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Review of Various Contamination Index Approaches to Evaluate Groundwater Quality with Geographic Information System (GIS)

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Abstract: Groundwater is important substance for many rural, agricultural and industrial regions and their associated cultures and populations across the globe. It is the major source of drinking and other domestic purposes. Intense urbanization and industrialization, improper waste disposal and landfill, excessive use of fertilizer and unsanitary condition has contaminated the groundwater quality to a larger extent. Contamination indexes are such tool which helps to protect groundwater quality from contamination. It is an effective tool for evaluating and mapping the degree of groundwater contamination. It is the factor of single component that exceeds the maximum permissible concentration of water quality parameters. The present paper focuses various contamination index method used in groundwater quality evaluation. This approach has been used for the grading of area according to contamination level like Low, Medium and High grade. There are several contamination index methods distinct for any region because many national and international agencies define water quality criteria for various uses considering various parameters in groundwater quality assessment and pollution control. Various contamination index methods have been developed and their relevance area also discussed here.
Keywords: Contamination Index, Groundwater, Mapping, Water Quality.

1.0 Introduction:

Water is the most important, abundant and useful natural resources on the earth because no life is possible without water [1]. It is essential for the survival of all living beings and plays an important role in our life. Groundwater is about 0.6% of the total global water resources and out of this only 0.3% is being used for economical purpose [2]. In India, most of the people depend on the groundwater as only source of drinking water because groundwater is comparatively much clean and free from pollution than the surface water [3]. Contamination and over exploitation are the major reason for groundwater quality deterioration [4]**.** Though recent years shift in usage from surface water to groundwater has controlled microbiological problems in rural India to a certain extent, but the same has led to newer problems of fluorosis, arsenicosis and salinity due to overexploitation of groundwater [5]. Excess iron is an endemic water quality problem in many part of the India [6] .Access to safe drinking water remains an urgent necessity, as 30 % of urban and 90 % of the rural Indian population still depends completely on untreated surface or groundwater resources [7]. While access to drinking water in India has increased over the past decades, the tremendous adverse impact of unsafe water for health continues. It is estimated that about 21 % of the communicable diseases in India are water borne [8]. Extensive use of fertilizers, pesticides, discharge of industrial effluents, domestic sewage and solid waste dump, landfills and many other anthropogenic activities are the major sources of the groundwater contamination. It is rising continuously day by day across the world due to extreme residential, municipal, commercial, industrial, and intensive agricultural practices because the rate of discharge of the pollutants into the groundwater is higher than the rates of their purification [9].Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab [10] . Population growth and lack of awareness among the people are also responsible groundwater pollution problem increases to a large scale [11]. Therefore, it has become important to protect the groundwater resource against contamination in recent time, because they have negative effects on the human beings, plants and animals [12] [13]. Developing countries are comparatively more affected than developed country due to groundwater contamination because of poor maintenance of water quality, high cleanup costs, high costs for alternative water supplies due to low economy [14]. In the developing countries ~1.8 million people, especially children die every day, because of the contaminated groundwater [15]. Groundwater quality is declining slowly but surely all over the world. Groundwater quality problems are not easy to assess and difficult to manage. Thus, regular monitoring and proper management of groundwater quality has become important. Assessment of groundwater quality is important to assess the quality of water for ecosystem, health and hygiene, industrial, agricultural and other domestic purposes [16]. The quality of groundwater at any point below the surface reflects the combined effects of many processes along the groundwater flow path. Chemical reactions such as weathering, dissolution, precipitation, ion exchange and various biological processes commonly take place below the surface [10]. Groundwater contamination monitoring is not easy to assess for huge samples containing concentrations for various parameters .So, contamination index methods are such tool which minimizes the data volume to a large extent and simplifies the expression of groundwater contamination status. Evaluation of contamination index is based on number of Physico-chemical parameters. It is an effective tool for evaluating and mapping the degree of groundwater contamination. It is the sum of the individual factors of single component that exceeds the maximum permissible concentration of water quality parameters [17]. Thus; the Contamination Index shows the combined effects of overall water quality parameters of an area. Different contamination index methods has been developed all over the world for groundwater quality assessment such as heavy metal indexing approach (HMI), degree of contamination (Dc), contamination factor (C*f*), Modified degree of contamination index (*m*Dc), Metal pollution index(MPI), Pollution index (PI) pollution load index(PLI) enrichment factor (EF). By using these methods, we can easily calculate the overall water quality of a particular area rapidly and efficiently because these methods present the single value by comparing different parameters. GIS also play important role in groundwater contamination assessment by using various thematic maps. By this technique we can foresee the level of groundwater contamination in future. The objective of this paper is a brief focus on different contamination index methods for groundwater quality monitoring and for its management.

2.0 Background:

Firstly, In 1980 Håkanson [18] used contamination factor (C*f*) and the degree of contamination (C_d) to determine the overall contamination position of sediment and water. Backman *et al.* [19] studied in two distinctly different geological regions: the area between Uusikaupunki and Yläne in southwestern Finland and the Brezno area in central Slovakia and evaluated the degree of groundwater contamination by applying the contamination index (*Cd*) method. Odukoya & Abimbola [20] investigated concentrations of dissolved elements in streams and groundwater around both active and abandoned dumpsites in Lagos, Southwestern Nigeria by using pollution index method and found NO3 and Fe are the most critical in the water system. Total coliform were also very high in all the samples according to USEPA standard. Prasad & Sangita [21] collected groundwater an Abandoned Open Cast Mine Filled with Fly Ash from the periphery of a fly ash filled open cast mine, from within the mine property, and from a half kilometer away from the site .By using HPI the concentrations of heavy metals such as Cu, Zn, Cd, Pb, and Cr found every time below the permissible limit for drinking water, but concentrations of Fe and Mn found above the permissible limit. Soma Giri *et al*. [22] collected surface and groundwater samples around a Proposed Uranium Mining Site, Jharkhand, India for the assessment of Metal Contamination using metal pollution index. Bilgehan Nas & Ali Berktay [23] was studied in Konya City, which is locate in the central part of Turkey determined spatial distribution of groundwater quality parameters such as pH, electrical conductivity, chloride ,sulfate , hardness, and Nitrate concentrations by using GIS and Geostatistics techniques. Nalawade *et al.*[24] collected water samples from both surface and groundwater (from wells and bore well) resources in surrounding areas of Parli Thermal Power Plant fly ash dumping sites and investigated the level of heavy metal concentration by using heavy metal pollution index.V**.** Milu *et al.*[25] determined large amounts of toxic elements (Al, Fe, Cu, Zn, Pb, As, Cd, Sr, etc.) on stream and mine waters in the area of the largest porphyry copper deposit in the Apuseni Mountains (western Romania), the Rosia Poieni ore deposit. Akoteyon [15] investigated the level of heavy metal concentration (Iron, Lead, Manganese, Copper, Chromium, Cadmium and Zinc) around landfills in Igando-Lagos, Nigeria during dry season by using degree of contamination index method. Prasanna *et al.*[26]developed an integrated approach of pollution evaluation indices and statistical techniques was employed to assess the intensity and sources of pollution in Curtin Lake water, Miri City, East Malaysia by applying HPI and degree of contamination index method. Sajil Kumar *et al.*[27] investigated heavy metal contamination in Chennai city using a heavy metal pollution index (HPI) model in combination with the spatial distribution maps. Metals such as Cd, Cr, Cu, Pb and Zn in the groundwater had determined using standard methods and the resultant data utilized in the development of a HPI model. According to spatial distribution maps of heavy metals and the HPI the SW region, especially Adyar and Thiruvanmiyur regions was highly contaminated with the metals. Industrialization and improper waste dumping were identified as the major cause for the accumulation of metals in the groundwater of Chennai city.Chen Jie *et al.* [28] evaluated the groundwater quality of northern water source of Yinchuan by using improved Nemerow index method based on entropy weight, and then get a comprehensive and objective evaluation results. Bably Prasad *et al.* [29] collected 20 ground water samples from different places of Dhanbad Township which is located very near to Jharia coalfields, for 3 different seasons of the year 2011. Concentration of seven important heavy metals such as iron, manganese, lead, copper, cadmium, chromium and zinc calculated through heavy metal pollution index. The value of HPI was found below the critical index limit of 100. R. K Yankey *et al*. [30] evaluated heavy metal pollution index for groundwater in the Tarkwa mining area, Ghana. Concentrations of eight heavy metals: Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn selected to evaluate the heavy metal pollution index (HPI) by using two different approaches. HPI value of the groundwater was found less than critical limit 100.

3.0 Methods of Contamination Index

3.1. Heavy Metal Pollution Index

HPI model was developed [31]. It represents the total quality of water with respect to heavy metals. It is a technique of ranking which shows the combined influence of individual heavy metal on the overall quality of water. The ranking system is an arbitrary value between 0 and 1. It can be assessed by making values inversely proportional to the recommended standard (Si) for the equivalent parameter [31] [32]. Water quality and its suitability for drinking purpose can be examined through this quality index [31] [21] [33].

For the calculation of heavy metal index the following steps are involved.

1. calculation of weightage of i^{th} parameter;
2. calculation of the quality ranking for each of the heavy metal;
3. Summation of these sub-indices in the overall index

The weightage of i^{th} parameter is:

$$W_i = K/S_i \qquad (1)$$

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

Individual quality rating is given by the term

$$Q_I = 100V_i /S_i \qquad (2)$$

Where, Q_i is the sub index of i^{th} parameter; V_i is the monitored value of the i^{th} parameter in μg/L and S_i the standard or permissible limit for the i^{th} parameter.

The heavy metal index is then calculated as follows:

$$HPI=\sum_{i=1}^{n}\frac{QiWi}{\square}\sum_{i=1}^{n}Wi \qquad (3)$$

Where, Q_i is the sub index of i^{th} parameter. W_i is the unit weightage for i^{th} parameter, n is the -number of parameters considered. Generally, the critical pollution index value is 100.

3.2 Metal Pollution Index (MPI):

Metal Pollution index (MPI) approach has been used for the evaluation which shows the composite influence of individual parameters on the overall quality of water [34]. Higher be the concentration of a metal as has been compared to its maximum tolerable concentration, the poorer quality of the water [35] .It is also a combined physio - chemical and microbial index which makes it possible to compare the water quality of various water bodies [36]. It has wide application and it is used as the indicator of the quality of sea [36] and river water [37] [38] as well as drinking water [34] [39] .The MPI represents the sum of the ratio between the analyzed parameters and their equivalent national standard values [40] as given below:

$$\mathbf{MPI} = \sum_{i=1}^{n} \left[\frac{C_i}{(MAC)i} \right] \qquad (4)$$

Where: C_i: mean concentration
MAC: maximum allowable concentration

3.3. Contamination Factor:

This formula was introduced by Hakanson [18]. This method is based on the contamination factor (C_f) calculation for each pollutant. The aim of calculating contamination factor is to provide a measure of the degree of overall contamination in a sampled site. However, the C_f requires that at least five surficial sediment samples are averaged to produce a mean pollutant concentration which is then compared to a baseline pristine reference level. The formula is given as fallow:

$$C_f = C / C^0$$

The C_f is the ratio obtained by dividing the mean concentration of each metal in the sample (C) value by the baseline or background (concentration in unpolluted sample, C^0).

3.4. Degree of Contamination:

It is a modified and generalized form of the degree of contamination (C_d) formula; this formula was also proposed by [18]. It is calculated by this equation:

$$C_d = \sum_{i=1}^{N} CFi \qquad (5)$$

Where *N* is the number of metals studied and *CF* is the contamination factor. According to [18] Contamination factor and the degree of contamination have been categorized in to four classes.

Table: 1 Contamination factors and degree of contamination categories and terminologies based on Håkanson (1980).

CF classes	***CF* and *Cd* terminologies**	***Cd classes***
CF < 1	Low *CF* indicating low contamination / low *Cd*	*Cd < 8*
1 ≤ *CF* <	Moderate CF / *Cd*	8 ≤ *Cd* < 16
3 ≤ *CF* < 6	Considerable CF / *Cd*	16 ≤ *Cd* < 32
CF ≥ 6	Very high CF / *Cd*	*Cd ≥ 32*

3.5. Modified Degree of Contamination (mC_d)

Abrahim [41] presented a modified and generalized form of the [18] equation for the calculation of the overall degree of contamination at a given sampling site. The modified equation for a generalized approach to calculating the degree of contamination is given below:

$$mC_d = \frac{\sum_{i=1}^{i=n} C_f^i}{n} \quad (6)$$

Where n = number of analyzed elements and i = i^{th} element (or pollutant) and C_f = Contamination factor. Using this generalized formula to calculate the mC_d allows the incorporation of as many metals as the study may analyze with no upper limit. For the classification and description of the modified degree of contamination (mC_d), the following gradations have been given below.

Table: 2 Hakanson(1980) classification of the modified degree of contamination and description

***mC_d* classes**	**Modified degree of contamination level**
$mCd < 1.5$	Nil to very low degree of contamination
$2 \leq mCd < 4$	Moderate degree of contamination
$4 \leq mCd < 8$	High degree of contamination
$8 \leq mCd < 16$	Very high degree of contamination
$16 \leq mCd < 32$	Extremely high degree of contamination
$mCd \geq 32$	Ultra high degree of contamination

3.6. Single-factor index analysis:

Single factor index analysis was applied by [42]. The single factor index evaluation method has been used to find actual quantitative information of key pollution elements and excessive multiples. It is one of the most recent methods used in assessment of the degree of heavy metal pollution. This method has been calculated as follows,

$$P_{ij} = \frac{C_{ij}}{S_i} \quad (7)$$

Where, P_{ij} is the pollution index of the heavy metal *j* in the i^{th} functional area. C_{ij} is the measured contamination value of heavy metal *j* in the i^{th} functional area, and S_i is the background contamination value of heavy metal *j*. According to the value of P_{ij} we can find out which type of pollutants exceeds and the excessive multiple in study area and further we can determine what are the most serious pollutants and most serious polluted regions. The grading standard of single-factor has been shown in this given Table 3:

Table.3 The evaluation grading standards of the single-factor index method

Sub-index	**Quality status**
$P_{ij}<1$	Clean
$1\leq P_{ij}<2$	Potential pollution
$2\leq P_{ij}<3$	Slight pollution
$3\leq P_{ij}$	Heavy pollution

3.7 Nemerow Index Comprehensive Evaluation Method:

Comprehensive pollution index was introduced by [43]. The single factor index method has been used to assess the pollution of heavy metals in the useful areas, but different study shows that the above method cannot express exactly the comprehensive impact caused by all type of heavy metals.

While, The Nemero index method does not take only the extreme value but it gives the environmental quality index based on weighted multi-factors.

$$P_i = \sqrt{\left[(P_{ijmax})^2 + (P_{ijave})^2\right]/2} \quad (8)$$

Where, P_i is the compressive pollution index of the i^{th} functional area, and P_{ijmax} is the corresponding maximum value in the single-factor pollution index, and P_{ijave} is the corresponding average value in the single-factor pollution index.

Table 4: standard of the Nemerow index method

Grade	P_i	pollution status
I	$P_i \leq 0.7$	clean
II	$0.7< P_i \leq 1$	Warning limit
III	$1< P_i \leq 2$	Slight pollution
IV	$2< P_i \leq 3$	Moderate pollution
V	$Pi>3$	Heavy pollution

3.8 Improved Nemerow Index Method:

This method was applied by [28] [42] for groundwater evaluation. Nemerow index does not consider the weight factor and treated every pollution factor equally. But any high value of pollution factor will cause the composite value higher. In reality, the different pollution factors have different influences on environmental toxicity, degradation, and removal, so the different pollution factors at the same level should be treated differently, i.e., to increase the weight factor.

Because of these disadvantages, the improved Nemerow index method has been developed as follows:

$$P'_{ijmax} = \frac{P_{ijmax} + P_{iw}}{2} \qquad (9)$$

Where, P'_{ijmax} is the top pollution factor of weight in all the pollution factors in the -th functional area (C_{ij} /S_j).Pollution factor weights (ω_j) are calculated according to different pollutants with varying degrees of harm to the environment and human body.

$$\omega_j = \frac{R_j}{\sum_{j=1}^{n} R_j} \qquad (10)$$

$$R_j = \frac{S_{max}}{S_j} \qquad (11)$$

Where, S_j is the background value of each pollution factor, the maximum value is selected to compare with each S_j, and R_j ($R_j = \frac{S_{max}}{S_j}$) is defined as the relative importance ratio of heavy metal.

3.9 Pollution Load index (PLI):

Pollution load index for a particular site has been evaluated following the method proposed by [44]. PLI can be calculated by given equation.

$$PLI = (CF_1 \times CF_2 \times CF_3 \ldots\ldots\ldots\ldots CF_n)^{1/n} \qquad (12)$$

Where n is the number of metals and CF is the contamination factor. The contamination factor can be calculated from the following relation:

$$CF = \frac{\text{metal concentration in sample}}{\text{background value of the metal}} \qquad (13)$$

3.10 Elemental Contamination Index (ECI) and overall Metal Contamination Index (MCI):

Introduced Element contamination index (ECI) and overall metal contamination index (MCI) was developed by [45] for the expressions of single metal contamination within a sample or combined metal contamination for a sample comparative to the background values of the individual metal and are expressed as:

$$ECI = \left(\frac{Cm - Bm}{Bm}\right) \quad (14)$$

$$MCI = \sum\left(\frac{Cm - Bm}{Bm}\right)_i \quad (15)$$

Where, i. represents the individual metals (i.e. Cu, Pb, Zn, Cd), Cm is the measured concentration in sample while Bm is the baseline information on the anthropogenic impact of background (adjacent forest) concentration value of metal within the study area. According to [46], MCI was designed to describe general trace elements contamination on a scale from 0 to 100, with MCI of < 5 implying very low contamination; 25 – 50 high contamination; 50 – 10 very high contamination and > 100 implying extremely high contamination.

3.11 Role of GIS in groundwater contamination assessment:

GIS is a computer based system designed tool applied to geographical data for integration, collection, storing, retrieving, transforming and displaying spatial data for planning and management of natural resources [47]. Geographical information system (GIS) has been suggested that it is a very useful tool for groundwater pollution problem assessment and water resource management. It has been widely used for many purposes all over the world and also recently recognized as a powerful tool in environmental studies and modeling [47]. We can use GIS technique for the effective management of groundwater [48]. GIS is broadly used for collecting diverse spatial data and for overlay analysis in spatial record area to represent spatially variable phenomena [49] [50] [51]. It is a simple and current water quality indices tool for rapid transfer of information to water resources managers and the public. GIS technique is very useful for taking quick decision as graphical representation and it would be easy to take decision by the policy makers [52]. For all the above mentioned different methodologies, the role of GIS is the most important for the take decision by the public, government and policy makers. The different water quality parameters have to analyze first and representation of the data can be done by making different thematic maps and contour mps.

4.0 Conclusion:

This study shows that contamination index is a valuable tool for determining the important factors of groundwater resources to contamination and for those areas which are being contaminated rapidly. On the available literatures, most of the developed contamination index like, HPI, and MPI, C_d has been used for the estimation of large number of heavy metals and ionic species in groundwater. The contamination indices methods provide a suitable technique to evaluate the actual and potential groundwater contamination of any area. But this is the best method for the preservation of groundwater to protect groundwater from pollution before being contaminated**.** GIS technique is the best tool for this evaluation. Through GIS technique we can predict future condition of the groundwater quality by preparing different thematic maps. Contamination indices and GIS are very helpful tool to the planners and policy makers for selecting the appropriate area to waste disposal and industrial sites etc. Further, decision makers and planners convey this information to the public for that area which is more or less contaminated for solving the groundwater contamination problem because quality, quantity and availability of drinking water are one of the most important environmental, social and political issues at global level. So these indices with GIS tool are very helpful to represent water quality in a simple and understandable manner. In this study we found that by using these methods with the help of GIS how we can protect groundwater water resources from contamination through grading of areas for monitoring purpose, protection, and further investigation; and the development of risk assessments, resource characterization, education and awareness.

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