CHAPTER 4 : RESULTS

4.1 Results of Analyzed Samples

The results of all analyzed 80 samples were presented in the table 2a to 2h.

Table 2 : Data of analyzed samples with 16 parameters during May to December.

a) May

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	23.6	23.7	24.1	29.6	32.1	28.2	28	33.1	30.4	27.2
conductivity	294	75	307	212	317	523	208	277	199	108
velocity	0.67	0.21	0.28	0.39	0.17	0.75	0.37	0	-	-
pH	7.8	7.6	8.7	7.8	7.9	7.4	7.8	8.4	8.1	7.5
acidity	0	0	0	0	0	0	0	0	0	0
alkalinity	145	45	155	100	100	170	85	100	85	45
hardness	180	60	160	180	100	120	120	140	140	80
DO	7.3	6.7	7.3	6.1	5.9	0	5.8	8.7	6.1	5.5
BOD_5	0.2	1	0.1	0.7	9	15	0.7	1.3	8.1	0.6
NO_3-N	1.19	0.59	1	0.75	0.89	0.97	0.91	0.6	0.65	0.99
NH_3-N	0.012	0.5	0.026	0.012	2.202	3.338	0.312	0.025	0.217	0.04
Fe	0.28	1.36	0.4	1.8	1.84	0.88	0.6	0.12	0.48	0.48
Cu	0.003	0.006	0.002	0.005	0.004	0.003	0.003	0.002	0.003	0.003
Zn	0.196	0.107	0.214	0.178	0.143	0.107	0.107	0.196	0.125	0.089
Mn	0.15	0.35	0.15	0.15	0.5	0.65	0.1	0.05	0.05	0.05

b) June

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	18.7	20.4	21.6	25.6	27.7	27.8	28.4	29	30	24.3
conductivity	253	91	199	189	292	539	199	307	186	72
velocity	0.31	0.12	0.37	0.46	0.24	0.9	0.38	0.01	0.14	0.17
pH	7.9	8	8.5	7.9	7.4	7.3	7.8	7.4	8.2	7.8
alkalinity	117	39	90	72	97	155	80	102	72	29
hardness	124	31	93	76	85	132	82	107	80	27
DO	7.1	6.6	7.6	6.1	1.5	0.5	5.8	10.5	6.5	6.5
BOD_5	1.2	0.6	0.5	0.1	8	8	0.1	1.5	0.6	0.5
NO_3-N	2.0	1.2	1.7	1.1	1.9	1.7	1.3	1.5	0.86	0.95
NH_3-N	0.02	0.02	0.02	0.08	0.72	1.72	0.1	0.05	0.19	0.1
PO_4-P	0.075	1.07	0.075	0.92	0.42	1.53	0.49	0.58	0.16	0.79
Fe	0.48	0.52	0.24	1.52	2.56	1.00	1.48	0.32	0.24	0.84
Cu	0.002	0.002	0.002	0.004	0.003	0.002	0.002	0.002	0.002	0.002
Zn	0.018	0.018	0.018	0.89	0.018	0.036	0.054	0.018	0.018	0.018
Mn	0.05	0.05	0.05	0.25	0.6	0.9	0.15	0.2	0.05	0.05

table 2 continued

c) July

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	24.1	23.4	23.8	28.6	29.6	29	29.7	28.7	28.2	25.4
conductivity	341	120	208	201	205	495	193	155	154	65
velocity	0.34	0.3	0.56	0.23	0.36	0.56	0.12	0.58	0.63	0.31
pH	8	8.1	8.5	7.9	7.7	7.7	8.1	8.3	8.3	7.8
acidity	0	0	0	0	0	0	0	0	0	0
alkalinity	140	40	80	100	90	160	80	100	60	40
hardness	165	33	82	84	76	111	82	72	72	24
DO	6.9	7.1	7.2	5.8	2.6	0	5.9	6.3	6.4	7
BOD_5	0.2	1	-	0.8	3.6	10.8	0.7	1	0.7	0.2
NO_3-N	1.9	1.3	1.2	1.9	1.9	2.5	2.1	1.8	1.9	1.2
NH_3-N	0.01	0.08	0.01	0.01	0.75	2.64	0.21	0.08	0.14	0.02
PO_4-P	0.24	0.2	0.05	1.34	0.73	2.68	0.34	0.18	0.26	0.54
Fe	0.4	0.7	0.25	1.55	1.55	0.7	0.95	0.75	0.69	0.25
Cu	0.004	0.003	0.002	0.003	0.005	0.004	0.003	0.006	0.005	0.003
Zn	0.099	0.06	0.11	0.11	0.15	0.24	0.17	0.19	0.18	0.1
Mn	0.19	0.12	0.19	0.15	0.22	0.66	0.1	0.15	0.1	0.05

d) August

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	24.3	23.6	24	26.5	27.8	25.6	26.7	24.6	24.8	24.4
conductivity	219	89	142	148	247	347	167	127	115	50
velocity	0.79	0.3	0.79	0.59	0.42	0.57	0.86	0.55	0.58	0.54
pH	7.6	7.7	8	7.4	6.99	6.97	7.4	7.6	7.6	7.6
acidity	0	0	0	0	18	23	0	0	0	0
alkalinity	93	42	66	61	0	0	66	55	45	19
hardness	87	29	58	64	85	107	107	8.2	47	14
DO	6.8	7.1	7	5.8	1.5	0.6	5.2	6.8	7.4	6.8
BOD_5	-	-	-	-	-	-	-	-	-	-
NO_3-N	2.1	1.1	1.8	1	2.1	2.2	1.2	2	1.1	1.2
NH_3-N	0.01	0.01	0.01	0.02	0.4	1.05	0.01	0.05	0.01	0.01
PO_4-P	0.12	0.09	0.12	0.32	0.06	0.93	0.34	0.09	0.13	0.26
Fe	0.6	3.467	0.867	2.067	1.133	104	3.8	2.067	1.533	0.667
Cu	0.002	0.002	0.002	0.006	0.004	0.003	0.002	0.002	0.002	0.002
Zn	0.35	0.2	0.038	0.062	0.051	0.025	0.037	0.012	0.051	0.038
Mn	0.125	0.325	0.35	0.35	0.1	0.425	0.375	0.275	0.275	.01

table 2 continued

e) September

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	24	22.5	24	28	27	27.5	27	25.5	25.5	22.5
conductivity	214	99	185	196	240	448	211	155	146	47
velocity	0.87	0.15	0.55	0.61	0.35	0.46	0.46	0.56	0.51	0.5
pH	7.2	7.1	7.8	7.2	6.8	6.9	7.2	7.4	7.4	7.1
acidity	0	0	0	0	10	21	0	0	0	0
alkalinity	96	18	80	86	0	0	83	62	61	19
hardness	92.7	65.9	74.2	84.5	68	109.2	82.4	55.6	55.6	8.2
DO	6.1	6.7	6.7	5.6	1.6	0.6	5.5	6.1	6.4	7.1
BOD_5	-	-	-	-	-	-	-	-	-	-
NO_3-N	2.41	1.47	2.47	2.56	2.93	5.29	2.59	2.06	2.6	1.38
NH_3-N	0.01	0.06	0.01	0.15	1.00	3.36	0.29	0.06	0.27	0.01
PO_4-P	0.08	0.11	0.19	0.28	0.46	1.34	0.17	0.17	0.15	0.08
Fe	1.89	0.6	0.4	1.18	1.3	1.06	1.64	0.96	0.91	0.1
Cu	-	-	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-	-	-
Mn	0.32	0.07	0.26	0.28	0.54	0.71	0.28	0.17	0.17	0.05

f) October

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	22.8	22.1	23	28.4	28.1	28.2	28.3	28.1	27.2	24.7
conductivity	225	102.4	187.8	221	192.7	446	231	169.6	174.7	48.8
velocity	0.57	0.2	0.65	0.42	0.39	0.52	0.72	0.61	0.58	0.17
pH	7.6	7.7	8.2	7.9	7	7.1	7.6	8	8	7.4
acidity	0	0	0	0	0	0	0	0	0	0
alkalinity	94	42	57	97.5	59	135	97.5	53	55	21
hardness	102.5	32	46.5	89	55	80.5	96	66.5	64.5	12.5
DO	7.4	7.5	8	6.7	2.6	1.5	6.5	7.2	7.1	7.3
BOD_5	0.1	0.1	0.1	1.4	4.2	5.88	0.75	0.35	0.9	0.1
NO_3-N	4.39	2.72	4.25	4.02	3.63	8.09	6.04	4.39	3.23	1.98
NH_3-N	0.24	0.01	0.01	0.01	0.88	3.36	0.29	0.01	0.01	0.01
PO_4-P	0.18	0.15	0.14	0.19	0.35	1.5	0.21	0.16	0.16	0.22
Fe	1	1.52	0.6	1.52	1.3	1	0.73	1.26	0.88	0.21
Cu	0.004	0.005	0.002	0.003	0.003	0.004	0.002	0.003	0.002	0.003
Zn	-	-	-	-	-	-	-	-	-	-
Mn	0.18	0.14	0.12	0.23	0.26	0.52	0.19	0.14	0.22	0.08

table 2 continued

g) November

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	21	21	21	24	24.5	24	24	24.5	23.5	20
conductivity	235	97.7	173	228	252	441	242	176	180.2	43.7
velocity	0.5	0.15	0.44	0.6	0.26	0.6	0.55	0.39	0.11	0.15
pH	7.8	7.7	8.1	7.8	7.3	7.25	7.8	7.9	7.9	7.6
acidity	0	0	0	0	0	0	0	0	0	0
alkalinity	108	35	77.5	96.5	83.5	135	100	80	82	17.5
hardness	127	30.5	98	121	75	90	115.5	81	90	7.18
DO	7.5	7.2	7.9	7.2	1.8	0.8	7.0	7.2	7	8.6
BOD_5	0.3	0.35	0.3	6.6	3.9	10.05	1.4	1.45	0.8	0.4
NO_3-N	6.62	2.42	4.67	4.07	4.27	8.09	4.2	5.26	4.16	1.5
NH_3-N	0.03	0.03	0.01	0.11	1.56	3.1	0.27	0.09	0.05	0.01
PO_4-P	0.2	0.04	0.07	0.11	0.39	1.42	0.17	0.07	0.05	0.06
Fe	0.94	1.16	1.66	3.11	1.88	1.05	1.66	0.33	0.27	0.22
Cu	0.005	0.004	0.002	0.003	0.002	0.003	0.002	0.002	0.002	0.002
Zn	0.286	0.189	0.2	0.216	0.216	0.189	0.178	0.216	0.167	0.151
Mn	0.116	0.06	0.33	0.23	0.41	0.66	0.183	0.066	0.033	0.033

h) December

Parameter	ST1	ST2	ST3	R1	SC1	SC2	R2	IC2	IC1	ST4
temp	19	17.5	18	22	21.5	21	20	17.9	18	16
conductivity	231	84	169	231	184	463	263	158	154	270
velocity	0.33	0.19	0.44	0.18	0.16	0.28	0.39	0.49	0.37	0.41
pH	7.99	7.82	8.17	7.82	7.25	7.06	7.85	7.99	7.96	7.44
acidity	0	0	0	0	0	0	0	0	0	0
alkalinity	117	41	84.5	104	71	161	115	75	76	25
hardness	122.2	27.2	86.8	107.1	64.6	108.1	110.1	75.7	76.7	13.1
DO	7.6	8.4	8.4	7.7	4.2	0.7	7.3	8.5	8.8	9.4
BOD_5	0.75	1.35	0.1	4.85	3.6	9.9	2.05	0.9	2.1	1.4
NO_3-N	6.57	2.73	6.65	6.89	5.96	11.8	7.4	5.6	5.03	1.8
NH_3-N	0.01	0.05	0.01	0.29	0.98	3.32	0.53	0.11	0.07	0.01
PO_4-P	0.13	0.02	0.05	0.07	0.02	1.68	0.13	0.01	0.06	0.07
Fe	1.33	1.77	1.16	2.33	1.44	1.00	1.11	1.05	1.05	0.11
Cu	0.002	0.003	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002
Zn	0.265	0.259	0.135	0.065	0.054	0.059	0.2	0.038	0.176	0.005
Mn	0.183	0.133	0.116	0.312	0.25	0.7	0.22	0.133	0.083	0.033

4.2 Multiple Analysis of Variance

The Multiple Analysis of Variance (MANOVA) in SPSSWIN was used in this study. The multivariate tests of significance using three testing methods (Pillais, Hotelling, Wilks) showed that at least two types of water were significantly different by consider the F values based on 15 parameters involved. (Appendix A) The univariate F-test showed individually the F values and significant of F of such parameters. There were five parameters showing non-significant differences; hardness, velocity, zinc , nitrate and copper.

In order to test which water is different from the others, LSD test with significant level 0.05 was applied. The dependent involved in this test obtained from factor analysis (Factor 1) with ten parameters ; alkalinity, BOD5, conductivity, iron, manganese, ammonia, pH, total phosphate, saturated oxygen and temperature. The result indicated significant differences were shown in the Fig.12.

* indicates significant differences between groups

Means	Location	Grp 1	Grp 3	Grp 2	Grp 4	
-.6287	Grp1					Grp 1 = a
-.4751	Grp3					Grp 2 = b
.0431	Grp2	*	*			Grp 3 = a
1.6894	Grp4	*	*	*		Grp 4 = c

Fig. 12 Significant differences among four types of water

From Fig. 12, it could be seen that streams and irrigation groups have similar condition of water body but they have different condition from river and sewage groups. The water condition of river and sewage groups were also significantly different.

4.3 Cluster Analysis

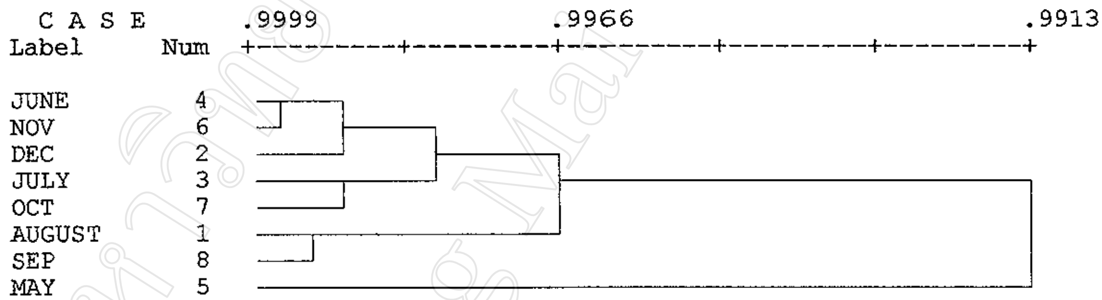
Cluster analysis was applied in this study in order to try to classify water quality between the dry and wet seasons. Dendograms of eight months per sampling site are shown in Fig. 13a to 13j.

Fig. 13 : Differentiation of water quality by Clustering

a) ST1

site ST1

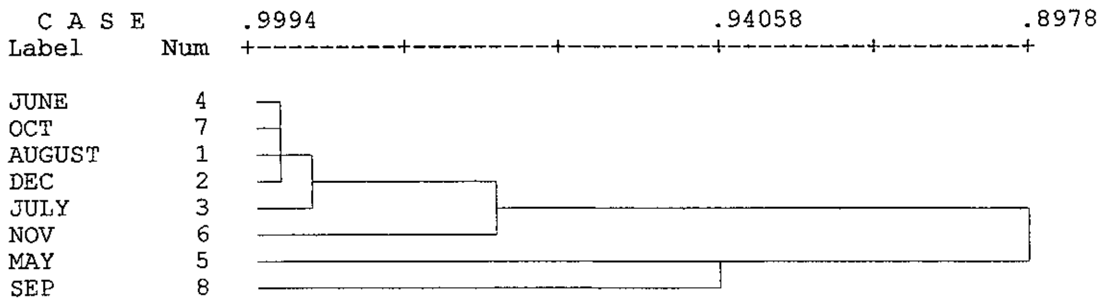
Dendrogram using Average Linkage (Between Groups)



b) ST2

site ST2

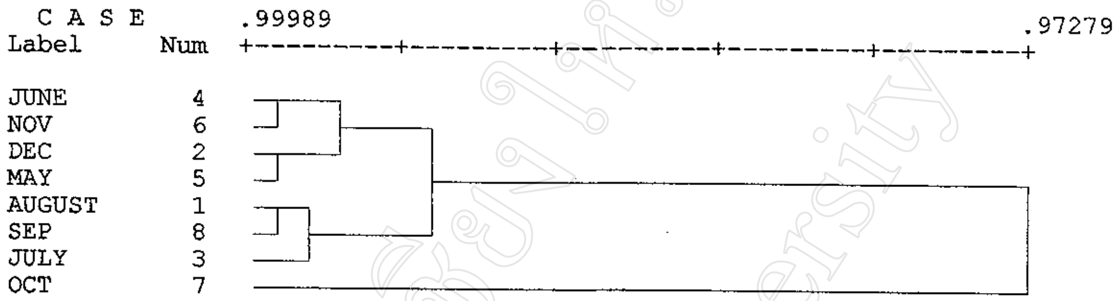
Dendrogram using Average Linkage (Between Groups)



c) ST3

site ST3

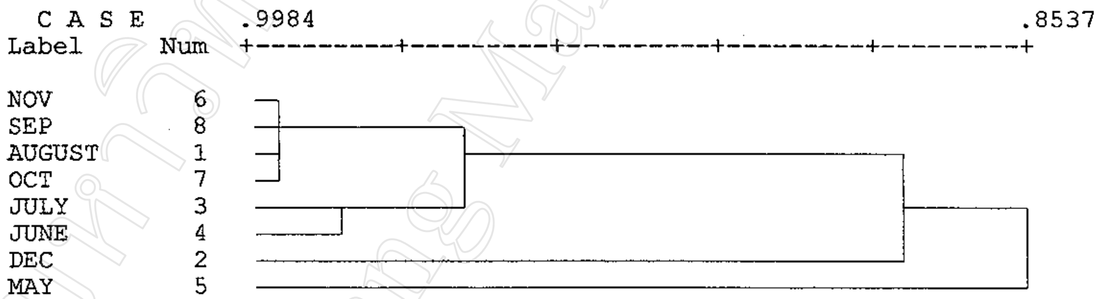
Dendrogram using Average Linkage (Between Groups)



d) ST4

site ST4

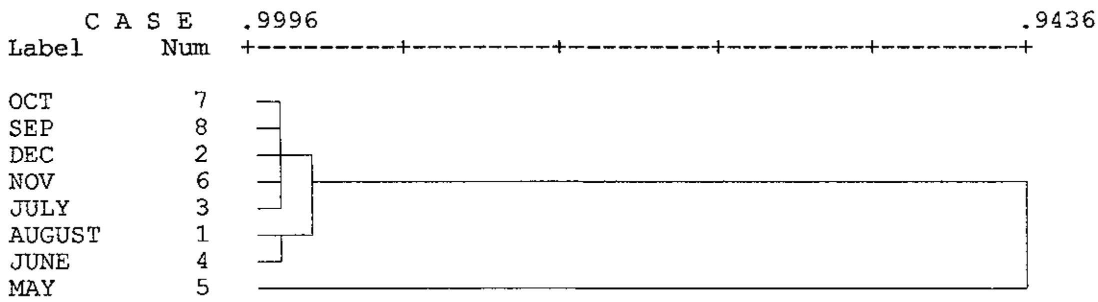
Dendrogram using Average Linkage (Between Groups)



e) R1

site R1

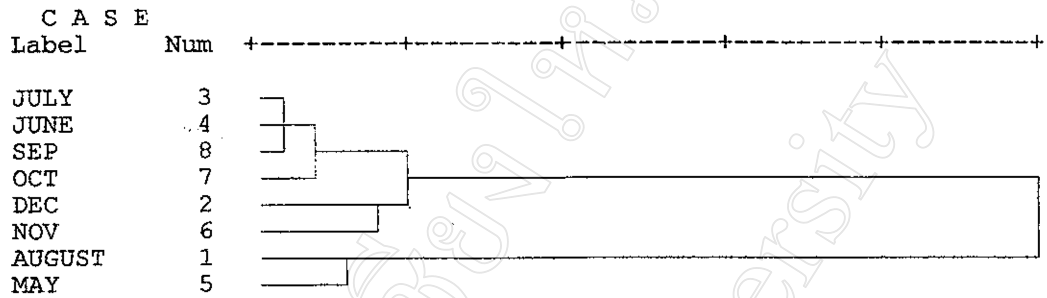
Dendrogram using Average Linkage (Between Groups)



f) R2

site R2

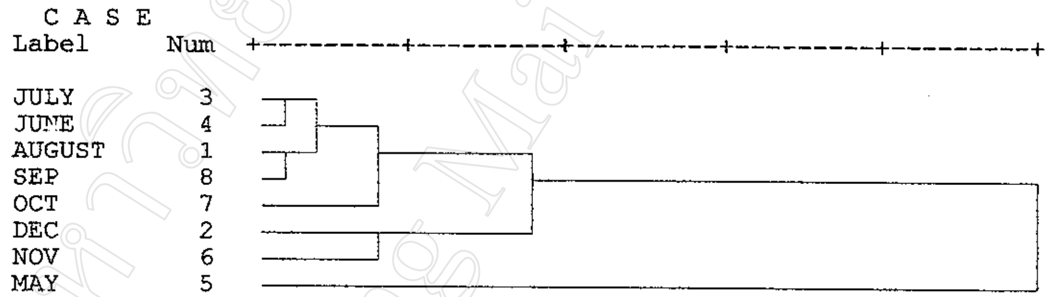
Dendrogram using Average Linkage (Between Groups)



g) IC1

site IC1

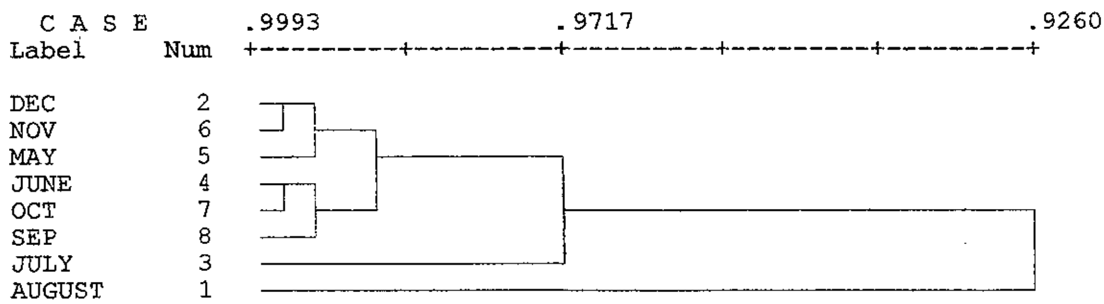
Dendrogram using Average Linkage (Between Groups)



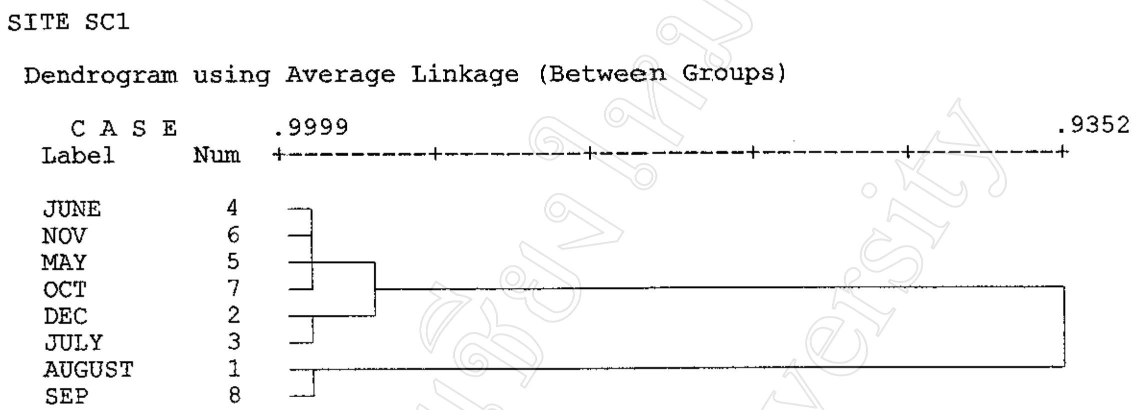
h) IC2

site IC2

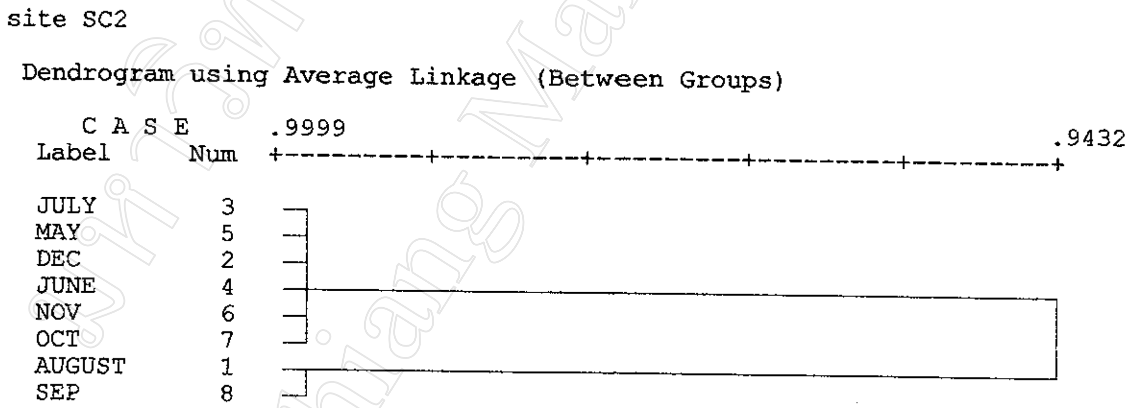
Dendrogram using Average Linkage (Between Groups)



I) SC1



j) SC2



Six sites of ten which are ST1, ST2, ST4, R1, R2 and IC1, indicate that the water conditions in dry and wet seasons were relatively different whist the other four sites were not. However , 60 % (6 sites) of results have followed the theory. It would, therefore, be concluded that water condition in dry season (May) was different from wet season (June to December).

4.4 Water Quality Index

Selection of Determinands

The appropriate indicators must be selected from the determinands having high effects or strong relation to the water quality in that particular area. To select the determinands, factor analysis was applied and the parameters which have the correlation coefficient from 0.7-1.0 were considered. Determinands, which would be included in the index, were selected using two statistical treatments, cluster analysis and factor analysis. Three dendograms of cluster analysis presented that there were two clustering groups. (Fig. 14a, 14b, 14c)

Group A consists of BOD_5, Mn, NH_3, PO_4, Alkalinity and conductivity.

Group B consists of pH and saturated oxygen.

These two groups had high correlation among their parameters. The rest parameters were classified as outliers because of very low correlation, and were excluded. From Fig. 14, group A and B were placed far apart. It was because of the opposite patterns. The degree of pollution increased with increasing of the concentration of group A membership, but conversely to group B .

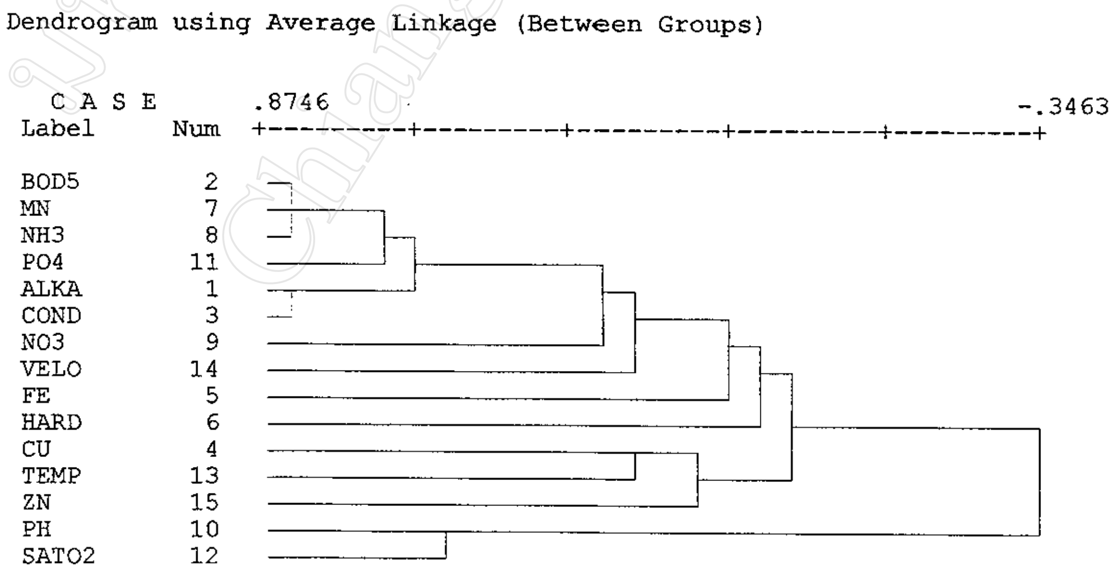


Fig. 14a : Cluster analysis using Pearson correlation; dendogram of using average linkage method.

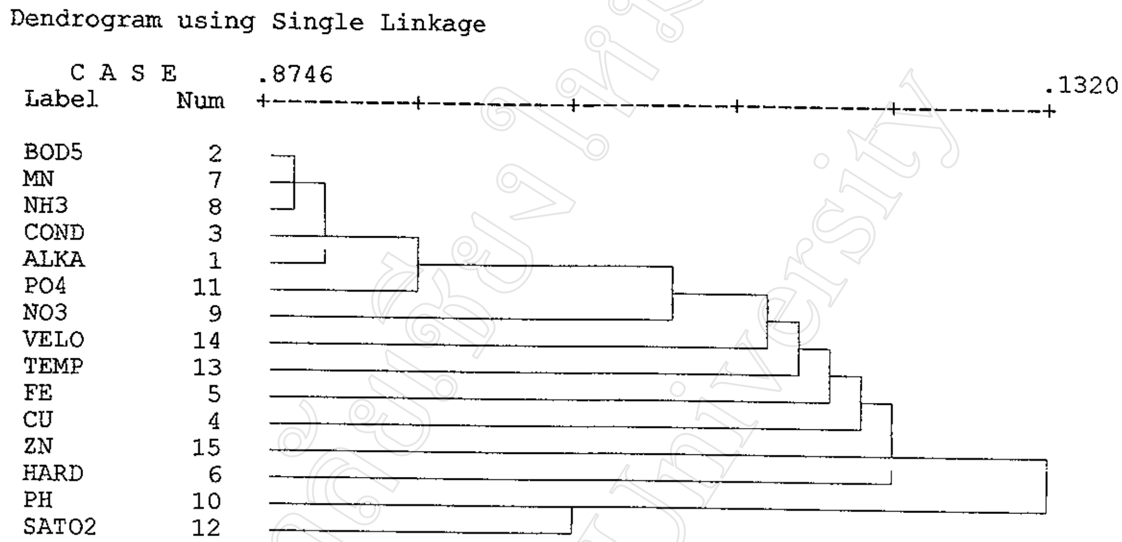


Fig. 14b : Cluster analysis using Pearson correlation ; dendogram of using single linkage method.

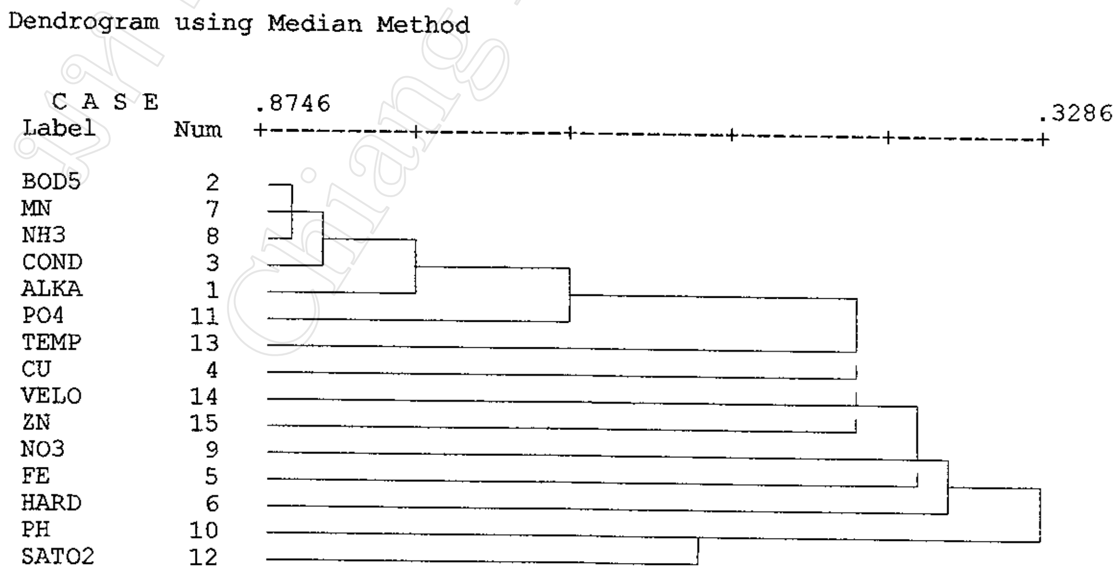


Fig. 14c : Cluster analysis using Pearson correlation ; dendogram of using median method.

In order to ensure the results of clustering method and to assess which parameters provided high effect to the water quality , factor analysis was applied. There were two extracted factors showing high eigenvalues greater than 1.0. Factor 1 had the highest percentage of variance, 55.7%, whilst factor 2 had lower, 12.9% which suggested to be omitted from consideration. Therefore, only factor 1 would be considered. There were five parameters obtained from the extraction. The correlation coefficient of such parameters were presented in table 3. The higher correlation coefficient indicates higher effect. Transformed ammonia had the highest coefficiency and then saturated oxygen , BOD_5, conductivity and transformed total phosphate respectively.

Table 3 : Correlation coefficiency of rotated factor matrix , significance, KMO values, and % of variance.

Variables	Factor scores of Factor 1
NH_3-N	0.93350
BOD_5	0.90905
Saturated O_2	-0.90462
Conductivity	0.87857
total PO_4	0.81100
% of variance	55.7
KMO measure of sampling adequacy	0.80511
Bartlett Test of sphericity	324.70370 **

** (Significant at 99%)

KMO values indicate the adequacy of sampling . In this study, KMO value = 0.81 (greater than 0.5) indicating the good variation of data. The F value of Bartlett Test of sphericity showed F = 324.7037 which was significant at 99 %.

Weighting

In this research, weights of selected parameters were converted from the correlation coefficiency (obtained from factor analysis). The sum of all weighting factors is generally 1.0 This way, the most important parameters are given the higher relative weights, and conversely. See Appendix C for derivation of weighting factors. Weighting to each parameter indicates the relative importance of individual parameters to overall water quality. Weighting factor of selected parameters converted from their correlation coefficient (Table 3) were shown in Table 4.

Table 4 : Weights of selected variables from Factor 1 which explain 55% of water quality.

Variables	**Unit**	**Weight**
NH_3-N	mg/l	0.21
BOD_5	mg/l	0.20
Saturated O_2	%	0.20
Conductivity	μS/cm	0.20
total PO_4	mg/l	0.19
n = 5		sum = 1.0

Derivation of weighting factors is presented in Appendix C.

Rating curves

Transformation was achieved by using of specific rating curves, 10 to 100 scale, which relate determinand concentrations, use-related water quality standard and criteria, to the index scale. Scale 100 means good quality and 10 means bad quality. To develop rating curve, an index scale (Y-axis) was devided into 5 classes (0-20, 21-40, 41-60, 61-80, and 81-100). The determinand concentrations (X-axis) were then plotted to those classes according to the surface fresh water quality standard and classification (SWQC). For example, rating curve development of BOD5.

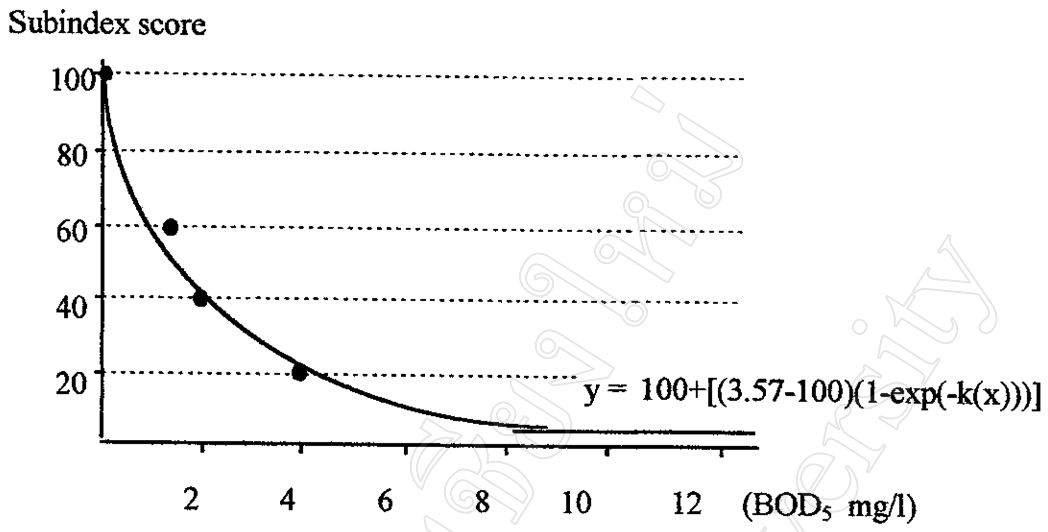


Fig. 15 : BOD rating curve development

The arranged BOD_5 concentration was modified according to its weight. Mathematical expression function was developed using FIG program. The same steps were repeated for the rest selected determinands.

The rating curves for each parameters were constructed with reference to generally accepted standards and criteria and graphically expressed parameter concentration on a scale of 0-100 . Mathematics/expressions for such curves were developed. Table 5 shows mathematical functions for each parameters.

Table 5 : Mathematical expression functions for each parameter.

Variables	**Equations obtained from producing rating curves by FIG.P**
NH_3 -N	y=99.85+[(4.64-99.85)(1-exp(-k(x)))]
BOD_5	y=100+[(3.57-100)(1-exp(-k(x)))]
Sat.O_2	$y = 7.08E\text{-}5(x^3) - 0.006(x^2) + 0.88(x) + 0.12$
Cond.	$y = -5.44E - 10(x^4) + 1.24E\text{-}6(x^3) - 7.71E\text{-}4(x^2) - 0.03(x) + 109.3$
Total PO_4	y=99.89 x exp (-1.75(x))

* Rating Curves for each parameters are shown. in Appendix C.

Aggregation process

It is a process used to consolidate all quality scores of rating curves and weight these scores in term of a given weight, then the final results can be obtained. Table 6 lists the principle methods and their corresponding aggregation function used in this study.

Table 6 : Aggregation functions

Methods	Equations
Weighted multiplicative function	$CI = \prod_{i=1}^{n} q_i^{w_i}$
Weighted additive aggregation function	$CI = \frac{1}{100} \left(\sum_{i=1}^{n} q_i w_i \right)^2$
Minimum operator	$CI = \min (q_1, q_2, \ldots, q_n)$

Three aggregation functions were used in order to compare the efficiency of such methods to the existing standard and classification.

Water Quality Indexing and Classification

For water quality classification, five classes of water were defined as shown in table 7 in order to determine how scores should be aggregated to an index value, it was necessary to determine what class of samples would indexed.

Table 7 : Scores range and class of water

Score range	Class	Verbal description
81-100	I	excellent
61-80	II	good
41-60	III	medium
21-40	IV	bad
0-20	V	very bad

Fig. 16 : A diagram of water quality index construction

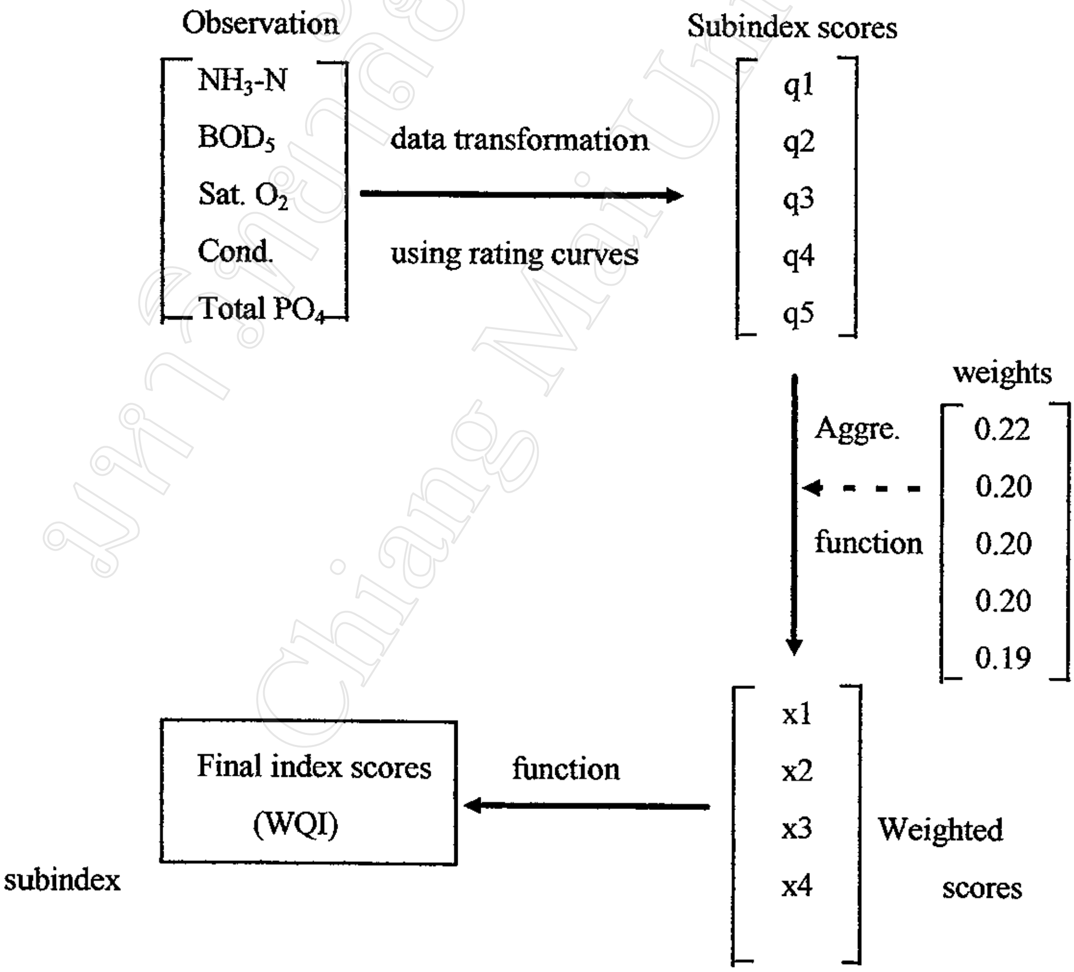


Fig. 16 shows the steps, involved in water quality index construction, in which , determinand concentrations (data) are transformed to subindex score on the basis of their rating curves (0-100 scale) using rating curves.

The subindex scores were then weighted by their weighting factors. The weighted subindex scores are aggregated to produce the final index score using aggregation function. In the application of water quality index to water quality classification. The score of 81-100 indicates excellent water quality, on the other hand , below 20 score indicates very bad water quality.

For example : water quality index calculation of Ping River site in June 1996. Determinand concentrations are shown below :

NH_3-N= 0.08 mg/l

BOD_5 = 0.1 mg/l

Sat.O_2 = 75.9 %

Cond. = 188 µs/cm

Total PO_4 = 0.92 mg/l

Determinand concentrations are transformed to subindex score using rating curves , for example, NH_3-N transformation (Fig. 17) :

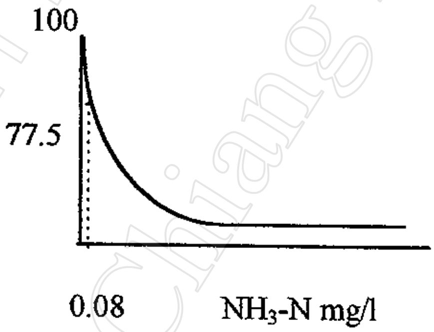


Fig. 17 : Derivation of subindex score.

Then aggregation process, for example $WQI = \prod_{i=1}^{n} qi^{wi}$ was then carried on as shown in table 8. The calculation of WQI is much easier if all weighted subindices can be taken from tables directly. The tables of subindices and weighted subindices are represented in Appendix C.

Table 8 : Calculation for final index score using GW function.

Determinands	weights(wi)	Subindex scores (qi)	Weighted subindex scores
NH_3-N	0.21	77.5	2.49
BOD_5	0.20	97.5	2.49
Sat. O_2	0.22	62	2.28
Cond.	0.20	84	2.42
total PO_4	0.19	19.3	1.75
Final index score			59.8

The obtained final index score is 59.8 which falls into class III, indicating medium clean water quality (Table7).

4.5 The application of water quality index

The WQI was applied in which three aggregation functions were used(Table 6). The consequences of WQI classifying by these three functions as well as classifying by surface water quality standard classification (SWQC) were presented in table 9a to 9h.

Table 9: Water quality classification using SWQC and WQI with three aggregation functions

a) May

Sites	Class			
	SWQC	GW	SW	Min.
st1	I	II	II	II
st2	V	III	III	IV
st3	I	I	II	III
st4	III	II	III	III
r1	II	II	III	III

table 9 continued

Sites	Class			
	SWQC	GW	SW	Min.
r2	III	II	III	IV
ic1	V	III	IV	V
ic2	II	II	II	II
sc1	V	V	V	V
sc2	V	V	V	V

b) June

Sites	Class			
	SWQC	GW	SW	MO
st1	II	II	III	II
st2	II	II	III	V
st3	I	I	II	II
st4	II	II	III	IV
r1	II	II	III	V
r2	III	II	III	III
ic1	II	II	III	III
ic2	II	III	III	V
sc1	V	V	V	V
sc2	V	V	V	V

table 9 continued

c) July

Sites	Class			
	SWQC	GW	SW	MO
st1	II	II	III	III
st2	II	II	II	II
st3	I	I	II	II
st4	I	II	II	IV
r1	III	III	III	V
r2	III	II	III	III
ic1	II	II	III	II
ic2	II	II	III	II
sc1	V	IV	V	V
sc2	V	V	V	V

d) August

Sites	Class			
	SWQC	GW	SW	MO
st1	II	I	II	II
st2	I	I	II	II
st3	I	I	II	II
st4	I	I	II	II
r1	III	II	III	III
r2	III	II	III	III
ic1	II	II	II	III
ic2	II	II	II	II
sc1	V	IV	IV	V
sc2	V	V	V	V

table 9 continued

e) September

Sites	Class			
	SWQC	GW	SW	MO
st1	II	II	II	III
st2	II	I	II	II
st3	II	II	II	II
st4	I	I	II	II
r1	III	III	IV	III
r2	III	II	IV	III
ic1	II	III	IV	III
ic2	II	II	III	II
sc1	V	IV	V	V
sc2	V	V	V	V

f) October

Sites	Class			
	SWQC	GW	SW	MO
st1	I	II	III	III
st2	I	I	I	II
st3	I	I	I	II
st4	I	I	I	II
r1	II	II	III	II
r2	II	II	III	III
ic1	I	I	II	II
ic2	I	I	II	II
sc1	V	IV	V	V
sc2	V	V	V	V

table 9 continued

g) November

Sites	Class			
	SWQC	GW	SW	MO
st1	I	I	II	II
st2	I	I	II	II
st3	I	I	II	I
st4	I	I	I	I
r1	V	III	IV	II
r2	II	II	III	III
ic1	I	I	II	II
ic2	II	II	III	III
sc1	V	IV	V	V
sc2	V	V	V	V

h) December

Sites	Class			
	SWQC	GW	SW	MO
st1	I	II	II	II
st2	II	I	II	II
st3	I	I	I	I
st4	II	II	II	II
r1	V	III	IV	III
r2	V	III	IV	IV
ic1	III	II	II	II
ic2	I	I	II	II
sc1	V	IV	IV	IV
sc2	V	V	V	V

Percentage of agreement for each aggregation methods were computed by counting the water classification obtained from WQI which presenting the same class as those obtained from the SWQC.

Table 10 : % of agreement of three aggregation functions compared to the existing standard and classification used in Thailand.

SWQC	GW	SW	MO
80	52	36	39
% of agreement with SWQC	65%	45%	48.75%

From table 10, it had been seen that WQI using GW method had highest percentage of agreement (65%) comparing to SWQC, while the SW method and Min. method had 45% and 48.75% of agreement respectively.

4.6 **Testing of the Water Quality Indexing System**

To verify the performance of the index system developed in this study , the other different data set of rivers were applied. The 16 samples from Pong river were tested. (Source of data : means of June 1986 to May 1987 samplings, report of the studies of impacts of manufactural & agricultural activities on the qualities of water in Lum Num Pong, 1987) The consequences of WQI using three aggregation functions were presented in table11 ;

Table 11 : Water quality Classification of test data using SWQC and WQI with 3 aggregation functions.

site	Class			
	SWQC	Gw	Sw	Min
Pong1	III	III	IV	IV
Pong2	III	III	IV	IV
Pong4	III	III	IV	IV
Pong5	III	III	IV	IV
Pong6	III	III	IV	IV
Pong7	V	V	V	V
Pong8	III	III	IV	V
Pong8/1	V	V	V	V
Pong8/2	IV	III	IV	IV
Pong9	IV	II	IV	V
Pong10	IV	III	IV	V
Pong11	II	III	IV	IV
Pong12	III	IV	V	V
Pong12/2	II	III	IV	V
Pong13	V	IV	V	V
Pong14	IV	III	IV	IV

Table 12 : % of agreement of three aggregation functions compared to the existing standard and classification used in Thailand.

SWQC	GW	SW	MO
16	8	7	5
% of agreement compare to SWQC	50%	43.75%	31.25%

The agreement of the test samples showed that WQI using GW method gave the highest percentage of 50%, whilst the others gave 43.75% and 31.25% respectively.

4.7 Water quality monitoring using WQI

Key indicator, as a part of water quality monitoring, is set using dissolved oxygen at concentration 2 mg/l. The diagram of water quality monitoring process showed in Fig. 18.

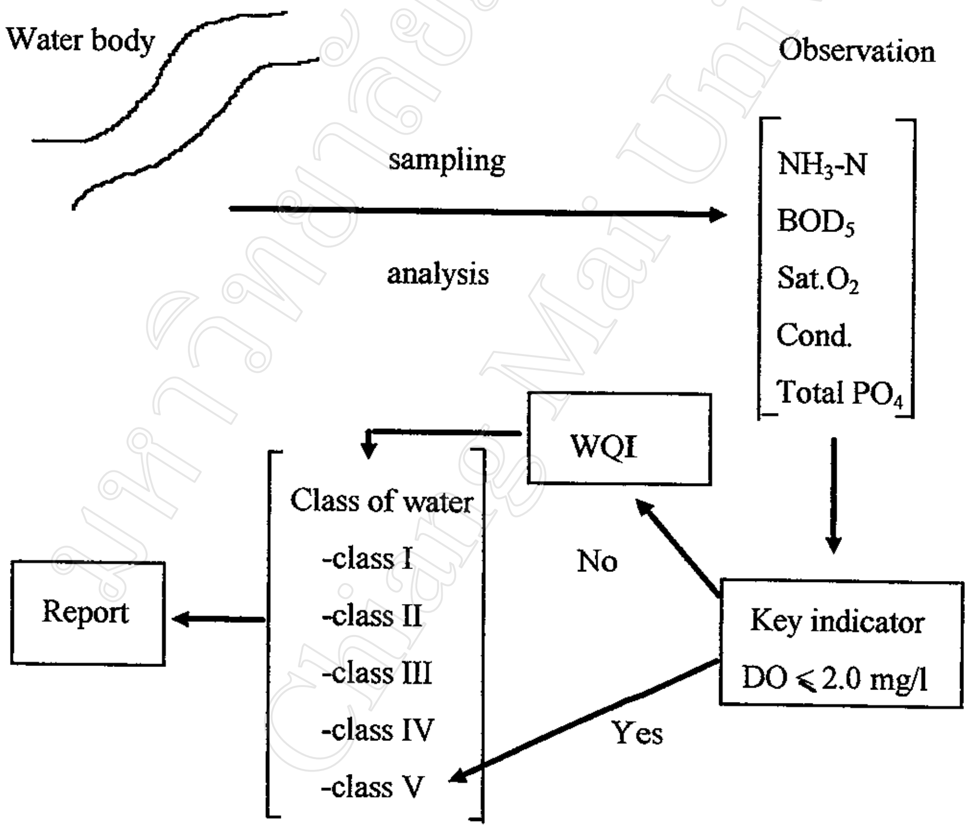


Fig. 18 : Water quality monitoring process

Fig. 18 shows the step of water quality monitoring process, in which, water samples are collected and analyzed for the observation (indices). Determined DO concentration is then compared with the key indicator. If concentration of DO is less than 2 mg/l, quality of water will be falling to class 5, if not the process of WQI will be carried on. Finally, the consequences of water quality classification using WQI will be reported .

In addition, the study of trends of water quality was done following the process above. The Fig. 19-22 showed the trends of water quality of sampling sites classified by WQI using GW formulation and the Fig. 23-30 showed mapping of water quality classification during the sampling period. From the results, trends of water quality of stream sites as well as irrigation canal sites have increased both in their WQI scores and classes. Trends of water quality of sewage canal sites have also increased in WQI scores but they are still falling to the same class. On the other hand, river sites have constant trends of water quality except in the last two months, November and December, found to be decreasing in water quality from class 2 to class 3.

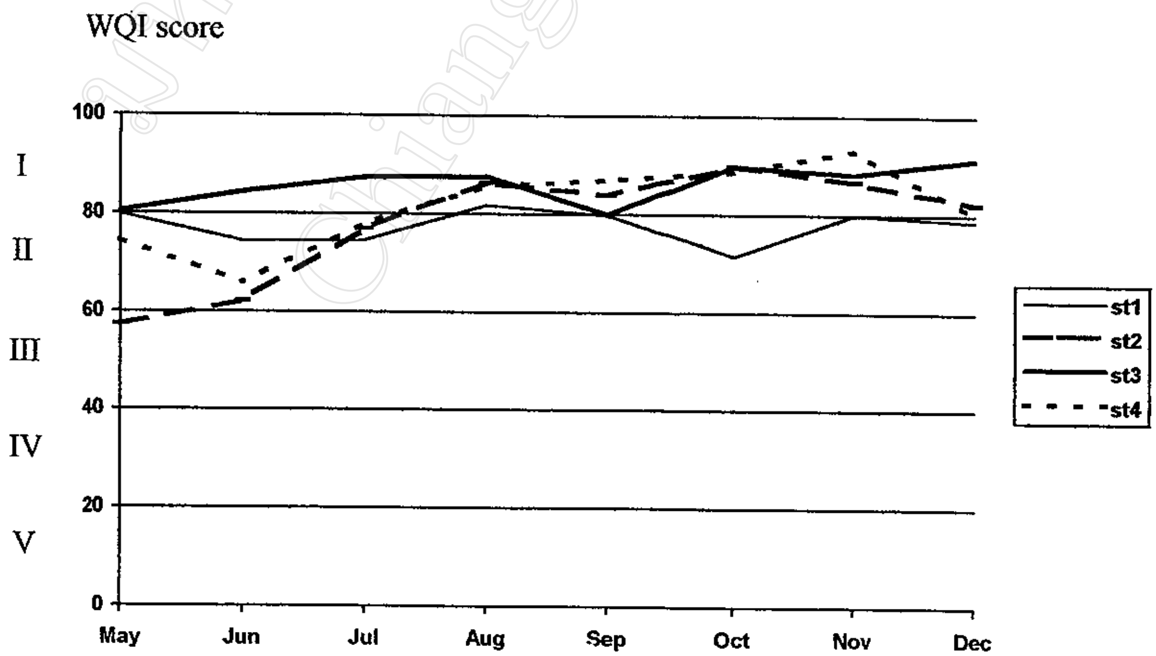


Fig. 19 : Trend of water quality of stream sites.

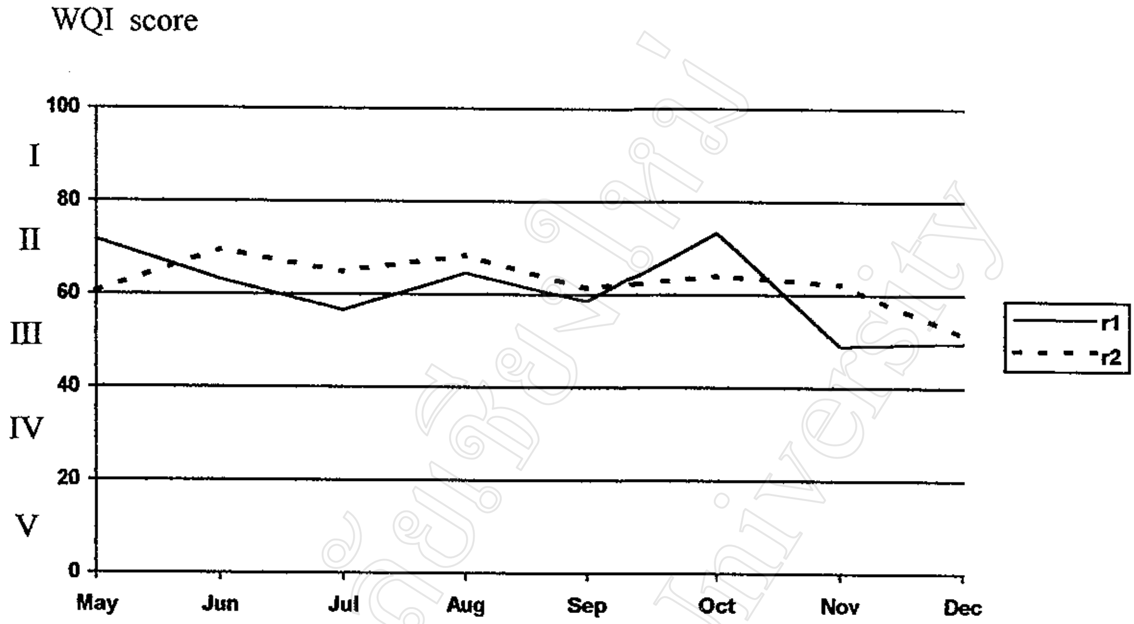


Fig. 20 : Trend of water quality of river sites.

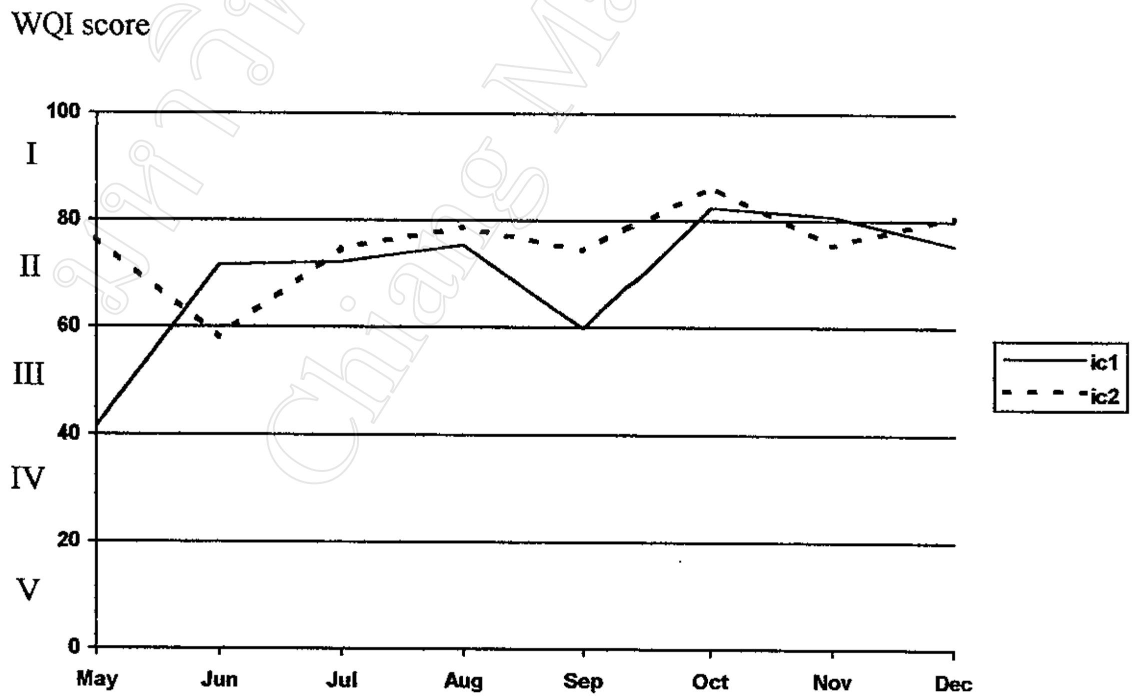


Fig. 21 : Trend of water quality of irrigation sites.

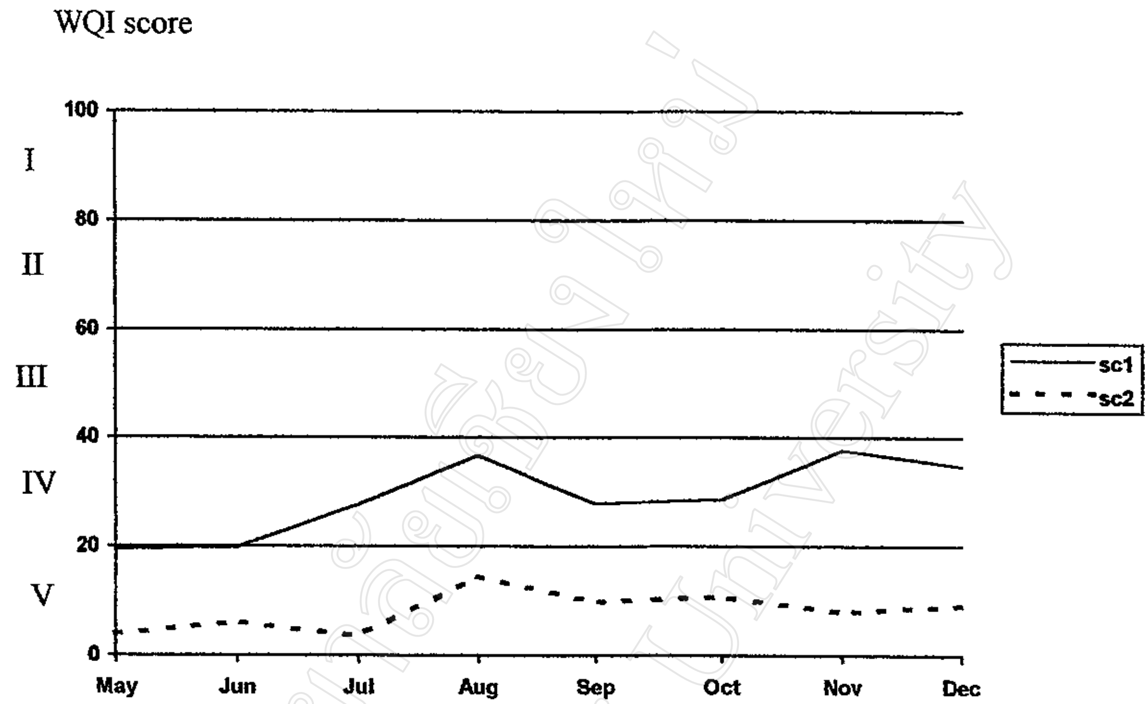


Fig. 22 : Trend of water quality of sewage sites.

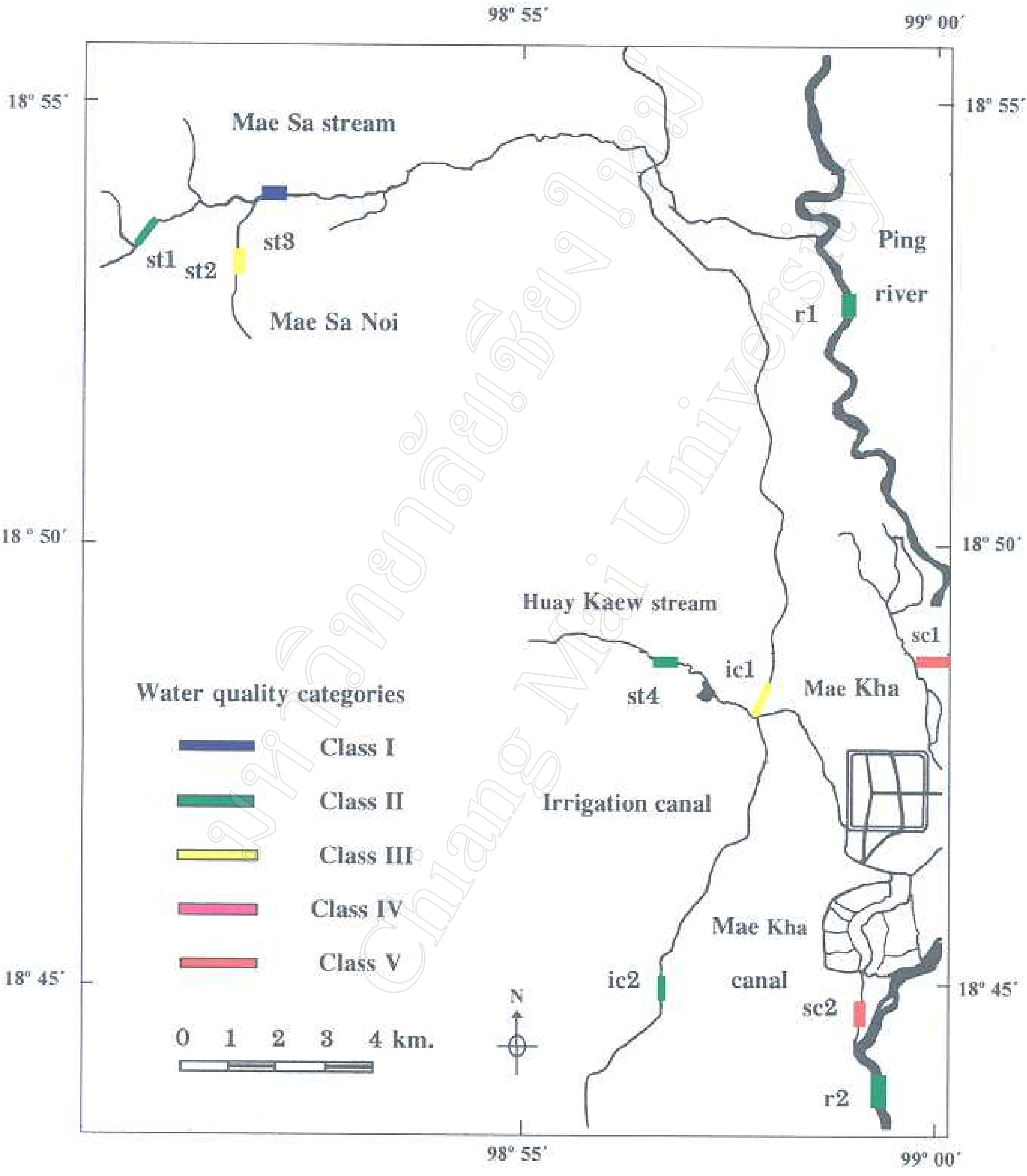


Fig. 23 : Map of water quality classification in May

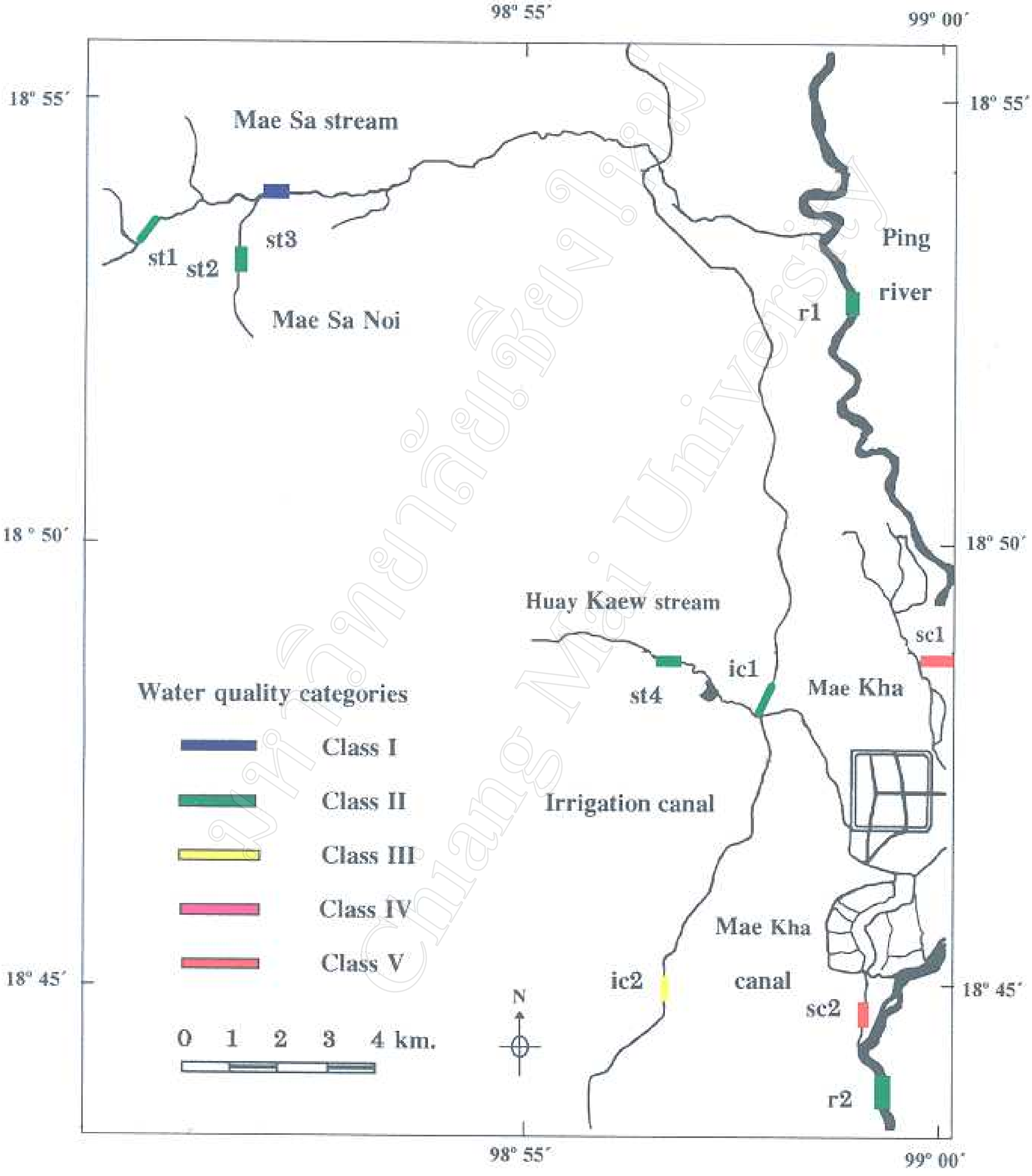


Fig. 23 : Map of water quality classification in June

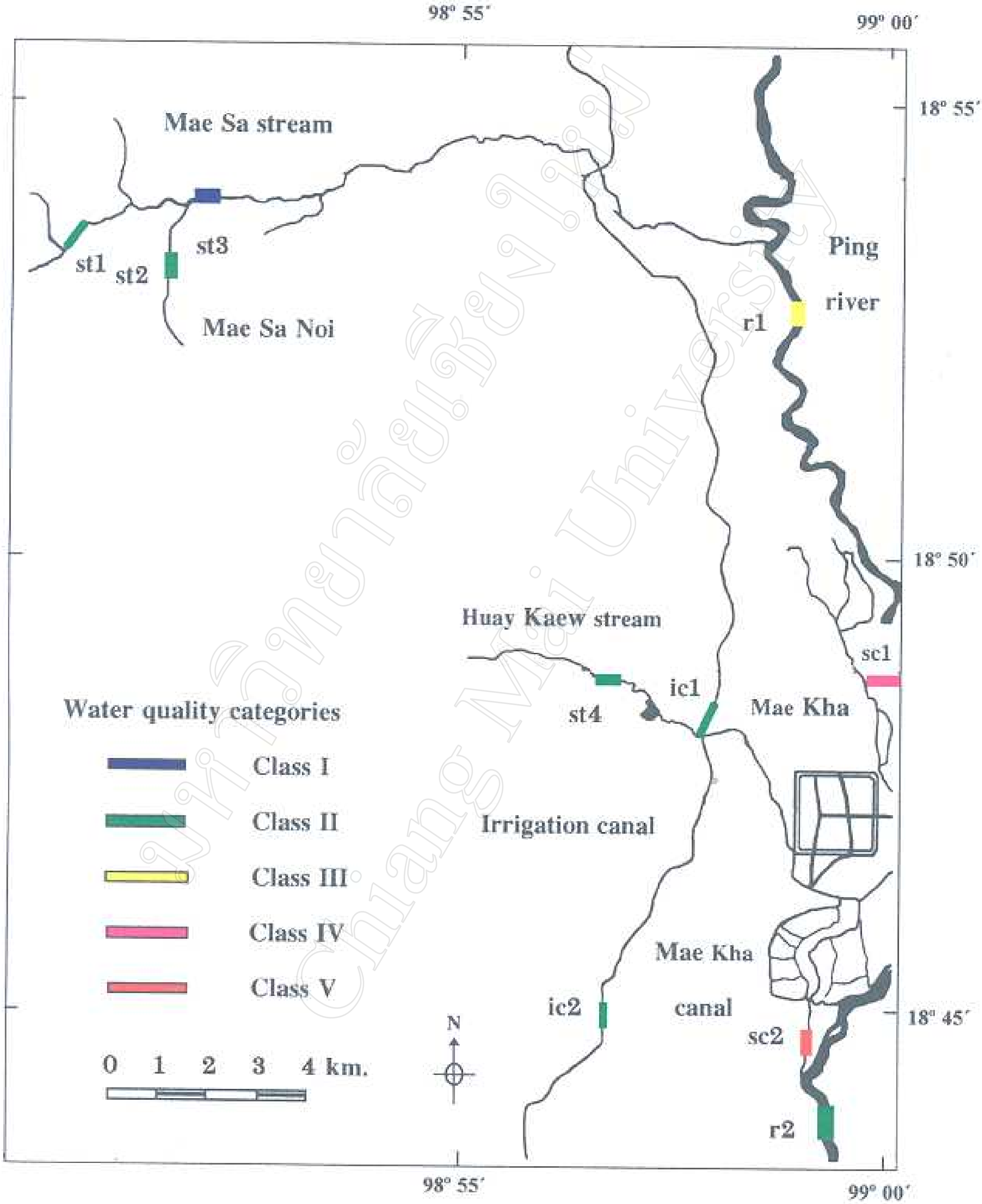


Fig. 23 : Map of water quality classification in July

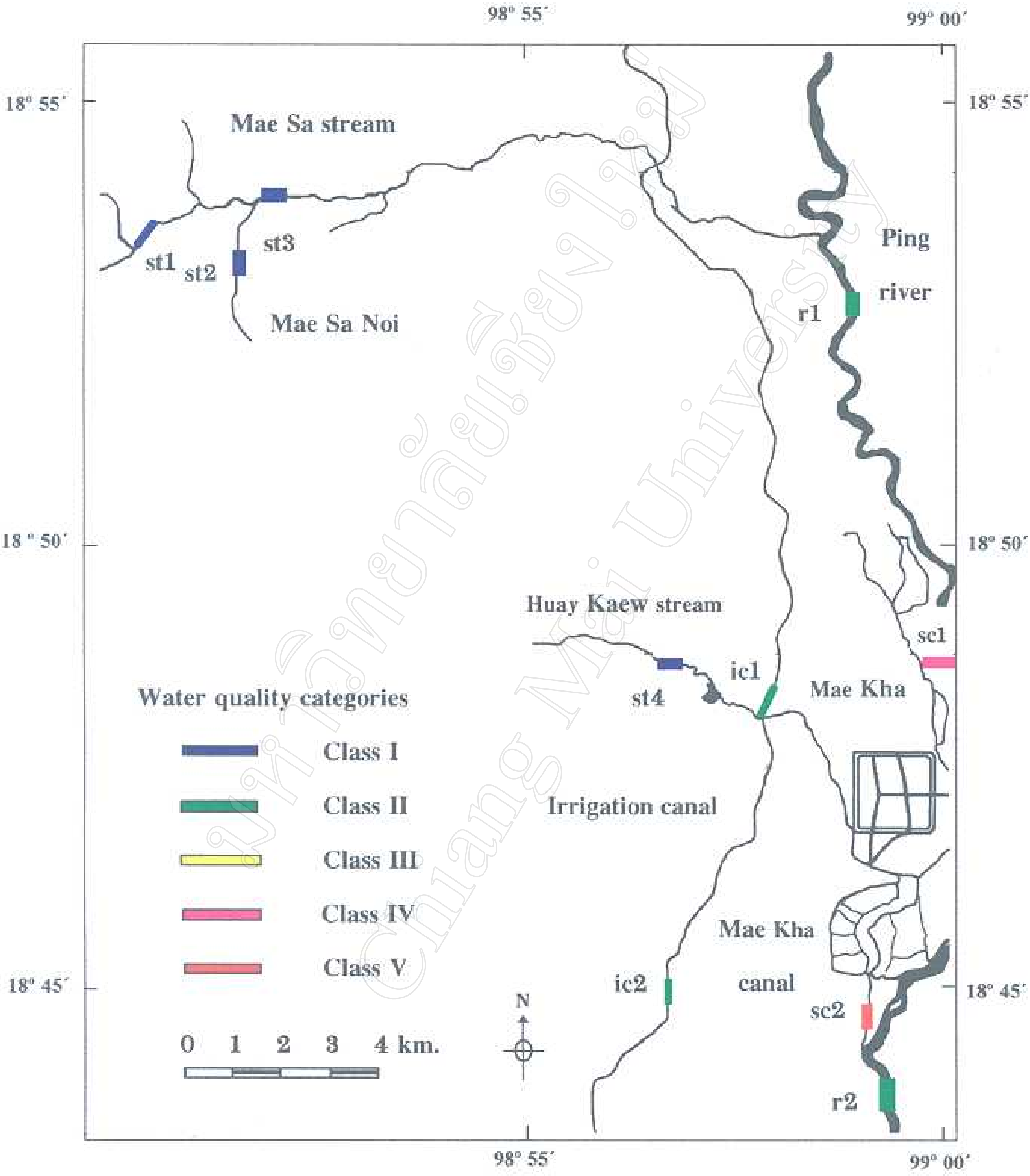


Fig. 23 : Map of water quality classification in August

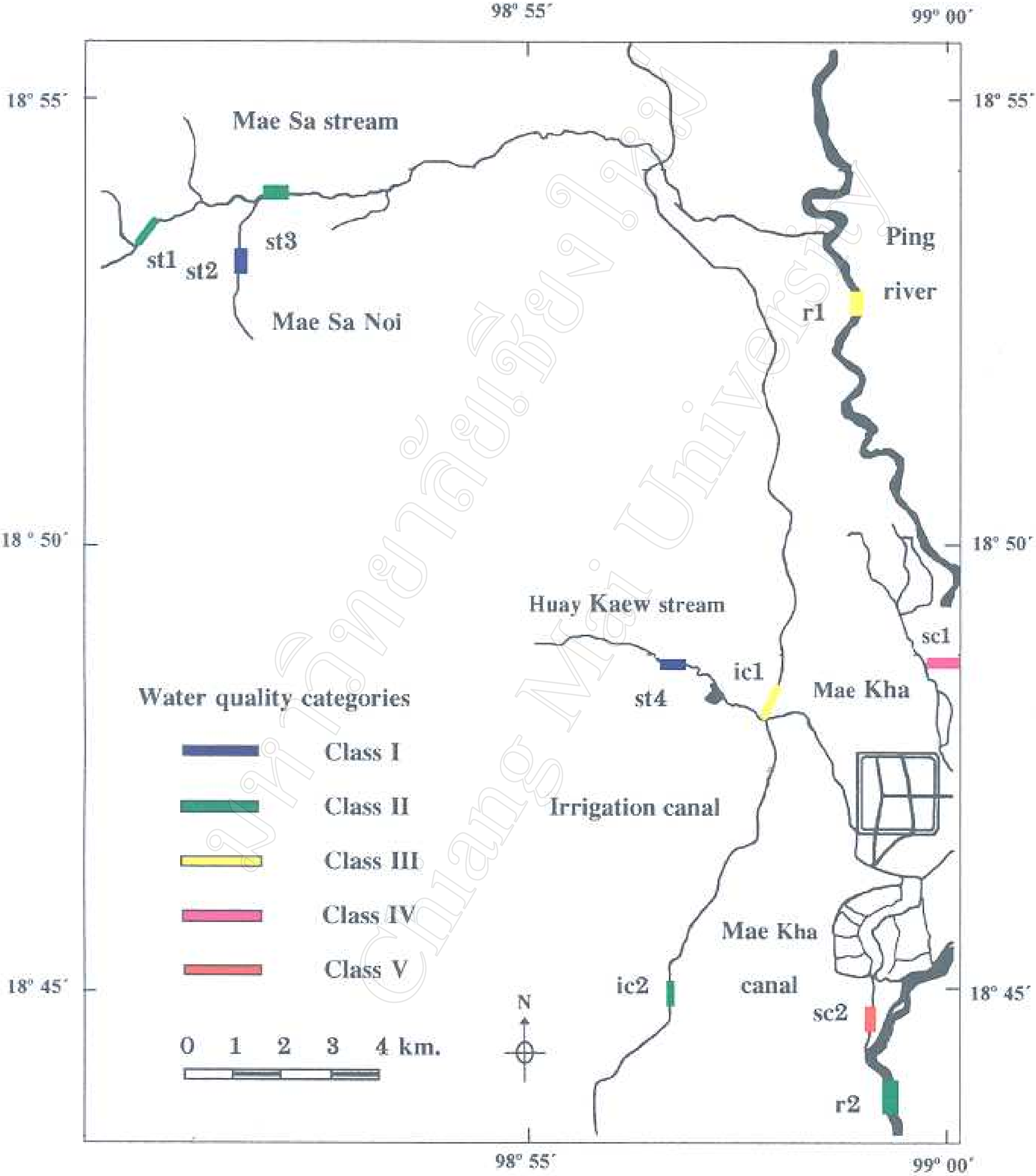


Fig. 23 : Map of water quality classification in September

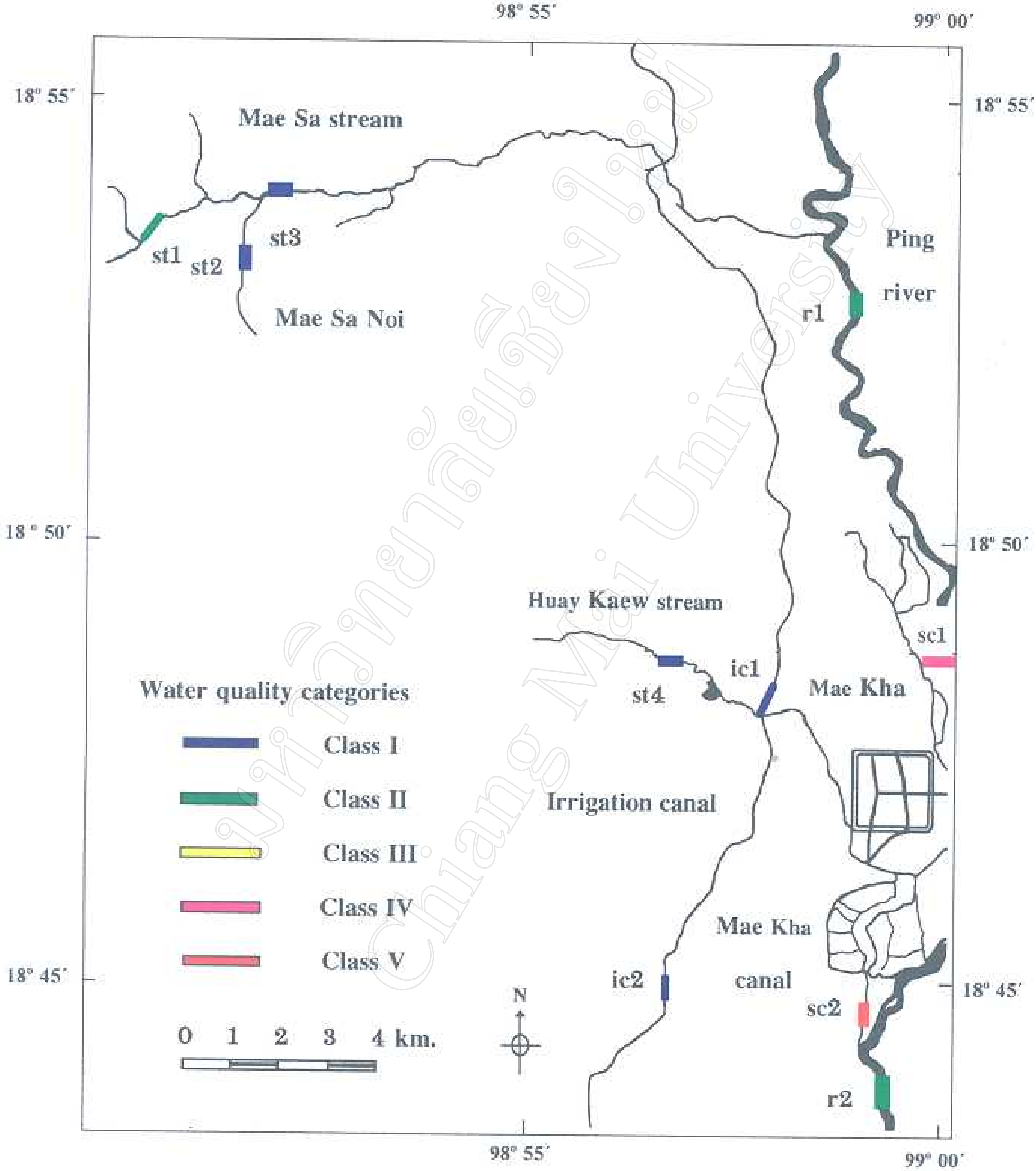


Fig. 23 : Map of water quality classification in October

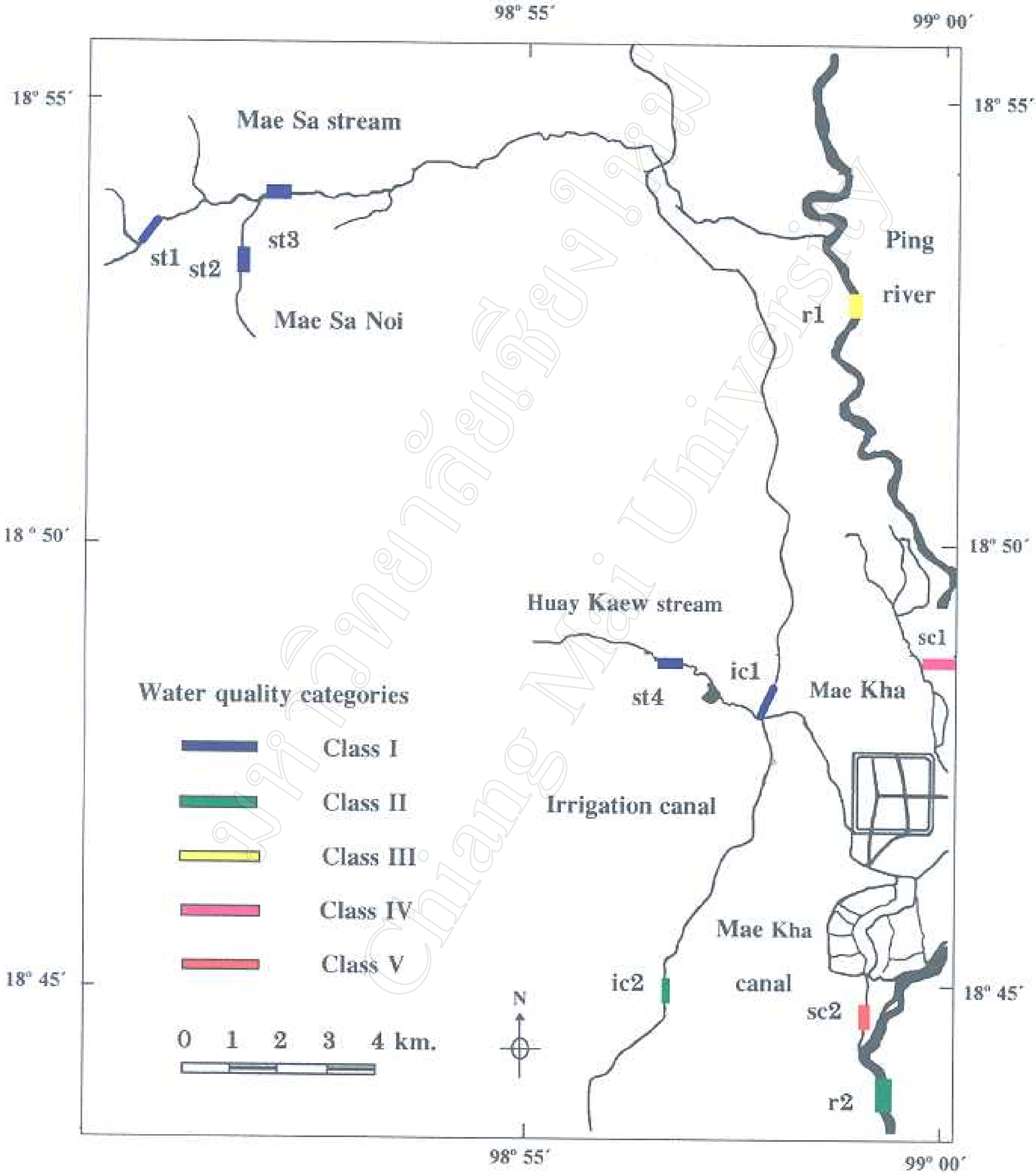


Fig. 23 : Map of water quality classification in November

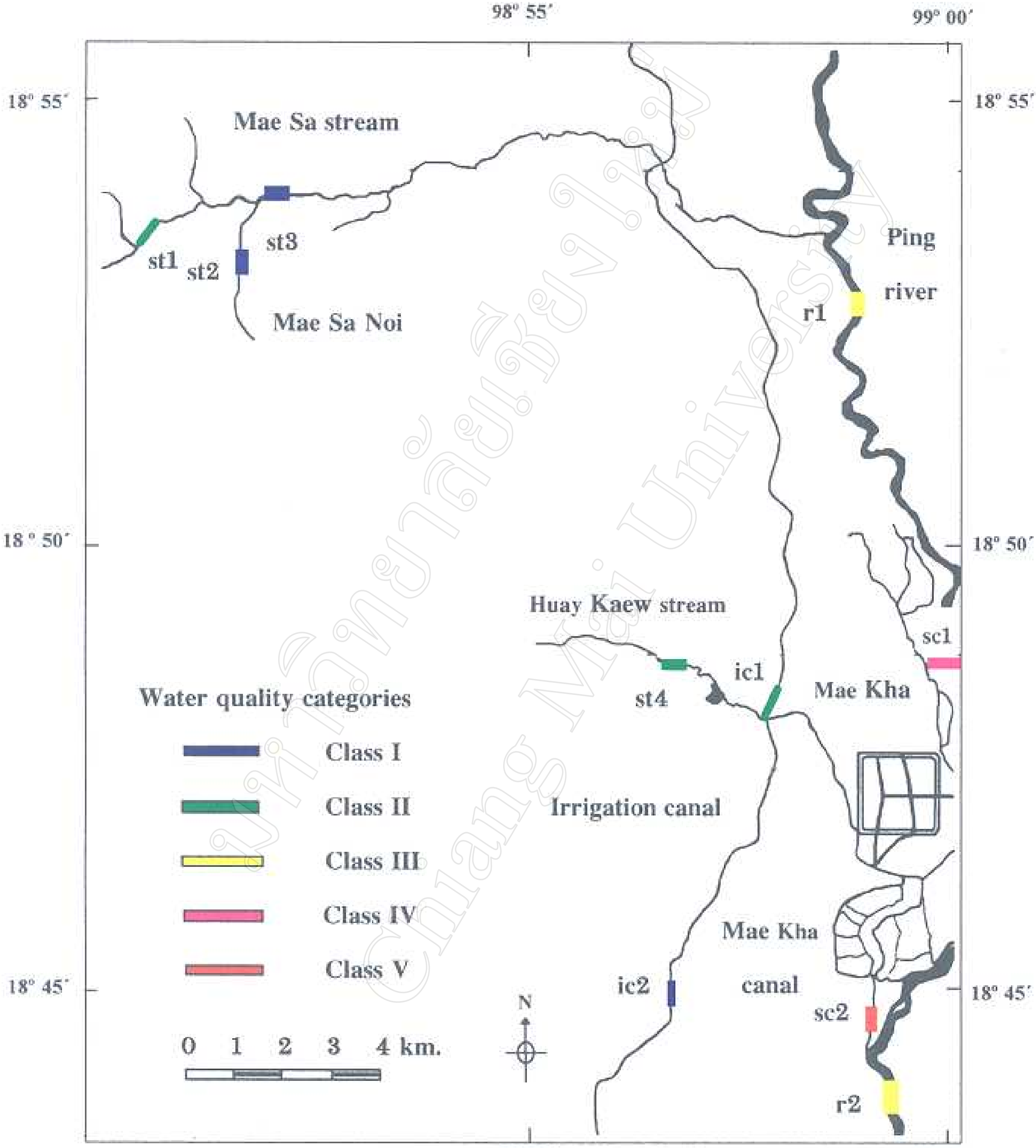


Fig. 23 : Map of water quality classification in December

4.8 Relationship Between Physico-Chemical Parameters and Macroinvertebrate Faunas

Up to date, there is very few researches have been done in the organization and structure of macroinvertebrate faunas in running waters, particularly in relation to the relative influences of abiotic and biotic factors. It is interesting to study the relationship between physio-chemical variables and macroinvertebrates. This study seems to be a confirmation technique for testing a reliability of physio-chemical data in water quality classification compare to macroinvertebrate data. The macroinvertebrate data (collected by conventional sampling method and identified to family level) was obtained from Guruge (Guruge, 1997).

Ordination

The primary and secondary axes of ordination, which together explained 33.15% of the variance in the entire data-set (Table 13) whilst the remaining axes (axis 3 and 4) together explained < 10% of the variance and could not be related clearly to any physiochemical variables.

Table 13 : Eigenvalues, % of total variance explained and cumulative percentage variance explained of each DECORATE axis.

Axis	Eigenvalue	% of total variance explained	Cum. % variance explained
1	0.565	23.29	23.29
2	0.239	9.86	***33.15***
3	0.115	4.74	37.89
4	0.049	2.00	39.89

Table 14 shows the Log $_{10}$ transformation applied and the abbreviation name for the variables which were not normally distributed.

Table 14 : Transformation applied and the abbreviations of each variables

Variables	Transformation	Abbreviated name
Conductivity	none	Cond
Velocity	none	Velo
pH	Log_{10}	LpH
Alkalinity	none	Alka
Total Hardness	none	Hard
DO	Log_{10}	LDO
BOD_5	Log_{10}	$LBOD_5$
Nitrate	Log_{10}	LNO_3
Ammonia	Log_{10}	LNH_3
Iron	none	Fe
Copper	none	Cu
Zinc	none	Zn
Manganese	none	Mn

Correlation coefficients between the ordination scores for axes 1-4 and the physiochemical variables listed in Table 14 were given in Table 15. On Axis 1 the highest correlation observed were BOD_5 ($LBOD_5$ = -0.786) and NH_3 (LNH_3 = -0.589). In contrast, the highest correlation on Axis 2 was pH (pH = -0.338)

Table 15 : Product-moment correlation coefficients between sites scores on DECORANA axes 1-4 and physio-chemical variables.

Variables	Axis 1	Axis 2	Axis 3	Axis 4
Cond	-0.399	-0.038	-0.207	-0.428
Velo	-0.137	-0.284	0.034	-0.128

Table 15 continued

Variables	Axis 1	Axis 2	Axis 3	Axis 4
LpH	0.367	***-0.342***	-0.042	-0.167
Alka	-0.231	-0.188	-0.214	-0.508
Hard	-0.031	-0.253	-0.280	-0.475
LDO	***0.559***	0.017	0.314	0.290
$LBOD_5$	***-0.786***	-0.217	-0.437	-0.310
LNO_3	-0.024	0.120	0.322	0.445
LNH_3	***-0.589***	0.158	-0.218	-0.092
Fe	-0.242	-0.016	-0.278	-0.299
Cu	0.130	0.230	0.077	-0.024
Zn	0.078	-0.105	-0.247	-0.568
LMn	-0.507	-0.015	-0.196	-0.363

It would appear that, both axes 1 and 2 displayed the variation between different types of waters. Correlation between physio-chemical variables and axes 3 and 4 were much lower than those observed on axes 1 and 2.

Classification

Fig 31 presented a dendogram of the sites classification produced by TWINSPAN to level 3, when 6 groups of sites had been generated and the comparison with the DECORANA axes indicated that the classification was strongly related to water BOD_5 and NH_3 , and to a lesser extent, to pH (Fig. 31).

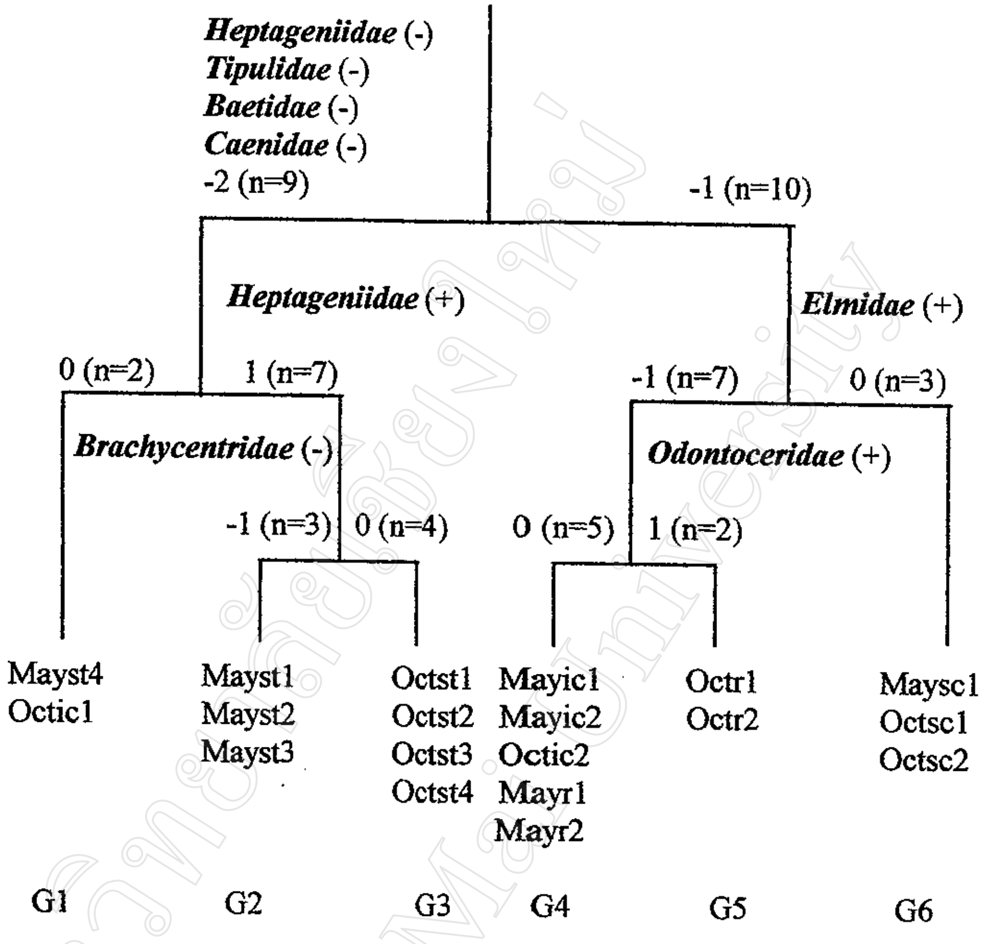


Fig. 31 : Dendogram of TWINSPAN classification of sites on the basis of macroinvertebrate faunas.

6 groups obtained from the classification by TWINSPAN were shown as following :

Group G1 : Mayst4, Octic1

Group G2 : Mayst1, Mayst2, Mayst3

Group G3 : Octst1, Octst2, Octst3, Octst4

Group G4 : Mayic1, Mayic2, Octic2, Mayr1, Mayr2

Group G5 : Octr1, Octr2

Group G6 : Maysc1, Octsc1, Octsc2

A dichotomous key indicator was established with the *Heptageniidae, Tipulidae, Baetidae* and *Caenidae* were indicators at level 1 (Fig. 31). Those 4 families played as main factors to separate stream group from the others (Table 16). Group G1, G2 and G3 had higher frequencies occurrence than Group G4, G5 and G6 which are sewage canal, river and irrigation canal. *Elmidae,* indicator at level 2, separated sewage canal (Group G6) from river and irrigation canal (Group G4 and G5) whilst *Heptageniidae* separated Mayst4 and Octic1 (Group G1) as outliers from Group G2 and G3. At level 3, *Brachycentridae* separated stream into dry season (Group G2) and wet season (Group G3) and also *Odontoceridae* separated river in wet season (Group G5) from dry season (Group G4).

Table 16 : Frequencies of occurrence of taxonomic (families) in TWINSPAN groups. (* < 20%, ** 20-40%, *** 40-60%, **** 60-80%, ***** 80-100%)

Family	Group G1 (n=2)	Group G2 (n=3)	Group G3 (n=4)	Group G4 (n=5)	Group G5 (n=2)	Group G6 (n=3)
Baetidae	*****	*****	*****	**	*	*
Caenidae	***	****	*****	*	*	*
Heptageniidae	*	*****	*****	*	*	*
Neoephemeridae	***	*****	****	***	*	*
Leptophlebiidae	***	****	*	**	*	*
Ephemeridae	***	**	*	*	*	*
Tricorythidae	*	*	*	*	*	*
Hydroptilidae	***	*****	****	**	*	*
Hydropsychidae	*****	*****	*****	****	*	*
Brachycentridae	*	*****	*	**	*	*
Helicopsychidae	*	**	**	*	*	*
Rhyacophilidae	*	**	*	*	*	*
Limnephilidae	***	****	*	*	*	*

Table 16 continued

Family	Group G1 (n=2)	Group G2 (n=3)	Group G3 (n=4)	Group G4 (n=5)	Group G5 (n=2)	Group G6 (n=3)
Odontoceridae	*****	**	**	*	*****	*
Lepidostomatidae	*	**	*	*	*	*
Glossosomatidae	*	**	***	**	*	*
Philopotamidae	*	*****	*	*	***	*
Phryganeidae	*	*	**	*	*	*
Peltoperidae	*	**	*	*	*	*
Perlidae	*	****	*	*	*	*
Elmidae	*****	*****	****	*****	*****	*
Staphilinidae	*	**	*	*	*	*
Hydrophilidae	***	****	***	**	*	*
Helodidae	*	**	*	*	*	*
Halipidae	*	**	*	*	*	*
Hydraenidae	*	****	*	*	*	*
Psephenidae	*	**	**	**	*	*
Limnichidae	*	*	**	*	*	*
Dryopidae	*	*	***	*	*	*
Chironomidae	*****	*****	*****	****	*****	*****
Simuliidae	*	*****	*****	*	*	*
Athericidae	*****	*	**	*	***	*
Ephydridae	***	**	*	*	*	*
Tipulidae	***	**	*****	*	*	*
Tabanidae	*	****	*	*	*	*
Empididae	***	**	*	*	*	*
Nematocera	***	*	**	*	*	*
Psychodidae	*	**	***	*	*	*
Ceratopogonidae	***	****	***	*	*	**
Blephariceridae	*	*	**	*	*	*

Table 16 continued

Family	Group G1 (n=2)	Group G2 (n=3)	Group G3 (n=4)	Group G4 (n=5)	Group G5 (n=2)	Group G6 (n=3)
Stratiomidae	*	*	**	*	*	*
Belostomatidae	*	****	***	*	*	*
Corixidae	***	*	*	*	*	*
Naucoridae	*	*****	***	*	*	*
Veliidae	***	*	*	*	*	*
Gerridae	*	*	**	*	*	*
Gomphidae	*****	****	***	****	*	*
Cordulegestridae	***	*	**	*	*	*
Libellulidae	*	*	*	*	*	*
Aeshriidae	*	**	***	*	*	*
Macromidae	*	*	**	*	***	*
Pyralidae	***	*	***	*	*	*
Atyidae	***	**	***	*	*	*
Grapsidae	*	**	*	*	*	*
Paratheiphusidae	*	*	*****	*	*	*
Poduridae	***	*	*	*	*	**
Isotomaidae	***	*	*	*	*	*
Lumbricidae	***	****	*****	****	***	*****
Tubificidae	***	*	**	**	***	****
Naididae	*	**	*	*	*	**
Ampularidae	***	**	*	*	*	****
Corbiculidae	***	*	**	*****	*****	**
Thairidae	*****	*	***	*****	*****	**
Viviparidae	*	**	**	*	*	***
Buccinidae	*	*	***	**	***	*

Family	Group G1 (n=2)	Group G2 (n=3)	Group G3 (n=4)	Group G4 (n=5)	Group G5 (n=2)	Group G6 (n=3)
Uninoidae	*	*	*	**	*	*
Planorbidae	***	*	*	*	*	**
Lymnaeidae	***	*	***	*	*****	****
Bithynidae	*	**	**	***	***	*
Ancyclidae	*	*	*	*	*****	**
Melanoidae	***	*	*	*	*	*
Ostracoda	***	*	*	*	*	*

Source : raw data from Guruge ,1997.

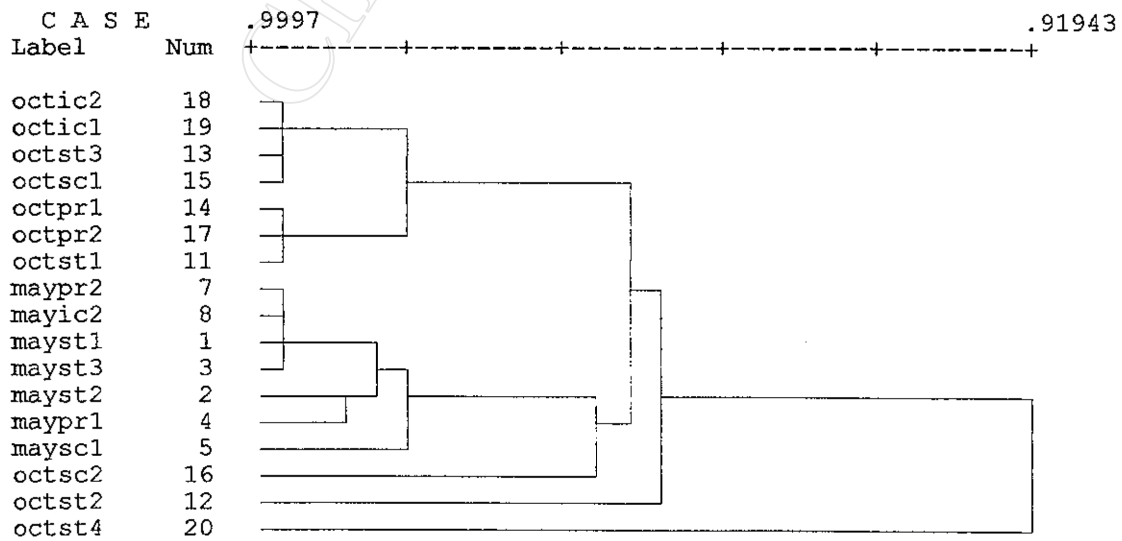
From the site classification using physio-chemical variables, 3 dendograms obtained by 3 different methods of hierarchical clustering showed same results (Fig. 32a, 32b, 32c). 4 groups were clustered in which stream and sewage canal were separated from the others.

Fig. 32 : Cluster analysis using Pearson correlation measurement.

a : single linkage, b : centroid method, c : median method

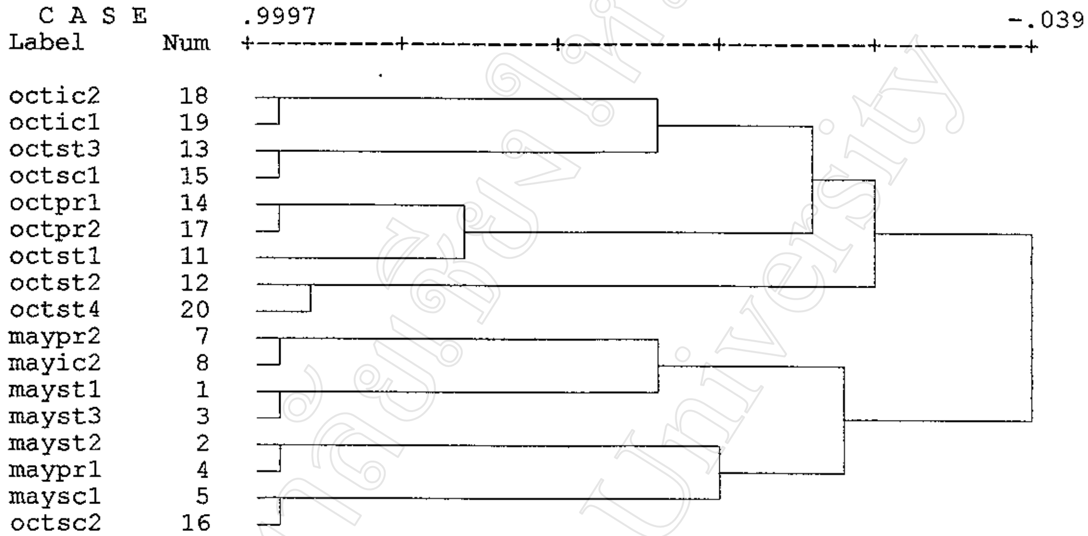
a

Dendrogram using Single Linkage



b

Dendrogram using Centroid Method



c

Dendrogram using Median Method

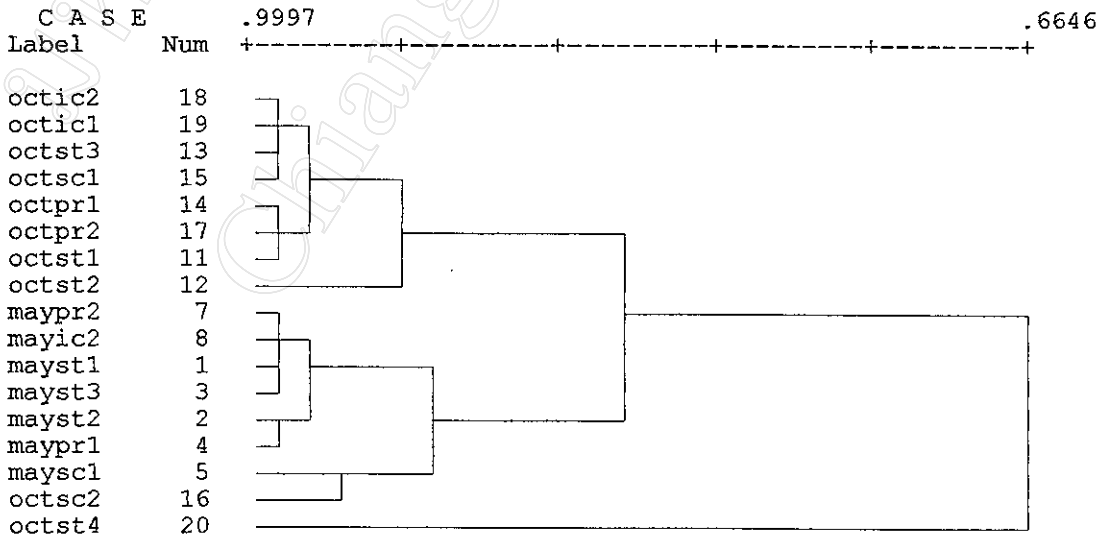


Fig. 34 shows DECORANA plot of macroinvertebrate faunas grouped by TWINSPAN. When comparing with DECORANA plot grouped by single linkage (Fig. 33), the comparison found that group A,C are equivalent to group G2, G4, G5, group B is equivalent to group G3, and group D is equivalent to group G6. 2 samples, Mayst4 and Mayic1 were classified as outliers. Considering to the Fig.33 and 34, There was a gradient from G3 to G2 to G5 to G4 and to G6 of increasing level of BOD_5 and NH_3 concentration on axis 1 and a gradient from G6, G3, G2 to G4, G5 of increasing in the level of pH on axis 2.

Table 17: Correlation with canonical discriminant functions and standardized discriminant function coefficient (using stepwise method) at $P < 0.05$

Level of TWINSPAN division(No. of groups)	1 (2)		2 (4)		3 (6)	
Variables	Function 1		Function 1		Function 1	
	CORR	SDCF	CORR	SDCF	CORR	SDCF
Alkalinity	**0.71**	-0.25	0.07	-1.62	-0.02	-3.12
Conductivity	0.32	1.23	0.21	2.17	0.14	3.95
LBOD5	0.31	0.83	**0.55**	0.78	**0.48**	0.39
LDO	-0.29	0.27	-0.42	-0.31	-0.34	-0.13
LMn	0.22	-1.22	0.20	-0.35	0.12	-1.24
LNH3	0.18	-0.03	0.33	0.008	0.25	0.16
pH	0.08	-0.37	-0.16	-0.33	-0.16	-0.52
Fe	-0.06	0.99	0.14	0.68	0.12	1.42
Canonical correlation	0.8198		0.9489		0.9554	
Chi squared	14.492		40.232*		61.765*	
% correct prediction	85%		95%		90%	

CORR : Pooled within-groups correlation between discriminating variables and canonial discriminant functions.

SDCF : Standardized canonial discriminant function coefficients.

* : Significant at 5%

Multiple discriminant analysis (MDA) established that alkalinity, in separate analyses, was the major environmental variable reflecting the TWINSPAN division of sites at level 1. This variable was highly correlated with function 1 (CORR = 0.71) By using alkalinity and seven other low-correlated variables, 85% of sites could be classified to the correct TWINSPAN group at level 1 using physio-chemical data alone. At level 2, MDA established that BOD_5 was the major variable effecting the TWINSPAN sites grouping. 95% of sites were successfully classified using eight variables together. At level 3, BOD_5 was also strongest discriminator (CORR = 0.48) reflecting the TWINSPAN division of sites which 90% of sites were successfully classified.

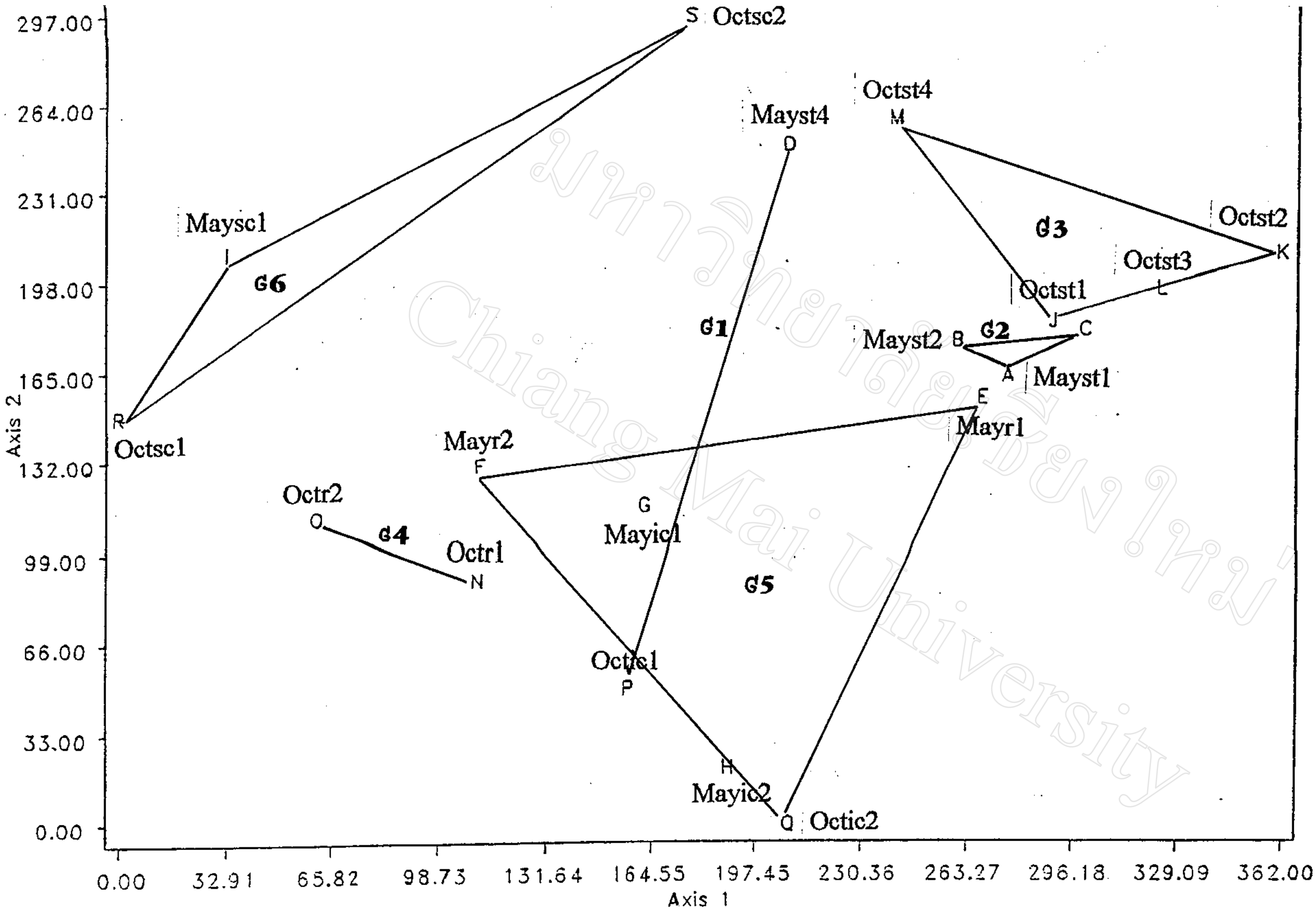


Fig. 33 : DECORANA plot grouped by TWINSPAN sites classification on the basis of macroinvertebrates

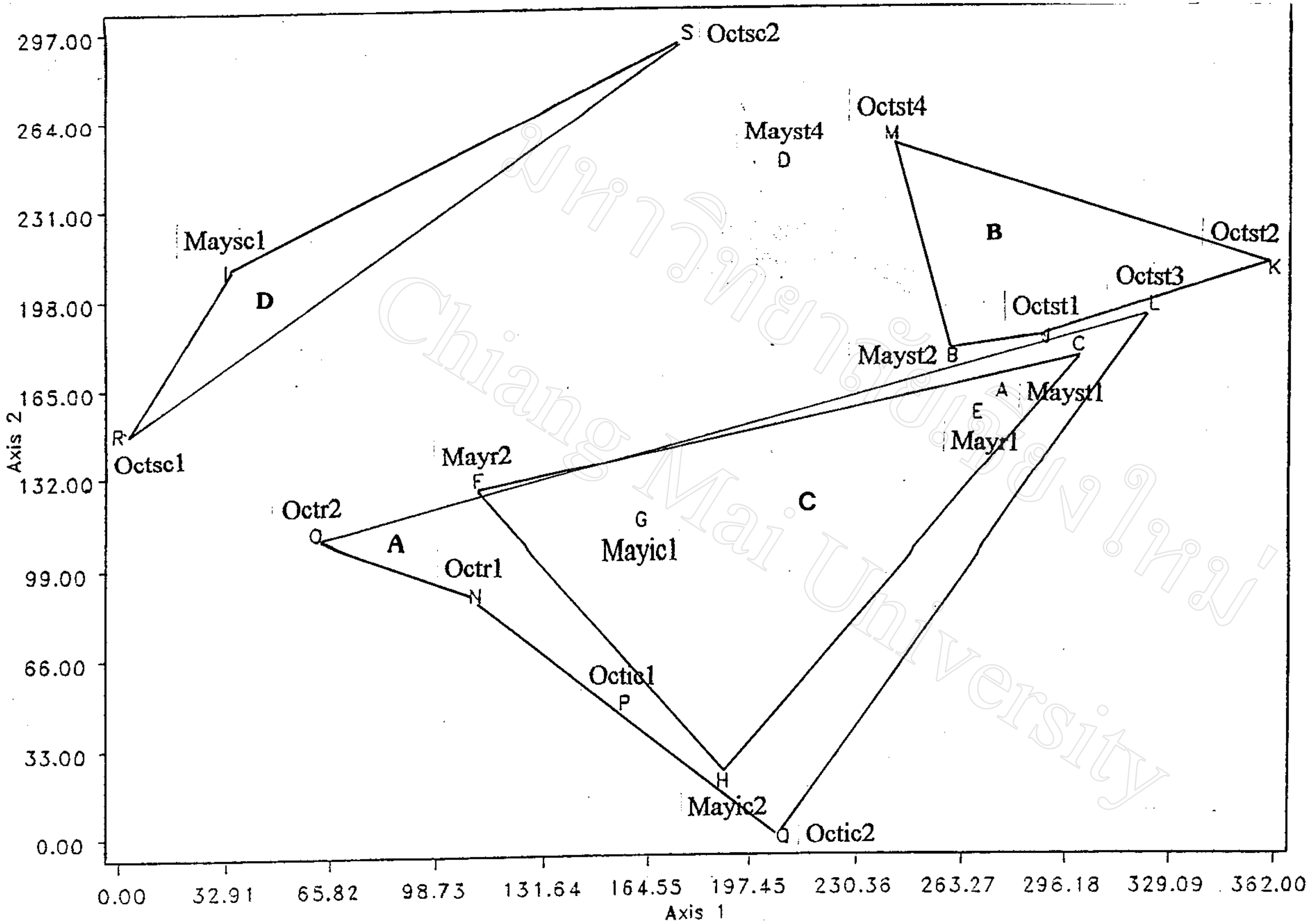


Fig. 34 : DECORANA plot grouped by CLUSTER sites classification on the basis of physico-chemical parameters