An Appraisal of the Mayurakshi River System Water Quality – the Agrarian Basin

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Abstract

The Mayurakshi River system is an important interstate river system in India, and is widely exploited for various purposes. A preliminary assessment of the water quality of the Mayurakshi system, at eleven strategically selected locations in the West Bengal (India), was carried out. Most of the water quality parameters were found to be within the regulatory limits of the recommended standards and other indices, including water quality index (WQI). The WQI values varied from 70.45 to 84.09, and designated the Mayurakshi system ecologically in the range of good water quality type. Agglomerative hierarchical cluster analysis (AHCA) grouped the sampling sites into three clusters based on river water utilization criteria: degree of domestic use, agricultural practices, and fisheries. The study showed the utility of AHCA in decreasing the number of sampling sites and increasing the efficacy of continuous monitoring of the Mayurakshi basin. Overall the basin water quality was found ecologically sustainable with limited anthropogenic impact on the river water environment.

Keywords — *Cluster Analysis; Multivariate Analysis; Water Quality Index; River Water Environment.*

I. INTRODUCTION

Since ancient times, the rivers in India have played enormous roles in the country's economic and cultural development. Even today, the river valleys account for a very high concentration of the country's population and agricultural activities. However, these life-giving rivers are increasingly getting polluted, both from point and non-point sources, threatening the survival of hydrobiota as well as putting human-lives at risk [1]. Rivers are called the lifeline of the country as they provide freshwater for all the needs of the human population. The availability of freshwater depends on two basic components, namely, quantity and quality. Not only the per capita water availability is falling year by year, the quality of water is also under threat [2], [3], [4]. It should be beyond doubt that water is an increasingly scarce resource in India. The country's population has quadrupled since 1951, but shares the same 4000 billion cubic meters (BCM) of precipitation. Therefore, in the context of a growing economy, India needs better management of its freshwater resources [5]. Water pollution decreases the availability of water for consumption. The treatment of polluted water for consumption enhances the economic burden. The biggest dilemma is that the rivers are the sources of water supply, and after use they become the sinks for mostly untreated wastewaters. This problem is more relevant for the developing countries where proper infrastructure for the water management and, prevention and control of pollution is still inadequate.

Progressive urbanization and industrial development have increased the use of rivers as waste disposal bodies. The pollution arising from these anthropogenic activities and other sources, such as increased application of agricultural chemicals, has made rigorous assessment and monitoring of the river water quality indispensable [6]. In recent years, research on river environment has increasingly gained momentum in India (for details see review work of Manoj and Padhy [3]). The baseline study of all possible stretches of rivers in India is necessary to prepare an inventory of the river water environment. Water quality assessment provides information on aquatic ecosystem health; sheds light on water quality trend analysis; identifies the types of water quality problems; defines the probable reasons behind deterioration of the aquatic health; and provides a collective information source that can essentially be used by the regulatory agencies and resource managers to make decisions and evaluate other alternatives [6]. This is necessary for proper management of the river basins, and prevention and control of river water pollution. Based on some above mentioned points, a baseline assessment of the Mayurakshi River system, in the Indian state of West Bengal, was carried out. The Mayurakshi River water during its course is used for irrigation, drinking, as a source for capture fisheries, and various other purposes [7].

II. MATERIALS AND METHODS

A. The Mayurakshi River System

The Mayurakshi River originates from the Trikut Mountain in the Jharkhand state, and further downstream flows through the state of West Bengal. The river is a tributary of the Hoogly River. It drains Birbhum and Murshidabad districts of the West Bengal before meeting the Hoogly. The Bakreshwar River is a tributary of the River Mayurakshi. The Bakreshwar also has its origin in the Jharkhand state. It passes through the Birbhum district and then meets the Kopai River. The combined Bakreshwar-Kopai stream drains into the Mayurakshi. The Mayurakshi River has two dams: Massanjore Dam (also called Canada Dam), located about 65 kilometers upstream of the Seori (the district headquarter of the Birbhum); and the Tilpara Dam, located about 32 kilometers downstream of the Massanjore Dam [8]. The Mayurakshi River is a rainfed river. The river in its course is joined by a number of tributaries and rivulets. During Monsoon the river swells up, and during summer gets reduced to a narrow stream. The bed material of the river is mostly sandy [7]. The Mayurakshi forms one of the three major reservoirs in West Bengal. The Mayurakshi reservoir project is one of the seven major irrigation projects in the state of West Bengal. The total irrigation potential created in the state, till 2013-14 AD, through various schemes, including Mayurakshi project, is 16.50 lakh hectares. The total catchment area of the Mayurakshi-Babla basin is 5,958 square kilometers; out of which 2,720 square kilometers is in the West Bengal [9].

B. Study Area, Water Sampling and Analysis

The present study was carried out on the Mayurakshi River system, spread over Birbhum and Murshidabad districts, in West Bengal, India (Fig. 1). The river water in the study area is mainly used for agricultural activities, domestic purposes, and fisheries. Water samples were collected from 11 locations along the Mayurakshi River system. The collected samples were delivered on the same day to the laboratory and kept at 4°C until processing and analysis. The samples were analyzed for 15 physicochemical parameters, namely, pH, total dissolved solids (TDS), total hardness (TH), sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), nitrate (NO_3^{-}), chloride (Cl^{-}), dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) following standard methods [10]. The pH and DO were determined at the sampling spots.

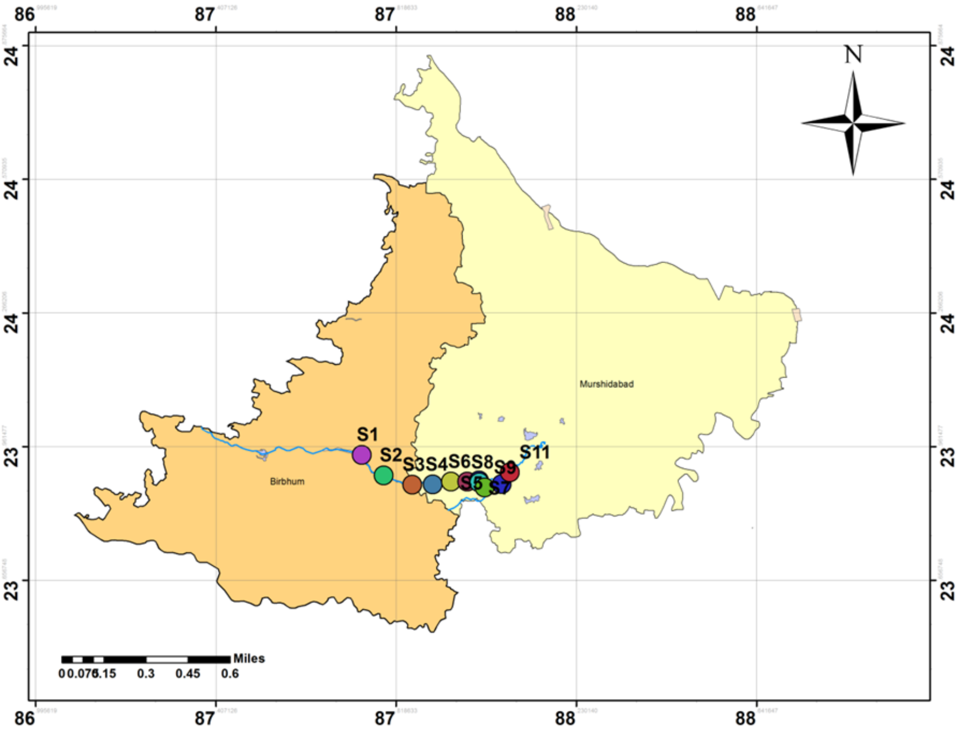

Fig 1: Sampling Sites Along the Mayurakshi River System

C. Computation of Water Quality Index

Water quality index (WQI) was computed using the equation and classification described below.

$$WQI = k\frac{\sum_i CiPi}{\sum_i Pi}$$

Where, ‘k’ is the subjective constant; represents visual impression of the water; and its magnitude can be: 0.25 (for highly contaminated water), 0.5 (for moderately contaminated water), 0.75 (for lightly contaminated water) and 1.00 (for apparently good quality water). The WQI of each sampling site was determined from 12 water quality parameters, namely, pH, TDS, TH, Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^-, Ca^{2+}, Mg^{2+}, DO, BOD and COD. The equation employs a normalized (*Ci*) and a relative weight (*Pi*) values assigned to each parameter. These values are available in the published works of authors [11] and [12]. In this method of WQI calculation, a higher *Pi* is allotted to those parameters which are considered most vital for the hydrobiota (for example, DO = 4). The parameters considered relatively less important for the hydrobiota are allotted comparatively lower *Pi* values (such as, pH = 1). To do away with the subjective evaluation of the Mayurakshi water quality, constant k was not considered in the present study. The size of WQI ranges from 0-100, and is separated into five classes, namely, 0-25 (represents very bad water quality), 26-50 (represents bad water quality), 51-70 (represents medium water quality), 71-90 (represents good water quality) and 91-100 (represents excellent water quality) [13], [12], [14].

D. Agglomerative Hierarchical Cluster Analysis

The agglomerative hierarchical cluster analysis (AHCA), a type of multivariate statistical technique, was used to classify water quality of the Mayurakshi River system. Recently, Manoj and Padhy [15] have provided in detail various multivariate statistical techniques commonly used for water quality data exploration. Cluster analysis is an exploratory data analysis statistical technique to classify the objects into homogeneous clusters or groups from an unclassified data [16], [17]. Members who belong to the same cluster display stronger affinity than the members of other clusters [16]. Both hierarchical and non-hierarchical cluster analysis techniques are available. However, the former has some advantages over the later, since it doesn't require the number of clusters to be fixed in advance [18]. The hierarchical mode employs a stepwise method to combine or split objects, which ultimately makes a tree like configuration called dendrogram. The hierarchical cluster analysis is of two types: agglomerative and splitting (divisive). The agglomerative clustering begins with each object as its own cluster which successively joins the next closest object forming a new cluster. This course of action repeats continuously until there is only one final cluster [19]. To classify water quality samples, in the present study, AHCA was conducted using Ward's method and squared Euclidean distance as a proximity measure. The squared Euclidean distance measure can be expressed in the form of equation as [20]:

$$d_{ij}^2 = \left[\sum_{l=1}^{q} (x_{il} - x_{jl})^2\right]$$

Where, d_{ij}^2 = Squared Euclidean distance for two individuals *i* and *j*, each measured on *q* variables, x_{il}, x_{jl}, l = 1, …., q.

III. RESULTS AND DISCUSSION

A. Physicochemical Description

The physicochemical assessment of the water quality of the Mayurakshi River system showed that the values of pH ranged from 7.12 to 7.95; TDS from 155.53 to 231.14 mg/l; DO from 4.43 to 7.28 mg/l; BOD from 1.4 to 3.7 mg/l; COD from 15.4 to 30.9 mg/l; TH from 52 to 92 mg/l; Na^+ from 26.14 to 26.67 mg/l; K^+ from 10.67 to 19.24 mg/l; Ca^{2+} from 17.83 to 18.35 mg/l; Mg^{2+} from 9.27 to 19.88 mg/l; HCO_3^- from 80 to 150 mg/l; SO_4^{2-} from 15.4 to 15.94 mg/l; NO_3^- from 32.83 to 36.60 mg/l; PO_4^{3-} from 0.32 to 1.32 mg/l and Cl^- from 10.23 to 45.6 mg/l (Table 1). A comparative account of the obtained results with that of the Bureau of Indian Standards, BIS [21] and Central Pollution Control Board, CPCB [22] water quality guidelines is discussed below in the text.

B. Non-ionic Parameters

Arvind [7] reported some hydrological factors of the upper Mayurakshi River in the Dumka district (presently in Jharkhand state). The various parameters measured, along with their range values, were: pH: 7-8.6 units; DO: 4-12.6 mg/l; alkalinity: 39-170 mg/l; hardness: 30-90 mg/l; BOD: 2.5-12.8 mg/l; and Cl^- 7.8-90.5 mg/l. The river waters generally display pH in the range of 6.8-7.8 units and, therefore, are usually classified as alkaline water type [23], [3]. The Mayurakshi River system displayed pH in the range of 6.8 to 7.8 units or near to it. The pH of the river water was also found within the desirable limit (6.5-8.5) of the BIS. The present study, and the study of Mayurakshi by Arvind [7], showed that the Mayurakshi River is alkaline. The TDS of the river water is an important indicator of environmental quality because it represents the concentration of ions in water. Dissolved solids influence palatability of water for domestic consumption. Based on World Health Organization, WHO [24] classification, the TDS can be indexed as: excellent (<300 mg/l); good (300-600 mg/l); fair (600-900 mg/l); poor (900-1200 mg/l); and unacceptable (>1200 mg/l). The present study displayed TDS content within the desirable limit (500 mg/l) of the BIS as well as WHO (all samples <300 mg/l). Based on hardness, in terms of $CaCO_3$ equivalent, the water quality can be classified into four groups [25]: soft water (<75 mg/l); moderately hard water (75-150 mg/l); hard water (150-300 mg/l); and very hard water (>300 mg/l). The Mayurakshi waters ranged from soft to moderately hard. Hardness of the river was within the BIS recommended desirable limit (300 mg/l). The content of DO in rivers indicates the degree of organic pollution load as well as the intensity of their self-purification capacity [6], [3]. When the DO is below 5 mg/l, the functioning and survival of the aquatic biotic communities may be severely affected; and DO below 2 mg/l may lead to mortality of most fish [6]. As per the recommendation of the CPCB, DO should be 5 mg/l or more and 6 mg/l or more for outdoor bathing (organized sector) (class B) and drinking water source (class A) respectively. However it recommends DO to be 4 mg/l or more for the propagation of wildlife and fisheries. None of the sites along the Mayurakshi displayed DO less than 4 mg/l, and only 2 sites showed DO less than 5 mg/l (Fig. 2). Radojević and Bashkin [26] have provided a water quality classification based on BOD: <1 mg/l (very clean); 1.1–1.9 mg/l (clean); 2–2.9 mg/l (moderately polluted); 3–3.9 mg/l (polluted); 4–10 mg/l (very polluted) and; >10 mg/l (extremely polluted). Based on this classification, 3 sites along the Mayurakshi were found to be moderately polluted and 2 sites polluted. These sites also violated the CPCB standards for classes A and B, as well as class C. The BOD of the river water should be maintained at a level below 4 mg/l, because at level greater than 4 mg/l the self-purifying capacity of the river is lost [26]. The unpolluted surface waters display COD concentration generally below 20 mg/l [6]. Four sites along the Mayurakshi showed COD level considerably greater than 20 mg/l, while two sites displayed concentration vey near to it (Fig. 2).

Table 1: Descriptive statistics of the water quality of the Mayurakshi River system

Parameters	Min	Max	Mean	SD#
pH	7.12	7.95	7.36	0.25
TH	52	92	62.91	14.32
Na^+	26.14	26.67	26.35	0.17
Ca^+	17.83	18.35	18.04	0.17
K^+	10.67	19.24	14.77	2.55
Mg^+	9.27	19.88	12.37	3.64
SO_4^{2-}	15.4	15.94	15.63	0.16
NO_3^-	32.83	36.6	34.71	1.16
PO_4^{3-}	0.32	1.32	0.73	0.33
Cl^-	10.23	45.6	26.84	12.24
HCO_3^-	80	150	120	20.98
TDS	155.53	231.14	195.08	25.69
DO	4.43	7.28	5.94	0.96
BOD	1.4	3.7	2.15	0.77
COD	15.4	30.9	20.71	5.52

All values in mg/l except pH in pH units; #standard deviation

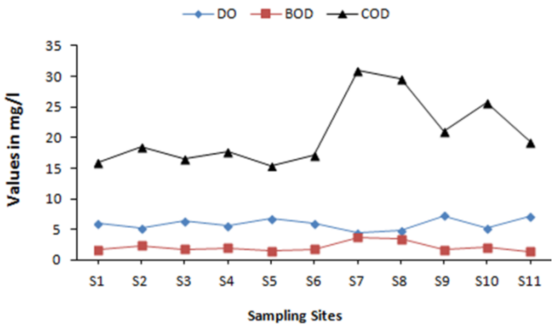

Fig. 2: Measured values of DO, BOD and COD at different sites of the Mayurakshi system

C. Ionic Chemistry

Sodium, in its ionic form Na^+, is a widely distributed component of most of the natural waters. Its concentration in surface water may range from less than 1 mg/l to greater than 300 mg/l [27]. The concentration of Na^+ in the Mayurakshi showed almost uniform distribution along the sampling sites, suggesting its presence in the river system predominantly from the natural sources. A similar situation was observed for the Ca^{2+} ions, suggesting its natural origin in the river water. The concentration of Ca^{2+} was also within the recommended desirable limit (75 mg/l) of the BIS. The concentration of K^+ ions, though less than the level of Na^+ ions, showed a wide range along the Mayurakshi sites. The content of K^+ is lower in surface waters due do its weak migratory capacity. It is actively involved in biological activities such as absorption by the living organisms [23]. In addition to natural origin, the presence of K^+ in the Mayurakshi might also be due to human-induced activities. Application of potash chemical fertilizers, for agricultural practices, probably was responsible for the wide variation of K^+ in the Mayurakshi waters. Bicarbonate is the most important contributor to alkalinity in natural waters [26], [27]. Subramanian [28] reported average chemical composition of some South Asian Rivers, and found HCO_3^- ions as the dominant factors. The same is true for the Mayurakshi system. The piper diagram also shows dominance of the HCO_3^- ions in the Mayurakshi system (Fig. 3). The SO_4^{2-} ions in the river were within the desirable regulatory limit (200 mg/l) of the BIS. Almost uniform pattern of SO_4^{2-} ions in the river indicated its natural origin. For the freshwater, the Cl^- ion concentration between 1 and 100 mg/l is considered normal [29]. The concentration of Cl^- fluctuated in the Mayurakshi system. This could be due to use of salts such as potassium chloride in agrochemical fertilizers and their subsequent run-off. However, the Cl^- ion concentration was within the BIS desirable limit (250 mg/l). Along with potassium, nitrogen and phosphorus are the other two primary plant nutrients. However, presence of 0.1 mg/l total phosphorus in water bodies is unacceptably high; and its concentration in water at 0.02 mg/l is often a problem [30], [31]. The addition of phosphorus, in the form of PO_4^{3-} ions, to the surface waters is a major environmental threat due to its role in causing eutrophication [26], [31]. Although, NO_3^- overload also contributes to eutrophication, phosphate is the main factor in freshwaters [26]. Higher nutritional status of the water accelerates the process of eutrophication [32], [33]. The Mayurakshi waters displayed PO_4^{3-} ions much beyond the acceptable levels, suggesting its presence from various anthropogenic sources. Agricultural run-off of chemical fertilizers and discharge of wastes could be chief sources of phosphate burden in Mayurakshi waters. The BIS recommended desirable content of NO_3^- in waters for palatability is 45 mg/l, beyond which it may cause methaemoglobinemia or blue-baby syndrome. Although NO_3^- levels were within the regulatory limit, its concentration was significantly higher among major ions. Two major factors behind the occurrence of NO_3^- ions in the Mayurakshi could be agriculture and domestic waste discharge. For NO_3^- overload of the surface waters, agriculture is a major source due to N-containing chemical fertilizers and run-off from animal feedlots [26].

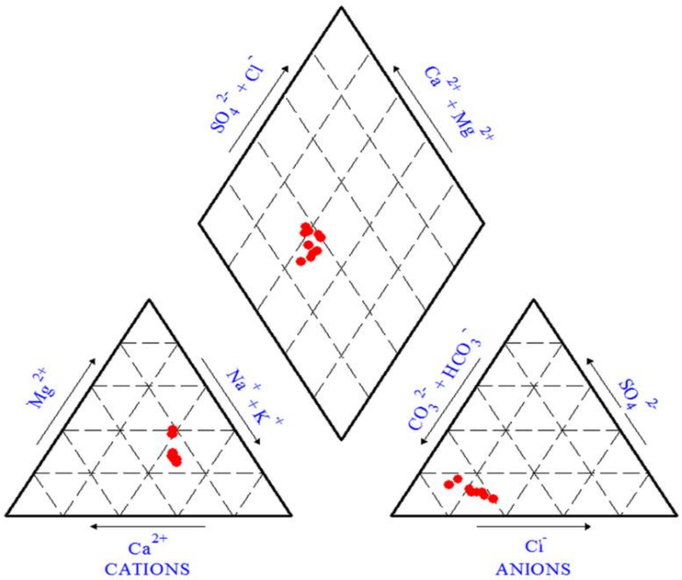

Fig 3: Piper Trilinear Diagram of the Mayurakshi Water Quality Data

D. Water Quality Index

Statistically, WQI is a univariate expression which is obtained by combining sub-indices of the measured variables. It is often advocated as a suitable indicator of surface water pollution [12], [14]. The WQI not only provides information about the nature of the water body, but is also highly useful in trend analysis [17 and reference within]. The WQI developed for the Mayurakshi basin varied from 70.45 to 84.09 (Fig. 4). Thus, the river system can be designated with a good quality water type. Individual characterization of the water body using water quality parameters does not provide clear picture about the overall status of the water system. This gap can be bridged with WQI, which then conveys information in simple and effective terms to the stakeholders, such as, general public, policy makers and regulators about quality assessment, and conservation and management of water bodies. Moreover, it overcomes many hurdles associated with the mathematical-computational modeling of the aquatic systems [17 and references within]. The index analysis approach can also be used in preparation of the water quality map of the river basin.

E. Agglomerative Hierarchical Cluster Analysis

Agglomerative Hierarchical Cluster Analysis was used to identify similar members among the sampling sites. The dendrogram representing AHCA is shown in Fig. 5. The software application grouped 11 sampling sites into three clusters, namely, Cluster-I, Cluster-II and Cluster-III. Cluster-I comprised sampling sites S7 and S8; Cluster-II included sampling sites S1, S3, S4 and S5; and Cluster-III contained sampling sites S2, S6, S9, S10 and S11. This grouping of the Mayurakshi sampling sites in effect characterized the use of river system. Locations S7 and S8 are mainly used for the domestic purposes such as human bathing, washing clothes, and cattle bathing; S1, S3, S4 and S5 sites are chiefly used for agricultural activities; and S2, S6, S9, S10 and S11 sites are used for fisheries. The Cluster-I can be effectively named ‘domestic group’; Cluster-II ‘agricultural group’; and Cluster-III ‘fisheries group’.

The grouping of Mayurakshi sampling sites into three well defined groups suggested the efficacy of cluster analysis technique in water quality research. For continuous monitoring of the Mayurakshi system in the West Bengal, the sampling sites may be reduced. This reduction in sampling sites may not only provide quick monitoring and assessment, but may also help in cutting down environmental and financial costs associated with the water management programmes.

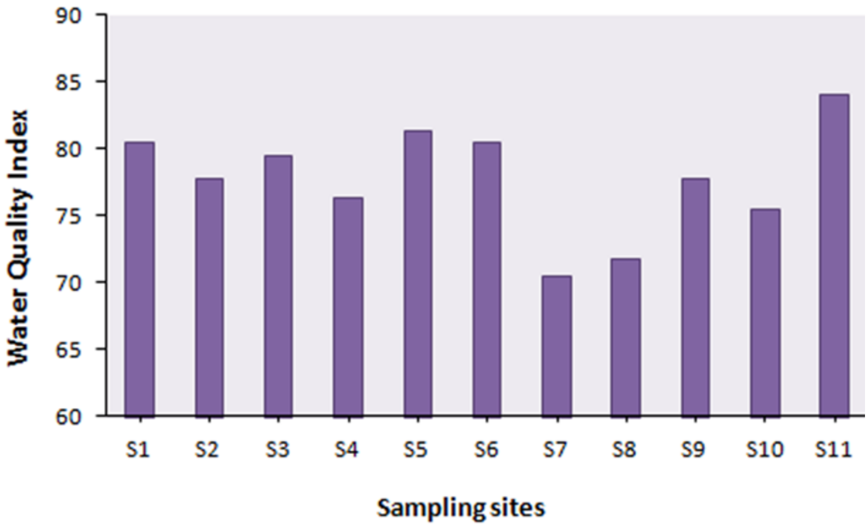

Fig 4: Water Quality Index Values Obtained at Different Sites of the Mayurakshi System

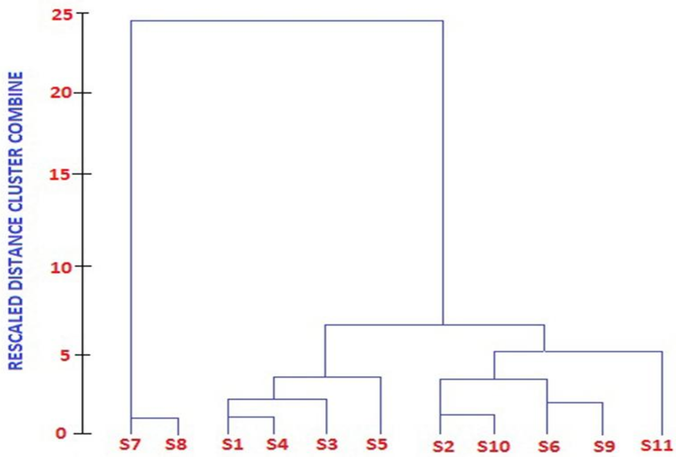

Fig 5: Dendrogram of Multivariate Cluster Statistical Analysis Exhibiting Three Differentiated Groups

IV. CONCLUSIONS

The study showed limited human-influenced disturbance of the water quality of the Mayurakshi system. Most of the sites displayed water quality parameters within the regulatory standards. The river system showed 'good water quality' type, which was evident from the WQI values, which ranged from 70.45 to 84.09. AHCA assembled the Mayurakshi sites into three categories, based on utilization criteria of the river water: degree of domestic use, agricultural practices, and fisheries. The present study, therefore, demonstrated the convenience of AHCA in reducing the number of sampling sites along the river basin and increasing the efficacy of continuous monitoring. Overall the basin water quality was found ecologically sustainable with self-purification capacity of the river system still unharmed.

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