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WATER PURIFICATION: A BRIEF REVIEW ON TOOLS AND TECHNIQUES USED IN ANALYSIS, MONITORING AND ASSESSMENT OF WATER QUALITY

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Abstract

Drinking water sources are regularly polluted by various human activities that cuase sever health problem all over the world. In recent years, water quality research has drawn great attention of scientific communities. A lot number of tools and techniques are used for proper water quality analysis, monitoring and assessment. This paper includes brief information about some of the them namely, physio-chemical water analysis (PCWA), adsorption, metal pollution index (MPI), water quality index (WQI), water quality modelling tools (WQMT) and multivariable statistical models that includes five multivariate data mining approaches i.e. cluster analysis (CA), principal component analysis (PCA), factor analysis (FA), multiple linear regression analysis (MLRA), discriminant analysis (DA). Present paper also explores the interaction between science and technologies and provides basic knowledge of emerging tools and techniques used in water purification.

Keywords: Water purification, adsorption, metal pollution index, water quality index and water quality

INTRODUCTION

Water plays a vital role for sustainbility of life on the earth. Use of water in multiple streams such as drinking, agricultural and industrial purposes, fisheries and energy production mainly depends on its qaulity [1]. Water quality defined in terms of its chemical, physical and biological composition is mainly governed by both the natural (i.e. precipitation, watershed geology, climate, topography) and anthropogenic (i.e. point and non-point sources like urban and industrial activities, other domestic activities, agricultural run off) factors [2]. Contaminated water critically alters the balanced eco-system that is essential for the complementary beneficial interactions of the environment and living beings and also leads to disturbance of hormony in the nature [1]. Water quality measurment analysis, monitoring and assessment is very important to stimulate and pridict the distribution, risk and level of various chemical and biological pollutants present in water body [3]. Water quality management programmes includes the identification of the factors controlling their behavioural properties in addition to assessment of quslity of the aquatic systems.

This mini-review mainly focused to describe basic knowledge of tools and techniques used in water purification and their interaction with science. Thus, I hope this review provides brief information about tools and techniques used in analysis, monitoring and assessment of water quality and also inspire research and development in R&D sector in this field.

EMERGING TOOLS AND TECHNIQUES USED WATER PURIFICATION

Number of emerging tools and techniques now a days frequently used in water purification study are physio-chemical water analysis (PCWA), adsorption, metal pollution index (MPI), water quality index (WQI), water quality modelling tools (WQMT) and multivariable statistical models (MSM) that includes five multivariate data mining approaches i.e. cluster analysis (CA), principal component analysis (PCA), factor analysis (FA), multiple linear regression analysis (MLRA), discriminant analysis (DA).

PHYSICO-CHEMICAL WATER ANALYSIS (PCWA)

Physico-chemical water analysis is a method for the measurement of the water quality status either surface water resources or groundwater resources. The analysis comprises for different types of the chemical constituents which are present naturally or anthropogenically which becomes the beyond the prescribed limits of World Health Organization (WHO), US Evironmental Protection Agency (USEPA), Bureau of Indian Standards (BIS) and other International Standards become harmful for drinking and other purposes. The different parameters such as, colour, turbidity, total suspended solid, total Solid , total dissolved solid, alkalinity, hardness, chloride, flouride, nitrate, nitrite, lead, chromium, mercury, lead, Iron, zinc, arsenic and all other parameters can be analysed and results will show the actual water quality status.

ADSORPTION

Adsorption is a surface phenmenon and is very efficient techniques to purify the polluted water. Among the number of treatment methods (i.e. reduction, ion exchange, electrolysis, electrochemical precipitation, evaporation, oxidation, solvent extraction, reverse osmosis, chemical precipitation) used for the removal of metal ions from aqueous solutions adsorption proofes itself better than other. Adsorption isotherm modeling based water purification techniques attract more and more attention of researcher working in this field.

Generally, adsorption isotherm is an invaluable curve describing the phemenon governing the retention (or release) or mobility of a substance from the aqueous porous media or aquatic environments to a solid-phase at a constant temperature and pH [4 5]. The mathematical correlation which constitutes an important role towards the modeling analysis, operational design and applicable practice of the adsorption systems, is usually depicted by graphically expressing the solid-phase against its residual concentration [6]. In last decade, a wide variety of equilibrium isotherm models namely Langmuir, Freundlich, Brunauer-Emmett-Teller, Redich-Peterson, Dubinin-Radushkevich, Temkin, Toth, Kolbe-Corrigan, Sips, Khan, Hill, Flory-Huggins and Radke-Prausnitz isotherm have been formulated in terms of three fundamental approaches (kinetic, thermodynamic and potential energy approaches) [7]. Kinetic approaches conveys the adsorption equilibrium i.e. a state of dynamic equilibrium where rate of adsorption is equal to the rate of desorption, thermodynamic approaches can provide a framework of deriving numerous forms of adsorption isotherm models while potential theory usually conveys the main idea in the generation of characteristic curve [8]. Table 1 summarized the basic and brief information about the various adsorption isotherms used in water purification sectors [9].

Table 1: Brief information about various adsorption isotherms used in water purification

Two parameter isotherms		Three parameter isotherms	
Models	**Physical Significant**	**Models**	**Physical Significant**
Langmuir Isotherm Model	Langmuir adsorption mainly used to describe gas-solid phase adsorption of pollutants present in water. It is restricted to monolayer adsorption, localized and fixed active sites on adsorbent materials.	**Redlich-Peterson Isotherm Model**	Redlich-Peterson isotherm is a hybrid isotherm model featuring both the Langmuir and Freundlich isotherms which incorporate three variables into its empirical consideration. It has a linear dependence on concentration in the numerator and exponential function in the denominator to represent adsorption equilibrium over a wide concentration range that can be applied either in heterogeneous and homogeneous system due to its versatility.
Freundlich Isotherm Model	Freundlich isotherm is the oldest one model to describe the relationship between non-ideal and reversible adsorption and not restricted to the formation of monolayer formation. It is applied to the multilayer adsorption with non-uniform distribution of adsorption heat and affinities over the heterogeneous surface.	**Sips Isotherm Model**	Sips isotherm is a combined form of Langmuir and Freundlich expressions derived for predicting the heterogeneous adsorption systems and circumventing the limitation of the increasing adsorbate concentration associated with Freundlich adsorption isotherm model.
Dubinin-Radushkevich Isotherm Model	Dubinin-Radushkevich isotherm initially conceived for adsorption of subcritical vapors onto micropore solids obeying a pore	**Toth Isotherm Models**	It is another empirical isotherm equation developed to improve Langmuir isotherm fittings (experimental data) and useful in describing heterogeneous adsorption

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Two parameter isotherms		Three parameter isotherms	
Models	**Physical Significant**	**Models**	**Physical Significant**
	filling mechanism. It is an empirical model and applied to express the adsorption mechanism with a Gaussian energy distribution onto the heterogeneous surface. It is usually applied to distinguish the physical and chemical adsorption to metal ions.		systems which satisfying both low and high level of the concentration.
Temkin-Isotherm Model	Temkin isotherm is the early model describing the adsorption of hydrogen onto platinum electrodes within the acidic solutions. This model contains a factor that explicitly taking into the account of adsorbent-adsorbate interactions. It is excellent isotherm for predicting the gas phase equilibrium, conversely complex adsorption systems including the liquid-phase adsorption isotherms are usually not appropriate to be represented.	**Kolbe-Corrigan Isotherm Model**	Kolbe-Corrigan isotherm model is more similar to the Sips Isotherm Model and is also a three-variable equation which includes both Langmuir and Freundlich isotherm models for representing the equilibrium adsorption data.
Flory-Huggins Isotherm Models	Flory-Huggins isotherm is occasionally deriving the degree of surface coverage characteristics of adsorbate onto adsorbent can express the feasibility and spontaneous nature of an adsorption process.	**Khan Isotherm Model**	It is a generalized model suggested for the pure solutions. At comparatively high correlation coefficients and minimum ERRSQ or chi-square values, its maximum uptake values can be well determined.
Hill Isotherm Models	Hill isotherm models originated from the Non-ideal competitive adsorption (NICA) model which is postulated to describe the binding of different species onto homogeneous substrates.	**Radke-Prausnitz Isotherm Model**	The correlation of Radke Prausnitz isotherm is usually predicted well by the high RMSE and chi-square values. Its model exponent is represented by ˇR, where aR and rR are referred to the model constants.
Multilayer Physio-sorption Isotherm Model		Multilayer physio-sorption is well defined by Brunauer–Emmett–Teller (BET) isotherm which is a theoretical equation, most widely applied in the gas solid equilibrium systems. It was developed to derive multilayer adsorption systems with relative pressure ranges from 0.05 to 0.30 corresponding to a monolayer coverage lying between 0.50 and 1.50.	

Metal Pollution Index (Mpi)

Metal pollution index (MPI) [10] provide information about water quality and suitability for drinking purpose. MPI is a method of water quality rating that shows the composite influence of individual parameters on the overall quality of water. The rating value may

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vary between zero and one, reflecting the relative importance individual quality considerations. The higher the concentration of a metal compared to its maximum allowable concentration, the worse the quality of the water. Due to its combined characteristics to showing both the physio-chemical and microbial index, it becomes applicable to compare the water quality of various water bodies. It has wide application and it is used as the indicator to express the quality of sea and river water, as well as drinking water. The MPI represents the sum of the ratio between the analyzed parameters and their corresponding national standard values [11] as shown in equation (1):

$$MPI = \sum_{i=1}^{n} \left[\frac{Ci}{(MAC)i} \right] \qquad (1)$$

Where Ci- mean concentration; MAC- maximum allowable concentration

Water Quality Index (WQI)

Water quality index [12] is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption. It is an important technique for evaluating ground water quality and its suitability for drinking purposes. The standards for drinking water purposes as recommended by WHO and IS 1510500 have been considered for the calculation of WQI. WQI may be calculated by following the steps given below:

1. Calculation of weightage of ith parameter (Wi)

2. Calculation of the quality rating for each ofthe water quality parameters (Qi)

3. Then, summation of these sub-indices in the overall index

The Weightage of i^{th} Parameter (generally ten parameters are considered i.e. pH, turbidity, TDS, total hardness, Cl^-, NO_3^-, F^-, Mg^{2+}, Ca^{2+}, and Fe) may be given equation (2):

$$Wi = k/Si \qquad (2)$$

Where Wi is the unit weightage and Si the recommended standard for i^{th} parameter (i = 1-6), k is the constant of proportionality.

Individual quality rating is given by the equation (3):

$$Qi = 100Vi/Si \qquad (3)$$

Where Qi is the sub index of i^{th} parameter, Vi is the monitored value of the i^{th} parameter in μg/L and Si the standard or permissible limit for the i^{th} parameter.

The Water Quality Index (WQI) is then calculated as follows

$$WQI = \sum_{i=1}^{n} (QiWi) \Big/ \sum_{i=1}^{n} Wi \qquad (4)$$

Where, Qi is the sub index of i^{th} parameter. Wi is the unit weightage for i^{th} parameter, n is the number of parameters considered.

WATER QUALITY MODELING TOOLS (WQMT)

Water quality models are very important tool to identify water environmental pollution and the final fate and behaviors of pollutants in water system. These modeling results under different pollution scenarios using water quality models are very important components of environmental impact assessment. More than hundreds water quality models have been developed around all over the World. Some of the more significant models [3] are listed in Table 2.

Table 2: Some important water quality models, their versions and characteristics

Water quality models	Model versions	Characteristics
EFDC MODELS	EFDC MODELS	First time, Virginia Institute of Marine Science developed EFDC model and US EPA approved it's as a tool for water quality management in 1997. EFDC model is suitable for water quality simulation in rivers, lakes, reservoirs, estuaries, and wetlands, including one-, two-, or three dimensional models.
QUASAR MODELS	QUASAR MODELS	In 1997, Whitehead established the QUASAR model. It is suitable model for dissolved oxygen simulation in larger rivers, and it is a one dimensional dynamic model including PC QUA SAR, HERMES, and QUESTOR modes.
WASP MODELS	WASP 1-7 MODELS	In 1983, US Environmental Protection Agency developed WASP model. It is suitable model for water quality simulation in rivers, lakes, estuaries, coastal wetlands, and reservoirs, including one-, two-, or three-dimensional models.
BASINS MODELS	BASINS 1	In 1996, US EPA developed these models as multipurpose environmental analysis systems. BASINS models are suitable for water quality analysis at watershed scale
	BASINS 2	
	BASINS 3	
	BASINS 4	
QUAL MODELS	QUAL I	US Environmental Protection Agency has developed this model in 1970. These models are suitable for dendritic river and non-point source pollution, including one-dimensional steady-state or dynamic models.
	QUAL II	
	QUAL 2E	
	QUAL 2E UNCAS	
	QUAL 2K	
STREETER-PHELPS MODELS	S-P MODEL	In 1925, Streeter and Phelps established the first S-P model. S-P models mainly focus on oxygen balance and one-order decay of BOD and they are one dimensional steady-state models.
	THOMAS BOD-DO MODEL	
	O'CNNOR BOD-DO MODEL	
	DOBBINS-CAMP BOD-DO MODEL	
MIKE MODELS	MIKE 11	Mike models are developed by Denmark Hydrology Institute which are suitable for water quality simulation in rivers, estuaries, and tidal wetlands, including one-, two-, or three dimensional models.
	MIKE 21	
	MIKE 31	

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MULTIVARIABLE STATISTICAL MODELS (MSM)

It has become accepted in today's world that in order to learn about something, you must first collect data. Statistics is the art of learning from data. It is concerned with the collection of data, its subsequent description, and its analysis, which often leads to the drawing of conclusions. Statistical analysis begins with a given set of data and statistics further used to describe, summarize and analyze these data. Now, statistical analysis can be categorized into univariate, bivariate and multivariate techniques. A common example of univariate statistics is the computation of arithmetic mean while correlation and simple regression analysis is the bivariate statistical tools. Relating to a multivariate analysis, it simply involves simultaneous examination of more than two variables [13]. All statistical systems concerned with simultaneous analysis of multiple measurements on many different variables constitute the multivariate analysis [14 13]. This system is also called variable-directed multivariate analysis. However, in environmental studies, identification of relationships between samples are equally as important as revealing their relationships between the variables. The former defines the sample-directed multivariate analysis [15]. Environmetric techniques use multivariate statistical models for better interpretation of the data quality. Some commonly used multivariate statistical models for environmental data analysis are: cluster analysis (CA), principal component analysis (PCA), factor analysis (FA), multiple linear regression analysis (MLRA) and discriminant analysis (DA). These intelligent data mining techniques are very helpful in pattern recognition and exploratory data analysis driving hidden information from the data set [16]. Table 3 summerized the brief information about five more commonly used multivariate statistical models [17].

Table 3: Summerized characteristics of five more useful multivariate statistical models

Multivariate statistical models	Characteristics
Cluster analysis (CA)	CA is a classification technique which can be used to determine existence of natural subgroups or classes of individuals in a given dataset. Here, individuals are grouped based on their similarities and dissimilarities. Each group represents a cluster of individuals or objects with homogeneous properties separated from a heterogeneous large population. The analysis contains two fundamental steps or choices: a proximity measure and a group-building algorithm.
Principal component analysis (PCA)	PCA technique extracts the eigen values and eigen vectors from the covariance matrix of original variables, thus, reducing the dimensionality of the data set. The principal components (PCs) are the un-correlated (orthogonal) variables, obtained by multiplying the original correlated variables with the eigenvector (loadings). The eigenvalues of the PCs are the measure of their associated variance, the participation of the original variables in the PCs is given by the loadings, and the individual transformed observations are called scores. PCA was performed on normalized (z-scale transformation) on 20 variables after sorting out the highly correlated variable from the data sets.
Factor analysis (FA)	Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. For example, it is possible that variations in four observed variables mainly reflect the variations in two unobserved variables. Factor analysis is used to identify "factors" that explain a variety of results on different tests. For example, intelligence research found that people who get a high score on a test of verbal ability are also good on other tests that require verbal abilities. Researchers explained this by using factor analysis to isolate one factor, often called crystallized intelligence or verbal intelligence, which represents the degree to which someone is able to solve problems involving verbal skills.
Multiple linear regression analysis (MLRA)	Regression analysis in simple terms, discloses average relationship between two variables, designated as dependent and independent variable, which makes estimation or prediction mathematically possible. The relationship may be linear or non-linear. A linear relationship is obtained when the dependent variable shows constant absolute change in response to change in the independent variable by one unit. Linear regression analysis is conducted to predict a

Multivariate statistical models	Characteristics
	dependent variable, also known as response or criterion variable, mathematically from one or more independent variables, also known as predictor or explanatory variables.
Discriminant analysis (DA)	Multiple linear regression analysis is used in situations where the dependent variable is a metric variable whereas in discriminant analysis, the dependent variable is non-metric (nominal or categorical). The basic objectives of DA are to differentiate between population groups and to assign new observations into the classified groups. It is also a classification and dimension reduction technique and is exploratory in nature. Thus, unlike cluster analysis, which creates groups or clusters from an unclassified data, DA operates when the data set is already classified. A minimum of two groups are required for the DA to perform. When only two groups are involved, the technique is called "two-group DA" and when three or more groups are identified, the technique is called "multiple DA". In data mining, DA is also employed to discover most important quantitative variables separating the groups and for testing the hypothesis on the differences between the groupings expected

CONCLUSION

Water quality analysis and its proper monitoring are very important to sustain the quality of water on the earth. Now a day, a worldwide mission is activily engaged in water quality assessment and monitoring. Some of the developed countries have mandated the quidance on water enviromental quality assessment and provided some regulated models for water quality simulation. So, it is necessary for developing countries also to use some more widely used water quality models for efficient environmental impact assessment. Better understanding of tools and techniques is very useful to design new experimental set up to purify the contaminated water. Thus, I hope that this mini-review provides brief elementary information about some of the most useful tools and techniques used water quality analysis, assessment and monitoring and also inspire research & development in this field.

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