# EFFECTIVENESS OF THE DRASTIC MODEL TO PREDICT AGROCHEMICAL-INDUCED GROUNDWATER POLLUTION

**Adeniran K..A.**[1] **and Ajamu, S. O.**[2]
Department of Agricultural Engineering, University of Ilorin, PMB 1515, Ilorin.
Corresponding author K A Adeniran
[1]E-mail:-*kadeniran_ 2003@yahoo. Com*
[2]E-mail.-*ajamubenchmark23@yahoo.com*

## ABSTRACT

An investigation was carried out on the effectiveness of using the DRASTIC model to predict groundwater vulnerability to pollution from an agricultural land Best Food Farm Ikoyi, Ogbomoso Oyo State, Nigeria during the 2003 Raining Season. Groundwater contamination potential was evaluated with the assumption that the aquifer is uniform and groundwater flow is steady. Seven parameters were measured for the project site and the corresponding weights and ratings attributed to each measured value were obtained from tables developed for DRASTIC Index. These parameters include depth to water table recharge (net), aquifer media soil media topography (slope) impact of vadose zone and hydraulic conductivity. The value of the DRASTIC Index obtained for the study site was 173, showing that the area under investigation has moderately high vulnerability. The result of the DRASTIC Index obtained was confirmed by carrying out chemical analysis of the water collected form a well located within the farmland compared to two other wells about 2 kilometers away from the farmland, where relatively little or no agricultural activities occurred. Using WHO (1993) and APHA (1995) Standards for drinking water to compare the results obtained for the three well water samples, the values obtained for nitrate were found to be highest for the water samples collected from the well within the study area. Also the values obtained for all the wells were by far lower than the 10 mg/L set by WHO (1993) and APHA (1992) Standards. The study thus shows that the DRASTIC model is a useful tool for evaluating groundwater vulnerability to pollution

## Introduction

Tchobanoglous (1987) defined groundwater contamination as any addition of undesirable substances to groundwater caused by human activities. Ground water contamination is extremely difficult and sometimes impossible to clean up. Ground water contamination vary from region to region and are influenced by climate, population density, intensity of industrial and agricultural activities, the hydrogeology of the region, and the status and enforcement of federal and state regulations that can be used to protect ground water. Groundwater can be and has been contaminated by a variety of pollution sources, including landfills and septic tanks, sewage treatment plants and mining operations, chemical waste, lagoons and leaking pipelines and tanks, feedlots, golf courses and agricultural practices (Glenn, 2002). Its quality, according to the National Academy of Sciences (1984) is affected by virtually all-human activity and by a wide range of natural processes. Even before water leaves the atmosphere as rain and snow, it may become contaminated by air pollution. Once on the ground, water running across the land (runoff) picks up pollutants that may enter groundwater As the "universal solvent" water traveling underground will dissolve and carry with it constituents from the surrounding soil and rocks. Depending upon the local geology, groundwater can contain naturally high levels of minerals like sodium, potassium, chloride, iron, sulfate or arsenic. It may carry naturally occurring radioactive material or bacteria as well. It may also become contaminated by constituents that have been introduced by human activities. Mackay, et al. (1993) reported that among the pollutants frequently found and associated with human activity are solvents and cleaning agents like trichloroethylene (TCE) and tetrachlorethylene (PCE), gasoline components such as benzene, toluene and xylene and the fuel additive methyl tertiary butyl ether (MTBE), creosote, nitrates from septic tanks and cesspools, fertilizer application and animal wastes, as well as pesticides like dibromochloropropane (DBCP), atrazine ethylene dibromide (EDB) and aldicarb

Groundwater generally takes longer time to become contaminated but the natural cleansing process also may take much longer. The levels of contaminants in drinking water are seldom high enough to cause health effects. Examples of acute health effects are nausea, lung irritation, skin rash, vomiting dizziness, and even death. Contaminants are more likely to cause chronic health effects effects that occur long after repeated use of the contaminated water. Examples of chronic health effects include cancer, liver and kidney damage, disorders of the nervous system damage to the immune system, and birth defects (Oluwande, 1983).

Different models have been developed to determine groundwater vulnerability to agricultural wastes. Some of these models include CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard et al., 1987) and USDA (1990), NLEAP (Nitrate Leaching and Economic Analysis Package) (Williams, 1990) and the DRASTIC (Depth, Recharge, Aquifer, Soil, Topography, Vadose Zone, Hydraulic Conductivity) index (TWC, 1990 and Deichert, 1992). Models generally are location specific; most of them perform best in locations with conditions similar to the environment where they are developed. The DRASTIC model unlike CREAMS, GLEAMS and NLEAP is not nitrate-nitrogen based and is not popularly used to predict groundwater pollution. The objective of this study was to determine the effectiveness of the DRASTIC model to predict groundwater vulnerability to pollution from agricultural wastes.

## Materials and Method

### Field Data Collection

The study site, Best Food Limited Ogbomosho (Fig 1) is located along Ogbomosho–Ikoyi road in Ogbomosho North Local Government. It is located between Latitude $8^0$ 15'N and Latitude $8^0$ 00'N and Longitude $4^0$ 00'E and Longitude $4^0$ 15'N. The water samples used for analysis were taken from a well located within the premises of study area and two others not too far from the farm. Three samples each of well water was collected from a well located within the vicinity of the study site and from two other wells about 2 kilometres from the study site using a clean white plastic bottle of two-litre capacity.

### Water Quality Analysis

The World Health Organisation (WHO, 1993) and American Public Health Association (APHA, 1995) standards for drinking water were used for the verification of each parameter tested for in the samples collected. The test procedures on the physical, chemical and bacteriological parameters were carried out at the Water Laboratory of the Lower River Niger Basin Development Authority, Ilorin. The test procedures were in accordance with standard method of examination of water. Water qualities tested include, phenolphthalein alkalinity, methyl orange alkalinity, total hardness, calcium hardness, magnesium, lead, copper, chloride, sulphate, nitrate, ammonia and electrical conductivity.

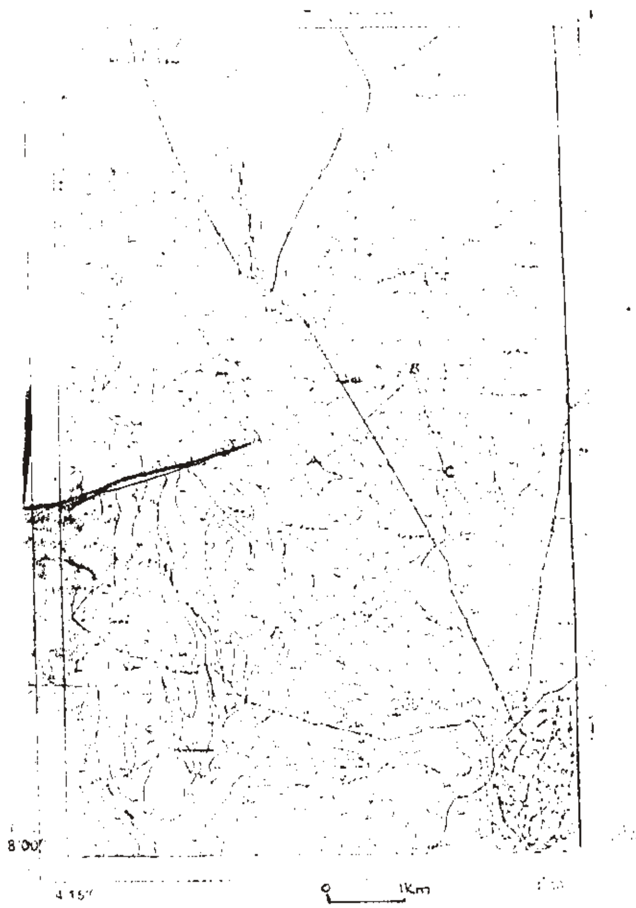


**Fig. 1: Topographic site of the study map**

### Determination of Drastic Index Parameters

The DRASTIC index was developed in the United States of America (USA). The U.S. Environmental Protection Agency (EPA), working with the National Water Well Association (NWWA) and a large number of other experts, have identified seven key factors that determine aquifer vulnerability (Deichert, 1992). These include depth to groundwater, recharge rate to groundwater; aquifer media; soil type, topography; impact of the vadose zone and hydraulic conductivity of the aquifer. Each of these factors is assigned a combination of weights and ratings. The typical ratings ranges are from 1-10 and the weights are from 1-5. Combining the first letters of the seven key factors arrives at the acronym for this index. The DRASTIC index is then used to evaluate the relative vulnerability of different aquifers or different segments of a given aquifer. DRASTIC evaluates pollution potential based on the above seven hydro-geologic settings. The DRASTIC Index, a measure of the pollution potential, is computed by summation of the products of rating and weights for each factor as follows

$$\text{DRASTIC Index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \quad (1)$$

Where:

$D_r$ = Ratings for the depth to water table,
$D_w$ =Weights assigned to water table depth
$R_r$ = Ratings for ranges of aquifer recharge.
$R_w$ = Weights for the aquifer recharge.
$A_r$ = Ratings assigned to aquifer media,
$A_w$ = Weights assigned to aquifer media
$S_r$ = Ratings for the soil media,
$S_w$ = Weights for soil media.
$T_r$ = Ratings for topography (slope),
$T_w$ = Weights assigned to topography.
$I_r$ = Ratings assigned to vadose zone,
$I_w$ = Weights assigned to vadose zone.
$C_r$ = Ratings for rates of hydraulic conductivity,
$C_w$ = Weights given to hydraulic conductivity.

**Depth from the surface to water level**

The depth to, from the surface to water level was measured as 10 m (30ft). Using the table reported by Deichert (1992) the DRASTIC rating and weight for the well located in the study area was determined.

**Recharge**

The net recharge of the aquifer was taken as the average change in depths of water in wells across the farmland. The recharge depends largely on the frequency of rainfall and its intensity. Table 1 shows the result of the net recharge for a period of eight weeks. This is the amount of water that actually becomes groundwater after precipitation.

**Aquifer Media**

Sieve analysis was used to determine the size range for the soil collected within the aquifer media surroundings. This was found to vary from 1.50-3.00 mm. Using this size range and the table developed by Deichert (1993) the rating of the aquifer media was determined.

**Soil Media**

Soil texture was determined using the USDA soil textural classification chart as reported by Michael (1993). Soil texture shows the relative proportion of sand, silt and clay contained in a given soil sample. The sol texture forms the basic matrix and the geometry of voids created in the soil matrix is dependent on the class of soil texture. Soil texture therefore influences considerably the passage of air and water on the soil media. Soil texture is constant and does not change with time. Using the USDA soil textural classification chart the soil within the aquifer media was found to be massive sandstone

**Topography**

The field slope of the study was determined using the topographic map covering the project area. Average value of the slope obtained from the attached topographical map gives 0.0050%. Using the table reported by Deichert (1992) the DRASTIC rating and weight for the location was determined

**Impact of Vadose Zone**

Chemical transport in vadose zone was investigated by using piezometers and vadose sampling techniques to determine chemical concentrations of the study site. The DRASTIC rating of the impact of the vadose zone for the study area was determined using the table reported by Deichert (1992)

**Conductivity (Hydraulic)**

Test for hydraulic conductivity was carried out on each core sample collected. Each sample was trimmed at one end and covered with cloth. The sample was then placed in water basin for 48 hours to allow it to saturate. The samples were then trimmed at he other end and core of the same size was placed on the one containing the soil. Both cores were then joined together by cellotape to make it watertight. The core arrangement was then supported by retort stand. Water from the tap was allowed into the core by first falling on wire gauze matting until about 4cm of water level was attained. The gauge was then removed and more water was added to a depth of 7cm. After two hours of running the effluent water from core bottom was collected and measured at a time interval of ten minutes. Saturated hydraulic conductivity can be estimated by rearranging Darcy's formula as follows

$$K = (V \times L) / (A t H) \quad (2)$$

Where

K=hydraulic conductivity (cm/s). H=head of water lost in flow through the sample
L = the length of the sample (cm). V = Volume of outflow ($cm^3$).
t = time of outflow (s). A = cross-sectional area of the sample ($cm^2$).

**Procedures for the Chemical Analysis of the Water Samples**

(1) Total Solids

100 ml of sample was taken into evaporating dish and was oven dried for 24 hours. It was then reweighed after cooling.
Weight of evaporating dish=A(mg). Weight of evaporating dish + the sample=B (mg)
Total Solids (mg/l) = (B-A) x 10 (3)

(2) Nitrate ($NO_3$)

Colorimetric method was used. 10 ml of sample was measured into Nessler tube and the same amount of distilled water into another Nessler tube. 0.5 ml of Brucine was added and 20 ml of concentrated sulphuric acid into each tube. Potassium nitrate was added drop by drop into the tube containing distill water until a colour match is obtained.
$NO_3$ (mg/l) = ml of $KNO_3$ x 0.1 x 1000/10ml of sample (4)

(3) Potassium ($K^+$)

Flame photometry test using flame photometer was used. Good distilled water in de-ionized water was used as the blank. The meter was set to zero using the blank.

(4) pH

pH meter was used to determine the pH of the samples.

**Results and Discussion**

**Determination of DRASTIC Index Parameters**

The depth of water in the well located within the study site was 10 m. The DRASTIC rating of 7 with a weight of 5 was obtained for depth of water. Fig 2 shows the net recharge during the period of study. Using the values of the net recharge obtained in Fig 2 a DRASTIC rating of 9 with an attributed weight of 4 was obtained for net recharge. The aquifer was classified as massive media was classified as massive sandstone (1.50 – 3.00 m), the DRASTIC rating of 6 with an attributed weight of 3 was obtained for this aquifer media. The result of sieve analysis for the soil media shows that the soil is aggregated clay with a DRASTIC rating of 7 with a weight of 5.

The slope of the study site was determined as 0.0050 %. The DRASTIC rating was found to be 10 with a weight of 3. For the vadose zone, the DRASIC rating of 3 with a weight of 1 was obtained. Fig 2 and 3 were used in determining the volume of outflow in equation 2, which enabled the hydraulic conductivity to be computed. Table 1 shows the computation of the DRASTIC Index for the area under study using equation 1 with the using weights and the ratings for the seven parameters determined in the study. The DRASTIC Index of 173 obtained indicates that the area is fairly high vulnerability.

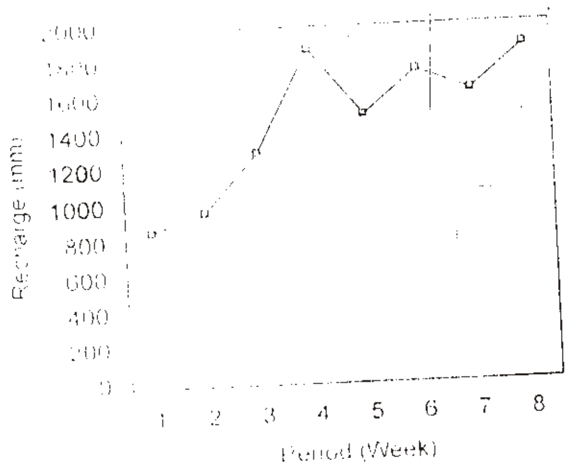


Fig. 2: Recharge for the period of study

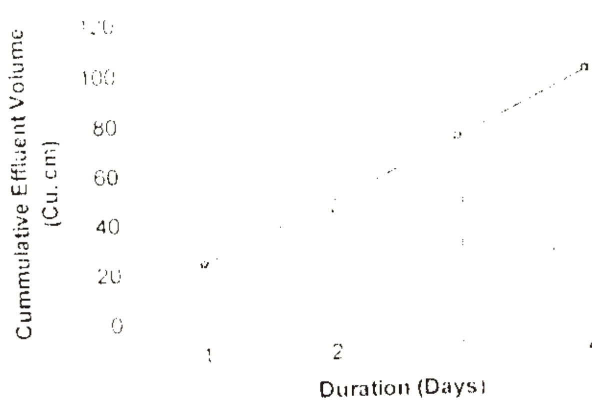


Fig. 3: Cummulative effluent volume

**Validation of the Model Results**

The result of the DRASTIC model was validated by carrying out chemical analysis on the groundwater samples taken from the project site and on the samples of groundwater taken from wells outside the project site, where there was relatively little or no agricultural activities taken place. The parameters tested for were Total solids (TS) Nitrate ($NO_3^-$), Potassium ($K^+$), pH and Electrical Conductivity (E C) The tests were carried out for a period of eight weeks between 4th July and 18th August 2003 Samples were taken once in each of the week usually a day or two after a rainfall event Table 2 shows the result of the chemical analysis of the water samples For nitrates, the values obtained for the well located within the study site (3.12 – 8.42 mg/l) were by far higher than those obtained for the two wells located far from the study site (0.12 – 5.52 mg/l) Table 2 reveals that the level of nitrate content for the three wells was below the guide line value of 10 mg/l set by the WHO [12] and APHA [13] standards for drinking water. This also shows that the Nitrate contamination has detected using DRASTIC model

## Conclusion

The study shows that the DRASTIC model is a useful tool for predicting vulnerability to groundwater pollution from agricultural wastes. The result using the model parameters on the study site compares favourably with that of the analysis water collected from the study site and two others outside the study site.

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**Table 1. Determined DRASTIC parameters**

| DRASTIC parameters | Rating | Weight | Factor |
|---|---|---|---|
| Depth to groundwater | 7 | 5 | 35 |
| Recharge rate to groundwater | 9 | 4 | 36 |
| Aquifer media | 6 | 3 | 18 |
| Soil type | 7 | 5 | 35 |
| Topography | 10 | 3 | 30 |
| Impact of the vadose zone | 3 | 1 | 3 |
| Conductivity of the aquifer | 4 | 4 | 16 |
| DRASTIC Index | | | 173 |

**Table 2. Results of water analysis**

| Week | Total solids (mg/L) | | | Nitrate (mg/L) | | | Potassium (mg/L) | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C |
| 1 | 13.00 | 20.50 | 25.60 | 3.12 | 2.48 | 2.70 | 0.13 | 0.13 | 0.13 | 7.0 | 7.8 | 7.6 |
| 2 | 19.42 | 35.40 | 50.60 | 5.61 | 0.64 | 0.25 | 1.17 | 0.13 | 0.06 | 7.5 | 7.6 | 7.5 |
| 3 | 23.15 | 20.40 | 47.90 | 7.12 | 0.57 | 0.43 | 0.15 | 0.14 | 0.12 | 6.7 | 6.8 | 7.0 |
| 4 | 24.10 | 35.54 | 45.81 | 5.31 | 0.12 | 1.35 | 0.23 | 0.13 | 0.13 | 7.0 | 7.0 | 7.5 |
| 5 | 25.24 | 38.43 | 40.95 | 6.81 | 1.14 | 3.23 | 0.24 | 0.13 | 0.11 | 7.5 | 7.0 | 7.0 |
| 6 | 31.35 | 41.60 | 42.84 | 8.42 | 0.43 | 5.52 | 0.19 | 0.12 | 0.12 | 7.5 | 7.0 | 6.8 |
| 7 | 32.20 | 45.42 | 51.24 | 4.24 | 4.15 | 0.53 | 0.24 | 0.14 | 0.07 | 6.8 | 7.5 | 7.0 |
| 8 | 37.12 | 50.45 | 50.43 | 5.20 | 4.25 | 0.15 | 0.24 | 0.12 | 0.09 | 6.8 | 7.5 | 7.5 |

A = Sample of water collected on the farmland. B & C= Samples of water collected outside the farmland about 2km away.