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A Comparative Study of Water Quality Indices of River Godavari

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Abstract*—The study related to the assessment of water quality parameters of River Godavari was carried out to evaluate the various water quality parameters and to calculate water quality index. In this paper the seasonal variations of WQI of the developed Actual measured and Time series models during the study period (2009-2012) and future period (2012-2015) of Rajahmundry and Dowlaiswaram water quality monitoring stations in Andhra Pradesh state, India, are discussed. The monthly values of eight water quality parameters viz., pH, Dissolved Oxygen, Electrical Conductivity, Total Dissolved Solids, Total Alkalinity, Total Hardness, Calcium and Magnesium were used to calculate the WQI. The results of the statistical performance test indicated that the developed models of respective stations exhibited significant performance with MAE= 4.97 & 3.41, RMSE=7.31 & 5.82 and MAPE=5.15% & 3.48% respectively. It was found that due to high weightage factor the fluctuations of DO levels caused significant variations. From the present study it is concluded that the future water quality of River Godavari at Rajahmundry and Dowlaiswaram stations will be of excellent to good quality. WQI can be successfully tool to transform the complex water quality data into information that is easily understandable and useable by the general public and decision makers.

***Keywords*—Dowlaiswaram, Rajahmundry, Rating factor, River Godavari, Weightage factor, WQI**

I. INTRODUCTION

Water is the prime requirement for the existence of life and thus it has been man's endeavor for the time immemorial to utilize the available resources. The unbridled exploitation of water for irrigation, drinking and industrial purposes has caused a drastic decline of the quality and availability of water. The over-exploitation of limited resources has not only caused a perceptible decline in the water table, but also resulted in the enormous increase of pollutants concentration. The ever growing population exerts a great pressure on this resource. The never ending growth of population and ill-planned exploitation of the water resource created a situation, where the very survival of man has become endangered. The concern for protecting the quality and overuse of earth's natural resources has been increasing in recent years all over the world. The global awareness and concern for the environment have paved way for the installation of various policies to control and prevent environmental pollution. Implementation of these policies has resulted in development of various technologies, which will allow for the sustainable utilization of earth's resources. Thus preventing and controlling the overall degradation of the quantity and quality of these resources. Hence proper management of available water resources is essential for the survival of mankind.

Interpretation of complex water quality data is difficult to understand and to communicate during decision making process. Assembling the various parameters of the water quality data into one single number leads an easy interpretation of data, thus providing an important tool for management and decision making purposes. The purpose of an index is to transform the large quantity of data into information that is easily understandable by the general public. Water quality index exhibits the overall water quality at a specific location and specific time based on several water quality parameters. WQI is a set of standards used to measure changes in water quality in a particular river reach over time and make comparisons from different reaches of a river. A WQI also allows for comparisons to be made between different rivers. This index allows for a general analysis of water quality on many levels that affect a stream's ability to host life and whether the overall quality of water bodies poses a potential threat to various uses of water.

The WQI was first developed by Horton in the early 1970s, is basically a mathematical means of calculating a single value from multiple test results. The index result represents the level of water quality in a given water basin, such as lake, river or stream. After Horton a number of workers all over the world developed WQI based on rating of different water quality parameters. 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.*,[1] 1986). The different statistical approaches were followed for analyzing water quality data based on rank order of observations and factor analysis (Shoji *et al.*,[2], 1966). For the evaluation of water quality, WQI was applied to river water (Ashwani Kumar *et al.,* [3], 2009, Rita.N.Kumar et al., [4], 2009, N. Singkran. et al, [5], 2010).

The objectives of the present paper are (1) to determine the future situations of water quality index using the standards of Central Public Health Environmental Engineering Organization (CPHEEO) [6], 1991 & Indian Council of Medical Research (ICMR) [7], 1975 and (2) to categorize the conditions of water quality as per the classification criteria standards based on National Sanitation Foundation Water Quality Index (3) to compare the future water quality of the River at Rajahmundry and Dowlaiswaram stations.

II. STUDY AREA

Godavari is the largest river in south India and ranks 3rd among the Indian rivers, flows 1465Km and empties into the Bay of Bengal. It rises in the Sahayadri hills, in Maharastra state and it reaches Andhra Pradesh receiving water from the Manjira, the Pranahita (which itself is itself formed by the confluence of the three rivers viz., the Wardha, the Painganga and the Wainganga); the Mannair, the Indravathi and the Sabari. The last major tributary of Godavari is Sabari which falls into Godavari about 1268Km from its source. After the confluence with Sabari, the Godavari begins to wind amongst the hills of the Eastern Ghats, which gradually close on it, till it is forced to go through a picturesque gorge at Papikonda which for five kilometers is as narrow as 60mts to 90mts at flood time. The river enters the Andhra Pradesh state near Bhadrachalam and flows along Godhavarikhani, Rajahmundry, Kovvur, Tallapudi and Narsapur in a southeast direction until it empties into the Bay of Bengal through two mouths. The upper waters of the Godavari are scarcely utilized for irrigation, but the entire delta has turned into a garden of perennial crops by means of the anicut at Dowlaiswaram, constructed by Sir Arthur Cotton 145 years ago.

Rajahmundry is located at 16.98°N 81.78°E with an average elevation of 14 meters (45 feet). It is the fourth largest city in Andhra Pradesh, on the banks of the River Godavari, well known as the Cultural Capital of Andhra Pradesh. The city's origins can be traced back to the rule of the Chalukya king Rajaraja Narendra who reigned around 1022 A.D after whom it is named Rajamahendri or Rajamahendravaram. The Dowlaiswaram town, located at 16.34°N 81.29°E a suburb and part of Rajahmundry urban agglomeration, in the East Godavari district of Andhra Pradesh, India. It is approximately four kilometers distance from Rajahmundry and Sir Arthur Cotton barrage across river Godavari is located in Dowlaiswaram. This barrage serves a command area of nearly10lakh acres in East and West Godavari districts. River Godavari is a inseparable part in the lives of population living in and around Dowlaiswaram and Rajahmundry. There are a few corporate and multinational companies as part of its industrial development. Hence the present research work has been taken up to assess the seasonal water quality variation and to forecast the fate of River Godavari due to various developmental activities taking place in and around Rajahmundry and Dowlaiswaram.

III. MATERIALS AND METHODS

Water samples were collected once in every month from the water quality monitoring stations of Rajahmundry and Dowlaiswaram, from the surface waters of the River. The water samples were analyzed as per the standard methods of practice at "Water Quality Level –II Laboratory", Dowlaiswaram, Hydrology Project, Irrigation & CAD Department, Government of Andhra Pradesh, India. The water quality data of various parameters were studied during the period Jan 2009 to May 2012 and historic data obtained from the Hydrology Department, Govt of Andhra Pradesh, was used in the analysis. The analysis of the water quality data for estimation of quality parameters and WQI values was made based on season wise. The values of the parameters predicted were used for the calculation of the WQI values of Time series model (09-12). The WQI obtained by the actual measured model and Time series (09-12) of respective stations were compared using the statistical criterion for performance (Mean Absolute Error, Root Mean Square Error and Mean Absolute Prediction Error). Using the overall data available till date, the water quality parameters for the future years June 2012 to May 2015 were estimated and used for the prediction of WQI of Time series (2012-2015). A comparison study was done basing on the forecasted WQI values of the two stations for the future period (2012-2015) to identify the existence of significance if any. The yearwise trend patterns of WQI of both stations were studied.

Water quality index was calculated for each and every month for assessing the quality of water. It was done by considering eight important physio-chemical properties using Central Public Health Environmental Engineering Organisation (CPHEEO), 1991 & Indian Council of Medical Research (ICMR), 1975 standards. In order to calculate WQI eight important parameters, pH, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), Total Alkalinity (Alk), Total hardness (Har-T), calcium (Ca) and magnesium (Mg) were used . These parameters maximum contribute for the quality of river. The steps for determining water quality index are as follows:

3.1 WEIGTHGE FACTOR

Factors which have higher permissible limits are less harmful because they can harm quality of river water when they are present in very high quantity. So weightage of factor has an inverse relationship with its permissible limits.

Therefore $Wi \propto 1/Xi$

Or $Wi = k/Xi$

Where, k = constant of proportionality

Wi = unit weight of factor

Xi = maximum permissible limits as recommended by Indian Council of Medical Research / Public Health Environmental Engineering Organization

Values of k was calculated as:

$$k = \frac{1}{\sum_{i=1}^{8} \left(\frac{1}{Xi}\right)}$$

Where

$$\sum_{i=1}^{8} \left(\frac{1}{Xi}\right) = \frac{1}{Xi\,(pH)} + \frac{1}{Xi\,(DO)} + \frac{1}{Xi\,(EC)} + \frac{1}{Xi\,(TDS)} + \frac{1}{Xi\,(Alk)} + \frac{1}{Xi\,(Har-t)} + \frac{1}{Xi\,(Ca)} + \frac{1}{Xi\,(Mg)}$$

The weightage of all the factors were calculated on the basis of the above equation.

Table I: Water Quality factors: the ICMR / CPHEEO standards assigned unit Weights

Water quality Factors	**ICMR / CPHEEO Standards (Xi)**	**Unit Weight (Wi)**
pH	7.0 – 8.5 **	0.322
Dissolved Oxygen	>5*	0.548
Electrical Conductivity	<300*	0.009
Total Dissolved solids	< 1500**	0.002
Total Alkalinity	<120*	0.023
Total Hardness	<600**	0.005
Calcium	<75*	0.037
Magnesium	<50*	0.055

*ICMR Standards (1975) **CPHEEO Standards (1991)

3.2 RATING FACTOR

Rating scale (Table 3) was prepared for range of values of each parameter. The rating varies from 0 to 100 and is divided into five intervals. The rating Xr = 0 implies that the parameter present in water exceeds the standard maximum permissible limits and water is severely polluted. On the other hand Xr = 100 implies that the parameter present in water has the most desirable value. The other ratings fall between these two extremes and are Xr = 40, Xr = 60 and Xr = 80 standing for excessively polluted, moderately polluted and slightly less polluted respectively. This scale is modified version of rating scale given by Tiwari and Mishra [8] (1985).

Table II: Rating Scale for Calculating WQI

Water Quality Parameter	Ranges				
pH	7.0–8.5	8.6 - 8.7 6.8 – 6.9	8.8 – 8.9 6.7 – 6.8	9.0 – 9.2 6.5 – 6.7	>9.2 < 6.5
Dissolved Oxygen	> 7.0	5.1 - 7.0	4.1 – 5.0	3.1 – 4.0	<3.0
Electrical Conductivity	0 – 75	75.1– 150	150.1 – 225	225.1 - 300	>300
Total Dissolved Solids	0 - 375	375.1– 750	750.1- 1125	1125.1– 1500	>1500
Total Alkalinity	21-50	50.1- 70 15.1 - 20	70.1 – 90 10.1 – 15	90.1 – 120 6 – 10	>120 <6
Total Hardness	0 - 150	150.1 – 300	300.1– 450	450.1 – 600	>600
Calcium	0 – 20	20.1 – 40.0	40.1 – 60.0	60.1 – 75.0	>75
Magnesium	0 – 12.5	12.6 – 25.0	25.1 – 37.5	37.6 -50	>50
Xr	100	80	60	40	0
Extent of Pollution	Clean	Slight pollution	Moderate Pollution	Excess Pollution	Severe Pollution

Table III: Rating Scale for Quality of water

Value of WQI	Quality of Water
90 – 100	Excellent
70 – 90	Good
50 – 70	Medium
25 - 50	Bad
0 - 25	Very Bad

3.3 Water Quality Index Calculation

Essentially, a WQI is a compilation of a number of parameters that can be used to determine the overall quality of a river. WQI is calculated for each month and is given in Table 4. The parameters involved in the WQI are dissolved oxygen, pH, Dissolved Oxygen, Electrical Conductivity, Total Dissolved solids, Total alkalinity, Total Hardness, Calcium and Magnesium. The numerical value is then multiplied by a weighting factor that is relative to the significance of the test to water quality. The sum of the resulting values is added together to arrive at an overall water quality index.

WQI = Wi x Xr
i.e. Water Quality Index is equal to the product of rating (Xr) and unit weight (Wi) of all the factors.

Wi x Xr = Wi(pH) x Xr(pH) + Wi(DO) x Xr(DO) + Wi(EC)
+ Xr (EC) + Wi(TDS) x Xr(TDS) + Wi(Tot.Alk)
x Xr(Tot.Alk) + Wi(Hardness) x Xr(Hardness)
+ Wi(Ca) x Xr(Ca) + Wi(Mg) x Xr(Mg)

The values of Xi, Wi and Xr are given in Tables 2 and 3. Hence by multiplying Wi and Xr we can get the value of WQI. The WQI result represent the level of water quality in a given water basin such as lake, river or stream. Similar WQI was given by Mariappan *et al.,* [9], (1998) by using nine important water quality parameters.

IV. RESULTS AND DISCUSSIONS

The descriptive statistics of the three developed models viz., Actual Measured WQI model, Time Series (09-12) model and Time Series (12-15) model of the two monitoring stations are tabulated below (Tab:IV). Significant correlation was found for the two stations, which is attributed to the consistency in the estimation of the forecasted water quality parameters. The trend patterns of WQI for both stations for the future period were significantly identical except for a few months. The values of the WQI for both the stations matched well except for a few month, which is due to variations of Dissolved oxygen levels. The results of the statistical performance test of the Actual measured and Timeseries model (09-12) are tabulated in Table:V. The values of the WQI of Rajahmundry station and Dowlaiswaram are significantly identical for all the four seasons of the future period (2012-2015) except for a few months during NorthEast monsoon season (Oct to Dec).

The availability of dissolved oxygen plays an important role in the health of the river; hence higher weightage factor was given to dissolved oxygen. As such slight change of D.O altered the rating factor, and WQI which is obtained by the product of weigthage factor and rating factor significantly altered, thereby affecting the pattern of the WQI. The rating factor Xr= 100 and Xr=80 were adopted for D.O > 7.0 and <=7.0 respective ly with a weigth factor of 0.548 which led to the difference of WQI values by 10units.

The higher values of WQI indicated that the water is very much clear and free of any impurities, and the water is in good condition to support the biotic communities. Identical values of WQI were obtained for the Southwest monsoon season (June to Sep), Winter season (Jan to Feb) and summer season (Mar to May) for all the future three years. Almost similar values were obtained for the year 2012-2013; which indicated that the water quality is of excellent grade.

Table IV: Descriptive Statistics of Water Quality Index of Rajahmundry and Dowlaiswaram Water Quality Monitoring Station

Time Period	**Min**	**Max**	**Mean**	**Std. Dev**	**Variance**
RAJAHMUNDRY					
Actual Measured	88.04	99.46	96.53	4.74	22.51
Time Series (09-12)	87.68	99.28	93.98	5.68	32.22
Time Series (12-15)	88.32	99.46	95.07	5.17	26.72
DOWLAISWARAM					
Actual Measured	88.32	99.28	98.31	2.38	5.65
Time Series (09-12)	87.86	99.28	95.41	5.02	25.16
Time Series (12-15)	87.86	99.46	93.93	5.26	27.62

Table V: Results of Statistical Performance Test

Station	MAE	RMSE	MAPE
Rajahmundry	4.97	7.31	5.15
Dowlaiswaram	3.41	5.82	3.48

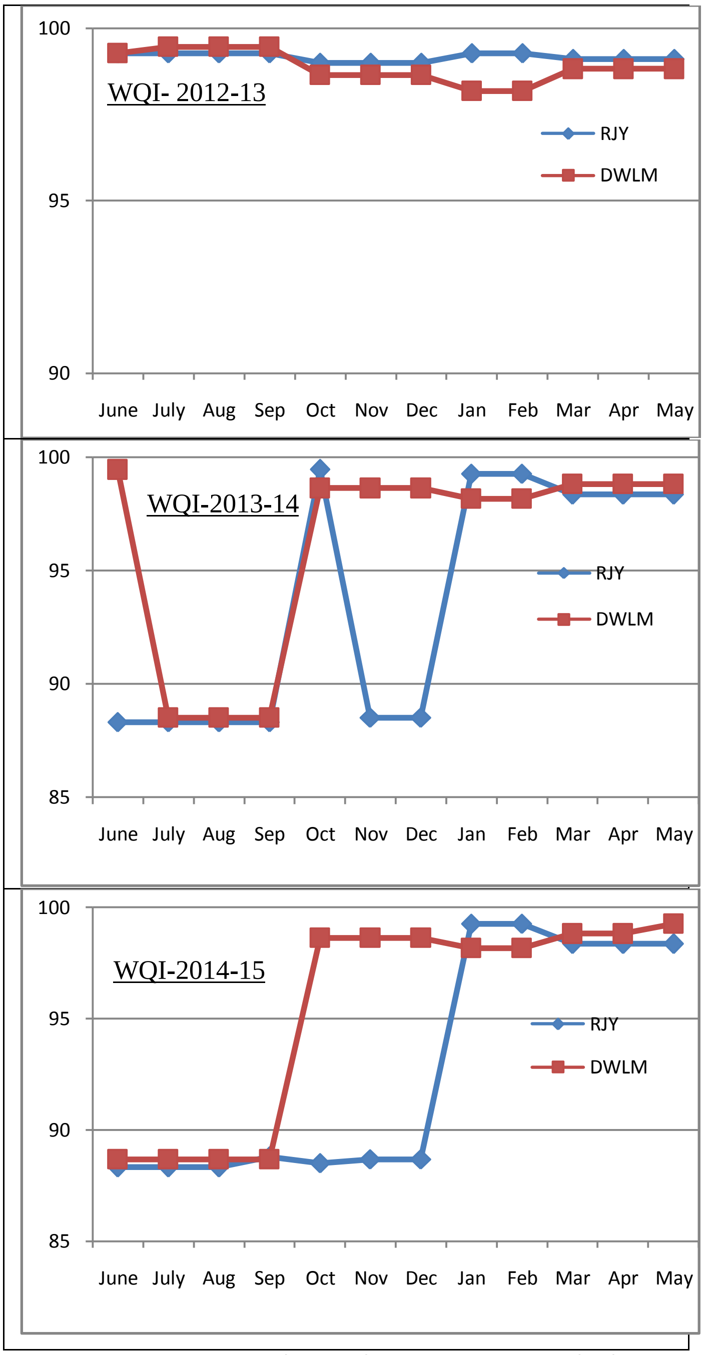

Figure showing the Variations of WQI of Monitoring Stations for future years

V. CONCLUSION

The results of the study indicated that the water quality of Rajahmundry and Dowlaiswaram water quality monitoring stations exhibited significant seasonal trend pattern for the future period (2012-2015). The statistical criterion revealed that the MAE= 4.97 & 3.41, RMSE=7.31 & 5.82 and MAPE=5.15% & 3.48% respectively for the two stations, which indicated that the developed models were performing well. The variations of WQI during NorthEast monsoon season are attributed to the fluctuations in Dissolved Oxygen levels. The predicted values of WQI for the future years (2012-2015) reveals that the water quality of River Godavari is Excellent to Good quality.

The factors with high weightage factor dictated the evaluation of WQI. The low values reported in the historic data controled the accuracy of prediction of the developed model using time series forecasting methods. However necessary preventive measures to maintain high water quality of the Mighty River must be taken up to ensure the safety of the river and to preserve this valuable resource to the future generations. Water Quality Index may be used as a tool to convey the information regarding the quality of water in an easy and understandable way to the public and policy makers.

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