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RESEARCH ARTICLE

SPATIAL AND TEMPORAL ANALYSIS OF WATER QUALITY PARAMETERS OF A HIMALAYAN LAKE (DAL LAKE) BY MULTIVARIATE STATISTICAL ANALYSIS.

S. K. Singh and Shah Manaan.
Department of Environmental Engineering, Delhi Technological University, Delhi, India.

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Abstract

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Dal Lake is one of the topmost attraction of tourists in Kashmir valley and is subjected to a steadily expanding rate of eutrophication and siltation. Considering the significance of this world acclaimed water body for Kashmiri human advancement and economy, the main objectives of this study was long term assessment of water quality of the Dal Lake by using multivariate statistical tools. The period of water quality assessment was 5 years from September 2010 to August 2015.Significant spatio-temporal variability in most parameters indicated considerable spatio-temporal variations. From the principal component analysis it can be construed that the lake water quality is mainly influenced by waste water discharge and agricultural run-off in the form of proliferation of nutrients like nitrate-nitrogen, ammonium-nitrogen, phosphates and chlorides. From the spatial cluster analysis it is clear that the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal are the most polluted sites of Dal Lake and need immediate remediation strategies.Overall, this study may contribute towards the advancement of knowledge and development of conservation strategies for the Dal Lake.

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Introduction:-

More than 70% of earth's surface is covered with water in the form of streams, lakes, rivers, and oceans. Water is most essential topographical agent that adjusts the surface morphology of the planet on an exceptionally great scale. Any aperture of extensive size in the surface of the earth that is loaded with water might be characterized as a lake. Unequivocally a lake is an assemblage of stagnant, semi stagnant or new water. Most lakes are impermanent in character. Lakes demonstrate an immense diversity in form. In size lakes may run from a couple square kilometers to a few hundred thousand square kilometers in territory. Likewise in shape lakes appear as round, semi round, half-moon shape, rectangular and triangular. Lakes assume an imperative part in the economy of an area or nation and are of colossal scholarly, societal and financial significance. They go about as characteristic water supplies and store a substantial amount of water, which can be utilized for drinking, modern, water system, stylish and different purposes including era of hydro-power.

Dal Lake, a warm monomictic lake, situated at a height of 1587m above the sea level and at 34°07′N latitude and 74°52′E longitude with a catchment area of 316 square kilometers, is one of a progression of freshwater lakes of Kashmir valley. Dal Lake is a multi-basined, bull bow kind of lake, with shallow saucer-molded bowls framed by the changing course of stream Jhelum. The principle source of water for the lake is TelbalNallah in the

Corresponding Author:-Shah Manaan.
Address:-Department of Environmental Engineering,Delhi Technological University, Delhi, India.

Dachigamterritory, various springs emerging from the base of lake and outwash from encompassing mountains. The surge of lake happens through a weir-n-bolt framework. The greatest depth is 6.5m, while the normal/average depth is under 3m. The pH estimations of the lake fall inside the alkaline range as of not long ago.

Atmosphere of Kashmir is montane valley atmosphere with a professed icy season from October to March (mean temperature 7.5 degree Celsius) and warm summers mean temperature 19.8 degree Celsius). January is the coldest month (temperature of - 2 degree Celsius to 3 degree Celsius), and July the hottest (34 degree Celsius to 35 degree Celsius). The main proportion of the precipitation is received as snow (December-February). The waters of Dal Lake bolster a changeless drifting populace of somewhere in the range of 7000 individuals, with entire towns having essentially been illicitly made in the lake. The lake underpins an enormous drifting business sector, cultivation industry, an imperative fishery and a blasting traveler industry. Weeds are collected for dairy cattle feed. The lake additionally goes about as a sump for a lot of the waste items from Srinagar. Violations of water from structures and by swelling of floating gardens and installation of lake bed materials and removing weeds on current solid land masses and obviously by transformation of floating gardens in to lasting land masses by way of accumulative weight and mass by planting of materials withdrawn from the lake. Solid waste management in the lake remains a great predicament for the following explanations that in wider terms Dal Lake is a city in itself in the interior of the city with following factors. About 2.5 lac people (source:JKLWDA) living in the surrounding areas discharge wastes which one way or the other reaches into the lake The population living in the interior of the lake discharges their solid wastes into the lake. Resident population going to the lake, commuters and tourists also discharge their solid wastes straight into the lake.

Dal Lake, subjected to a steadily expanding rate of eutrophication and siltation, has been assessed to thoroughly vanish inside the following 50 years. Siltation has expanded essentially since various streams and rivulets which joined the lake on its western edge were dammed or filled amid the development of a roundabout street around the old city in later past. The volume of nutrients achieves a top amid the mid-year months, when more than 1700 houseboats and many inns bolster an additional 500,000 individuals for every season. Jammu and Kashmir is one of the delightful parts of this planet with rich water assets. Dal Lake is world renowned water body which should be saved. The Government of Jammu and Kashmir has authorized an agency to spare this water body from contamination called Jammu and Kashmir Lakes and Waterways Development Authority (JKLWDA). This lake has truly been the focal point of Kashmiri progress and has assumed a noteworthy part in the economy of the state through its fascination of visitors and additionally its usage as a wellspring of sustenance and water. Considering the significance of this world acclaimed water body for Kashmiri human advancement and economy, the main objectives of this study was long term assessment of water quality of the Dal Lake by using multivariate statistical tools. The period of water quality assessment was 5 years from September 2010 to August 2015.

Material and Methods:-

Study area:-

The study is focused on Dal Lake which is situated in Srinagar city, capital of state Jammu and Kashmir, India (Figure 1). The lake is located at an altitude of 1583m and Lat. 340 – 6‟ N, 740-45‟ E. The main sources of feed to the lake are large perennial channel called TelbalNalawhci carries out runoff from the catchment area of about 145 km^2 and contributes to about 80% of the total inflow to the lake (Jellani 2006). Other streams such as PeshpawNala, Shalimar Nala, MerakhshaNala and Harshikul also contribute to the flow in the lake. These small streams feed to the lake around the shoreline along with some contribution from the groundwater. Kundangar et al. (1995) also reported presence of a number of springs within the lake basin itself acting as a permanent source of water to the lake. The division of the lake is into four basins Hazratbal, Boddal, Nageen and Gagribal. The maximum depth of the lake is approximately 6m which is in the Nageen basin and the shallowest basin is Gagribal basin with a maximum depth of 2.5m. Inside the lake there are floating gardens covering an area of $4.1m^2$ where vegetables are cultivated and is a source of income to residents living along its shoreline. The submerged land within the lake is 1.51 km^2 and the marshy area is 2.25 km^2.

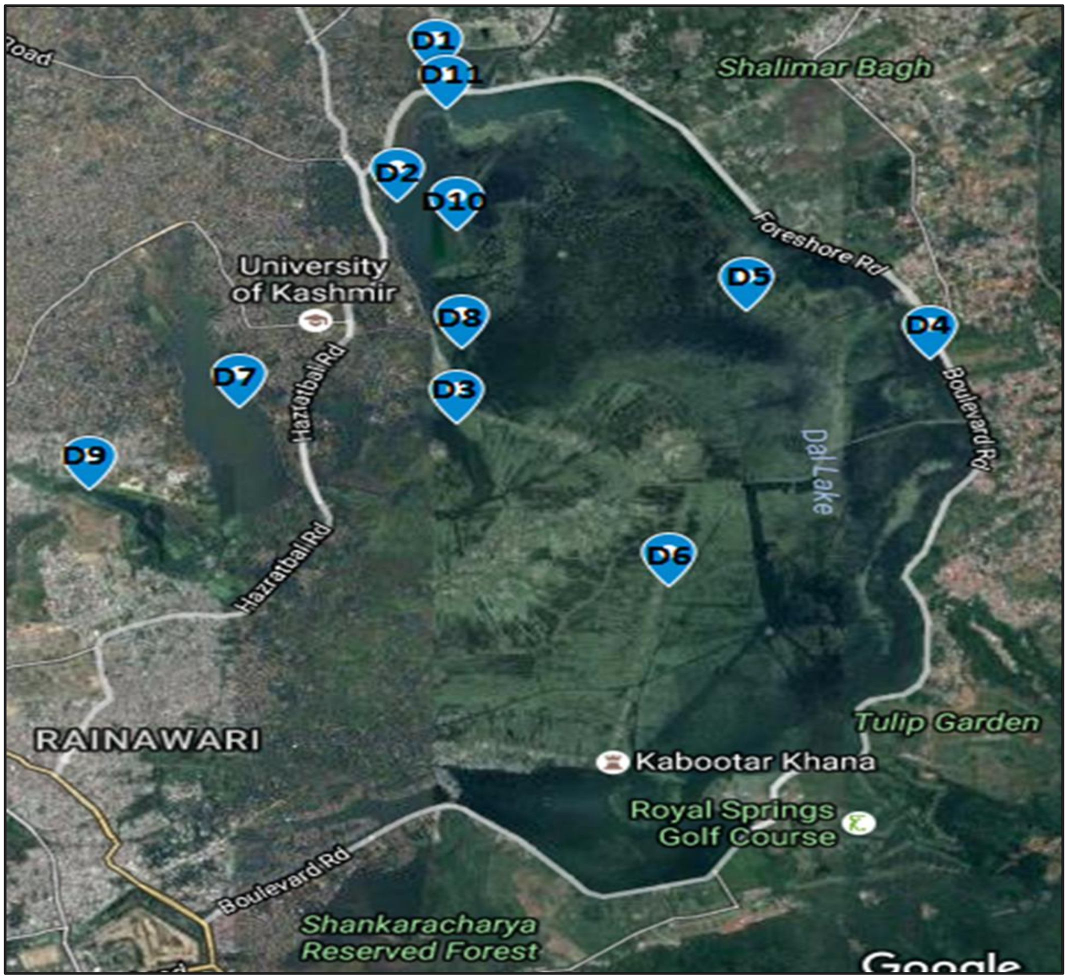

Figure 1:- Google map showing the shoreline of Dal Lake and sampling sites.

Sample collection and analysis:-

Water quality Data was acquired from the Jammu and Kashmir Lakes and Waterways Development Authority (JKLWDA). The month wise collected data for the lake from the year 2010-11 till 2014-15 was obtained.The collected data is for the following parameters: Electrical conductivity (EC), Calcium, Magnesium, Chloride, Ortho Phosphate, Total Phosphate, Nitrate-Nitrogen, Ammonical Nitrogen ,pH, Dissolved Oxygen(DO), Sulphate , Total Alkalinity and Chemical Oxygen Demand(COD). Sampling was generally done monthly from 11 locations as per the standard guidelines. Figure 1shows the location of sampling sites and the location of sampling sites are shown in Table 1.

Table 1:- Location of the sampling sites and their description.

Name of the site	Description of the site
D1	Inside Lake near the entry of TelbalNallah
D2	Dhobi Ghat area
D3	Central site near Sonilank
D4	Near Nishat Pipe line bund (Culvert 1)
D5	Central site near Char Chinari
D6	Near KabootarKhana
D7	Central site Nigeen
D8	Saderabal Area
D9	Pokhribal area
D10	Outlet site of Hazratbal STP
D11	Outlet site of Habak STP

Principal components analysis (PCA):-
PCA converts a large dataset of variables to new, uncorrelated variables known as the principal components. These principal components are towards the directions of maximum variance. PCA helps in minimizing the variation in the data (Sarbu and Pop, 2005). It indicates the most important parameters that describe the whole data, and summarizes the statistical correlations among the constituents with minimum loss of original information (Helena et al., 2000).

Cluster analysis (CA):-
The CA technique is an unsupervised machine learning classification technique that measures the similarity between different objects. The clusters that are produced through this technique lead to groups or clusters that have high internal homogeneity but high external heterogeneity. The most common CA procedure is hierarchical agglomerative clustering, which provides similarities between a sample and the entire dataset. This is usually shown in a dendogram or a tree diagram (McKenna, 2003), which provides a visual narrative of the clustering process. It shows the groups, their proximity in the original data. For simple objects, a Euclidean distance is used a similarity parameter between two samples (Otto, 1998). In this study, CA was applied to check the extent of spatial similarity in the data to group sites under the monitoring network. Hierarchical agglomerative clustering was used on the data set, normalized through Ward's method according to Kazi et al. (2009). Further, squared Euclidean distances were used as a measure of similarity.

Data analysis:-
Excel 2003, a part of the Microsoft Office Suite and SPSS 10 (IBM Corporation, Windows version) were used for mathematical and statistical computations.Various examiners have reported the significance of standardizing variables for multivariate analysis. Else, variables recorded at dissimilar measures do not add correspondingly for the exploration. For instance, in boundary detection, a parameter that varies from 0 to 100 will overshadow a parameter that varies from 0 to 1. Expending these parameters devoid of standardization in consequence gives the parameter with the greater range a load of 100 in the analysis. Altering the data to equivalent measures can avert this difficulty. Characteristic data standardization measures level the range. The data was therefore standardized to their corresponding z-scores by employing in the following Equation below, in order to achieve the objectives of normal distribution and homogeneity.

$$\mathbf{z} = \frac{\mathbf{x} - \boldsymbol{\mu}}{\boldsymbol{\mu}}$$

Where $x =$ Data and

$\mu =$ Mean

Results and Discussion:-

Seasonal principal component analysis:-
PCA was applied on the available data after breaking up the acquired/available data into four sets season wise i.e. Spring(March-April-May),Summer(June-July-August), Autumn(September-October-November), Winter(December-January-February). The total number of factors generated from a typical factor analysis indicates the total number of possible sources of variation in the data. Principal Components are hierarchical in order of merit. The first factor or component has the highest eigenvector sum and represents the most important source of variation in the data. The last factor is the least important process contributing to the data variation. The number of factors is determined using a scree plot. A scree plot displays the eigenvalues associated with a component or factor in descending order versus the number of the component or factor. Factor loadings on the factor loadings tables are interpreted as correlation coefficients between the variables and the factors. Factor analysis was performed using Statistical Package for the Social Sciences (SPSS 20).

Kaiser-Meyer-Olkin (KMO) is an index for comparing the magnitude of the observed correlation coefficients to the magnitude of the partial correlation coefficients. The closer the KMO measure to 1 indicates a sizeable sampling adequacy (0.8 and higher are great, 0.7 is acceptable, 0.6 is mediocre, less than 0.5 is unacceptable). Reasonably large values are needed for a good factor analysis. Small KMO values indicate that a factor analysis of the variables may not be a good idea. The measure was more than 0.8in every season so, this indicates that the sampling size is adequate and the correlation between parameters is generally accepted.

From PCA of summer data, two principal components were obtained having eigen values greater than 1accounting for 48.653 % of the total variance The first Principal Component PC1 accounts for about 33.644 %. Principal Component two PC2 accounts for about 15.009 %Loadings of the principal components are shown in Table 2. The first Principal Component PC1 shows a significant loading with orthophosphate, total phosphate, ammonicalnitrogen, sulphate, calcium, magnesium, cod, chloride and a negative loading with dissolved oxygen (DO). PC2 shows significant loading with, nitrate, total alkalinity and electrical conductivity. Positive loadings of COD, ammonical nitrogen, chloride and phosphates are associated with anthropogenic pollution. Negative loading of DO in PC1 with other parameters like phosphates and ammonical nitrogen occurs because high levels of dissolved organic matter consume large amounts of oxygen for decomposition. Sources of phosphates, nitrates and chloride may be traced to agricultural run-off, generation of waste water/sewage from the hospitality sector (hotels and houseboats). Calcium, magnesium and sulphates are naturally present in lakes and are representative of catchment geology and would thus exhibit noteworthy contribution to total variance in all seasons. Their proliferation may be due to the anthropogenic activities in the lake catchment.

Table 2:- Rotated Component Matrix (summer)

	Component	
	1	2
pH	.004	-.147
conductivity	.266	.642
DO	-.678	-.039
total alkalinity	.333	.686
chloride	.578	.539
calcium	.547	.360
magnesium	.656	.285
sulphate	.706	.327
COD	.583	.047
nitrate nitrogen	-.116	.575
ammonical nitrogen	.632	.298
orthophosphate	.822	-.119
total phosphate	.861	-.056

In winter, total numbers of significant principal components were twoaccounting for 56.921 % of the total variance,the first Principal Component PC1 accounts for about 31.667 %. Principal Component two PC2 accounts for about 25.254%.And their loadings on various parameters are shown in Table 3. PC1 shows a significant loading with electrical conductivity, total alkalinity, calcium, magnesium, and nitrate nitrogen .Electrical conductivity is an indicator of nutrient enrichment.Lone et al. (2014)had the same findings and has attributed it to the elevated value of total dissolved solids (TDS) in the winter season due to the decreased water levels (water levels are generally highest during summer because of melted glacial inflow) which results in increased concentration of different salts in water.PC2 shows significant loadings with chloride, sulphate, ammonical nitrogen and phosphates. Positive loadings of calcium, magnesium and sulphate relate to catchment geology. Negative loading of DO in PC2 with positive loading of other parameters like ammonical nitrogen and phosphates shows inverse relationship due to nutrient decomposition by phytoplankton.

Table 3:- Rotated Component Matrix (winter)

	Component	
	1	2
pH	.170	-.323
conductivity	.830	.036
DO	-.011	-.671
total alkalinity	.787	.088
chloride	.484	.658
calcium	.773	.298
magnesium	.831	.190
sulphate	.064	.801
COD	.439	.020
nitrate nitrogen	.693	.111
ammonical nitrogen	.307	.764
ortho phosphate	.409	.694
total phosphate	.563	.665

In autumn also, three principal components were derived as shown in Table 4accounting for 63.830% of the total varianceThe PC1 accounts for about 32.497%. PC2 accounts for about 16.406% and PC3 accounts for 14.927%.PC1 shows a significant loading with electrical conductivity, total alkalinity, chloride, calcium, magnesium, chemical oxygen demand (COD) and nitrate nitrogen.Electrical conductivity remains significant for the same reason as mentioned earlier for winter season.PC2 shows significant loadings with orthophosphate and total phosphate.PC3 shows positive loadings with sulphate, ammonical nitrogen and a negative loading with dissolved pH again depicting an inverse relationship. This is because of more restrained phytoplankton activity as compared to summer season leading to less consumption of ammonical nitrogen and less consumption of soluble carbon dioxide which lowers pH.

Table 4:-Rotated Component Matrix (autumn)

	Component		
	1	2	3
pH	-.191	-.238	.360
conductivity	.729	.148	.034
DO	-.041	-.023	-.758
total alkalinity	.770	.196	.006
chloride	.713	.123	.508
calcium	.793	.113	.238
magnesium	.802	.124	.129
sulphate	.444	.186	.695
COD	.638	-.281	.056
nitrate nitrogen	.667	.200	.059
ammonical nitrogen	.448	.284	.634
ortho phosphate	.095	.929	.066
total phosphate	.160	.935	.089

In spring, four principal components were derived as shown in Table 5accounting for 68.535% of the total variance . The PC1 accounts for 19.12%, PC2 for 17.38%, PC3 for 16.34% and PC4 for 15.69%.PC1 shows a significant loading with chloride, calcium andmagnesium.PC2 shows significant loadings with conductivity and nitrate nitrogen. Also conductivity was observed more in this season which may be caused by high concentration of dissolved solids at lower water levels. PC3 shows positive loadings with sulphate, ammonical nitrogen and a negative loading with dissolved oxygen and pH. This can again be attributed to the opposite relationship between phytoplankton proliferation and availability of dissolved oxygen. More phytoplankton activity means lesser available ammonical nitrogen and vice versa. Thus when dissolved oxygen decreases ammonical nitrogen content increases.PC4 has a significant loading with COD and the phosphate derivatives.

Table 5:- Rotated Component Matrix (spring)

	Component			
	1	2	3	4
pH	-.345	.403	-.447	-.075
conductivity	.075	.729	.136	.154
DO	.026	-.157	-.810	-.178
total alkalinity	.133	.801	.204	.124
chloride	.583	.084	.437	.179
calcium	.814	.334	.100	.131
magnesium	.856	-.040	.137	.087
sulphate	.505	.216	.526	.220
COD	.335	-.431	-.014	.574
nitrate nitrogen	.327	.609	-.281	.311
ammonical nitrogen	.336	.021	.763	-.017
ortho phosphate	.083	.232	.177	.859
total phosphate	.119	.350	.143	.833

Spatial cluster analysis:-

Cluster Analysis is an unsupervised learning statistical methodology. Cluster analysis is used to organise groups of cases of which the alignment is not known beforehand. Since it is unsupervised it does not make any difference between response and explanatory parameters. The many cluster analysis methods that SPSS 20 provides resources to entertain binary, nominal, ordinal, and scale (interval or ratio) data.

Hierarchical cluster analysis (HCA) was applied to the data after breaking up the data, season wise and also location wise with regards to the sampling locations. Hierarchical cluster analysis is one of the more popular methods of cluster analysis. It divides datasets into hierarchies based on similarity or dissimilarities in the field. In this study HCA grouped seasons and sampling locations into clusters. The method used for clustering was Wards Linkage which is based on a minimum variance criteria**.**

A hierarchical cluster analysis using Ward Linkage was performed to highlight the spatial inter-relationships and similarities as per the hydrochemical data hydrochemistry between the sampling locations considered in the lake study based on the 5 year average data from September 2010 to August 2015.The Dendogram shows that that the sampling locations have been clustered into four groupsas shown in Figure 2.The sites D7, D10 and D11 corresponding to sampling locations near Central site Nigeen, Outlet site of Hazratbal STP, and Outlet site of Habak STP respectively have been grouped together. These are the sites with the highest nutrient and pollution levels due to the anthropogenic nutrient proliferation from the various houseboats at Nigeen and the sewage disposal from STPs at Habak and Hazratbal.The second cluster pertains to sites D2, D8 and D9 which represents sampling locationsnear Dhobi Ghat area, Saderabal Area and Pokhribal area respectively. All three areas are proximate to high density population centres and thus receive nutrient rich effluents from the same.The third group includes sites D3, D4, D5 and D6 referring to locations aroundSona lank, Nishat Pipe line bund, Char Chinari and KabootarKhana. Sonalank and Char Chinari are tiny islands within the lake which attract lots of tourists and consequent nutrient enrichment. The other two sites (Nishat Pipe line bund and KabootarKhana)are peripheral sites near the shore of the lake.

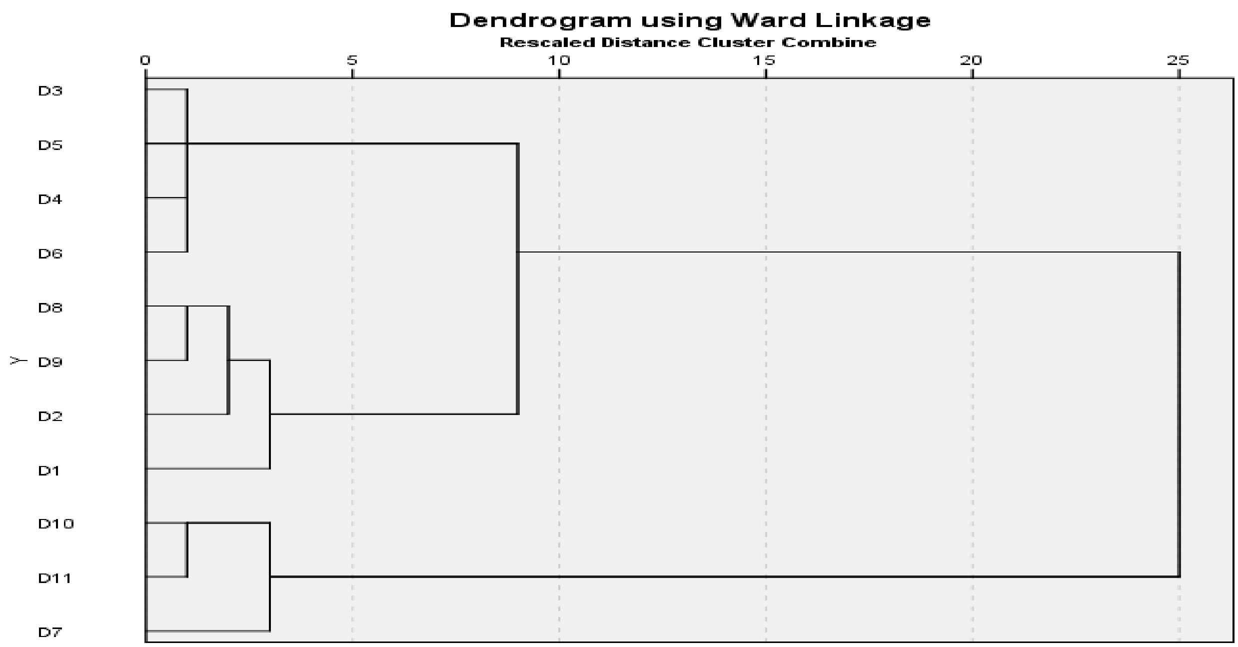

Figure 2:-Dendogram showing clustering of sampling sites

Seasonal cluster analysis:-

Another hierarchical cluster analysis using Ward Linkage was conducted to depict the temporal relationship and similarities as per the hydro-chemical data between the four weather seasons prevailing in the region based on the 5 year average data from year 2010-11 to 2014-15.Figure 3 shows the sesonaldendogram. The dendogramindicates that the hydro-chemical behavior of lake is most similar during spring and winter perhaps because of the comparable metrological conditions followed by autumn but the dissimilarity in autumn was much higher than that of spring and winter. Summer is most dissimilar to all other seasons because of the high anthropological activities and consequent nutrient loadings and also high biological activity of phytoplankton due to elevated temperatures.

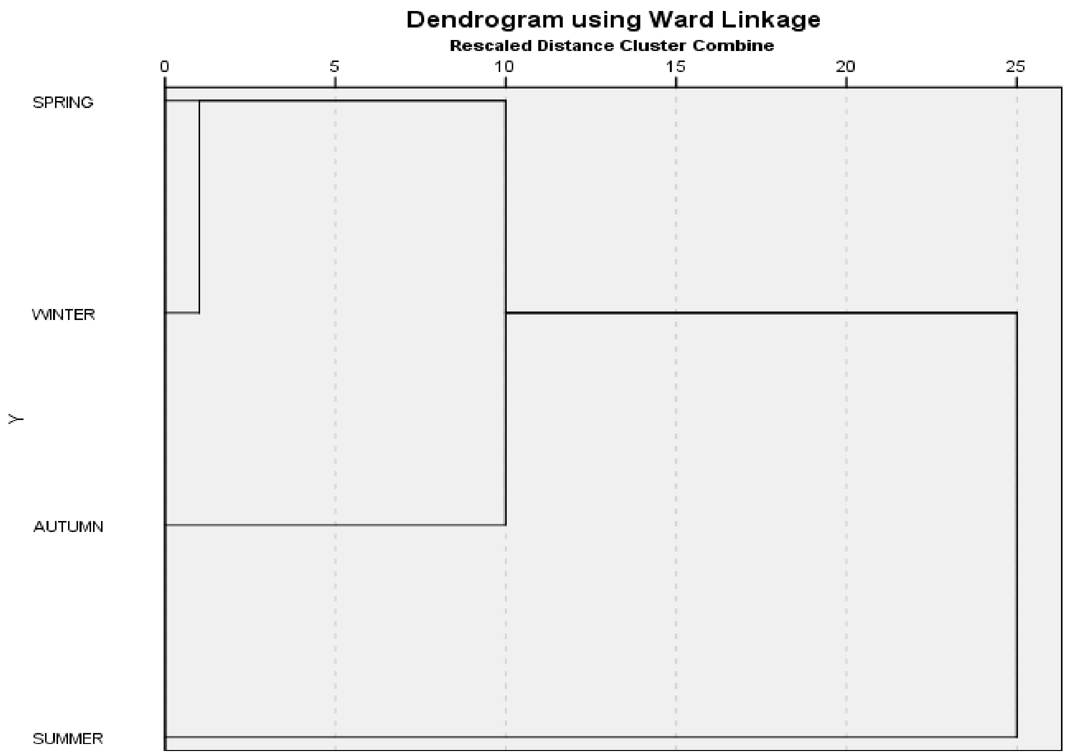

Figure 3:-Seasonal dendogram showing clustering of similar seasonal data

Conclusions:-

The study was conducted to evaluate the water quality of Dal Lake. The outcome of the study was that Dal Lake suffers steady eutrophic deterioration. There is significant spatio-temporal variability as most parameters indicated considerable spatio-temporal variations. From the principal component analysis it can be construed that the lake water quality is mainly influenced by waste water discharge and agricultural run-off in the form of proliferation of nutrients like nitrate-nitrogen, ammonium-nitrogen, phosphates and chlorides. From the spatial cluster analysis it is clear that the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal are the most polluted sites of Dal Lake and need immediate remediation strategies.From the temporal cluster analysis it is clear that spring and winter are the most hydro-chemically similar seasons of the year followed by autumn. Summer is significantly varied in hydro chemical behavior to all other seasons.

On the basis of this study there are some recommendations that may improve the status of the Dal Lake. Gradual dislodgement of houseboats and hotels, and rehabilitation of respective proprietors at a more appropriate locality.Setting up of STPs at all entry channels and immediate up gradation of existing STPs. For instance the STPs at Habak and Hazratbal are the major causes of eutrophic acceleration in the proximate lake area.Systematically regulated application of chemical pesticides by the cultivators in the lake catchment. Strategies to develop biological pest control measures to mitigate pest problem should be encouraged.Systematically regulated application of chemical fertilisers by the cultivators in the lake catchment. Methodologies should be developed to reduce the necessity of chemical fertilisers for agricultural soils near and around the Dal Lake. Overall, this study will contribute towards the advancement of knowledge and development of conservation strategies for the Dal Lake by the authorities of J&K state.

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