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# APPLICATION OF MULTIVARIATE STATISTICAL ANALYSIS IN RIVER WATER QUALITY MODELLING: A STUDY ON RIVER GODAVARI AT DOWLESWARAM, ANDHRA PRADESH

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**ABSTRACT:**

The quality of water and human health are closely related. The never ending growth of population, the unprecedented development of urban centers and industrial corridors and ill-planned exploitation of the water resources created a situation, where the availability of pure water is highly apprehended. Thus, the issues related to quality and quantity of water supplies became issues of national and international importance in determining the health of individuals and whole communities. Hence, in the present work an attempt is made to know the quality of the river Godavari at Dowleswaram location in the state of Andhra Pradesh. The water quality index was determined using the two familiar methods NSFWQI and WAIWQI through which it is observed that the quality of water is suitable for irrigation purposes at the location of the study. However, the quality of water is found to be *poor* at Dowleswaram w.r.t the domestic usage, which necessitates suitable treatment mechanism before the water is supplied to the consumers. In order to identify the majorly influencing parameters in the quality of water Multivariate Statistical Analysis i.e., FA, PCA and CA are applied. It is found that TDS and EC_GEN along with Alk_Tot and Har_Total are majorly influencing parameters in the FA and PCA for physico-chemical parameters and for irrigation parameters, SAR, Na_A and Na , Alk_Tot and Har_Total are the influencing parameters affecting the quality of River Godavari.

**KEYWORDS:** Multivariate statistical Analysis, Factor Analysis, Cluster Analysis, Principal Component Analysis, Water Quality Index, River Godavari, Dowleswaram.

## INTRODUCTION:

Most of the water for public water supplies and irrigation purposes is drawn from surface water sources like rivers and reservoirs as they facilitate the withdrawals of large amounts of fresh water. However, these surface water resources are getting severely stressed due to the pressures of ever increasing human needs and activities. Moreover, the surface waters are most vulnerable to pollution due to their easy accessibility for the disposal of wastewaters both domestic and industrial. The modern agricultural activity with large scale use of chemical fertilizers and pesticides also contribute to the contamination of surface water resources due to the joining of excess agricultural drainages. Thus, the quality of surface waters along with the quantities became a major concern globally. River water quality monitoring became a necessity in the present day society all over the world for an effective management of river water systems, especially for the rivers that are affected by urban and industrial effluents (Njenga, 2004). The changes caused to the water chemistry due to the mixing of domestic, industrial and agricultural drainages into the river bodies and the subsequent deterioration of water quality further emphasize the aforesaid necessity (Pereira *et al*. 2007). And on the other hand, there is an ever increasing demand for safe water supplies due to the rapid growth of population and accelerated pace of industrialization and urbanization. In this regard, the determination of several physical, chemical and biological parameters which enables the development of an index representing the overall quality of the water bodies is of great help for the establishment of large scale water supply systems to cater the domestic, agricultural and industrial needs (Ramakrishnaiah *et al.* 2009, Amadi *et al.* 2010). Thus, the Water Quality Index (WQI) which is calculated from the point of view of suitability of river waters for human consumption became an effective tool these days, for taking policy decisions both at regional and national levels in various countries for the effective utilization and management of their surface water resources. WQI is a scale used to estimate the overall quality of a water body and is a grade reflecting the composite influence of various water quality parameters. Though WQI provides an insight on the overall quality of a water body, the influencing parameters that cause the variation in the water quality from time to time can be determined by analyzing the data sets related to the quality of water bodies, statistically. The evaluation of the quality of water of a water body over a period of time from a large number of samples analyzed at regular intervals of time, and each containing different concentrations for many parameters is complex in nature. Water quality indices aim at providing a single value to the water quality of a source reducing large number of parameters into a simpler expression for easy interpretation. Since a number of national and international agencies are involved in the assessment of water quality and pollution control activities, there exists a number of criteria for the evaluation of water quality indices. Accordingly, a number of WQIs specific to regions and with different degrees of applications are developed world wide (Bharati, 2011). Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality (Miller *et al.* 1986). Different methods are being used to process the data related to water quality parameters in a water quality monitoring system and to turn into useful information for the effective management of these water bodies. A large portion of these approaches are statistical methods. When the number of these variables is more, the employment of multivariate statistical techniques gives simpler and more easily interpretable results in the analysis of the observed data (Mazlam *et al.* 1999). Therefore, different approaches like multivariate statistical analysis can effectively be used along with the water quality indices for conducting research on water quality related problems. Multivariate statistical analysis is an effective tool for processing the large data sets. This analysis gives reliable results and these results obtained are integrated from vast data to simple and easily understandable format which is convenient to be interpreted. Multivariate Statistical Analysis like Principal Component Analysis, Factor Analysis and Cluster Analysis are being widely used in assessing water quality. These analyses help in identifying the major factors affecting the overall water quality and also bring out the patterns for certain periods of time which help in predicting the water quality in future. Factor Analysis (FA) attempts to extract a lower dimensional linear structure form the data sets to give the factors whose significance can be interpreted in relation with the variables. The factors are chosen in such a way that the overall complexity of the data is reduced by taking the advantages of inherent interdependencies (Davis 2002). The factor analysis yields a general relationship between the measured variables by showing multivariate patterns that helps to classify the original data. It evaluates correlation coefficients in matrix format which gives an insight of how well the variance of each constituent can be explained by relationships with each other (Lewis 1994). The most important aspect of Factor Analysis is to determine the number of factors that need to be extracted for an accurate analysis of the data by executing the rotation of the factor axis and by evaluating the Eigen values and the Eigen vectors. The Principal Component Analysis (PCA) also works in similar fashion. PCA starts by building the correlation matrix. The diagonal of this matrix provides Eigen values and Eigen vectors. Since the variance explained by each Eigen vector is proportional to its Eigen value only those Eigen vectors with Eigen values greater than one are selected as significant, independent principal components. The correlation of these components with the original variables is called loadings which on interpretation will give an insight on the variation of the quality of the water bodies (Indrani Gupta et al. 2013). The Cluster Analysis (CA) assembles the variables based on their characteristics and classifies the objects in such a manner that each variable is similar to the others in a cluster w.r.t. a predetermined selection criterion. Thus, the resulting clusters exhibit both the internal homogeneity and external heterogeneity ie, similarities within the clusters and dissimilarities between the clusters. Hierarchical agglomerative clustering is the most common approach which provides the intuitive similarity relationships between any one sample and the entire data set and is typically illustrated as a dendrogram (Gupta et al. 2009, Thareja *et al.* 2010).

**STUDY AREA:**

This study is bonded with the water quality of River Godavari. Godavari is the largest river of all peninsular rivers in India. It originates in Western Ghats at Trimbakeshwar, Maharashtra and flows eastward across Deccan plateau through the states of Maharashtra, Telangana and Andhra Pradesh. It flows through 1465 km eastwards and empties into the Bay of Bengal. It enters Andhra Pradesh at Gundala near Kunavaram, East Godavari District. The study was conducted at an important location on the banks of River Godavari i.e., Dowleswaram. Dowleswaram is located on the banks of river Godavari at a distance of 152.4 km respectively from the entry point into the state. At Dowleswaram, a barrage built by Sir Arthur Cotton in the year 1850 exists with the main purpose of providing water for the agricultural and domestic needs of East and West Godavari districts. The location map of the points of study is herewith presented in figure 1.

**METHODOLOGY:**

The data related to the sampling location i.e., Dowleswaram is collected from Irrigation & CAD department, Hydrology project circle, Hyderabad, Govt. of Andhra Pradesh, for the period from 2002 to 2017. The data comprises the values of the following physico-chemical, biological and irrigation parameters recorded daily. The parameters considered in Physico-chemical category are Electrical Conductivity(EC), pH, TDS, Temperature, Alkyl-Phenol, Alkyl-Total, Calcium(Ca), Chlorides($Cl^-$), Carbonates($CO_3^-$), Fluorides($F^-$), Bicarbonates ($HCO_3^-$), Potassium(K), Magnesium(Mg), Sodium(Na), Nitrite Nitrate($NO_2$+$NO_3$), Nitrite-Nitrogen($NO_2$-N), Nitrate-Nitrogen($NO_3$-N) and Phosphates(O-$PO_4$–P). The parameters considered in biological category are Dissolved Oxygen (DO), DO Saturated (DO_Sat%) and Biochemical Oxygen Demand (BOD). The parameters considered under irrigation category are pH, EC, TDS, $Cl^-$, Calcium Hardness, Total Hardness, Na%, Residual Sodium Carbonate (RSC) and Sodium Absorption Ratio (SAR). The missing values of the data collected are incorporated at the respective places using the standard procedures of SPSS 20.0.After incorporating the missing values, the entire data is validated and the data is segregated as per the seasons viz., pre-monsoon (March-June), monsoon (July – October), Post-monsoon (November – February).

The two most popular methods viz., National Sanitation Foundation Water Quality Index (NSFWQI) and Weighted Arithmetic Index Water Quality Index (WAIWQI) are used in the present work, to evaluate the water quality indices representing the quality of water for both domestic and irrigation purposes at the sampling station. The water quality indices that are calculated in the present work are differentiated against the following seasons: a) Pre-monsoon (March–June), b) Monsoon (July – October), c) Post monsoon (November – February), in order to study the seasonal variations of water quality.

The Multivariate Statistical analysis of data involved in this study comprises of Cluster Analysis (CA), Factor Analysis (FA) and Principle Component Analysis (PCA). The factors that are responsible for the variation of water quality seasonally are identified from the Factor Analysis and Principal Component Analysis. The Clusters of parameters causing seasonal variations in the quality of water are also identified using the Cluster Analysis. The results of both WQI based studies and the Multivariate Statistical Analysis is compared to have an insight on the seasonal variations of water quality in River Godavari at both the sampling stations.

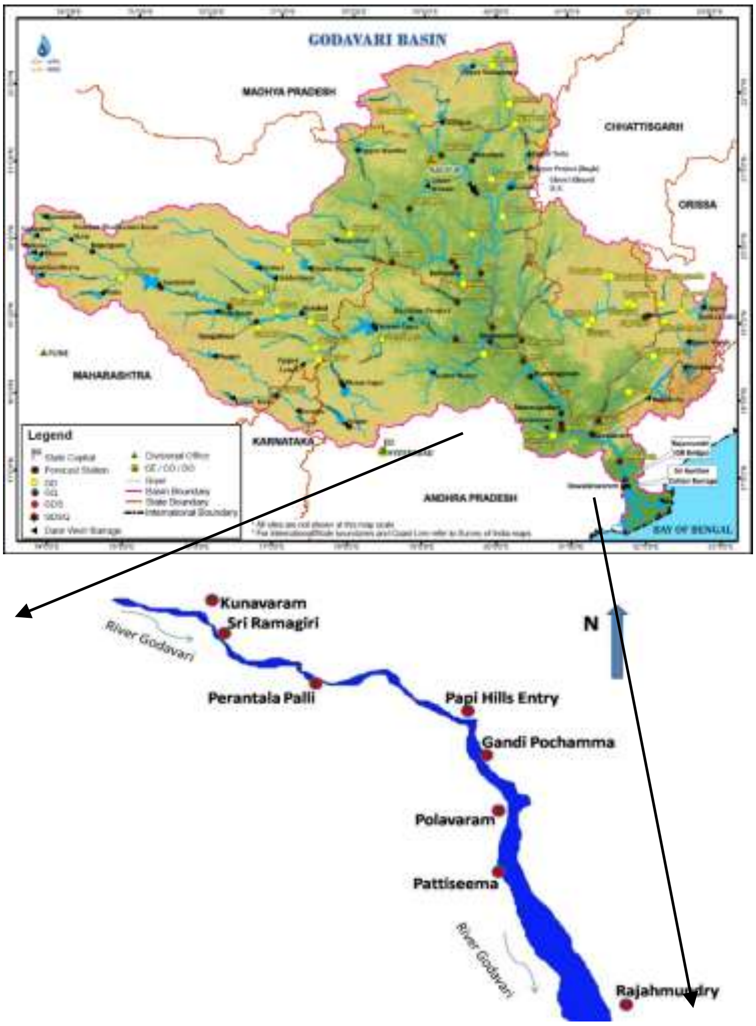


Figure 1: Location map of the points of the study

**RESULTS AND DISCUSSION:**

**WQI Based Studies:**

The missing value analysis is conducted for the generation and incorporation of the missing values at the respective places in the data sets. The results of the missing value analysis are shown in the following table no. 1. The missing values are then generated taking into consideration the below cited results and the total data sets for both the sampling stations are prepared for further analysis with due incorporation of the missing values. The data sets generated for the sampling station after incorporating missing values, the entire data set is subjected to validation process. The results of the validation of the data sets are presented in the following table no. 2. From these tables, it is observed that, the data sets are complete without any missing values which enable the further statistical modelling.

Table 1: Results: Missing value analysis for Dowleswaram

| Parameter | Missing | | Valid N | Mean | Std. Deviation |
|---|---|---|---|---|---|
| | N | Percent (%) | | | |
| $SO_4$ | 44 | 24.6 | 135 | 37.29 | 25.21 |
| Alk-TOT | 37 | 20.7 | 142 | 71.91 | 20.64 |
| Alk-Phen | 36 | 20.1 | 143 | 1.72 | 4.77 |
| $F^-$ | 31 | 17.3 | 148 | 0.31 | 0.26 |
| Har_Total | 30 | 16.8 | 149 | 74.02 | 20.97 |
| SAR | 29 | 16.2 | 150 | 0.68 | 0.37 |
| RSC | 28 | 15.6 | 151 | 1.09 | 2.12 |
| $CO_3^-$ | 28 | 15.6 | 151 | 2.00 | 5.45 |
| $BOD_{3-27}$ | 25 | 14.0 | 154 | 2.26 | 1.08 |
| Na% | 20 | 11.2 | 159 | 24.72 | 7.06 |
| $HCO_3^-$ | 20 | 11.2 | 159 | 79.81 | 23.15 |
| $NO_2+NO_3$ | 19 | 10.6 | 160 | 0.82 | 0.92 |
| Na | 18 | 10.1 | 161 | 11.32 | 4.65 |

Table 2: Results of data validation: Dowleswaram Station

| Parameter | Valid | Missing | Mean | Std. Deviation | Skewness | Std. Error of skewness |
|---|---|---|---|---|---|---|
| DO | 179 | 0 | 7.48 | 0.97 | -0.14 | 0.18 |
| pH_GEN | 179 | 0 | 7.89 | 0.45 | 0.06 | 0.18 |
| EC_GEN | 179 | 0 | 196.77 | 57.32 | 2.09 | 0.18 |
| TDS | 179 | 0 | 103.58 | 34.77 | 1.45 | 0.18 |
| DO_SAT% | 179 | 0 | 100.14 | 11.34 | 1.13 | 0.18 |
| $NO_2+NO_3$ | 179 | 0 | 0.83 | 0.88 | 1.66 | 0.18 |
| $BOD_{3-27}$ | 179 | 0 | 2.30 | 1.03 | 1.83 | 0.18 |
| Har_Total | 179 | 0 | 74.36 | 19.83 | 2.24 | 0.18 |
| Ca | 179 | 0 | 16.98 | 5.39 | 1.1 | 0.18 |
| Mg | 179 | 0 | 7.76 | 3.44 | 1.51 | 0.18 |
| Na | 179 | 0 | 11.49 | 4.77 | 1.64 | 0.18 |
| $Cl^-$ | 179 | 0 | 20.67 | 10.66 | 1.07 | 0.18 |
| $SO_4$ | 179 | 0 | 37.70 | 23.05 | 0.23 | 0.18 |
| $CO_3^-$ | 179 | 0 | 1.93 | 5.11 | 4.37 | 0.18 |
| $HCO_3^-$ | 179 | 0 | 81.38 | 23.01 | 2.21 | 0.18 |
| RSC | 179 | 0 | 1.06 | 1.97 | 2.3 | 0.18 |
| Na% | 179 | 0 | 24.56 | 6.78 | 1.38 | 0.18 |
| SAR | 179 | 0 | 0.69 | 0.35 | 0.98 | 0.18 |
| $F^-$ | 179 | 0 | 0.31 | 0.24 | 0.86 | 0.18 |
| Alk_Phen | 179 | 0 | 1.63 | 4.41 | 4.22 | 0.18 |
| Alk_Tot | 179 | 0 | 72.66 | 19.26 | 1.95 | 0.18 |

**Seasonal Variations of Water Quality at Dowleswaram Based on NSFWQI:**

The average WQI values for all seasons are found to have the quality ratings varying from *medium* to *fai*r w.r.t physico-chemical parameters. It is observed that the quality ratings are varying from *medium* to *poor* against the WQI values obtained from the biological parameters. The predicted values of the WQI are found to have a rating of *medium* to *fair* and *fair* to *poor* w.r.t physico-chemical and biological parameters.

Regarding the water quality rating related to WQI values based on irrigation parameters, it is observed that the quality ratings vary from *good* to *medium* and the predicted values are also found to vary from *medium* to *fair* showing that the water is suitable for irrigation purposes.

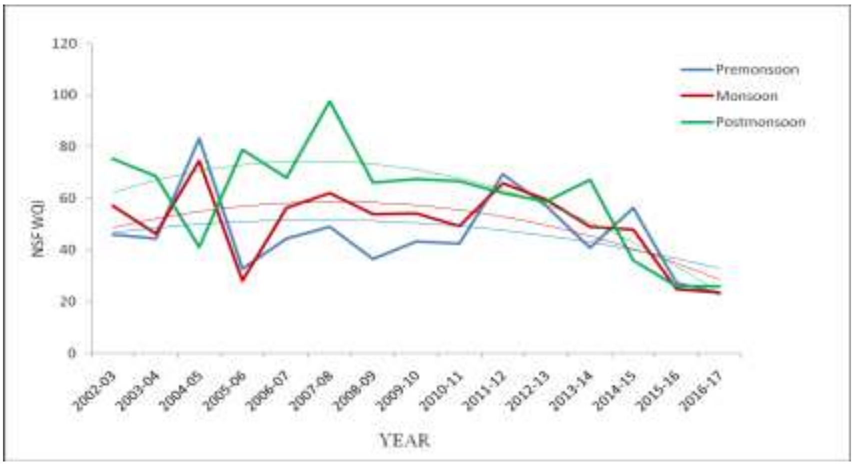


Figure 2: Seasonal variation of NSFWQI values at Dowleswaram w.r.t Physico-chemical parameters, 2002-2017

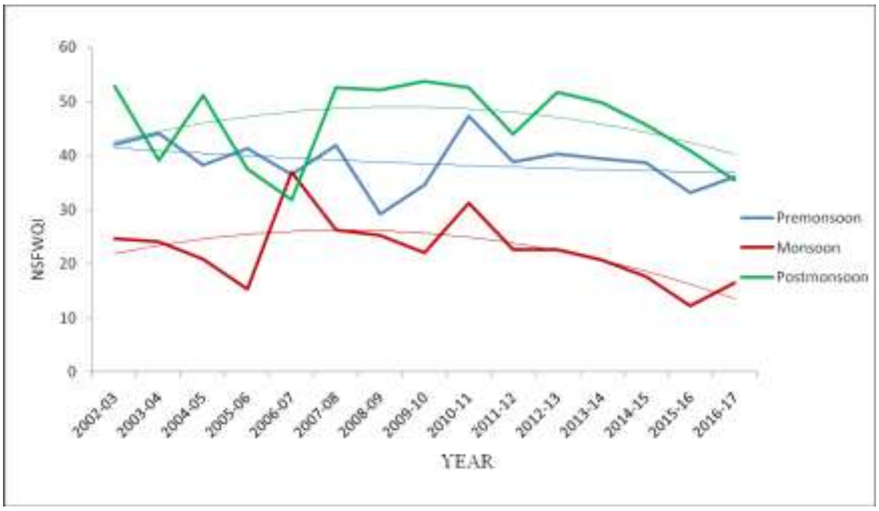


Figure 3: Seasonal variation of NSFWQI values at Dowleswaram w.r.t Biological parameters, 2002-2017

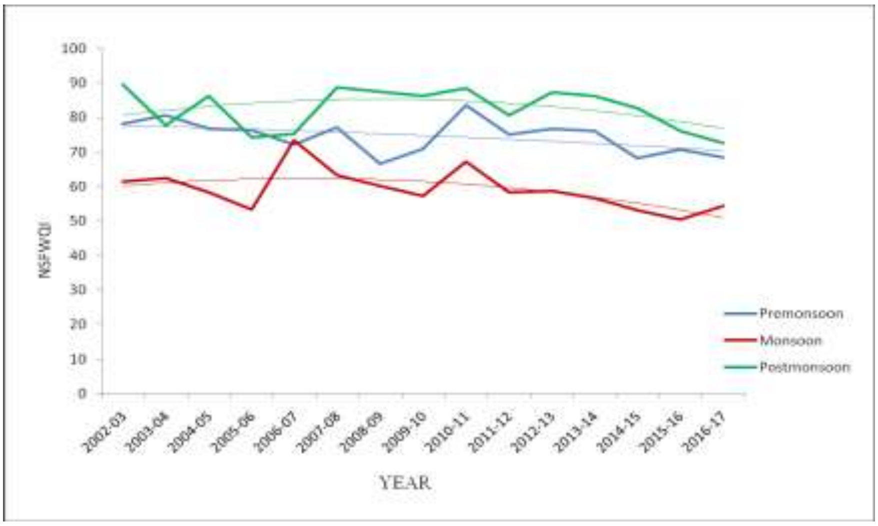


Figure 4: Seasonal variation of NSFWQI values at Dowleswaram w.r.t Irrigation parameters, 2002 – 2017

**Seasonal Variations of Water Quality at Dowleswaram Based on WAIWQI:**

The average WQI values for all seasons are found to have the quality ratings varying from *medium* to *fai*r w.r.t physico-chemical parameters. It is further observed that, the quality ratings are varying from *medium* to *poor* against the WQI values obtained from the biological parameters. The predicted values of the WQI are found to have a rating of *medium* to *fair* and *fair* to *poor* w.r.t physico-chemical and biological parameters.

Regarding the water quality rating related to WQI values based on irrigation parameters, it is observed that the quality ratings vary from *good* to *medium* and the predicted values are also found to vary from *medium* to *fair* showing that the water is suitable for irrigation purposes.

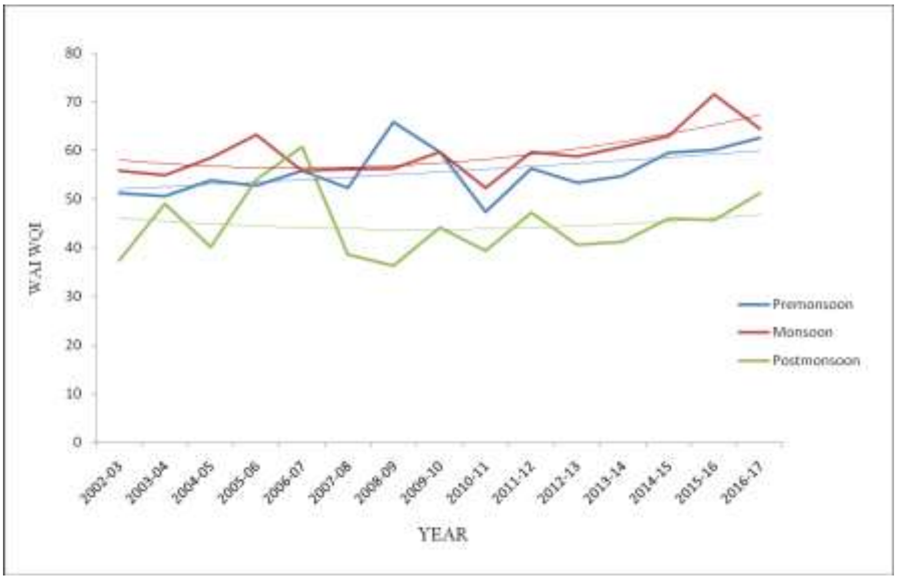


Figure 5: Seasonal variation of WAIWQI values at Dowleswaram w.r.t Physico-chemical parameters, 2002-2017

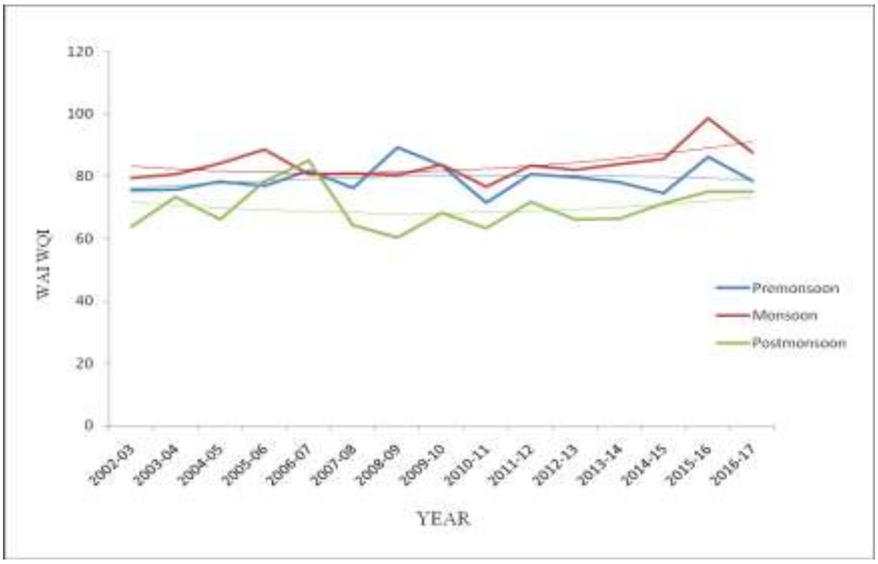


Figure 6: Seasonal variation of WAIWQI values at Dowleswaram w.r.t Biological parameters, 2002 – 2017

**MULTIVARIATE STATISTICAL ANALYSIS:**

The factor analysis w.r.t physico-chemical parameters at Dowleswaram has shown very strong correlation between Alk_Tot and $HCO_3^-$ in Pre-monsoon and post-monsoon seasons whereas Ca and Har_Tot are strongly correlated in monsoon season. The total variances of 26.73%, 22.55%, 9.62%, 5.72% and 5.15% are extracted for 5 factor groups in the factor analysis w.r.t pre-monsoon season. $HCO_3^-$ and Alk_Tot had highest positive loadings of 0.87 and 0.89 in factor group 1. TDS, Ca, $CO_3^-$ had highest positive loadings in factor groups 2, 3 and 4 respectively. Total variance is extracted for 4 factor groups in the monsoon period as 31.75%, 9.83%, 8.91% and 6.28% with Alk_Tot had highest positive loading of 0.88 in factor group 2. Similarly, in the post-monsoon period four factor groups are extracted with $HCO_3^-$, Alk_Tot, Ca, EC_GEN, Har_Tot, as components having highest positive loadings as 0.82, 0.83, 0.86, 0.88 and 0.97 respectively. The factor analysis w.r.t Biological parameters at Dowleswaram have shown highest correlation between DO and DO_Sat in all the three seasons. The total variances observed in pre and post-monsoon seasons are 65.81% and 49.06% for the factor group 1 in which DO_Sat recorded the highest positive loadings of 0.98 and 0.93 respectively. For the monsoon period, the total variances observed are 36.05%, 11.83% in which DO and DO_Sat are observed to have highest positive loadings of 0.73 and 0.72 respectively.

From the cluster analysis, the total parameters are classified into two clusters: 1) highly polluting ($NO_2$+$NO_3$, F, $CO_3^-$, pH_GEN, Mg, $SO_4$, Ca, $Cl^-$, Na) and 2) moderately polluting (Har_Total, Alk_Tot, $HCO_3^-$, EC_GEN, and TDS) in all the three seasons' w.r.t physico-chemical parameters at Dowleswaram. The biological parameters are classified into two clusters: 1) highly polluting (DO and $BOD_{3\text{-}27}$) and 2) moderately polluting (DO_SAT) in all the three seasons. The irrigation parameters are classified into two clusters: 1) highly polluting ($NO_2$+$NO_3$, RSC, SAR, pH_GEN, Mg, $SO_4$, Na, Ca, $Cl^-$, Na_A) and 2) moderately polluting (Har_Total, Alk_Tot, $HCO_3^-$, EC_GEN, and TDS) in all the three seasons at Dowleswaram.

The principal component analysis w.r.t physico-chemical parameters at Dowleswaram has shown very strong correlation between Alk_Tot and $HCO_3^-$ in Pre monsoon and post monsoon seasons and Ca and Har_Tot are strongly correlated in monsoon season. From the total variances of 28.42%, 24.54%, 11.47%, 8.41% and 7.59% are extracted for 5 components in which EC_GEN, Mg and TDS had highest positive loadings of 0.81, 0.86 and 0.90 in component group 1. pH_GEN, Alk_Tot, Ca had highest positive loadings in component groups 2, 3 and 4 respectively. Total variance is extracted for 4 component groups in the monsoon period as 34.03%, 12.87%, 11.13% and 10.42% with Alk_Tot, $HCO_3^-$ and $CO_3^-$ as highest positive loading in component group 2 and 3 respectively. Similarly in the post monsoon period 39.34%, 14.44%, 12.60% and 7.75% are extracted as percentage of total variance with four component groups forming Ca, $HCO_3^-$, Alk_Tot, Har_Tot and EC_GEN as 0.85, 0.86, 0.88, 0.89 and 0.94 respectively. Na and $NO_2$+$NO_3$ are found to be having highest positive loadings as 0.84 and 0.82 w.r.t components 3 and 4. From the principal component analysis w.r.t Biological parameters at Dowleswaram during have shown highest correlation between DO and DO_SAT in all the three seasons. The total variance observed in pre-monsoon season is 75.44% for component 1 in which $BOD_{3\text{-}27}$, DO, and DO_SAT are recorded highest positive loadings of 0.80, 0.87 and 0.92 respectively. The total variances of 50.52%, 35.09% are observed for 2 component groups in which DO and DO_SAT are observed to have highest positive loadings of 0.88 and 0.85 and 0.97 for $BOD_{3\text{-}27}$ in monsoon seasons. The total variance of 61.09% is observed for component 1 in which DO, DO_SAT are found to have highest positive loadings with 0.82, 0.91 for post-monsoon season. The principal component analysis w.r.t Irrigation parameters at Dowleswaram has shown very strong correlation between Alk_Tot and $HCO_3^-$ is observed in pre and post-monsoon seasons where as strong correlation is observed in Na_A and Na in monsoon. Five component groups have been extracted for the pre-monsoon with 28.43%, 20.85%, 11.93%, 11.36% and 7.04% variances. In the component group PC1, it is observed that TDS and Mg are found to have highest positive loadings of 0.92 and 0.87. These positive loadings are followed by the positive loadings for $SO_4$, Na_A and Ca as 0.85, 0.94 and 0.94 in the component groups PC2, PC3 and PC4 respectively. In case of monsoon season, four component groups are extracted with variances of 34.89%, 14.57%, 10.42% and 8.49%. Har_Tot as highest positive loading is 0.89 component group PC1 and Na_A as highest positive loadings with 0.80 followed by Alk_Tot and $SO_4$ as 0.82 each in PC3 and PC4 respectively. In case of post monsoon season, 4 component groups are extracted with variances 34.89%, 14.57%, 10.42% and 8.49%. The highest positive loadings are observed for, Na_A as 0.80, Alk_Tot and $SO_4$ as 0.82 each and Har_Tot as 0.89 in PC1, PC2, PC3 and PC4 respectively.

**Conclusions:**

The quality of water is found to be suitable for irrigation purposes at the location of the study. However, w.r.t the domestic usage, the quality of water is found to be *poor* at Dowleswaram, which necessitates suitable treatment mechanism before the water is supplied to the consumers. It is found that the quality of water is at lower rating during the monsoon seasons when compared with that of pre and post-monsoon seasons. This is because of the joining of flood water into the river and thereby increasing turbulence in the river water causing an increase in the turbidity and other suspended solids. The factor and Principal Component Analysis conducted at the identified two more influencing parameters i.e., TDS and EC_GEN along with Alk_Tot and Har_Total, which shows that more amount of impurities are joining the river course and increasing the dissolved solids component and thereby decreasing the quality of water. From the Cluster Analysis conducted on various physico-chemical, biological and irrigation parameters at Dowleswaram, it is found that despite the number of clusters observed at different stages, the individual parameters in respective categories are grouped into two clusters, one representing the highly polluting parameters and the second one representing the moderately polluting parameters. From the Factor Analysis and the Principal Component Analysis conducted using various irrigation parameters, it is found that the primary influencing parameters for irrigation water quality are SAR, Na_A and Na and the secondary parameters are Alk_Tot and Har_Total which are in permissible limits at the sampling location. This shows that the river water quality for irrigation purposes has not changed much during its flow and is found suitable for irrigation purposes.

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