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# Review of significant works in assessment of ground water vulnerability in India.

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***Abstract*— Ground water pollution is the artificially induced degradation of natural ground water quality. In India, water pollution is a serious problem as almost 70% of its surface water resources and the ground water reserves are already contaminated by biological, organic and inorganic pollutants. Vulnerability mapping is a technique for quantifying the sensitivity of the resource to its environment, and as a practical visualization tool for decision-making. In recent years, Geographic Information Systems (GIS), Optimised DRASTIC index method, neural networks and fuzzy logic techniques and other mathematical and statistical methods have been used for the assessment of GW vulnerability across the world using several hydrological database of concerned basin. This paper reviews the significant research work of groundwater vulnerability assessment done in different states of India.**

***Index Terms*—Ground water, contamination, vulnerability assessment, DRASTIC, AHP, fuzzy logic.**

## I. Introduction

Ground water is one of the important sources which are popularly exploited for the various purpose related to life. Over the last few decades the level of ground water usages has been increased remarkably. The increasing rate of urbanization, increasing agricultural activity, uncontrolled uses of pesticides and fertilizers and industrialization has posed many threats to the quality of ground water. The innovation & development of new methodologies based on soft computing tools in last two decades or so has made the research in this field more versatile and popular. The annual utilizable groundwater resource of India is estimated as 396 $km^3$ per year, this accounts for about 80% of domestic water requirement and more than 45% of the total irrigation requirement of the country (Ravinder Kaur and K.G Rosin, 2007). Along with awareness about the ground water quality issues, the vulnerability assessment taken up in the various state of India are also gaining impetus, however this field is still marginally explored.

## II. Ground water vulnerability

Vulnerability of ground water means water quality starts deteriorating and contaminated severely up to certain extent beyond the potable standard. Water quality is one of the very important aspects for considering water for drinking, agricultural, industrial and other uses. The water fell in the form of rain, infiltrated through the soil, reached the water table, and began flowing to its present location. The sub-surface hydrological parameters have a primary influence on groundwater movement and hence pollutant migrates to the subsurface water. But usually it is difficult to monitor ground water contamination, as it requires the drilling of many tube well/open well and piezometers, which are very expensive. If the Vulnerability Map (VM) is generated using the advanced modeling techniques, a decision maker have very comprehensive idea of area that need to be closely monitored, as well as those areas which are less likely to become contaminated and required les intensive mentoring (Atiqur Rahman, 2008). Normally groundwater is not easily contaminated but if once it become vulnerable, it is difficult to remediate. In current developing era, such remediation may not be practically viable. Thus it is important to identify which aquifer systems and settings are most vulnerable to degradation. The vulnerability assessment enable of how severe the likely consequences of pollutant loading may be. The severity of the consequences is measured in terms of water quality deterioration.

## III. Various approaches for study of ground water vulnerability

There are various approaches have been observed and reviewed for the study of ground water vulnerability. In order to monitor and assess the quality of water from the regions where the primary source of drinking water is groundwater wells, several groundwater vulnerability and risk mapping models have been developed which estimate the sensitivity of groundwater to contamination and it is expressed in the form of vulnerability map (Prashant Kumar et al., 2015). Major approaches are Index based mapping model, Statistical methods and Process based simulation model. The Index-based techniques remain the most widely used techniques because of its large scale aquifer sensitivity and simple implementation. Index-based models can be divided into three categories, namely parametric, non-parametric and hybrid models (Prashant Kumar et al., 2015). Index methods (and closely associated "overlay methods") assign numerical scores or ratings directly to various physical attributes to develop a range of vulnerability categories. Overlay methods (National Research Council, 1993) will not be distinguished from index methods for the purposes of this report as they both combine maps of physical attributes by assigning scores that generally include subjective rankings of vulnerability (Michael J. Focazio, et al., 2002).

Process-based methods approach either to simulate or physical processes of water movement and transport of contaminants in the environment. Simple models such as the Behavior Assessment Model (*BAM*) or the Attenuation Factor (*AF*) can be used to map groundwater vulnerability, but they can also serve for screening purposes. They can compare the environmental fate of a new compound with other pesticides (Ravinder Kaur and K.G Rosin, 2007).

Statistical methods use statistics to determine associations between the spatial variables and the actual occurrence of pollutants in the groundwater. Simple descriptive statistics such as means, medians, and percentiles are often used to summarize the point locational information on the map, which eventually can be useful for more detailed analyses such as exploring relations with geology (Michael J. Focazio, et al., 2002).

Of these major approaches, the Index based model has been most widely adopted approach for large scale aquifer sensitivity and ground water vulnerability assessments.

## IV. OVERVIEW OF METHODOLOGY FOR STUDY

To assess the ground water vulnerability one has to study entire study area in detail to know various sources of contamination and various industries located in the area. Extensive study of available literature should be carried out to identify various models applicable for the assessment of vulnerability and various hydrological, geological, water quality, satellite images and other relevant data requirement. Using data of lithologs, aquifer mapping can be done to characterize aquifer system in the study area.

### *A. Assessment of ground water vulnerability techniques.*

- DRASTIC Index method:

The DRASTIC index model/method is standard system for evaluating ground water pollution potential used in many countries because the input information required for its application is either readily available or can easily be obtained from various local government departments(Aller Linda et al. (1985). This model was developed for the purpose of GW protection in the United States of America and its methodology is referred as ''DRASTIC.'' It was designed to provide systematic evaluation of GW pollution potential. Each of the seven parameters wide D, R, A, S, T, I and C are mapped and classified(Aller Linda et al. (1985).

TABLE: 1 ASSIGNMENT OF WEIGHT FOR DRASTIC FEATURES
*Source: Aller Linda et al. (1985)*

| Feature | Weight |
|---|---|
| **D=Depth to water** | 5 |
| **R=Net recharge** | 4 |
| **A=Aquifer media** | 3 |
| **S=Soil media** | 2 |
| **T=Topography** | 1 |
| **I =Impact of vadose zone** | 5 |
| **C=Hydraulic conductivity** | 3 |

TABLE: 2 ASSIGNMENTS OF RANGE AND RATING FOR DRASTIC FEATURES
*Source: Aller Linda et al. (1985)*

| Thematic layer | Range | Rating |
|---|---|---|
| **Depth to water (feet)** | 0-5 | 10 |
| | 5-15 | 9 |
| | 15-30 | 7 |
| | 30-50 | 5 |
| | 50-75 | 3 |
| | 75-100 | 2 |
| | 100+ | 1 |
| **Net recharge (inches)** | 0-2 | 1 |
| | 2-4 | 3 |
| | 4-7 | 6 |
| | 7-10 | 8 |
| | 10+ | 9 |
| **Aquifer media** | Massive shale | 2 |
| | Metamorphic/Igneous | 3 |
| | Weathered Metamorphic/Igneous | 4 |
| | Thin Bedded Sand stones, Limestone Shale Sequences | 6 |
| | Massive Sandstone | 6 |
| | Massive Limestone | 6 |
| | Sand and Gravel | 8 |
| | Basalt | 9 |
| | Karst Limestone | 10 |
| **Soil media** | Thin or Absent | 10 |
| | Gravel | 10 |
| | Sand | 9 |
| | Peat | 8 |
| | Shrinking and/or Aggregated Clay | 7 |
| | Sandy Loam | 6 |
| | Loam | 5 |
| | Silty Loam | 4 |
| | Clay Loam | 3 |
| | Muck | 2 |
| | Nonshrinking and Nonaggregated Clay | 1 |
| **Topography (percent slope)** | 0-2 | 10 |
| | 2-6 | 9 |
| | 6-12 | 2 |
| | 12-18 | 3 |
| | 18+ | 1 |

| | | |
|---|---|---|
| **Impact of vadose zone media** | Silt/Clay | 1 |
| | Shale | 3 |
| | Limestone | 6 |
| | Sandstone | 6 |
| | Bedded Limestone, Sandstone, Shale | 6 |
| | Sand and Gravel with significant Silt and Clay | 6 |
| | Metamorphic/Igneous | 4 |
| | Sand and Gravel | 8 |
| | Basalt | 9 |
| | Karst Limestone | 10 |
| **Hydraulic conductivity (GPD/FT$^2$)** | 1-100 | 1 |
| | 100-300 | 2 |
| | 300-700 | 4 |
| | 700-1000 | 6 |
| | 1000-2000 | 8 |
| | 2000+ | 10 |

Each factor or parameter is assigned a subjective weight (Table 1), range and rating (Table 2).

The final vulnerability map is based on the DRASTIC index (Di) which is computed as the weighted sum overlay of the seven layers using the following governing equation:
*DRASTIC Index*

$$(Di)= DrDw + RrRw+ ArAw + SrSw +TrTw + IrIw + CrCw, \quad (1)$$

Where D, R, A, S, T, I, and C are the seven parameters, r is the rating value, and w the weight assigned to each parameter.

- Optimized DRASTIC method:

By introducing a supervised committee machine with artificial intelligence (SCMAI) model to the DRASTIC method for groundwater vulnerability assessment can be optimized for the concerned aquifer (Elham Fijani et al., 2013). Four different AI models are considered in the SCMAI model, whose input is the DRASTIC parameters. The SCMAI model improves the committee machine artificial intelligence (CMAI) model by replacing the linear combination in the CMAI with a nonlinear supervised ANN framework.

To calibrate the AI models, the pollutants data are divided in two datasets for the training and validation purposes. The target value of the AI models in the training step is the corrected vulnerability indices that relate to the first pollutant concentration dataset (Elham Fijani et al., 2013).

- Geostatistical analysis:

Geostatistics can be applied in a diverse range of issues including groundwater, surface water, ecological studies, air pollution, climate data analysis and soil contamination. The trend accelerated with the advent of increasingly powerful computer systems and sophisticated geostatistical analysis tools in particular those integrated within Geographic Information System (GIS) applications.

Geostatistics approach is powerful tool to achieve the objective, where a continuous surface representing a given variable is calculated from point data based on the potential presence of correlation among data points as a function of the modulus and direction of vector separating them. Geostatistics is based on the notion that the set of measurements represents a single realization of the random function for all possible values in the medium (H.Assaf, M. Saadeh, 2009).

The application of Geostatistics can be apply by following basic steps:

- A data exploration characterizes its spatial continuity and assesses its suitability for trend analysis of the data in order to find out presence of global trends.
- Structural analysis to develop a semi variogram model, and
- Application of the Ordinary Kriging System to produce concentration prediction surfaces and probability of exceedance maps (H.Assaf, M. Saadeh, 2009).

- Analytical Hierarchical Process (AHP):

The foundation of the Analytic Hierarchy Process (AHP) is a set of axioms that carefully delimits the scope of the problem. It is based on the well-defined mathematical structure of consistent matrices and their associated right eigenvector's ability to generate true or approximate weights (P. Tirkey et al., 2013). AHP is an approach to decision making that involves structuring multiple choice criteria onto a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion and determining an overall ranking of the alternatives.

The AHP uses a fundamental scale of absolute numbers that have been proven in practice and validated by physical and decision problem experiments.

Given that the three basic steps are reasonable descriptors of how an individual comes naturally to resolve a multi-criteria decision problem, then the AHP can be considered to be both a descriptive and prescriptive model of decision making (P. Tirkey et al., 2013).

The AHP is the most widely used decision making approach due to its validity is based on the thousands of actual applications in which the AHP results were accepted and used by the cognizant decision makers.

Analytic Hierarchy Process with GIS demarcate the hazard and risk level in terms of severe, high, moderate and low. The basic model approach is the conversion of all the thematic layer attributes into a normalized weighted raster as per the water holding capacity through AHP and Multi Criteria Decision Support System (Nityananda Sar et al., 2015).

- Neuro-Fuzzy technique:

In recent years, Geographic Information Systems (GIS), neural networks and fuzzy logic techniques have been used in several hydrological studies. The research is to examine the sensitivity of neuro-fuzzy models used to predict groundwater vulnerability in a spatial context by integrating GIS and neuro-fuzzy techniques (B Dixon, 2004).

Soft computing tools such as fuzzy logic and artificial neural network are efficient in solving variety of issues related to ground water vulnerability.

To assess the sensitivity of neuro-fuzzy models in a spatial domain using GIS by varying;

(i) Shape of the fuzzy sets,
(ii) Number of fuzzy sets, and
(iii) Learning and validation parameters (incl. rule weights).

The neuro-fuzzy models were developed using NEFCLASS-J software on a JAVA platform and were loosely integrated with a GIS (B Dixon, 2004).

### *B. Data requirement to assess of Ground water vulnerability*

TABLE: 3 AQUIFER DATA REQUIREMENT TO ASSESS VULNERABILITY

| Hydrological Parameters | Characteristics for Analysis |
|---|---|
| D=Depth to water | Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur. |
| N=Net recharge | Represents the amount of water that penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants. |
| A=Aquifer media | Refers to the saturated zone material properties, it controls the pollutant attenuation processes. |
| S=Soil media | Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward. |
| T=Topography | Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone. |
| I= Impact of vadose zone | Is defined as the unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone. |
| C=Hydraulic conductivity | Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system. |

## V. SIGNIFICANT WORKS IN GROUND WATER VULNERABILITY IN INDIA

A large verity of literature is available on assessment of Ground water vulnerability and quality.

This study carried out to review the significant research works in this field in India. However, a considerable amount of work seems to have been done in the countries other than India.

Over viewing repertoire of available literature, significant researches have been selected for discussion here in Table 4. Amongst research done with in India, the work of Atiqur Rehman in Aligarh in shadow of Delhi(2007); Sunderrajan Krishnan et al.in Central regions of Gujarat(2007); Shrinivas Y. et al. in Kanyakumari, Tamilnadu(2014), Silki Puri et al. in Bardhaman, West Bangal(2014); Arina Khan et al. in Bulandsagar and Aligarh district(2014); K. Brindha, L. Elango in Nalgonda district, Telangana(2015); P. Tirkey et al. in Hazaribaugh district, Jharkhand(2013); K. G. Rosin et al. in Peri-urban agricultural land, Hariyana(2013); R. Krishna et al. in Ranch district, Jharkhand(2015); Nityananda Sar et al. in Keleghai river basin(2015) and Lathamani R. et al. in Mysore, Karnataka(2015) were cited in the Table 4 with detail outcome inclusive of their method/ Technique adopted for research.

All above researchers have attempted to study/ assess ground water quality/ vulnerability by verities of approach wise Statistical approach, Process base models and Index-base models etc. Many advanced tools like GIS, RS and soft computing techniques like ANN etc. have been used.

Amongst work done in other countries, B. Dixon of South Florida (2004), Alan Mair et al.of Honululu (2013), M.Chitsazan, Y.Akhtari of Iran (2009), Mohammad N. Almasri of Palestine (2008), H. Assaf & M. Saadeh of Lebanon (2009) and Elham Fijani et al. of Iran (2013) are worth noticing. These researchers in other countries have attempted to study water vulnerability by verities of models/ method wise Optimized DRASTIC method, Geostatistical tool, Logistic regression modeling, Neuro-fuzzy techniques, in addition to DRASTIC model. Many advanced tools like GIS, RS and soft computing techniques like ANN, etc. have been used.

## VI. DISCUSSIONS AND CONCLUSIONS

It is observed while literature study carried out so far that there are few conventional methods applied in majority of research which may be check with the help of alternative worldwide accepted another model to minimize the limitation of conventional method. So far, the DRASTIC or Optimized DRASTIC method has turn out to be the most popular and basic tool for the assessment of ground water vulnerability. However, in the light of modern developments of soft computing technique and availability of more diverse, accurate and reliable data analysis can be taken further beyond the first step of analysis by DRSTIC index method. Also it has been noticed that majority research work are preparing VM (Vulnerability Map) and assessing various contaminants such as Nitrate Nitrogen, Arsenic, contaminant transport through aquifer media, etc but it is necessary to develop suitable model by adding some new parameter to overcome the limitation of conventional models which can be helpful to show a relationship between the vulnerability parameters with actual ground water quality by laboratory tests in the study area.

From the results obtained, effect of various contaminants and its risk on public health can also be assessed by appropriate method or to suggest the management strategy to minimize the risk on public health.

TABLE: 4 SIGNIFICANT WORKS IN GROUND WATER VULNERABILITY IN INDIA

| **TITLE of Research** | **Method /Technique** | **Outcome/Remarks** | **Reference (Author)/ Publication** |
|---|---|---|---|
| "DRASTIC: A standardized system to evaluate groundwater pollution potential using hydrological settings. National Water Well Association Worthington". | The DRASTIC Index/ model is based on 7 input (Acronym DRASTIC) parameters vise;<br>(D)Depth to water, (N)Net Recharge, (A)Aquifer media, (S)Soil media, (T)Topography, (I)Impact of the vadose zone and (H)Hydraulic Conductivity. | Standard Numerical ranking system to assess ground water vulnerability. Assignment of weight, range and rating to each DRASTIC parameter. | Aller Linda et al. (1985)<br>National Water Well Association Worthington, Ohio. |
| "Ground Water Vulnerability Assessment – Challenges and Opportunities, Division of Environmental Sciences, Indian Agricultural Research Institute". **(Review)** | Many approaches discussed vise;<br>(1) Overlay/ Index Models<br>(2) Process Based Simulation Models<br>(3) Statistical Inference Models | The overlay/ index models are less constrained by data shortage and computational difficulties. | Ravinder Kaur and K.G Rosin. (2007)<br>*Procedia Environmental Science*<br>*http://cgwb.gov.in/documents/paper* |
| "Groundwater and well-water quality in Alluvial aquifer of Central Gujarat" .<br>*Geographical Location: Central regions of Gujarat, India.* | Laboratory testing of Water sample of entire study area. | High Salinity, Fluoride, Nitrate and pollution from industrial effluents have caused contamination of aquifers in different parts of the state. | Sunderrajan Krishnan et al. (2007)<br>http://www.indiawaterportal.org/site |
| "A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India".<br>*Geographical Location: Aligarh, India.* | DRASTIC model<br>GIS and ILWIS software | More than 80% of the city's groundwater is under medium to high vulnerability to water pollution in Aligarh.<br>This model can be used for prioritization of vulnerable areas to prevent the further pollution. | Atiqur Rahman (2008)<br>*Applied Geography, ELSEVIER.* |
| "Groundwater quality assessment using Water Quality Index (WQI) approach – Case study in a coastal region of Tamil Nadu, India".<br>*Geographical Location: Vedaranyam Taluka, ,Coastal region of Tamil Nadu, India.* | Water Quality Index (WQI) approach. | This coastal area is very complex due to multitude of factors viz., seawater intrusion and pollution phenomena.<br>The above study indicates that natural as well as Anthropogenic sources are contaminating the groundwater | Ganeshkumar B, Jaideep C. (2011)<br>*International Journal of Environmental Sciences and Research Global Skope* |
| "Physico chemical Characterization of ground water of Anand district, Gujarat, India".<br>*Geographical Location:Anand Dist.,Gujarat,India.* | Data analyzed for the Physico-chemical parameters using the standard procedures as per APHA respectively.<br>Water Quality Index (WQI) approach. | TDS, total hardness and Boron were higher concentrations. Fe was found to be notably high in all the sampling locations. Fluoride was present in Borsad. Chloride was considerably high only in Khambhat. | Bhattacharya T.et al. (2012)<br>*Research Journal of Environment Sciences,ISCA.* |

 

| TITLE of Research | Method /Technique | Outcome/Remarks | Reference (Author)/ Publication |
|---|---|---|---|
| "AHP-GIS Based DRASTIC Model for Groundwater Vulnerability to Pollution Assessment: A Case Study of Hazaribag District, Jharkhand, India".<br>*Geographical Location:Hazaribag District, Jharkhand, India.* | To Assess Ground water vulnerability to pollution of the aquifer, the method used were Analytical Hierarchy Process (AHP) with GIS based DRASTIC model in combination. | The range of the vulnerability index has been classified into five classes vide low, moderately low, moderate, moderately high, and high.<br>The study results delineate areas that are more susceptible to contamination. It shows areas of greatest potential of groundwater contamination. | P. Tirkey et al. (2013)<br>*International Journal of Environmental Protection* |
| "Current status of fluoride contamination in ground water of Kheralu block of Mehasana district, Gujarat".<br>*Geographical Location: Kheralu, Mehsana, Gujarat, India.* | Data analyzed for the Flouride contamination using standard procedures as per APHA respectively. | Flouride concentration were found beyond\d permissible limit in 45% of villages in Kheralu taluka. | Punita Parikh, Rahul Parikh. (2013)<br>*International Journal of Environmental Sciences* |
| "Groundwater vulnerability to contaminated irrigation waters-A case of peri-urban agricultural lands around an industrial district of Haryana, India".<br>*Geographical Location: Peri-urban agricultural land, Haryana, India.* | Field scale Decision support system-IMPASSE Model | Industrial effluents in study area are not responsible for ground water contamination.<br>Major cause of salt affected groundwater was primarily geogenic. | K.G.Rosin et al. (2013)<br>*Procedia Environmental Sciences,ELSEVIER.* |
| "Assessment of Groundwater Quality Using GIS Techniques: A Case Study of Mysore City".<br>*Geographical Location:Mysore, India.* | Inverse distance weighted (IDW) analysis with ArcGIS 9.2 were used to prepare the distribution map of physico-chemical parameters of groundwater.<br>Overlay method evaluate temporal changes and prepare groundwater quality zones. | The comparison of pre- and post-monsoon groundwater quality shows that good and moderate zone areas decreased and the poor and very poor areas increased.<br>This is due to rain waters which are recharged to the ground during the monsoons react with the minerals present in the soils, weather and rock. | B.Mahalingam et al. (2014)<br>*International Journal of Enginnering and Innovative Technology(IJEIT)* |
| "Geospatial approach for ground Water Quality Mapping in Malda District, West Bengal".<br>*Geographical Location:Malda District, West Bengal, India.* | Inverse Distance weighted (IDW) interpolation technique.<br>Geographic Information System.<br>Correlation between water quality and the existing Lithgeom type. | Approach assesses the efficiency of the existing network of wells, hydro geological characteristics of the aquifer and the potential for anthropogenic pollution.<br><br>The results indicate that certain parameters such as TDS, chlorides and fluorides in areas. | Emtiaj Hoque, Sonam Yogel Bhutia. (2014)<br>http://www.academia.edu/9026954 |

 

| TITLE of Research | Method /Technique | Outcome/Remarks | Reference (Author)/ Publication |
|---|---|---|---|
| "Quality assessment and hydro geochemical characteristics of groundwater in Agastheeswaram taluka, Kanyakumari district, Tamil Nadu, India".<br>*Geographical Location : Kanyakumari district, Tamil Nadu, India.* | Groundwater samples were collected from dug wells and bore wells during post monsoon and pre-monsoon seasons. Data analyzed for the physico-chemical parameters using the standard procedures as per APHA respectively. | This study reveals chemical variations in pre-monsoon and post-monsoon seasons due to the effect to rock-water interactions, ion-exchange reactions and runoff of fertilizers from the surrounding agricultural lands. | Srinivas Y.et al. (2014)<br>*Chin.J.Geochem, SPRINGER.* |
| "GIS-Based Geospatial Mapping of Arsenic Polluted Underground Water in Purbasthali Block in Bardhaman,Weat Bengal".<br>*Geographical Location: Bardhaman,Weat Bengal, India.* | DRASTIC method<br>Geospatial Mapping with GIS. | Geospatial mapping shows severely affected block of study area from the contamination of Arsenic. | Silky Puri et al. (2014)<br>*Conference paper ELSEVIER (International Conference on Communication and Computing)* |
| "An integrated approach for aquifer vulnerability mapping using GIS and rough sets: study from an alluvial aquifer in North India".<br>*Geographical Location: Kali watershed in Bulandshahr and Aligarh district, India.* | Modified DRASTIC, GIS coupled with 'Rough set' (information analytic technique) were used. | The coupling of GIS and 'Rough set' were used to enhance the utility of vulnerability map. This combination gives new insight for better understanding vulnerability feature. | Arina Khan et al. (2014)<br>*Hydrology Journal, SPRINGER.* |
| "Index-based groundwater vulnerability mapping models using hydro geological settings (CSIR)". **(Review)** | All the Ground water vulnerability Mapping models were discussed used in the world vise;<br>(1) Statistical Model<br>(2) Process Based Simulation Models<br>(3) Index –based Models<br>Index based models were further classified by Parametric, Non-parametric and Hybrid models. | The model selection depends on the scale of mapping, data availability, hydro geological setting and the end use of the map. A particular model with suitable modification including other environmental parameters can be employed for ground water vulnerability mapping. | Prashant Kumar et al. (2015)<br>*Environmental Impact Assessment Review, ELSEVIER.* |
| "Cross comparison of five popular groundwater pollution vulnerability index approaches".<br>*Geographical Location : A weathered rock aquifer forming a part of Nalgonda district, Telangana, India.* | DRASTIC and 4 other models derived from it,vise;<br>(1) Pesticide DRASTIC,<br>(2) Modified DRASTIC,<br>(3) Modified Pesticide DRASTIC,<br>(4) Susceptibility Index (SI)<br>Compared five models to determine the most suitable one in mapping zones vulnerable to groundwater pollution in weathered rock regions. | DRASTIC, and Pesticide DRASTIC was similar but different from the other three models.<br>The outcome of the modified Pesticide DRASTIC gives more reliable results in highly weathered hard rock regions with shallow aquifers and intensive irrigation practices. | K. Brindha, L. Elango. (2015)<br>*Journal of Hydrology, ELSEVIER.* |

 

| TITLE of Research | Method /Technique | Outcome/Remarks | Reference (Author)/ Publication |
|---|---|---|---|
| "Coastal vulnerability assessment studies over India: **a review**". *Geographical Location :Entire coastal area of India.* | This review focused on different vulnerabilities to coast of India and one of the assessment methods, coastal vulnerability index methodology, applied over India.<br>(1) Coastal vulnerability Index<br>(2) Indicator-based approach<br>(3) GIS-based decision support systems<br>(4) Methods based on dynamic computer models | Human activity is the major driver of the problem of coastal vulnerability. For the prevention of natural hazard impact, coastal managers need to know the intrinsic littoral vulnerability using information on the physical and ecological coastal features, human occupation, population, and past/present shoreline trends. | N. N. V. Sudha Rani et al. (2015) *Nat Hazards, SPRINGER.* |
| "Assessment of heavy metal concentrations in surface water sources in an industrial region of central India". *Geographical Location :Industrial region, Chhattisgarh, India.* | Atomic Absorption Spectrometry (AAS) was used for measuring quantities of chemical elements present in water samples by measuring the absorbed radiation by the chemical element of interest. | Heavy metals that leached out from these disposal points and may contaminate the ground water as well as surface water resources nearby area could affect the health and livelihood of local population. | Manoj Kumar Tiwari et al. (2015) *Karbala International Journal of Modern Science, ELSEVIER.* |
| "Groundwater vulnerability to pollution mapping of Ranchi district using GIS". *Geographical Location: Ranchi District, Jharkhand, India.* | DRASTIC method with GIS. | The range of the vulnerability index has been classified into five classes vide low, moderately low, moderate, moderately high, and high.<br>The results reveal that moderate vulnerable class covers the maximum percentage of the area (38.85 % of the total area). | R. Krishna et al. (2015) *Appl Water Science, SPRINGER.* |
| "Integrated remote sensing and GIS based spatial modeling through analytical hierarchy process (AHP) for water logging hazard, vulnerability and risk assessment in Keleghai river basin, India". *Geographical Location: Keleghai river basin, India.* | Remote sensing and GIS through Analytical Hierarchy Process (AHP). N.D.V. Index and W.D.R. Index. | The outcomes of the present study are waterlogged hazard and the risk map which can be used for the management of soil, water resources, fishing and crops land. | Nityananda Sar et al. (2015) *Model. Earth Syst. Environ, SPRINGER.* |
| "Evaluation of Aquifer Vulnerability Using Drastic Model And GIS:A Case Study Of Mysore City, Karnataka, India". *Geographical Location: Mysore City, Karnataka, India.* | DRASTIC method with GIS. | Study assesses the aquifer vulnerability for contamination. Very high nitrate in the post monsoon season gives more credence to this model. Combination of DRASTIC, GIS and Physico-chemical analysis are very effective and practical in assessing groundwater pollution risk. | Lathamani .R et al. (2015) *Aquatic Procedia, ELSEVIER.* |

 

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