Chapter 5

RESULTS AND DISCUSSIONS

5.1. PHYSICAL AND CHEMICAL CHARACTERISTICS OF WATER

5.1.1. Temperature of surface and ground water during the study period

Water temperature is presented in Table 5.1.1, Figure 5.1.1, and Appendices 2.1 and 2.2. It ranged from 22-34°C and significantly decreased from November to December when the cool-dry season came. Based on a statistical analyses presented in Appendices 1.1 and 1.3, average values of temperature can be separated into three significantly different groups. The lowest temperature (24.1°C) was recorded in December while the highest is about 1.3 times higher in October (31.7°C). The water temperatures were not significantly different between the three reservoirs.

Ground water temperatures differ greatly between study sites. Its trend decreased from November to December when the cool-dry season came. Because the ground water temperatures are controlled by the soil, they did not fluctuate as much as the surface water temperatures. The lowest temperature (21°C) was recorded in the southern well of the mine in December while the highest value (48°C) was found in the well inside mining area in August. According to the statistical analyses shown in Appendices 1.2 and 1.6, ground water temperatures were found to be less significant differences during the study period. These temperatures mainly depended on the sites and can be increasingly distinguished as three significant different groups as well as northern-southern wells (27.4°C), seepages (30.9°C), and mining wells (41°C) respectively.

5.1.1: Temperature (°C) of surface and ground water during the study period

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	30	30	31	34	31	25
MKR2	28	28	30	33	31	26
MKR3	31	30	31	32	30	26
Average	*30*	*29*	*31*	*33*	*31*	*26*
MMR1	29	29	30	30	27	22
MMR2	31	32	31	31	30	23
MMR3	31	33	30	32	29	23
Average	*30*	*31*	*30*	*31*	*29*	*23*
AR1	32	32	30	32	29	24
AR2	33	32	30	32	29	24
AR3	33	32	31	32	29	24
Average	*33*	*32*	*30*	*32*	*29*	*24*
Ground water						
N1	27	27	27	28	28	26
N2	27	27	28	29	28	26
SP1	28	28	28	29	28	26
SP2	34	35	34	35	35	31
SP3	28	32	30	33	30	*
SP4	30	32	*	*	*	*
M1	36	40	37	38	39	36
M2	42	44	46	34	*	*
M3	47	48	35	46	47	46
S1	27	27	26	29	27	24
S2	30	30	31	31	30	28
S3	27	26	26	28	29	21
S4	29	27	27	29	28	23
CT1	30	28	29	29	27	22
CT2	29	28	28	30	28	22
CT3	29	28	29	30	29	23

*: *No sample*

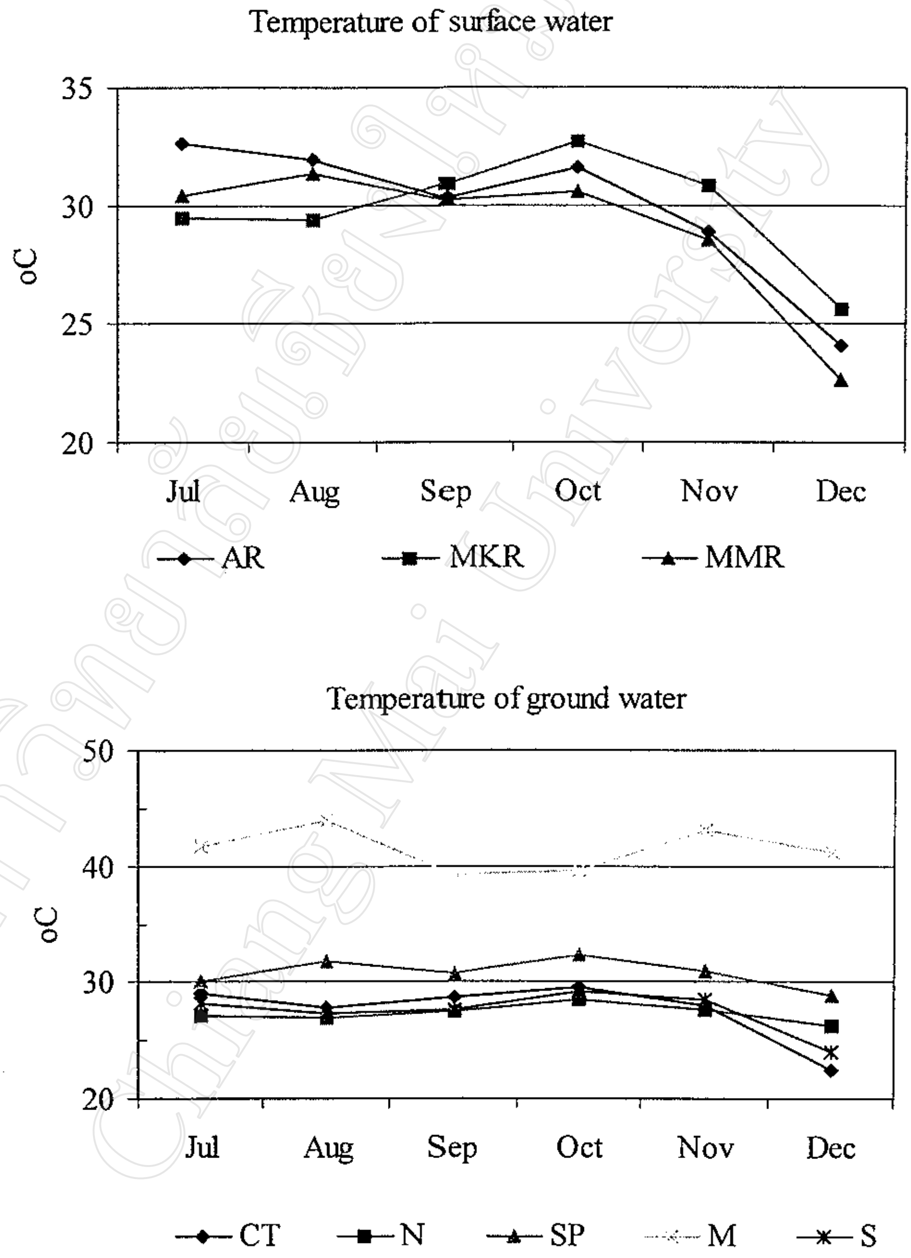


Figure 5.1.1: Temperature of surface and ground water during the study period

Looking to control wells, there are no significant differences between the reference sites, the north, and south of the mine. It is very different with these wells inside the mine and seepages surrounding the mine.

Unusual ground water temperatures from 35 °C up to 48 °C in three wells inside the mining area may be caused by geothermal association from deep seat or fracture.

5.1.2. pH value of surface and ground water during the study period

The pH values of water samples are shown in Table 5.1.2, Figure 5.1.2, and Appendices 2.1 and 2.2. For surface water, the pH values varied from 6.5 to 8.7 at all sites during the study period. Generally, it can be said that pH values range from slightly acid to alkaline. pH variations mostly depended on both the month and the site (Appendices 1.1, 1.3, and 1.4). Its variations were mostly caused by both chemical and biological conditions in water bodies. The biological effects include photosynthesis and respiration cycles of algae in water bodies, and respiration of aquatic organisms (Chapman, 1996). Chemical characteristics of water also significantly contribute to the pH of water. Abundant alkaline elements in the earth's crust, e.g. calcium (Ca) and magnesium (Mg) may affect water pH. In this case, biological activities have a more important role than chemical ones. The lowest average pH (7.5) was recorded in the Mae Moh Reservoir and respectively differed with the Mae Kham Reservoir (7.9). There is slightly different in comparison with the Ang Kaset.

The underground water pH ranged from 5.1 to 7.2 in the wells to the north of

Table 5.1.2: pH values of surface and ground water during the study period

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	8.7	8.1	8.5	8.5	8.1	7.8
MKR2	6.5	7.1	8.0	7.7	7.4	7.8
MKR3	8.4	7.5	8.1	8.2	8.1	7.9
Average	*7.9*	*7.6*	*8.2*	*8.1*	*7.9*	*7.8*
MMR1	7.7	7.6	7.5	7.9	7.7	7.6
MMR2	7.8	7.5	7.0	7.4	7.3	7.1
MMR3	7.6	8.0	7.5	7.6	7.8	7.4
Average	*7.7*	*7.7*	*7.3*	*7.6*	*7.6*	*7.4*
AR1	8.3	8.3	7.2	7.4	7.9	6.8
AR2	8.5	8.3	7.2	7.8	7.8	7.1
AR3	8.5	7.9	7.3	8.0	7.9	7.1
Average	*8.4*	*8.1*	*7.2*	*7.7*	*7.9*	*7.0*
Ground water						
N1	6.7	6.9	6.6	7.2	7.1	6.8
N2	6.4	6.7	6.5	5.1	6.4	6.4
SP1	6.7	7.0	6.8	4.3	7.1	6.5
SP2	7.1	7.0	6.9	4.3	7.5	6.9
SP3	7.2	7.1	7.5	7.4	7.4	*
SP4	6.8	6.7	*	*	*	*
M1	7.5	7.5	7.5	7.7	7.9	7.4
M2	7.9	7.5	6.9	8.3	*	*
M3	7.1	7.4	7.8	7.1	7.3	6.7
S1	5.8	6.5	6.0	4.4	4.2	3.9
S2	10.0	9.3	9.5	9.6	9.7	9.4
S3	6.6	7.0	6.6	4.3	7.5	7.0
S4	7.1	7.3	7.0	4.5	7.2	6.8
CT1	5.2	5.1	5.2	5.2	4.5	4.4
CT2	5.8	5.9	5.3	5.8	5.3	5.5
CT3	5.4	5.5	4.6	5.3	4.6	4.7

**: No sample*

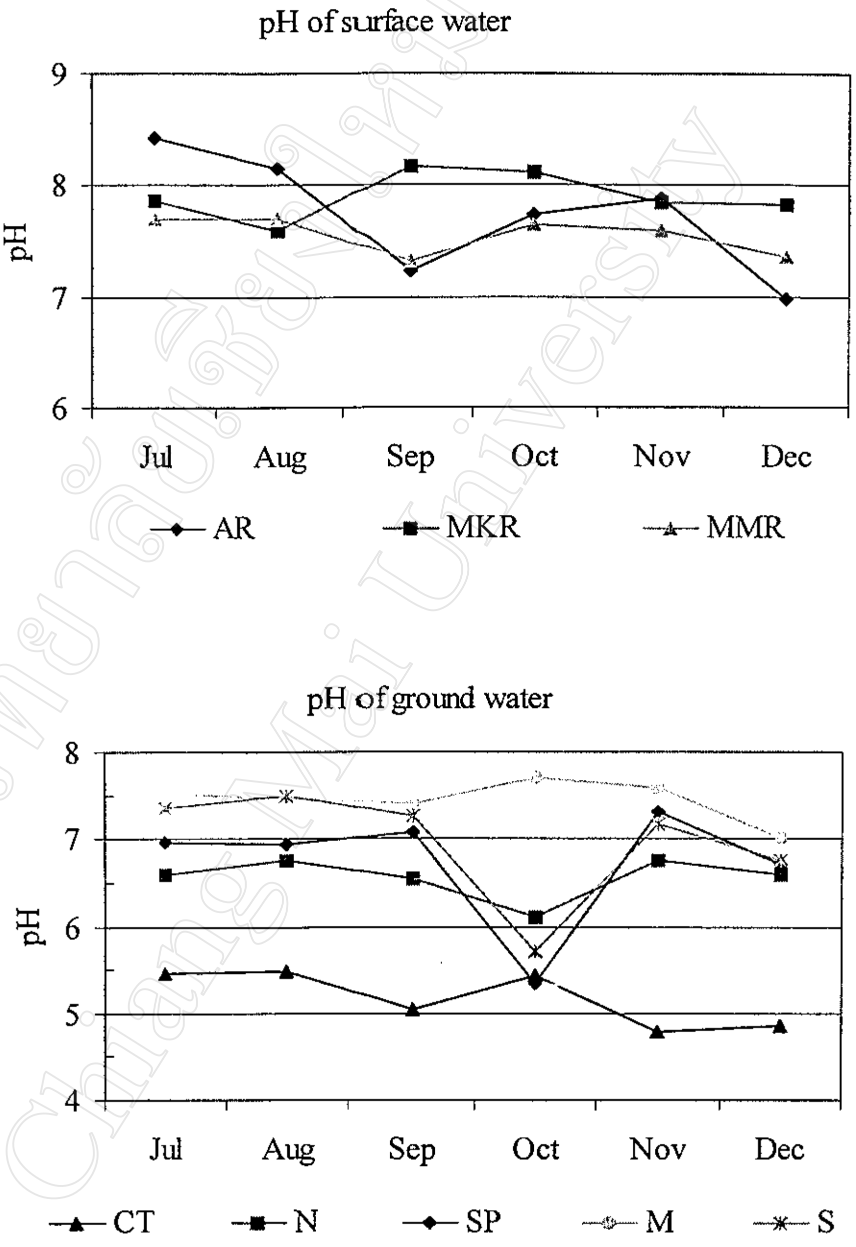


Figure 5.1.2: pH values of surface and ground water during the study period

the mine. In seepages surrounding the mining area, the pH varied from 4.3 to 7.5 with much fluctuation from September to November. Inside the mining area, the pH was stable (6.7 to 8.3) during the study period. In the wells south of the mine, the pH varied from 3.9 to 10 between wells. The high values came from the iron pipe well whose water contained high iron concentration. In the control wells, the pH was low (4.4 to 5.9). There was not much variation during the study period for each well. High range of pH is due to differences between sites. The statistical analysis shown in Appendix 1.2, also indicated that the average pH values mostly depended on the sites or direction. The average values increased from the northern wells (6.5), seepages (6.7), southern wells (7.0), and mining wells (7.5). Due to be bordered by limestone surrounding the Mae Moh Mine and Power Plant site, the average pH was about 1.4 times higher than in the control site (Appendices 1.6 and 2.2).

Due to a lack of photosynthetic process in ground water, the pH is dependent on soil characteristics. Variations in abundance of alkaline element concentrations, viz. Ca, Mg, and the total hardness values of ground water, is related to pH changes in ground water. Salts of calcium, together with those of magnesium, are responsible for hardness of water. High total hardness is often contributed by high amounts of calcium and magnesium salts. These salts may react between water and solid species. These reactions consume large amounts of positive hydrogen ions. Consequently, the pH of water will increase. Thus, there is a slightly positive correlation between total hardness and pH in ground water.

5.1.3. Conductivity of surface and ground water during the study period

The results of surface and ground water conductivity are shown in Table 5.1.3, Figure 5.1.3, and Appendices 2.1 and 2.2. At Ang Kaset, the conductivity values ranged from 176 to 2,480 µS/cm. Highest conductivity values appeared in November. In the Mae Kham Reservoir, it ranged from 238 to 1,304µS/cm. High values often came from outlet sub-site and is associated with high amounts of metal concentrations. A range of 196 to 2,500 µS/cm was recorded in the Mae Moh Reservoir. Average values mostly increased during the study period and strongly depended on electricity generating activities (Appendix 2.1). According to the drainage system at Mae Moh, the Mae Moh Reservoir receives two main wastewater sources, one is from mining activities, including water runoff on the soil surface plus leaching from waste dumps, and the other is from power plant operations producing large amounts of wastewater. Less dilution by rainwater also leads to higher concentration of dissolved, mostly mineral, solids. Consequently, the conductivity of water in the Mae Moh Reservoir increased at the end of rainy season.

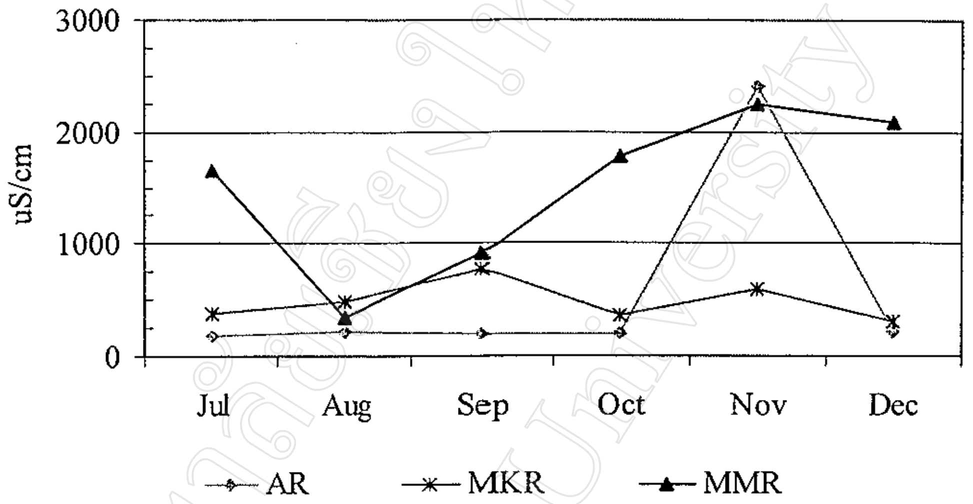
The conductivity of surface water was found to depend specific on sites rather than months. The average values in the Mae Moh Reservoir (1504µS/cm) is about 3 times higher than in the Mae Kham Reservoir (Appendices 1.3 and 1.4). This also indicates that the Mae Moh Reservoir is more affected by mining and power plant activities than the Mae Kham Reservoir. There is lightly different with the control reservoir.

With ground water, the conductivity was found to depend on the particular sites. According to the statistical analyses shown in Appendices 1.2 and 1.6, conductivity can be grouped into two different groups, viz. Northern-southern wells

Table 5.1.3: Conductivity of surface and groundwater during the study period (µS/cm)

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	341	381	517	303	339	335
MKR2	579	714	1,304	474	1,076	328
MKR3	238	345	473	299	343	273
Average	*386*	*480*	*765*	*359*	*586*	*312*
MMR1	2,210	616	1413	1,656	1,863	1,466
MMR2	1,356	196	427	1,897	2,360	2,430
MMR3	1,382	202	916	1,798	2,500	2,380
Average	*1649*	*338*	*919*	*1784*	*2241*	*2092*
AR1	176	200	192	207	2,430	215
AR2	189	215	200	203	2,310	207
AR3	191	220	193	200	2,480	215
Average	*185*	*212*	*195*	*203*	*2407*	*212*
Ground water						
N1	791	372	625	720	857	737
N2	578	1413	666	551	674	509
SP1	795	213	865	862	838	826
SP2	4,020	986	4,300	3,830	4,690	4,110
SP3	1,517	840	1,842	2,030	2,010	*
SP4	5,130	1,123	*	*	*	*
M1	2,320	2,015	2,640	2,300	2,790	2,820
M2	1,485	446	1,523	1,552	*	*
M3	1,528	749	1,553	1,940	1,910	1,600
S1	578	913	628	560	957	436
S2	745	748	758	729	863	801
S3	879	233	1,095	1,152	972	950
S4	860	255	870	356	1,093	840
CT1	159	2,160	318	180	1,853	180
CT2	202	1,215	251	214	2,400	238
CT3	194	738	212	214	2,020	212

*: No sample


Conductivity of surface water

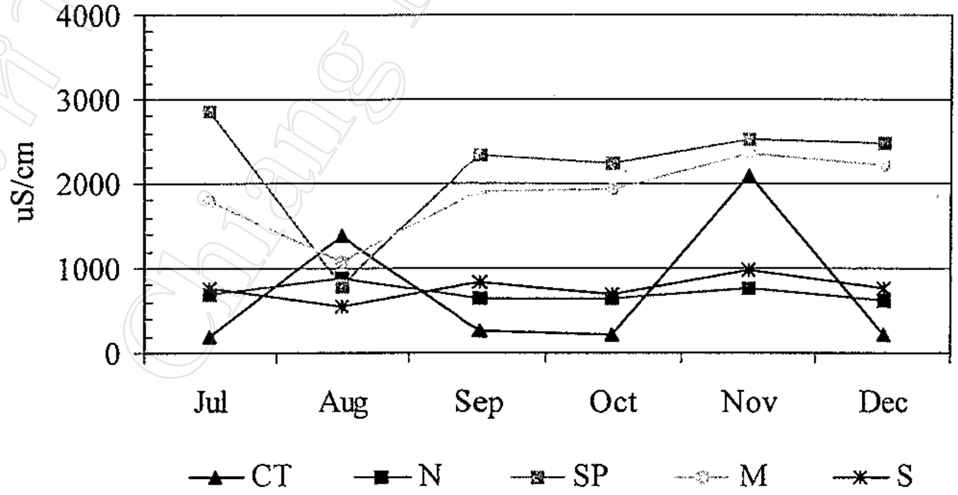

Conductivity of ground water

Figure 5.1.3: Conductivity of surface and ground water during the study period

and mining wells-seepages. The range is from 133 to 1,413 μS/cm in the first group and from 213 to 5,130 μS/cm in the second group during the study period.

Since the northern wells-southern wells are located far from the mine and the power plant, there is less impact from mining and power plant activities. The conductivity values are lower than those at the mining wells-seepages. High water temperature in the wells inside the mine and seepages surrounding is also influences the conductivity. Dissolved mineral salts and their mobility increase with high temperature (Chapman, 1996). Consequently, higher conductivity was found in the second group.

5.1.4. Total dissolved solid (TDS) of surface and ground water during the study period

The total dissolved solids in surface and ground water samples are shown in Table 5.1.4, Figure 5.1.4, and Appendices 2.1 and 2.2. It varied from 120 to 543 mg/l in the Mae Kham Reservoir, from 435 to 1,280 mg/l in the Mae Moh Reservoir, and from 81 to 1,260 mg/l in Ang Kaset. There is a correlation between total dissolved solids and water conductivity values. Total dissolved solids (in mg/l) can be obtained by multiplying the conductance (in μS/cm) by a factor which is commonly between 0.55 and 0.75 (Chapman, 1996). Thus, variations of total dissolved solids can be caused by the factors discussed above for conductivity. Average values of total dissolved solids can be divided into two significant different groups viz. Mae Kham Reservoir (227mg/l) and Mae Moh Reservoir (908 mg/l; Appendix 1.4). This also indicates that the Mae Moh Reservoir has more impact from mining and power plant

Table 5.1.4: Total dissolved solids in surface and ground water during the study period (mg/l).

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	169	186	249	152	172	168
MKR2	289	193	641	242	543	167
MKR3	120	185	245	153	172	140
Average	*193*	*188*	*378*	*182*	*296*	*158*
MMR1	1180	730	746	833	933	735
MMR2	674	877	714	950	1210	1,240
MMR3	690	853	435	993	1,280	1,280
Average	*848*	*820*	*632*	*925*	*1141*	*1085*
AR1	81	101	97	103	1130	107
AR2	84	106	101	101	1190	102
AR3	96	106	98	100	1,260	107
Average	*87*	*104*	*99*	*101*	*1193*	*105*
Ground water						
N1	416	397	313	361	427	367
N2	289	297	333	280	339	259
SP1	400	460	440	438	458	410
SP2	1,980	2,330	2,110	1,910	2,370	2,030
SP3	758	1010	926	1060	1030	*
SP4	2,570	2,610	*	*	*	*
M1	1,500	1,220	1,260	1,140	1,450	1,340
M2	738	221	765	774	*	*
M3	758	235	777	866	943	797
S1	291	305	310	281	481	876
S2	376	430	400	369	433	393
S3	440	515	528	582	486	480
S4	431	494	430	276	543	817
CT1	80	96	158	91	903	90
CT2	101	117	126	107	1,230	124
CT3	99	131	104	107	1,080	113

*: No sample

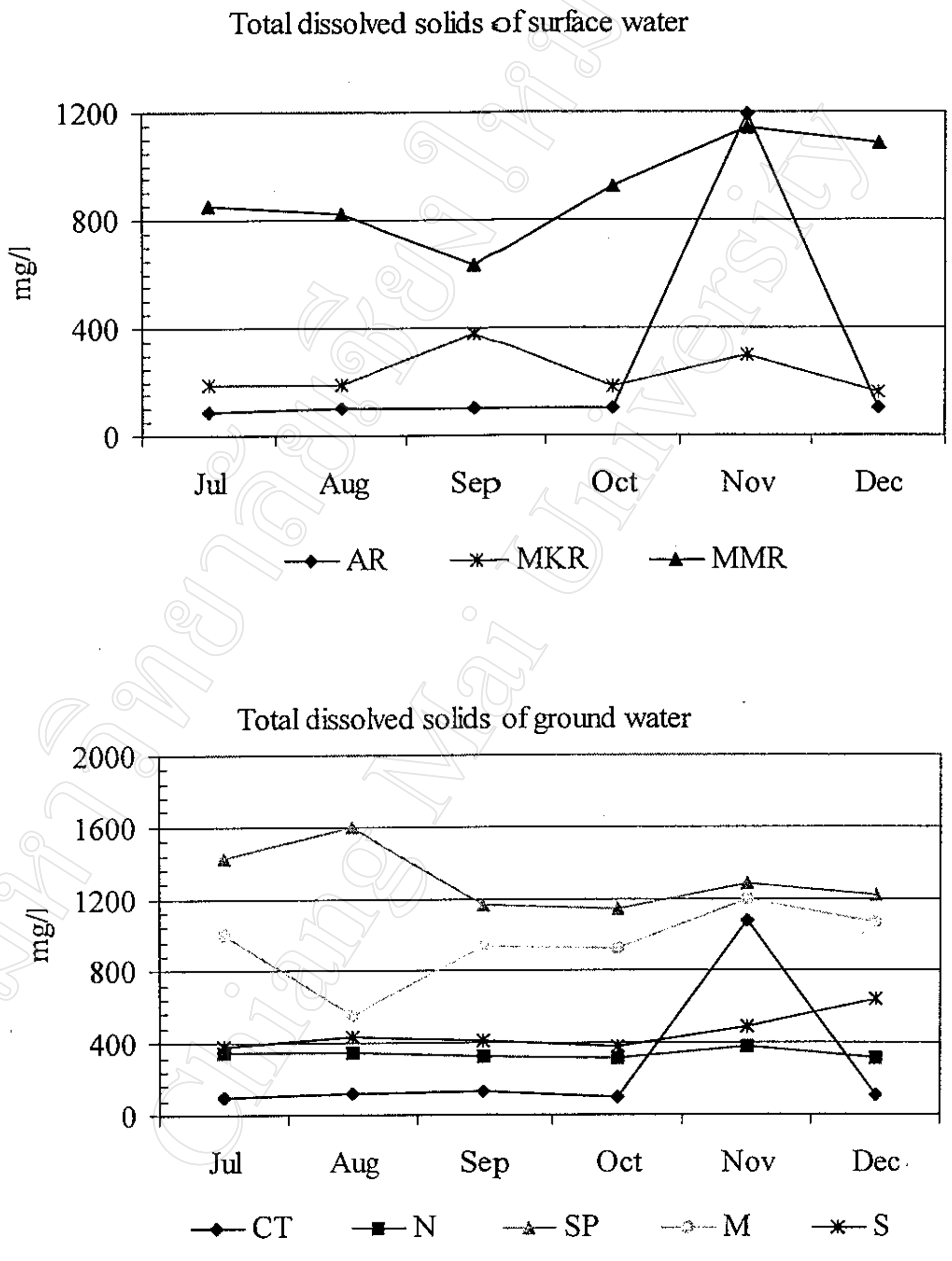


Figure 5.1.4: Total dissolved solids of surface and ground water during the study period

operations than the Mae Kham Reservoir. The control reservoir was is not significantly different from the Mae Kham Reservoir but was very different from the Mae Moh Reservoir.

For ground water, total dissolved solids ranged from 259 to 427 mg/l in the wells to the north of the mine and 276 to 876 mg/l in the wells to the south of the mine. Variation from 400 to 2,610 mg/l was recorded in the seepages surrounding the mining area, while a range of 221 to 1,500 mg/l was found in the wells inside the mining area. The low values of total dissolved solids were mostly found in the control sites since they had no impact from mining and power plant activities. Based on statistical analyses shown in Appendix 1.6, total dissolved solids can be separated into three significantly groups, viz. northern wells-southern wells (340-457mg/l), mining wells (924mg/l), and seepages (1,332mg/l). Again, it is clearly that the wells inside the lignite deposit area and surrounding seepages always had higher amounts of total dissolved solids than in the other zones. That is good evidence to prove that there is a strong environmental impact to water system from mining and power plant activities.

5.1.5. Dissolved oxygen (DO) in surface and ground water during the study period

The dissolved oxygen data is summarized in Table 5.1.5, Figure 5.1.5, and Appendices 2.1 and 2.2. Surface water is mostly influenced by the photosynthetic process of algae and aquatic plants. Additionally, diffusion of dissolved oxygen from the air into water is also very important. Oxygen is consumed by the respiratory process of aquatic organisms and decomposition of organic materials.

Table 5.1.5: Dissolved oxygen in surface and ground water during the study period (mg/l).

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	4.8	6.1	5.6	5.2	5.1	5.0
MKR2	2.4	3.4	4.5	3.8	4.8	5.0
MKR3	5.2	4.8	4.9	5.0	5.4	5.6
Average	*4.1*	*4.8*	*5.0*	*4.7*	*5.1*	*5.2*
MMR1	2.0	2.2	3.6	3.0	3.5	3.7
MMR2	6.0	3.0	1.7	3.8	3.9	5.7
MMR3	4.9	7.0	4.2	4.2	7.2	6.7
Average	*4.3*	*4.1*	*3.2*	*3.7*	*4.9*	*5.4*
AR1	6.0	6.2	4.4	4.4	4.6	4.4
AR2	6.2	6.0	3.7	4.0	4.0	4.3
AR3	6.0	6.0	3.6	4.5	4.4	4.4
Average	*6.1*	*6.1*	*3.9*	*4.3*	*4.3*	*4.2*
Ground water						
N1	1.2	1.6	1.0	0.9	0.9	0.0
N2	3.3	4.2	1.7	2.1	1.8	1.5
SP1	1.8	2.3	1.6	1.1	1.0	0.0
SP2	1.0	1.6	0.9	1.1	0.6	0.2
SP3	4.0	5.0	4.5	4.2	5.9	*
SP4	2.5	3.2	*	*	*	*
M1	1.1	2.5	1.0	1.1	4.1	0.8
M2	3.5	4.0	1.5	1.2	*	*
M3	1.8	5.5	2.5	1.8	1.8	0.3
S1	1.6	2.6	1.6	2.2	1.7	1.0
S2	1.8	2.8	1.8	0.7	1.1	0.6
S3	2.0	2.6	2.2	2.3	1.0	0.0
S4	0.9	1.8	1.4	0.4	2.1	3.5
CT1	4.1	4.2	1.1	3.0	2.6	2.8
CT2	4.0	4.1	3.4	2.5	3.1	2.8
CT3	1.8	1.7	3.0	1.3	0.5	0.0

*: *No sample*

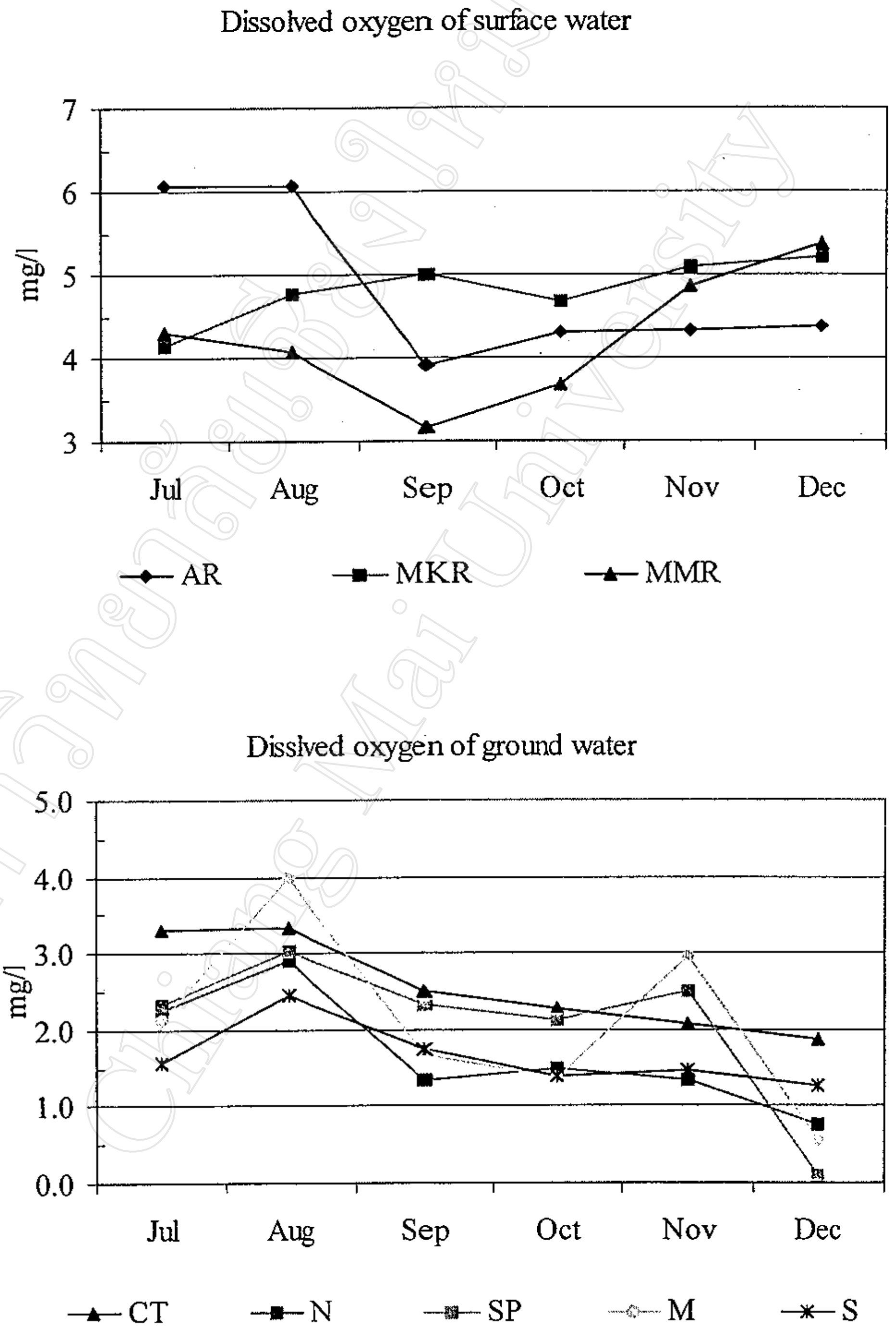


Figure 5.1.5: Dissolved oxygen of surface and ground water during the study period

During the study period, the dissolved oxygen ranged from 1.7 to 7.2 mg/l. The variation of dissolved oxygen between sites and months was great. Its variation depend on the time of measurement, biomass of aquatic plants. Higher biomass can produce more DO during photosynthetic process. High DO in surface water is often recorded after noon time (12:00) in case of sunny day while the lowest DO is found at the time before sun rise. High organic matter also cause low DO at the early morning.

The ground water samples contained low dissolved oxygen and ranged from zero to 5.9 mg/l. Due to the oxygen is supported to ground water through recharge and by movement of air through unsaturated materials above water table. It reacts with materials along flow path of water. Consequently, most ground water contains little or no dissolved oxygen. In some cases, ground waters can contain oxygen concentrations similar to those in surface water if the recharge does not pass through oxidizable materials below the ground surface (Hem, 1985). The amounts of dissolved oxygen (Appendices 1.5 and 1.6) in the study area indicated the aeration and short distance of recharge system.

5.1.6. Total alkalinity of surface and ground water during the study period

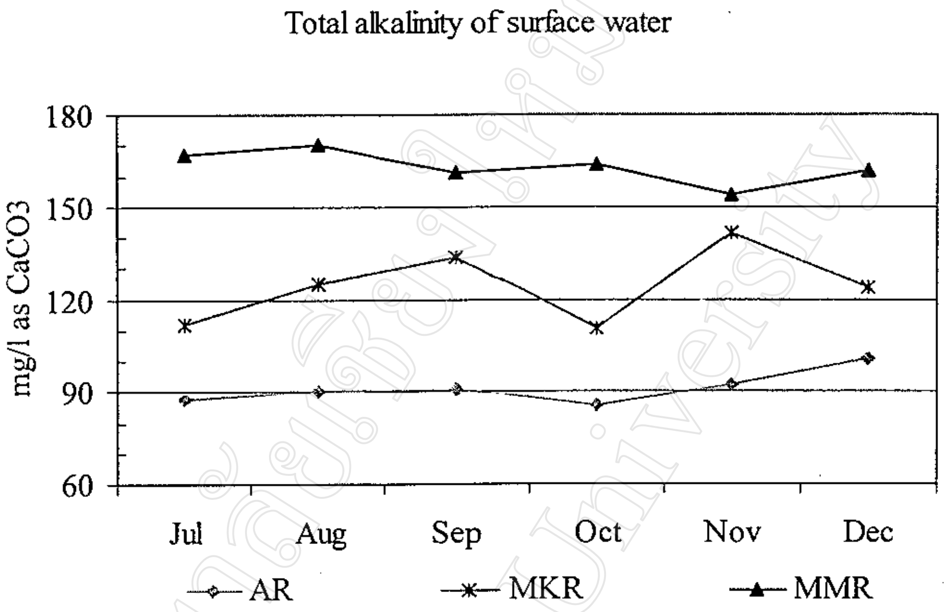
Total alkalinity of the water samples is shown in Table 5.1.6 and Figure 5.1.6. A range of 118 to 242 mg/l as $CaCO_3$ was recorded in the Mae Moh Reservoir and from 83 to 105mg/l as $CaCO_3$ in Ang Kaset. In the Mae Kham Reservoir, it ranged from 101 to 181 mg/l $CaCO_3$.

These results indicate that surface water has a high buffering capacity and can

Table 5.1.6: Total alkalinity of surface and ground water during the study period (mg/l as $CaCO_3$).

Time	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	112	126	121	104	124	125
MKR2	102	115	148	127	181	123
MKR3	121	133	131	101	119	123
Average	*112*	*125*	*133*	*111*	*141*	*124*
MMR1	228	191	131	214	198	242
MMR2	141	162	180	133	120	125
MMR3	132	157	172	145	143	118
Average	*167*	*170*	*161*	*164*	*154*	*162*
AR1	89	92	89	90	91	99
AR2	86	89	89	83	93	105
AR3	88	89	95	84	91	97
Average	*87*	*90*	*91*	*86*	*92*	*101*
Ground water						
N1	234	251	267	234	255	233
N2	157	186	210	159	193	200
SP1	310	321	364	305	234	316
SP2	1,668	1,380	1,532	1,445	1,753	1,701
SP3	127	144	167	149	249	*
SP4	661	612	*	*	*	*
M1	1,393	1,351	1,491	1,212	1,528	1,305
M2	771	766	818	700	*	*
M3	763	745	814	680	768	736
S1	72	88	125	42	40	13
S2	414	230	278	229	273	194
S3	150	165	165	163	570	535
S4	535	521	534	521	181	157
CT1	8	15	21	23	13	11
CT2	42	49	49	54	21	47
CT3	30	38	42	42	17	21

** : No sample*



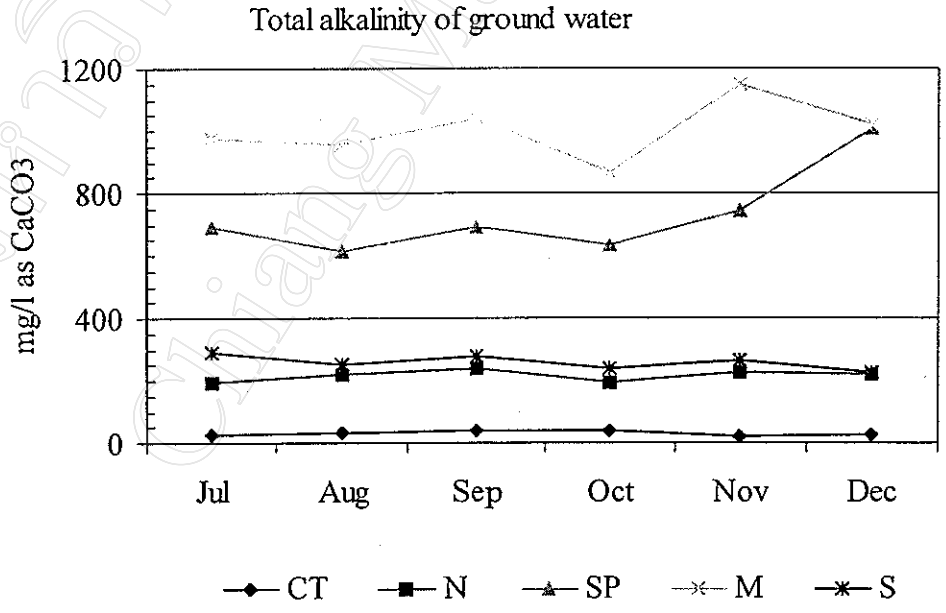


Figure 5.1.6: Total alkalinity of surface and ground water during the study period

control alteration in pH. According to a statistical analyses shown in Appendices 1.1 and 1.4, average monthly values from the Mae Kham Reservoir (163 mg/l as $CaCO_3$ were higher than at the Mae Moh Reservoir (124 mg/l as $CaCO_3$). This was due to the location rather than the month sampled.

The total alkalinity of ground water varied from 8 to 54 mg/l as $CaCO_3$ in the control wells, from 157 to 267 mg/l as $CaCO_3$ in the wells to the north of the mine, and from 13 to 570 mg/l as $CaCO_3$ in the wells to the south of the mine. Values from 127 to 1,753 mg/l as $CaCO_3$ were recorded in the seepages surrounding the mine and from 700 to 1,528 mg/l as $CaCO_3$ in deep wells inside the mining area. The high variation here did not mean that total alkalinity vastly fluctuated during the study period. Appendix 2.2 indicates that total alkalinity was stable. High values were often recorded in the wells in the mine pit and seepages surrounding.

The Figure 5.1.6 and an Appendix 1.2 also indicate that total alkalinity did not fluctuate much and were no significant differences during the study period. It mostly depended on the sites where there is an increasing trend viz. northern-southern wells (215-258mg/l as $CaCO_3$), seepages (707mg/l as $CaCO_3$), mining wells (990mg/l as $CaCO_3$) (Appendix 1.6). In the control well, total alkalinity was low because the pH was low.

5.1.7. Acidity of surface and ground water during the study period.

The acidity of surface and ground water are shown in Table 5.1.7 and Figure 5.1.7. The acidity decreased from July to October because of dilution by rain. In the Mae Moh Reservoir, acidity ranged from 8 to 20 mg/l as $CaCO_3$, and from zero to 13

Table 5.1.7: Acidity of surface and ground water during the study period (mg/l as $CaCO_3$)

Time	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	7	0	0	0	8	7
MKR2	12	13	8	7	10	7
MKR3	6	7	4	0	2	4
Average	*8*	*7*	*4*	*2*	*6*	*6*
MMR1	16	15	11	8	14	10
MMR2	11	16	19	14	20	14
MMR3	18	8	8	13	11	15
Average	*15*	*13*	*13*	*12*	*15*	*13*
AR1	2	0	6	4	7	6
AR2	1	0	6	4	5	4
AR3	1	0	5	4	5	4
Average	*2*	*0*	*6*	*4*	*6*	*5*
Ground water						
N1	44	43	42	27	22	22
N2	34	35	42	62	45	46
SP1	45	39	53	54	55	44
SP2	81	49	166	84	83	133
SP3	13	11	12	17	42	*
SP4	96	122	*	*	*	*
M1	73	44	48	27	20	49
M2	17	34	48	0	*	*
M3	35	10	17	51	47	53
S1	28	42	55	73	132	100
S2	0	0	0	0	0	0
S3	18	23	23	21	32	43
S4	26	34	48	38	22	8
CT1	36	66	46	74	45	54
CT2	52	43	51	58	36	48
CT3	83	90	61	122	31	109

*: No sample

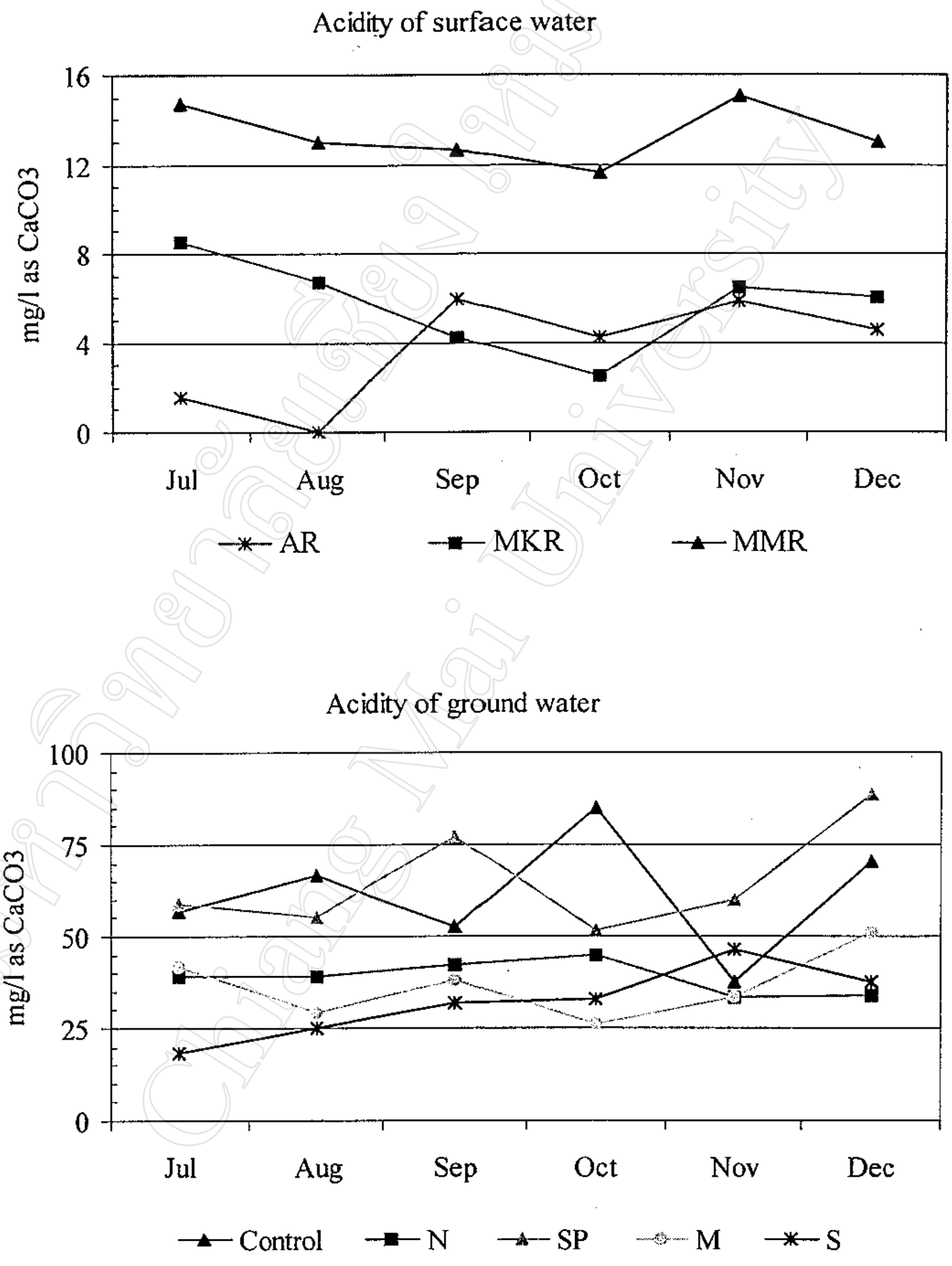


Figure 5.1.7: Acidity of surface and ground water during the study period

mg/l as $CaCO_3$ in the Mae Kham Reservoir. Water sample collected from Ang Kaset had values of zero to 7 mg/l as $CaCO_3$. Regarding the statistical analysis shown in Appendix 1.1, the acidity of water samples depended on the reservoirs. The Mae Kham Reservoir (13 mg/l as $CaCO_3$) is 2 times more acidic than the Mae Moh Reservoir (Appendix 1.4).

Acidity of ground water varied from 31 to 122 mg/l as $CaCO_3$ in the control wells, 22 to 62 mg/l as $CaCO_3$ in the wells in the north of the mine, from 11 to 166 mg/l as $CaCO_3$ in the seepages, from zero to 73 mg/l as $CaCO_3$ in the three wells inside mining area, and from zero to 122 mg/l as $CaCO_3$ in the four wells to south of the mine. The acidity of ground water is directly related to the pH. A high pH is associated with low acidity. Thus, acidity has a negative correlation with pH in ground water.

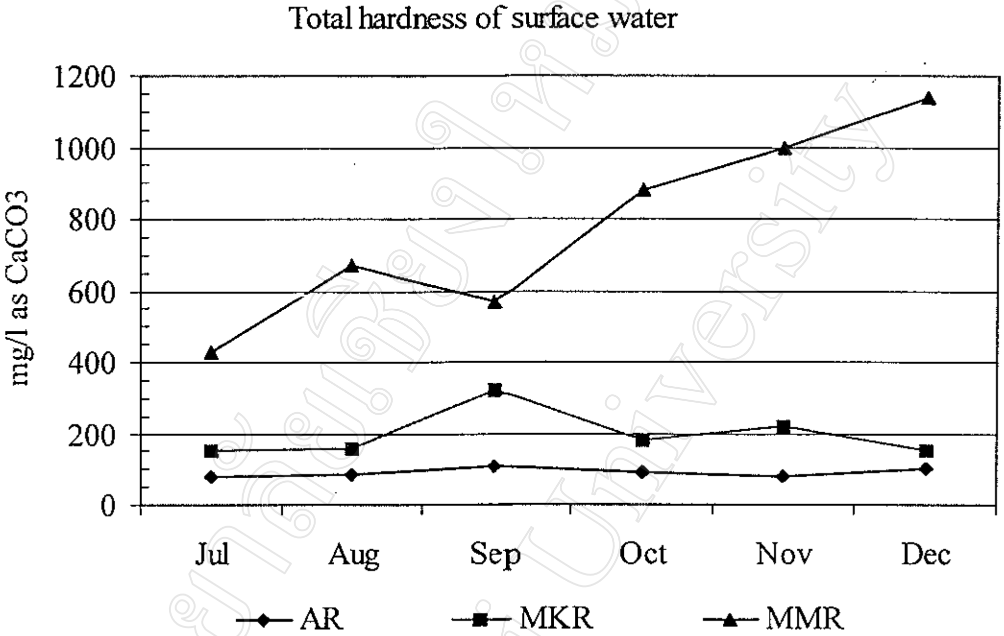
5.1.8. Total hardness of surface and ground water during the study period

The total hardness of the water samples is shown in Table 5.1.8, Figure 5.1.8, and Appendices 2.1 and 2.2. Total hardness is mainly due to dissolved calcium and magnesium. In practical analysis, the hardness is obtained by multiplying the sum of milliequivalents per liter of calcium and magnesium by a factor of 50 (Hem, 1985). In terms of "soft" and "hard" water, water is classified into four groups based on the hardness range: from 0 to 60 mg/l of $CaCO_3$ is soft water, from 61-120 mg/l as $CaCO_3$ is moderately hard, 121-180 mg/l as $CaCO_3$ is hard, and more than 180 mg/l as $CaCO_3$ is very hard (Sawyer, 1960).

Table 5.1.8: Total hardness of surface and ground water during the study period (mg/l as $CaCO_3$).

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	130	149	173	145	131	147
MKR2	205	163	611	244	401	167
MKR3	126	163	173	149	124	146
Average	*154*	*158*	*319*	*179*	*219*	*153*
MMR1	621	884	638	545	642	489
MMR2	184	704	660	1,021	1,190	1,356
MMR3	484	424	409	1,063	1,164	1,564
Average	*430*	*671*	*569*	*876*	*999*	*1137*
AR1	86	75	109	88	82	105
AR2	73	96	94	95	84	105
AR3	79	88	113	91	75	99
Average	*79*	*86*	*105*	*91*	*80*	*103*
Ground water						
N1	310	384	289	350	325	357
N2	183	216	274	236	204	229
SP1	343	417	476	453	410	419
SP2	340	616	600	396	358	334
SP3	718	1,363	956	979	934	*
SP4	1,653	1,721	*	*	*	*
M1	48	65	71	80	61	111
M2	62	90	109	69	*	*
M3	79	105	86	133	101	149
S1	177	227	236	229	260	279
S2	19	46	34	27	14	29
S3	530	365	338	320	423	505
S4	350	467	446	457	252	190
CT1	20	55	56	27	17	54
CT2	32	61	49	50	32	58
CT3	22	33	49	42	6	25

*: No sample



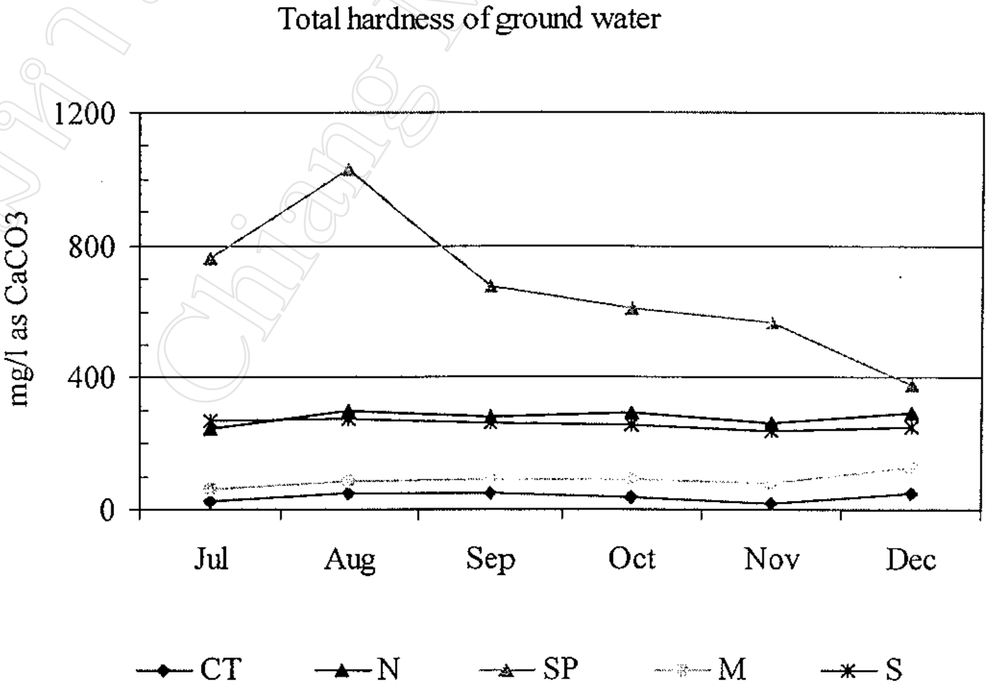


Figure 5.1.8: Total hardness of surface and ground water during the study period

In the Mae Kham Reservoir, the total hardness ranged from 124 to 611 mg/l as $CaCO_3$, from 409 to 1,564 mg/l as $CaCO_3$ in the Mae Moh Reservoir, and from 73 to 113 mg/l as $CaCO_3$ in Ang Kaset. According to the statistical analysis shown in Appendices 1.1 and 1.4, it can be stated that hardness of water samples mostly depended on the site rather than the month sampled. Hardness can be separated into two different groups viz. Mae Kham Reservoir (193 mg/l as $CaCO_3$) and Mae Moh Reservoir (780 mg/l as $CaCO_3$). It also indicates that surface water in Mae Moh area is very hard and moderately hard in the control reservoir. That is water in Mae Moh area contained higher calcium and magnesium salts than at the control site.

The ground water samples ranged from 6 to 61 mg/l as $CaCO_3$ in the control site whereas the highest range of 334 to 1,721 mg/l as $CaCO_3$ was found in the seepages surrounding the mining area. Total hardness varied from 183 to 384 mg/l as $CaCO_3$ in these wells to the north of the mining area, from 48 to 149 mg/l as $CaCO_3$ in the wells inside the mine, and from 14 to 530 mg/l as $CaCO_3$ in the wells to the south of the mining area.

Ground water hardness was mostly lower than surface water. Depending on the sites, ground water hardness belongs to soft, moderately hard, hard, and very hard. According to a statistical analysis shown in Appendices 1.2 and 1.6, total hardness can be divided in three different groups viz. mining wells (89 mg/l as $CaCO_3$), southern wells-northern wells (259-280 mg/l as $CaCO_3$), and seepages (710 mg/l as $CaCO_3$). Water from seepages contained higher dissolved calcium and magnesium than the other places. Average values in the control well, northern well, southern well and mining well were not much different during six months of monitoring.

5.2. CONCENTRATIONS OF HEAVY METALS IN SURFACE AND GROUND WATER DURING THE STUDIED PERIOD

5.2.1. Arsenic (As)

The amounts of arsenic in surface and ground water samples are shown in Table 5.2.1, Figure 5.2.1, and Appendices 2.1 and 2.2. In Ang Kaset, samples were mostly under the detection limit and from 2 to 16μg/l in the Mae Moh Reservoir. The amount of arsenic varied from under the detection limit to 2 μg/l in the Mae Kham Reservoir. The results shown in Table 5.2.1 also indicate that Ang Kaset was not affected by mining and power plant activities in term of arsenic concentration.

The high arsenic concentration in the Mae Moh Reservoir comes from mining and power plant activities. Because of the drainage system at the Mae Moh, wastes from electricity generating are mostly discharged to the Mae Moh Reservoir after in wetland treatment. The fluctuation of arsenic concentrations in the Mae Moh Reservoir could depend on how the amounts of electricity generation has been generated. High capacity was run, greater amounts of wastes are released into the Reservoir with containing arsenic.

Arsenic in the Mae Moh Reservoir is also produced by the interaction between sediment and water. Hastuti (1998) reported that arsenic in the sediments of Mae Moh Reservoir varied from 767 in the hot and 71,550 part per billion during the cool season. The re-adsorption of arsenic from sediments to water also contributes to increasing arsenic in water column. Rainfall percolating through the mining area and waste dumps also brings much arsenic to the reservoir. Assuming that the same

Table 5.2.1: Arsenic in surface and ground water during studied time (μg/l)

	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	1	2	1	1	1	1
MKR2	2	1	1	1	<dl	1
MKR3	1	2	1	1	<dl	1
Average	*1*	*2*	*1*	*1*	<dl	*1*
MMR1	7	5	2	5	3	4
MMR2	8	6	2	16	2	14
MMR3	9	7	3	5	3	5
Average	*8*	*6*	*2*	*8*	*3*	*8*
AR1	<dl	<dl	<dl	<dl	<dl	<dl
AR2	<dl	<dl	<dl	1	<dl	<dl
AR3	<dl	<dl	<dl	<dl	<dl	<dl
Average	*<dl*	*<dl*	*<dl*	*<dl*	*<dl*	*<dl*
Ground water						
N1	3	3	3	3	2	3
N2	<dl	1	1	<dl	<dl	<dl
SP1	4	2	2	2	2	2
SP2	6	3	3	3	<dl	<dl
SP3	<dl	4	5	3	4	*
SP4	4	3	*	*	*	*
M1	101	52	107	77	86	84
M2	452	482	502	400	*	*
M3	492	444	491	424	310	422
S1	6	3	3	<dl	<dl	<dl
S2	1	1	<dl	<dl	<dl	<dl
S3	<dl	<dl	1	<dl	<dl	<dl
S4	<dl	<dl	<dl	<dl	<dl	<dl
CT1	<dl	<dl	<dl	<dl	<dl	<dl
CT2	<dl	<dl	<dl	<dl	<dl	<dl
CT3	<dl	<dl	<dl	<dl	<dl	<dl

dl: detection limit = 0.7 μg As/l

*: No sample

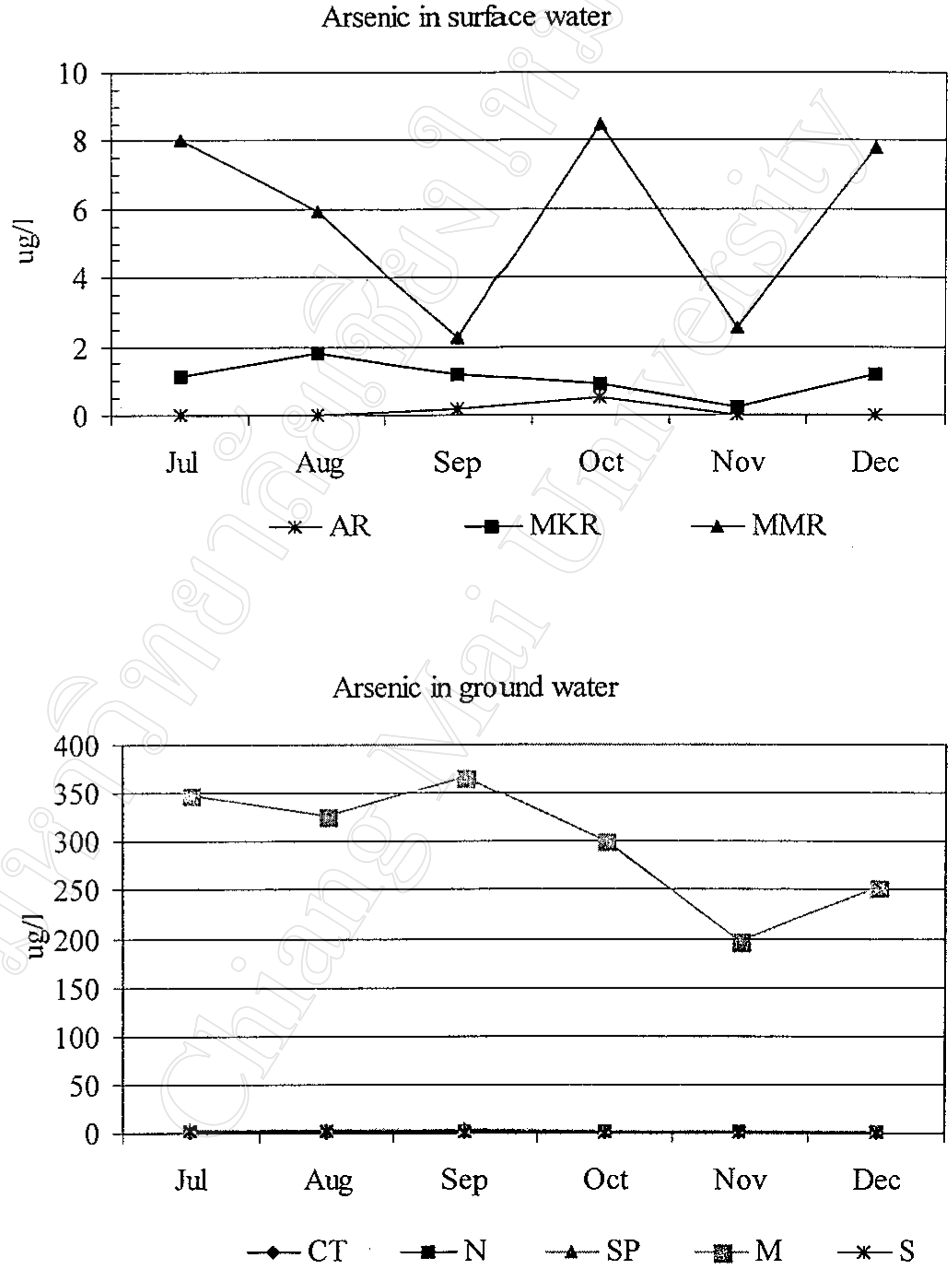


Figure 5.2.1: Arsenic in surface and ground water during the study period

amounts of wastewater from the power plant is constantly discharged into the reservoir, less dilution by rainwater will lead to high concentrations of wastes, including arsenic in the reservoir water.

The Mae Kham Reservoir, arsenic comes from mining activities, including weathering from waste dumps plus rock and fly ash deposits. It does not receive wastewater from power plant activities. This is why water from the Mae Kham Reservoir contains less arsenic than the Mae Moh Reservoir.

According to the statistical analysis shown in Appendix 1.1, an average As concentration in surface water samples depended mainly on the reservoirs and indicated that arsenic in the Mae Moh Reservoir was 6 times significantly higher than in the Mae Kham Reservoir (Appendix 1.4).

The ground water from two wells in the north of the mine contained trace amounts of arsenic ranging from under the detection limit to 3μg/l. In wells south of the mine, arsenic varied from to 6μg/l to under the detection limit during the study period. For seepages, arsenic concentrations decreased from 6μg/l the under the detection limit during the study period. Arsenic concentrations in northern, southern wells and seepages are always below the WHO standard (1993). In ground water from the northern wells, southern, and seepages surrounding mining area were uncontaminated. Arsenic concentrations were often detectable at the beginning of the study period and decreased to under the detection limit when the cool-dry season came. During the rainy season, surface water flow brought arsenic to the surface water system, another path was infiltration of surface water to ground water which increased concentration during the rainy season. When the cool-dry season came, the temperature decreased so chemical reaction rate in ash and rocks also decreased. This is reason why arsenic concentrations decreased when the cool-dry season came.

High concentrations of arsenic were found in the wells inside the mining area varying from 52 to 502μg/l. Due to being located at the lignite deposit the high arsenic background in coal may contributed directly to high arsenic in the well water. Ratanasthien (1991) reported that lignite from Mae Moh Mine contained 45.45 mg/kg of arsenic, 18.3 mg/kg from the bottom ash, and 213 mg/kg from the fly ash. Badulis (1998) pointed out that the background levels of the topsoil, yellow bed, and the upper red bed layer contained 32.4 mg/kg of arsenic. Leaching of arsenic in fly ash had an average of 413 μg/l, of 10.7 μg/l for bottom ash, and 3.54 μg/l for mine wastes. With a high arsenic background of high arsenic plus its readily leaching characteristic, high concentrations of arsenic are found in ground water. High temperatures (up to 48°C) also contribute to increase mobility of arsenic to the ground water (Nriagu, 1994). Variations in pH also affect arsenic concentrations. The peak of 502 μg/l of arsenic in September came from well M2 where the pH dropped to 6.9 from 7.5. Similarly, arsenic concentrations in well M3 increased from November to December while pH values decreased from 7.3 to 6.7. There was no evidence to show As is present in the control wells. According to the statistical analysis shown in Appendices 1.2 and 1.6, arsenic in ground water mainly depends on the sites instead of the study period. It can be divided into two groups viz. one containing high concentrations of arsenic in wells located inside the mining area and low concentrations in the northern wells, southern wells, and seepages.

5.2.2. Lead (Pb)

Lead concentrations are shown in Table 5.2.2, Figure 5.2.2, and Appendices 2.1 and 2.2. Concentrations greatly fluctuated during the study period. Lead was often detectable at the beginning of the study period and decreased to under the detection limit when the cool-dry season came. Concentrations of lead varied from under the detection limit to 69 µg/l in the Mae Kham Reservoir, from under the detection limit to 33µg/l in the Mae Moh Reservoir, and from under the detection limit to 36µg/l in the Ang Kaset.

These trends may be caused by rainfall leaching lead from the soil surface, rocks, and overburden in waste dumps. Lead released from petrol during transportation. Badulis (1998) reported that the background of the top soil, yellow bed, and the upper red bed layer at Mae Moh Mine contained 13.9 mg/kg of lead. Leaching of lead from mine wastes only ranged from 2.84 to 8.76 µg/l. This means that the background level of lead at the study site does not contributed much lead to surface water, but mainly comes from transportation system.

Lead was found intermittently in the ground water. Water from two wells north of the mine and the seepages contained from under the detection limit to 29 µg/l of lead, and decreased during six months of monitoring. In three wells inside the mining area, lead varied from under the detection limit to 32µg/l. South of the mine, ground water contained from under the detection limit to 43µg/l, and from under the detection limit to 19µg/l in the control wells. Average values in the northern wells and seepages decreased during the study period while the control wells, wells in the

Table 5.2.2: Lead in surface and ground water during the study time (μg/l)

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	<dl	<dl	<dl	<dl	15	<dl
MKR2	69	38	21	<dl	<dl	<dl
MKR3	<dl	33	7	5	<dl	<dl
Average	*23*	*24*	*9*	*2*	*5*	<dl
MMR1	<dl	<dl	<dl	21	<dl	<dl
MMR2	<dl	18	<dl	8	<dl	<dl
MMR3	<dl	<dl	<dl	<dl	22	<dl
Average	<dl	*6*	<dl	*10*	*7*	<dl
AR1	36	19	<dl	<dl	<dl	<dl
AR2	<dl	<dl	<dl	<dl	<dl	<dl
AR3	<dl	<dl	<dl	<dl	16	<dl
Average	*12*	*6*	<dl	<dl	*5*	<dl
Ground water						
N1	29	26	8	8	<dl	7
N2	<dl	<dl	<dl	<dl	<dl	<dl
SP1	<dl	25	<dl	9	29	5
SP2	<dl	<dl	<dl	<dl	15	<dl
SP3	<dl	<dl	<dl	<dl	23	*
SP4	<dl	<dl	*	*	*	*
M1	<dl	<dl	<dl	5	32	<dl
M2	31	<dl	5	<dl	*	*
M3	<dl	20	<dl	<dl	<dl	<dl
S1	43	<dl	<dl	16	<dl	4
S2	18	<dl	5	5	<dl	6
S3	<dl	<dl	<dl	<dl	<dl	<dl
S4	<dl	29	<dl	4	<dl	<dl
CT1	<dl	<dl	<dl	<dl	<dl	<dl
CT2	<dl	<dl	<dl	<dl	<dl	<dl
CT3	<dl	<dl	5	6	19	<dl

dl: detection limit = 4 μg Pb/l

*: No sample

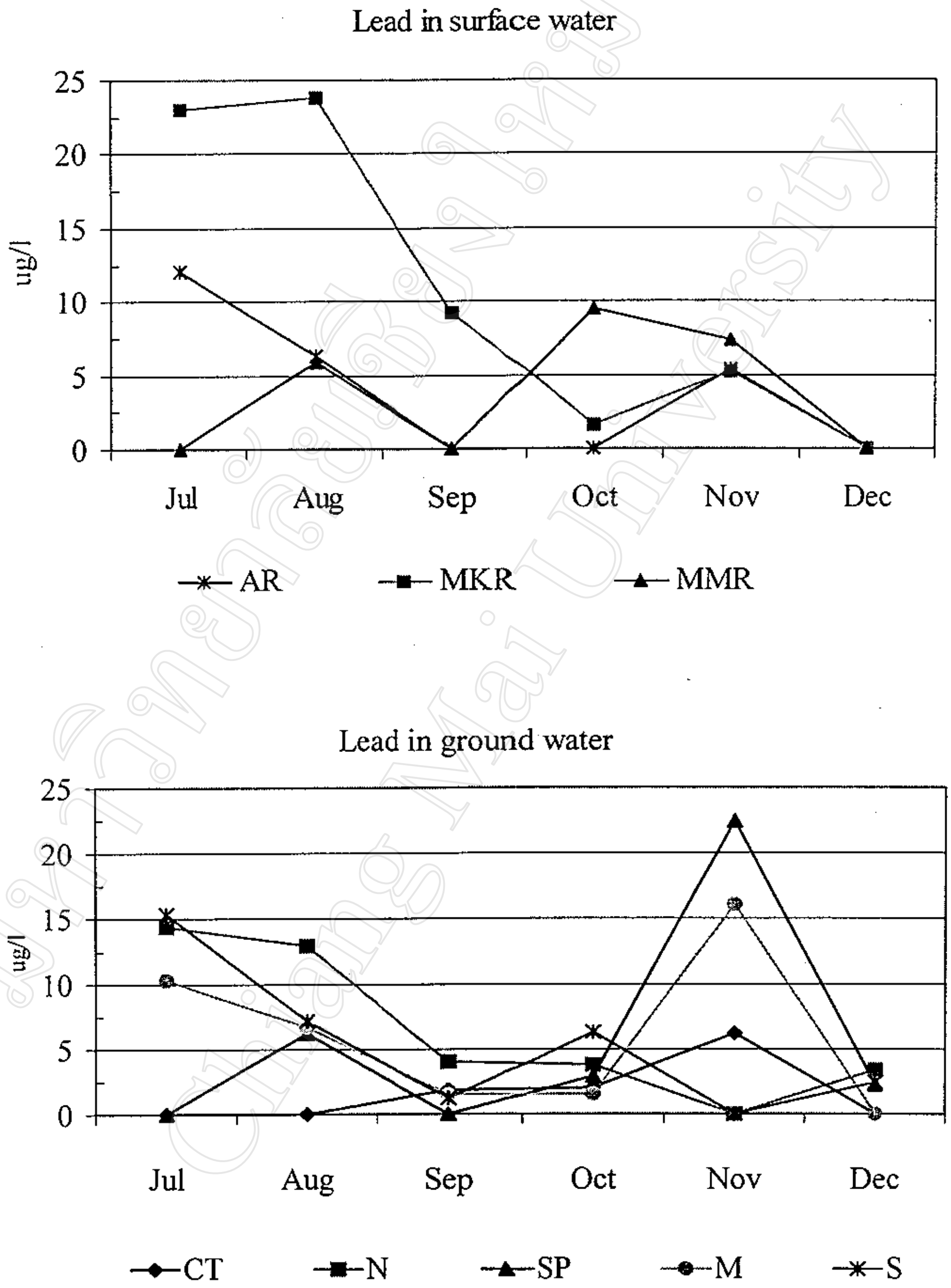


Figure 5.2.2: Lead in surface and ground water during the study period

mining area, and southern wells seem to be have same trend as the northern wells and seepages, but increased in November. Individually, lead was higher in surface water than in ground water due to surface water be directly affected from water runoff from the soil surface, which may result of high lead from transportation and mining activities three.

5.2.3. Mercury (Hg), chromium (Cr), and molybdenum (Mo)

The trace elements mercury, chromium, and molybdenum were found to be under the detection limit in all water samples during the study period. There is no evidence to indicate any environmental risk these elements in the study area. The detection limit of mercury is 0.09 µg/l and 10µg/l for chromium.

5.2.4. Manganese (Mn)

Variations in manganese in surface and ground water samples are shown in Table 5.2.4, Figure 5.2.4, and Appendices 2.1 and 2.2. Manganese concentration decreased from 824 to 13 µg/l in the Mae Kham Reservoir during time of study and increased from 70 to 586 µg/l in the Mae Moh Reservoir, and was stable with the lowest values from 13 to 36µg/l in Ang Kaset.

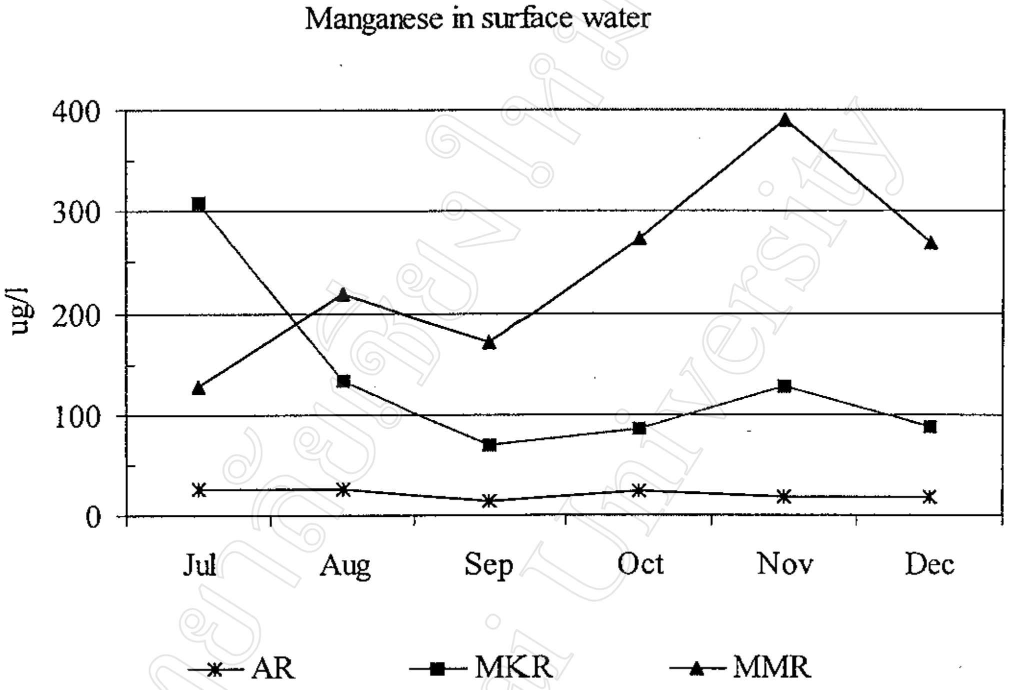
The variations of manganese in the surface water may be related to location of the study site. Huyen (1995) reported that manganese concentrations in soil samples surrounding the Mae Moh Reservoir (1624 to 2416 mg/kg) were higher than in soil samples surrounding the Mae Kham Reservoir (199 to 1035 mg/kg). Water runoff and fly ash deposits may be factors adding manganese to the reservoirs during the rainy season. Rock weathering and leachates from waste dumps are also not less important.

Table 5.2.4: Manganese in surface and ground water during study time (μg/l)

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	48	36	27	13	69	84
MKR2	824	276	146	231	274	114
MKR3	54	89	37	13	39	64
Average	*309*	*134*	*70*	*86*	*127*	*87*
MMR1	109	276	122	184	586	213
MMR2	128	213	322	265	304	190
MMR3	146	170	70	370	283	401
Average	*128*	*220*	*171*	*273*	*391*	*268*
AR1	22	22	13	23	17	17
AR2	22	27	13	23	16	17
AR3	36	27	18	23	22	17
Average	*27*	*25*	*15*	*23*	*18*	*17*
Ground water						
N1	1,414	1,066	1,025	564	640	675
N2	54	8	9	9	19	9
SP1	202	204	217	217	186	185
SP2	72	94	131	70	54	36
SP3	226	141	2,189	1,893	1,807	*
SP4	272	261	*	*	*	*
M1	8	<dl	18	23	10	6
M2	17	17	4	18	*	*
M3	<dl	<dl	42	40	<dl	<dl
S1	128	70	165	289	277	285
S2	179	151	193	37	36	39
S3	<dl	8	<dl	9	81	86
S4	137	108	169	103	22	<dl
CT1	31	17	37	32	30	25
CT2	22	32	27	18	13	12
CT3	165	151	98	141	138	142

dl: the detection limit =5 μg Mn/l

*: No sample


Manganese in surface water

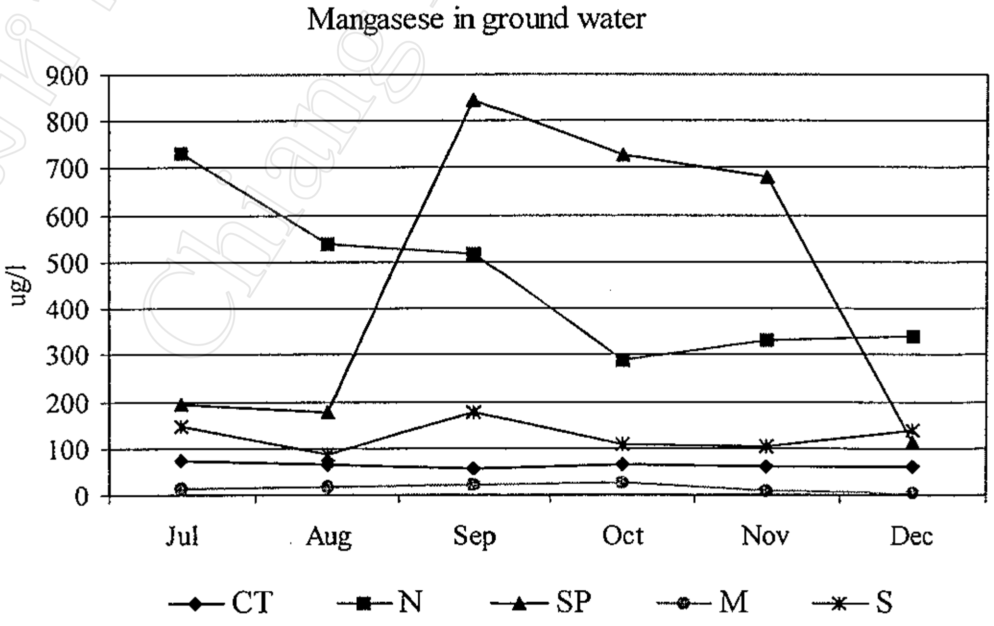

Mangasese in ground water

Figure 5.2.3: Manganese in ground water during the study period

The variation of manganese in the Mae Moh Reservoir also depends on power plant activities. According to the statistical analysis shown in Appendices 1.1 and 1.4, manganese in the surface water was different between reservoirs, but was similar through the study period. An average values shown that water from the Mae Moh Reservoir contained (242 μg/l) about 2 times more manganese than the Mae Kham Reservoir. Regarding to the control site, it is clearly that the surface water in the Mae Moh Mine were more impact by activities there in term of manganese.

For ground water, manganese varied from 8 to 1,414μg/l in the wells in the north of the mine, from 36 to 2,189 μg/l in the seepages, from under the detection limit to 42 μg/l in the mining area, from under the detection limit to 289 μg/l in the southern wells, and from 12 to 265 μg/l in the control wells.

Manganese in ground water mostly depended on the site and usually associated with iron. According to Huyen (1995), the highest manganese concentration of 2,654 mg/kg was found in a soil sample from Ban Tha Si village (northern mine) whereas other zones had less than 2,000 mg/kg. The background concentration of manganese in soil is the most likely source of manganese in ground water. The highest concentration of manganese, found in well N1, indicates that there is no relationship between distance from the mining and power plant areas with the amounts of manganese in ground water. The control wells also show that manganese is a natural deposit.

The statistical analysis shown in Appendices 1.2 and 1.6 indicate that concentrations of manganese in ground water are different between sites or directions but were not significantly different between months. High values were often found in well N1 and seepage SP3. Average manganese concentrations also indicate that manganese concentrations in seepages-northern sites (445-458μg/l) was about 4 times higher than the mining-southern sites.

Manganese concentrations mostly decreased from July to December. This may be related to decreasing rainfall and temperature. High temperature causes increased mobility of metals to ground water. High precipitation causes more infiltration of surface water to underground water.

5.2.5. Iron (Fe)

Total iron in surface and ground water samples is presented in Table 5.2.5, Figure 5.2.5, and Appendices 2.1 and 2.2. It varies from under the detection limit to 302μg/l in the Mae Kham Reservoir, from under the detection limit to 587μg/l in the Mae Moh Reservoir, and from under the detection limit to 151μg/l in the Ang Kaset.

The increasing trend in the Mae Moh Reservoir is associated with manganese. This may be caused by electricity generating activities. Fyfe *et al.* (1993) reported that coal from Mae Moh Power Plant contained 3.01% iron. Ratanasthien *et al.* (1991) also mentioned that fly ash has up to 11.01% iron in it at Mae Moh and 8% in bottom ash. Waste materials discharged daily into the reservoir during the operation of the power plant are major source of contribution to iron in the Mae Moh Reservoir.

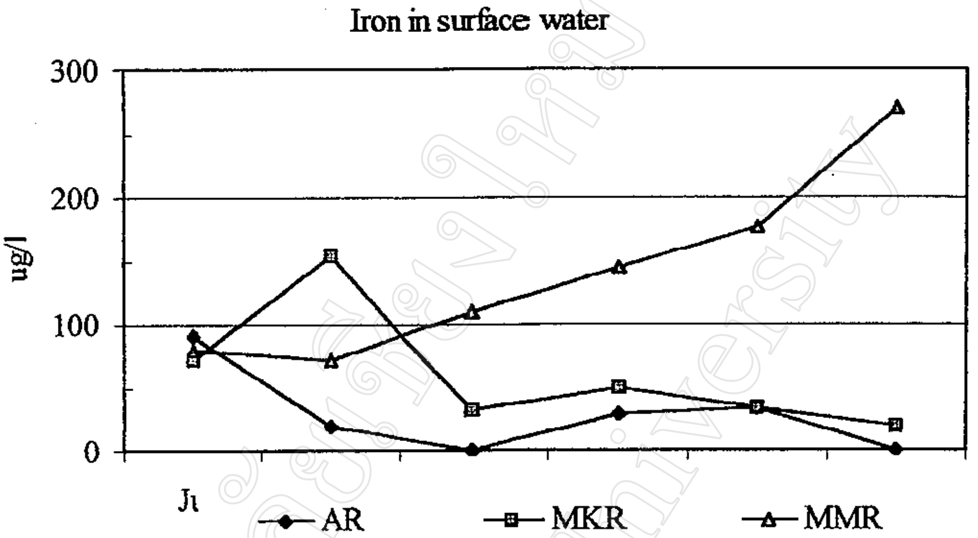
Decreasingly trends are found in the Ang Kaset and Mae Kham Reservoir mainly depended on rainfall. At the beginning of the study period, rain water runoff and weathered iron from rock, soil surface, overburden, fly ash and bottom ash to the

5.2.5: Iron (Fe) in surface and ground water during time of study (μg/l)

Site	Jul	Aug	Sep	Oct	Nov	Dec
Surface water						
MKR1	<dl	31	<dl	35	<dl	57
MKR2	127	302	96	114	70	<dl
MKR3	88	129	<dl	<dl	28	<dl
Average	*72*	*154*	*32*	*50*	*33*	*19*
MMR1	174	164	104	291	315	587
MMR2	65	51	190	96	129	40
MMR3	<dl	<dl	34	44	87	182
Average	*80*	*72*	*109*	*144*	*177*	*270*
AR1	88	31	<dl	26	28	<dl
AR2	34	24	<dl	26	36	<dl
AR3	151	<dl	<dl	35	36	<dl
Average	*91*	*18*	<dl	*29*	*33*	<dl
Ground water						
N1	4,374	4,178	9,827	13,480	7,582	7,154
N2	<dl	51	<dl	<dl	<dl	<dl
SP1	<dl	<dl	<dl	<dl	28	<dl
SP2	34	51	560	665	238	<dl
SP3	65	121	2,704	1,297	2,844	*
SP4	325	129	*	*	*	*
M1	57	229	1888	407	883	706
M2	1,062	1,846	<dl	863	*	*
M3	<dl	<dl	2,752	52	45	<dl
S1	301	121	73	131	470	424
S2	576	1,776	2,199	1,077	1,054	487
S3	462	31	34	44	<dl	<dl
S4	454	136	845	61	349	<dl
CT1	<dl	<dl	<dl	<dl	<dl	<dl
CT2	206	121	151	122	78	<dl
CT3	50	121	26	105	61	208

dl = 20 μg Fe/l.

*: No sample



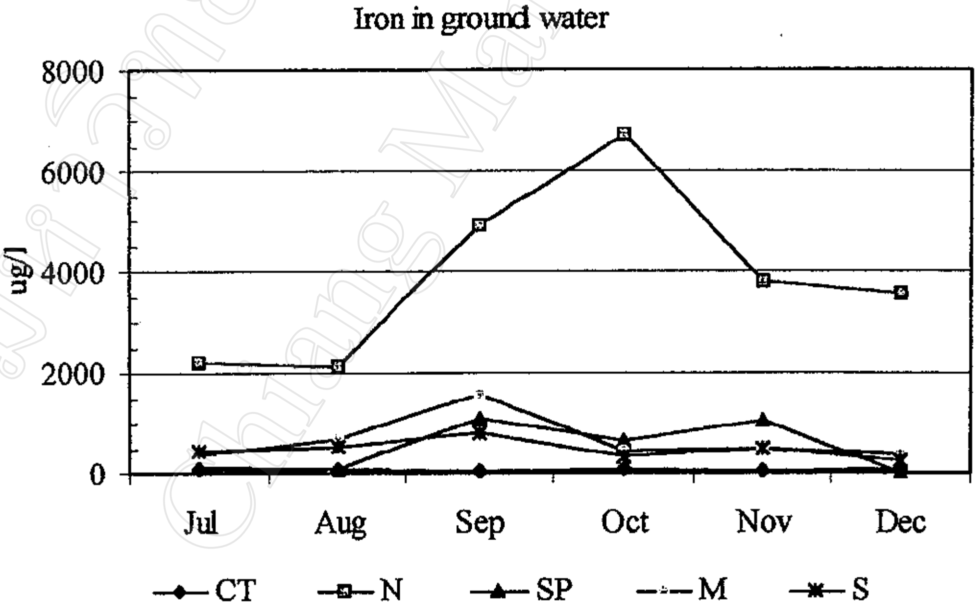


Figure 5.2.5: Iron in surface and ground water during the study period

Mae Kham Reservoir. When the cool-dry season came, these processes stopped and resulting decreasing iron concentrations. Referring to the Appendices 1.1 and 1.4, the average concentrations of iron are significantly different between the reservoirs, but are not according to the month sampled. A high value (587μg/l) was detected in the Mae Moh Reservoir in December. The average iron concentration in the Mae Moh Reservoir (242μg/l) is about 2 times more than in the Mae Kham Reservoir. The concentrations of iron in the control site also indicate that water in the Mae Moh area has been affected by mining activities.

Iron varied from under the detection limit to 13,480μg/l in ground water. The highest value came from a well in the north of the mine with a range of 4,178 to 13,480μg/l, from under the detection limit to 2,844μg/l in the seepages, from under the detection limit up to 2,752μg/l in the wells in the mining area, from under the detection limit to 2,199μg/l in the wells in the south of the mine, and from under the detection limit 208μg/l in the control wells.

The highest iron concentration of 13,480μg/l in the northern well can be correlated with the manganese concentration (Hem, 1985) up to 1,414μg/l. As with manganese, iron in ground water depends on soil background levels behaves similar to manganese. According to Appendices 1.2 and 1.6, average iron concentrations in ground water are significantly different between sites or directions and can be separated into two groups viz. northern well (3,890μg/l) and mining-seepages-southern wells (462-677μg/l).

5.3. RISK ASSESSMENT OF HEAVY METALS CONTAMINATION IN SURFACE AND GROUND WATER

Risk assessment often starts when a standard is being considered. If there is sufficient information, the magnitude of risk can be determined and, if a dose-response relationship can be established, a level of exposure can be derived for any acceptable level of risk. Even if a dose-response relationship can not be established, risk assessment will be also identified and indicate the relative significance of each source of exposure and the options for controlling exposure from each source (King, 1998).

5.3.1. Surface water

Guidelines for drinking-water quality (WHO, 1993) and standards on pollution control in Thailand (1989) were considered for water quality assessment.

Based on results and concentration trends of heavy metals during six months of study, arsenic, lead, iron, and manganese concentrations in surface water are mostly below surface water standards of Thailand (Table 5.3.1).

Arsenic is relatively high in Mae Moh Reservoir and close to the standard limit of WHO (1993). It occurred in high concentrations at the beginning of the study period with the amounts nearly reaching the WHO standard (1993). Because of the drainage system at Mae Moh, arsenic concentrations are directly related to mining and power plant activities. Aquatic plants in wastewater treatment system of the reservoir are also have a very important role in treating wastewater. Since they absorb heavy metals, the old aquatic plants should be harvested and replaced with a younger one for more heavy metal removal efficiency. These wetlands should be regularly monitored. There is a definite potential risk for arsenic contamination in the Mae Moh Reservoir especially if the wetland waste treatment system is not maintained. The possibility of pollution could be occurred at the beginning of the study period *i.e.* July to August. However, there is far less risk of arsenic contamination in case of standards of Thailand is concerned (Figure 5.3.1g). There are no evidences to indicate potential risk for arsenic contamination in the Mae Kham Reservoir and Ang Kaset (Table 5.3.1 and Figure 5.3.1d).

Lead in surface water is decreased during the study period. Table 5.3.1 and Figure 5.3.1c indicates that lead concentrations in three reservoirs was at above Thai and WHO standards. The maximum value in the Mae Kham Reservoir is over 1 to 7 times of the Thai and WHO standards. In the Mae Moh Reservoir and Ang Kaset, the maximum lead concentrations were under the Thai standard, but 2 and 4 times above the WHO standard. All area, especially the Mae Kham Reservoir has lead contaminated risk.

Manganese in the Mae Kham Reservoir also decreased during the study period (Figure 5.3.1a). The maximum concentration was found to be 2 times of the Thai and WHO standards (Table 5.3.1). The Mae Moh Reservoir has slightly less manganese contamination, and the possibility occurs at the end of the study period *i.e.* October and November (Figure 5.3.1e).

As with manganese, iron concentrations also decreased during the study period in the control and Mae Kham Reservoir and were always below the Thai standards (Table 5.3.1). Iron in the Mae Moh Reservoir increased during the study period and sometimes is over both WHO and Thai standards. The maximum concentration is about 2 times of the WHO standard. Iron contamination could occur during the cool-dry season in the Mae Moh Reservoir (Figure 5.3.1f).

Table 5 .3.1: Comparison concentration of selected elements in surface water with WHO and Thai standards.

Site	Element	µg/l	Standard		% of highest standard limitation	
			Thailand*	WHO**	Thailand*	WHO**
MKR	As	<dl-2	50	10	U-4	U-20
MMR		2-16			4-32	20-160
AR		<dl-1			U-2	U-10
MKR	Pb	<dl-69	50	10	U-138	U-690
MMR		<dl-22			U-44	U-220
AR		<dl-36			U-72	U-360
MKR	Mn	13-824	300-500	500	3-165	3-165
MMR		70-586			14-117	14-117
AR		13-36			3-72	3-72
MKR	Fe	<dl-302	500-1000	300	U-30	U-101
MMR		<dl-587			U-59	U-196
AR		<dl-151			U-15	U-50

* Environmental Quality Standards Division Office of National Environment Board, 1989. Laws and Standards on Pollution Control in Thailand

** World Health Organization, 1993. Guidelines for Drinking-water Quality.

dl = detection limit; U = under

MKR = Mae Kham Reservoir

MMR = Mae Moh Reservoir

AR = Ang Kaset

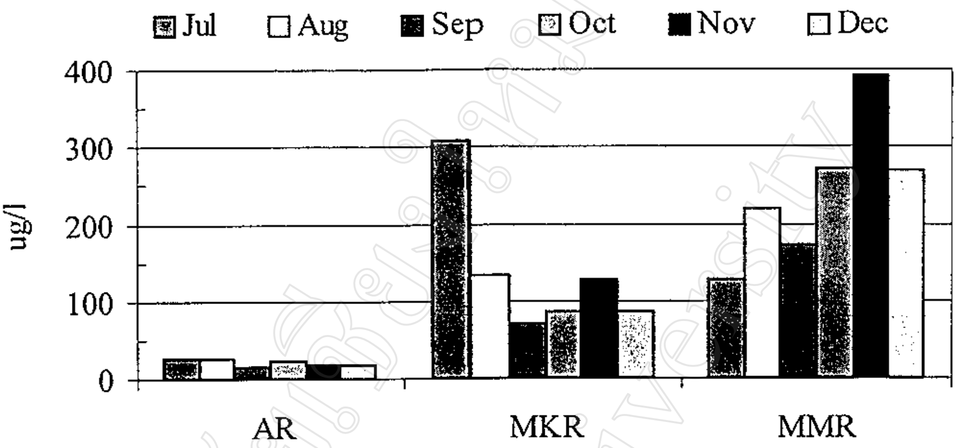


Figure 5.3.1a: Manganese in surface water

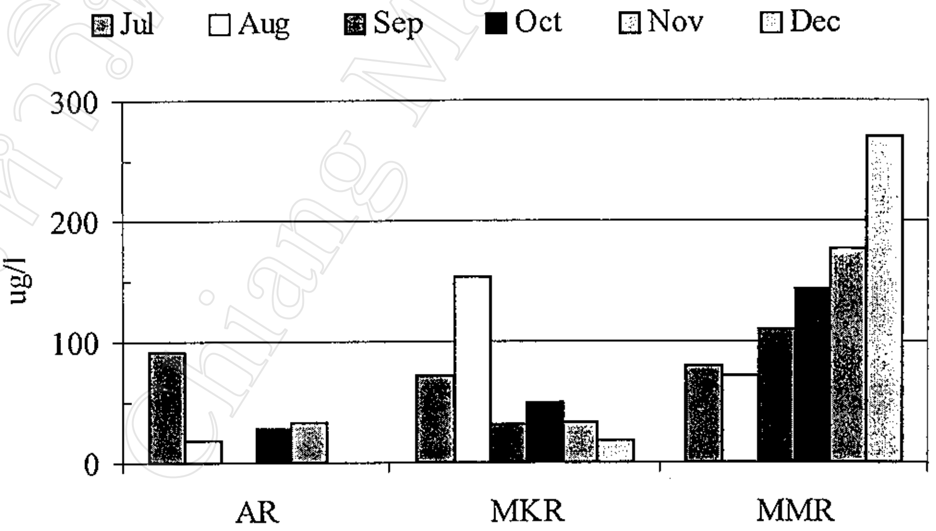


Figure 5.3.1b: Iron in surface water

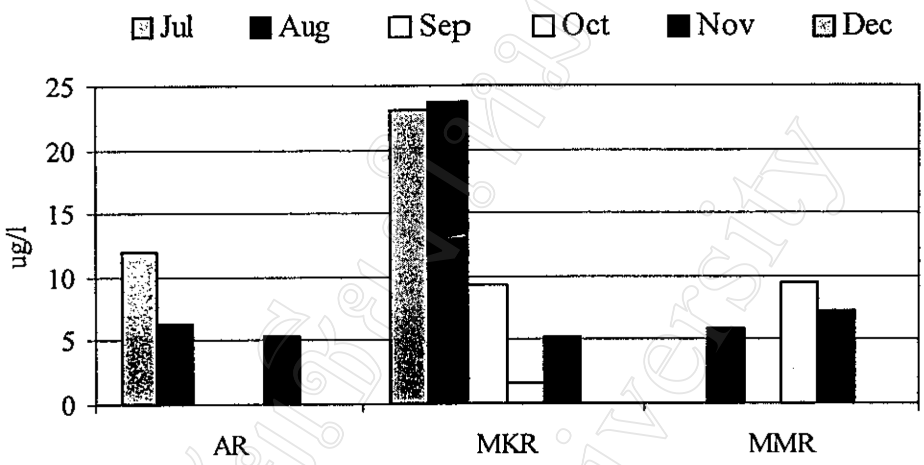


Figure 5.3.1c: Lead in surface water

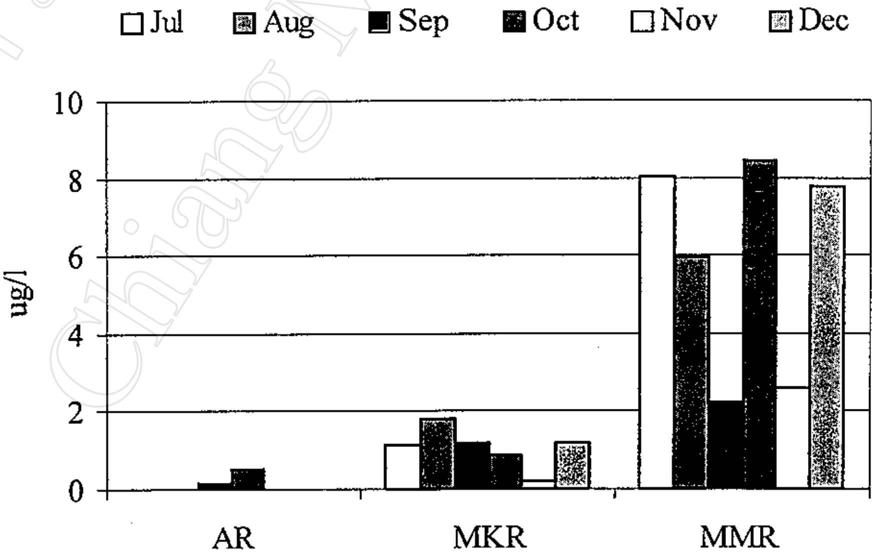


Figure 5.3.1d: Arsenic in surface water

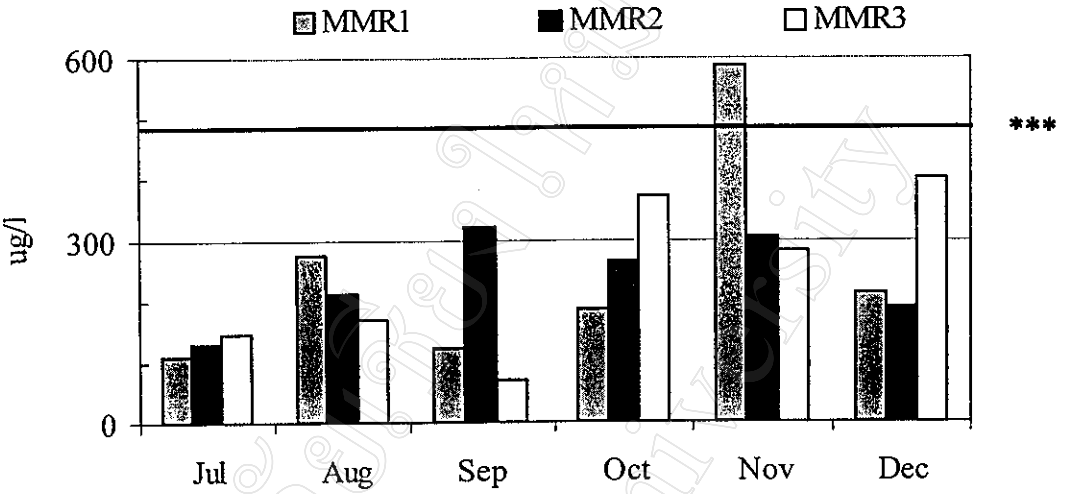


Figure 5.3.2e: Manganese in the Mae Moh Reservoir

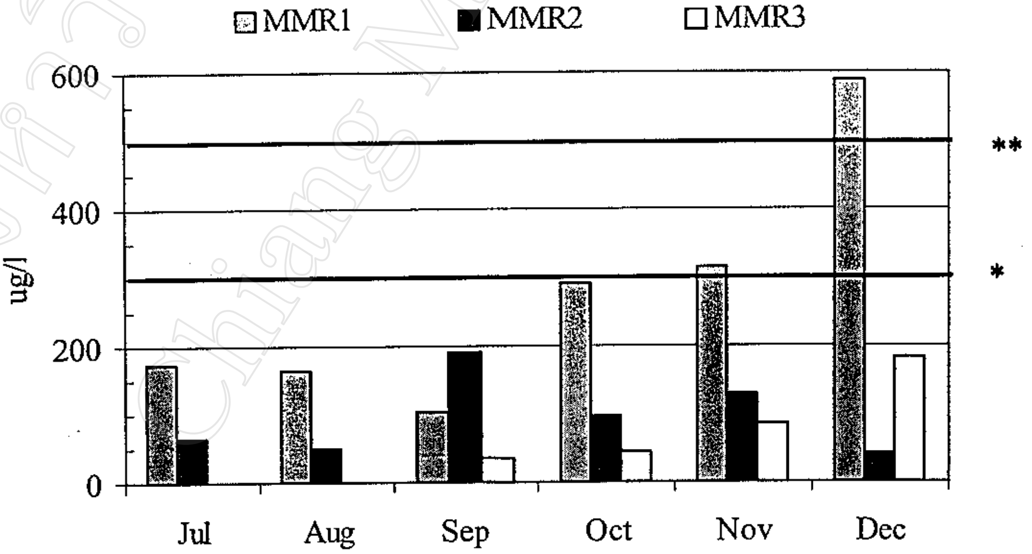


Figure 5.3.1f: Iron in the Mae Moh Reservoir

* Standard of WHO (1993)
** Standard of Thailand (1989)
*** Standard of Thailand (1989) and WHO (1993)

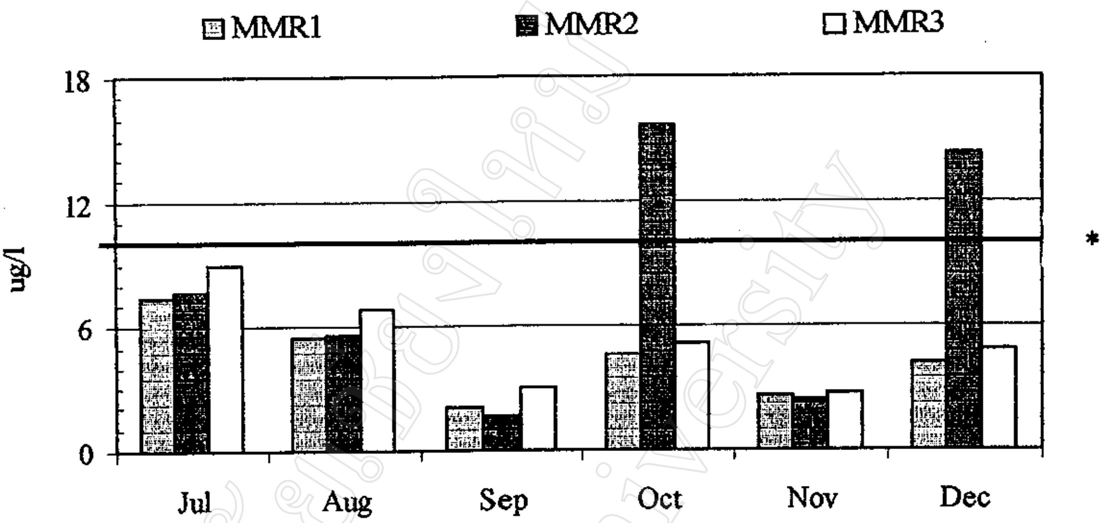


Figure 5.3.1g: Arsenic Mae Moh reservoir

* Standard of WHO (1993)

5.3.2. Ground water

WHO (1993) drinking eater standard and standards of Thailand for drinking water, and water discharged to ground water (1989), are considered to assess risk of heavy metal contamination in ground water.

Results show that most selected elements are presented at levels of under the standards of WHO and Thailand. There are, however, some places with high concentration of arsenic, manganese, and iron (Table 5.3.2).

For manganese, high concentrations were found only at site N1 in the north and seepage SP3 in the west of the mine. The maximum concentration is about 4 times over the WHO standard (1993) and the National Standard of Thailand for drinking purposes and discharge to ground water (Figure 5.3.2a).

Table 5 .3.2: Comparison concentration of selected elements in ground water with WHO and Thai standards.

Site	**Element**	**µg/l**	**Standard**		**% of highest standard limitation**	
			Thailand*	WHO**	Thailand*	WHO**
N	As	<dl-3	50	10	U-6	U-30
SP		<dl-6			U-12	U-60
M		452-502			104 - 1040	520-5200
S		<dl-6			U-12	U-60
CT		<dl			U	U
N	Pb	<dl-29	50	10	U-58	U-290
SP		<dl-29			U-58	U-290
M		<dl-32			U-64	U-320
S		<dl-43			U-86	U-430
CT		<dl-19			U-38	U-190
N	Mn	8-1414	300-500	500	2-283	2-283
SP		36-2189			8-438	8-438
M		<dl-42			U-8	U-8
S		<dl-289			U-58	U-58
CT		12-165			2-33	2-33
N	Fe	<dl-1,3480	500-1000	300	U-1348	U-4493
SP		<dl-2844			U-284	U-948
M		<dl-2752			U-275	U-917
S		<dl-2199			U-220	U-733
CT		<dl-208			U-21	U-69

* Environmental Quality Standards Division Office of National Environment Board, 1989. Laws and Standards on pollution Control in Thailand

** World Health Organization, 1993. Guidelines for Drinking-water Quality.

dl = detection limit
U= under
N = Northern wells
SP = Seepage
M = Mining wells (wells inside the mine pit)
S = Southern wells
CT = Control wells

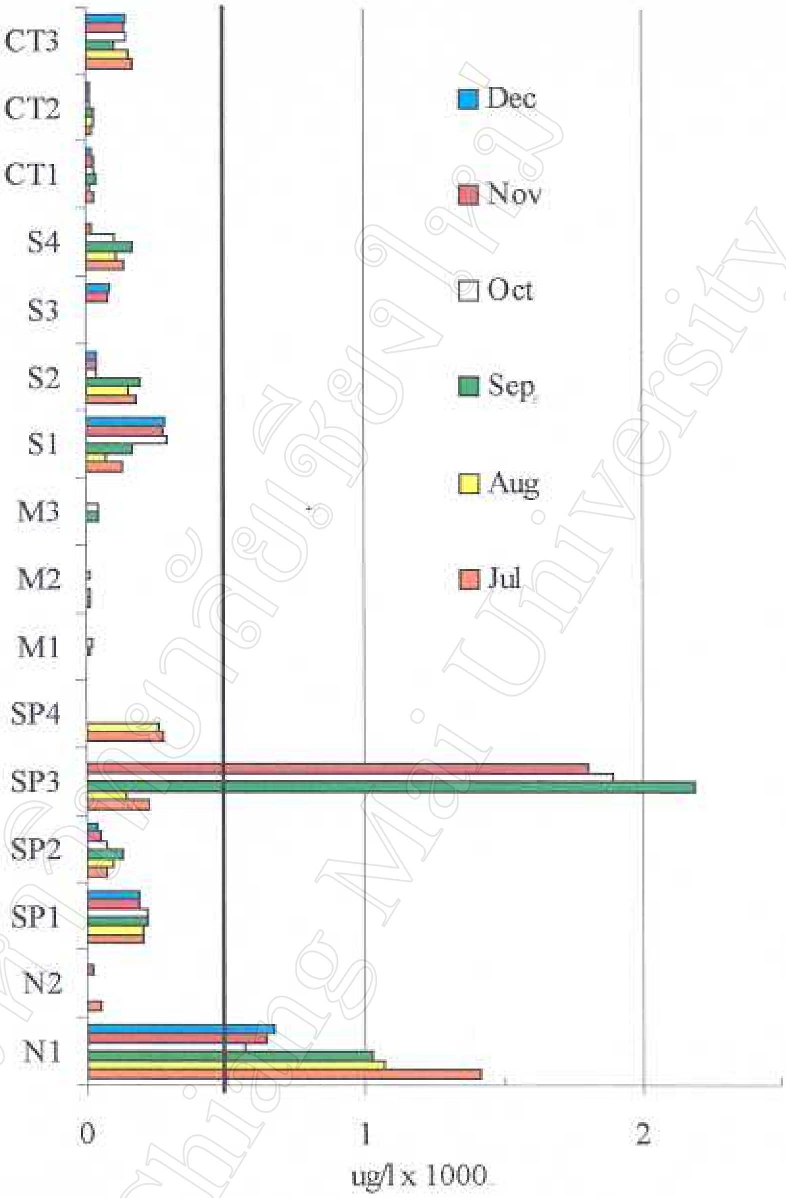


Figure 5.3.2a: Manganese in ground water

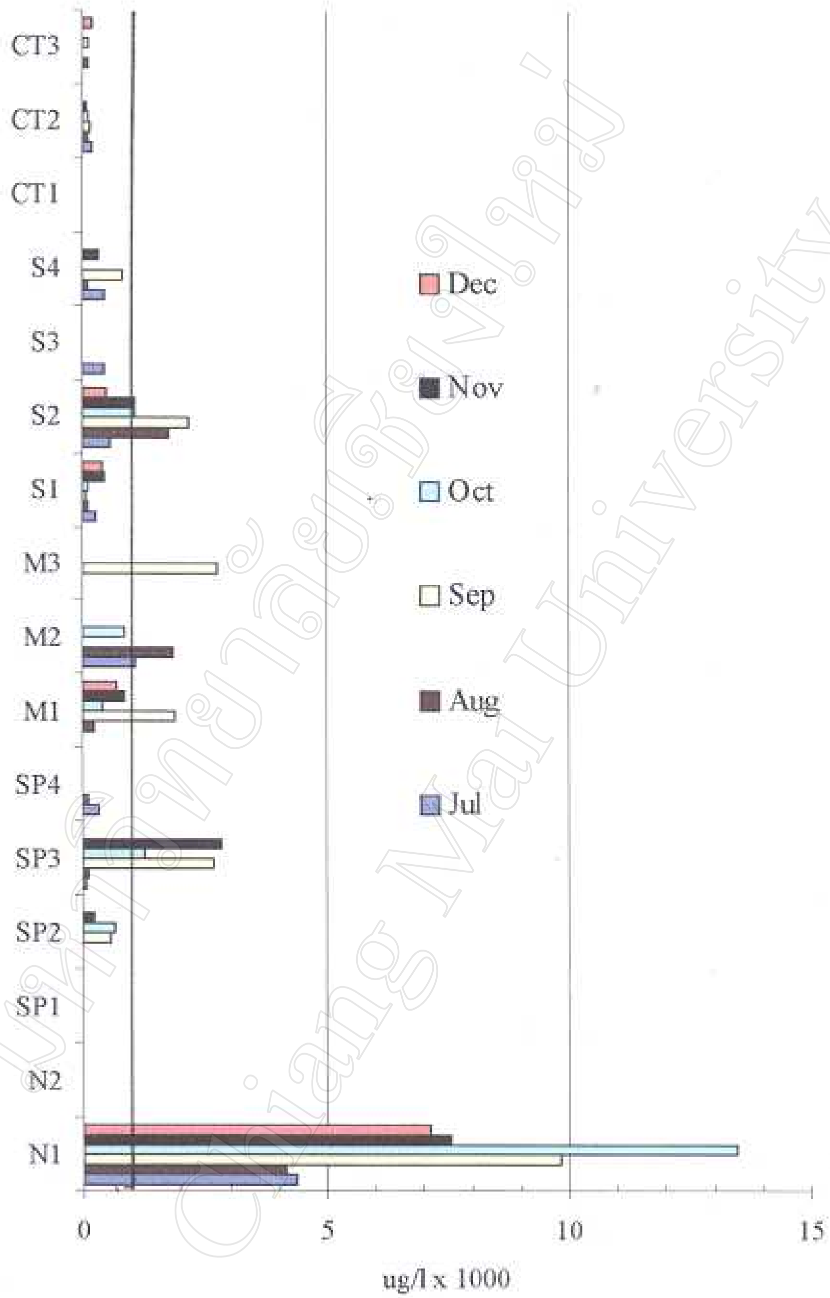


Figure 5.3.2b: Iron in ground water

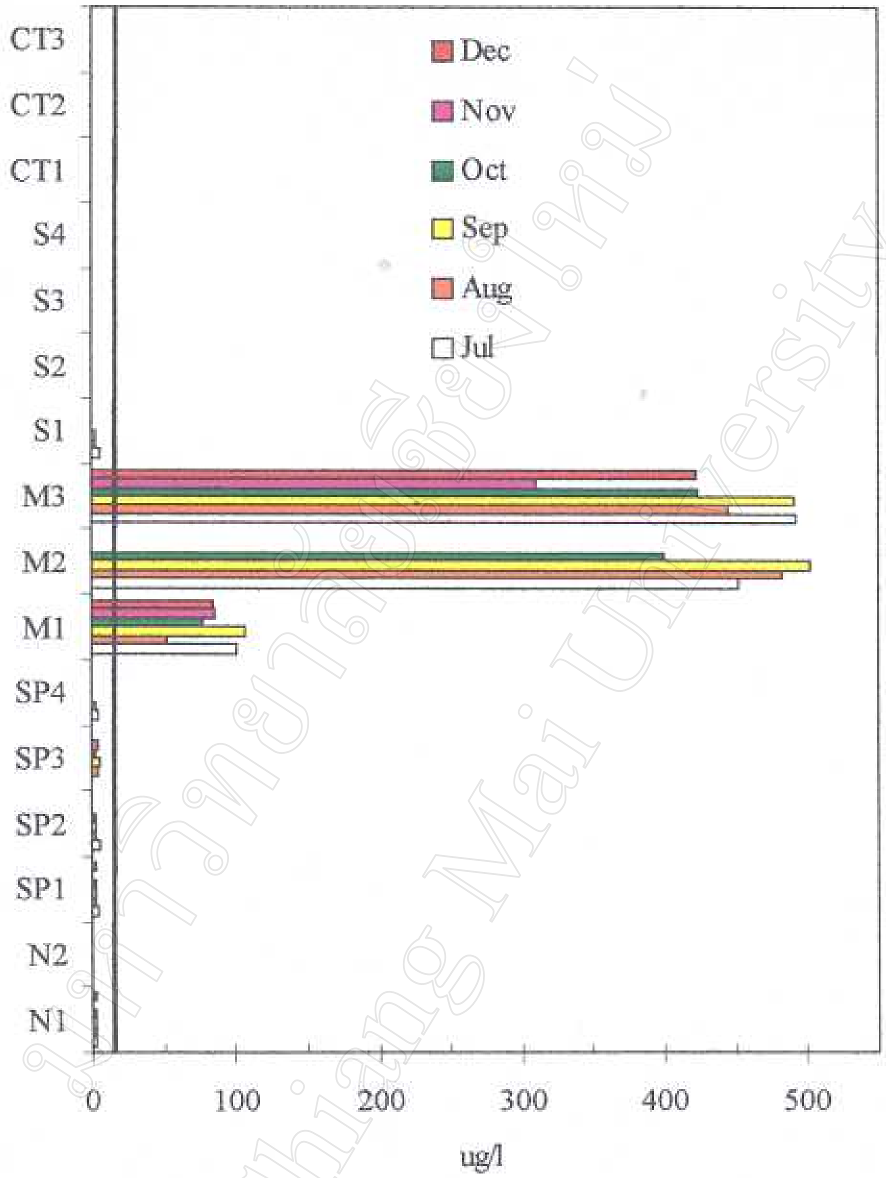


Figure 5.3.2c: Arsenic in ground water

The iron concentration in most sites is relatively close to the WHO standard for drinking purpose and National Standard of Thailand for discharge to ground water, some is over. The maximum concentration is about 13 times over the Thai standards and 50 times more than the WHO standard (Table 5.3.2 and Figure 5.3.2b). Water from the well N1 is heavily contaminated with iron and should not be used for any purpose even bathing or washing, unless probably treated.

For arsenic, three deep wells (M1, M2, and M3) are located inside the mining area contained high arsenic concentrations. The maximum value is about 50 times over the WHO (1993) standard and 10 times more than Thai standard (Table 5.3.2). The ground water is very contaminated with arsenic.

Arsenic in other ground water sites was present at very low concentrations. Thus, the ground water in the northern mine wells and southern mine wells can be used for domestic consumption but have to treat probably. The control site was free of arsenic (Figure 5.3.2c).

Because of high levels of heavy metals, the ground water in well N1, seepage SP3, and wells M1, M2, M3 inside the mine pit can not be used for any purposes which would cause a risk to human health and living thing.