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Water Quality Modelling – Statistical Approach

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Abstract: The present study involves the assessment of water quality modelling w.r.t surface water sources especially rivers. Water Quality Index (WQI) provides a single number like a grade that expresses the overall water quality at a location and at a specific time based on several water quality parameters. A model is a small object usually built to scale, that represents another larger object. Such a model of water quality can be represented generally as a function of physico-chemical and biological characteristics of water. Water quality modelling has developed appreciably since its innovation in the early years of the twentieth century. Several statistical methods viz., Factor Analysis (FA), Discriminant Analysis (DA), Cluster Analysis (CA), Prinicipal Component Analysis (PCA) etc can be effectively in the studies related water quality modelling.

Keywords: Water Quality Index (WQI), Factor Analysis (FA), Cluster Analysis (CA), Principal Component Analysis (PCA), Discriminant Analysis (DA).

I. INTRODUCTION

Most of the early water quality modelling work focused on the problems related to urban waste load allocation into the rivers. The seminal work in this field was the model developed by Streeter and Phelps on the Ohio River. The subsequent investigations provided a means to evaluate dissolved oxygen levels in streams and estuaries. In addition, biological models were also developed. Because of the non-availability of computers, model solutions were of closed form. This meant that applications were usually limited to linear kinetics, simple geometrics and statistics. Thus, the scope of the problems that could be addressed was constrained by the available computational tools.

Water quality modelling is used to predict the pollution causing agents in a water body by using mathematical and numerical simulations, analytical and statistical methodologies. Each water quality has its own unique purpose and simulation characteristics. In which statistical analysis plays a major role in the water quality modelling area. There are several methods of statistical analysis such as Multivariate analysis, Chemo metrics techniques etc. in which techniques such as Cluster Analysis (CA), Factor Analysis (FA), Discriminant Analysis (DA) and Principal Component Analysis (PCA) are most popularly used. Other methodologies include Neural Networks, Linear and Non-linear Regression Analysis, Descriptive statistics, Analysis of variance (ANOVA), Correlation etc. Several computational programmes have been developed for water quality modelling such as XLSTAT, EXCELL, R statistical package version 2.11.0, MINITAB, MATLAB. The most widely used statistical software in recent times for modelling the water quality of rivers Statistical Product and Service Solutions (SPSS).

Water quality index (WQI) forms a basic component of water quality modelling. The basic objective of calculating WQI is to convert complex water quality data into a form that is easily understandable to the scientific community. It is a well-known method of expressing water quality that offers a stable and reproducible unit of measure which responds to changes in the principal characteristics of water. It is a mechanism for presenting a cumulatively derived numerical expression defining certain level of water quality. WQI summarizes large amounts of water quality data into simple terms viz., excellent, good, bad etc. for reporting to water management bodies and to the public in a consistent manner.

II. HISTORY OF WATER QUALITY MODELLING AND WATER QUALITY INDEX

From 1960s onwards digital computers became widely available. This led to major advances involving numerical expressions of the analytical frameworks. Oxygen was still the focus in water quality modelling. However the advent of computers allowed analysts to address more complicated system geometrics, kinetics, and time-variable simulations.

The sixties also brought changes in the ways in which the models were applied. Rather than focusing on local effects of single point sources, one could view the drainage basin as a system. Tools developed originally in the field of operations research were coupled with the models to generate cost – effective treatment alternatives. Although the focus was still on point sources, the computer allowed models at present focus on various number of water quality parameters to improve the authenticity of water quality index.

In the mid-twentieth century, Horton[11] (1965) coined WQI. The parameters considered for the calculation of WQI were DO, pH, Coliforms, specific conductance, alkalinity and chlorides. The index weightage ranged from 1 to 4. The summations of the indices were divided by the sum of weights and were multiplied by two coefficients M_1 and M_2 i.e., coefficient of temperature and coefiicient of obvious pollution.

Prati[21] (1971) used a parametric scale varying them from 0 to 13 with values more than 8 denote heavy pollution.

Brown[6] (1972) proposed multiplicative form of WQI where individual weights were assigned to the parameters. The assigned weights reflect the significance of the parameters which has a considerable impact on the index. Similar methodologies have been considered by various other researchers depending on the usage and parameters considered.

In an entirely different system by Harkins[9] (1974, 1977), values are given standard rankings in relation to selected control values for parameters and then it is used to compute the standardized distance from the control values for each parameter to produce an index.

In another method by Inhaber[14] (1975) different parameters were introduced to the two distinct sub-indices where the first one dealt with industrial and domestic wastes and the second one dealt with background water quality with equal weightages and was averaged to give the WQI which ranges from 0 for best quality and increasingly large number for worse quality of water.

For the recreational purpose Walski and Parker[28] (1974) gave an index based on empirical information on the suitability of water. Dinius[7] (1987) attempted to design a rudimentary social accounting system which would measure the costs and impact of pollution control efforts and applied WQI on an illustrative basis to data of several streams in Alabama, USA.

III. WATER QUALITY MODELLING - STATISTICAL APPROACH

Water Quality Modelling (WQM) can be conducted in so many ways such as analytical, numerical, and statistical. Though there were several ways, statistical methods are the most prominent compared with the others. Especially the multivariate statistical methods i.e. Cluster Analysis (CA), Principle Component Analysis (PCA), Factor Analysis (FA), and Discriminant Analysis (DA), Regression etc, are most popularly used methods.

HulyaBoyacioglu[12] et.al, (2005) assessed the surface water quality in Buyuk Menderes River basin located at western Turkey, using Factor Analysis a multivariate technique.

Tripathy and Sahu[26] (2005) studied on the seasonal hydrochemistry of Groundwater in the Barrier spit system of the Chilika lagoon, India, taking the Pre-monsoon and Post-monsoon variations into consideration.

For the assessment of surface water quality for the River Fuji in Japan, Shrestha and Khazama[24] (2006) used multivariate analysis techniques taking into consideration the data of 12 parameters for the period 1995-2002 monitored at 13 different sites. The multivariate statistical techniques viz, cluster analysis, factor analysis, discriminant analysis and principal component analysis were applied to evaluate the spatial and temporal variations and for interpreting large water quality data set. This study illustrated the usefulness of multivariate statistical analysis techniques and interpretation of complex data sets by identifying the pollution sources/factors and understanding temporal/spatial variations in water quality management.

Arzualtin[3] et.al, (2008) conducted a study on assessment of seasonal variations of surface water quality characteristics for Porsuk Stream in Turkey. Data collection and analysis are based on Standard Hydraulic Works (SHW) at Esenkara monitoring station within their long-term monitoring program. A ten years data of 29 parameters measured in four seasons i.e. winter, spring, summer and fall, is analyzed using Factor Analysis.

Multivariate statistical techniques are used for assessing the surface water quality of the two rivers Juru and Jegawi in Malaysia using the data of 10 parameters at 10 different sites by Abbas F.M. Alkarkhi[1] et.al, (2008). The analysis was done to explore the extent of resemblance among the sampling sites, to identify the variables responsible for spatial variations in river water quality to locate the hidden factors explaining the structure of the database, and to quantify the influence of possible natural and anthropogenic sources on the water parameters of the two selected rivers.

Yogendra.K and E.T.Puttaiah[29] (2008), conducted a study for determining the water quality of an urban water body Gopidhettykere for public consumption, recreation and other purposes in Shimoga town, Karnataka, and determined seasonal variation of Physico-chemical parameters.

KakoliBanerjee[15] et.al, (2009) conducted a study on seasonal variation in the biochemical composition of red seaweed from Gangetic delta, Northeast coast of India with season wise sampling. March to June is considered as Pre-monsoon period, July – October as Monsoon period and November – February as Post-Monsoon period and the analysis was carried out using SPSS 9.0, 1999.

Assessment of WQI in Mahanadi and Atharabanki rivers and Taldanda canal in Paradip area, India was done by PradyusaSamantray[19] et.al, (2009) taking into consideration the seasonal variations. Surface waters were collected from all the rivers and streams on a monthly basis and segmented as per three seasons post-monsoon, winter season and summer season for the year 2006. Using NSFWQI method, WQI is calculated by considering pH, DO, BOD, Fecal Coliforms parametric variables.

Water quality modelling of river Ravi at Madhopur was conducted by Ashwin Kumar and Anish Dua[4] (2009),calculating WQI for each month to assess the suitability of water for drinking purposes, considering eight important physico-chemical properties using Central Public Health Environmental Engineering Organization (CPHEEO), 1991 & Indian Council of Medical Research (ICMR), 1975 standards.

Using chemo- metric multivariate statistical analysis Prakashraj Kennel[20] et.al, (2010) conducted a study for the assessment of seasonal variation of water quality of Bagmati River. Seasons considered for the analysis are Pre-monsoon (March – May), Monsoon (June – August), Post-Monsoon (September – November) and winter (December – February).

A study on application of water quality index for groundwater quality assessment at Thirumanimuttar sub-

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basin, Tamilnadu was conducted by Vasanthavigar[26] et.al, (2010) for irrigation and drinking water purposes. Parameters considered for the calculation of WQI related to irrigation are SAR, RSC, Na%, TH. Water quality for these parameters was calculated using the recommendations of salinity laboratory of the US department of agriculture.

Water quality modelling of Klang River was done using combined Principal component analysis and Multiple Linear Regressions by MohdFahmiMohdNasir[18] et.al, (2011). Klang River is the major River that flows through Kaulalampur, Shah Alam, Petaling Jaya and Klang cities, which was polluted due to industrial activities and domestic wastes. The WQI was developed to evaluate the water quality status. Normality test were perform using XLSTAT2010 software based on Anderson-Danling test.

ZareGarigi[30] et.al, (2011) studied on seasonal variations of chemical characteristics of surface water using multivariate statistical techniques for the Chehelchay watershed in northwest of Iran. Methods such as Multivariate analysis of variance (MANOVA), DA, PCA, FA were used.

Soledad[25] Olive Gonzalez et.al, (2011) conducted a study on the assessment of water quality for the river Potuero de los Funes in Argentina using 16 physico-chemical and bacteriological parameters measured over a period of one year. Multivariate statistical techniques such as CA, DA, and PCA are used to evaluate spatial and temporal variations in the water quality.

As different National and International Agencies involved in water quality assessment and pollution control defines water quality criteria for different uses of water considering different indicator parameters, there are numerous WQI specific to any region or area. Eight WQI's perceived as simple, basic and most important indices for water quality assessment and the related mathematical structure of parameters, calculation, aggregation formula and flaws are presented in detail by Bharati and Katyal[5] (2011).

A Statistical Analysis for identification of anthropogenic influences of Aras River located in Northwest of Iran was conducted by EbrahimFateai[8], et.al, (2012), based on the instructions introduced by EPA standard methods. Sampling and analysis was done for 24 physical and chemical parameters. Statistical methods like ANOVA, Correlation, Cluster Analysis were used. All the mathematical and statistical calculations were done by $Excell_{2007}$, $SPSS_{18}$, and $MINITAB_{15}$. The Kolmogoror-smirnor (K-S) statistics were used to test the goodness of fit of the data to log-normal distribution.

Assessment of water quality index of river Godavari at Rajahmundry was done by Mahesh Kumar[16] et.al, (2012), in which seasonal variations of WQI during the study period 2009-2012 were calculated and future period 2012-2015 were predicted. NSFWQI method was used to calculate WQI values.

Rumman Mowla Chowdhury[22] et.al, (2012) assessed the quality of water bodies along Faridpur – Barisal road in Bangladesh taking the seasonal variations into consideration. Shinde Deepak and NingwalUdaySingh[23] (2013) conducted a study on the water quality of the Groundwater at Dhar town, Madhya Pradesh, India for public consumption. Ali Behmanesh and YaserFeizabadi[2] (2013) studied the quality of water of Babolrood River at Mazandaran, Iran by using NSFWQI and WAIWQI methods.

To evaluate the state of health of marine waters, Maharashtra Pollution Control Board (MPCB) implemented a monitoring marine program. The statistical methods CA, PCA, DA were used by Indrani Gupta[13] et.al. (2013) to assess marine water quality, taking into consideration nine different parameters viz.., pH, DO, BOD, EC, Total Coli forms, NH_3-N, NO_3-N, Phosphates, and Temperature, measured at 34 different sites.

A study was conducted by Majid Ajorlo[17] et.al, (2013) to assess the seasonal variations in water quality by using CA, DA and FA for the catchment TPU, Kualalumpur, Malaysia for one year dataset considering 14 parameters at 6 sampling stations. The seasons considered as dry season (May to September) and rainy season (October to April). CA yielded the data into two groups as less polluted and moderately polluted, whereas DA was used to predict group membership from a set of variables.

The two most popular methods for calculating WQI are as follows.

A. National Sanitation Foundation Water Quality Index (NSFWQI) Method

In the present study, the NSFWQI is used to calculate the water quality index. NSFWQI was developed by Brown in 1970 by assigning weights to the selected parameters. The work done by Brown was supported by National Sanitation Foundation and that is why it was referred as NSFWQI. Since this seems to be a most comprehensive method, it was followed by so many researchers in water quality modeling.

WQI is given as,

$$WQI = \sum SI_i$$

Where,

$$SI_i = w_i \times q_i$$

For computing the WQI, the SI is first determinedfor each chemical parameter, which is thenused to determine the

WQI

Where SI_i is the sub – index of the i^{th} parameter,
w_i is the relative weight and is computed by using the following equation:

$$w_i = 1/s_i$$

s_i indicates the standard values of the parameters**.**

$$q_i = (c_i / s_i) * 100$$

q_i indicates quality rating of i^{th} parameter.
c_i indicates the experimental value.

Based on the WQI obtained, the type of water can be categorized using the following rating scale grades as per NSF norms.

TABLE I: NSFWQI rating scale

WQI Range	Type of water
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Fair
0-25	Poor

B. *Weighted Arithmetic Index (WAI) Method*

Water Quality Index (WQI) can be calculated using the Weighted Arithmetic Indices. In this model, different water quality components are multiplied by a weighted factor and are then aggregated using simple arithmetic mean. For assessing the quality of water in this study, firstly, the quality rating scale (q_i) for each parameter is to be calculated by using the following equation;

$$q_i = \{[(V_{actual} - V_{ideal}) / (V_{standard} - V_{ideal})] * 100\}$$

Where,

q_i= Quality rating of i^{th} parameter for a total of n water quality parameters

V_{actual}= Actual value of the water quality parameter obtained from laboratory analysis.

V_{ideal} = Ideal value of that water quality parameter can be obtained from the standard tables.

$V_{standard}$= Recommended BIS standard for a particular water quality parameter.

Then, after calculating the quality rating scale (qi), the relative (unit) weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) for the corresponding parameter using the following expression;

$$W_i = 1/ S_i$$

Where,

W_i = Relative (unit) weight for nth parameter

S_i= Standard permissible value for nth parameter

I = Proportionality constant.

The overall WQI is calculated by aggregating the quality rating with the unit weight linearly and by using the following equation:

$$WQI = \sum W_i q_i / \sum W_i$$

Where,

Q_i = Quality rating

W_i = Relative weight

WQI for the drinking water was taken as 100 score.

The obtained WQI ranges, the quality of water can be obtained using the following rating scale grades against their respective WQI ranges.

Table II: WAIWQI rating scale

WQI Range	Quality of water
0-25	Excellent
26 – 50	Good
51-75	Poor
76-100	Very poor
>100	Unsuitable for usage

IV. CONCLUSION

1. Water Quality Modelling can be done using analytical, numerical and statistical approaches. Statistical approaches are more popular in arriving at WQM.
2. Multivariate Statistical methods viz.., Cluster Analysis (CA), Principal Component Analysis (PCA), Factor Analysis (FA), and Discriminate Analysis (DA) are most widely used methods in the studies related to WQM.
3. WQI which converts the complex water quality data into a unified value representing the quality in an easily understandable manner facilitating an effective water management systems.

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