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Surface Water Quality Status of the Nayaru Lagoon in Sri Lanka and its Impacts on Aquatic Organisms

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Abstract:- Lagoon ecosystems are an integral part of the aquaculture and fisheries sector in Sri Lanka. Among the brackish lagoons around the island, Nayaru Lagoon is considered a complex socio-ecological entity of great importance since the economic value provided by the lagoon is mostly associated with the biological production of aquatic animals and plants. The lack of recent and reliable ecological information prevents the authorities from assessing the ecological importance of the lagoon and the possible impacts on Aquatic organisms. Thus, this study, in a preliminary phase, aims to determine the ecological importance of the lagoon, with the objectives of assessing the Physico-chemical parameters of the lagoon water and evaluating the impacts of water quality on aquatic organisms. Water samples were collected from 25 sampling points within the lagoon using a random sampling method, consisting of shallow and deep areas of the entire lagoon and the lagoon mouth. Both in-situ [pH, Water Temperature (WT), Electrical Conductivity (EC), Salinity, Turbidity, Total Dissolved Solids (TDS), and Dissolved Oxygen (DO)] and laboratory analysis [Nutrients and Total Suspended Solids (TSS)] of water samples were carried out using the APHA standard method. Results were compared using standards provided in the Inland water quality guidelines provided in the National Environmental Act 01 of 2019, Sri Lanka. The results showed that pH, WT, and DO levels were within the ambient levels which are suitable for aquatic organisms. However, a significant spatial variation in salinity, TDS and EC levels were identified in the lagoon water samples. A comprehensive study on this lagoon is recommended to understand the seasonal variation in parameters and their collective impacts on the aquatic organisms as a way forward.

Keywords:- *Hazardous, Water Quality, Brackish water, Lagoon, Ecosystem, Aquaculture.*

I. INTRODUCTION

Lagoon ecosystems are very productive in terms of providing nursery and breeding grounds for several types of both fin and shellfish species and being a source for aquaculture and fisheries activities [1]. In particular, lagoon ecosystems function as one of the eminent natural resources for the fisheries sector in Sri Lanka. There are around 82 lagoons in Sri Lanka along its 1338 km of coastal stretch, including 4 lucrative brackish water lagoon ecosystems namely Chalay, Nanthikadal, Nayaru, and Kokkilai in the Mullaithivu district [2].

Among these four lagoons, Nayaru Lagoon is a major coastal habitat, spanning roughly 1,760 ha in the Northeastern part of the Island [3]. The lagoon's major freshwater sources are Nay Aru and Palidai Aru which enter from the western part of the lagoon [4][5]. These rivers drain large quantities of water into the lagoon during rainy months from October to December [5]. A wide lagoon mouth is located at the Southeastern part of the lagoon with a maximum depth of 3-4 m, through which the lagoon receives seawater [3]. During the rainy season, due to the peak water content of the lagoon, the sandbar mouth is usually removed at the lagoon sea connection point and the sandbar mouth closes after the end of the rainy season [5]. Nayaru Lagoon is surrounded by a thick cover of vegetation including a well-developed mangrove cover. Notably, mangroves are the most dominant type of vegetation present around the lagoon with a variety of species including; *Avicennia officinalis, Lumnitzera racemosa, Rhizophora mucronata,* and *Scyphiphora hydrophyllacea* [6]. The southern and western shores of the lagoon have a comparatively dense cover of mangroves.

The lagoon shores are bordered by the nearby villages; Chenmalai, Simmalai, Thangapuram, Kalampil, and Kumulamunai where a considerable proportion of the population conduct lagoon fisheries as their main livelihood [4]. Rich and dense vegetation covers the lagoon waters and the relatively undisturbed nature of the environment are providing pristine habitat conditions, and spawning and breeding grounds for different fauna species, especially aquatic and avifaunal species. Although catadromous and anadromous finfish and sedentary and sessile shellfish species are the mainstays of pragmatic importance of the Nayaru lagoon, it also provides excellent habitats for migratory birds [2].

However, the recent development activities implemented around the Nayaru Lagoon area have eventually catalyzed the clearing of some mangrove patches and the construction of an overhead bridge across the lagoon mouth for transportation. This may have led to significant hydrological changes in the lagoon which could eventually result in the collapse of the lagoon fishery and the vast decline of the mangrove vegetation cover around the lagoon over the years [7]. Due to the country's situation during the

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previous three decades of civil war, these lagoons in the Mullaitivu district have been abandoned [3]. Further, demarcating lagoon zones as high-security zones led to the inability to exploit resources, and people around the lagoon faced a loss of livelihood opportunities [2]. Nevertheless, the biological resources of the lagoon ecosystem are being exploited for commercial, residential, agricultural, aquacultural, and industrial development activities during the past decade without considering the value of this ecosystem. And these development activities considerably impact the changes in the Nayaru Lagoon ecosystem [7].

As one of the consequences of establishing the high-security zones around Nayaru Lagoon, there has been a very limited number of studies carried out so far on these lagoon ecosystems. The lack of availability of well-founded and latest updated aquatic-ecological information on the Nayaru lagoon ecosystem prevents the relevant authorities from determining the ecological, social, and potential economic importance of the Nayaru Lagoon. Further, to determine the magnitude of the impacts of development-based resource exploitation, a comprehensive set of baseline data on lagoon water quality is essential, in terms of making vital decisions for the sustainable management, conservation, restoration, and utilization of the lagoon ecosystem and its resources. Therefore, ensuring the ambient physicochemical and biological status of the aquatic environment in the lagoon is very important for aquatic life in terms of maintaining the survival and breeding potential of aquatic organisms, and conserving the biodiversity of species endemic to the environment.

Thus, this study aims to evaluate the baseline water quality status of the Nayaru Lagoon and how the changes in the parameters impact the aquatic organisms of the lagoon ecosystem. Further, this study also intends to widen the conservation scope on brackish water lagoon ecosystems by providing baseline data acquired in this study.

II. MATERIALS AND METHODS

A. Study Area

Initially, 25 sampling locations were selected covering the entire area of the Nayaru lagoon based on the judgmental sampling techniques while considering the channels, nearby agricultural lands, and pollutant input through the river from domestic waste, farming waste, and agricultural waste. Sampling locations were demarcated using GPS coordinates and depicted in Fig 1.

B. Field sampling and analytical procedures

In-situ measurements of water quality parameters, Water Temperature (WT), pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Turbidity, Salinity, Total Dissolved Solids (TDS), and depth were taken during the field investigation. The surface water temperature was measured with nearest to 0.1^{0}C accuracy, while water depth was measured manually.

Further, water samples from each sampling location were collected in glass and polypropylene bottles, preserved, and transported to the laboratory for further analysis. Physico-chemical parameter assessment is done to understand the existing environmental condition of Nayaru Lagoon in terms of overall water quality. Measurements of parameters such as Ammoniacal-Nitrogen, Nitrate-Nitrogen, Nitrite-Nitrogen, Dissolved Phosphate, Total Suspended Solids (TSS), and Primary Productivity were assessed after necessary laboratory experiments. The methods of sample collection, preservation, transportation, storage, and analysis of Physico-chemical parameters were strictly aligned with the Standard Methods for the Examination of Water and Wastewater (22nd Edition, 2012) and the Standard Methods prescribed by the American Public Health Association [8].

III. RESULTS AND DISCUSSION

A. The physicochemical characteristics of the Nayaru Lagoon

The summarized data of both in-situ and laboratory analysis of the physico-chemical parameters of water samples from the Nayaru Lagoon are provided in Table 1. The months between December and February receive rainfall from the North-East Monsoon and are considered a comparatively wet season in Mullaitivu district [9]. Mullaitivu district receives an annual average rainfall of 1340 mm [10] and the Nayaru Lagoon receives annual rainfall of 1492.5 mm [11].

The pH is one of the most important environmental factors that determines aquatic organisms' survival, metabolism, physiology, and development [12]. When comparing the data, no difference is observed for near sea mouth and inside the lagoon. The highest and the lowest pH were recorded as 7.8 and 6.7 respectively. The pH of surface water is normally influenced by bottom sediment characteristics, microbial activities, and photosynthesis by dense phytoplankton blooms, but it may also be influenced by total alkalinity and acidity, as well as runoff water from nearby soil [13]. Present study results showed that the mean pH of lagoon lies within the range of 6.0 to 8.5 which is suitable for aquatic life.

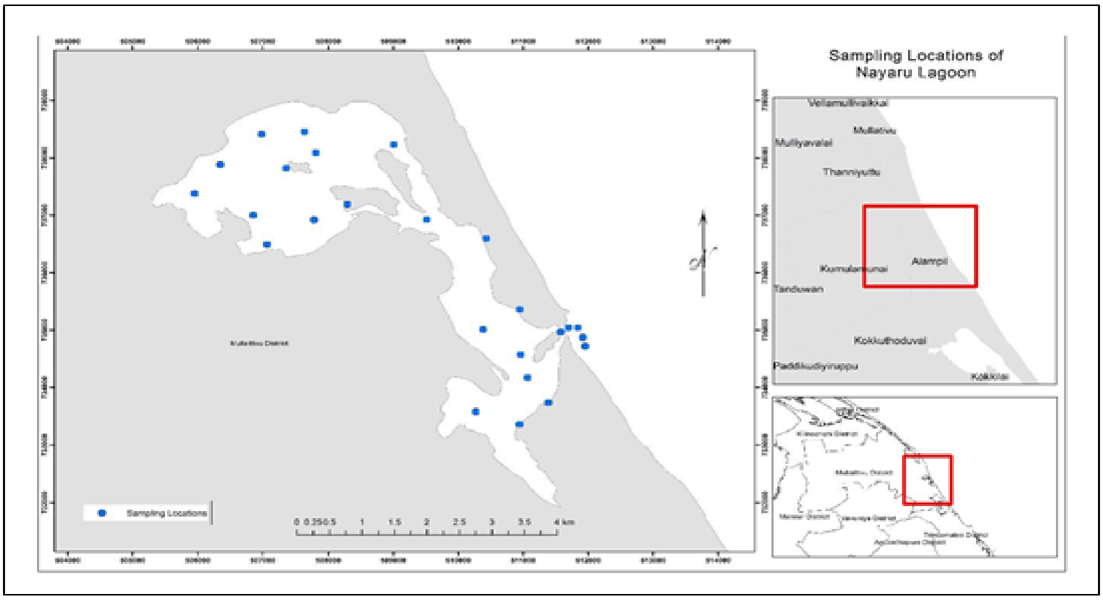

Fig. 1: The Nayaru lagoon system showing the different water quality monitoring stations

TABLE 1: WATER QUALITY DATA OF NEAR SEA MOUTH, LOW DEPTH AND HIGH DEPTH

Parameter	**Unit**	**Near sea mouth** (Mean ± Std)	**Low depth** (Mean ± Std)	**High depth** (Mean ± Std)
pH	-	7.2 ± 0.1	7.2 ± 0.5	7.2 ± 0.2
DO	(mg/L)	7.3 ± 0.1	5.9 ± 0.2	6.9 ± 0.9
EC	(mS/cm)	47.6 ± 0.7	15.5 ± 8.4	23.2 ± 8.3
TDS	ppt	29.33 ± 0.50	9.50 ± 5.04	14.37 ± 5.16
Water Temperature	°C	28.7 ± 0.2	28.6 ± 0.6	28.9 ± 1.5
Turbidity	NTU	5.8 ± 1.3	18.8 ± 2.4	19.9 ± 7.7
Salinity	ppt	31.29 ± 0.38	7.46 ± 2.70	14.49 ± 5.45
Phosphate	mg/L	0.0045 ± 0.0013	0.0050 ± 0.0012	0.0131 ± 0.0044
Nitrite	mg/L	0.0039 ± 0.0014	0.0066 ± 0.0057	0.0039 ± 0.0015
Nitrate	mg/L	0.0051 ± 0.0012	0.0062 ± 0.0033	0.0072 ± 0.0031
Ammonia	mg/L	0.0759 ± 0.0280	0.1068 ± 0.0305	0.0959 ± 0.0218
TSS	mg/L	32.8 ± 22.2	31.8 ± 6.3	43.8 ± 10.9

WT is a limiting factor in the aquatic environment and one of the most critical environmental variables. It has an impact on aquatic organisms' metabolic activities, development, feeding, reproduction, distribution, and migratory patterns [14]. The mean temperature of the lagoon was 28.8°C during the sampling period. The lowest temperature was observed as 27.1°C and the highest temperature was 32.6°C. The slight differences may be due to the changes in atmospheric temperature and wind activity inside the lagoon area during the sampling. However, these values were within the acceptable levels for survival, metabolism and physiology of aquatic organisms.

The DO refers to the amount of oxygen dissolved in the water and it is particularly important in limnology [15]. The fate and behavior of DO is of critical importance to marine organisms in determining the severity of adverse impacts [16]. The highest DO value obtained was 9.2 mg/L and the lowest was 5.6 mg/L. If DO levels drop below 3.9 mg/L some fish and other aquatic organism can be stressed and if it drops below 2.0 mg/L many species can die off [12]. All the DO levels recorded in this study were above the permissible level (min 5 mg/L) which is suitable for aquatic life.

The maximum EC observed was 48.2 mS/cm and the lowest was 7.02 mS/cm. When analyzing the data received with the sampling locations, it is clearly visible that the locations nearby sea mouth have high EC values (NYR 6, 7,8,9,10,24 and 25). The same variation can be observed in salinity levels correspondingly. Salinity is a complex measure of the exchange system's existence. It's measured as the total amount of electrically charged ions (cations) in a given volume of water and specifies how animals are distributed in aquatic environments [13]. The maximum salinity observed was 31.7 ppt and the lowest was 3.8 ppt. When analyzing the data received with the sampling locations, it is clearly visible that the locations nearby sea mouth have high salinity values (NYR 6,7,8,9,10,24 and 25). The salinity of the Nayaru

Lagoon water clearly showed the occurrence of sea water intrusion through the bar mouth. Similarly, reference [17] also reported that in Koggala Lagoon, temporal and spatial complexities of lagoon mouth affect transport and mixing of saline water and intrusion into the lagoon. Although Nayaru Lagoon is a dry zone lagoon, the waters never recorded becoming hyper saline to form crystalline salts so far. It may have been due to the large quantity of fresh water received during rainy seasons [2].

The maximum TDS was 29.8 ppt. The United States Environmental Protection Agency Secondary Regulations advise a Maximum Contamination Level (MCL) of 500 mg/L (0.5 ppt) for TDS [20]. When TDS levels exceed 1000 mg/L (1 ppt) it is generally considered unfit for human consumption [12]. Present study revealed that TDS concentrations exceed the desirable limit of 1 ppt for all the locations. Despite the fact that lagoon water is not used for domestic water, it can have an effect on the groundwater in the surrounding areas.

B. Laboratory analysis of water quality

The primary source of the eutrophication phenomena, which results in unfavorable disturbance to the balance of organisms and affects the water quality, is the excessive amount of nutrients, such as nitrogen and phosphorus, discharged to the lagoons' water bodies. No matter how salinity-saturated a body of water is, eutrophication can occur in lakes, rivers, seas, and oceans. The accumulation of aquatic organic matter due to the overuse of fertilizers and pesticides in the aquatic ecosystem is producing hypoxia and anoxia, which endangers the productive, commercial, and recreational fisheries [18].

The phosphate values varied within the range of 0.003 mg/L to 0.0198 mg/L (Fig. 2). According to the reference [19], the defined value for phosphate is 0.4 mg/L where all the selected locations had lower values compared with it. The maximum nitrates were 0.0153 mg/L and the lowest was 0.002 mg/L. However, the defined value for nitrates is 10 mg/L [19] and the nitrate concentrations are lower than the defined limit for all the locations (Fig. 3). The mean ammonia concentration was 0.095 mg/L. According to the reference [19], the limit is varied with the pH value. The defined value for ammonia less than pH of 7.5 should be 0.94 mg/L (Fig. 4). It can be stated that the ammonia is below the standard limits [19].

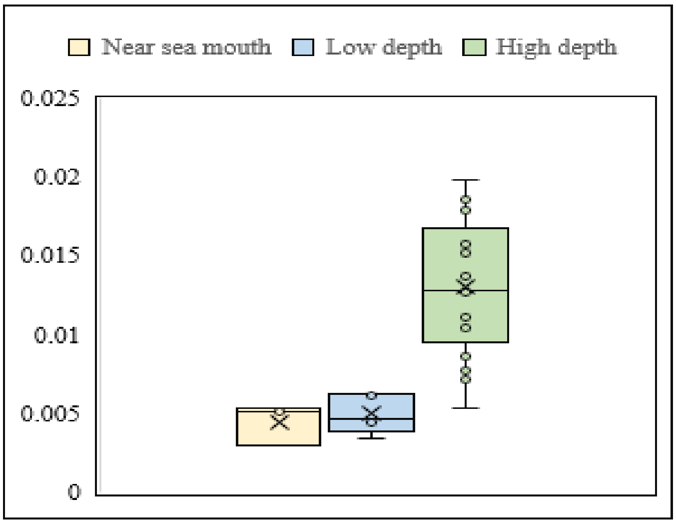

Fig. 2: Phosphate variation at near sea mouth, low depth & high depth

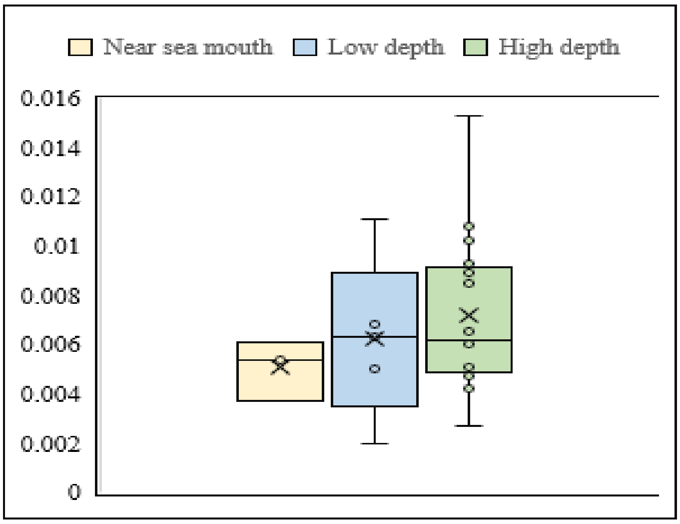

Fig. 3: Nitrate variation at near sea mouth, low depth & high depth

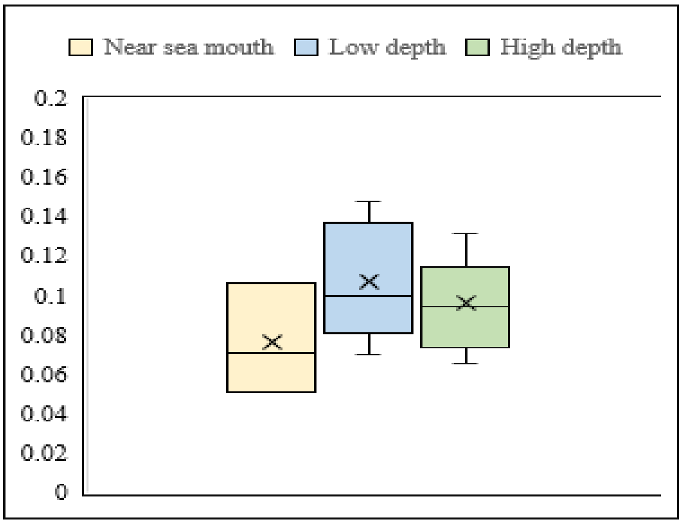

Fig. 4: Ammonia variation at near sea mouth, low depth & high depth

Total Suspended Solids (TSS) play a key role in determining water clarity; the higher the TSS, the less clear the water is. All of the sediment, sand, and silt in the water as well as plankton and algae are considered to be part of these solids. Although bacteria and algae can also contribute to the total solid concentration, inorganic minerals make up the majority of suspended solids [18]. The highest TSS observed was 61.6 mg/L which has exceeded the defined limits for TSS in National Environmental (Ambient Water Quality) Regulations, No. 01 of 2019 [19]. However, the average TSS value of all the locations is within the standard limit. High suspended solids concentrations can reduce the photosynthetic rate of aquatic plants by obstructing light penetration into the water body, reducing the oxygen required for aquatic life [12]. TSS levels rise with increased rainfall, causing dissolved oxygen and carbon dioxide levels to drop, as well as affecting the metabolism and physiology of fish and other aquatic species [13].

C. Principal Component Analysis

Principal Component Analysis (PCA) is an important tool which is used to analyze and interpret complex datasets by reducing the dimensionality of the data and identifying the underlying factors or sources of variation [21-23]. In the context of assessing lagoon water quality, performing the PCA on physicochemical parameters of lagoon water enables the identification of main sources of pollution and supports in understanding the behavior of the water quality indicators along the scale of spatial and temporal variation [22-24]. In the current study, the spatial dataset of the physicochemical parameters has been statistically analyzed and interpreted to identify the significant pollution implications, their sources and spatial patterns. Thus, it is essential to standardize the water quality of the Nayaru Lagoon by examining the difference between different indicator groups and identify the main sources of variation in spatial water quality data. By reducing the dimensionality of the data, PCA simplifies the analysis and interpretation of water quality data, making it easier to identify patterns and trends of lagoon pollution, characterize the pollution sources, describe the water quality indicators, and interpret the main factors contributing towards the spatial variation of the water quality where this information provides valuable insights for water quality management and pollution control efforts in lagoon ecosystems.

Table 2 Eigen Analysis of The Correlation Matrix

Eigenvalue	3.4647	2.7354	1.3452	0.9698	0.8695	0.6442	0.4930	0.2592	0.2001	0.0187
Proportion	0.3150	0.2490	0.1220	0.0880	0.0790	0.0590	0.0450	0.0240	0.0180	0.0020
Cumulative	0.3150	0.5640	0.6860	0.7740	0.8530	0.9120	0.9570	0.9800	0.9980	1.0000

Table 3 Eigen Vectors

Variable	**pH**	**DO**	**EC**	**TDS**	**WT**	**Salinity**	**Phosphate**	**Nitrites**	**Nitrates**	**Ammonia**	**TSS**
PC 1	0.097	0.281	0.514	0.516	0.126	0.516	-0.011	-0.055	-0.167	-0.255	0.059
PC 2	-0.262	-0.401	0.107	0.109	-0.426	0.072	-0.507	0.273	-0.358	-0.045	-0.314

The interpretation of the correlation between each water quality parameter across every sampling location is complicated since the spatial dataset describes the variation of 11 physicochemical parameters within 25 sampling locations. Therefore, Principal Component Analysis was applied to characterize the most significant correlation structures between water quality parameters and sampling locations and interpret the variation of water quality across the spatial scale.

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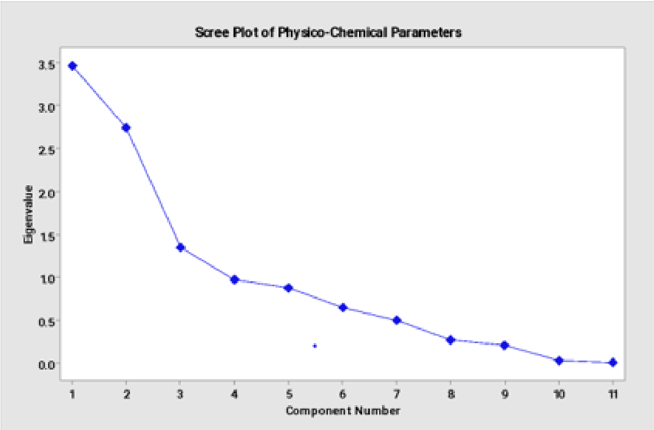

Fig. 5: Scree plot from the PCA

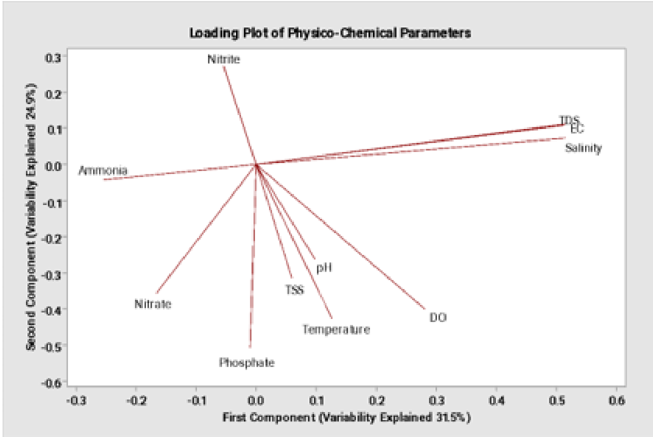

Fig. 6: Loading plot from the PCA

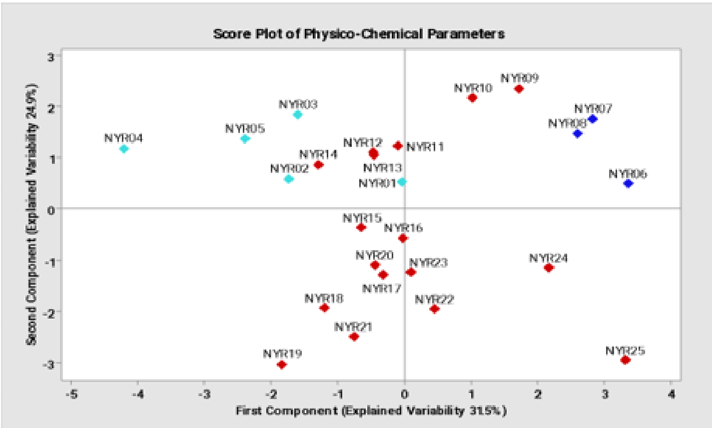

Fig. 7: Score-plot from the PCA

According to the Eigen analysis of the correlation matrix (Table 2), the first two principal components describe the cumulative variation of 56.4% and scree plot (Fig.5) represents a steep curve within the first two points of principal components.

Also, Eigen values of first three components greater than one and first two components among them are significantly higher. Therefore, PC1 and PC2 are used to characterize the dataset since they adequately describe the variation of water quality among the 25 sampling locations of Nayaru Lagoon. Eigen vectors (Table 3) of the first principal component have a large positive association with TDS, Salinity, and EC indicating that these components primarily measure the parameters that are highly varied with physical characteristics of the water column. Second principal component has a large negative correlation with DO, Phosphate, Temperature, Nitrate, TSS and pH implying that it substantially describes the nutrient enrichment and the chemical characterization of the water column. Loading plot (Fig.6) comprehensively shows the loading factors on each principal component.

According to the score plot (Fig.7) above, sampling locations are characterized according to the variation patterns of the physicochemical parameters of surface water in Nayaru Lagoon. NYR 06, NYR 07 and NYR 08 locations have similar characterization and according to the corresponding coefficient values, all these three locations can be primarily characterized by EC, salinity and TDS. The three sampling sites are located closer to the lagoon mouth where mixing of water during high tides results in higher salinity ranges. According to the PCA results these three sites are not only characterized by salinity but also have significant variation of EC and TDS values as result of the mixing process and frequent tidal actions in the lagoon mouth. In addition, NYR 02, NYR, 03, NYR, 05 and NYR 14 can be characterized with the Nitrite- Nitrogen content in surface water while locations from NYR 15 to NYR 21 are characterized by other nutrient parameters; Nitrate-Nitrogen, Phosphate and Ammoniacal Nitrogen. All these sampling locations show significant trends of variation in the nutrient levels and therefore the water quality of these locations can be primarily interpreted and determined by the nutrient levels in surface waters. Therefore, PCA results clearly implicates that the water quality characterization of the Nayaru Lagoon can be primarily interpreted through the physico-chemical parameters; salinity, EC, TDS, Nitrate, Nitrite, Phosphate and ammoniacal nitrogen and the overall water quality of the lagoon is mainly controlled through these water quality parameters.

IV. CONCLUSIONS

In this study, physico-chemical parameters of surface water at Nayaru Lagoon were assessed during the wet season. As it was aimed at evaluating the impact of surface water quality on aquatic organisms, the basic physico-chemical parameters were assessed and compared with the ambient water quality standards. The salinity, EC and TDS values were higher in sea mouth and locations near to the sea mouth. Most of the locations had higher TSS values, probably due to the seasonal flooding which introduces a lot of suspended particles into the lagoon. The DO level of the lagoon water is favorable for aquatic species as it exceeds the minimum limit of 5 mg/L. Nutrient concentrations were also within the limits defined suitable for aquatic lives. It is recommended to continuously monitor the water quality of Nayaru Lagoon in order to understand the pattern of spatial and temporal variation in water quality parameters depending on the seasons. Then the comprehensive results can be used to plan, protect and manage the lagoon for various purposes and receive the potential benefits from the lagoon. further, it is also strongly advised to investigate and model the influence of tidal action and bar mouth opening on water quality as well for a clearer understanding of the lagoon ecosystem.

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