GROUND WATER PATTERNS OF JAFFNA-VALIKAMAM REGION.

ANKUMARAN.

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GROUND WATER QUALITY PATTERNS OF THE JAFFNA - VALIKAMAM REGION

A STATISTICAL RETROSPECTIVE STUDY

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This Publication is the revised and modified version of the Research Report 1991 submitted to the Research and Higher Degrees Committee of the University of Jaffna, Sri Lanka during October 1992. The comments made at the presentation of a portion of this work at the annual session of the Jaffna Science Association have also been incorporated. This work postulates the background information about the drinking water problems of the Jaffna-Valikamam sector of the Jaffna Peninsula and highlights a clear picture about the drinking water quality patterns by Cluster Analytic Approach of the Multivariate Statistical Analysis. This is a retrospective study and the latest information and data available at the Water Resources Board of Jaffna for 1979, 1981, and 1983 were utilised.

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PREFACE

During my Undergraduate work at the University of Jaffna Professor J. B. Selliah, Professor of Statistics had suggested to me to take more interest in Applied Statistics and Computing Methods as this is a growing field and will be an alround discipline in the future. In the final year of my Special degree in Statistics, Dr. S. Ganesalingam, Senior Lecturer in Statistics, motivated me greatly to gain knowledge in the field of Applied Statistics. He also supervised my undergraduate research work 'A Statistical Analysis of Jaffna Ground Water'. When both my teachers left the Department of Mathematics and Statistics, they suggested many ideas for my studies towards the development of statistical applications at this University.

While I was reading for my Postgraduate degree at the Indian Statistical Institute, Calcutta, India, I preferred to offer the research area 'Applied Statistics and Data Analysis' in the completion of my postgraduate dissertation, with the intention of rejoining this university and working towards the development of Applied Science disciplines. My supervisors Professor B. K. Sinha, Professor of Theoretical Statistics encouraged and motivated me very sincerely to achieve my goals.

When I returned to this University after obtaining my postgraduate degree at the Department of Mathematics and Statistics I wanted to promote my supervision of an undegraduate dissertation as the first research work. I was further motivated to do this job quickly when I joined the Department of Economics, since this work is related to a Socio-Economic Health problem of the Jaffna Society. Professor C. Sivagnanasundram, Professor of Community Medicine, my adviser on my research work. emphasised the need for studying the influence of the quality of ground water on the health of the people of this region. Professor N. Balakrishnan also encouraged my study when I sent an application for research grant and recommended me to do this work.

My intention has been fulfilled with the help of the Research and Higher Degrees and Publication Committees of the Senate of the University of Jaffna. The credit and performance of this research work goes to my well - wishers mentioned above.

C. Elankumaran,
Department of Economics,
January 1994.

SUMMARY

Principal Components Analysis and Cluster Analysis were applied to a widely differing sets of Ground water Hydro-Chemical data. The data used in this study was obtained from the records of the Water Resources Board of Jaffna and referred to sixty eight spatially distributed random wells ih the Jaffna-Valikamam region for the years 1979, 1981 and 1983.

The first two Principal components used suggest that there are ten major recognizable groups; seven of them are classified as ideal and the remaining three are different to the region, in the hydro-chemical statistical data obtained for the year 1983. The remaining components described were relatively unimportant. Discrimination boundaries by Principal components were also found. Ideal groups were utilized to update the statistical parameters and are proposed for subsequent research. The Principal components were used for discrimination axes as an alternative to the Canonical axes.

A hierarchical agglomerative clustering procedure applied revealed the development of ground water clusters in relation to Mahalanobi's distance measure. The ideal cluster of ground water source area of the region appeared single in 1979, segregated into two clusters with three portions in 1981 and further segregated into six identified clusters in 1983. None of the clusters met the drinking water standard recommended by WHO. Four of them had fair quality and the remaining two had poor quality drinking water.

The methods applied and conclusions made from the results obtained were moderately successful in the sense that the results do not contradict basically with the results already drawn by geographers and other scientists.

Keywords

Hydrochemical data, Salinity, Hardness, Spatial distribution, Reduction of dimension, Principal components, Bi-plot, Mahalanobi's distance, Dissimilarity matrix, Dendrogram, Hierarchical clustering.

1 : INTRODUCTION

Ground water is the major natural water resource in the Jaffna Peninsula and it is used for domestic, agricultural and industrial purposes. Owing to the rapidly increasing population the demand of water is also relatively increasing and various human activities have been causing several serious problems, such as saline intrusion, nitrate pollution and the bacterial multiplication etc. in ground water. Salinity problems arise not only by the increased use of water by the people but also by the greater rainful variability. As rainfall is the only source of recharge, it predominantly affects the ground water.

Salinity problems were perceived as a hazard during 1950's and 1960's and dry phases have been identified during those two decades (Puvaneswaran, K. M., 1985). It was emphasised in this study that preservation of rain water in concrete tanks in every common place must be encouraged, a substantial amount of water consumed from the source area of Valikamam by the Jaffna Provincial (Teaching) Hospital must be cut down, regulation must be enforced for construction of septic tanks and dig wells etc. (1).

Further pumping removes water from ground water storage, causing heads to decline and salt water fresh water interface to rise. Salinity varies seasonally, being lowest during the rainy season and highest during dry season. Largely, because of low fresh water heads in the aquifer and large amount of withdrawals from wells, salt water intrusions have occured in several areas of the peninsula (Nandakumar, V., 1983). The intensive agricultural pattern adopted in the last three decades also led to the increase of salinity of water in the wells. Several wells once used to supply potable water are not in use now due to increase of salinity (2).

The above problem was concentrated over the major area, Jaffna-Valikamam, of the penisula and the Chloric and Hardness concentration of water were analysed (Elankumaran, C., 1986) with the aid of basic statistical analysis to observe the tendencies of the concentrations. The findings show that while the chloride concentrations increased with time significantly, hardness tends to remain unchanged with time over this region. Particularly the concentrations were increasing and decreasing in different wells (3).

The purpose of the present research is to identify a clear picture of ground water patterns or groupings in relations to Chloride and Hardness concentrations which cause salinity problems in Jaffna-Valikamam area. The advanced statistical methods, Principal components and Cluster analytic methods of Multivariate analysis have been utilized.

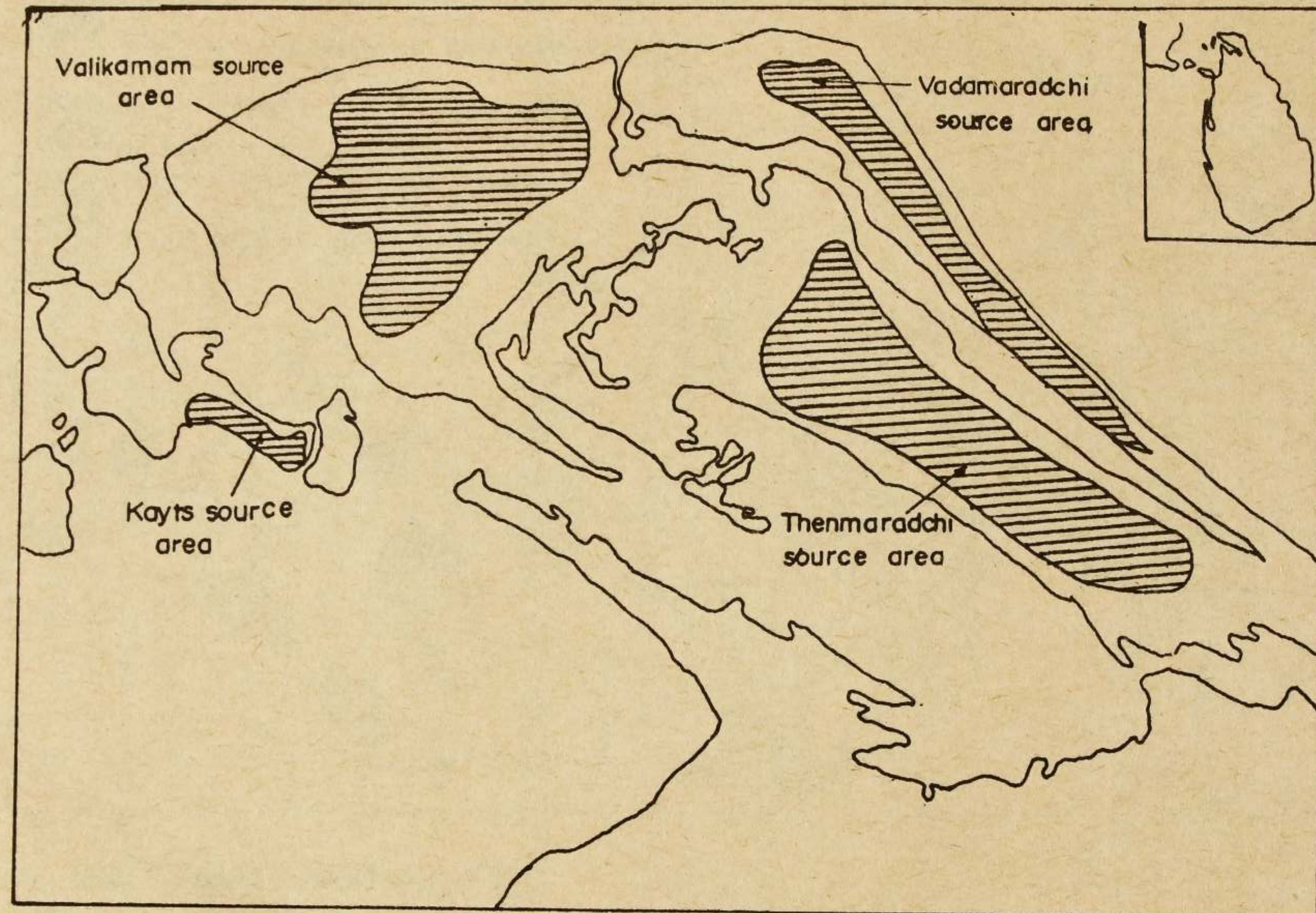
2 : STUDY AREA, PHYSICAL BASE AND HYDRO-CLIMATOLOGICAL ASPECTS

The peninsula is situated in the northern extremity of the Island of Sri Lanka with the extent of 1065 square km. It has a remarkable formation in the Geological history of Sri lanka. The study area Jaffna-Valikamam section alone constitutes around 50 percent of the western peninsula. It is bounded by sea on the western sides and by Jaffna lagoon on the southern side and Vadamaradchi and Thenmaradchi on the eastern side separated by inland salt water lagoons. These lagoons divide the study area from the rest of the peninsula, with the northern outlet at Thondaimanaru and the southern outlet at Navatkuli. Figures 1, 2, and 3 show the above description.

Study area has lime stone base in some sections that it is completely covered by sand. Some area is being covered by pockets of grey and red loams. There are many tanks both large and small in size. Tanks and wells are the major water suppliers in the area. Several wells have been drilled by the National Water Supply and Drainage Board for Market town water supply scheme (1). The topography of the peninsula is mainly low flat land with an elevation of less than 9 meters above sea level except around Tellippalai. The Study area is devoid of any perennial rivers with the exception of a very small intermittent stream called 'Valukkai Aru', Analysis of Geomorphology of the Valukkai Aru drainage basin revealed that the salinity of the ground water in a particular place is inversely correlated to the distance of this place from the sea (4).

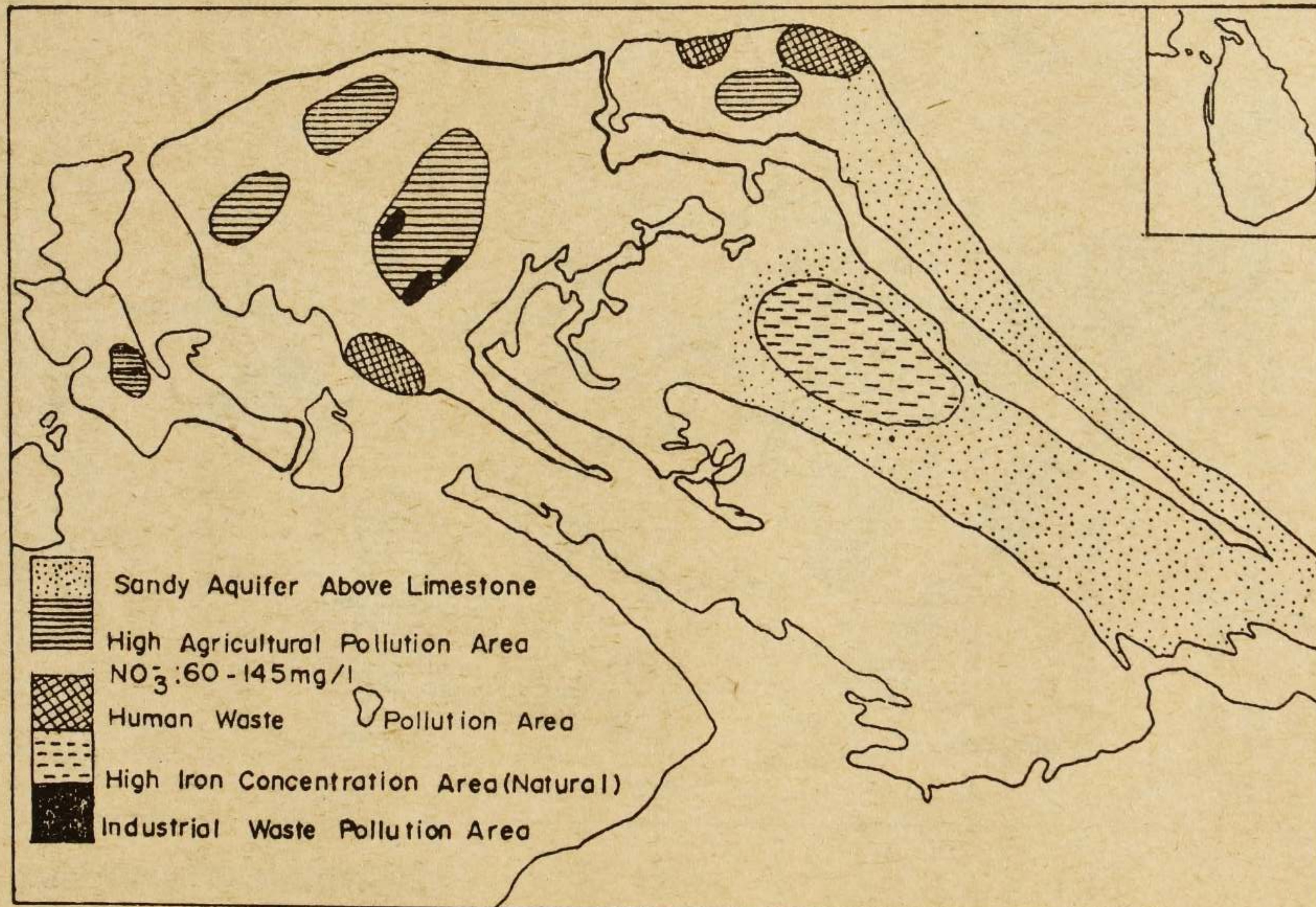
Climatically a uniform high temperature with an average of 28 degrees centigrade prevails which leads to high evaporation. The rainfall and evaporation combined with the wind and high intensity of solar radiation, are playing a significant role in groundwater standard or quality. Rainfall in the peninsula is purely seasonal and annual rainfall variation is also very high.

FIG. 1. GROUND WATER SOURCE AREAS OF THE JAFFNA PENINSULA



Source : K.M.Puvaneswaran, 1985

FIG. 2. GROUND WATER CONTAMINATION IN THE JAFFNA PENINSULA



Source : C. B. Dissanayake et.al., 1984

Although the rainy season lasts from September to January, in some years th peninsula receives more than 50 per cent of the annual rainfall within 24 hours. It is estimated that nearly 10 to 15 per cent of the annual rainfall is lost as direct run-off. About 40 to 48 per cent of the total rainfall is lost by evaporation, only 30 to 32 per cent of the rainfall is left over for ground water recharge. Very high evapоration is one of the reasons of water loss in the peninsula. Variability of rainfall over the region is a key factor which has been emphasised by a number of local authorities on various occasions. Ground water recharge has been viewed as a function of effective rainfall. Ground water recharge is the amount of surface rain water which reaches the water table by percolation (5).

The recharge to ground water in the peninsula depends almost entirely on rainfall percolation. Since Predisposition is irregular and unreliable as a source of water and also due to the fact that there are no major streams in the study area, the only source of water that can be tapped is ground water. Withdrawal from wells is the major discharge compared to other methods (Springs and Seeps). The deviation (from wet to dry) in the water table is larger in Valikamam region compared to other areas of the peninsula. This is related to the population density and land utilization of the region.

3 : WATER QUALITY AND SALINITY PROBLEMS

The fresh water body of Jaffna peninsula is floattng in lens formation on the saline water due to their relative densities; the fresh water - sea water interface occurs at a depath 40 times the difference in levels between the water table and sea level at that locality. When pumping is done, the depression by a centimetre of the fresh water table (above sea level) will reduce the thickness of the fresh water lens below sea level by 40 centimetre. Excess pumping in many areas has resulted in salinity intrusion into the fresh water. About 55 to 65 percent of the area was free from salinity in 1972 (2), but the major problem of the peninsula now is the rate of incresing chloride concentrations in the ground water.

As water travels on the earth's surface it reacts dissolved minerals on its way. The modified chemical composition will therefore depend on the terrain and the availability of readily soluble minerals. In addition, evaporation concentrates the mineral content of the water. Run-off water dissolves minerals and transports organic debris and silt from the watershed area to defined streams. There, the water again evaporates and percolates to ground water basins. The mineral content of surface water therefore becomes progressively higher in the down-streem areas.

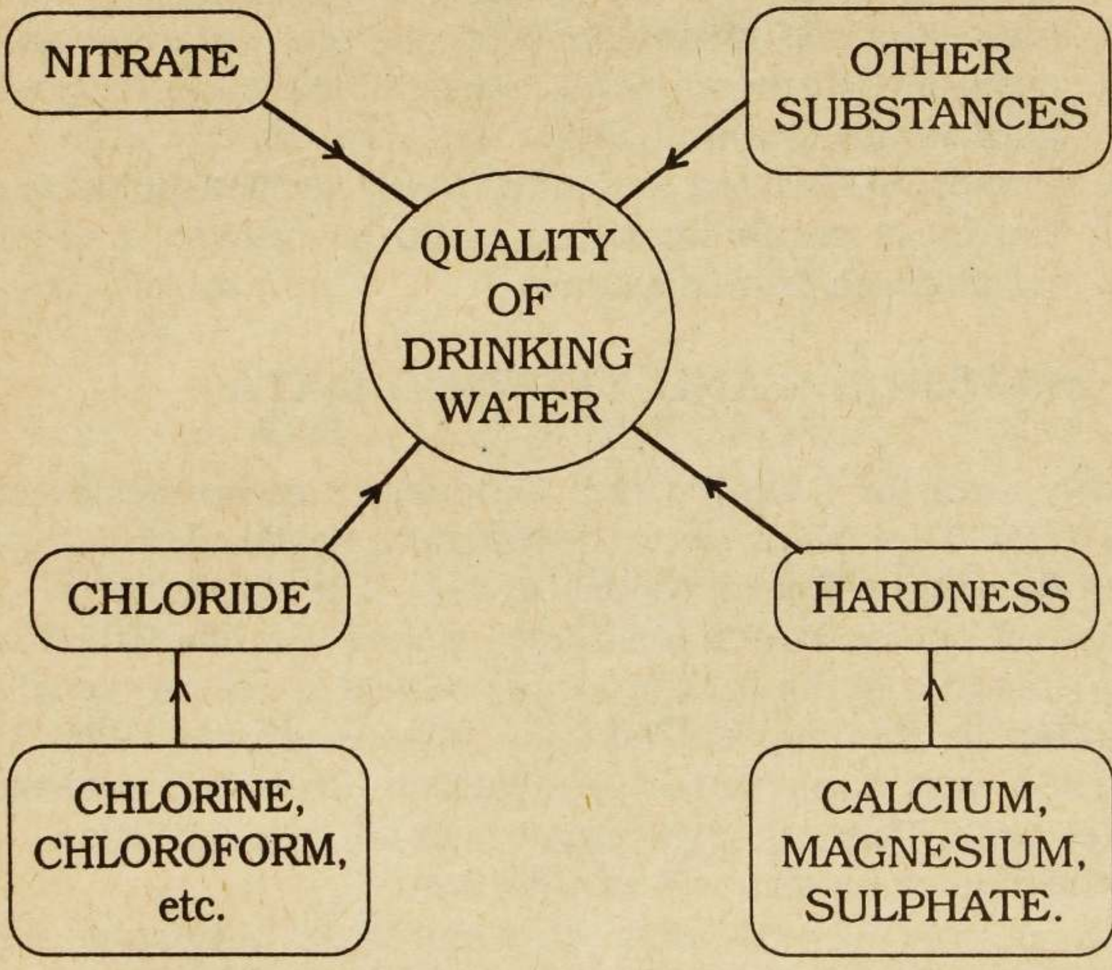
Jaffna peninsula has reportedly the highest nitrate content in the ground water in all of Sri Lanka. Further, 80 per cent of the ground water of the region is being extracted from the lime stone aquifer and utilized for drinking, domestic, agriculatural and industrial purposes, the rest being obtained from the sand aquifer. It was also found that 80 per cent of the well water yielded unacceptable bactereological quality contaminated by faecal caliform (6). A major factor responsible for poor water quality in this region is considered to be the abundant use of agricultural fertilizers, mainly urea which contains 46 per cent nitrogen.

When water reaches the ground water basin, it usually contains a much higher concentration of salts than the rainwater. The chemical charactor of such a percolate will vary from one area to another depending on the terrain and extent of chemical deposits in the soil. The dissocciated salt ions in the porous medium will dissolve in the percolating water and mix with the ground water slowly, guided by convection, hydrodynamic dispersion, and chemical diffusion. The poor quality of ground water in the Jaffna peninsula is also caused by improper planning of soakage pits and latrines as these contribute to the serious contamination of the ground water (6). Figure 2 explains the aobve situation.

Fertilizers, including manuare, applied to the irrigated soils contain nitrogen in different forms; amino groups as in urea, ammonia as in ammonium sulphate and liquid ammonia, and nitrate as in calcium nitrate. Most of the applied nitrogen fertilizers eventually change into nitrates through bacterial degradation, if aerobic conditions prevail. Both quantity and quality of water are important variables that must be taken into account in the management of water resources. Although water may be abundantly available, it may not be fit for use. There are specific quality standards for the different beneficial uses of water.

If the quality of the available water resources does not meet these standards, treatment becomes necessary. As water becomes more saline by natural processes and through man's use, reuse of water becomes difficult, unless the quality still meets the standards for the different uses. Diversions of run-off, impounding of surface water and transfer of surface waters by man made aqueducts modify the natural hydrologic cycle and result in changes of the natural surface water quality and the quality of local ground water (7).

The identified hydrochemical substances influencing the quality of Jaffna ground water are given in the following schematic diagram :



Water containing Chloride upto 150 parts per million (ppm) is classified as 'good' quality water and that containing 150 to 500 ppm as 'fair' quality. Water with over 500 ppm is considered brackish. Hardness is a measure of the dissolved calcium in water. Water containing dissolved calcium below 100 ppm is classified as 'soft' and over 300 ppm as 'hard'. This concept has been recommended by the World Health Organizaation (WHO) (15). The author's previous study (3) also was done on the basis of this criteria.

The problems described above are common and becoming a serious issue in every location in the Jaffna peninsula. The people of many areas are facing difficulties to get drinking water. People sometimes have to go far away from their residence every morning and evening to fetch drinking water. In view of this, a scientific study of the ground water situation is necessary for the betterment of the people of this region.

Hence, in view of the various factors discussed above, this study focuses on the following specific objectives :

(1) Finding homogenous sub-regions of the Jaffna - Valikamam sector in respect of the drinking water quality.
(2) Analysing the sub-regions or clusters obtained on the basis of WHO recommendations on Salinity and Hardness, for drinking water quality.
(3) Proposing updated and statistically verified Chloride and Hardness parameters that could be utilised for further research on related studies.

4 : MATERIALS AND EXISTING DATA

Monthly data for Chloride and Hardness concentrations from 1979 to 1984 are available at the Northern Regional Offffce of the Water Resources Board (WRB), Jaffna. The collection of data conducted by the Water Resources Board was disturbed after June 1984 due to the conditions of political unrest and civil war prevailing in this region. The data collected during 1979, 1981 and 1983 were subjected to Multivariate Statistical analysis in this research. These three alternate year data were utilized to see how the cluster patterns differ with time.

The data available during the years 1980 and 1982 were not utilised in this study because the available data is not adequate to use methods such as Stochastic processes and Time series analysis. Hence, the cross-section data at equi-distance of years was chosen for this study. Only 150 wells out of 250 wells in the study area had complete data as the data for the remaining had been left out, from time to time, by the field workers of the WRB, Jaffna. Sixty eight wells among the 150 wells were sampled according to spatial distribution of wells in the study area.

Figure 3 indicates the spatial distribution or Cartogram of the complete data used. The locations and sampled wells in this study are given in the appendix of this research report. The classification of sampled wells according to the AGA divisions of the Jaffna-Valikamam area is given in table 1.

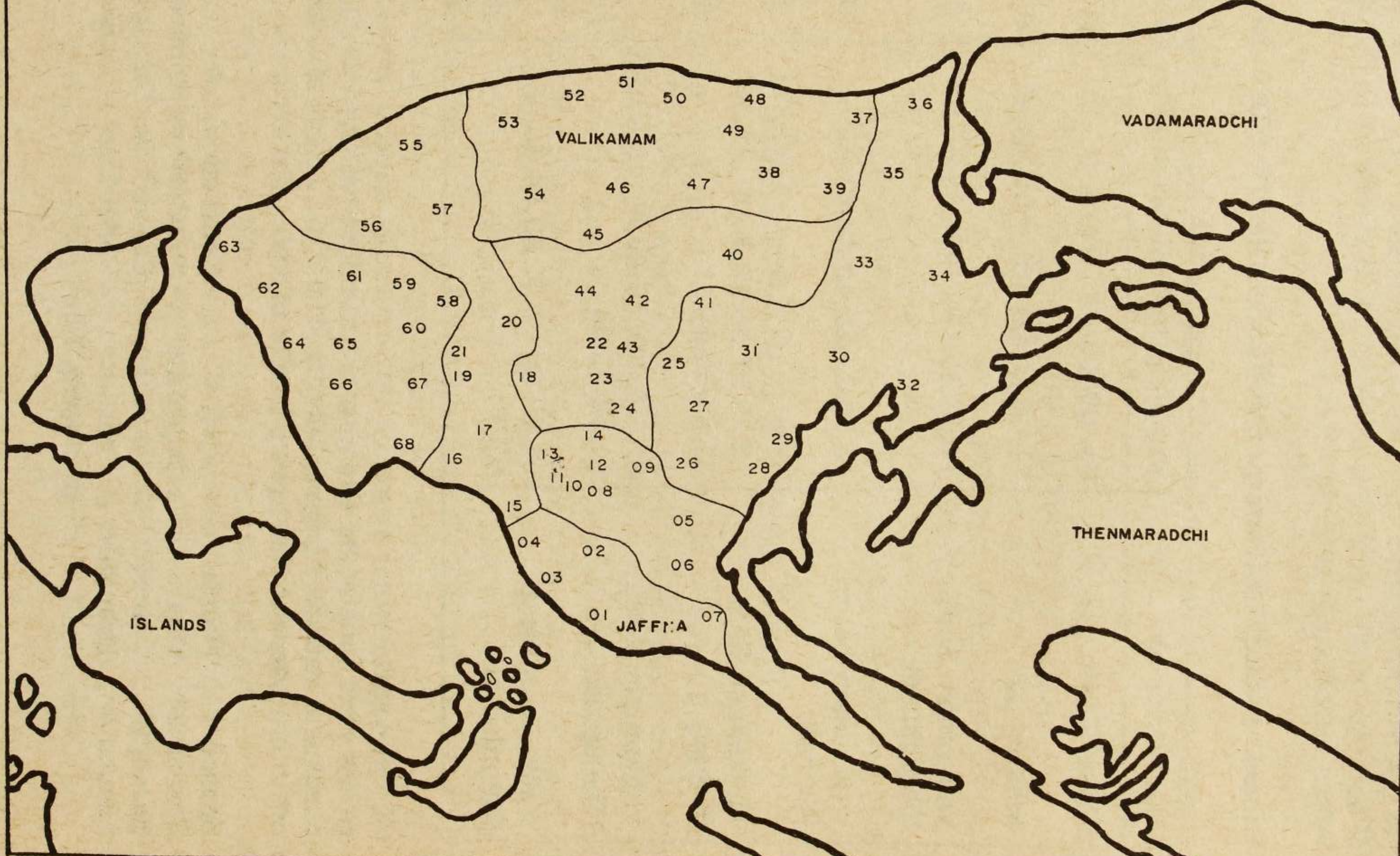
Table 1: Location of Sampled wells classified by AGA divisions

AGA Divisions	Sample identification number	(Size)
Jaffna Town	01, 02, 03, 04, 07	(05)
Nallur	05,06,08,09,10,11,12,13,14	(09)
Valikamam South-West (Sandilipay)	15,16,17,19,20,21,55,56,57	(09)
Valikamam South (Uduvil)	18,22,23,24,40,42,43,44	(08)
Valikamam East (Koppy)	25,26,27,28,29,30,31,32,33 34,35,36,41	(13)
Valikamam North (Thellipalai)	37, 38, 39, 45,46,47,48,49,50, 51,52,53,54	(13)
Valikamam West (Chankanai)	58,59,60,61,62,63,64,65,66 67,68	(11)

Climatological water resource and recharge aspects menioned earlier were considered to categorise the data type and assigning Statistical variables approporiately. The Climatological seasons prevailing over the Northern province of Sri Lanka are as folows :

Season 1 : March - April : Convectional season I,
Season 2 : May - Sepember : South West Monsoon,
Season 3 : October - November : Convectional season II,
Season 4 : December - February (Following Year) : North-East Monsoon.

FIG. 3. SPATIAL DISTRIBUTION OF THE SAMPLE POINTS



The average concentrations of Chloride and Hardness during the periods March-April (S1), May-September (S2), October-November (S3), and December-February (S4) were defined as random variables in this study.

The notations of the defined variables are as follows ;

X1 - Average Chloride concentration during S1,
X2 - Average Chloride concentration during S2,
X3 - Average Chloride concentration during S3,
X4 - Average Chloride concentration during S4,
X5 - Average Hardness concentration during S1,
X6 - Average Hardness concentration during S2,
X7 - Average Hardness concentration during S3.
and X8 - Average Hardness concentration during S4.

The North-East monsoon season covers the period from December of a year to February of the following year. In this study the variables X4 and X8 were defined, for a particular year, by considering January, February and December of the SAME year.

The unit of the above variables is parts per million (ppm). The concentrations mentioned above were those obtained by WRB of Jaffna. The Major components observed and subjected to laboratory testing of Jaffna ground water are Chlorine, Calcium, Magnesium, Sulphate and Nitrate substance. The minor components Manganese, Iron, Copper,Phenolic, Carbon and Chloroform extract were not taken into consideration as they do not significantly affect the water quality of Jaffna peninsula.

The defined Chloride concentration is the level of chlorine in the water which is related to the salinity of water, and the hardness concentration is the total level of
Calcium, Magnesium and Sulphate substances. A drawback in this study is the nonavalability of Nitrate level in the water from each of the sampled well. As mentioned earlier, the nitrate concentration which mostly determines the water quality, has been quantified by a coding method described below.

The coding work has been incorporated according to the distribution of nitrate concentration in the potable water of Sri Lanka (6). The codes of the coding variable X9, related to each sampled well, have been defined with the above subjective reasons. Codes were assigned according to figure 2 and the cartogram of the study area given in figure 3. The variable X9 assumes integer values from 1 to 4 (ie. X9 = 1, 2, 3, 4). The center of the area has the highest concentration which takes coding value 4 and the sea-sides have the lowest concentration which takes coding value 1 and the values vary between 1 and 4 according to the spatial distribution.

The population density throughout the study area is also an influencing factor of water quality. Intensive market gardening in the fertile red soil region with good under ground water resource are the primary factors for the high density of population in the Valikamam region. Further the population density is directly correlated to the use of ground water (8).

The population size data surrounding each well are not available for the years 1979, 1981 and 1983 which is another drawback to this study. Unfortunately the population density in every local council division is available only in the year 1987. However the spatial distribution or density of the population is comparatively homogenious in Jaffna and Nallur AGA divisions and in all the other Valikamam AGA divisions. These are urban and urban-rural mixed sectors respectively. The density difference between these two sectors is a matter to be reckoned; but being comparatively low, the difference has been neglected in the study.

Under the above circumstances it is strongly emphasised that all the above described nine variables are adequate enough to postulate the dissimilarity measures and highlight resemblences within the wells. This emphasis is laid on the basis of subjective as well as statistical theoretical considerations.

5 : ANALYTIC METHODS

Cluster analysis, applied to widely differing sets of ground water hydro-chemical data, appears to be moderately successful as a statistical tool for revealing hydrochemical and hydrogeological features. Moderately successful refers here to the agreement with the previous results obtained in the other studies using other approaches. It possesses advantages over the traditional graphical methods of solving similar problems, principally in its systematic nature, and it can generate inter-parameter relationships that may be overlooked in the less sophisticated traditional methods.

One of the major problems of hydrochemical investigations in hydrogeology is the ease with which large quantities of data are generated. In a comprehensive study, particulary a regional study, every water sample collected and analysed should be of some use but the sheer numebr can frequently cause confusion and error both to the interpreter and to those to whom he presents his conclusions.

From the methods available, Cluster analysis has obvious attractions for use in ground water chemistry in which large quantities of data can be processed rapidly and systematically with the aid of digital computers. There has been very little previous work in applying Cluster analysis specifically to hydrochemical data, although other statistical methods have been applied. For Example, Multiple regression analysis by Khan et. al. (1972) and Discriminant analysis by Drake and Harmon (1973). (Ashley, R.P. & Lloyd, J.W. : 1978) have been used before.

In view of the limitations of the existing methods and the increasing number of chemical parameters now being measured in ground water studies, there is a need for more wide ranging statistical analysis of data. In other scientific fields Multivariate analysis is proving fruitful. Cluster analysis, however, allows the grouping of waters according to their chemical composition (9). The groups may be termed as 'homogenious clusters of ground water' in terms of hydrochemical data.

5.1 : Description of Variables

The reduction of dimensionality and classification via distance measures, completely depend on the variation of the individual variables and co-variation of the paired variables. That is, the Variance-Convariance matrix only plays an important role in this method. Hence, although the estimation of parameters of the Nine-variate distribution is required, the Multivariate normality is not necessary for the methods Principal Components Analysis (PCA) and Cluster analysis applied in this research.

Therefore, the Mean vectors and Variance-Covariance matrices for the above mentioned three years 1979, 1981 and 1983 have been estimated by using all the sixty eight observation vectors in a nine-dimensional space.

$$\text{Let } \underset{\sim}{X} = \begin{pmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \\ X6 \\ X7 \\ X8 \\ X9 \end{pmatrix} \quad \text{and} \quad \underset{\sim}{M} = \begin{pmatrix} M1 \\ M2 \\ M3 \\ M4 \\ M5 \\ M6 \\ M7 \\ M8 \\ M9 \end{pmatrix}$$

both of dimension (9x1) be the vector of variables and its sample mean vector respectively.

Then, the sample Variance - Covariance matrix could be defined and denoted by;

$$S = E\,[\,(\underset{\sim}{X} - \underset{\sim}{M})'\,(\underset{\sim}{X} - \underset{\sim}{M})\,]$$

of dimension (9x9) as follows:

$$
S = \begin{pmatrix}
s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} & s_{17} & s_{18} & s_{19} \\
s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} & s_{27} & s_{28} & s_{29} \\
s_{31} & s_{32} & s_{33} & s_{34} & s_{35} & s_{36} & s_{37} & s_{38} & s_{39} \\
s_{41} & s_{42} & s_{43} & s_{44} & s_{45} & s_{46} & s_{47} & s_{48} & s_{49} \\
s_{51} & s_{52} & s_{53} & s_{54} & s_{55} & s_{56} & s_{57} & s_{58} & s_{59} \\
s_{61} & s_{62} & s_{63} & s_{64} & s_{65} & s_{66} & s_{67} & s_{68} & s_{69} \\
s_{71} & s_{72} & s_{73} & s_{74} & s_{75} & s_{76} & s_{77} & s_{78} & s_{79} \\
s_{81} & s_{82} & s_{83} & s_{84} & s_{85} & s_{86} & s_{87} & s_{88} & s_{89} \\
s_{91} & s_{92} & s_{93} & s_{94} & s_{95} & s_{96} & s_{97} & s_{98} & s_{99}
\end{pmatrix}
$$

where S is symmetrical. Then $\underset{\sim}{X} \approx (\underset{\sim}{M}, S)$.

5.2 : Reducing the dimensionality of the problem : PRINCIPAL COMPONENTS ANALYSIS (PCA)

The study of Principal Components Analysis was developed by Hottelling (1933) after its origination by Pearson (1901). Kendall (1957) and Seal (1962) also worked on this area and found additional properties. It was further developed by Rao (1964) for further details and various applications (11).

Principal Components analysis has been utilised in this study to reduce the dimension of the nature of data. The important practical objectives of this method are given as follows :

(1) Examination of correlations between the variables of a selected list :

(2) Reduction of basic dimension of the variabilities in the measured set to the smallest meaningful dimension;

(3) Elimination of variables which contribute relatively little extra information;

(4) Allocation of individuals to previously demarcated groups; and

(5) Recognition of misidentified individduals. etc.

The first step involved the calculation of Principal Components is to maximize the variation explained in a nine-dimensional data set in this study. Unrotated components (Origional variables) may not usually produce a meaingful patterning of variables in the original data. To ascertain the underlying meaning embodied in the row data set, varimax rotation of the principal components was done. All nine hydro-chemical vaariables form a suitable number of linear combinations through eigen values and corresponding eigen vectors. The reduction of dimensionality also further enables the analysis to proceed with the bi-plot explanation for recognizing grouped elements and discarding unusual elements.

The eigen values and eigen vectors corresponding to all the three matrices have been calculated. Mathematically, these matrices need not be of full rank, nor need contain more than one distinct characteristic root (10). However, the exigenity of simplicity in our description of the latent structure of the variables calls for a data matrix of full rank.

Let u1, u2, ..., u9 be the characteristic roots of the sample Variance-Covariance matrix S, in descending order, and e1, e2, ..., e9 be the correspoding characteristic vectors of size 9 x 1.

Let E = (e1, e2, e3, e4, e5, e6, e7, e8, e9) of dimension 9 x 9,

Then, E is an orthogonal matrix.

Further, E'SE = D = Diag (u1, u2, ..., u9)

and

Tr (S) = Tr (D) = Total variation.

Therefore, the Principal Components of the original variables given in $\underset{\sim}{X}$ are the linear combinations defined by;

$$\underset{\sim}{Y} = E'(\underset{\sim}{X} - \underset{\sim}{M})$$

Where $\underset{\sim}{Y}$ = (Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9)' of dimension 9x1.

constitutes the principal components.

and V(Yi) = ui ; i = 1, 2, ..., 9.

Thus the Principal Components are the weighted averages of the deviation of the observations from their means, the weights being the corresponding elements of the eigen vectors. This is described as the Varimax rotation of data.

The first two principal components Y1 and Y2, which explain the major portion of the total variation, were plotted one against another. The scatter plot was observed for discrimination boundaries. This plot is called a bi-plot, which is expected to explore the nature of clusters by varimax rotation of data. The odd elements or outliers may be identifed and discarded to update the mean vector and Variance-Covariance matrix for future research. This can be done by inspecting the bi-plot of the principal components.

5.3 : Clustering procedure

In our treatment of Multivariate data, we always assume that the sample comes from a homogeneous pouplation with a single mathematical form and set of parameters. If the distribution is Multinormal, we tacitly assume a smooth and unimodal density function. Often the data belie those assumptions; the observation vectors may clump together in clusters, or contain gaps that appear to indicate that the source may be a mixture of several displaced distributions.

The clusters suggest that they are highly dependent on the sampling variation and measurement error in the observations. Small perturbations in the data might lead to very different clusters. The choice of the number of clusters may not follow from the clustering procedure, but may have to be made subjectively. For these reasons cluster analysis is not a rigorous and sharp statistical tool, and should be applied with care and with the assistance of any other information about the sampling units. This is why the Principal Components analysis and in the beginning descriptive statistical analysis were employed.

The first two principal components of the set of nine hydrochemical data have been utilized for classification and for comparison with Hierarchical clustering. A hierarchical agglomerative clustering procdure was applied to the spatial random sample mentioned above. The clustering for all three years was done separately.

The clustering process begins with measures of the distances of the observation vectors from one onother. Several distance measures are available. The Euclidian distance d (i, j) defined by

$$d(i,j) = \text{Squareroot}\ [\ (\underset{\sim}{X}(i) - \underset{\sim}{X}(j))'\ (\underset{\sim}{X}(i) - \underset{\sim}{X}(j))\ ]$$

does not usually satisfy many statistical properties. Hence the following distance measure, Mahalanobi's distance 1 (i, j) was defined and utilised for discriminating observation vectors from each other in statistical sense, as

$$1(i,j) = \text{Squareroot}\ [\ (\underset{\sim}{X}(i) - \underset{\sim}{X}(i))'\ S^{-1}\ (\underset{\sim}{X}(i) - \underset{\sim}{X}(j))\ ]$$

Where X (i) and X (j) are two arbitary observation vectors of dimension nine. The dissimilarity matrix constituting intrastructural distances among the sampled observations could be denoted by ;

$$\begin{pmatrix} 0 & 1(1,2) & 1(1,3) \ldots\ldots\ldots\ldots & 1(1,N) \\ 1(2,1) & 0 & 1(2,3) \ldots\ldots\ldots\ldots & 1(2,N) \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ 1(N-1,1) & 1(N-1,2) & \ldots\ldots\ldots\ldots & 1(N-1,N) \\ 1(N,1) & 1(N,2) & 1(N,3) \ldots\ldots\ldots\ldots & 0 \end{pmatrix}_{N \times N}$$

Three dissimilarity matrices of the above type for 1979, 1981 and 1983 were constructed using the Mahalanobi's Distances among the samples calculated.

The correspoding 'Dendrograms', via Linkage method, were drawn to form clustes at different distance levels. Dendrogram is a tree diagram in which the X-axis represents the objects, while the Y-axis represents the distances. The technique of drawing dendrogram operates on the dissimilarity matrix of distances.

Average linkage method was adopted to merge the sample points or objects as clusters (12). That is, we might form clusters in a rudimentary way by scanning the dissimilarity matrix for smallest distances and grouping the observations into clusters on that basis. The distance between a classifying sample point (observation vector) and a cluster already formed, has been calculated by taking the average of the distances to the individuals belonging to that cluster, which is called average linkage method.

The linkage algorithm combines the original N single-point clustees hierarchically into one cluster of N points. The clusters formed by this way were subjected to further analysis and interpretation. The mean vector and Variance-Covariane matrix for the year 1983 were readjusted after eliminating the outliers identified by Principal Components analysis.

5.4 : Data Processing

The 'Pascal' programmes written on the basis of standard algorithms developed during auther's earlier studies (12) were performed to complete many data processing works in this study. Construction of data matrices, calculating the values for principal components, calculating Mahalanobi's distances, construction of dissimilarity matrices, and operation for dendrogram were completed using these programmes.

Standard statistical calculations were obtained using 'MINITAB' statistical package. Construction of mean vectors and Variance Convariance materices, calculating characteristic roots and corresponding characteristic vectors, drawing bi-plots, etc. were performed using the above package.

6 : RESULTS AND DISCUSSIONS

6.1 : Descriptive Statistics

The hydro-chemical data matrices, formed after variability assignment for the three years, were subjected to descriptive statistical analysis. The simple description of the available data are given in the following three tables for the total number of sample points, n. The sample point locations are given in Appendix 1 and the raw data of Chloride and Hardness levels in Appendix 2 respectively.

Table 2 : Descriptive statistics for the year 1979 (n=68)

Variable	Minimum	Maximum	Mean	Std Error
X1	40.0	5560.0	548.3	96.0
X2	52.0	15484.0	845.0	249.0
X3	40.0	5970.0	645.0	107.0
X4	43.3	4393.3	515.9	79.1
X5	155.0	2265.0	478.5	39.1
X6	216.0	6188.0	596.1	95.0
X7	175.0	2475.0	517.9	42.6
X8	146.7	1836.7	432.2	34.4

Table 3 : Descriptive statistics for the year 1981 (n=68)

Variable	Minimum	Maximum	Mean	Std Error
X1	45.0	6450.0	724.3	153.0
X2	43.0	11875.0	911.0	234.0
X3	60.0	6813.0	727.0	138.0
X4	66.7	4055.0	583.1	83.9
X5	120.0	3765.0	527.9	66.4
X6	164.0	4328.0	581.0	88.9
X7	150.0	2405.0	562.6	56.6
X8	166.7	2376.7	513.5	44.6

Table 4 : Descriptive statistics for the year 1983 (n=68)

Table 4 : Descriptive statistics for the year 1983 (n=68)

Variable	Minimum	Maximum	Mean	Std Error
X1	53.0	7813.0	680.0	137.0
X2	43.0	28492.0	1104.0	427.0
X3	53.0	7000.0	903.0	166.0
X4	56.7	3908.3	583.5	81.6
X5	135.0	3070.0	455.0	49.1
X6	148.0	8946.0	617.0	134.0
X7	160.0	3215.0	602.4	72.8
X8	165.0	1675.0	474.5	32.9

The following facts are revealed from the above tables. It is observed that the chloride variable X2 has the maximum concentration compared to its associated variables X1, X3 and X4. Similarly the hardness variable X6 has the maximum concentration compared to its associated variables X5, X7 and X8. The variables X2 and X6 stand for the period 'May to September', i. e. the season of the South-West monsoon, Further, the average concentrations of X2 and X6 are the highest compared to their associated variables. Therefore, the salinity problems increase during the period May to September and decline during the other seasons. The climatological relationship with the hydro-chemical variables mentioned earlier is therefore verified or confirmed.

It can also be inferred from the above tables that the average Chloride concentrations for X2, X3 and X4, ie, during January - February and May - December (ten months), steadily increse from 1979 to 1983. The average chloride concentration of X1, ie, during March - April, increases from 1979 to 1981 and decreases to 1983. As anticipated, the concentration during December - February is the lowest for all these years. Again, as anticipated, the chloride concentrations increase during March - April for all the three years.

It is known that Jaffna region does not get any rainfall of significant amount during the period May - September and as such, an apriori anticipation should be that concentration should rise during this period. This is infact observed for all these years; a fact more worrying is that the concentration has progressively increased over the years 1979 to 1983. During the period October - November, one would expect a decrease in Chloride concentration As rainfall sets in Jaffna region in the month of October; although the levels of concentration in any one year is seen to drop from that of the correspoding May - September period, the concentration levels over the years is found to progressively increase. This suggests that the rainfall has not been sufficient to reduce the mean chloride level. It has been suggested that the rise in Chloride levels immediately after the first rains is due tothe leaching of the salt from the soil layers through which the water percolates.

However, with more rain in the December - February period, the Chloride concentration is found to drop to a more steady level over all the years. Therefore, although the means for chloride concentrations as given above make sense, the salinity problems caused by progressively increasing chloride concentrations over the years 1979 to 1983 are remarkably worrying for serious precautionary actions.

The Hardness concentrations in the above tables do not present a clear picture of any trend, although the concentration is found to peak during the May-September period, as in the Chloride levels. These results have been roughly obtained already by different analysis (3). Statistical inference was not applied as it is not within the scope of this research to extract different results for interpreting different purposes. The standard error of the estimates of the average concentrations listed in the above tables are meaningful and support the unbiasedness of the statistical point estimation.

Descriptive statistics of the coded variable X9 are not given in the above tables, because those statistics are not relevant for the interpretation of the statistical nature of the nitrate data. However, those codes are essential for the discrimination or clustering of the observation vectors.

The important parameter of this research is the sample Variance Covariance matrix. Sample Variance-Covariance materices for the years 1979, 1981 and 1983 were calculated. The corresponding three Correlation matrices were also estimated and are given in the following tables:

Table 5 : Correlation matrix for the year 1979 (n=68)

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.000								
X2	0.708	1.000							
X3	0.939	0.560	1.000						
X4	0.923	0.547	0.902	1.000					
X5	0.929	0.598	0.840	0.855	1.000				
X6	0.682	0.991	0.523	0.521	0.608	1.000			
X7	0.883	0.477	0.940	0.872	0.864	0.472	1.000		
X8	0.747	0.380	0.701	0.898	0.763	0.387	0.755	1.000	
X9	-0.287	-0.239	- 0.323	-0.265	-0.308	-0.252	- 0.322	-0.189	1.000

Table 6 : Correlation matrix for the year 1981 (n=68)

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.000								
X2	0.974	1.000							
X3	0.837	0.875	1.000						
X4	0.905	0.849	0.879	1.000					
X5	0.946	0.895	0.688	0.830	1.000				
X6	0.971	0.977	0.807	0.831	0.952	1.000			
X7	0.829	0.828	0.879	0.834	0.769	0.831	1.000		
X8	0.826	0.735	0.637	0.838	0.870	0.798	0.790	1.000	
X9	-0.342	-0.300	- 0.325	-0.348	-0.336	-0.309	- 0.383	-0.301	1.000

Table 7 : Correlation matrix for the year 1983 (n=68)

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.000								
X2	0.897	1.000							
X3	0.689	0.520	1.000						
X4	0.896	0.732	0.655	1.000					
X5	0.963	0.894	0.632	0.855	1.000				
X6	0.888	0.991	0.577	0.726	0.898	1.000			
X7	0.579	0.451	0.942	0.532	0.577	0.533	1.000		
X8	0.782	0.643	0.530	0.880	0.835	0.655	0.510	1.000	
X9	-0.284	-0.207	- 0.325	-0.327	-0.250	-0.231	- 0.354	-0.305	1.000

Significance testing of the correlation co-efficeents is not needed as said earlier. The Variance-Covariance matrices were only used for consequent calculations. However, a carefrul examination of the co-efficients of correlation in the above tables suggests the following facts.

It is observed from all the above correlation tables that the nitrate variable X9 is negatively correlated to all the chloride and hardness variables, and particularly highly negatively correlated with the chloride variable X4 and hardness variable X7. Therefore it can be concluded that the nitrate concentration of ground water inversely affects the chloride concentration most during December to February and hardness concentration during October to November.

The above tables further reveal that the eight chloride and hardness variables are positively correlated with each other. Particularly among the chloride variables, X1 and X2 have the maximum association and among hardness variables, X5 and X6 have the maximum association. Therefore we can conclude that the first two seasons, March-April and May-September, have similar characteristics as far as salinity problems are concerned. It may seem that the association between X1 and X4 is not significantly different from the association between X1 and X2 indicated above. However, a study of the Hardness variable X6 with Chloride variables X2 and X4 indicates that the chloride variable X2 and hardness variable X6, for the same period May-September, have the maximum correlation compared to the other pair X4 and X6. Hence, we may conclude that the salinity problems are highly influenced by hardness substances during May-September, the so-called summer season of the Jaffna penisula.

As discussed above, one of the important aspects highlighted in the correlation matrices of the three years given in Tables 5,6 and 7 is a high degree of correlation between Chloride and Hardness concentrations of the ground water. However, the study is concerned mainly with the importance of Chloride rather than Hardness. The dummy variable X9 for nitrate also does not offer any additional information. Therefore, simple descriptive statistical analysis of Chloride concentration is considered necessary to throw more light on this aspect.

The raw data subjected to seasonalization in the year 1983 (latest year for which data is available) could be classified into GOOD, FAIR, POOR, VERY POOR, and BAD quality drinking water according to the Chloride conentrations. The classification by code numbers of the wells is given in the following table :

Table 8 : The classification of sample points by Chloride concentration for 1983.

Chloride Concent-ration range. (ppm)	Wells by Location (Code)			
	March -April (S1)	May -September (S2)	October -November (S3)	December -February (S4)
0 -< 150 (GOOD)	05,11,18,20, 25,27,33,35, 38,41,51,53, 58,59.	05,11,18,20, 25,27,33,35, 38,41,43,53,, 58,59.	05,18,20,25, 27,33,35,38, 43,50,53,58.	11,18,20,25, 27,33,35,51, 53,58,59.
150 -< 500 (FAIR)	02,06,07,08, 09,10,12,13, 14,19,22,23, 24,26,29,31, 34,39,40,42, 43,45,47,49, 50,54,56,66, 67,68.	02,06,07,08, 09,10,12,13, 14,19,22,23, 24,26,31,34, 39,40,42,44, 45,47,49,50, 51,54,55.	02,06,07,08, 09,10,11,12, 13,14,19,22, 23,24,26,31, 34,39,40,41, 42,45,47,49, 51,54,55,59, 68.	02,05,06,07, 08,09,19,22, 23,24,26,31, 38,39,40,41, 42,43,45,46, 47,49,50,54, 56,63,68.
500-<2000 (POOR)	01,03,04,15, 17,21,30,32, 37,44,46,48, 52,55,57,60, 61,62,63,65.	03,04,15,17, 21,29,30,32, 37,46,48,52, 56,57,60,61, 65,66,67,68.	01,03,04,15, 17,29,30,32, 37,44,46,48, 52,56,57,60, 61,65,66,67.	01,03,04,10, 12,13,14,15, 16,17,21,29, 30,32,34,37, 44,52,55,57, 60,61,62,64, 65,66,67.
2000-<5000 (VERY POOR)	16,28,64.	01,28,62,63, 64.	21,28.	----------
Above 5000 (BAD)	36.	16,36.	16,36,62,63, 64.	28,36,48.

6.2 : Principal Components Analysis

Varimax rotation of the original data gives orthogonal components together with their eigen values or the Principal components together with their variances. With the aid of 'MINITAB' statistical package the eigen values and their associated eigen vectors were extracted from the respective Variance-Covariance matrices. The variances of the principal components and the percentage variability in relation to the total variation are given in the following table:

Table 9 : Eigen values (Variances of the Principal components) and percentage of variation in three yeras.

	1979		1981		1983	
Principal Component	Eigen Value	Percent. Variabi.	Eigen Value	Percent. Variabi.	Eigen Value	Percent. Variabi.
1	5787530	82.91	7673553	92.60	15793090	88.62
2	1047961	15.01	345783	4.17	1622043	9.10
3	78467	1.12	174216	2.10	294451	1.65
4	34356	0.49	56498	0.69	55052	0.32
5	23036	0.33	14883	0.18	41741	0.23
6	3990	0.06	11878	0.14	7805	0.04
7	3339	0.05	7556	0.09	5550	0.03
8	2068	0.03	2101	0.03	2370	0.01
9	1	0.00	1	0.00	1	0.00
Total	6980748	100.00	8286469	100.00	17822103	100.00

It is necessary to decide on the number of components which have any practical significance. A simpler but arbitary rule of thumb, which has proved to be useful, in practice, is to consider only those components which have percentages 1.000 or greater as having any practical significance (13). The above table reveals that only the first three principal components are suitable for further analysis. Hence the redueced meaningful dimension is three.

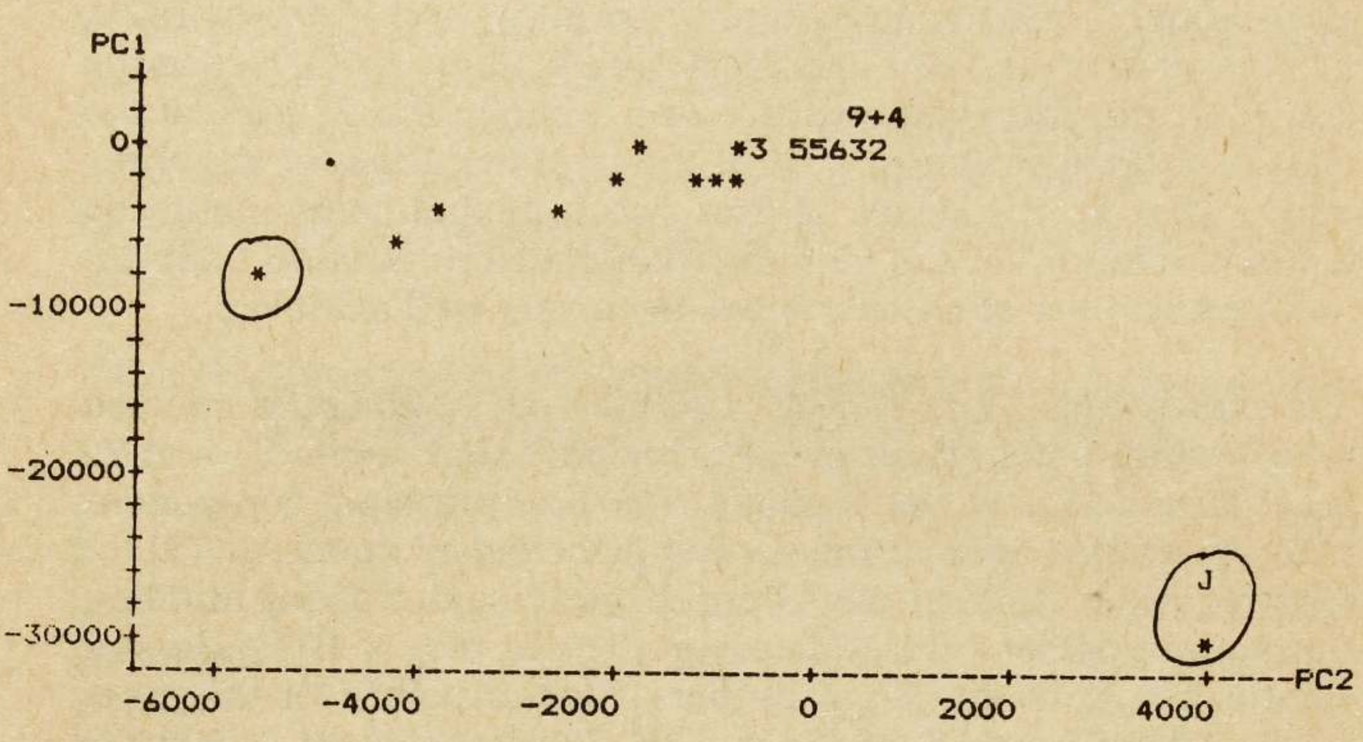
From the above table, we can observe that the total variation has increased from 1979 to 1983 with maximum variation in 1983. Hence we may conclude that the total variability of the hydro-chemical data increases. Further, the percentages of the first two eigen values in relation to their total are 82.91 and 15.01 for 1979, 92.60 and 4.17 for 1981 and 88.62 and 9.10 for 1983. Hence the first two principal components alone describe the 97.92% of the total variations of almost 97% of the total variation for the three years. That is, the usage of first two principal components by varimax rotation for the identification of discrimination boundaries and number of clusters have been very well achieved.

The expressions Y1 = e1' (X-M) and Y2 = e2' (X-M) could be used for calculating the values of the principal components Y1 and Y2 (ie, PC1 and PC2 in the bi-plots). The first principal component (Y1) was plotted against the second principal component (Y2) for all three years. These bi-plots were checked for identifying outliers, but are not presented in this report. The bi-plot of 1979 showed sample points 16 and 36 as outliers. Similar points for the years 1981 and 1983 are 16, 36, 63 and 16, 36 respect ively. (Appendix 1). Hence it is found that the areas surrounding Anaikoddai west (16) and Idaikkadu (36) are entirely different clusters of the ground water in this area. The area surrounding Moolaai (63) is also different one, but this is not strongly emphasised because it occurred only in 1981.

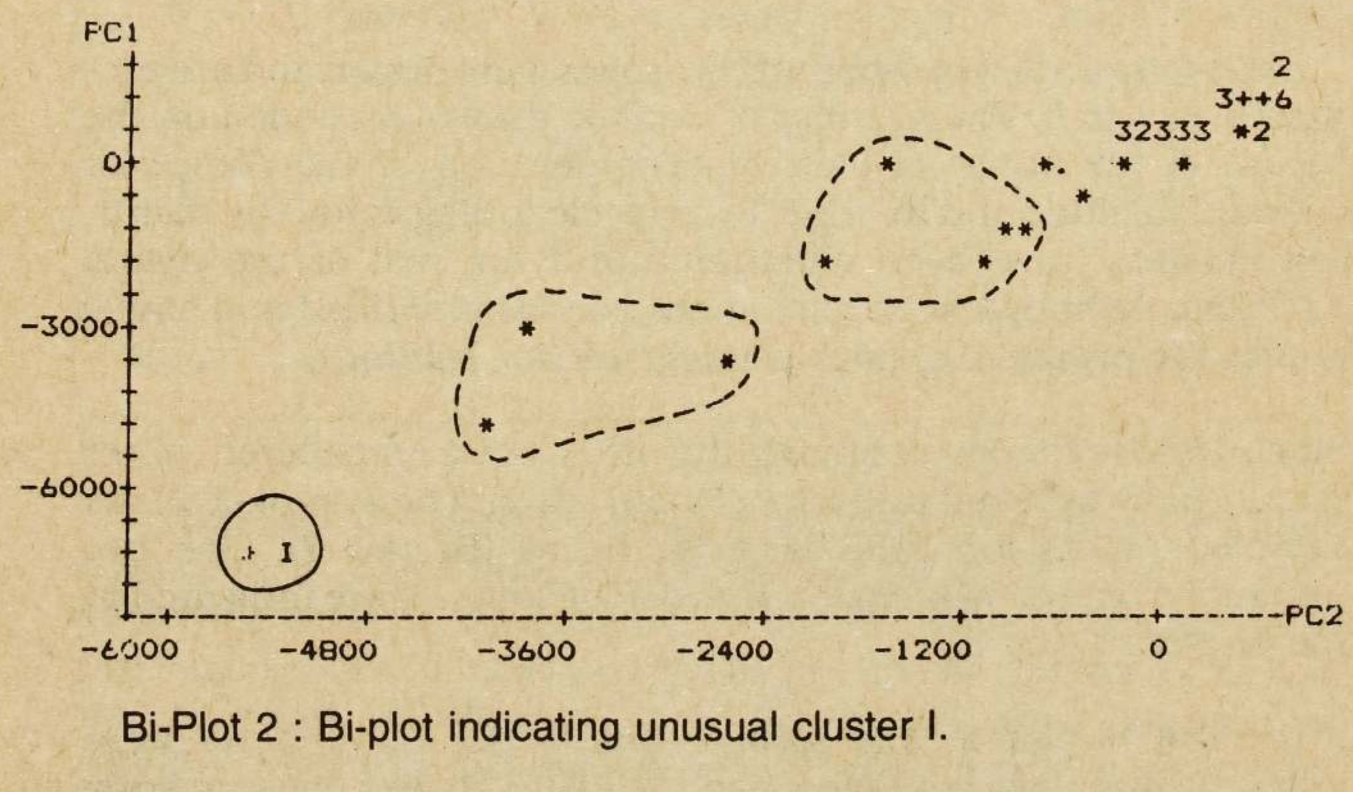
The bi-plots of 1983 at different Y2 ranges were drawn and are presented as 1 to 9. The number of bi-plots drawn depended on the nature of the initial bi-plot. In consideration of the computer software facilites and in order to draw clear diagrams, the identified clusters have been eliminated and the rest of the points replotted. Although several clusters may be identified in a single bi-plot the principal cluster is enclosed in a fullline.

Since 1983 is the latest among the other years considered, other year bi-plots were not taken for classification. The bi-plot of all the sampled points for 1983 is given below (Bi-plot 1). The two unusual clusters 36 (Cluster J) and 16 (Cluster I) are indicated in the bi-plots 1 and 2.

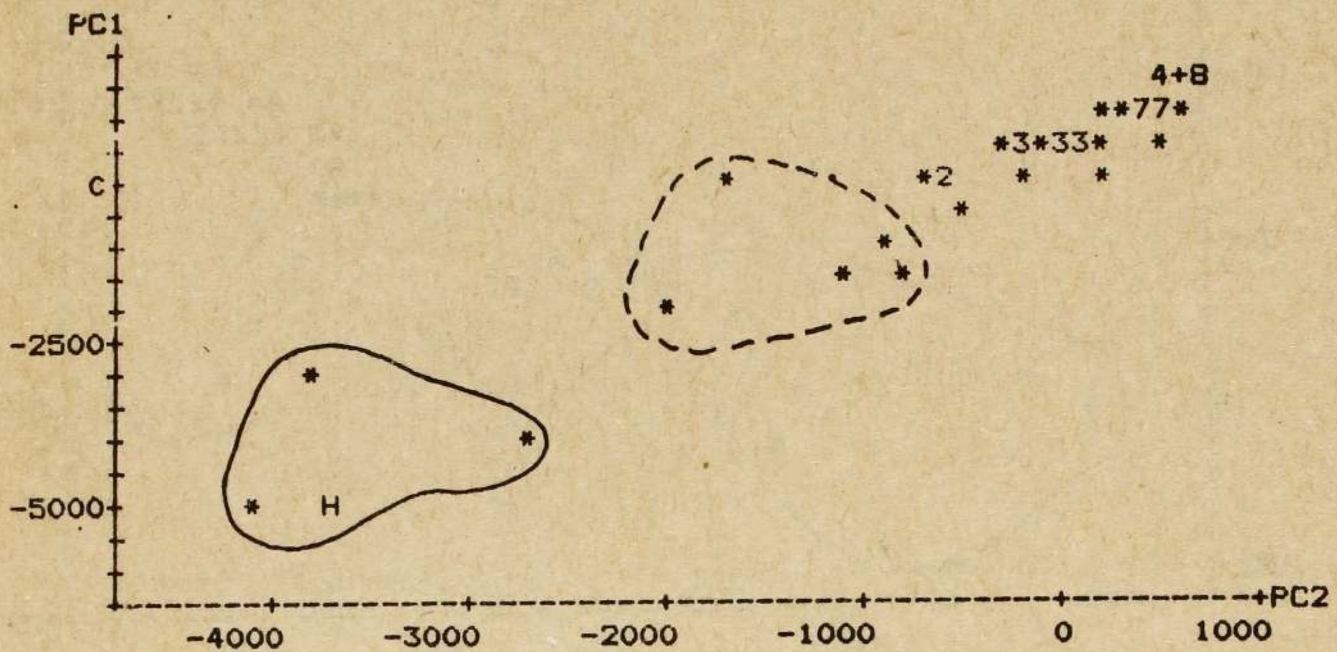
From the bi-plot 2, the sample points 62, 63 and 64 were indentified to form a single cluster (Cluster H) and consequently 1, 3, 21, 28 and 48 were separated as another cluster (Cluster G). The clusters are indicated in the bi-plots 3 and 4.



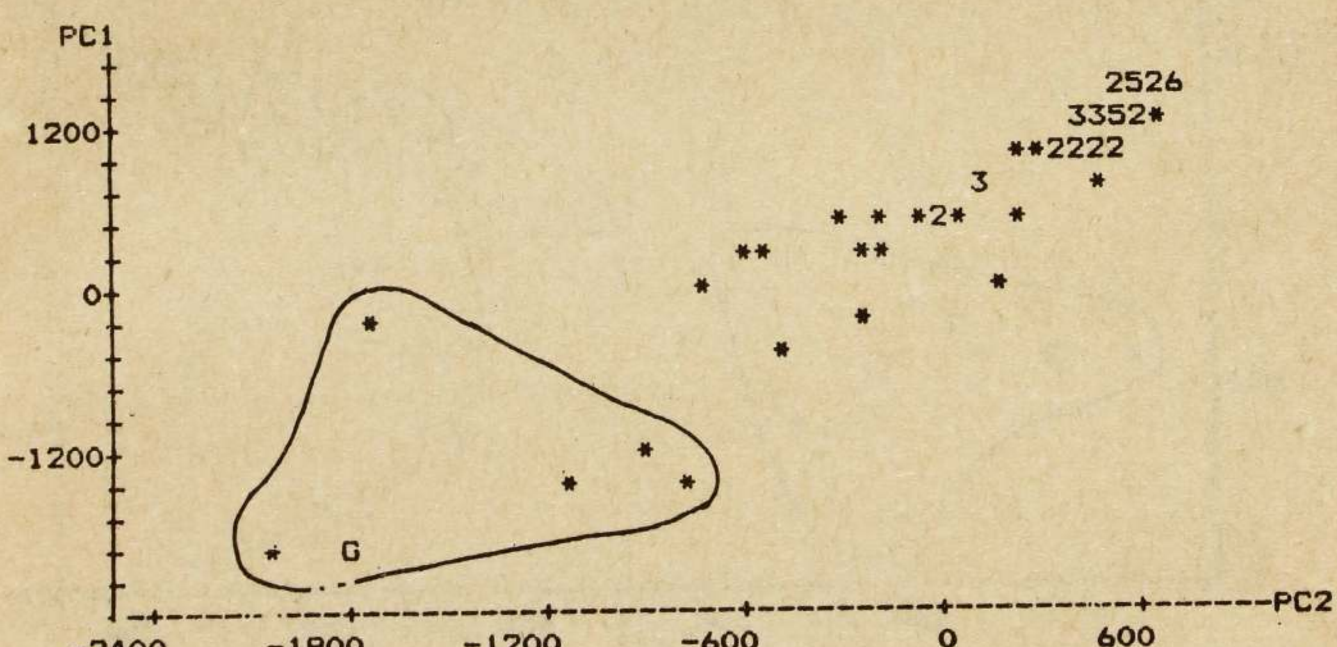
Bi-Plot 1 : Bi-plot indicating unusual cluster J.



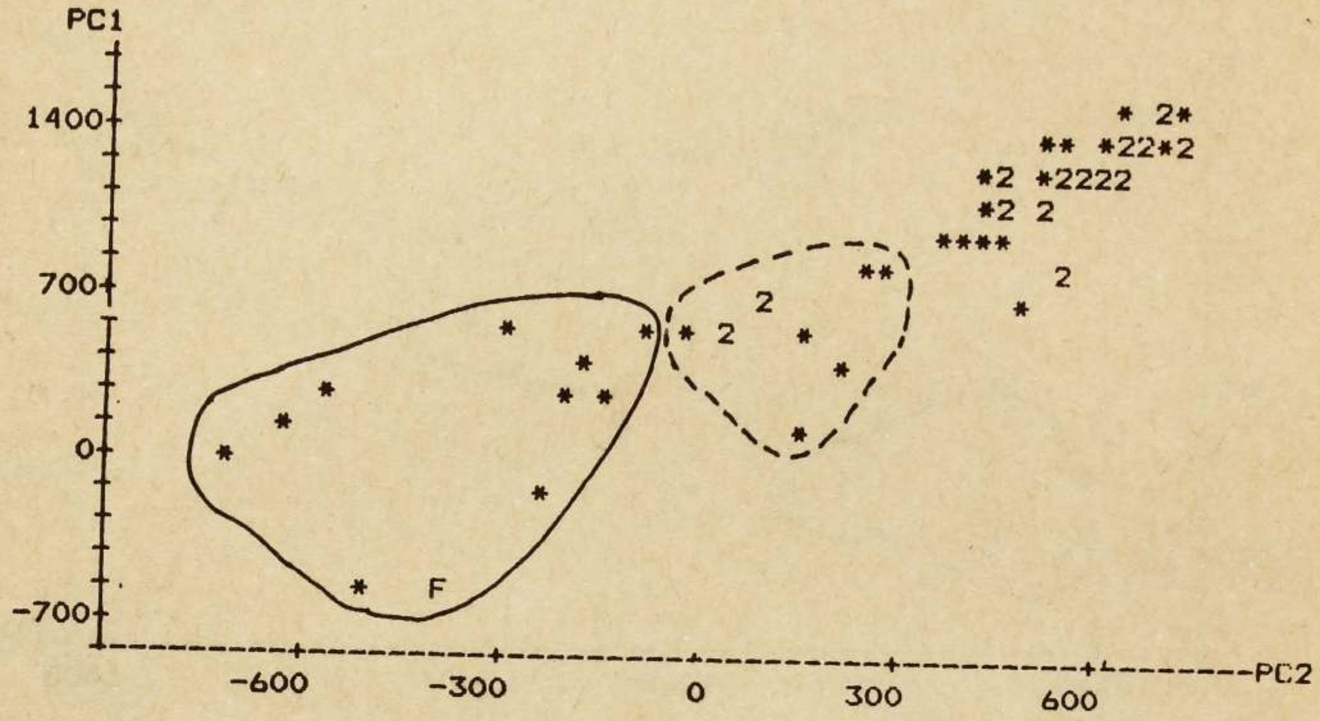
Bi-Plot 2 : Bi-plot indicating unusual cluster I.



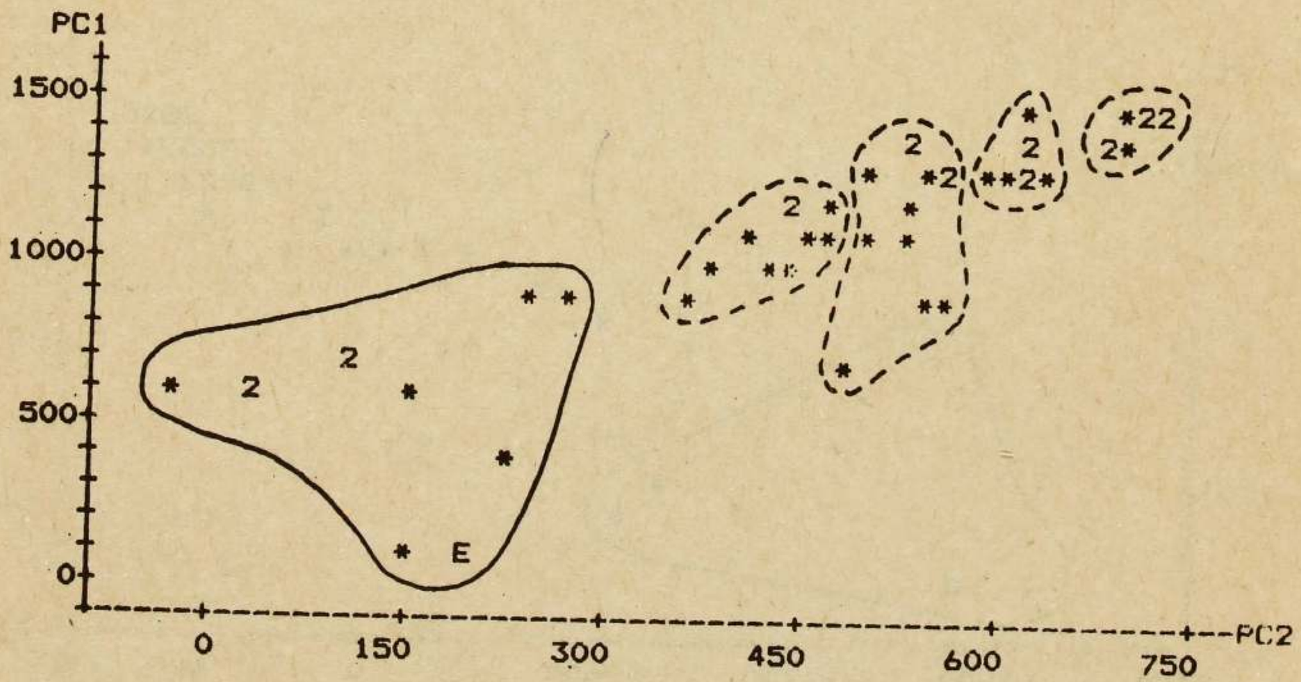
Bi-Plot 3 : Bi-plot indicating unusual cluster H.



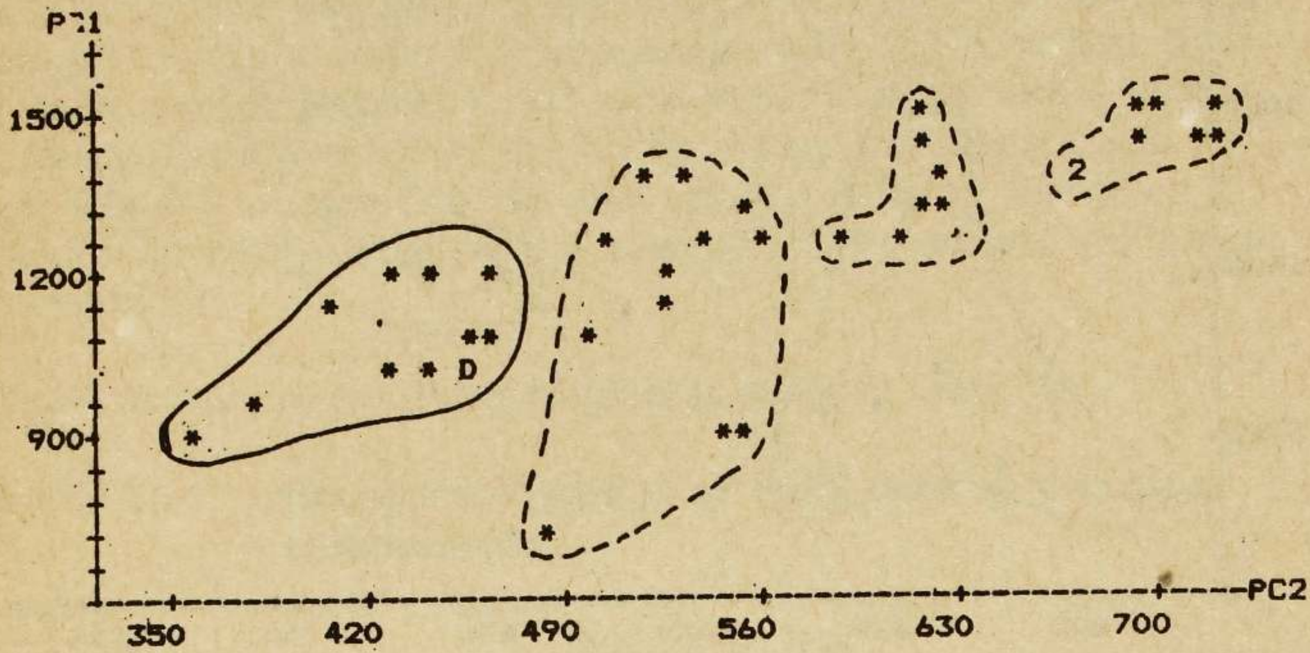
Bi-Plot 4 : Bi-plot indicating identified Cluster G.



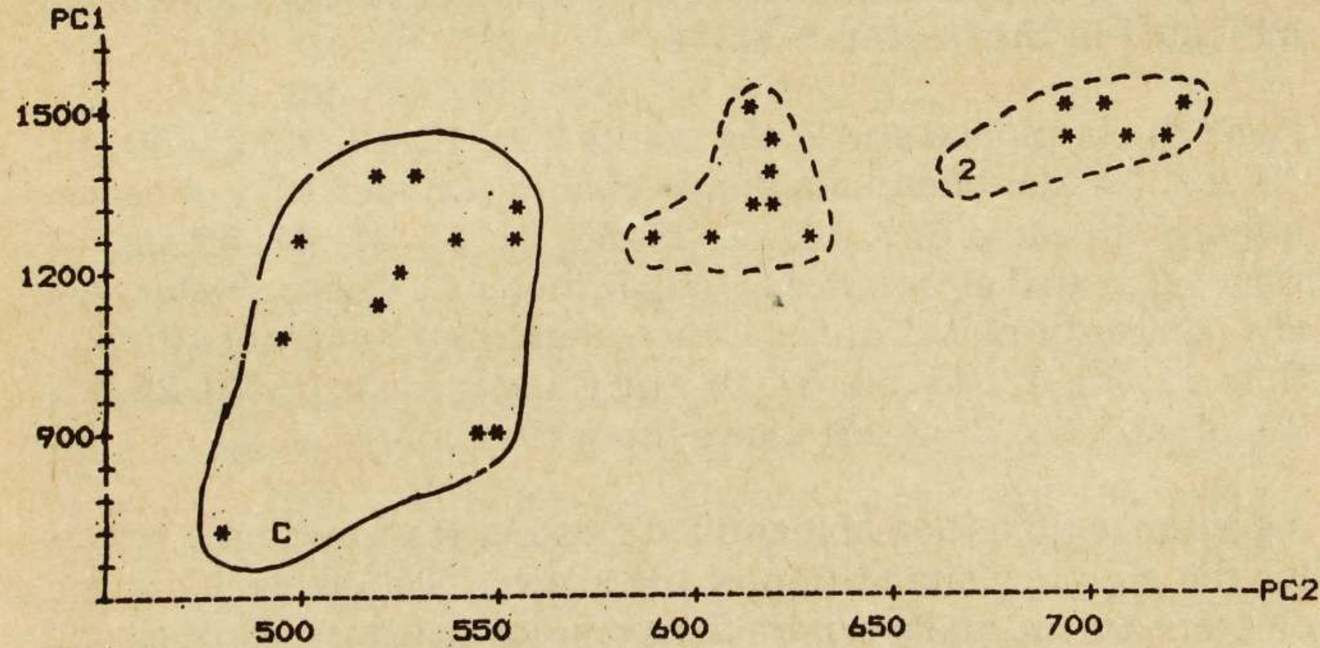
Bi-Plot 5 : Bi-plot indicating identified Cluster F.



Bi-Plot 6 : Bi-plot indicating identified Cluster E.

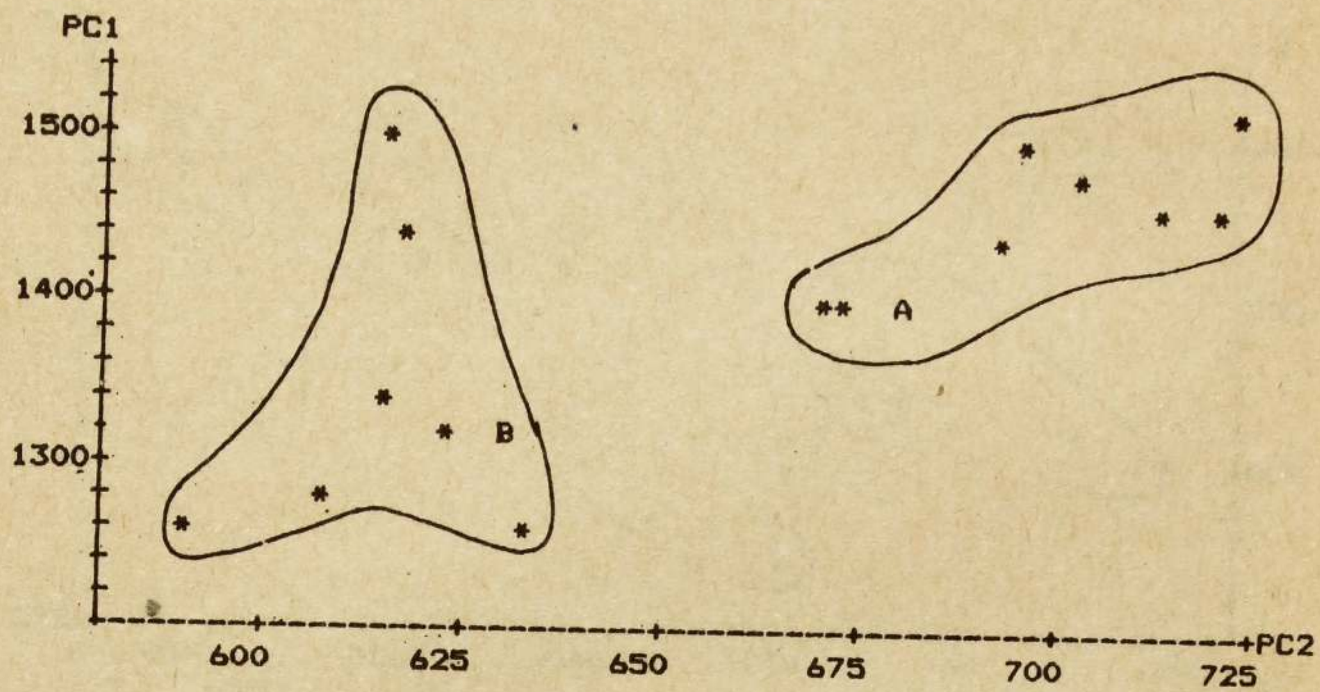


Bi-Plot 7 : Bi-plot indicating identified Cluster D.



Bi-Plot 8 : Bi-plot indicating identified Cluster C.

4693
0.0

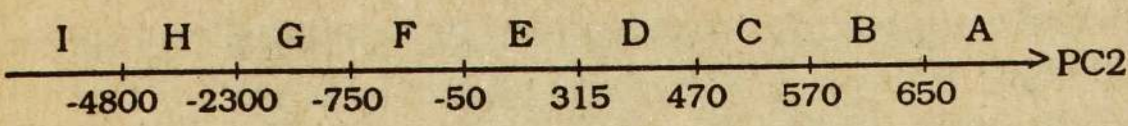


Bi-Plot 9 : Bi-plot indicating identified Clusters A and B.

From the bi-plot 4, the sample points 4, 15, 17, 30, 32, 44, 57, 61, 65 and 67 were identified to form a single cluster (Cluster F) and consequently the sample points 10, 29, 34, 46, 52, 55, 56, 60 and 66 were separated as another cluster (Cluster E). The clusters are indicated in the bi-plots 5 and 6.

From the bi-plots 6 and 7, the points 2, 9, 12, 13, 19, 24, 39, 40, 49 and 54 identified as a single cluster (Cluster D) and consequently the pints 6, 7, 14, 22, 23, 26, 31, 41, 45, 47, 59 and 68 were separated as another cluster (Cluster C). These clusters are given in the bi-plots 7 and 8, Consequent new clusters are Cluster B: 8, 11, 38, 42, 43, 50, 51, 58 and Cluster A : 5, 18, 20, 25, 27, 33, 35 and 53, Bi-plot 9 shows these clusters.

A gradual elimination of identified clusters results in nine biplots for the simple visualization of the scatter. The above identified clusters are mutually separable in relation to the values of second principal component. Hence the discrimination boundaries in terms of Y2 (PC2) are defined and given below:



All the nine bi-plots given above suggest that there are ten major groups of ground water patterns recognizable in this region. Nine of them were determined by PC2 and one by PC1, the initial cluster J being discriminated by the first principal component and the consequent cluster I to the last cluster A being identified or discriminated by cosidering the range of the second principal component.

The summary of the above bi-plots is given in table 10.

Table 10 : Recognized groups of 1983 data by principal components

Cluster	Sample points
A	05, 18, 20, 25, 27, 33, 35, 53.
B	08, 11, 38, 42, 43, 50, 51, 58.
C	06, 07, 14, 22, 23, 26, 31, 41, 45, 47, 59, 68.
D	02, 09, 12, 13, 19, 24, 39, 40, 49, 54.
E	10, 29, 34, 37, 46, 52, 55, 56, 60, 66.
F	04, 15, 17, 30, 32, 44, 57, 61, 65, 67.
G	01, 03, 21, 28, 48.
H	62, 63, 64.

The summary of these bi-plots incorporated on the spatial distribution of the sample points are clearly shown in Figure 4 below. In this figure, it is observed that the cluster C obtained by eliminating the other identified clusters clearly indicates that the cluster C reflects the major portion of the ground water available in this study region, Further, the clusters G, H, I and J showing unusual or entirely different clusters, may be the poor standard water clusters. The other clusters A, B, D, E and F are inferred as intermediate water standard clusters.

The principal components are calculated by obtaining their corresponding eigen vectors. Eventhough only the first two principal components show practical significance, the first five eigen vectors are listed in the following tables to understand the nature of weights or loadings in the components. The values of a principal component in an year can be calculated using the original nine hydro-chemical data and the appropriate eigen vector given in the tables.

Table 11 : Eigen vectors describing first five principal components in 1979.

Variable	Components Y1	Y2	Y3	Y4	Y5
X1	-0.27440	-0.41080	0. 03217	-0.47731	-0.50921
X2	-0.83679	0.40534	-0.03996	0.14344	-0.10309
X3	-0.26088	-0.58334	-0.58622	0.27754	0.11926
X4	-0.18858	-0.42264	0.56418	0.41119	-0.13500
X5	-0.09766	-0.17089	0.15410	-0.65247	0.10616
X6	-0.31462	0.17512	0.10584	-0.22582	0.41648
X7	-0.09268	-0.24150	-0.10962	-0.12300	0.64382
X8	-0.06141	-0.17275	0.53707	0.11686	0.31369
X9	0.00011	0.00013	0.00035	0.00014	-0.00106

Tabel 12 : Eigen vectors describing first five principal components in 1981.

Variable	Components Y1	Y2	Y3	Y4	Y5
X1	-0.44959	0.26187	-0.27482	-0.27433	-0.49258
X2	-0.69065	0.20287	0.49893	-0.04483	-0.05653
X3	-0.37261	-0.81684	0.08258	0.01864	0.21499
X4	-0.22570	-0.20619	-0,58430	-0.43378	0.12712
X5	-0.17964	0.29275	-0.28347	0.16675	0.54387
X6	-0.25764	0.22707	0.02702	0.30541	0.46116
X7	-0.14669	-0.18737	-0.19175	-0.73062	-0.42770
X8	-0.10451	0.09036	-0.45767	0.28167	-0.01980
X9	0.00011	0.00011	0.00038	-0.00032	-0.00060

Table 13 : Eigen vectors describing first five principal components in 1983.

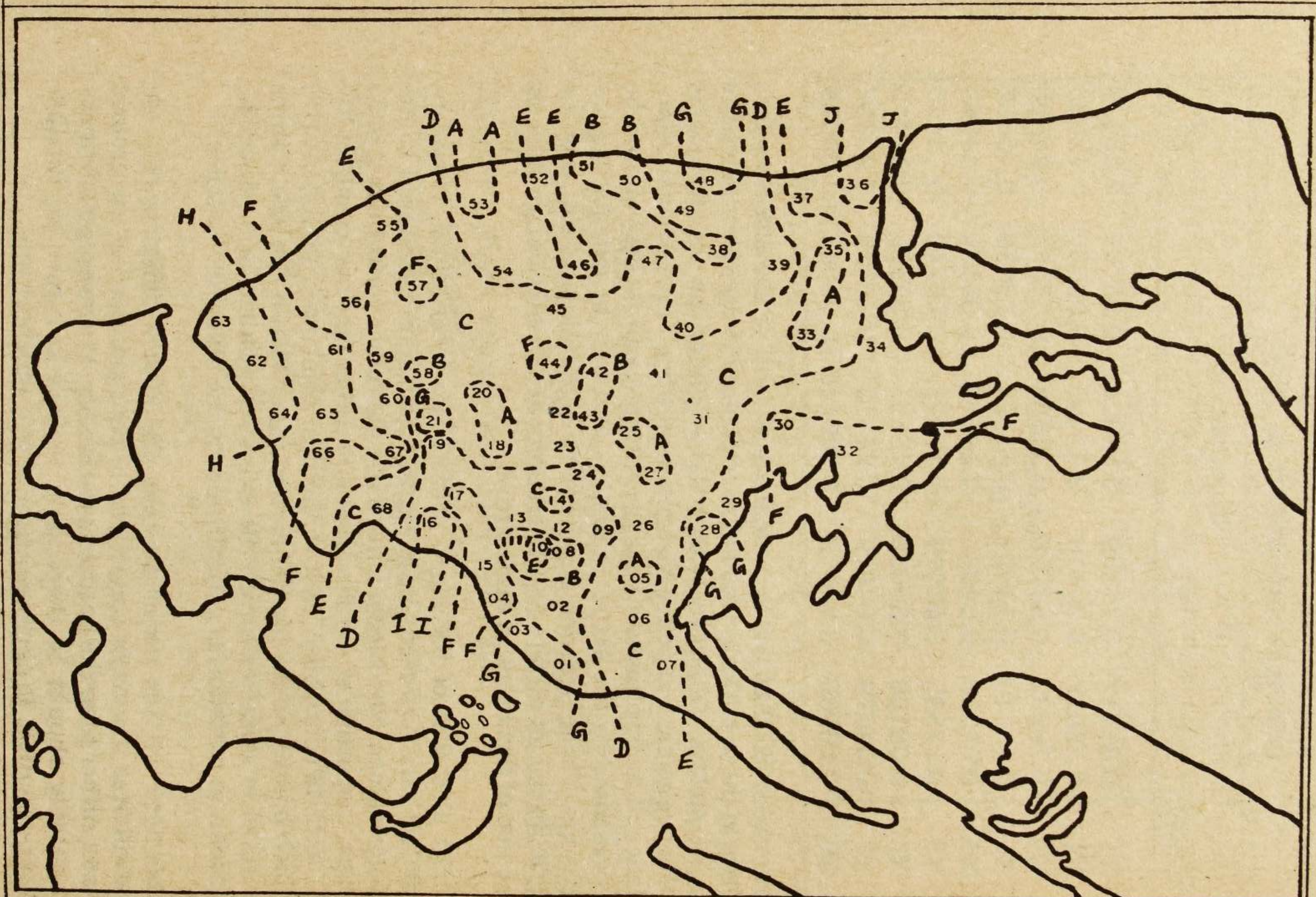
Variable	Components Y1	Y2	Y3	Y4	Y5
X1	-0.26417	-0.16439	-0.58324	-0.53768	-0.38579
X2	-0.88027	0.30418	0.17489	-0.02535	0.12830
X3	-0.20992	-0.84796	0.21388	-0.17589	0.28808
X4	-0.13240	-0.14931	-0,63391	-0.46538	0.46886
X5	-0.09396	-0.04074	-0.18442	0.05189	-0.44660
X6	-0.27595	0.03309	0.17648	0.29240	-0.14405
X7	-0.08108	-0.36639	0.23751	0.39994	-0.51415
X8	-0.04679	-0.04612	-0.24513	0.46325	-0.21757
X9	0.00006	0.00018	0.00014	-0.00062	-0.00016

It is observed that the last element of each of the eigen vectors given in these tables is very small compared to the other elements in the vectors. This reveals that the weight of the coded variable X9 is negligible and hence X9 contributed least for discrimination. Hence, it is emphasised that the nitrate variable (X9) should be represented by the actual statistics, and may be categorised for seasons. These seasons need not be climatological but may be agricultural as nitrate concentrations are mostly determined by the use of fertilizers in agriculture.

Other elements of the eigen vectors are meaningful. However, smaller values present little extra information compared to the bigger values. The bigger values are definitely contributing variables. Inspection of the above vectors reveal that the variables X5, X7 and X8 contribute least to the first principal component (Y1) which possesses the maximum variation. That is the above three hardneess variables have little extra information and hence the maximum variation is contributed by the chloride variables.

Therefore we can conclude that the widely differing chloride variation is the major cause for the poor standard of the ground water rather than the hardness variability. However the hardness variability should be thoroughly studied in future for furtther discrimination. It might contribute in a different way.

FIG. 4. GROUND WATER CLUSTERS IN 1983 BY PRINCIPAL COMPONENTS



The practical objectives of the use of principal components analysis such as recognition of misidentified individuals, the examination of the grouping of individuals in n-dimensional space and the elimination of variables which contribute relatively little extra information have been very well applied in this study.

6.3 : Hierachical Clustering

The application of Hierachical Clustering in this study is made the data obtained from the samples of water obtained at the specified sample points. In this context, a cluster represents a set of wells with water homogeneous in quality in the Statistical sense.

The data matrices of the said three years 1979, 1981 and 1983 were adjusted after principal components analysis. That is the odd elements disturbing the calculations by large variation were eliminated. The sample points 16 and 36 from 1979, 16, 36 and 63 from 1981 and 36 from 1983 were eliminated due to the above reason.

All three data matrices were subjected to the calculation of dissimilarity measures. The Mahalanobi's distances among them were calculated and three dissimilarity matrices were constructed. These dissimilarity matrices were used for forming clusters at different distance levels (dissimilarity levels) by average linkage methods. The three dendrograms drawn were inspected clearly for the formation of clusters at different dissimilarity levels.

From the dendrogram of 1979 data, the following cluster formations were observed at 9.897 dissimilarity level. The largest cluster formed at the distance 9.897 is ;

A1 : [01,02,04,05,06,07,08,09,11,12,13,14,18,19,20,22,23, 25,26,27,29,30,31,33,34,35,37,39,40,41,42,43,44,45, 46,47,49,51,52,53,54,58,59,61,66].

This cluster formed by 45 of the total of 68 sample points should have been the ideal cluster of the Jaffna-Valikamam region in the year 1979. Further, this cluster would have contained good ground water resource. The second and third largest clusters of sizes 6 and 3 observed were;

B1 : [03,15,17,56,57,60] and
C1 : [38,63,68] respectively.

The remaining 14 sample points;

10, 16, 21, 24, 28, 32, 36, 48, 50, 55, 62, 64, 65, 67;

did not join in any definite clauster formation. Figure 5 shows clearly these patterns. In this figure it is observed that the ground water source area given in the figure 1 is agreeable by this analysis. The cluster A1 indicated is the ideal cluster suitable to this study region on the basis of 1979 data.

Smilar inspection of the dendrogram of 1981 data reveals the following results. The observed dissimilarity level is 7.765. The largest cluster formed at distance 7.589 had 35 sample points which is given by,

A2 : [01,02,03,05,06,07,08,09,11,12,13,15,17,18,29,30,32,33,
34,35,37,38,39,40,45,46,49,50,53,54,55,58,59,66,68].

The second largest cluster of size 12 observed is ;

B2 : [14,19,20,22,23,24,25,26,27,31,41,42].

The small clusters with two sample points are;

C2 : (04,52), D2 : (10,47),
E2 : (21,48), F2 : (44,60)
and G2 : (57,67).

The remaining 11 sample points;

16, 28, 36, 43, 51, 56, 61, 62, 63, 64, 65;

had no evidence of forming any definite clusters. The nature of this pattern could be observed in figure 6. It may be noticed from figures 5 and 6 that the ideal cluster A1 of 1979 has segregated in 1981. The two portions of cluster A2 and cluster B2 of 1981 in figure 6 show this nature.

A further comparison of the figures 5 and 6 with the figure 3 of the spatial distribution given on page 10 explains that the sample points 58 and 59 of the Valikamam West AGA division have been clustered into Valikamam South-West AGA division and the points 56 and 57 of the Valikamam South-West AGA division into Valikamam West AGA division. (See also table 1). It is a noteworthy point for the administraters planning water resource management. Similar comparison for the other AGA divisions could be made.

The important dendrogram of the 1983 data, 1983 being the latest year of study, given in figure 7, was inspected very carefully. The appropriate dissimilarity level is 5.810. The largest cluster formed at distance 4.919 with 19 sample points is given by,

A3 : [09,11,12,13,14,18,19,20,24,
25,26,27,31,33,39,41,45,58,59].

The second, third, fourth, fifth and sixth largest clusters of respective sizes 11, 7, 6, 5 are as follows ;

B3 : (02, 05, 06, 07, 29, 38, 49, 51, 53, 54, 66),
C3 : (08, 10, 40, 46, 47, 50, 55),
D3 : (01, 15, 35, 37, 52, 68),
E3 : (30, 44, 60, 61, 67),
F3 : (22, 23, 42, 43).

The two small clusters of sizes two each formed are as follows ;

G3 : (17, 34), and
H3 : (32, 56).

The remaiining 12 sample points;

03, 04, 16, 21, 28, 36, 48, 57, 62, 63, 64, 65;

were not involved in cluster formation. Figure 8 clearly indicates the cluster patterns. This figure explores the fact that six ground water clusters occured during 1983. Comparison of the figure 8 with those of the earlier years given in figures 5 and 6 reveals that the segregation of ground water clusters continues and hence we may conclude that the different segaregated clusters will have diffeerent drinking water standard.

On the whole, comparing the cluster formations of the three years, it is observed that the ground water cluster patterns differ from year to year. It is also important to notice that some of the sample points behave arbitarily and they may be classified into unusual patterns or cluster of poor standard water. The number of clusters formed increased from 1979 to 1983 and would have increased by now.

Therefore it may be concluded that the major cluster or source water area of this region is being partitioned or segregated by nature into different standards of ground water clusters as time moves on. Hence the largest cluster, considered to be the ideal cluster of this region, decreases in size and loses its sample points to the other poor standard clusters. The distance at the formation of the ideal cluster also decreases and it is a bad signal to the nature of the ideal cluster.

A comparison of the effectiveness of the three statistical tools employed in the methodology of this study is essential at this stage to understand te nature of this applied statistical research. The tools employed could be ranked in the following order: Descriptive Statistical Analysis; Principal Components Analysis; Cluster Analysis.

Descriptive Statistical Analysis has been utilised to extract the estimation of parameters and interpretation of the nature of the available data. Apart from this, point estimation, interval estimation and the consequent testing for significance of the parametric values have not been studied, because the aim of this study is mainly concerned with Clustering the Ground water resource of the Valikamam region.

The Principal Components Analysis (PCA) in this study is an intermediate work performed because this is necessary to verify the relevance of the Hierarchical clustering results. The results obtained by PCA have been based on the first two principal components which explain only 97.72 per cent of the total variation of the entire hydrochemical data in 1983. This is applied as a criterian tool in discriminating the individual observation vectors. Figure 4 explains the nature of discrimination.

FIG. 5. GROUND WATER CLUSTERS IN 1979

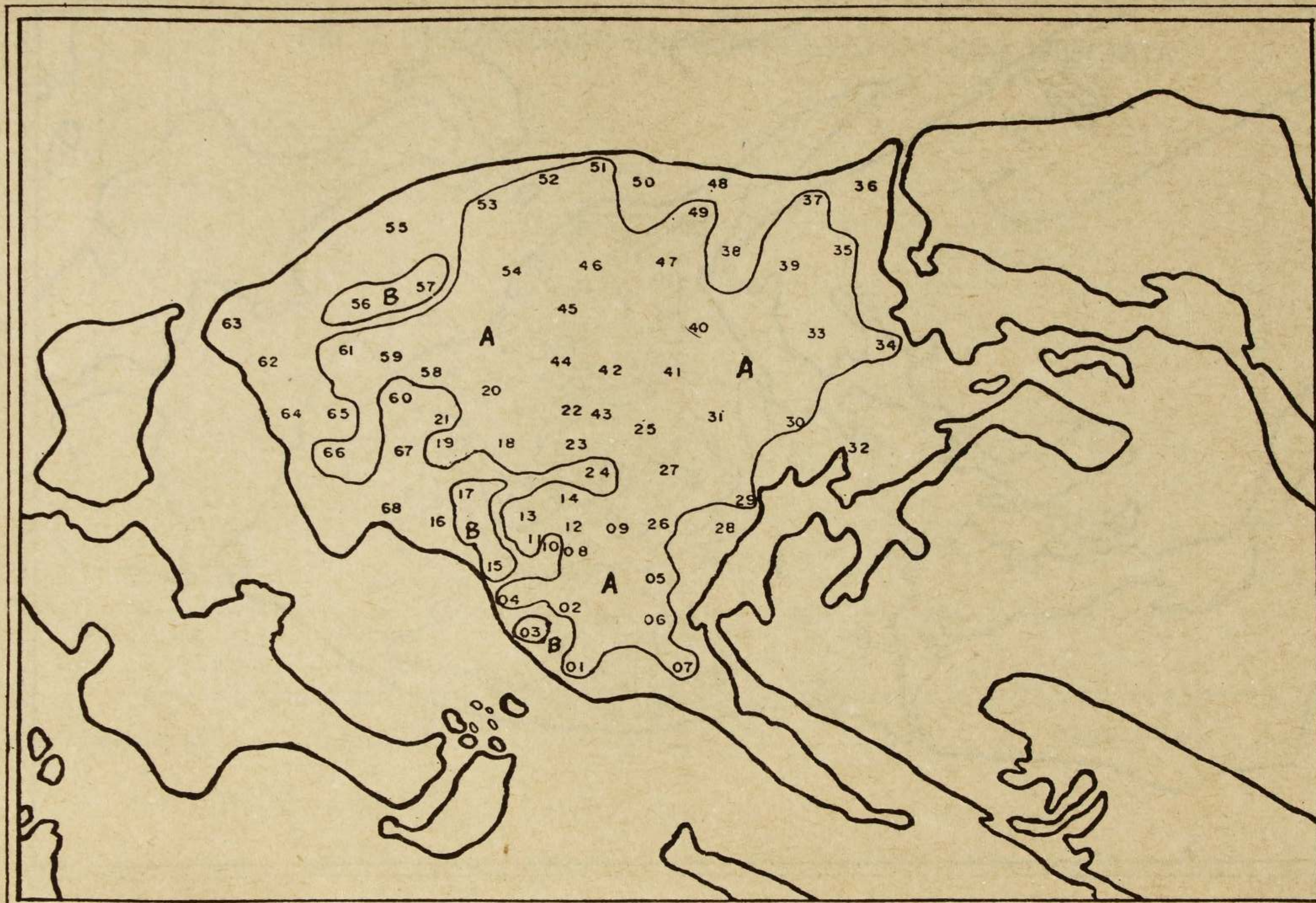
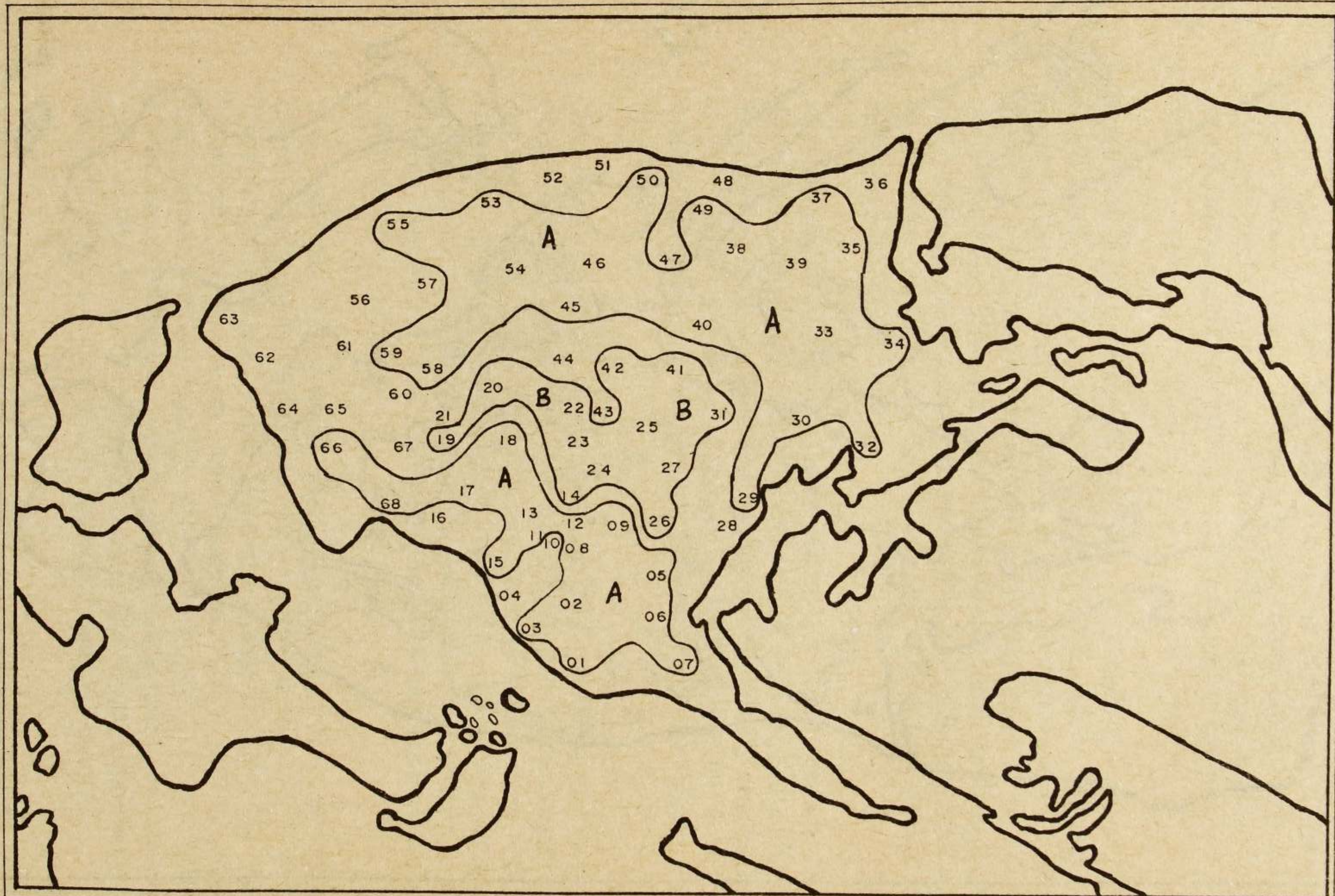


FIG. 6. GROUND WATER CLUSTERS IN 1981



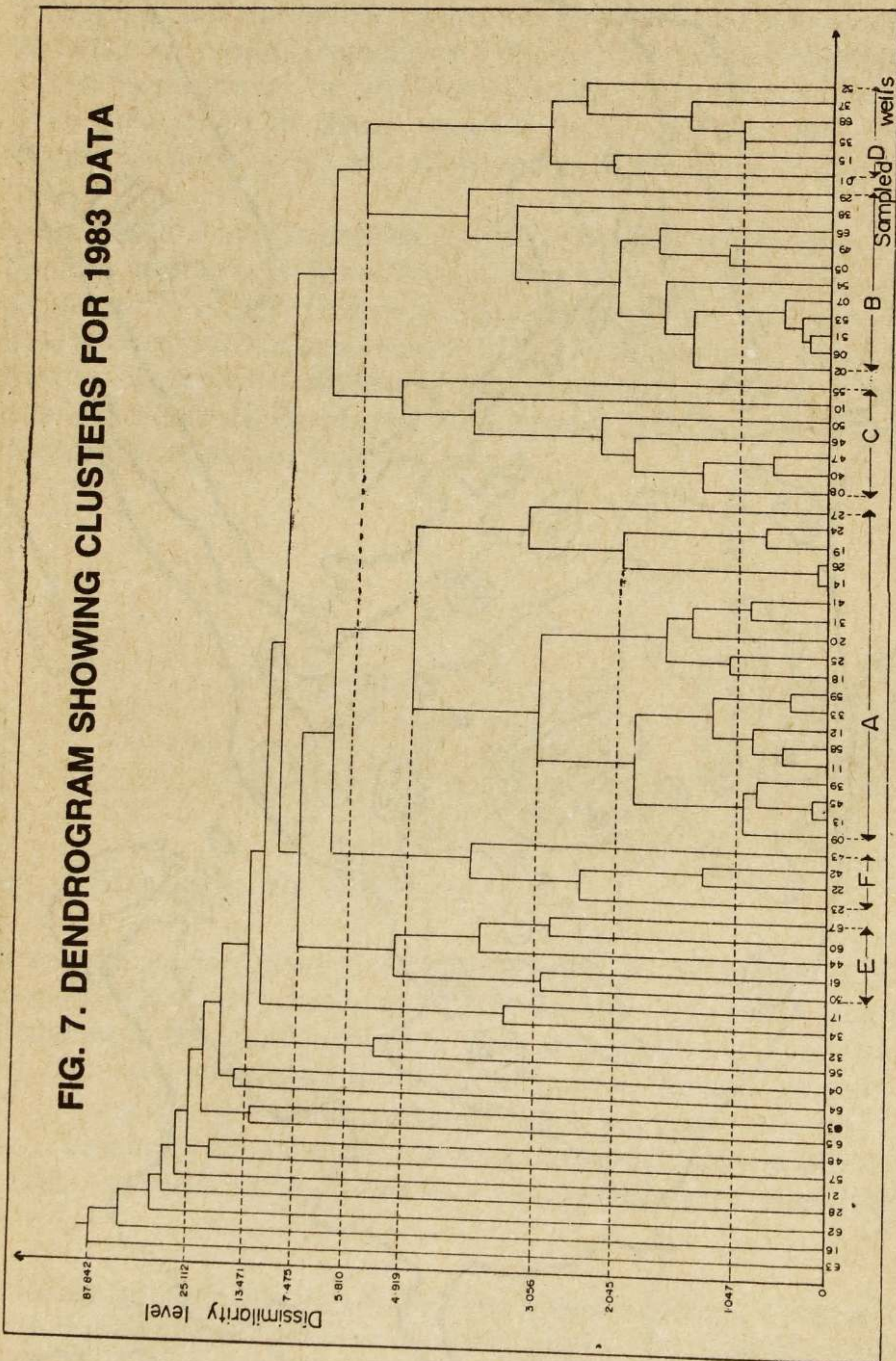
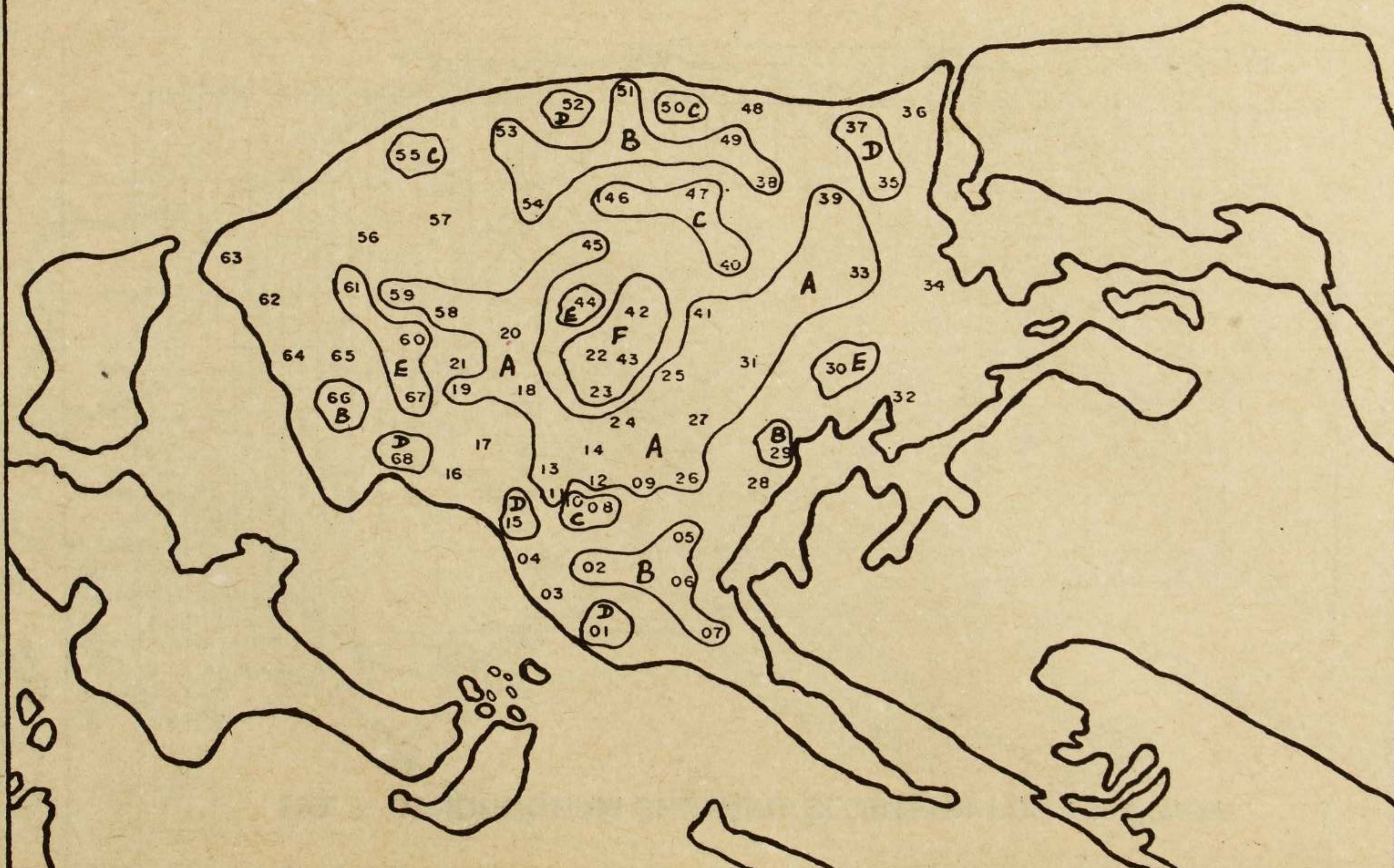


FIG. 7. DENDROGRAM SHOWING CLUSTERS FOR 1983 DATA

FIG. 8. GROUND WATER CLUSTERS 1983



The ultimate results explained here is due to Agglomerative Hierarchical Clustering procedure. The results obtained from the data of 1983 and presented in figure 8 give a complete picture. It is satisfying that the results presentes in this figure when compared with the results from figure 4 (from PCA) indicate that after the discrimination of the unusual clusters in the Ground Water Source area, both of them compare favourably; i.e the ideal clusters identified as A3 and F3 from figure 8 are confirmed.

It is not possible to compare each and every point available owing to the limitations and drawbacks in this study mentioned in the begining of this report. These are also indicated in the next section. The superiority of this tool compared to the second tool PCA is the utlization of all nine variables by nine dimesional real space. The Statistical Distance Measure "Mahalanobis Distance" has been successfully utlised in this real space.

6.4 : Analysis on Clusters

The average concentrations of Chloride in the wells for each of the clusters A, B, C, etc. as shown in the figures 5, 6 and 8 would indicate how the concentrations have changed over the three years. This behaviour would prompt to analyse the data as a time series. However, the data available is not adequate enough to apply this statistical method. A brief presentation of the Cluster Analytic Approach of this work was clearly discussed elsewhere (17).

The following table (Table 14) lists the grouped places of each of the six clusters identified from the 1983 hydro-chemical data. The means of the eight chloride and hardness variables for different clusters are also given in the subsequent table (Table 15).

Table 14 : Place in the identified six clusters for 1983.

Cluster	Some Places (Some parts only)
A	Kondavil, Manipay, Chankanai, Urumpiray, Avarankal.
B	Jaffna East, Nallur, Koppay, Vasavilan, Alaveddy, Vaddukoddai.
C	Kokkuvil, Punnalaikadduvan, Tellippalai,
D	Jaffna South, Anaikoddai, Arali, Keerimalai, Atchuveli.
E	Neerveli, Chunnakam West, Siththenkerny.
F	Maruthanarmadam, Chunnakam South and East.

Table 15 : The average concentrations of the identified Six clusters at different periods (Mean vectors).

Cluster (Size)	Chloride				Hardness			
	S1	S2	S3	S4	S1	S2	S3	S4
A (19)	219.7	207.8	215.8	228.9	277.6	285.2	301.1	323.2
B (11)	225.5	251.6	322.3	254.1	300.0	295.7	337.7	347.7
C (07)	373.6	347.9	365.0	403.5	372.1	379.6	432.9	564.3
D (06)	645.0	793.0	756.0	513.0	397.5	571.3	560.0	395.0
E (05)	632.5	822.0	952.0	685.0	543.0	619.2	749.0	527.0
F (04)	228.8	188.5	204.4	263.5	277.5	252.0	232.5	305.0

It is observed from table 15 that the clusters A and F have the least average Chloride and Hardness concentrations. Hence, it may be concluded that the ground water from the clusters A and F has the best drinking water standard compared with the other clusters. The clusters A and F constitute the ground water source area already identified as having the best quality drinking water.

The places Kondavil and Urumpiray located in the above said cluster, supply the drinking water to the Jaffna city and the Jaffna Provincial Hospital. Hence, a Careful inspection of Chloride concentrations at different periods of the year is useful.

A comparison of the average chloride concentrations during December-February and May-September is meaningful at this stage. The results obtained and discussed in section 6.1 based on (Table 4) agree with the results obtained with the clusters D and E given in the above table, while the results obtained for clusters A, B and F at first glance may seem to be contrary to the usual pattern. Hence 'Statistical Inference' was applied to study this behaviour and to demonstrate the true pattern. However only the results for the cluster A is presented. The corresponding null hypothesis that the "Average Chloride concentration during December-February (S4) is not significantly different from that of during May-September (S2)" was tested against the one sided alternative "During S4 is lower than during S2".

The results of the Hotteling's T test is as follows: The test value is -2.08077 and the table value t (36,5%) is -1.697 and therefore the null hypothesis is rejected. Hence we have to accept the alternative hypothesis which is the anticipated result. Hence, the sample information given in table 15 does not contradict the pattern. Similar testings have been done for the other clusters. The entire work on Statistical inference is not presented due to the reason already mentioned.

The clusters B and C may be accepted as having better drinking water stadard. All the above said clusters belong to the (150-500) ppm chloride range and hence they are classified as "Fairquality drinking water clusters". Further, no clusters belong to (0-150) ppm chloride range which relates to the Good quality water cluster". Inspection of the individuals which did not join in the cluster formation also confirmed these results.

Table 15 also indicates the poor quality standard clusters. The clusters D and E belong to (500-2000) ppm chloride range i.e, "Poor quality drinking water" and hence the water from this area is not drinkable. Some of the sample points which did not join in the cluster formation have indication of this type of clusters. The related places may be seen from table 14. The two small clusters G : (17,34) and H : (32,56) not described above are discussed below under unusual groups.

Excluding the above described six clusters, the remaining sample points were grouped or given as singletons on the basis of comparison with the results from principal components analysis (PCA). The identified groups are G,H,G* : (03, 21, 28, 48), H* : (62, 63, 64), I* : (16) and J* : (36). The singletons left are 04, 57 and 65. It is to be noted that G* has been obtained from the cluster G of PCA after losing 01 to the cluster D in hierarchical clustering. H*, I* and J* are the same as from PCA. The following tables 16 and 17 give the details.

Table 16 : Places in the unusual groups and singletons

Cluster	Some places (Some parts only)
G	Navali, Atchuvely South.
H	Puttur, Pandattarippu west.
G*	Jaffna west, Manipay west.. Koppay south, Myliddy.
H*	Chulipuram, Moolai, Tholpuram.
I*	Anaikkoddai west
J*	Idaikadu.
(04)	Jaffna north.
(57)	Pandattarippu east
(65)	Vaddukkoddai north

Table 17 : Average concentrations of the unusal clusers and single sample points at different seasons.

Cluster	Chloride				Hardness			
	S1	S2	S3	S4	S1	S2	S3	S4
G	248.7	528.0	638.0	854.0	315.0	449.0	565.0	547.5
H	535.0	625.5	758.8	547.0	660.0	635.0	820.0	657.0
G*	1165.0	1544.0	2222.0	1911.0	757.5	755.0	815.0	873.0
H*	1583.0	3731.0	4942.0	1105.0	780.0	1763.0	2525.0	620.0
I*	4392.5	5547.0	7000.0	1990.0	1460.0	2094.0	2980.0	970.0
J*	7812.5	28492.0	3820.0	3908.3	3070.0	8946.0	1570.0	1675.0
(04)	807.5	802.0	1422.5	855.0	250.0	256.0	500.0	415.0
(57)	770.0	631.0	1065.0	818.3	760.0	692.0	1330.0	935.0
(65)	1662.5	1254.0	1315.0	691.7	870.0	776.0	650.0	325.0

Table 17 reveals that all the groups and individuals give chloride concentration above 500 ppm. Hence, it may be concluded that these groups have very poor drinking water quality. It is further observed from the table, that the groups I* and J* are the places having the worst quality of water.

The values of the hardness variables given in tables 15 and 17 could be interpreted as follows. No clusters belong to the (0-100) ppm hardness concentration range. Therefore, no "Soft drinking water» is available in the study region. The clusters A and F belong to the (100-300) ppm range. Therefore, it is concluded that these two clusters are ideal to the region as similar lower range results were obtained for the chloride concentrâtion. The clusters B, C, D, E, G and singleton (04) belong to (300-700) ppm hardness range. Hence we accept that the ground water of these clusters is "hard water".

Inspection of the remaining clusters in the above table reveals that the groups H, H*, G*, (57) aad (65) belong to (700 and above) ppm harness and hence they may be classified as having "Very hard Water". The values of the clusters I* and J* do not belong to the range of smaller values but belong to the very high value range. Hence, these are classified as unusual clusters. The related locations could be seen in table 16.

At this stage it is possible to rank the clusters in an order depending on the quality of water. This ranking is called "Multi-dimensional scaling" in the discipline of Multivariate Analysis. It has not been possible to carry out the analysis as the software BMDP (Bio-Medical Data Processing Package) is not available at this University.

However, an overall comparison of the results shown in tables 15 and 17 for the clusters of 1983 data allow ranking of the clusters from Good to Bad in the following order ;

A - F - B - C - D - E - G - H.

It would have been useful to study how the concentration of Chloride varied in the identified clusters over the three years. Unfortunately, this has not been possible, since as could be seen the cluster identified, for example Cluster A1 in 1979 split subsequently into other clusters in years 1981 and 1983.

7 : CONCLUSIONS AND RECOMMENDATIONS

From the descriptive statistical analysis of the nine-dimensional observation vectors, it is concluded that the average chloride concentration in the study area steadily increases and is expected to increase the salinity problems in all the pockets of the region within the next ten year period.

When the 'Maximum allowable level' of Chloride in drining water recommended by the world health Organization (WHO) standard is exceeded by the increasing chloride contamination, the people of this region will face the scarcity of drinking water of acceptable quality. Such a situations would be a disaster to the people and the region. Therefore serious action should be taken by the authorities to arrest the situation. Heavy Chloride concentration may also cause serious chronic diseases like hypertmsion, cancer etc. (14).

The correlation co-efficients of the variables in this study support the conclusion that the Chloride concentration and Hardness concentration in the region in different seasons are associated to each other positively and one influences the other. Further, the seasons March-April and May-September have similar characteristics in the variation of hydro-chemical data and hence both seasons need not be considered separately for the continuous study. The summer season, March-September, has no identified variation in hydro-chemical data. The analysis further leads to the conclusion that the salinity problems during the summer season May-September are highly influenced by hardness substances.

The principal components analysis helped to identify and discard three clusters or grouped places which have entirely different standard of ground water. These places are (1) Anaikoddai west area, (2) Idaikadu area and (3) Chulipuram, Tholpuram and Moolai area. The remaining palces were formed into seven suitable groups of ground water standard in this region. The ground water source area explained in this study has been re-identified by a cluster (Cluster C) in this analysis. Step by step elimination of suitable groups led to the retention of this cluster. Two neighbouring clusters (Clusters B and D) were also identified to have similar standard ground water.

The total variation of the Chloride and Hardness concentrations (Table 9) heavily increased from 6980748 (in 1979) to 8286469 (in 1981) and then to 17822103 (in 1983). The increased variation in 1983 is 100% on the basis of 1979 variation. The high level variation is also a major cause which led to segregate the ideal cluster into different standard ground water clusters.

Discrimination boundaries in relation to principal components were also proposed. The hardness variables are observed to have little extra information and the maximum variation is contributed by the variation due to chloride variables. That is, the widely varying chloride variables influence the drinking water standard rather than the hardness variation. Therefore, it is recommended that the studies on Chlorie variables should be given first preference to those related to other substances. In this context, the need for taking actual nitrate statistics and collecting data for population density distribution is emphasised.

The hierarchical clustering procedure highlighted the following conclusions. In 1979, the ground water source area of the study region was a singleton cluster and it would have been an ideal or good cluster of this region. It would be recalled at this stage that 55 to 65 per cent of the area was free from salinity in 1972 (2). The 1981 data analyzed in the present study showed that the source area had two main clusters of which one of them had two separate big portions separated by the other cluster.

The latest 1983 data analyzed clearly showed that there were six major clusters that occured in the region with different standard of hydro-chemical data. None of the clusters satisfied the international drinking water standard recommended by the World Health Organization (WHO) in relation to chloride concentration or salinity. However, the center portion of the study area consisting of four out of six identified clusters had fair quality drinking water. The remaining two clusters and five other small identified groups showed that they possess poor standard drinking water. The remaining odd sample points postulated the occurrence of very bad standard drinking water.

In respect of hardness concentration, the following conculation is apporpriate. None of the clusters had soft drinking water. However, four of them had hard drinking water and other small groups and odd sample points had very hard drinking water. It has been pointed out that cancer disease may be caused by very hard drinking water (16). The hardness in this region is attributed to the presence of Ca ions from the carbonate rocks.

Therefore, an up-to-date data collection all over the peninsula should be made for furture research. The landless people should be evacuated from this region and may be colonised in the Wanni area. Agricultural fertilizer usage should be controlled or limited. The crops which do not consume chemical fertilizers may be recommended to the farmers.

In this respect, it is suggested that the old, broken, abandoned bunds found in the Valikamam West and Valikamam South-West AGA divisions be reconstructed to prevent the saline water from flowing into the land during the rainy season. The inland lagoons dividing the peninsula into Vadamaradchy, Thenmaradchy and Jaffna-Valikmam region too should be prevented from flowing into land by bunds so that the purity of the rain water collecting in the land will be maintained.

Specifically, the places indicated by the clusters G, H, G*, H*, I*, J*, (04), (57), and (65) having very poor quality driniking water should be taken into consideration for the development of this region for drinking water by Water Resources Board or Water Supply and Drainage Board or any other authority. Further, plants like palmyrah, Casuarina, etc. which can absorb the salinity from the soil could be planted in areas spoken of in the above paragraph by the Department of Forest or the Department of Lands and Lands Development or any other authority.

8 : FUTURE RESEARCH

Based on the results obtained and conclusions drawn above, the important tools or parameters of this research are updated and given for future research. That is, statistically tested and verified Mean vector, Covariance matrix, Correlation matrix, first five eigen values and corresponding eigen vectors are given below.

Researchers in the related disciplines, may utilize these statistical parameters for their consequent research. These parameters have been updated only for the Chloride and Hardness variables.

Further, these tools are given on the basis of the latest available data of 1983 after discarding the clusters H, I and J given in the analysis of principal components. The Mean Vector, Variance-Covariance matrix, and Correlation matrix (n=63) are as follows;

Mean Vector :

(465.4 473.7 567.1 483.6 382.1 406.9 457.8 440.6)

Varianc-Covariance Matrix :

209549.4	196944.8	235763.8	205567.3	72247.0	74035.3	79616.0	68982.0
196944.8	211786.6	237475.6	189478.9	68954.7	82416.8	86630.8	62620.1
235763.8	237475.6	354236.4	242873.7	81223.8	89198.7	108320.5	76211.8
205567.3	189478.9	242873.7	245881.3	66840.9	67369.0	76924.5	86593.8
72247.0	68954.7	81223.8	66840.9	35913.4	33396.0	39674.0	32827.3
74035.3	82416.8	89198.7	67369.0	33396.0	39671.8	43928.9	29195.3
79616.0	86630.8	108320.5	76924.5	39674.0	43928.9	63965.1	39155.5
68982.0	62620.1	76211.8	86593.8	32827.3	29195.3	39155.5	48138.3

Correlation matrix :

1.000							
0.935	1.000						
0.865	0.867	1.000					
0.906	0.830	0.823	1.000				
0.833	0.791	0.720	0.711	1.000			
0.812	0.899	0.752	0.682	0.885	1.000		
0.688	0.744	0.720	0.613	0.828	0.872	1.000	
0.687	0.620	0.584	0.796	0.790	0.668	0.706	1.000

The first five eigen values and their eigen vectors are as follows :

1032470 (85.39%)	64564 (5.34%)	53389 (4.42%)	36539 (3.02%)	12493 (1.03%)
-0.435205	-0.185758	-0.061556	0.402017	0.631034
-0.431154	0.121314	-0.308635	0.531561	-0.488252
-0.553268	0.606802	0.451246	-0.302238	0.074808
-0.452182	-0.633589	0.353121	-0.123309	-0.295172
-0.155282	-0.042018	-0.333922	-0.139209	0.484970
-0.167035	0.090391	-0.400357	0.015482	-0.125318
-0.192474	0.161378	-0.506848	-0.451433	-0.140592
-0.158333	-0.380991	-0.209652	-0.475249	0.004111

It is observed that the first five principal components describe 99.2% of the total variation. Other values are comparatively very small and the meaningful dimension is five.

The adjusted mean values given in the above mean vector are different compared to the mean values given in table 4 because the total number of observations 68 has become 63 after eliminating five outliers or unusual clusters which are not suitable to the commom ground water source area.

The drawbacks in the quality of data available and the method of data collection are considered seriously. Hence a modified research approach is suggested as follows, for future research.

1. A detail research plan consisting of at least five sample wells in every GS (Grama Sevakar) divisional level shold be drawn to explore the actual cluster patterns of this region.

2. Separate studies should be performed in the Jaffna metropolitan area with its suburbs and in the rest of Valikamam area. Vadamarachi and Thenmarachi area also should be considered separately.

3. Population density data giving ground water use in every place together with the agricultural water use and fertilizer usage should be taken into consideration in Agricultural research.

4. Mortality studies on Cancer, Chronic Heart Diseases (CHD), etc. related to drinking water standard should be done in relation to HEALTH of the people. The clusters of very hard drinking water should be taken into consideration in these studies.

5. Specifically, Nitrate data should be collected and studied separately as previous studies (6) indicate that nitrate pollution affects Agriculture and Health mostly in this region.

6. The Hydro-chemical data, Climatological data and other Geological data should be pooled to carry out a major Multivariate statistical analysis.

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APPENDIX 1

Location names of each of the sample point are given below;

01. Jaffna town south
02. Jaffna town east
03. Jaffna town west
*04. Jaffna town north
05. Nallur north
06. Nallur north
07. Ariyalai
08. Thirunelvely south
09. Thirunelvely north
10. Kokkuvil east
11. Kokkuvil west
12. Kondavil east
13. Kondavil west
14. Kondavil north
15. Anaikoddai east
*16. Anaikoddai west
17. Navali

35. Atchevely north
*36. Idaikkadu
37. Palaly
38. Vasavilan west
39. Vasavilan east
40. Punnalaikadduvan
41. Urelu
42. Chunnakam east
43. Chunnakam south
44. Chunnakam west
45. Mallakam
46. Thellippalai west
47. Thellippalai east
48. Myliddy
49. Kankesanthurai east
50. Kankesanthurai south
51. Kankesanthurai west

18. Uduvil
19. Manipay south
20. Manipay north
21. Manipay west
22. Maruthanarmadam north
23. Maruthanarmadam south
24. Inuvil
25. Urumpiray north
26. Urumpiray south
27. Urumpiray east
28. Kopay sorth
29. Kopay north
30. Neervely east
31. Neervely wst
32. Puttur
33. Avarankal
34. Atchuvely south

52. Keerimalai
53. Ampanai
54. Alaveddy
55. Mathagal
56. Pandattarippu west
+57. Pandattarippu west
58. Chankanai east
59. Chankanai north
60. Chandanai south
61. Siththankerny
*62. Chulipuram
*63. Moolaai
*64. Tholpuram
+65. Vaddukoddai north
66. Vaddukoddai south
67. Araly north
68. Araly south

* Unusual cluster points in 1983.
\+ Unclassified sample points in 1983.

Appendix 2 a

	January	February	March	April	May	June	July	August	September	October	November	December
1.	820	970	1030	1170	1200	1280	1380	1320	1570	1400	1240	360
2.	260	110	280	150	140	160	310	350	220	420	280	290
3.	700	1000	1200	1280	1420	1380	1460	1510	1530	1860	1670	740
4.	520	350	410	530	730	750	750	740	760	960	810	430
5.	220	170	190	200	200	200	190	190	180	190	200	260
6.	220	140	160	190	160	120	90	0	240	410	320	220
7.	60	150	110	130	140	130	110	110	110	100	100	60
8.	350	270	250	260	250	250	240	260	260	250	250	280
9.	190	200	200	240	200	170	190	190	180	180	180	230
10.	1650	1300	580	430	400	510	330	530	450	410	370	1690
11.	70	80	100	110	130	160	150	130	140	230	130	140
12.	120	200	230	260	270	250	240	240	220	270	410	150
13.	580	340	280	330	350	340	350	340	350	340	410	530
14.	350	360	340	350	400	350	350	160	220	150	150	120
15.	220	270	330	440	500	560	590	510	700	0	1020	190
16.	4340	4760	5220	5900	5540	7200	7890	8640	8340	6230	5710	4080
17.	700	520	400	720	710	770	790	850	850	1070	1100	670
18.	15	80	20	60	60	60	70	130	80	50	30	50
19.	600	610	520	480	470	470	470	470	490	500	480	550
20.	30	160	30	60	170	80	60	90	90	100	60	40
21.	350	360	380	390	480	520	590	680	680	980	850	200
22.	270	160	150	160	190	150	150	160	160	200	370	260
23.	260	170	180	190	180	200	170	190	180	190	230	220
24.	990	1120	1020	950	940	710	660	620	480	470	390	1100)
25.	40	130	110	80	50	440	120	120	120	70	210	80
26.	120	140	140	150	240	160	140	150	150	160	150	80
27.	330	230	230	450	340	350	240	250	250	250	250	260
28.	1890	1680	1850	1940	1700	1740	1580	1650	1610	3270	2980	1700
29.	230	200	330	570	490	480	420	450	580	630	580	160
30.	330	450	640	690	730	780	770	850	0	680	780	250
31.	420	320	230	220	210	200	200	190	170	180	250	310
32.	2330	460	510	490	530	540	580	560	590	640	640	330
33.	40	90	60	90	40	80	50	40	50	40	60	40
34.	460	430	550	350	315	300	240	205	260	260	875	350

	January	February	March	April	May	June	July	August	September	October	November	December
35.	75	80	80	70	60	80	65	90	60	75	95	60
36.	1660	2820	4400	8500	12400	10470	17280	9480	9745	9850	2160	2380
37.	460	470	500	500	725	590	665	740	695	680	725	480
38.	80	85	85	170	100	70	75	80	120	75	85	95
39.	260	270	240	205	260	300	315	270	270	220	885	350
40.	470	460	490	490	465	485	490	490	550	315	465	470
41.	340	205	115	85	185	330	80	150	105	120	490	465
42.	45	90	50	90	50	40	50	30	45	70	50	75
43.	260	0	0	0	90	70	270	205	70	75	90	520
44.	300	350	0	75	90	465	560	470	490	490	470	360
45.	260	270	0	240	240	240	270	240	240	260	205	260
46.	460	460	395	460	410	480	475	485	590	530	785	680
47.	330	290	330	330	350	340	340	340	300	315	300	350
48.	1760	1160	1380	1000	1620	1585	1390	1485	1390	1585	1860	1970
49.	330	380	370	370	350	350	370	260	320	170	410	465
50.	620	130	155	155	135	130	110	95	150	100	95	500
51.	90	120	860	240	1035	270	220	135	270	240	140	140
52.	900	845	785	895	1000	940	1020	665	740	885	650	530
53.	80	75	50	90	90	95	90	80	75	75	70	75
54.	350	370	330	370	350	370	400	315	340	315	370	330
55.	750	820	755	620	460	580	440	430	430	430	395	905
56.	390	440	350	330	390	650	690	920	1070	880	650	680
57.	100	665	490	475	470	620	480	500	500	500	695	650
58.	75	95	80	60	90	90	80	90	105	140	70	70
59.	620	85	80	80	80	80	80	80	80	90	130	80
60.	940	915	825	840	665	620	665	590	590	530	1460	815
61.	810	870	870	840	810	930	665	620	650	680	830	970
62.	2580	1790	2090	1200	2020	2305	1960	2625	2270	2940	3950	4000
63.	1270	2000	2580	3300	5940	6770	9000	8875	9165	8500	4200	1900
64.	1950	1920	2995	3230	3570	3620	4000	3860	4000	4000	3580	1720
65.	0	1025	1240	395	1280	1360	1240	395	1100	1365	1870	1240
66.	350	410	410	470	480	475	490	490	490	490	550	550
67.	900	875	560	680	770	895	1000	985	1165	925	1140	800
68.	205	240	260	330	460	485	665	490	680	475	300	60

Appendix 2 b

	January	February	March	April	May	June	July	August	September	October	November	December
1.	520	560	770	780	460	880	850	840	1000	790	920	410
2.	250	160	320	400	430	230	400	350	300	340	370	320
3.	620	560	730	840	750	1020	960	930	950	1090	1100	460
4.	200	210	250	240	360	300	270	150	310	380	430	280
5.	380	300	300	280	550	320	330	350	360	360	420	420
6.	150	120	200	110	270	240	130	0	240	370	440	280
7.	250	170	220	560	340	310	260	270	320	190	320	240
8.	390	340	290	340	340	340	310	300	360	320	410	440
9.	380	350	250	470	480	500	400	400	440	460	290	490
10.	1340	1130	480	440	330	370	370	520	550	500	480	1690
11.	170	230	280	300	470	390	180	230	230	320	330	190
12.	180	250	320	270	320	290	260	370	280	260	440	310
13.	360	270	430	460	250	550	310	390	280	270	420	420
14.	440	510	510	520	390	450	440	310	370	340	410	270
15.	190	300	350	430	410	600	580	580	510	0	700	240
16.	1830	1820	2180	2350	2250	2640	2930	3370	3360	2530	2420	1860
17.	540	580	340	650	430	590	670	570	620	740	690	640
18.	180	300	290	350	390	330	400	490	320	250	270	330
19.	330	400	410	370	420	350	330	440	450	440	500	440
20.	140	160	190	340	420	190	190	240	200	230	290	240
21.	230	250	320	200	410	400	460	450	540	700	780	240
22.	220	380	280	390	320	330	230	220	240	320	580	350
23.	350	380	440	390	410	390	460	370	320	350	330	420
24.	640	690	840	710	510	530	570	390	390	380	210	960
25.	150	210	190	180	290	320	330	180	210	210	230	190
26.	180	320	270	330	320	300	320	300	340	320	400	430
27.	350	370	300	500	420	340	430	350	320	440	390	480
28.	740	500	700	780	720	330	380	700	680	1010	970	690
29.	220	330	460	600	450	420	470	390	570	580	540	340
30.	250	440	690	700	550	550	550	580	0	590	590	350
31.	350	360	260	260	500	300	320	320	250	290	380	230
32.	1180	680	780	660	650	720	740	680	680	740	770	540
33.	190	170	220	240	260	270	190	230	190	170	190	120
34.	200	370	350	380	430	420	360	320	340	450	550	280

	January	February	March	April	May	June	July	August	September	October	November	December
35.	220	430	310	230	290	390	240	260	240	230	200	240
36.	520	470	1030	970	1140	3660	7740	9200	8900	950	360	530
37.	300	420	550	590	650	730	650	700	660	580	470	550
38.	180	240	220	420	330	1610	380	580	150	220	280	230
39.	360	400	430	330	380	410	400	360	380	290	300	300
40.	150	480	480	460	750	550	360	500	470	510	560	420
41.	220	210	190	150	240	320	350	190	260	310	200	130
42.	190	300	210	140	270	220	270	170	150	250	100	160
43.	295	390	210	360	300	350	380	160	230	210	260	150
44.	400	410	310	350	40	400	400	450	440	430	470	340
45.	310	390	300	420	380	360	330	400	330	410	420	320
46.	380	610	330	570	470	570	520	390	230	500	430	410
47.	450	360	510	430	560	560	480	550	410	440	560	500
48.	810	700	950	600	760	910	670	920	780	720	780	860
49.	440	480	610	510	560	540	430	580	420	460	530	470
50.	130	100	310	330	300	280	370	280	230	210	240	210
51.	180	190	190	300	260	260	280	330	210	260	220	220
52.	340	410	370	410	370	280	250	320	310	380	370	370
53.	210	330	240	350	210	360	440	230	220	220	190	210
54.	400	460	410	520	550	380	630	370	380	400	320	440
55.	900	1010	940	1080	1100	1030	980	830	620	680	730	1010
56.	365	430	330	260	400	400	430	410	560	600	710	410
57.	600	850	800	700	800	860	730	690	750	950	940	430
58.	240	400	260	300	430	310	400	280	220	360	450	280
59.	200	380	100	240	430	300	230	240	200	210	180	260
60.	510	610	690	800	720	550	560	700	580	980	920	640
61.	560	490	470	500	670	630	500	610	490	600	680	530
62.	1070	720	470	400	610	690	850	970	1170	1420	970	730
63.	150	550	340	390	520	370	430	1320	1580	300	400	270
64.	850	180	1390	1610	1510	1630	1430	1320	1520	1400	1440	1270
65.	540	760	790	730	830	1120	810	990	840	650	810	370
66.	110	340	500	430	460	390	350	490	390	380	380	320
67.	550	860	400	250	380	600	470	400	820	750	380	320
68.	140	480	560	610	770	770	790	1110	890	670	320	250

Appendix 3 a

	January	February	March	April	May	June	July	August	September	October	November	December
1.	875	880	925	940	1050	1050	1595	1460	1605	1560	1000	725
2.	205	220	240	185	240	220	240	205	260	240	220	90
3.	1145	1560	1485	1510	1485	1410	1610	1695	1675	1720	1790	860
4.	500	710	785	845	815	770	875	970	875	985	1050	830
5.	190	220	220	205	205	260	240	195	260	260	110	140
6.	185	160	195	135	240	260	160	0	330	255	300	360
7.	160	230	140	140	155	140	125	205	170	205	220	255
8.	395	230	205	240	205	200	135	0	195	185	220	330
9.	180	190	195	185	205	160	205	185	220	220	205	380
10.	490	490	395	330	330	370	350	330	360	330	330	740
11.	80	75	100	80	90	150	95	135	100	100	205	85
12.	290	260	260	205	195	250	260	270	710	285	470	150
13.	270	325	185	330	220	270	340	285	315	330	340	750
14.	370	435	380	370	430	390	380	410	370	410	380	465
15.	460	490	475	470	440	470	490	650	480	0	0	740
16.	2865	4300	4800	5000	5310	6500	8500	8500	8750	8625	5000	5000
17.	470	490	490	560	560	500	695	665	665	725	1310	860
18.	60	70	80	85	105	125	175	100	195	135	50	70
19.	430	370	390	395	440	430	430	430	460	440	440	490
20.	100	90	85	80	85	85	85	90	90	100	120	75
21.	470	475	490	500	560	560	530	500	530	500	1070	530
22.	205	190	185	185	195	185	195	180	155	195	220	465
23.	210	220	220	240	195	160	155	170	240	195	205	360
24.	460	450	460	300	430	420	410	380	380	370	380	500
25.	100	85	90	95	95	50	90	80	100	130	240	340
26.	115	110	140	150	185	150	195	300	95	140	180	130
27.	125	120	100	90	90	60	80	50	80	80	105	125
28.	1960	1930	1850	1840	1860	2190	1880	2030	1860	1875	2995	2235
29.	290	390	470	460	460	410	470	540	470	470	530	205
30.	810	725	725	725	800	665	800	195	800	770	845	470
31.	195	175	190	120	120	180	100	180	180	195	220	360
32.	490	480	490	490	495	600	630	500	495	495	490	495
33.	580	500	40	60	65	60	45	40	60	60	70	55
34.	260	290	310	310	370	360	310	290	290	750	640	210

	January	February	March	April	May	June	July	August	September	October	November	December
35.	30	70	80	90	100	140	60	60	60	90	80	30
36.	1100	1630	2350	2550	4170	9520	20110	229000	20720	2320	780	950
37.	270	340	440	590	680	780	1070	1120	1090	680	530	250
38.	70	130	120	80	100	560	530	690	70	70	60	70
39.	330	310	260	220	260	270	280	330	340	300	270	320
40.	450	420	490	470	550	550	560	540	570	510	470	440
41.	300	310	260	90	170	170	150	180	120	450	300	250
42.	30	90	80	40	60	50	75	40	40	90	40	110
43.	70	270	80	260	60	270	270	70	80	90	90	70
44.	340	350	340	340	360	360	370	370	400	400	290	250
45.	270	360	310	260	290	250	250	260	260	280	260	240
46.	480	610	570	530	520	520	520	520	530	580	590	420
47.	350	330	280	290	300	300	290	310	300	320	380	510
48.	1490	1450	1380	1140	1150	1360	1510	1220	1310	1330	480	1500
49.	440	400	370	350	370	350	370	360	360	430	430	610
50.	80	90	90	130	180	140	240	130	150	100	100	910
51.	40	90	100	100	140	180	280	250	220	130	90	50
52.	500	520	440	490	410	400	370	340	300	400	340	420
53.	70	100	65	70	110	90	100	90	70	60	80	70
54.	360	410	370	400	380	380	350	390	340	370	300	330
55.	1000	1000	1020	1060	970	920	900	830	660	630	620	1000
56.	290	240	220	220	240	300	420	460	600	630	700	370
57.	490	670	630	580	520	620	590	580	760	850	790	340
58.	40	120	60	90	80	80	100	110	90	170	70	50
59.	30	90	50	90	130	90	120	90	100	90	70	50
60.	600	790	880	820	760	680	650	700	700	1140	1050	660
61.	690	580	600	660	710	690	690	710	700	840	930	780
62.	2380	1700	1060	1070	1220	1340	1550	1660	2310	2500	1730	1220
63.	40	120	150	310	170	150	270	2050	2390	250	290	100
64.	1700	1500	2150	2550	2630	2720	3080	3140	3850	2700	2680	2260
65.	920	1470	1410	1350	1500	1420	1450	1460	1520	1360	1210	410
66.	150	170	450	490	570	490	550	600	690	520	480	450
67.	710	890	370	300	360	640	650	880	1100	810	720	1300
68.	210	460	660	320	1060	1230	1310	680	1140	870	280	80

Appendix 3 b

	January	February	March	April	May	June	July	August	September	October	November	December
1.	530	600	550	560	560	740	760	490	790	860	640	570
2.	270	250	400	230	330	250	270	120	110	180	290	320
3.	270	940	820	820	720	860	710	930	880	910	1100	670
4.	300	330	210	260	320	270	270	280	290	300	660	450
5.	310	430	340	340	440	300	460	250	250	830	310	300
6.	220	150	280	240	320	300	240	0	200	240	240	410
7.	220	300	330	290	340	240	240	260	210	280	330	470
8.	270	250	300	340	600	220	230	0	180	310	300	480
9.	430	330	360	360	380	400	370	350	220	410	410	420
10.	620	570	350	380	290	340	350	430	330	400	220	1490
11.	140	170	320	170	430	230	200	280	190	190	0	360
12.	290	220	290	290	260	350	210	340	460	340	480	290
13.	400	410	250	270	200	310	270	300	300	350	570	580
14.	400	440	560	490	460	440	370	360	390	480	200	440
15.	430	380	320	330	460	370	390	480	470	0	0	540
16.	1190	1570	1860	2030	3450	2340	2650	2520	2690	2680	2130	2160
17.	350	490	370	400	650	550	390	550	570	470	930	780
18.	250	200	190	340	310	410	360	300	450	290	270	190
19.	440	450	400	350	300	450	330	440	330	250	240	460
20.	300	160	170	160	170	130	110	210	200	140	280	200
21.	490	370	540	570	510	630	440	640	430	500	780	510
22.	330	200	320	290	300	160	230	350	310	310	320	490
23.	360	410	420	300	330	380	260	180	180	230	230	240
24.	360	350	340	400	340	320	320	300	320	330	330	380
25.	360	180	160	160	260	230	130	190	240	130	170	540
26.	290	270	290	250	310	320	340	240	210	300	430	360
27.	300	240	310	280	270	290	240	180	140	250	110	160
28.	650	610	750	570	620	630	590	680	640	670	820	800
29.	390	350	510	500	450	530	470	550	510	510	510	330
30.	690	560	630	590	550	540	530	550	570	570	900	330
31.	240	260	210	170	190	200	180	180	90	130	210	380
32.	720	620	700	660	660	670	560	760	590	630	760	650
33.	180	160	230	260	250	200	160	490	190	280	250	160
34.	360	390	470	380	270	370	360	470	340	300	470	230

	January	February	March	April	May	June	July	August	September	October	November	December
35.	250	250	400	270	290	240	260	270	200	360	340	160
36.	790	1190	1890	2920	4560	4180	5820	3450	3620	3590	1050	1070
37.	490	470	560	580	570	570	520	460	510	530	600	420
38.	200	220	270	330	200	240	160	220	230	260	230	230
39.	380	340	420	280	360	390	290	300	320	280	360	290
40.	430	420	580	490	400	570	400	550	410	470	460	440
41.	210	220	210	120	180	160	180	140	160	220	220	480
42.	110	230	210	170	190	140	440	120	170	250	190	210
43.	400	0	0	0	240	250	410	270	160	210	200	810
44.	350	390	0	160	230	450	500	440	520	500	510	420
45.	350	420		260	440	470	290	300	270	260	370	410
46.	410	450	250	330	380	470	360	360	400	450	670	720
47.	520	570	550	560	540	560	560	510	330	270	440	400
48.	1180	990	900	810	1060	1070	950	940	930	970	1060	1350
49.	500	560	520	590	490	500	450	500	360	380	460	360
50.	450	290	300	370	320	370	280	310	330	230	250	590
51.	240	230	360	290	300	390	260	210	340	350	260	300
52.	600	530	430	460	590	590	460	360	430	490	500	410
53.	210	170	150	180	240	200	180	190	210	280	290	110
54.	240	360	330	320	380	420	290	270	330	360	410	230
55.	870	1000	850	750	670	590	580	500	470	590	550	880
56.	530	520	480	470	560	650	620	810	860	770	860	800
57.	240	940	740	690	710	670	640	750	680	800	910	850
58.	240	300	210	210	320	250	260	210	310	390	310	210
59.	920	200	170	180	190	260	300	130	230	290	320	200
60.	880	880	750	720	780	650	640	580	660	530	1230	840
61.	800	760	700	670	680	600	520	640	640	670	770	810
62.	1320	840	920	1140	810	1080	1070	1360	920	1240	2370	2460
63.	1500	2270	2640	2570	3430	4100	4450	4066	3870	3750	3600	1290
64.	1440	1200	1310	1480	1520	1430	1610	1560	1650	1620	1670	960
65.	0	640	710	520	580	610	800	410	820	780	450	970
66.	320	380	450	440	550	370	370	410	820	780	450	970
67.	870	800	640	620	640	800	780	920	850	850	1040	760
68.	300	260	400	310	300	500	560	490	570	460	360	230

Appendix 4 a

	January	February	March	April	May	June	July	August	September	October	November	December
1.	725	970	1200	1585	1695	1935	1900	0	2605	1825	0	1100
2.	100	155	170	185	285	240	220	0	0	340	360	410
3.	680	1630	1615	1640	1670	1595	1605	1670	1650	1750	1840	1360
4.	620	845	815	800	815	750	755	875	815	1435	1410	1100
5.	105	260	100	110	120	120	90	0	0	110	0	195
6.	145	135	135	175	155	130	105	0	360	270	360	270
7.	260	135	135	165	180	155	110	0	240	220	240	260
8.	270	220	195	240	240	195	180	0	165	185	220	195
9.	220	195	205	220	220	220	195	100	0	0300	0	240
10.	815	490	465	410	410	350	330	0	0	410	460	30
11.	45	100	80	100	95	130	105	0	260	240	105	130
12.	330	185	220	270	300	270	220	0	0	330	0	485
13.	370	330	300	380	340	285	300	330	330	315	300	395
14.	410	460	465	465	470	430	395	0	0	205	0	500
15.	340	560	490	620	665	490	490	500	495	1075	1050	970
16.	1460	3510	3160	5625	5935	2020	2090	8875	8815	9000	5000	1000
17.	620	490	485	740	725	665	665	725	650	905	895	1125
18.	65	60	80	125	0	0	75	80	55	70	80	55
19.	430	380	410	360	370	0	380	470	395	380	480	360
20.	45	45	80	80	90	0	75	90	205	85	120	120
21.	500	560	760	885	0	0	710	775	770	830	4500	1780
22.	205	150	170	170	195	220	140	220	185	170	340	380
23.	270	185	205	260	260	205	270	185	260	260	240	0
24.	495	205	770	185	590	205	240	0	270	340	340	0
25.	160	50	75	75	75	65	45	45	50	50	55	60
26.	370	460	460	460	465	430	410	0	0	220	0	185
27.	130	85	110	90	90	200	100	95	95	95	140	0
28.	2900	2970	2650	1995	1970	1825	1860	1860	2540	1970	3655	3160
29.	395	470	470	465	440	430	430	460	120	680	695	725
30.	755	785	845	860	895	860	815	895	960	1340	1535	1000
31.	285	195	260	220	220	205	185	140	195	185	285	185
32.	665	560	590	710	695	700	500	680	695	785	830	785
33.	50	45	45	60	75	55	95	60	75	75	75	75
34.	895	630	530	440	440	350	360	315	380	370	380	1365

	January	February	March	April	May	June	July	August	September	October	November	December
35.	95	45	50	60	75	55	80	75	80	75	80	90
36.	3445	4700	5625	1000	17710	37500	39000	36000	12250	4700	2940	3580
37.	490	590	650	830	1000	1100	1000	985	845	710	680	665
38.	80	480	80	45	45	40	35	50	45	45	240	55
39.	300	270	315	300	315	285	340	270	300	300	340	460
40.	460	475	470	220	220	120	465	430	300	350	220	220
41.	460	150	120	100	110	95	80	80	90	125	370	395
42.	180	150	285	270	260	285	140	110	170	205	135	330
43.	850	105	285	185	130	140	90	205	100	80	205	130
44.	430	465	470	590	650	650	620	590	500	770	800	940
45.	270	0	260	260	260	260	270	300	220	205	240	270
46.	665	560	650	590	500	590	490	680	665	680	845	95
47.	330	300	315	270	340	430	350	260	240	285	260	90
48.	2380	2410	2055	1720	1650	1790	1730	1860	1840	1690	1640	2600
49.	370	350	315	410	160	105	350	270	40	260	270	110
50.	85	590	205	155	175	440	205	120	50	130	90	120
51.	90	90	115	120	135	135	220	205	195	205	170	120
52.	650	815	905	725	560	495	530	495	485	490	530	650
53.	95	80	100	85	90	95	80	85	80	85	70	90
54.	395	395	380	360	350	410	395	350	340	370	370	295
55.	0	665	560	485	475	480	430	460	470	480	495	495
56.	350	330	490	350	465	755	680	360	725	725	695	590
57.	680	725	770	770	710	880	480	560	725	1100	970	1050
58.	0	55	65	0	100	80	90	65	90	110	120	160
59.	85	85	110	105	110	85	95	90	90	205	260	260
60.	470	395	500	590	875	1560	490	490	475	495	665	1246
61.	665	695	740	770	770	530	620	785	590	755	855	915
62.	1630	430	1875	1265	2580	2450	2715	3195	3160	4800	4800	1585
63.	205	270	315	860	3860	4800	7710	340	7190	6250	5940	1000
64.	1740	460	1885	3300	2940	3495	3860	4000	3725	3860	4000	2625
65.	270	205	1730	1595	1575	1365	1240	1165	925	1000	1630	1600
66.	970	205	440	460	495	475	495	560	485	695	590	490
67.	560	205	470	490	770	895	1360	1585	1315	1125	1160	755
68.	155	185	260	370	485	695	725	710	495	490	240	140

Appendix 4 b

	January	February	March	April	May	June	July	August	September	October	November	December
1.	490	580	600	720	780	880	950	0	1300	920	0	0
2.	280	280	230	270	220	190	280	0	0	300	0	0
3.	500	490	810	680	750	790	780	850	860	910	0	0
4.	360	470	250	250	180	230	300	250	320	500	0	0
5.	310	440	230	270	220	280	220	0	0	200	0	0
6.	200	270	170	220	180	200	180	0	450	260	0	0
7.	240	230	170	210	140	190	170	0	430	280	0	0
8.	450	330	270	310	270	310	220	0	350	210	0	0
9.	430	370	330	360	340	330	400	0	0	410	0	0
10.	860	670	460	430	350	400	270	0	0	440	0	0
11.	170	210	150	180	170	250	210	0	390	300	0	0
12.	330	270	220	270	230	300	290	0	0	430	0	0
13.	260	450	340	350	250	570	300	340	440	370	0	0
14.	560	530	450	470	450	400	470	0	0	300	0	0
15.	150	430	300	280	380	600	400	460	540	620	0	0
16.	660	1280	870	2050	1890	1420	1380	2770	3010	2980	0	0
17.	500	530	330	370	520	440	550	530	620	750	0	0
18.	270	290	260	290	0	0	210	210	190	220	0	0
19.	340	410	370	350	300	0	370	370	490	350	0	0
20.	500	640	560	690	0	0	610	560	540	660	0	0
21.	290	330	210	250	240	310	250	260	240	250	0	0
22.	400	450	310	370	280	210	320	300	420	290	0	0
23.	420	370	570	260	480	250	360	0	220	270	0	0
24.	320	250	190	280	120	160	130	180	200	280	0	0
25.	510	520	440	450	420	430	450	0	0	300	0	0
26.	300	340	250	130	180	790	100	260	290	250	0	0
27.	920	1030	730	580	710	650	540	710	910	650	0	0
28.	480	650	470	450	410	450	400	430	600	460	0	0
29.	670	680	710	490	600	460	510	640	690	980	870	0
30.	310	330	340	150	230	180	120	250	280	220	0	0
31.	860	830	770	750	710	680	640	710	720	960	900	0
32.	150	560	230	330	340	390	510	310	280	370	220	0
33.	600	560	230	330	340	390	510	310	280	370	390	0
34.	250	280	160	250	220	390	470	360	310	370	190	0

	January	February	March	April	May	June	July	August	September	October	November	December
35.	1330	2020	2100	4040	5850	9490	10680	13950	4760	2000	1140	0
36.	440	520	460	520	610	690	740	800	540	600	490	0
37.	220	550	250	230	130	130	140	180	160	120	330	0
38.	320	370	290	260	280	300	440	350	290	330	320	0
39.	490	520	390	250	250	180	470	500	400	350	310	0
40.	350	300	210	200	160	160	150	180	240	220	0	0
41.	240	240	260	220	200	180	170	210	220	230	0	0
42.	180	310	380	220	280	220	190	260	280	160	0	0
43.	430	520	590	550	480	570	600	600	630	730	740	0
44.	350	0	350	310	260	270	430	460	290	410	340	0
45.	520	530	350	490	360	400	430	480	520	630	620	0
46.	490	520	350	360	370	490	210	470	380	350	370	0
47.	1430	1470	1100	910	670	1170	1050	730	1080	1080	1000	0
48.	410	440	310	390	220	200	400	350	130	350	380	0
49.	370	590	280	210	150	460	360	260	270	370	220	0
50.	200	250	200	190	180	230	350	340	270	280	300	0
51.	200	250	200	190	180	230	350	340	270	280	300	0
52.	530	520	400	480	350	400	570	400	410	450	540	0
53.	220	250	130	300	160	190	350	200	170	240	180	0
54.	360	430	380	410	250	310	450	420	400	430	400	0
55.	0	780	610	450	580	520	440	600	600	940	600	0
56.	500	440	640	480	380	360	680	720	750	750	600	0
57.	920	950	700	820	630	720	590	810	710	1480	1180	0
58.	0	250	200	220	0	180	370	220	280	400	370	0
59.	270	250	200	270	170	160	250	260	210	310	330	0
60.	430	410	460	470	430	810	670	480	460	480	0	0
61.	640	670	640	670	600	470	520	600	680	700	730	0
62.	910	410	790	850	1110	1050	1280	1480	1620	2680	0	0
63.	290	440	380	450	630	1680	3050	4060	3850	3430	3000	0
64.	1280	390	950	1260	1280	1390	1510	1630	830	1680	0	0
65.	310	340	860	880	800	760	800	810	710	650	0	0
66.	680	350	330	430	450	400	420	490	450	540	0	0
67.	450	370	400	450	550	770	1030	1170	460	890	0	0
68.	230	320	250	350	420	500	630	570	490	500	0	0