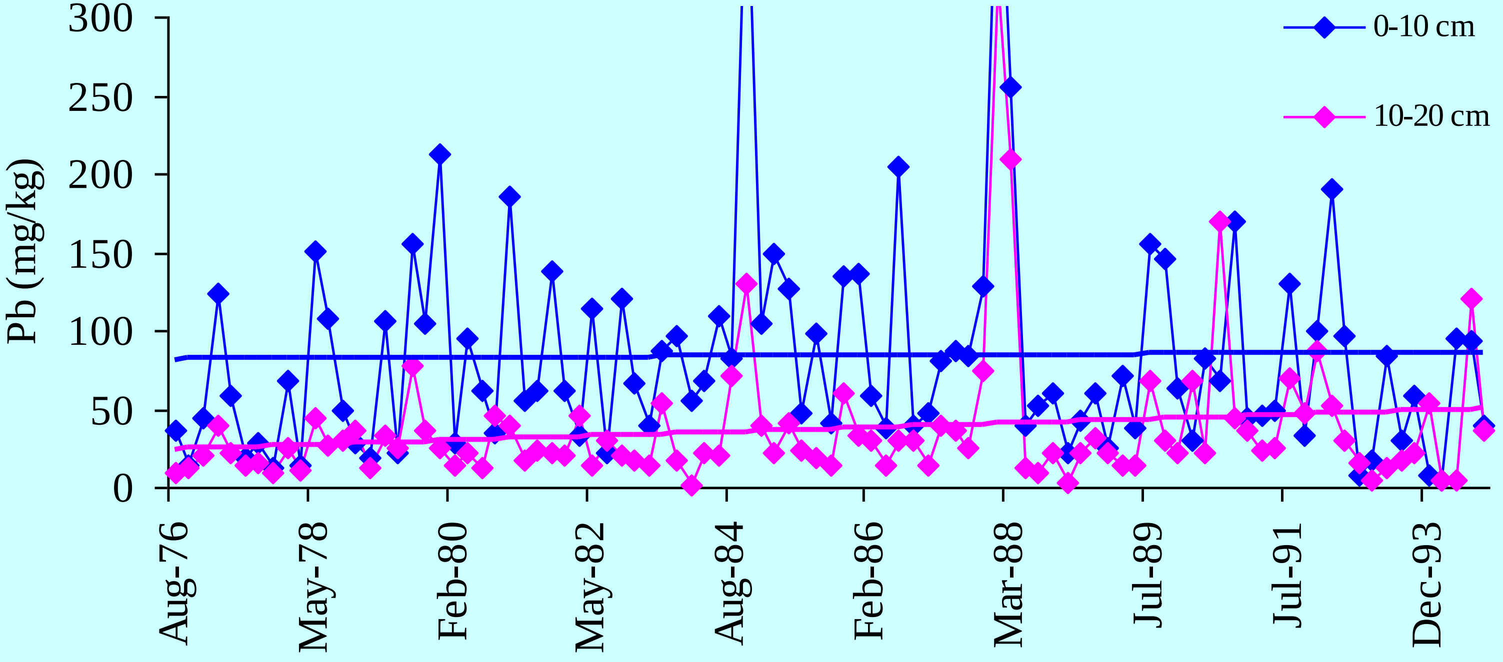


Figure 5 Lead in soil under grass filtration

0-10 cm,   Pb = 0.4877x + 126.81

10-20 cm, Pb = 0.849x + 42.344

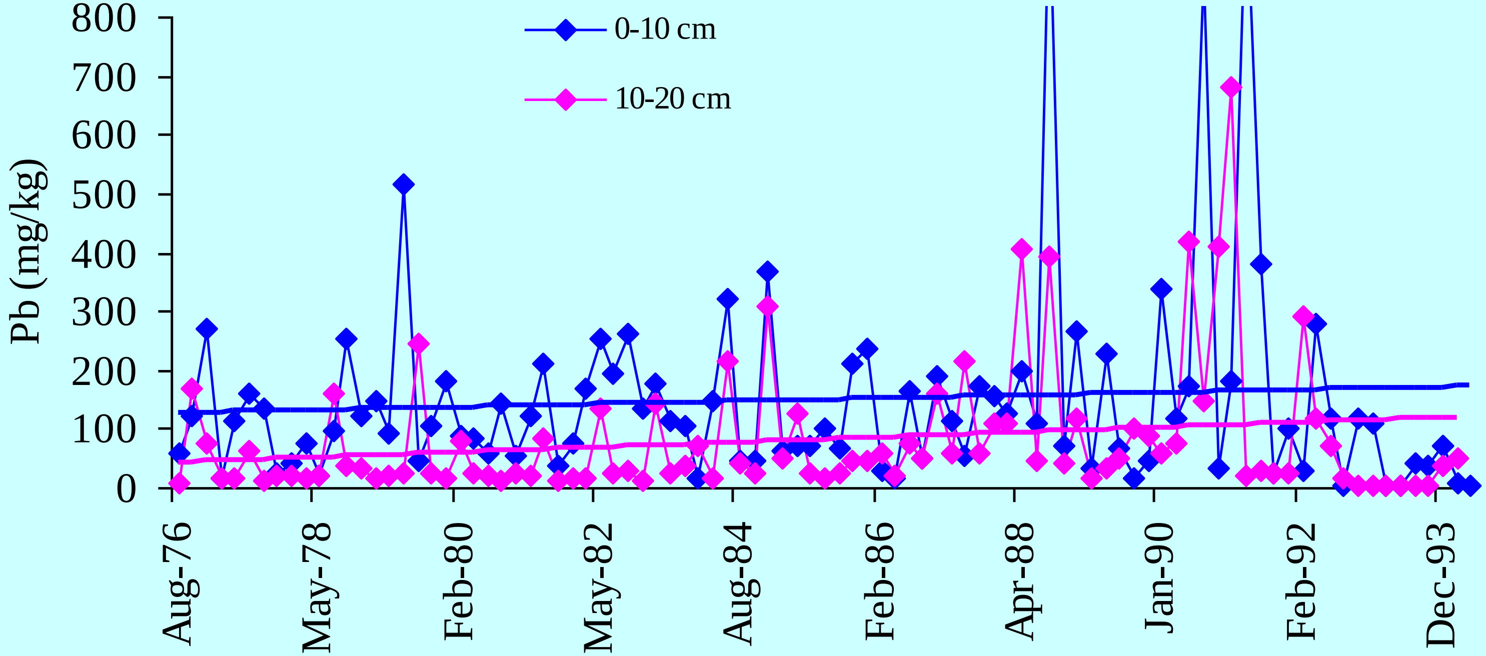


Figure 6 Lead in subsoil (10-20 cm) under land and grass filtration

Grass Filtration, Pb = 0.849x + 42.344

Land Filtration, Pb = 0.2733x + 24.162

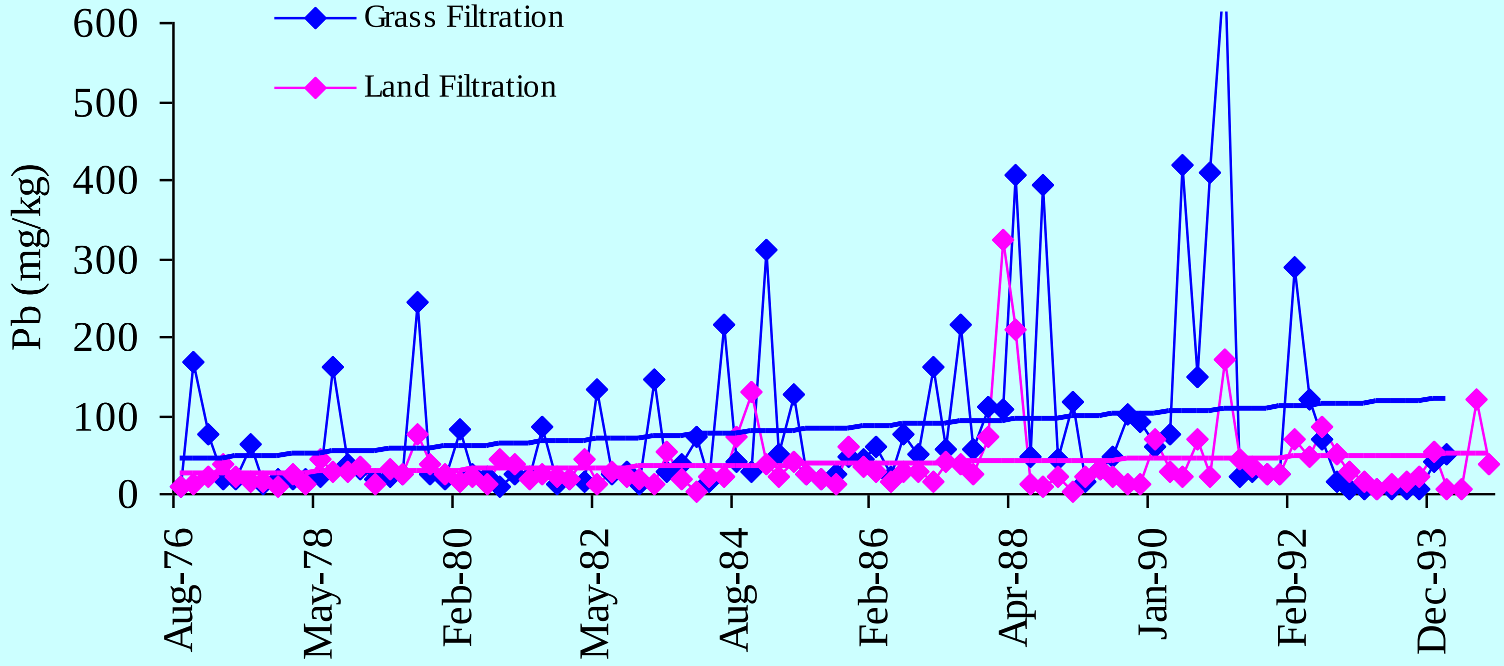


Figure 7 Cadmium in herbage under land filtration and grass filtration

Grass filtration, Cd = -0.00002 x + 0.167

Land filtration, Cd = -0.0014 x + 0.345

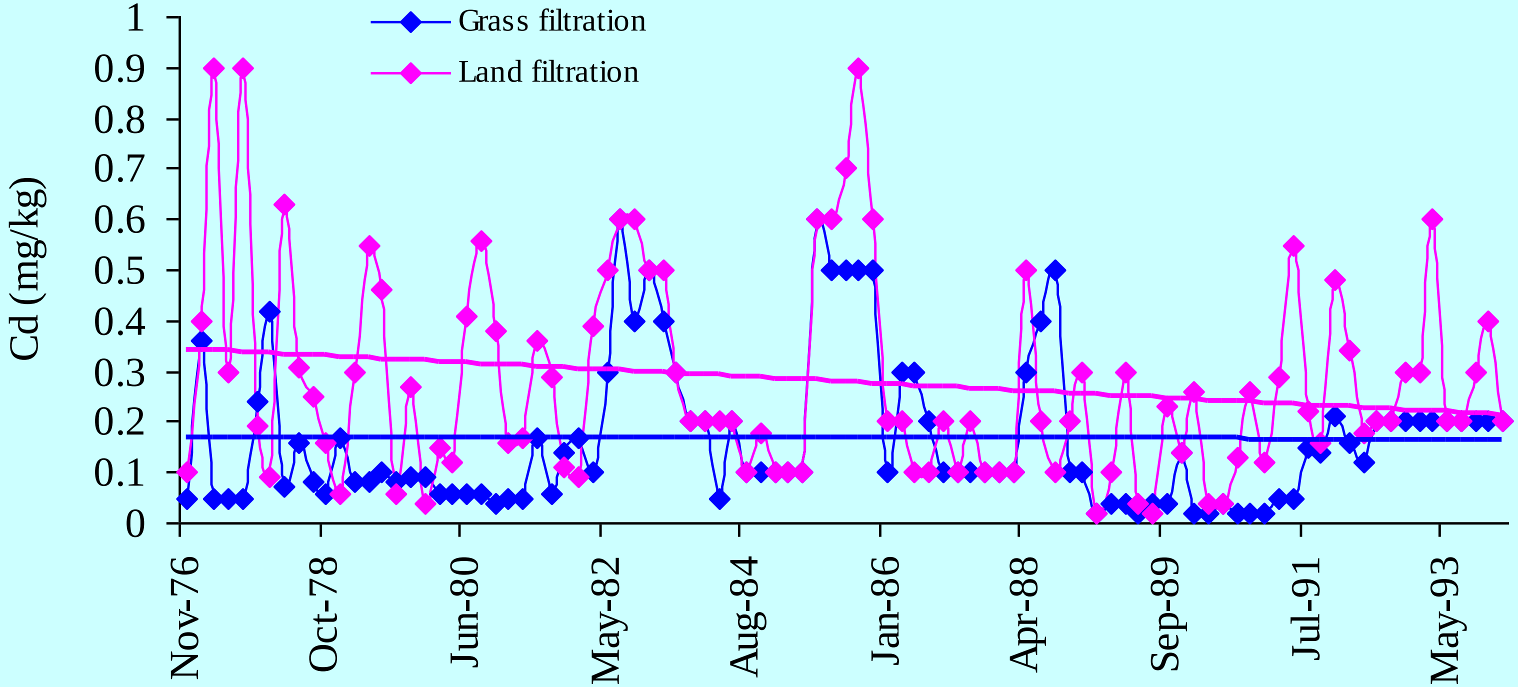
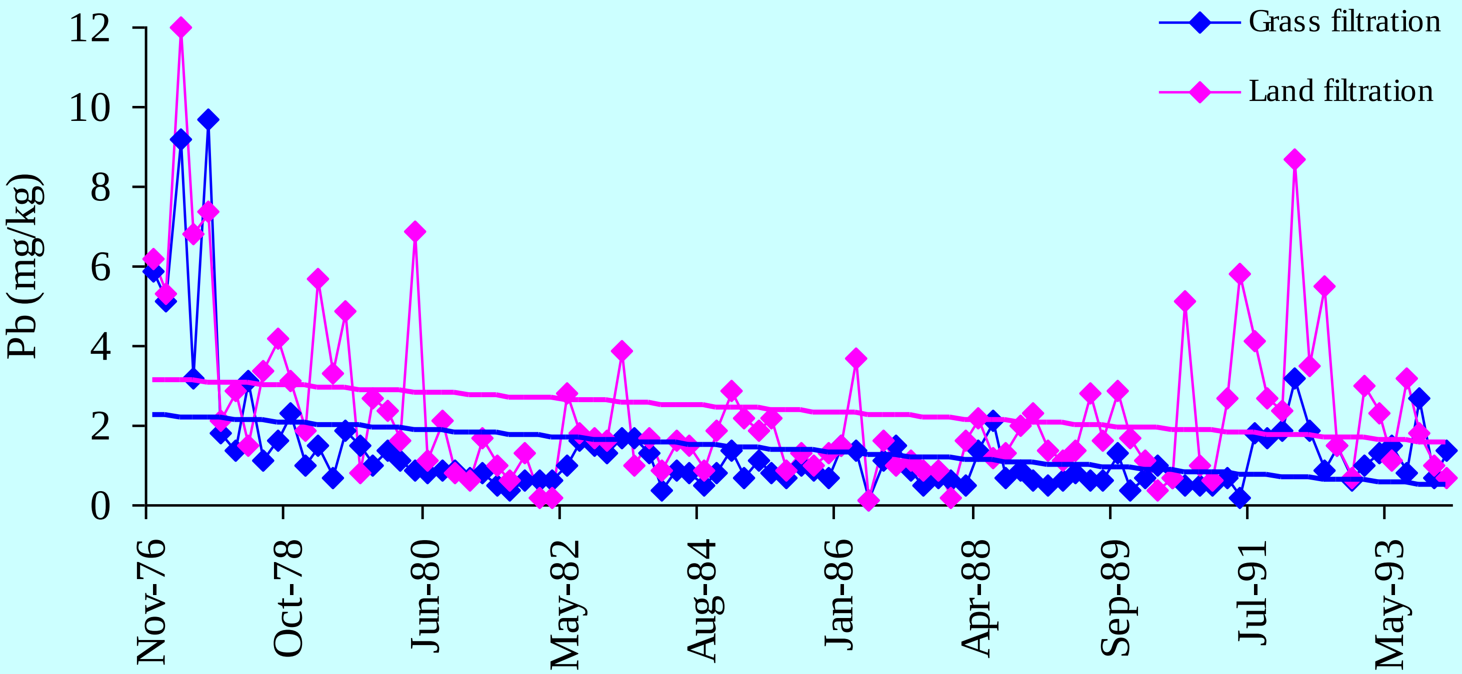


Figure 6 Lead in herbage under land filtration and grass filtration

Grass Filtration, Pb = -0.019 x + 2.2694

Land Filtration, Pb = -0.017 x + 3.1731



Findings of other authors: Evans, Mitchell and Salau (1978)

- Cd, Cr, Pb and Zn accumulate mostly in the top 20 cm in the irrigated soil
- Highest amount of Cd, Cr, Pb and Zn in 0-5 cm depth (organic matter)
- Cu and Ni have zones of higher metal concentration between 30-50 cm depth in both irrigated and control soils
- Calculated accumulation rates for top 5 cm

Evans, K.J., Mitchell, I.G. and Salau, B. (1978) *Heavy Metal Accumulation in Soils Irrigated by Sewage and Effect in Plant-Animal System*, MMBW.

Figure 8 Cadmium accumulation in soil (taken from Figure 1 from Evans et al. 1978)

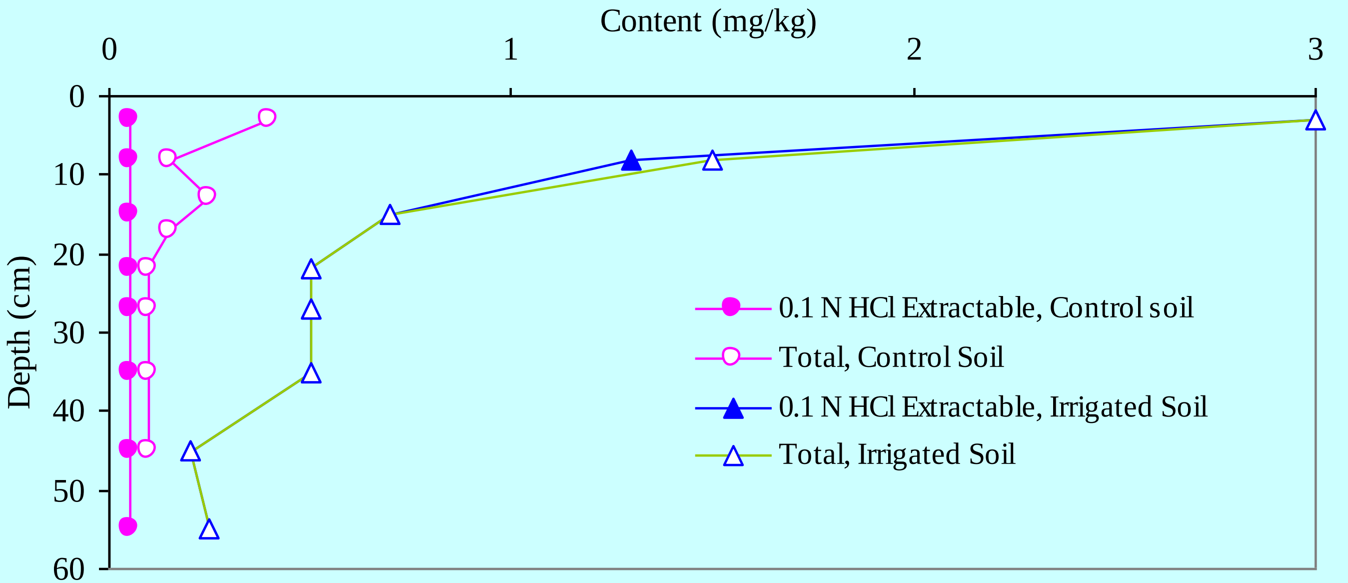


Figure 9 Chromium accumulation in soil (taken from Figure 1 from Evans et al. 1978)

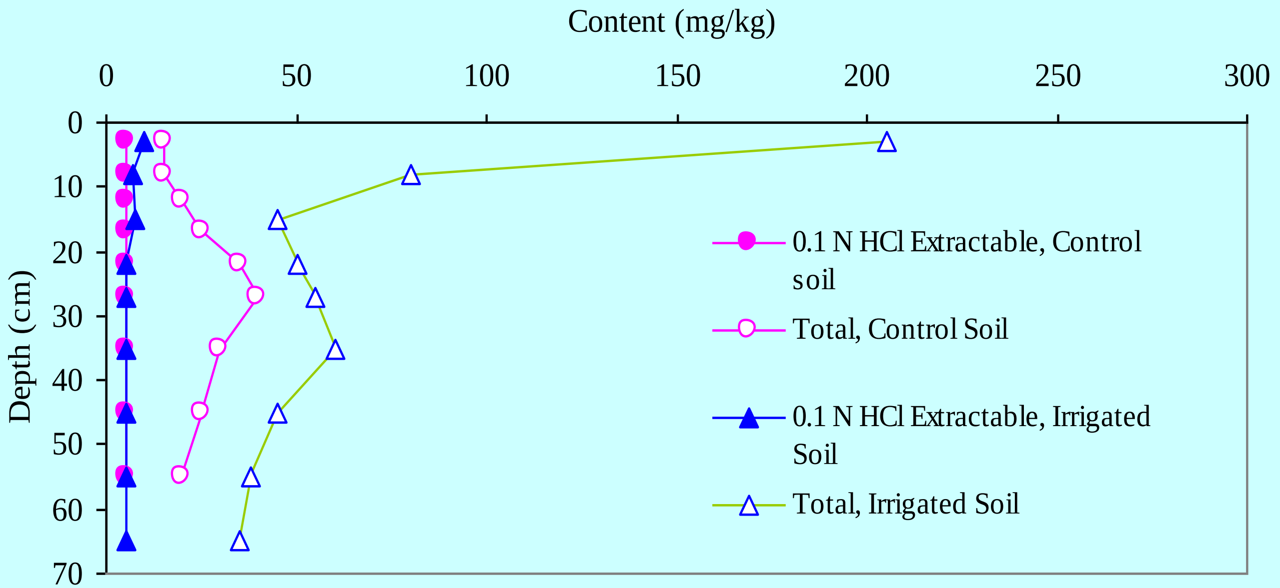


Figure 10 Lead accumulation in soil (taken from Figure 1 from Evans et al. 1978)

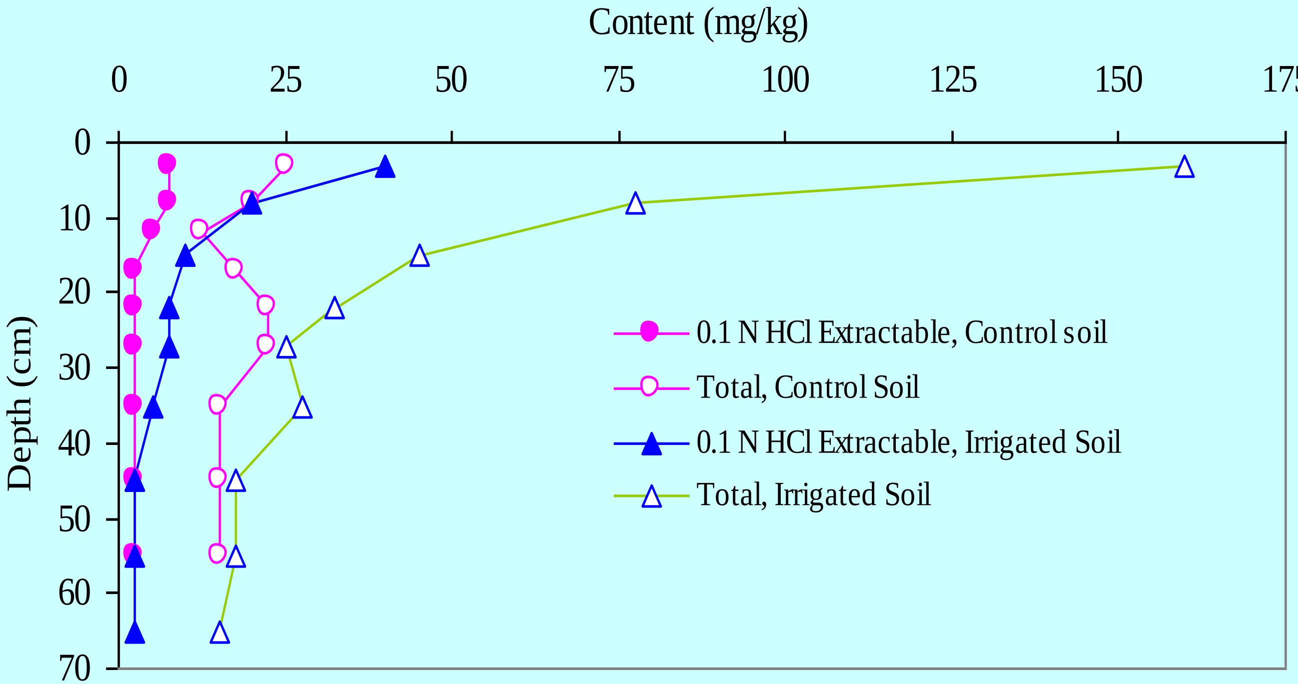


Figure 11 Zinc accumulation in soil (taken from Figure 1 from Evans et al. 1978)

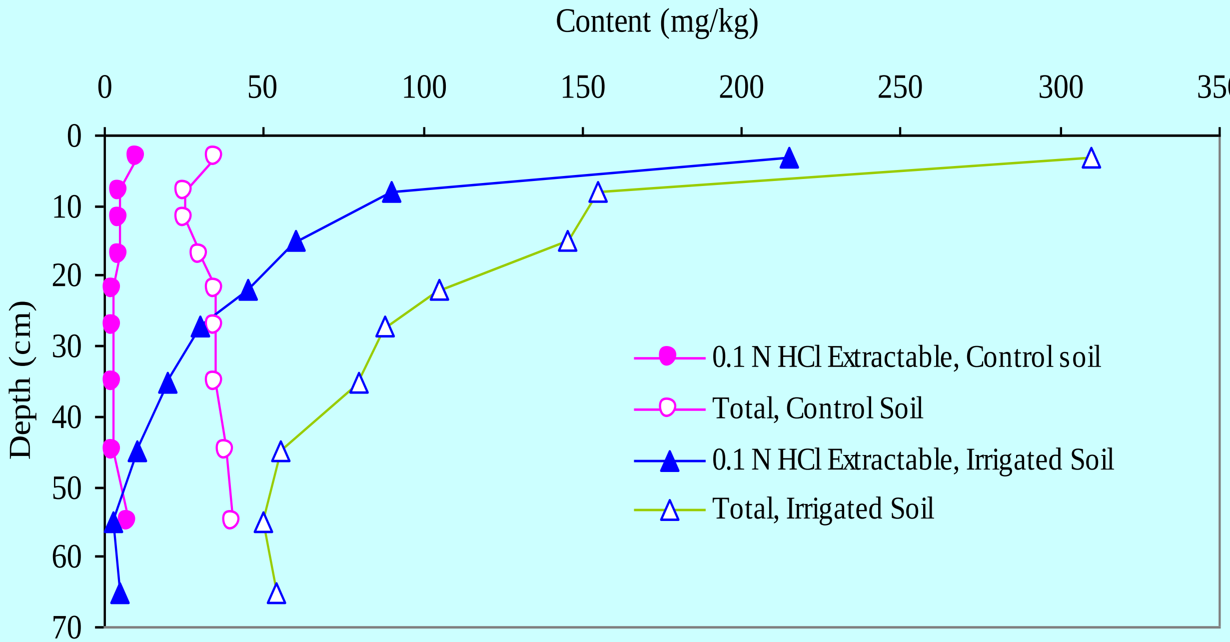


Figure 12 Copper accumulation in soil (taken from Figure 1 from Evans et al. 1978)

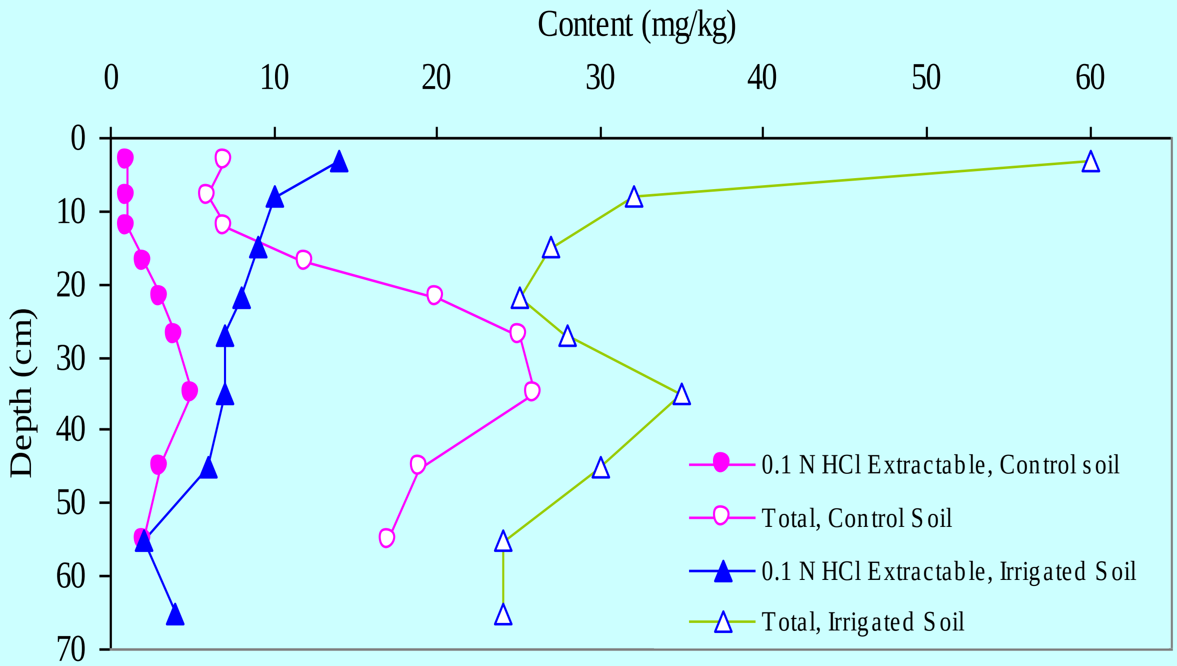


Figure 13 Nickel accumulation in soil (taken from Figure 1 from Evans et al. 1978)

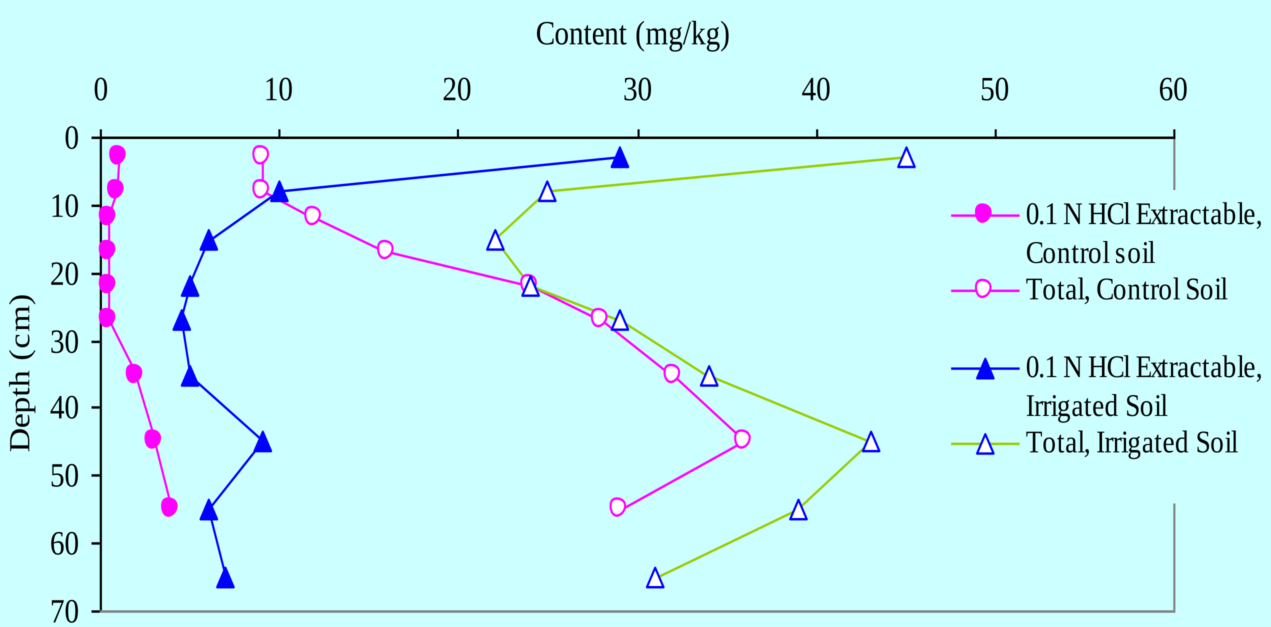


Table 4. Metal Accumulation Rates in top 5 cm (from Evans et al. 1978, Table 4)

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Time interval	Mean rate of accumulation (kg/ha.year)					
	Cd	Cr	Cu	Pb	Ni	Zn
1900-1976	0.06	4.3	1.4	3.2	1.0	7.8

Findings of other authors: Lawes (1993)

- Cd, Cu, Ni and Zn accumulated significantly in the upper 20 cm of soil
- Cr and Pb accumulated in the upper 15 cm of soil
- Irrigation increased the mobility of both the contaminant and native metals (0.25 M $BaCl_2$ extract)
- pH and sodicity increased at greater than 7.5 cm depth

Why are these results observed?

- Changing soil pH – decreased metal solubility
- Addition of Fe to soil – insoluble metal hydroxides and oxy-hydroxides form
- Addition of large quantities of P as phosphate – insoluble metal phosphates

Ionisation (-log K) vs pH

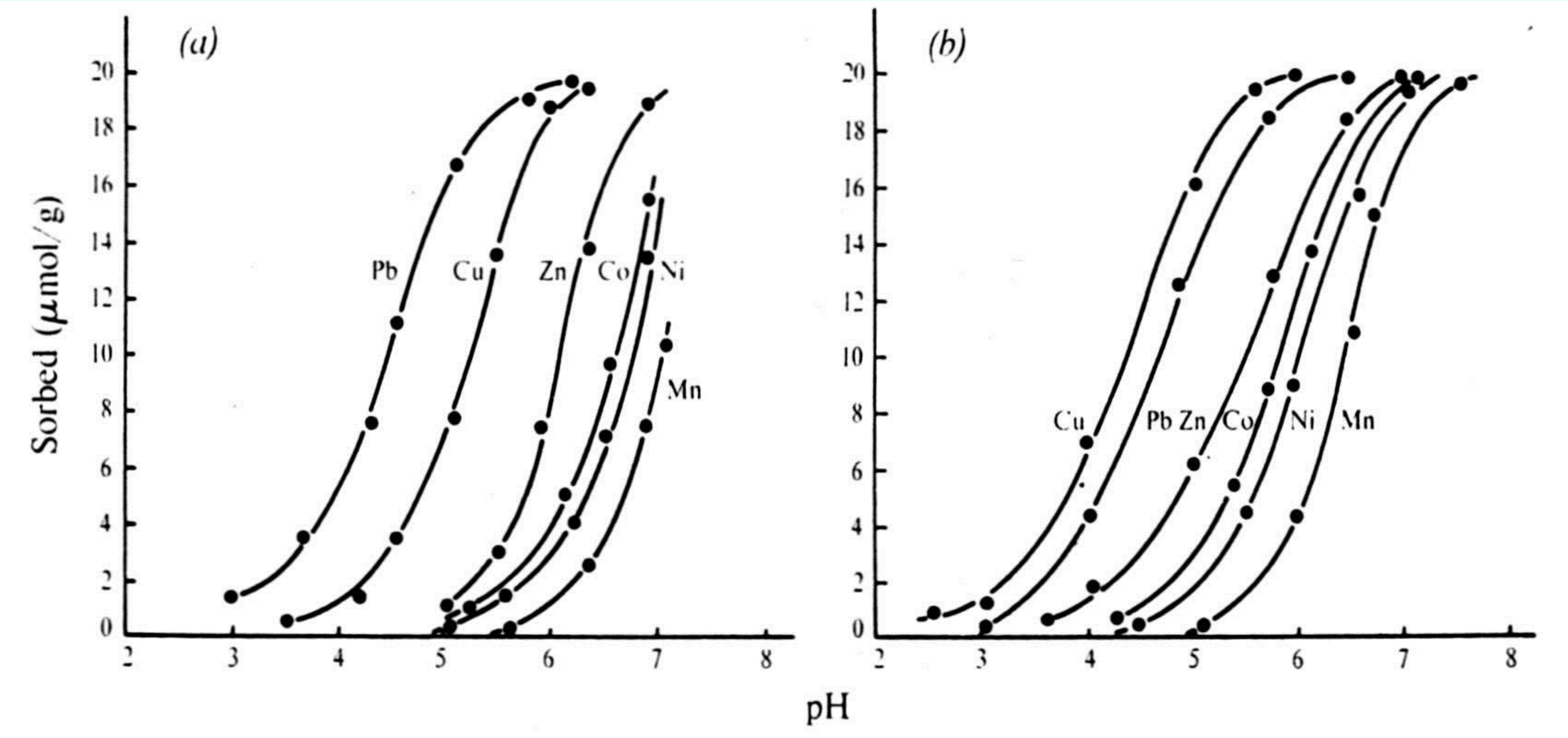
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
	$Cd(OH)_2$	$Cr(OH)_3$	$Cu(OH)_2$	$Fe(OH)_3$	$Ni(OH)_2$	$Pb_2O(OH)_2$	$Zn(OH)_2$
K_T	14.4	30.2	18.8	38	14.7	14.9	15.5
K_1	9.5	11.8	12.1	16	11.3	-	10.5
K_2	4.9	8.4	6.7	9.4	3.4	-	5.0
K_3	-	10.0	-	11.7	-	-	-

Empirical dependence of (Zn) in soil solution vs pH

Control	Limed	log(Zn) = 6.54 – 0.75pH	$r^2 = 0.97^{**}$
Control	Limed + peat	log(Zn) = 4.82 – 0.50pH	$r^2 = 0.96^{**}$
Metal enriched	Limed	log(Zn) = 8.67 – 0.79pH	$r^2 = 0.99^{**}$
Metal enriched	Limed + peat	Log(Zn) = 6.93 – 0.60pH	$r^2 = 0.99^{**}$

Adsorption of heavy metals on iron oxides & oxy-hydroxides

(a) Hematite; (b) Goethite



Solubility constants of metal phosphates

	$Cd_3(PO_4)_2$	$CrPO_4$	$Cu_3(PO_4)_2$	$Fe(PO_4)$	$Pb_4O(PO_4)_2$
pK_{sp}	38.10	17.00-22.62	36.89	21.89	65.17
	$Pb_3(PO_4)_2$	$Pb_5(PO_4)_3Cl$	$Pb_5(PO_4)_3OH$	$Zn_3(PO_4)_2$	
pK_{sp}	44.60	84.80	76.80	32.04	

Recommendations for monitoring wastewater irrigation sites

- Measure metals added and in soil
- Measure soil and effluent parameters that affect metal solubility and availability
  - pH
  - Salinity (Cl)
  - Phosphates
  - Iron
  - Manganese

Acknowledgements

- Melbourne Water for permission to use unpublished data
- Dr Nick Uren for helpful criticisms