Chapter 5
RESULTS AND DISCUSSION

5.1. Soil physicochemical parameters

The results of the soil physicochemical parameters at different study sites are summarized in Table 5.1 excluding the heavy metal concentrations.

Table 5.1. Averages of soil physicochemical parameters at different study sites irrespective of the observation period *

Site	pH	SOM (%)	SMC (%)	SFC (g)
N1	6.14 (bc)	11.31 (f)	33.80 (e)	1.56 (a)
N2	6.29 (cd)	8.32 (e)	23.24 (bc)	1.48 (a)
N3	6.30 (d)	2.79 (a)	18.25 (a)	1.46 (a)
N4	5.55 (a)	2.59 (a)	19.10 (a)	1.45 (a)
N5	6.07 (bc)	4.96 (c)	18.33 (a)	1.49 (a)
N6	7.28 (f)	6.58 (d)	24.74 (cd)	1.57 (a)
S1	7.70 (g)	16.49 (g)	33.78 (e)	1.79 (a)
S2	6.72 (de)	5.02 (c)	18.86 (a)	1.54 (a)
S3	6.19 (bc)	8.97 (e)	27.85 (d)	1.66 (a)
S4	6.91 (ef)	4.43 (bc)	23.07 (bc)	1.58 (a)
S5	5.77 (ab)	4.52 (bc)	20.27 (ab)	1.49 (a)
S6	7.07 (ef)	3.84 (b)	20.44 (b)	1.38 (a)

Note : SOM = *soil organic matter* SMC = *soil moisture content* SFC = *soil field capacity*

* *For each parameter column, values followed by the different letter in brackets were significantly different ($P \leq 0.05$)*

Soil pH

The averages of the soil pH were significantly different ($P \leq 0.05$) among the study sites. In general, the soil pH tended to be neutral, with slightly acidic or basic ranging from a minimum of 5.55 to a maximum of 7.7 in sites N4 and S1, respectively (Figure 5.1). From factorial analytical statistic the averages of the soil

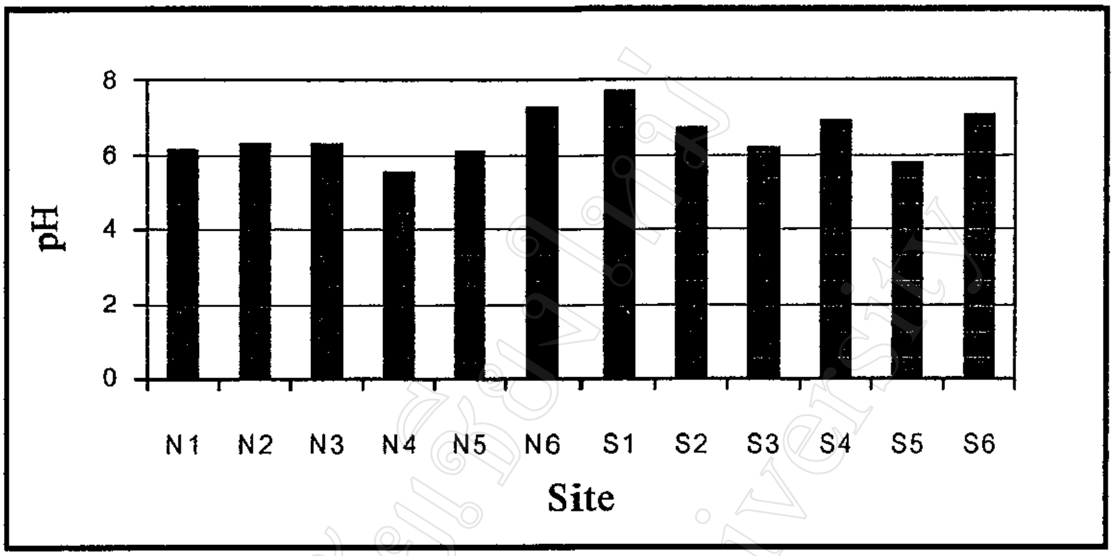


Figure 5.1. Average soil pH at the study sites

pH could be differentiated into three groups namely slightly acidic from 5.55 to 6.30 (*e.g.* sites N1, N2, N3, N4, N5, S3 and S5), neutral from 6.91 to 7.28 (*e.g.* sites N6, S4 and S6), and slightly basic by 7.70 (site S1). During the observation period from July to October the averages of soil pH were significantly different at every study site (Appendix 12). Considerable fluctuations mostly occurred in study sites located south of the power plant (*e.g.* sites S2, S3, S5, and S6) while in other study sites, especially north of the power plant, the values were only slightly variable (Appendix 4).

Soil organic matter

Variations in the amount of soil organic matter were recorded among the study sites (Figure 5.2) and they were significantly different ($P \leq 0.05$). Sites N1, N2, S1, and S3 had the highest amount organic matter with 11.31, 8.32, 16.49 and 8.97 %,

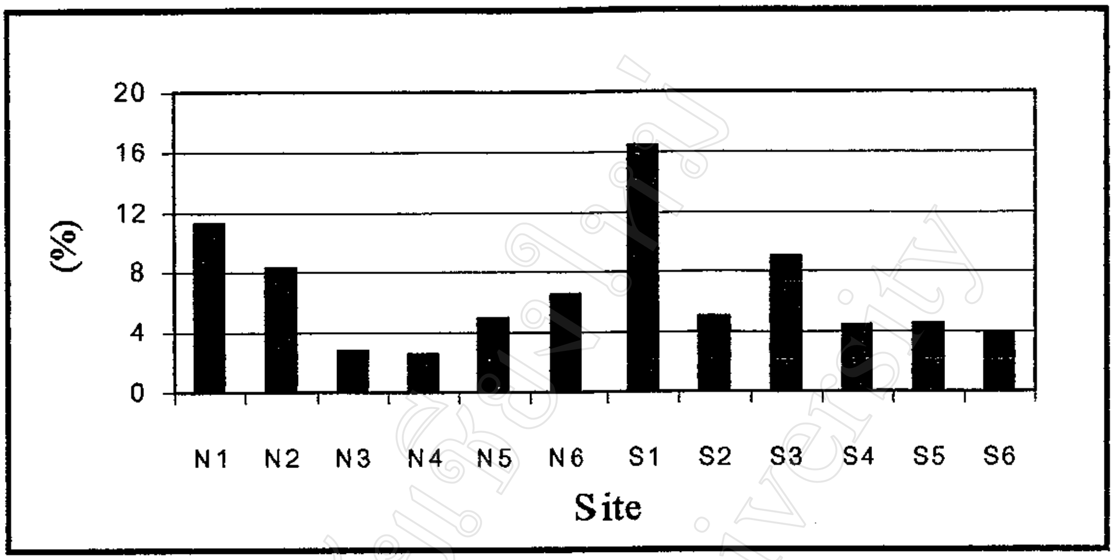


Figure 5.2. Average soil organic matter in the study sites

respectively. These values were much higher than those of sites N3 (2.79%), N4 (2.59%) and S6 (3.84%). Based on the soil organic matter, the study sites were categorized into three different levels namely low, medium, and high. Most of the study sites were considered to be low having organic matter of less than 5% *e.g.* sites N3 (2.79%), N4 (2.59%), N5 (4.96%), S4 (4.43%), S5 (4.52%), and S6 (3.84%). Sites N2, N6, S2, and S3 were medium by 8.32, 6.58, 5.02, and 8.97%, respectively. The high levels of organic matter were only indicated in sites N1 (11.31%) and S1 (16.49%). During the observation period, soil organic matter in every study site fluctuated (Appendix 5) and significantly different ($P \leq 0.05$) from time to time (Appendix 13).

Soil moisture content

Soil moisture varied among the study sites ranging from the lowest value of 18.25 % (N3) to the highest value of 33.8 (N1). All of the study sites had relatively

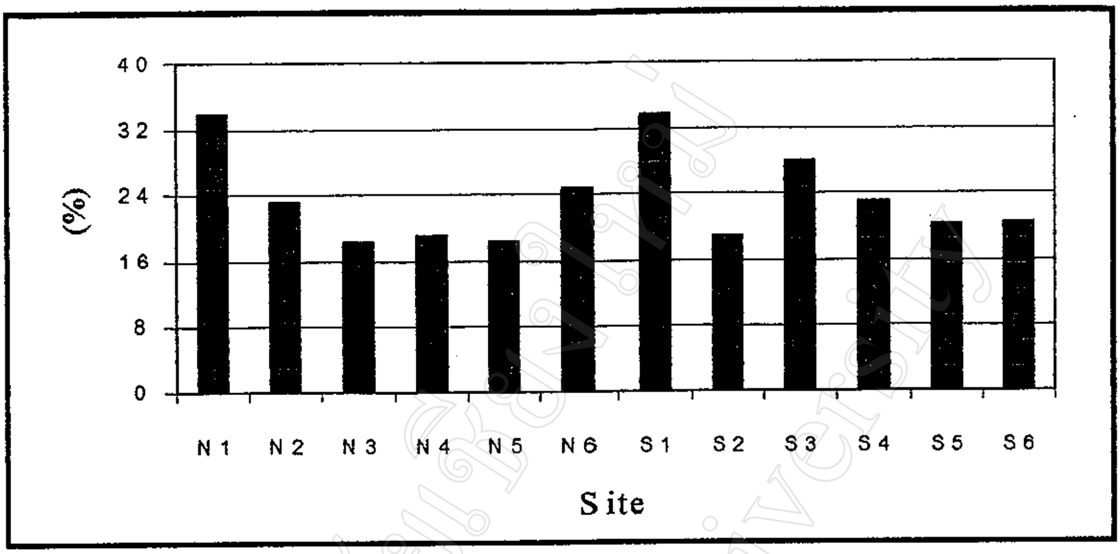


Figure 5.3. Average soil moisture content in the study sites

high soil moisture of more than 16 % since it was the rainy season (Figure 5.3). However, sites N1 and S1 were extremely high having averages of the soil moisture of 33.80 and 33.78%, respectively. Considerable variations of soil moisture were observed during the observation period (Appendix 6) and were significantly different ($P \leq 0.05$) from time to time at the same study site (Appendix 14).

Soil field capacity

No significant differences soil field capacity were found among the study sites and they could be classified in one group only. The values varied slightly from the lowest of 1.38 g to the highest of 1.79 g in sites S6 and S1, respectively (Figure 5.4). The values for soil field capacity during the observation period showed slight variation from time to time (Appendix 7) and they were significantly different ($P \leq 0.05$) (Appendix 15).

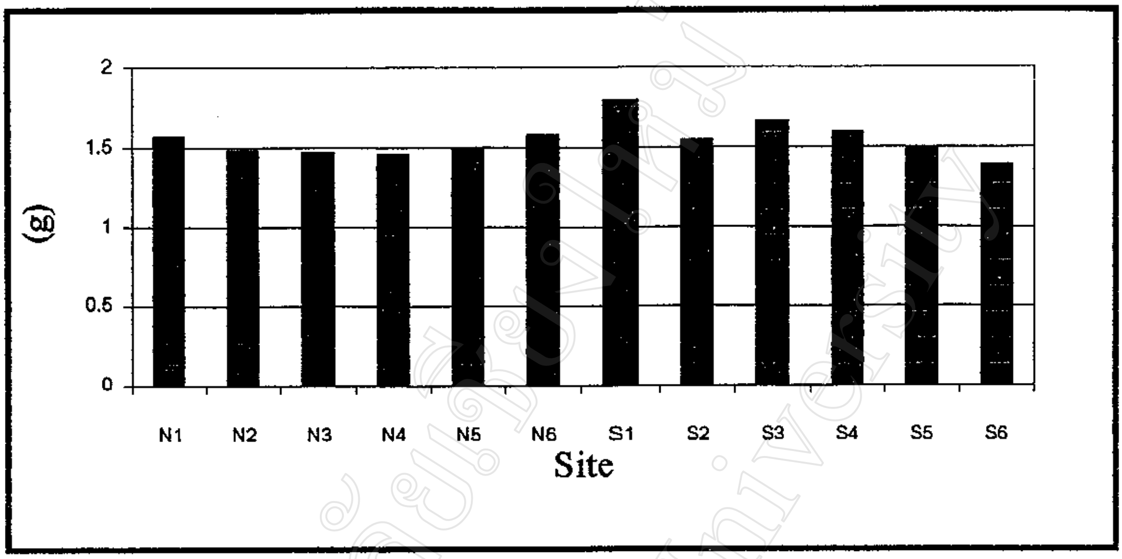


Figure 5.4. Average soil field capacity in the study sites

Addition of coal combustion residues such as fly ash to soil has been shown to exert major changes in the chemical properties of the soil, thereby affecting their physicochemical characteristic including the soil pH. The variations of the soil pH found in the surrounding area of the Mae Moh Power Plant and its relationship to other soil physicochemical parameters (soil organic matter, soil moisture content and soil field capacity) is now discussed.

In general, coal combustion products produce alkaline solutions when in contact with water. Some ash, however, may generate acidic solutions depending upon the characteristic of the coal. The acidity or alkalinity of the solutions is determined by the relative proportions of Ca and Fe oxides contained in the residues (Theis and Wirth, 1977). When mixed with soils, the alkaline solutions tend to induce an elevation in the soil pH. According to Elseewi *et al.*, (1986) the increase of the soil pH was dependent upon the buffering capacity of the recipient soil, the amount of fly ash added, and time of contact. In evaluating the variations of soil pH in the area studied, emphasis should be put on the differences of soil buffering capacities among the study sites. The buffering capacity of soils is determined by various factors such as mineralogical, physical, chemical, and biological properties of the soil. For example , calcareous and clayey soils are highly buffered compared with sandy soil. Thus, despite the increase of rain acidity was clearly correlated with increasing acidity of surface waters and the deleterious effects on plants and aquatic life for instance, no such correlation has been established with respect to soil acidity. This agrees with the results of this study that no significant correlations between the soil pH and other soil physicochemical parameters like soil organic matter, soil moisture content and soil field capacity were present (Table 5.2).

Table 5.2. Correlation coefficients and two-tailed significant values among soil physicochemical parameters

PARAMETER	pH		SOM		SMC	
	CC	P	CC	P	CC	P
pH	1	-				
SOM	0.465	0.127	1	-		
SMC	0.297	0.349	0.901	0.000	1	-
SFC	0.494	0.103	0.825	0.001	0.812	0.001

Note : SOM = *soil organic matter* SMC = *soil moisture content* SFC = *soil field capacity* CC = *correlation coefficient* P = *two-tailed significant value*

According to Malmer (1976), the failure to observe such changes of soil pH could be related to the fact that only a short amount of time has elapsed since the problem was first recognized. In most cases of this research, it was shown that study sites having higher organic matter (*e.g.* sites N1, N2 and S1) showed relatively stable soil pH during the observation period (Appendix 4). In contrast, the soil pH at sites S2, S3, S5, and S6 fluctuated from time to time and their soil organic matter was the lowest. There were significant correlations ($P \leq 0.05$) between soil organic matter, soil moisture content, and soil field capacity. This indicated that the soil organic matter was capable of retaining soil water, especially in the form of gravitaional, capillary, and hygroscopic water.

Gravitational water is ecologically important in terms of leaching and availability of important nutrient (Wallwork, 1970). When all of the gravitational water has drained from a soil layer, the layer was said to be at "*field capacity*" and the remaining was mainly held by capillary forces in soil particles. The capillary water is particularly important from a biological point of view, for not only does it retain water in soil for a relatively long period carrying important nutrients in solutions, but its presence also ensures that the soil atmosphere is saturated with water. This phenomenon is extremely important because most microarthropods for instance, perish in conditions with low relative humidity. Highly organic soils were favored in this respect, for humus has a relatively high capillary capacity due to the fact that it is a very porous material and much of the total pore volume is made up of capillary spaces.

Several kinds of soil organisms, such as protozoans, nematodes, rotifers, and tardigrades depend directly on free water for the maintenance of normal activity. Many more animals, particularly microarthropods, live in the larger spaces between soil particles, and were surrounded by a gaseous phase. The relationship between soil organic matter and soil moisture is, therefore, important for the life of soil faunas. In this study, however, lower species richness and diversity indices of the soil-inhabiting arthropod communities were shown in the study sites having higher organic matter and soil moisture content *e.g.* sites N1, N2 and S1. This might be due to higher heavy metal concentrations in those study sites that negatively affected the soil-inhabiting arthropods diversity. In other words, the communities of soil arthropods were more sensitive to heavy metal contamination instead of these physicochemical parameters. The correlation between the soil physicochemical and the biological parameters of the soil-inhabiting arthropod communities is discussed later

5.2. Heavy metal contamination in soil

The results of the average of heavy metal concentration in soils at different study sites are listed in Table 5.3. There are significant differences ($P \leq 0.05$) of the heavy metal concentrations among the study sites. The highest As and Ni concentrations were found in site S1, 48.14 and 19.78 mg/kg, respectively. The lowest concentrations of As were observed in sites N3 (6.48 mg/kg), N4 (6.29 mg/kg) and N5 (8.58 mg/kg). In sites N3, N4, N6, and S2, concentration of Ni were also relatively low by 2.14, 2.22, 5.39 and 4.71, respectively (Figure 5.6).

Factorial statistical analysis based on As concentrations have grouped the study sites into three levels of concentration. Sites N3, N4 and N5 were considered to be low showing As concentration of less than 10 mg/kg. On the other hand, sites N6, S2, S3, S4, and S5 were considered to be medium by 12.7, 13.3, 11.36, 13.87 and 11.35 mg/kg, respectively. The relatively high As concentration were indicated by sites N1 (19.49 mg/kg) and N2 (19.37 mg/kg). In site S1, the As concentration was very high by 48.14 mg/kg. Based on the Ni concentrations, the study sites were also grouped into three different levels namely low, medium and high. The low Ni concentrations were indicated by sites N3 (2.14 mg/kg) and N4 (2.22 mg/kg). In sites N1, S1 and S6 Ni concentrations were considered to be high by 15.68, 19.78 and

Table 5.3. Averages of heavy metal concentrations in soil (mg/kg) irrespective of the observation period *

Site	As	Co	Cr	Ni
N1	19.49 (d)	39.53 (ab)	7.47 (d)	15.68 (f)
N2	19.37 (d)	45.49 (b)	4.50 (ab)	6.47 (d)
N3	6.48 (a)	44.88 (b)	4.02 (a)	2.14 (a)
N4	6.29 (a)	54.43 (bc)	3.78 (a)	2.22 (a)
N5	8.58 (ab)	50.10 (b)	4.55 (ab)	6.01 (cd)
N6	12.7 (c)	35.83 (a)	4.53 (ab)	5.39 (bc)
S1	48.14 (e)	46.41 (b)	4.66 (ab)	19.78 (g)
S2	13.3 (c)	39.78 (ab)	7.29 (d)	4.71 (b)
S3	11.36 (bc)	45.92 (b)	5.70 (bc)	6.51 (d)
S4	13.87 (c)	42.64 (ab)	6.67 (cd)	6.59 (d)
S5	11.35 (bc)	50.31 (b)	7.77 (d)	6.70 (d)
S6	18.75 (d)	36.96 (a)	6.75 (cd)	10.19 (e)

* *For each parameter column, values followed by the different letter in brackets were significantly different (P ≤ 0.05)*

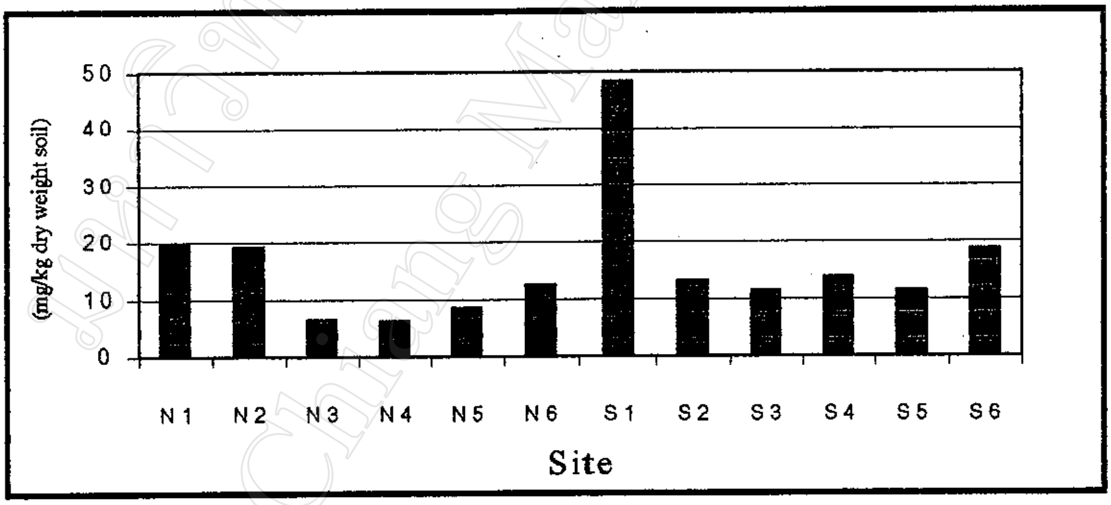


Figure 5.5. Average of the arsenic (As) concentration in soil at the study sites

10.19, respectively. However, most of the study sites showed medium values of Ni concentration of less than 10 mg/kg (*e.g.* sites N2, N5, N6, S2, S3, S4, and S5).

Concentrations of Co were significantly different among the study sites ranging from the minimum of 35.83 mg/kg (N6) to the maximum of 54.43 mg/kg (N4) as shown in Figure 5.7. Concentrations of Co in sites N6 and S6 were relatively low in compare to those of the other sites by 35.83 and 36.96 mg/kg, respectively. Most of the study sites indicated medium levels of Co concentration ranged from 39.53 mg/kg (site N1) to 46.41 (site S1). The high levels of more than 50 mg/kg were observed in sites N4, N5 and S4. All of the study sites, however, showed relatively low Cr concentrations which varied from the lowest of 3.78 mg/kg (N4) to the highest of 7.77 mg/kg (S5) (Figure 5.8). It seems that based on the Cr concentration the study sites can be differentiated into two groups only. Most of the study sites in south of the power plant (sites S2, S3, S4, S5, and S6) show higher Cr concentrations of more than 5 mg/kg. By contrast, lower Cr concentration of less than 5 mg/kg were mostly indicated by sites located north of the power plant, except site N1 (7.47 mg/kg).

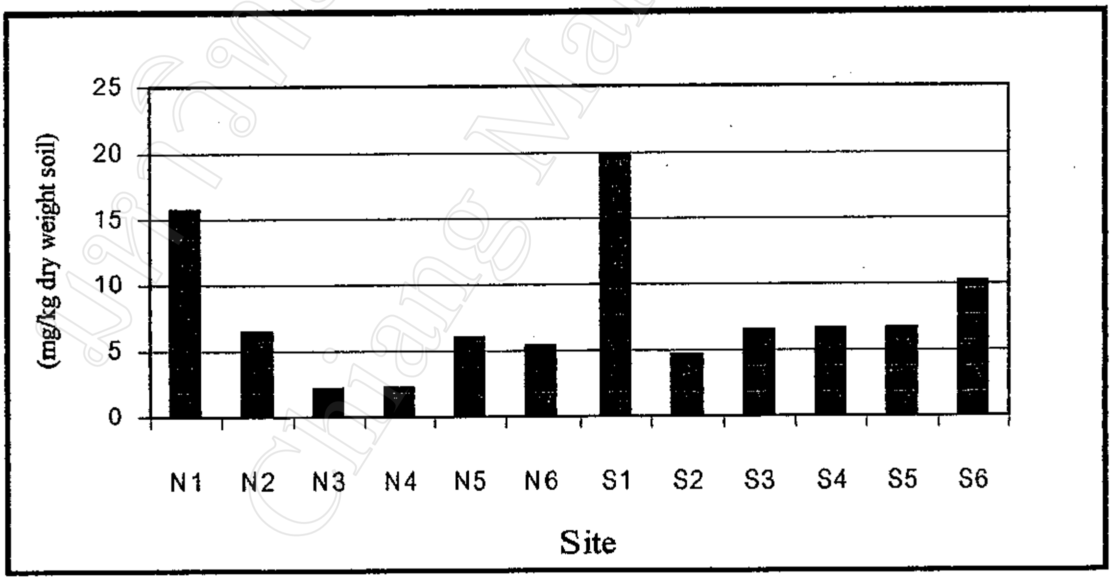


Figure 5.6. Average of the nickel (Ni) concentration in soil at the study sites

During the observation period, concentrations of heavy metals in soils showed significant differences ($P \leq 0.05$) at every study site. Most of the study sites in the north and some study sites south of the power plant showed slightly decreased As

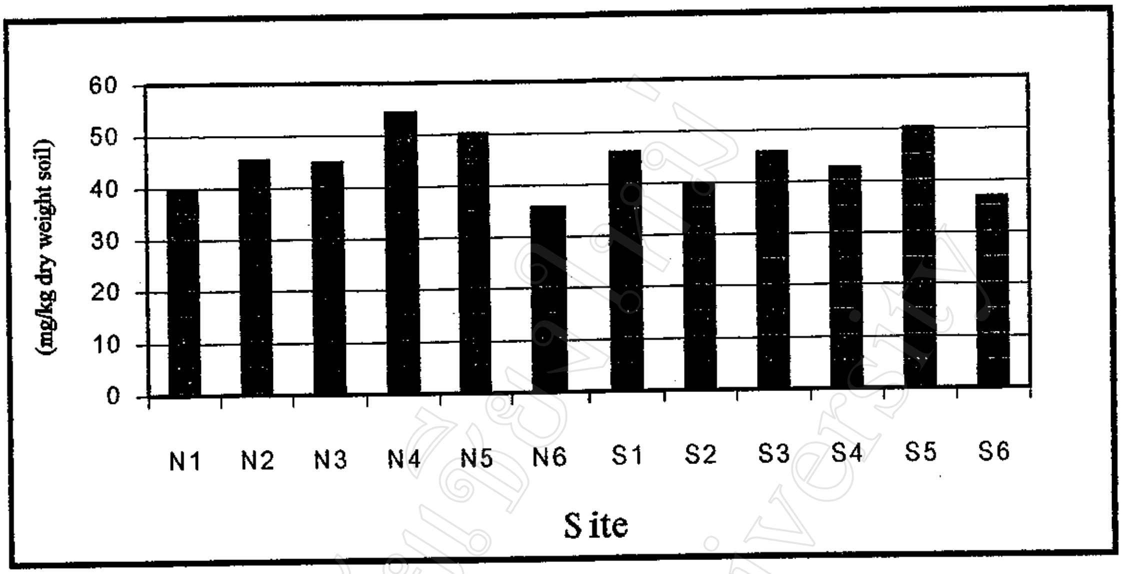


Figure 5.7 Average of the cobalt (Co) concentration in soil at the study sites

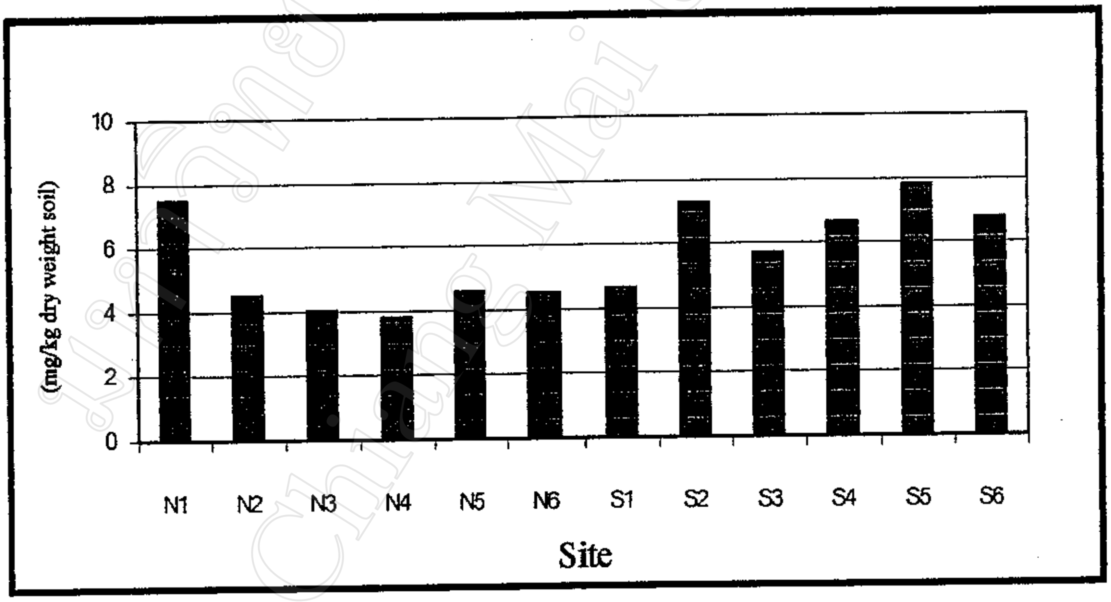


Figure 5.8. Average of the chromium (Cr) concentration in soil at the study sites

concentrations from the beginning of the rainy season to the end. Some study sites (*e.g* sites S2 and S6) were relatively constant between July to October. A considerable accumulation, however, occurred in site S1 (Appendix 8).The concentrations of Co and Cr fluctuated sharply during the observation period. These fluctuations were observed in most of the study sites (Appendix 9 and 10). Unlike Co and Cr, concentrations of Ni were relatively stable during the rainy season. Slight fluctuations were only observed in site N1, N2 and S6 (Appendix 11).

In comparison to normal heavy metal concentrations in 'uncontaminated' soils (Tables 2.3 and 2.4; Figure 2.1), most soils in the study areas of the have been contaminated by some heavy metals. Concentrations of As in sites N1, N2, S1, and S6 were beyond the normal ranges of the uncontaminated soils which varied from 1 to 14 mg/kg (Mitchell, 1964) or lower than 10 mg/kg (Bowen, 1979). The common concentration of As in soil was only 6 mg/kg (Straughan *et. al.*, 1978). The other study sites were also considered to be contaminated because their concentrations were higher than 6 mg/kg of As as a common concentration. However, all of the values were still in the range of As concentration in soils which varied from 0.1 to 40 mg/kg. All study sites clearly showed Co contamination having concentrations of more than the background concentration of 12 mg/kg (Salomons and Forstner, 1984) or more than the common concentration of 8 mg/kg (Straughan, 1978). Most of the study sites showed Co concentrations of more than the normal range which was 1 to 40 mg/kg. Considering the normal concentration of Ni in soils as 1 mg/kg (Purves,1985), all study sites were also considered to be contaminated. However, the common concentration of Ni in soils was 40 mg/kg (Straughan *et al.*, 1978) or 33.7 mg/kg (Salomons and Forstner, 1984). Bowen (1979) also suggested that the normal concentration of Ni in soils should be less than 100 mg/kg. If these standards were applied there would be no Ni contamination in the area studied because the highest Ni concentration was only 19.78 mg/kg in site S1. It should be realized, therefore, that natural variations and lack of reliable background levels were the major problems for assessing heavy metal contamination in soil based solely on their concentrations. No Cr contamination was observed during the study since the concentrations of Cr in all study sites were much lower than those of the normal soil which varied from 15 to 1000 mg/kg (Mitchell, 1964) or lower than 100 mg/kg (Bowen, 1979). Salomons and Forstner (1984) and Straughan (1978) set values of normal concentrations of Cr in soil at 84 and 100 mg/kg, respectively.

The variation of heavy metal concentration in soils is a natural phenomenon. It is determined by various factors such as the composition of the parent material, type and intensity of weathering processes, characteristic of climate and other factors operating during soil formation. Taking account of the daily amount of lignite consumption and higher concentration of heavy metals in coal and fly ash (Tables 2.1, 2.2 and 3.2), the power plant should be considered as an important source of heavy metal contamination in soil. Klein and Russel (1973) found that soils in the surrounding area of a Michigan power plant were enriched in Cd, Co, Cr, Cu, Hg, and Ni especially in the up-wind and down-wind directions. Concentrations of heavy metals in fly ash of the Mae Moh Power Plant was reportedly much higher than those in soils in its surrounding areas. Concentrations of As, Co, Cr and Ni in fly ash, for instance, were 213, 33.7, 66.5 and 53.3 mg/kg, respectively (Ratanasthien *et al.*, 1993).

This study revealed that heavy metal concentrations were not determined by the distance from the power plant. For example, concentrations of As in site N1, located about 19 km from the power plant, were higher than that at site N6 which was 5 km only away. It is also a fact that concentrations of As and Ni were highest in site S1, which was closest to the power plant. This indicates that heavy metals emitted from the stacks of the power plant are transported considerable distances. According to Klein and Russel (1973) the contamination could spread 21 km from a power plant and cover an area of 113 km^2. Since the wind direction tends to be the north and south, heavy metal contamination is not dependent on the up-wind and down-wind directions of the power plant.

At every study site, the heavy metal contamination changed during the observation period. For As, it was higher early in the rainy season from July to August than that of the end of it from September to October. The decrease was possibly caused by water runoff that leached-out heavy metals from the soil. The concentrations of Cr and Co fluctuated extremely during the observation period in comparison to those of As and Ni. According to Martin and Tyler 1978) this is due to the higher leachability of Cr and Co. The fluctuations also indicated that the concentration of heavy metals in soils was affected by other soil physicochemical parameters *e.g.* soil pH, soil organic matter, soil moisture content and soil field capacity. The evidence is that there are significant correlations between heavy metal concentrations and other soil physicochemical parameters (Table 5.4). Concentrations of As were clearly correlated with all of other soil physicochemical parameters. Significant correlation were observed between Ni and soil organic matter and soil moisture content and soil field capacity. Concentrations of Co correlated significantly with soil pH only. No significant correlation was shown by the concentration of Cr with all of the other soil physicochemical parameters.

It seems that study sites having higher organic matter tend to retain and even accumulate heavy metals. This study revealed that the highest heavy metal

Table 5.4. Correlation coefficients and two tailed significant values between heavy metal concentration and other soil physicochemical parameter ($P \leq 0.05$)

Parameter	As		Co		Cr		Ni	
	CC	P	CC	P	CC	P	CC	P
PH	0.677	0.016	-0.641	0.025	-0.06	0.986	0.504	0.095
Soil organic matter	0.87	0.000	-0.106	0.744	-0.007	0.828	0.754	0.005
Soil moisture content	0.651	0.022	-0.134	0.678	0.070	0.828	0.754	0.005
Soil field capacity	0.675	0.016	-0.021	0.950	-0.033	0.919	0.592	0.042

Note : *CC = Coefficient Correlation* *P = two-tailed significant value*

contamination, especially As and Ni, were recorded in sites rich with organic matter (*e.g.* sites N1, N2 and S1). This indicates that organic matter is capable of retaining heavy metals. As Martin and Coughtrey (1982) stated some heavy metals show a high affinity for organic material in soil. In some cases, the contamination depends on the heavy metal and soil pH. For example, concentration of Co at site S1 dropped at the end of the rainy season (Appendix 9) and so did the concentration of As at site S5 (Appendix 8) following the extreme decrease of soil pH. Phung *et al.*, (1979) stated that decreasing the pH has been shown to result in increased release of As, B, Pb, Cr, Ni, Mn, Zn, and Cd. However, fly ash of the Mae Moh Power Plant seems to maintain the pH levels of the soil nearby well about background levels. This means that mobilization of heavy metals in soils would not become a serious problem since it occurres only in the pH range of lower than 5.0 (Mayer, 1990). It can be concluded that the organic matter was particularly important in retaining heavy metals in soil. From the point of view of risk assessment this phenomenon is not only interesting, but also very valuable.

5.3. Biological parameters

The study of soil-inhabiting arthropod communities in the study area recorded a total of 112 species, 53 families, 20 orders and 6 classes of soil arthropods (Appendix 1). Figure 5.9 illustrates the difference of the total number of individuals, species, families and orders among the study sites. Sites N1, N2, N4, S1, and S6 had the lowest numbers compared to sites N3, N5, N6, S3, and S4. Among the soil arthropods, class Insecta was the most dominant with 13 orders and 43 families. The number of individuals per class is given in Figure 5.10.

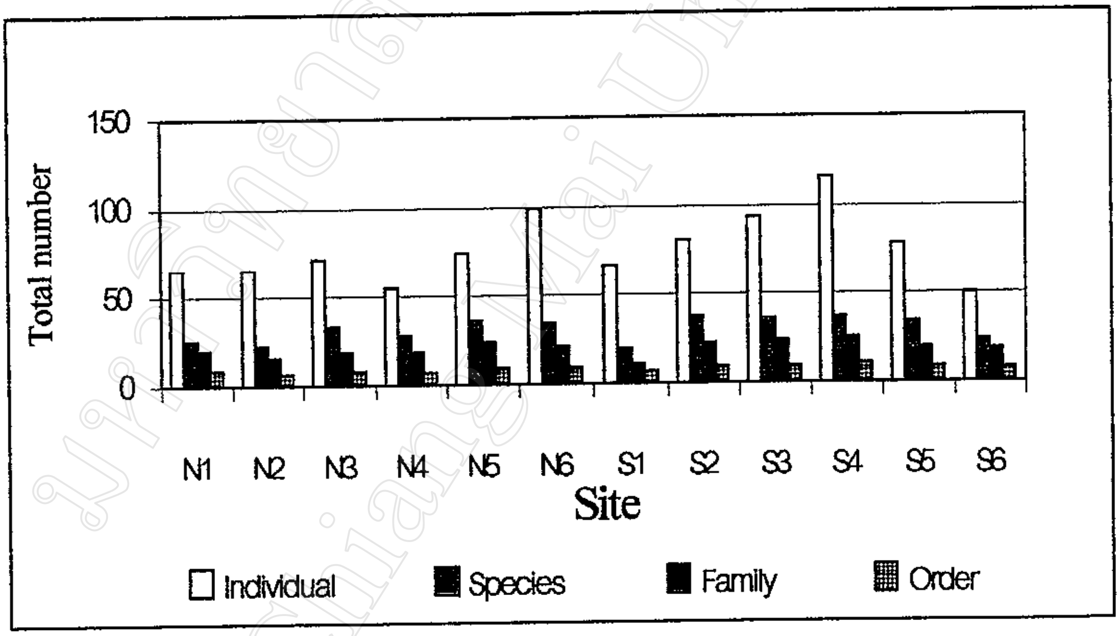


Figure 5.9 Total number of individuals, species, families and orders of soil-inhabiting arthropods at the study sites

The orders Coleoptera, Diptera, Hemiptera, Homoptera, and Lepidoptera were represented in all the study sites (Appendix 2) and ,therefore, were tested in order to know their sensitivity and correlation with the soil physicochemical parameters

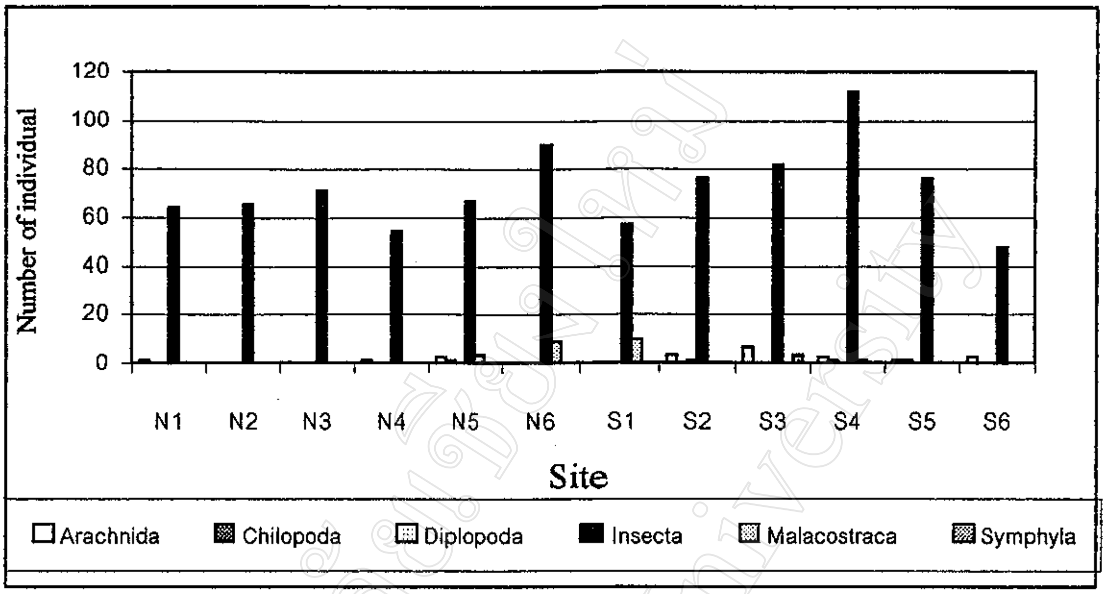


Figure 5.10 Total number of individuals per class at the study sites

including heavy metal concentrations. The results of these correlation coefficients are presented in Tables 5.5 and 5.6.

From Table 5.5 it is shown that most of the numbers of individuals in these orders were not significantly correlated ($P \leq 0.05$) with the soil pH, soil organic matter, soil moisture content, and soil field capacity. A significant correlation was only present by the number of individuals of Homoptera with soil field capacity. It means that the soil physicochemical parameters are not considered to be limiting factors that determine the community diversity of soil-inhabiting arthropods in this area. In contrast, a significant correlation is present between As concentration and the total number of individuals of Lepidoptera, Co concentration and the total number of individuals of Diptera, and Ni concentration with both the number of individuals of Coleoptera and Lepidoptera. No significant correlation was indicated between Cr concentration with the number of individuals of all orders (Table 5.6).

Table 5.5 Correlation coefficients and two-tailed significant values between soil physicochemical parameters and the total number of individuals per order.

ORDER	pH		SOM		SMC		SFC	
	CC	P	CC	P	CC	P	CC	P
Coleoptera	0.009	0.997	-0.470	0.123	-0.347	0.269	-0.010	0.976
Diptera	0.446	0.146	0.473	0.121	0.532	0.075	0.394	0.206
Hemiptera	-0.211	0.051	-0.217	0.499	-0.709	0.807	0.197	0.539
Homoptera	0.276	0.386	0.306	0.333	0.468	0.125	0.617	0.033
Lepidoptera	-0.213	0.506	0.535	0.073	-0.333	0.290	-0.234	0.464

Note : CC : *correlation coefficient* P = *two-tailed significant value* SOM = *soil organic matter* SMC = *soil moisture content* SFC = *soil field capacity*

Table 5.6 Correlation coefficients and two-tailed significant values between heavy metal concentrations and the total number of individuals per order.

ORDER	As		Co		Cr		Ni	
	CC	P	CC	P	CC	P	CC	P
Coleoptera	-0.490	0.106	0.014	0.967	-0.161	0.616	0.884	0.000
Diptera	0.340	0.279	-0.623	0.003	0.425	0.169	0.566	0.055
Hemiptera	-0.476	0.118	-0.013	0.967	0.222	0.488	-0.437	0.155
Homoptera	0.154	0.633	-0.047	0.884	-0.187	0.561	0.110	0.734
Lepidoptera	-0.0654	0.021	-0.037	0.908	-0.102	0.753	-0.603	0.038

Note : CC : *correlation coefficient* P = *two-tailed significant value*

Although statistical analysis of the correlation test did not explain "*cause and effect*" relationships between variables, instead of functional relationships, the results can give an idea about the sensitivity of these orders to certain concentrations of heavy metals and the possibility for being used as bioindicators. For example, the concentration of As in soils could be predicted and assessed by observing the total number of individuals of Lepidoptera and applying the linear regression line which results. The equation is:

$$L = 7.59 - 0.15\ As \quad \text{(Appendix 19)}$$

where L : *total number of individual of Lepidoptera*
7.59 : *a constant*
As : *As concentration in soil*

By a similar way, assessment of the heavy metal contamination in soils could be made for Co and Ni by considering the total number of individuals of Diptera and Coleoptera, respectively and applying the following linear regression line equations :

$$D = 31.4 - 0.44\ Co \quad \text{(Appendix 20)}$$

$$C = 23.04 - 1.01\ Ni \quad \text{(Appendix 21)}$$

where D : *total number of individual of order Diptera*
C : *total number of individual of order Coleoptera*
31.4 and 7.0 : *constants*
Co and Ni : *Co and Ni concentration in soil*

The correlation test was also done for each family with each heavy metal concentration and other soil physicochemical parameters (soil pH, soil organic matter, soil moisture content, and soil field capacity). For such purposes, 10 families that were present in all of the study sites were selected and tested . The results of the correlation coefficients are listed in Tables 5.7 and 5.8.

It was interesting to find that no significant correlations were observed between the heavy metal concentrations and the total number of individuals per family. Some families, however, were relatively sensitive to heavy metal concentrations and had two-tailed significant values of close to 0.05. For instance,

Table 5.7 Correlation coefficients and two-tailed significant values between heavy metal concentrations and the total number of individuals per family.

FAMILY	As		Co		Cr		Ni	
	CC	P	CC	P	CC	P	CC	P
Carabidae	-0.180	0.577	0.334	0.289	-0.393	0.206	-0.427	0.166
Staphylinidae	-0.269	0.397	-0.428	0.165	-0.081	0.804	-0.399	0.198
Tenebrionidae	-0.387	0.214	0.040	0.902	0.267	0.401	-0.435	0.158
Culicidae	0.131	0.684	0.250	0.434	-0.276	0.385	-0.076	0.815
Mycetophylidae	0.249	0.435	-0.562	0.057	0.168	0.602	0.464	0.129
Cixiidae	-0.197	0.540	0.252	0.429	-0.199	0.535	-0.161	0.618
Cycadellidae	0.065	0.842	-0.100	0.757	-0.188	0.559	0.023	0.943
Formicidae	-0.217	0.497	-0.278	0.382	0.466	0.127	-0.332	0.292
Troctidae	-0.149	0.643	-0.053	0.871	0.565	0.056	0.051	0.875
Noctuidae	-0.550	0.064	0.361	0.250	-0.182	0.571	-0.478	0.116

Note : CC : *correlation coefficient* P = *two-tailed significant value*

family Noctuidae (order: Lepidoptera) was sensitive to As concentrations (P = 0.064); family Mycetophylidae (order: Diptera) was not significantly correlated, but was relatively sensitive to Co concentrations (P = 0.057); and family Troctidae (order: Isoptera) was sensitive to Cr concentrations (P = 0.056). No single family was observed to be sensitive to Ni concentrations (Table 5.7). Most of the families were also not significantly correlated with the soil physicochemical parameters. Significant correlations were only observed between the number of individuals of family Tenebrionidae (order: Coleoptera) with soil moisture content and family Culicidae (order: Diptera) with soil field capacity (Table 5.8).

Table 5.8 Correlation coefficients and two-tailed significant values between soil-physicochemical parameter and the total number of individual per family.

FAMILY	pH		SOM		SMC		SFC	
	CC	P	CC	P	CC	P	CC	P
Carabidae	0.043	0.895	-0.199	0.536	-0.239	0.455	0.176	0.585
Staphylinidae	0.223	0.486	-0.193	0.548	-0.118	0.714	0.019	0.954
Tenebrionidae	-0.194	0.546	-0.476	0.117	-0.587	0.045	-0.376	0.228
Culicidae	0.128	0.693	0.292	0.358	0.205	0.523	0.622	0.031
Mycetophylidae	0.415	0.179	0.268	0.400	0.368	0.239	0.106	0.743
Cixiidae	-0.219	0.495	0.010	0.974	0.138	0.670	0.241	0.451
Cycadellidae	0.254	0.425	0.113	0.728	0.254	0.426	0.341	0.278
Formicidae	0.082	0.801	-0.297	0.349	-0.290	0.361	-0.078	0.810
Troctidae	-0.291	0.358	-0.164	0.611	-0.117	0.716	-0.399	0.199
Noctuidae	-0.516	0.086	-0.533	0.074	-0.385	0.217	-0.444	0.148

Note : CC = *correlation coefficient* P = *two-tailed significant value* SOM = *soil organic matter* SMC = *soil moisture content* SFC = *soil field capacity*

Table 5.9 shows the species richness and diversity indices of the soil-inhabiting arthropod communities at all study sites. The highest number of species (N0) were found in sites N5 (36 species), S3 (36 species), S4 (37 species) and S2 (38 species). These values were higher than those of sites N1 (26 species), N2 (23 species) and S1 (20 species). Similar figures were obtained by the diversity indices of N1 (the number of *abundant* species) and N2 (the number of *very abundant* species). The highest values of diversity indices were found in sites N4, N5, S3, and S4, while the lowest values were indicated in sites N1, N2 and S1 (Figure 5.11).

The results of the correlation test showed that the total number of taxa (individuals, species, families, and orders) is not significantly correlated with soil physicochemical parameters (Table 5.10). In contrast, the total number of species

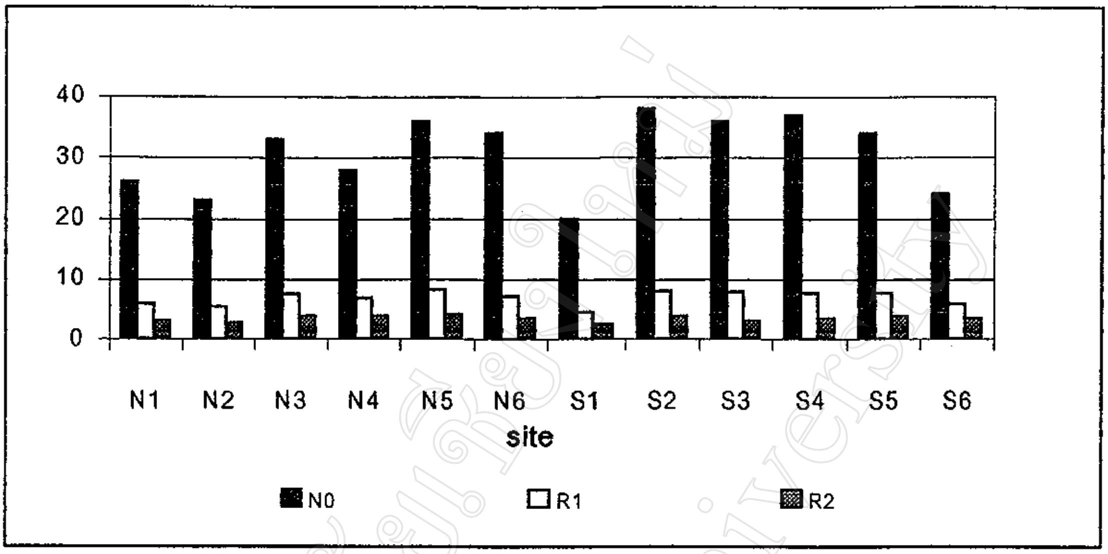
Table 5.9 Ecological indices of the soil-inhabiting arthropod communities at the study sites

	Site											
	N1	N2	N3	N4	N5	N6	S1	S2	S3	S4	S5	S6
Richness Indices												
N0	26	23	33	28	36	34	20	38	36	37	34	24
R1	5.97	5.27	7.49	6.8	8.13	7.18	4.54	8.04	7.78	7.66	7.58	5.94
R2	3.2	2.85	3.89	3.85	4.19	3.42	2.46	3.8	3.8	3.53	3.85	3.46
Diversity Indices												
λ	6.39	5.87	6.69	2.76	3.07	5.32	6.76	6.3	4.25	3.77	4.33	5.67
H'	2.89	2.85	2.98	3.2	3.34	3.09	2.7	3.12	3.26	3.3	3.2	2.87
N1	17.94	17.2	19.7	24.4	28.3	22.1	14.9	22.6	26.2	27	24.6	17.69
N2	15.66	17.1	15	36.3	32.5	18.8	14.8	15.9	23.6	26.5	23.1	17.63
Evenness Indices												
E5	0.87	0.99	0.75	1.51	1.16	0.85	0.99	0.69	0.9	0.98	0.94	1

Note : N0 = *total number of species* R1 = *Margalaef index* R2 = *Menhinick index*
λ = Simpson's index H' = *Shannon's index* N1 = *Hill's diversity number of abundant species* N1 = *Hill's diversity number of very abundant species*

correlated significantly to the As and Ni concentrations and the total number of families also correlated significantly with As concentrations (Table 5.11). These results support the previous discussion that heavy metal concentrations in soils, especially for As and Ni, affected and determined the soil-inhabiting arthropod communities more than the soil physicochemical parameters.

The evenness indices (E5) of the soil-inhabiting arthropod communities at different study sites are illustrated in Figure 5.12 and show no significant correlation with As, Cr and Ni concentrations. A significant correlation was only found between evenness indices and Co concentration (Table 5.12). This means that evenness



Note : H' = *Shannon's index* N1 = *Hill's diversity number of abundant species*
N1 = *Hill's diversity number of very abundant species*

Figure 5.11. Species diversity indices of the soil-inhabiting arthropod communities at the study sites.

Table 5.10 Correlation coefficients and two-tailed significant values between soil-physicochemical parameters and the total number of individuals, species, families, and orders.

TAXON	pH		SOM		SMC		SFC	
	CC	P	CC	P	CC	P	CC	P
Individual	0.023	0.464	-0.055	0.866	0.146	0.650	0.400	0.197
Species	-0.247	0.439	-0.544	0.067	-0.373	0.233	-0.084	0.796
Family	-0.298	0.347	-0.573	0.052	-0.347	0.269	-0.238	0.461
Order	0.077	0.812	-0.233	0.466	-0.043	0.895	-0.148	0.645

Note : CC = *correlation coefficient* P = *two-tailed significant value*

indices are very limited to figure out the soil-inhabiting arthropod communities and to compare the level of soil contamination. This may be due to small size of individuals found for each species. However, they can be applied for assessing soil contamination by cobalt (Co).

Table 5.11 Correlation coefficients and two-tailed significant values between heavy metal concentration and the total number of individuals, species, families, and orders

TAXON	As		Co		Cr		Ni	
	CC	P	CC	P	CC	P	CC	P
Individual	-0.187	0.561	-0.222	0.489	0.167	0.603	-0.218	0.496
Species	-0.687	0.014	0.004	0.990	0.209	0.514	-0.637	0.026
Family	-0.726	0.007	-0.118	0.715	0.334	0.289	-0.541	0.069
Order	-0.375	0.230	-0.312	0.324	0.449	0.144	-0.190	0.554

Note : CC = *correlation coefficient* P = *two-tailed significant value*

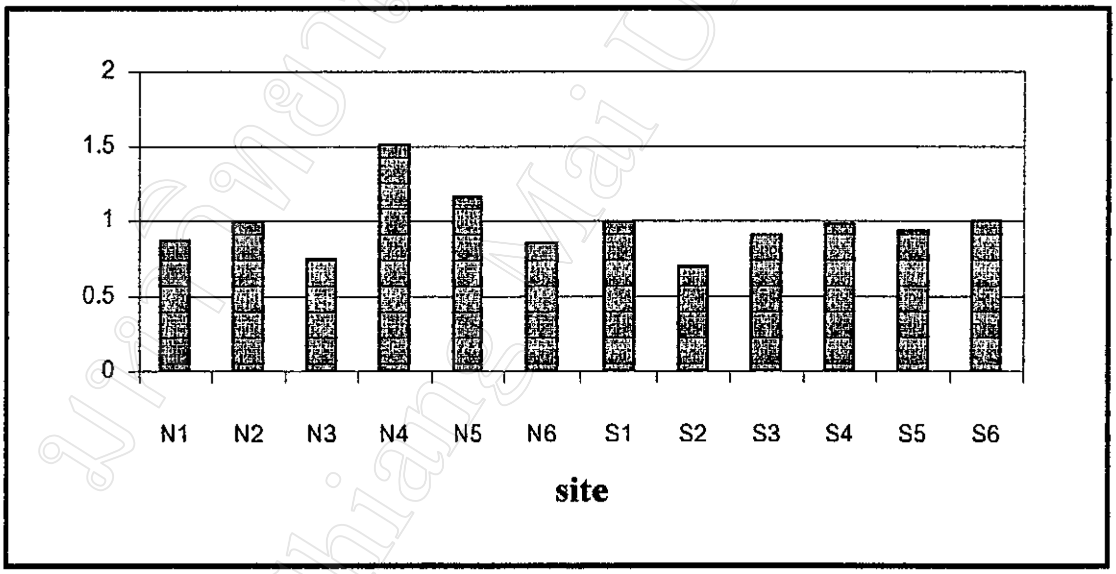


Figure 5.12. Evenness indices (E5) of the soil-inhabiting arthropod communities at the study sites

The similarities of the soil-arthropod communities between study sites are summarized in Table 5.13. The highest values are indicated by the similarities between sites N1-S6 (0.72), N3-S5 (0.67) and S2-S4 (0.64). In contrast, the lowest values are shown by the similarities between sites N1-N2 (0.18), N1-N3 (0.20) and

Table 5.12 Correlation coefficients and two-tailed significant values between heavy metal concentrations and evenness indices (E5)

	As		Co		Cr		Ni	
	CC	P	CC	P	CC	P	CC	P
Evenness indices	-0.098	0.763	0.668	0.018	-0.423	0.171	-0.111	0.730

Note : CC = *correlation coefficient* P = *two-tailed significant value*

Table 5.13. Similarity coefficients (Sorensen's indices) of the soil-inhabiting arthropod communities between the study sites

SITE	N1	N2	N3	N4	N5	N6	S1	S2	S3	S4	S5
N2	0.18										
N3	0.20	0.32									
N4	0.26	0.31	0.43								
N5	0.36	0.37	0.55	0.38							
N6	0.37	0.49	0.42	0.39	0.43						
S1	0.30	0.34	0.30	0.29	0.32	0.44					
S2	0.38	0.46	0.39	0.40	0.40	0.58	0.45				
S3	0.32	0.41	0.44	0.44	0.44	0.43	0.43	0.57			
S4	0.48	0.63	0.53	0.35	0.35	0.56	0.43	0.64	0.52		
S5	0.30	0.46	0.67	0.32	0.32	0.41	0.26	0.44	0.43	0.48	
S6	0.72	0.51	0.34	0.23	0.23	0.38	0.27	0.36	0.40	0.39	0.24

N1-N4 (0.26). These data also agreed with the results of chord distance indices (CRD) (Table 5.14). The chord distances between sites N1-S6, N3-S5, and S2-S4 were the lowest with 0.39, 0.85 and 0.97, respectively. Higher values of chord distances were present between sites N1-N2 (1.01), N1-N3 (1.02) and S5-S6 (1.2). This means that study sites having more different levels of heavy metal contamination showed lower

Table 5.14. Chord distance coefficients (CRD) of the soil-inhabiting arthropod communities between the study sites

SITE	N1	N2	N3	N4	N5	N6	S1	S2	S3	S4	S5
N2	1.01										
N3	1.02	1.21									
N4	1.18	1.24	1.02								
N5	0.86	1.03	0.83	0.83							
N6	1.2	0.86	1.27	1.27	1.19						
S1	1.26	1.13	1.22	1.23	1.25	1.11					
S2	1.18	1.10	1.32	1.28	1.28	0.96	1.27				
S3	1.13	1.07	0.87	1.12	1.07	1.06	0.95	1.23			
S4	1.09	0.85	1.13	1.19	1.16	0.84	0.94	0.97	0.92		
S5	1.03	1.23	0.89	1.22	1.02	1.24	1.27	1.30	1.00	1.20	
S6	0.39	1.04	1.13	1.19	0.94	1.24	1.33	1.23	1.21	1.17	1.20

similarities and/or higher values of chord distance of the soil-inhabiting arthropod communities. It is also evidence to show that the soil-inhabiting arthropod communities in the area studied were sensitive and influenced by the level of heavy metal concentration.

5.4. Assessment of soil contamination

Evaluating the potential use of soil-inhabiting arthropod communities as bioindicators for assessment of soil contamination by the heavy metals includes a thorough understanding of the processes operating in the ecosystem. First of all, it should be realized that soil itself represented a considerable conglomeration of various materials of diverse physical, chemical, and biological properties. Therefore, assessment could not be excluded from the biological and physicochemical factors.

In this work, assessment of soil contamination was based on both physicochemical and biological parameters. It means that the physicochemical parameters, especially the heavy metal concentrations, were confirmed with the biological parameters using ecological indices of the soil-inhabiting arthropod communities. The results clearly indicate that the more contaminated sites show lower species richness and diversity indices. This is attributed to the negative effects of heavy metals on the soil-inhabiting arthropod communities because the species in natural or uncontaminated habitats tend to be more diverse and abundant (Beeby, 1993). In a natural habitat some species are more specialized in feeding behavior due to interspecific competition that force them to use the resources more efficiently. The negative effect of heavy metals on soil arthropods was not only related to their accumulation in soils, but also in food chains (plants, litter, prey, *etc.*) and in the body of soil arthropods themselves to a certain level that caused toxicity and death. Any organism has a certain tolerable limit in accumulating heavy metal. If the limit is overloaded the organism can not be survived. In the more contaminated study sites there were only some species capable of surviving. Consequently, the population of certain species increased and became dominant. It was the reason why species richness and diversity in the more contaminated study sites were less abundant in comparison to those of the less contaminated study sites. The accumulation and negative effects of heavy metals on soil-inhabiting arthropod could not be excluded from their mobility in soil and especially their availability for plant or vegetation. Scanlon and Daggan (1979) stated that the foliage of plants grown on fly ash accumulated Bo, Ni, and Se and suggested both Bo and Se display greater bio-availability to plants from fly ash compared to soil. Cherry and Guthrie (1979) confirmed the accumulation of Se in plants grown on fly ash and reported similar bio-accumulation of As, Cu, Hg, and Zn. In the case of Ni, the elevated tissue levels of fly ash-grown plants simply reflected the higher fly ash concentrations of this metal compared to normal soil. It means that all of the soil-inhabiting arthropods would be in risk and affected by heavy metal contaminations regardless of their feeding habits.

From Appendix 3 it can be seen that some families were only found in relatively contaminated study sites *e.g.* Chironomidae (N1 and S1), Oligotomidae (S1), Plutellidae (N1), and Campodeidae (S1). Some families were very common at all of the study sites *e.g.* Carabidae, Staphylinidae, Tenebrionidae, Culicidae, Mycetophylidae, Cixiidae, Cycadellidae, Formicidae, Troctidae, and Noctuidae. Most of the families, however, were found in less contaminated study sites *e.g.* Erigonidae (S2 and S2), Chiloferidae (N5 and S4), Pselapidae (S2), and Dolichopidae (N4).

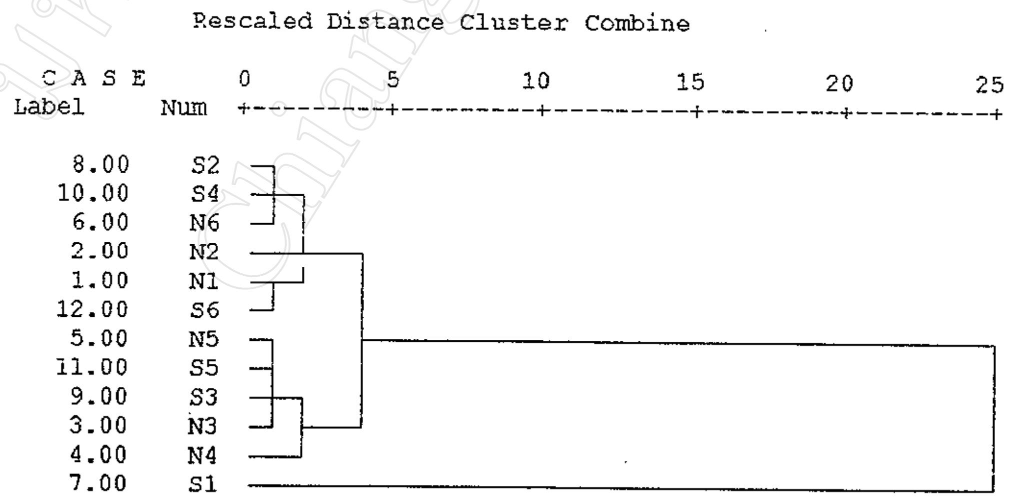


Figure 5.13. Cluster analysis of the study sites based on heavy metal (As, Co, Cr, Ni) concentrations

The results of the similarity and distance coefficients have strengthened the reason that heavy metal concentrations affected the pattern of soil-inhabiting arthropod communities. It can be shown that study sites having relatively equal heavy metal contamination indicate higher similarity and/or lower distance coefficients.

This means that soil-arthropod communities in these study sites were closely related and more similar. The similarity and distance coefficients between the study sites could also be confirmed with the result of cluster analysis based on heavy metal concentrations (Figure 5.13). The study sites belonging to the same group were indicated to have higher similarity and/or lower distance coefficients *e.g* between sites S2-S4, N6-S4, N1-S6, and N3-S5. In contrast, the lower values of similarity coefficients and/or higher distance coefficients were shown between the study sites of different groups resulted from the cluster analysis, for example, between sites N1-N3, N1-S5, S1-S6, and S1-S5.