International Journal of Current Research and Modern Education (IJCRME)
Impact Factor: 6.925, ISSN (Online): 2455 - 5428
(www.rdmodernresearch.com) Volume 3, Issue 1, 2018

A COMPARATIVE STUDY ON MULTI-OBJECTIVE FUZZY PATTERN RECOGNITION MODEL AND THE DRASTIC MODEL FOR ASSESSING GROUND WATER VULNERABILITY

P. Selvavathi* & R. Sophia Porchelvi**
* Research Scholar, Department of Mathematics, A.D.M College for Women (Autonomous), Nagapattinam, Tamilnadu
** Associate Professor, Department of Mathematics, A.D.M College for women (Autonomous), Nagapattinam, Tamilnadu

Cite This Article: P. Selvavathi & R. Sophia Porchelvi, "A Comparative Study on Multi-Objective Fuzzy Pattern Recognition Model and the Drastic Model for Assessing Ground Water Vulnerability", International Journal of Current Research and Modern Education, Volume 3, Issue 1, Page Number 457-463, 2018.

Abstract:

Ground water is an important natural resource throughout the world. The DRASTIC model has been used as a valuable tool in many parts of the world for assessing the vulnerability of groundwater. In the DRASTIC system, however, factors that influence groundwater must be divided into ranges and then be given ratings according to whether or not their values can be directly measured. The system may give the same range and rating to those having obviously different values. As a result, DRASTIC may be unable to actually reflect the difference between factors and hydrogeological settings. In fact, there exists a transition from the easiest to be polluted to the most difficult to be polluted so that the vulnerability of groundwater is of a fuzzy nature and therefore fuzzy set theory can be used to assess the vulnerability of groundwater. In this Paper, a Multi-Objective Fuzzy Pattern Recognition Model (MOFPR) is used for assessing the pollution potential of groundwater is presented. It is compared with the DRASTIC Model in a case study to evaluate the ground water vulnerabilities of the Cauvery Delta Region of Tamil Nadu in India. It is shown that the Fuzzy Pattern Recognition model can take the fuzziness into account more efficiently in the process of evaluating the vulnerability of groundwater.

Key Words: Ground Water Vulnerability, DRASTIC Model, Multi-Objective Fuzzy Pattern Recognition Model & Pollution Potential.

1. Introduction:

Water is the basic element of social and economic infrastructure and is essential for a healthy society and sustainable development. 97% of Earth's water are in the form of saline water present in the ocean and only 3% of fresh water is available. It is scientifically proved that 68.7% of fresh water is found to be stored in the form of glaciers and ice caps and 30.1% is available in the form of groundwater. Groundwater is one of the valuable earth's renewable resources for human life economic development, which occur as a part of the hydrologic cycle. Amongst the natural water resources, groundwater forms an invisible component of the system. In the last 50 years, it is observed that development of groundwater resources is unpredictable. An estimated 2 billion people worldwide rely on aquifers for drinking water supply. The annual utilizable groundwater resources in India are estimated at 428 km^3 per year. This accounts for about 80% of domestic water requirement and more than 45 % of the total irrigation requirements of the country. In recent years, the utilization of groundwater is increasing at a faster rate, which leads to the depletion of groundwater. On the other hand contamination of groundwater due to various anthropogenic sources is growing at a faster rate, so that it is no longer fits for a use for which it has previously been cited. This resulted in increasing pressures on available groundwater resources in terms of both quality and quantity.

The quality of groundwater depends on a large number of individual hydrological, physical, chemical and biological factors. Prevention of contamination is therefore critical for effective groundwater management. To properly manage and protect the resource, it is therefore important to determine areas with more aspects of vulnerable to contamination. Groundwater vulnerability is considered an intrinsic property of groundwater that depends on its sensitivity to humans and natural impacts and can be defined as the possibility of percolation and diffusion of contaminants from the ground surface into the groundwater system. Vulnerability maps have become an essential tool for groundwater protection and environmental management. Several methods have been proposed for vulnerability assessment of aquifers. This paper presents a standardized system DRASTIC approach which incorporates physical characteristics of any area into a methodology which can be used to evaluate the groundwater vulnerability of any hydrogeologic setting. In fact, there exists a transition from the easiest to be polluted to the most difficult to be polluted so that the vulnerability of groundwater is of a fuzzy nature and therefore fuzzy set theory can be used to assess the vulnerability of groundwater. Here, a Multi-Objective Fuzzy Pattern Recognition Model (MOFPR) is used for assessing the pollution potential of groundwater is presented. It is compared with the DRASTIC Model in a case study to evaluate the ground water vulnerabilities of the Cauvery Delta Region of Tamil Nadu in India. It is shown that the Fuzzy Pattern Recognition model can take the fuzziness into account more efficiently in the process of evaluating the vulnerability of groundwater.

1.1 Study Area:

The Delta region covers Central Tamil Nadu and East-Central Tamil Nadu. The region is sandwiched between the historical regions of Tondai Nadu in the north, the Madurai region in the south and Kongunadu in the west and roughly extends from Chidambaram in north to the southern frontier of the erstwhile Pudukkottai kingdom and from Tiruchirapalli in the west to the Bay of Bengal in the east.

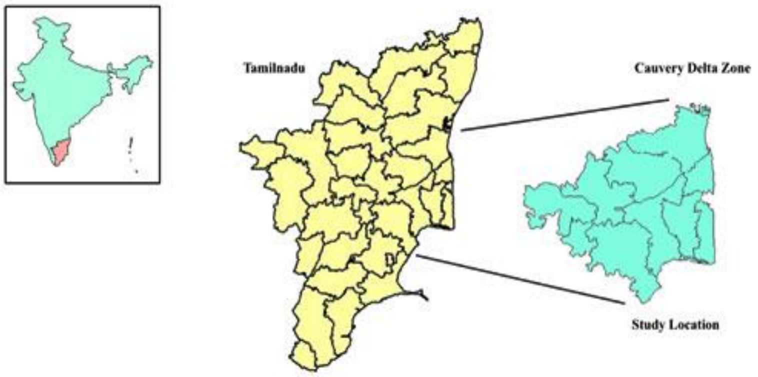

Fig 1. Cauvery Delta Zone Highlighted from Tamil Nadu

2. DRASTIC Methodology:

DRASTIC is a methodology which allows the pollution potential of any area to be systematically evaluated. The physical characteristics are inherent in each hydrogeologic setting which affects the groundwater pollution potential. After the factors such as aquifer chemistry, temperature, transmissivity, tortuosity, gaseous phase transport and some others have been evaluated, the most important factors that control the groundwater pollution potential have been determined to be depth to water (D), net recharge (R), aquifer material (A), soil type (S), topography (T), the impact of the unsaturated zone (I) and hydraulic conductivity of the aquifer (C), in short DRASTIC.

D - Depth of Ground Water: It is the depth from the ground to the water table, deeper the water table lesser will be the chances of pollutants to interact with groundwater.

R - Net Recharge: It is the amount of water/unit area of land that penetrates the ground surface and reaches the water table, it the reporting agents for pollutants to the groundwater.

A - Aquifer Media: It is the potential area for water storage, the contaminant attenuation of aquifer depends on the amount and sorting of fine grains, lower the grain size higher the attenuation capacity of aquifer Media.

S - Soil Media: Soil media are the uppermost and weathered part of the ground; soil cover characteristics influence the surface and downward movement of contaminants.

T - General Topography or Slope: It refers to slope or steepness, areas with low slope tend to retain water for longer, this allows a greater infiltration of recharge of water and a greater potential for contaminant migration and vulnerable to groundwater contamination and vice versa.

I - Vadose Zone: It is the ground portion found between the aquifer and the soil cover in which pores or joints are unsaturated, its influence on aquifer pollution potential similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media.

C - Hydraulic Conductivity of the Aquifer: It refers to the ability of the aquifer formation to transmit water; an aquifer with high conductivity is vulnerable to substantial contamination as a plume of contamination can move easily through the aquifer.

2.1 Weights of the DRASTIC Factor:

Each DRASTIC factor has been evaluated with respect to the others to determine its relative importance and has been assigned a relative weight ranging from 1 to 5 (Table 1). The weight value 5 is given to the most significant factors, i.e. D and R; the value 1 is given to the least significant factor, T.

Factor		**D**	**R**	**A**	**S**	**T**	**I**	**C**
Weight	Non-normalized	5	4	3	2	1	5	3
	Normalized	0.22	0.17	0.13	0.09	0.04	0.22	0.13

Table 1: Weights of the seven factors

2.2 Ranges of DRASTIC Factor:

Each DRASTIC factor has been divided into either ranges or significant media types that affect pollution potential. For example, factor D is divided into seven ranges according to depth in feet (Table 2). The media types such as aquifer material, soil type and impact of the vadose zone, cannot be measured numerically.

Range (m)	Rating	Membership Function
0-2	10	$r_{ij} = \frac{(x_{imax} - x_{ij})}{(x_{imax} - x_{imin})}$ $= \frac{(100 - x_{ij})}{100}$
2-4	8	
4-6	6	
6-8	4	
8-10	1	

Table 2: Ranges, ratings and membership function for depth to water, D

2.3 Ratings of DRASTIC Factor:

Each range for each DRASTIC factor has been evaluated with respect to the others to determine its relative significance to pollution potential, and has been assigned a rating between 1 and 10. The most vulnerable range was given the rating 10, and the least vulnerable, the rating 1, as shown in Table 2 for factor D. This evaluation system allows the user to determine a numerical value for any hydrogeological setting by using an additive model. The pollution potential or DRASTIC Index can be calculated by the following equation:

$$D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W = Pollution\ potential \qquad (1)$$

Where footnotes R and W represent rating and weight, respectively. Once a DRASTIC Index has been computed, it is possible to identify which areas are more likely to be susceptible to groundwater contamination relative to the others. The higher the DRASTIC Index is greater the groundwater pollution potential.

3. Multi-Objective Fuzzy Pattern Recognition Model (MOFPR):

If one assumes that a decision making problem is to identify an optimum value from *n* alternatives in which each one has *m* objectives, the values of *m* objectives in *n* alternatives can form an objective value matrix as follows:

$$X = \begin{vmatrix} x_{11} & x_{12} & \dots\dots\dots. & x_{1n} \\ x_{21} & x_{22} & \dots\dots\dots. & x_{2n} \\ & & \vdots & \\ x_{n1} & x_{n2} & \dots\dots\dots. & x_{nn} \end{vmatrix} = (x_{ij}) \qquad (2)$$

Where x_{ij} denotes the value of objective *i* in the alternative *j (i* = 1, 2,..., *m; j* = 1,2,...,*n*).

There exist differences between values and units *of m* objectives in matrix X. Furthermore, there are positive and negative correlations between the optimum value and its evaluation objectives. Hence it is necessary to normalize the elements of a matrix X.

If the optimum value and a particular factor are positively correlated, i.e. the bigger the factor value, the larger the membership degree to the optimum, the normalizing formula is defined as:

$$r_{ij} = \frac{(x_{ij} - x_{i\,min})}{(x_{i\,max} - x_{i\,min})} \qquad (3)$$

Alternatively, the normalizing formula for the negatively correlated factor is defined as:

$$r_{ij} = \frac{(x_{imax} - x_{ij})}{(x_{imax} - x_{imin})} \qquad (4)$$

In formulae (3) and (4), $x_{i\,max}$ denotes the absolute or a relative optimum value for objective *i;* and $x_{i\,min}$ denotes the corresponding minimum value. After normalizing, the matrix X becomes a normalized matrix R in which the values are within the interval [0, 1].

$$R = \begin{vmatrix} r_{11} & r_{12} & \dots\dots\dots. & r_{1n} \\ r_{21} & r_{22} & \dots\dots\dots. & r_{2n} \\ & & \vdots & \\ r_{n1} & r_{n2} & \dots\dots\dots. & r_{nn} \end{vmatrix} = (r_{ij}) \qquad (5)$$

In matrix *R*, if $r_{ij} = 1$, the alternative *j* is the optimum and if $r_{ij} = 0$, the alternative *j* is the worst, according to the objective *i* only. Supposing that there is an ideal optimum alternative in which all objective membership degrees to the optimum are equal to 1, denoted by $G = (g_1, g_2, \dots\dots g_m) = (1, 1, \dots, 1)$, the worst alternative is expressed as $B = (b_1, b_2, \dots\dots b_m) = (0, 0, \dots, 0)$.

In this case, the decision-making problem becomes a fuzzy pattern recognition problem, i.e. evaluating to what membership degree each alternative in matrix R belongs to the ideal optimum. Because different objectives have different contributions in the process of evaluating an alternative, different weights should be given to *m* objectives. The weighting vector is denoted by $W = (w_1, w_2, \dots\dots w_m)^T$ subject to a restriction,

$$\sum_{i=1}^{m} w_i = 1$$

In matrix R, alternative *j* can be expressed as

$$r_j = (r_{1j}, r_{2j}, \dots\dots r_{mj})^T \qquad (6)$$

The distance of alternative *j* to the w worst alternative can be described as

$$d_{jg} = \sqrt[p]{\sum_{i=1}^{m}[w_i(g_i - r_{ij})]^p} \qquad (7)$$

The distance of alternative *j* to the worst alternative can be described as

$$d_{jb} = \sqrt[p]{\sum_{i=1}^{m}[w_i(r_{ij} - b_i)]^p} \qquad (8)$$

In equations (7) and (8), *p* is a distance parameter. When *p* = 1 and *p* = 2, the distances are called Hamming and Euclidean distances respectively, which are commonly used . *b* It can be seen from equations (7) and (8) that if *djg* = 0, then alternative *j* is the optimum and if *djb* = 0, then alternative *j* is the worst.

If the membership degree to the optimum is denoted by u_j for alternative j ,(1 -u_j) is its membership degree to the worst. In the view of fuzzy sets, the membership degree may be regarded as a weight. Thus, the equation (9) or (10) will better describe the difference between alternative *j* and the optimum or the worst. The weighted distance to the optimum of alternative, *j* can be described as

$$D_{jg} = u_j \sqrt[p]{\sum_{i=1}^{m}[w_i(g_i - r_{ij})]^p} \qquad (9)$$

Similarly, the weighted distance of alternative *j* to the worst can be described as

$$D_{jb} = (1 - u_j) \sqrt[p]{\sum_{i=1}^{m}[w_i(r_{ij} - b_i)]^p} \qquad (10)$$

In order to solve optimal membership degree u_j, an objective function is established as follows:

$$\min\ F(u_j) = (D_{jg}{}^2 + D_{jb}{}^2)$$

$$= u_j{}^2 \{ \sum_{i=1}^{m}[w_i(g_i - r_{ij})]^p\}^{2/p} + (1 - u_j)\{\sum_{i=1}^{m}[w_i(r_{ij} - b_i)]^p\}^{2/p} \qquad (11)$$

Using the condition,

$$\frac{dF(u_j)}{du_j} = 0$$

A multi-objective fuzzy pattern recognition model can be obtained:

$$u_j = \frac{1}{1+[\frac{\sum_{i=1}^{m}(w_i|r_{ij}-1|)^p}{\sum_{i=1}^{m}(w_i * r_{ij})}]^{2/p}} \qquad (12)$$

According to this model the bigger the u_j, the better the alternative *j*.

4. MOFPR Model to Evaluate the Ground Water Vulnerability Using the DRASTIC System:

Aquifer vulnerability and its evaluation have an intrinsic property, i.e. fuzziness. By the DRASTIC system, this fuzziness is taken into account by dividing the values of each affecting factor into ranges, and then assigning a rating to each range. However, it should be noted that if a factor value can be measured numerically, the fuzziness should be described continuously rather than in the manner of ranges that are also difficult to be determined. The membership degree of '"vulnerability" can just describe the fuzziness continuously and efficiently. For example, factor D is divided into seven ranges which, in the DRASTIC system, are assigned seven ratings respectively, but using the MOFPR model, the membership degree decreases continuously from 1 to 0 calculated by equation (4), i.e.

$$r_{ij} = \frac{(x_{imax} - x_{ij})}{(x_{imax} - x_{imin})} = \frac{(100 - x_{ij})}{100}$$

Where x_{imax} = 100 and x_{imin} = 0 are determined according to the ranges of the upper and lower limits, respectively, in the DRASTIC system (Table 2).

Vulnerability assessment of groundwater can be transformed into a fuzzy pattern recognition problem. If one supposes that there is a setting "easiest to be polluted" denoted by $G = (g_1, g_2, \ldots\ldots g_m) = (1, 1, \ldots, 1$, and "most difficult to be polluted"expressed as $B = (b_1, b_2, \ldots\ldots b_m) = (0,0,\ldots,0$, then the given hydrogeological settings can be evaluated by the MOFPR model.

The evaluation result u_j (*j* = 1, 2, ...,*n)* is the degree of vulnerability for setting *j*. According to the evaluation results of MOFPR, the vulnerability order of giving settings can be obtained. Moreover, the value of u_j can a help decision maker to judge vulnerability using natural language, which is consistent with human thinking. In general, the decision of vulnerability for a hydrogeological setting can be made by means of natural language as follows:

Degree of vulnerability of u_j	**Decision**
$u_j > 0.8$	Very easy to be polluted
$0.6 \le u_j \le 0.8$	Easy to be polluted
$0.4 \le u_j \le 0.6$	May be polluted
$0.2 \le u_j \le 0.4$	Difficult to be polluted
$u_j < 0.2$	Very difficult to be polluted

4.1 Case Study:

There are five hydrogeological settings (*n* =5) in a studied area in the Cauvery Delta Region of Tamil Nadu (India). Their vulnerabilities on groundwater pollution need to be evaluated to identify the vulnerability owing to groundwater contamination with increasing population, industrialization and agricultural activities.

The influencing factors are the same as in the DRASTIC system (*m* = 7). The weights of the seven factors in multi-objective fuzzy pattern recognition model is also the same as in the DRASTIC model except they need to be normalized in the former (see Table 1). The factors $x_{i\,max}$ and $x_{i\,min}$ (*i* = 1, 2, ..., 7) are determined according to the ranges (for D, R, T and C) and the ratings (for A, S and I) of the upper and lower limits of the DRASTIC system (listed in Table 3).

	D	R	A	S	T	I	C
$x_{j\ max}$	30	394	9	10	35	14	1800
$x_{j\ min}$	3	158	2	1	1	2	200

Table 3: The maximum and minimum values of seven factors in the DRASTIC system

Setting	D	R	A	S	T	I	C
1	8	10	2	5	10	7	1
2	6	8	4	3	4	3	4
3	4	5	6	1	8	9	10
4	1	3	8	10	6	1	7
5	10	1	9	8	1	5	6

Table 4: Ratings of DRASTIC

Now, the Vulnerability index of aquifers and their order based on the DRASTIC system is calculated as follows:

Setting	1	2	3	4	5
DRASTIC Index	144	101	143	93	141
Order	1	4	2	5	3

Table 5: Vulnerability index of aquifers and their order based on the DRASTIC system

Setting	D (Feet)	R (Inches)	A	S	T (Slope %)	I	C
1	9.84	472.44	2	5	1	7	1800
2	16.40	393.70	4	3	25	3	1400
3	22.97	314.96	6	1	5	9	200
4	29.53	236.22	8	10	15	1	600
5	3.28	157.88	9	8	35	5	1000

Table 6: Value matrix of five settings in the MOFPR model

We have the normalized values of each setting of the DRASTIC system and the maximum r_{ij} is the value of the membership degree and it is given in the following table:

Setting	D	R	A	S	T	I	C
1	0.75	1	1	0.56	1	0.58	1
2	0.5	0.99	0.71	0.78	0.71	0.92	0.75
3	0.74	0.67	0.57	1	0.88	0.58	1
4	0.98	0.67	0.86	1	0.59	1	0.75
5	0.99	1	1	0.67	1	0.75	0.5

Table 7: Normalized matrix of membership degree

Finally, we have to calculate $u_j, (j = 1,2,\ldots\ldots,5)$ for each setting with using equation (13) and put p = 2, then we have the following:

$$\text{Since, } u_j = \frac{1}{1+\left[\frac{\sum_{i=1}^{m}(w_i\left|r_{ij}-1\right|)^p}{\sum_{i=1}^{m}(w_i * r_{ij})^p}\right]^{2/p}}$$

Therefore, the membership degrees of vulnerability and their order are given in the following table:

Setting	1	2	3	4	5
Membership Degree	0.95	0.92	0.88	0.98	0.97
Order	3	4	5	1	2

Table 8: Membership degrees of vulnerability and their order

Ratings for the five settings are listed in Table 4. The DRASTIC Index of each hydrogeological setting is calculated and listed in Table 5.

The value matrix X of the five settings in the MOFPR model is given in Table 6. The same ranges and ratings as in the DRASTIC system are given to the three factors A, S and I, which cannot be measured numerically. The other four factors (D, R, T and C), which can be quantitatively measured, are given directly by the original values. The membership matrix R calculated is listed in Table 7. Finally, u_j (j = 1, 2, ..., 5) has been calculated by equation (13) in which $p = 2$ (Table 8). It can be seen from Tables 5 and 8 that the orders of aquifer vulnerabilities are settings 1, 4, 2, 5 and 3 using the DRASTIC model and settings 3, 4, 5, 1 and 2 using the MOFPR model. The evaluation results of MOFPR can provide the direct results for the degrees of vulnerability for settings 3, 4, 5, 1 and 2 as 0.95, 0.92, 0.88, 0.98 and 0.97, respectively. In this case, decisions on vulnerability by means of natural language can be made: "very easy to be polluted" for all the five settings. It is shown that the evaluation results from MOFPR can offer better guidance to the agricultural planning as well as the industrial planning than the vulnerability indexes from the DRASTIC system.

5. Conclusion:

A multi-objective fuzzy pattern recognition model is used for assessing the pollution potential of groundwater and it is compared with the DRASTIC model in a case study. It shows that the fuzzy pattern recognition model can take the fuzziness into account more efficiently in the process of evaluating the vulnerability of groundwater. The evaluation results of MOFPR give all the five settings are in the category of the ground water is very easy to be polluted.

Drinking contaminated groundwater can have serious health effects. Diseases such as hepatitis, dysentery, liver and kidney damage, slowed growth, neurological disorders, and reproductive problems may be caused by contamination from various factors. Poisoning may be caused by toxins that have leached into well water supplies. Wildlife can also be harmed by contaminated groundwater. Other long term effects such as certain types of cancer may also result from exposure to polluted water. Groundwater quality monitoring programs should be implemented by the State Government in the Cauvery Delta Region. Groundwater quality should be regularly monitored. Contaminant levels can be compared to the World Health Organization (WHO) guidelines for drinking-water quality. Sufficient investment should be given to continuing monitoring over the long term. When a problem is found, action should be taken to correct it is the only way to reduce the ground water vulnerability.

6. Acknowledgement:

The authors are thankful to UGC for supporting this research work through Rajiv Gandhi National Fellowship.

7. References:

1. Aller, L., Bennet T., Lehr, J. H., and Petty, R. J. (1987), DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings, US EPA Report 600/2-85/018, US Environ. Protection Agency.
2. Aller, L., Bennet, T., Lehr, J.H., Petty, R., Heckett, G. (1987), DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeological Settings. U.S. Environmental Protection Agency, Washington, D.C., Document EPA/600/2-85-018.
3. Barber, C., Bates, L. E., Barron, R. and Allison, H., (1993), Assessment of the relative vulnerability of groundwater to pollution: a review and background paper for the conference workshop on vulnerability assessment, J. Austr. Geol. Geophys., 14(2/3): 1147–1154.
4. Bellman, R.., Kalaba, R.., and Zadeh, L.A. (1966), Abstraction and pattern classification, I. Math. Anal. and Appl. 2, 581-586.
5. Bellman, R.E., and Zadeh, L.A., (1970), Decision making in a Fuzzy Environment, Management Science, 17, B144-B164.
6. Bezdek, J. C. (1981), Pattern Recognition with Fuzzy Objective Function Algorithms, Plenum Press, New York.
7. Devijver, P.A., and Kitttler, J. (1982), Pattern Recognition: A Statistical Approach, Prentice-Hall, Englewood Cliffs, NJ.
8. Lobo-Ferreira, J. P., (1999), The European Union experience on groundwater vulnerability assessment and mapping, COASTIN A Coastal Policy Research Newsletter no. 1, September 1999, New Delhi, TERI, 8–10. http://www.teriin.org/teri-wr/coastin/newslett/coastin.pdf.
9. Lobo-Ferreira, J. P., (2000), GIS and mathematical modelling for the assessment of groundwater vulnerability to pollution: application to two Chinese case-study areas. In: Ecosystem Service and Sustainable Watershed Management Towards Flood Prevention, Pollution Control, and Socio-Economic Development in North China (Proc. Int. Conf., 23–25 August 2000, Beijing, China). http://www.dha.lnec.pt/nas/estudos/LF%20paper%20to%20Wolfgang%20CDRom.pdf
10. Lobo-Ferreira, J. P., and Cabral M. (1991), Proposal for an operational definition of vulnerability for the European Community's atlas of groundwater resources. In: Report of Meeting of the European Institute for Water, Groundwater Work Group (Brussels, February 1991).
11. Lobo-Ferreira, J.P., and Oliveira, M.M. (1993), Development of an inventory of the groundwater resources of Portugal: characterization of groundwater resources and DRASTIC vulnerability mapping of the aquifers of Portugal (in Portuguese). LNEC Report 194/93, GIAS/DH, Lisbon, Portugal.
12. Lynch, S.D., Reynders, A.G., Schulze, R.E., (1997), A DRASTIC approach to ground water vulnerability in South Africa. S. Afr. J. Sci. 93 (2), 59–60.
13. Magiera, P. (1999), GIS-based groundwater vulnerability assessment. In: Report of Management of Groundwater Resources, (The Geological Survey of Lower Saxony Conf., Hannover, Germany, November 1999).
14. Margat, J. (1968), Vulnérabilité des nappesd'eausouterraine à la pollution. BRGM-publication no. 68 SGL 198 HYD, BRGM (Bureau de recherché géologiquesetminières), Orléans, France.
15. Mc Kendrick, A.G. (1926), Applications of mathematics to medical problems, Proc. Edinburgh Math. Soc., 44, pp. 98130.
16. Meenakshi, A.R. (2008), Fuzzy Matrix theory and applications, MJP publishers.

17. Murali, K., and Elangovan, R. (2013), Assessment of Groundwater Vulnerability in Coimbatore South Taluk, Tamilnadu, India Using DRASTIC Approach, International Journal of Scientific and Research Publications, Volume 3, Issue 6, ISSN 2250-3153, 2013.
18. Patil, V.T., and Patil, P.R., (2011), Groundwater quality of open wells and tube wells around Amalner town of Jalgaon, District, Maharashtra, India, Electronic Journal of Chemistry,1: 53-78.
19. Srinivasamoorthy, K., Vijayaraghavan, K., Vasanthavigar, M., Sarma, V.S., Rajivgandhi, R., Chidambaram, S., Anandhan, P., and Manivannan, R. (2011), Assessment of groundwater vulnerability in Mettur region, Tamilnadu, India using drastic and GIS techniques, Arab J. Geosci, 4:1215-1228.
20. Vrba, J., and Zaporozec, A. (eds), (1994), Guidebook on Mapping Groundwater Vulnerability, International Contributions to Hydrogeology no. 16, Heise, Hannover, Germany.
21. Wahed, W. F., and Sinna, M. A. (2001), A hybrid fuzzy-goal programming approach to multiple objective decision making problems, Fuzzy Sets and Systems, 119, 71-85.
22. Yang, Q., and Luan, M. T. (1998), Application of the DRASTIC index to the assessment of vulnerability of Dalian peninsula using GIS. In: Progress Report-1998, National Laboratory of Civil Engineering, Lisbon, Portugal.
23. Zadeh, L.A. (1965), Fuzzy sets, Inform. and Control 8, 338-353.
24. Zeleny, M. (1982), Multiple Criteria Decision Making, New York: McGraw-Hill.
25. Zhou, H. C., Wang, G. L. and Yang, Q. (1999), A multi-objective fuzzy recognition model for assessing groundwater vulnerability based on the DRASTIC system. Hydrol. Sci. J. 44(4), 611–618.