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A NEW APPROACH FOR EVALUATION OF THE MANAGEMENT AND ENVIRONMENTAL IMPACTS ON NITROGEN IN AGRICULTURAL LANDS (MEINAL MODEL)

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ABSTRACT

There have been great public and international concerns about the groundwater contamination with agrichemicals especially with nitrogen fertilizers. Several simulation models were developed to describe the dynamics of nitrogen in the environment and its impact on groundwater pollution with nitrate lost by leaching. However, such models need large arrays of data sets, sophisticated instrumentation analysis, technical and scientific experiences. The MEINAL model was developed to evaluate the impacts of several soil, management and environmental factors that mainly affect nitrogen pathways in agricultural ecosystems and the potentiality of groundwater pollution with nitrate. Nitrification, denitrification, volatilization, mineralization/ immobilization and plant uptake were assumed to be the main processes that contribute to the level of residual soil nitrate. Deep water percolation was assumed to be controlled by the water balance components of the ecosystem and the hydraulic soil properties. A new procedure analogous to the land evaluation procedures was adapted. The extent of the influence of each factor on any process considered was given a rate ranged from 0 to 1 according to its mode of action. In addition, each factor was given a weight ranged from 1 to 5 relevant to its relative importance in controlling the process of interest. An index was calculated for each principal process as the weighted average of the ratings of the controlling factors encountered. Both Residual Soil Nitrate Risk Index (RSNRI) and Deep Water Percolation Index (DWPI) were calculated. A final index of the Nitrate Leaching Risk Index (NLRI) was calculated as a weighted average of the RSNRI and DWPI.

INTRODUCTION

Managing nitrogen for groundwater quality and farm profitability is of increasing national concern among the general public and within the agricultural community. Important health concerns for crops must be balanced with the requirements to maintain and encourage a strong and economically visible agriculture. Central to the issue of nitrogen management is nitrate leaching risk and contamination of groundwater. Nitrate is a natural constituent in virtually all soils and waters and can arise from numerous sources. However, it is a highly mobile N-form that can be leached through the crop root zone and eventually into groundwater.

Several simulation models have been developed (Zin El-Abedin, 1993; Addiscott et al., 1995) to describe the nitrogen dynamics and nitrate leaching through the root zone. Mathematical modelling of nitrogen behaviour in the soil system can be classified into three types. The first type of models considered the transport and transformations of nitrogen under steady-state water flow conditions. Most of these models were based on analytical solution of the convection-dispersion equation for nitrogen transport in semi-infinite media. The second type of models described the fate of soil N under non-steady or transient water flow in the soil profile (Addiscott, 1996). These models are somewhat complex and were based on numerical approximation of the water flow equation and the convection-dispersion equation for N transport and transformation. Moreover, these models utilized the concept of a mixing cell for segmented soil profiles to account for the mass flow and dispersion of nitrogen from one segment to another. The third type of models described the nitrogen transformation and transport using some regression and correlation equations and included most of the factors that affect N-transformations (Wright et al., 1989). These types of models need a huge bulk of data files and a lot of information to be incorporated in these models in order to obtain good simulation results. However, such models are always comprehensive, complex and need both detailed input data and sophisticated instrumentation for *in situ* measurements and model validation.

Studies on the evaluation of the existing models for predicting nitrate leaching in agricultural soils (Aggag, 2001; Hedia, 2000) revealed that most of these models developed to describe one or more processes in agricultural regimes. However, models used to predict N transformation and transport in agricultural land must be modified and simplified.

Attempts have been made to develop several land evaluation approaches (FAO, 1976, UNESCO, 1979). A two-stage approach has been adapted in land evaluation. A qualitative land suitability classification was made, based on matching physical, chemical and environmental factors using rating procedures for each factor. The result is a quantitative land suitability classification expressed in terms of an evaluation index. Analogous to the land evaluation approach, the DRASTIC model, proposed by Aller et al. (1987) is an empirical model for the evaluation of groundwater pollution potential on a regional scale using the hydrogeologic settings of Indiana State in the United States. They used an overly and index methods for the

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evaluation of public groundwater vulnerability to contamination. A study conducted by Eimers *et al* (2000) used a similar approach for rating unsaturated zone and watershed characteristics in respect to their pollution susceptibility with nitrate in North Carolina, U.S.A. In Begal, India, Shahid (2000) coupled GIS with DRASTIC model to evaluate the vulnerability of groundwater resources in Begal, India to pollution with municipal industrial or agrichemicals. However, no attempts have been made so far to develop an empirical evaluation model for the environmental impacts on nitrogen in agricultural ecosystems. Therefore, the objectives of this study were to

i) develop a new rating procedure to evaluate the impacts of various soil, environmental and management factors on nitrogen dynamics and water regime components in agricultural lands.
ii)integrate multidisciplinary knowledge on nitrogen dynamics and water management.
iii) introduce appropriate risk indices for the deep water percolation, soil residual nitrate and nitrate leaching.

MODEL DEVELOPMENT

1- Conceptualization of the Model:

Addsicott (1996) stated that movement of nitrate through the vadose zone and its leaching to groundwater is mainly determined by deep water percolation through the vadose zone to the groundwater and level of residual soil nitrate content of the vadose zone which is leached out with the percolating water.

A method was developed for rating the influences of the vadose zone properties, environmental and management factors on water percolation and soil residual nitrate and their impacts on the contamination of groundwater with nitrate. This method was used to construct the ratings by an index method. The procedures that are presented for rating unsaturated zone of an agricultural regime represent the potential for water with nitrate to travel through the unsaturated zone to reach the groundwater.

The important processes that can contribute significantly to deep water percolation and nitrate leaching were assigned as the principal processes considered by the model. Subsequently, the most important soil, environmental and management factors which were believed to influence each process were assigned. The extent of the influence of each factor on any process considered was given a rating ranged from 0 to 1 according to its mode of action. In addition, each factor was given a weight relevant to its relative importance in controlling the process of interest. The weight given to each factor ranged from 1 to 5. An index was calculated for each principal process as the weighted average of the ratings of the controlling factors encountered. Indices of all considered processes were used to calculate the surface water runoff index (SWRI), deep water percolation index (DWPI) and soil residual nitrate index (SRNRI). From these indices, the final nitrate leaching risk index (NLRI) was calculated. Figure (1) illustrates the flow chart of the MEINAL model.

2- Evaluation Procedures:

I. Evaluation of Deep Water Percolation Component:

The amount of deep water percolation is assumed to be directly related to both the hydrological balance and the hydraulic properties of the vadose zone. The hydrological balance was evaluated by considering the water input components (rainfall, irrigation, capillary rise and changes in soil water storage) and output components (surface runoff, evapotranspiration and deep percolation).

A- Surface Water Runoff Index (SWRI):

Surface water runoff was assumed to be mainly influenced by surface slope, crop cover, infiltration rate and soil moisture content (Williams et al., 1984). The influences of these factors were rated as follows:

1- Surface Slope Factor:

Surface water runoff is directly proportional to the surface slope (Williams et al., 1984). If the surface slope is equal to or greater than 30%, the surface slope factor (SLOPEF) was given a rating of 1. The rating of the surface slope less than 30% was calculated as

$$SLOPEF = 1.0 + 3.177\,(SLOPE/100 - 0.30)$$

where SLOPE is the percent of surface slope.

2- Crop Cover Factor:

According to Williams et al. (1984) the surface water runoff is reduced by increasing the percent of soil surface crop cover (COVER). During the emergence and germination stages (crop cover up to 10%), the surface water runoff is not influenced. Hence, the crop cover factor was given a rating 1. A further increase in the crop cover would decrease surface water runoff and its rating was calculated as;

$$COVERF = 1.0 + 1.06\,(COVER/100 - 0.10)$$

3- Infiltration Rate Factor:

Surface water runoff is inversely proportional to the infiltration rate of the surface soil layer or horizon. Cassel and Vasey (1974) classified soils into four hydrologic groups according to their surface infiltration rates (IR, cm h^{-1}). This classification was used in this model to calculate the rating of this factor. Soil with infiltration rate less than or equal to 0.127 cmh^{-1} was given a rating 1. However, soils with surface infiltration rate greater than 0.862 cm h^{-1} was given a rating 0.01 Rating of the surface infiltration factor having values between these two limits was calculated as;

$$IRF = 1.0 - 0.1569\,(IR - 0.127)$$

This rating scheme is valid only for surface irrigation practices. In farms where sprinkler or localized irrigation systems are used, the system is designed so that the application rate of irrigation water does not exceed the basic infiltration rate. Consequently, surface water runoff is not expected and hence this factor was given a rating of 0.01.

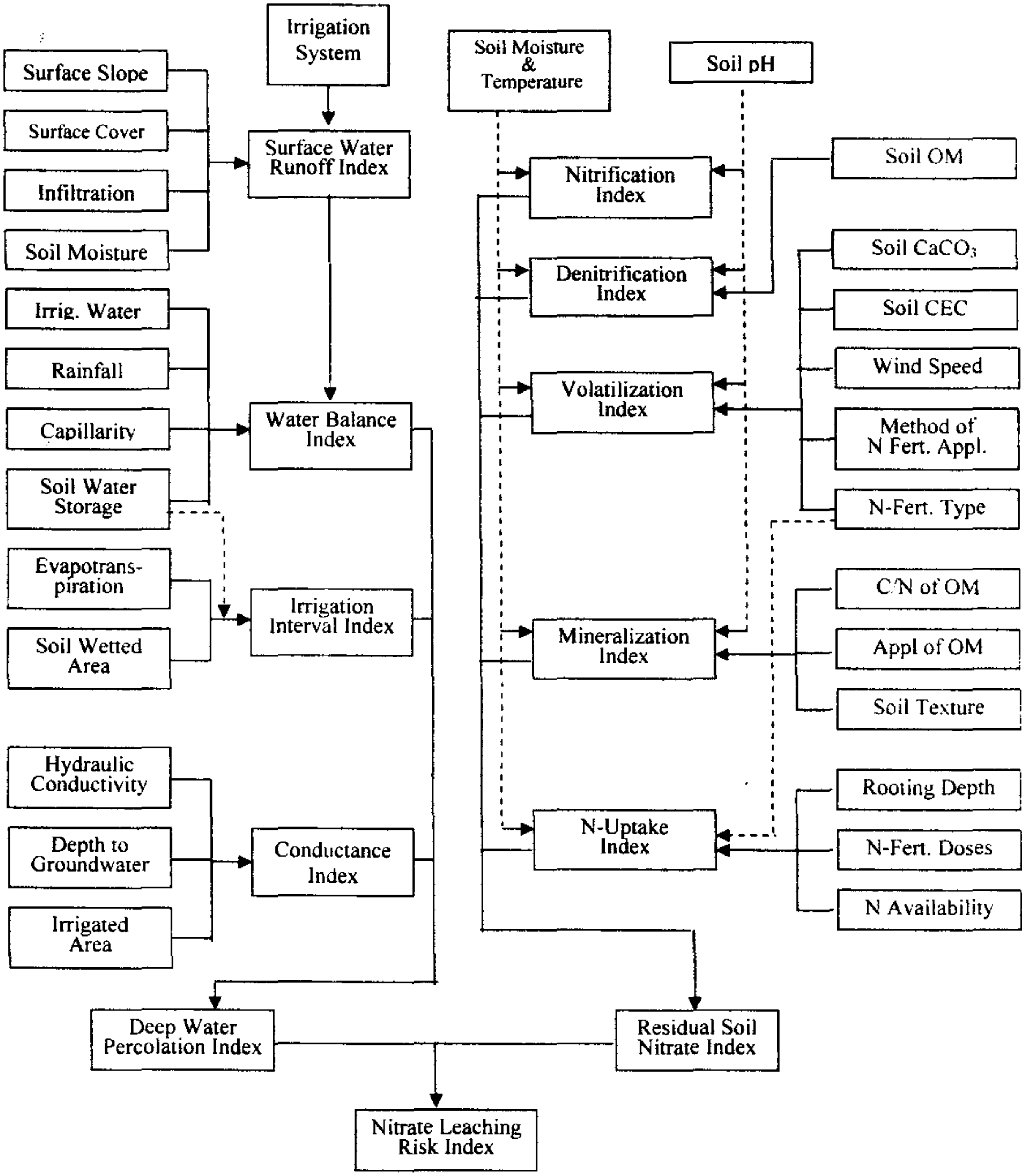

Figure (1): Flowchart of the proposed MEINAL model

4- Soil Moisture Factor:

During the irrigation process, water infiltration rate and hence surface water runoff is strongly affected by the initial soil moisture content. The higher the initial soil moisture content at irrigation the higher the susceptibility to surface water runoff. Therefore, when soil moisture content at irrigation is larger than its field capacity this factor was given a rating of 1. Otherwise, the rating of soil moisture factor was calculated as;

$$MOISTF = 1 - (FC - SMC)/(FC - WP)$$

where FC, SMC and WP are the volumetric soil moisture content at field capacity, irrigation and welting point, respectively.

According to the relative importance of the considered factors, weights of 5, 2, 4 and 2 were given to surface slope, surface cover, infiltration rate and soil moisture factors, respectively. The surface water runoff index (SWRI) was then calculated as the weighted average of the ratings these factors as;

$$SWRI = CF\,(5\,SLOPEF + 2\,COVERF + 4\,IRF + 2\,MOISTF)/13$$

where CF is a correction factor for the effect of irrigation frequency along the growing season calculated as;

$$CF = (10\,IW)/(ETC\ GRWTHP)$$

where IW is the depth of irrigation water in mm, ETC is the crop evapotranspiration in mm/day and GRWTHP is the growth period of the crop in days.

B- <u>Deep Water Percolation Index (DWPI):</u>

When water enters the soil profile, the susceptibility to deep water percolation depends on the water balance of the soil-plant system, irrigation intervals and the conductance of the vadose zone. Rating procedures of these factors were as follows:

1- Water Balance Factor:

The contribution from shallow water table is determined by its depth below the root zone, the capillary properties of soil and the soil water content in the root zone (FAO, 1988).

The amount of water driven by upward flow (CR) in mm was calculated as

$$CR = UPWARD\ II$$

Plots of the upward flow rate of water (mm/day) to the wet root zone due to capillary rise for different soil textures and groundwater table depth published by FAO (1992) were adapted to establish an exponential relationship of the form

$$UPWARD = a\,(FRINGE)^{-b}$$

The parameters *a* and *b* were fitted for each soil textural class and are listed in Table (1).

Table (1): Fitted parameters of the capillary rise for different soil textural classes.

Soil Texture	*a*	*b*
Sticky Clay	1.48E+02	1.5195
Loamy Sand	1.88E+03	2.1257
Clay	2.12E+05	3.2417
Peat	1.14E+04	2.9096
Clay Loam	4.19E+04	2.4349
Sandy Clay	3.05E+04	2.1997
Fine Sandy Loam	4.00E+07	3.4564

Where II is the irrigation interval in days and FRINGE is the depth from root zone to the shallow groundwater table in cm calculated as

$$FRINGE = DWT - (RZ\ KR)$$

where DWT is the depth of groundwater table in cm, RZ is the depth of the root zone in cm and KR is a modifying factor for crop cover factor calculated as

$$KR = 0.07 + 0.0102\ COVER$$

The irrigation interval (II) was calculated as;

$$II = P\,(AWC\ DEPL)/(100\ ETC)$$

where P is the wetted area from the irrigated field which differs according to the applied irrigation system. According to FAO (1988) the wetted area of the soil surface were assumed as listed in Table (2). DEPL is the percent of soil moisture depletion at irrigation and AWC is the available soil moisture content in mm calculated as

$$AWC = 10\,(FC - WP)\,RZ\ BD$$

where BD is soil bulk density Mg m^{-3}.

Table (2): Fraction of wetted area under different irrigation systems.

Irrigation system/ Method	Percent Wetted Area (P)
Surface Irrigation	
Furrow	0.85
Basin	1.00
Border	1.00
Sprinkler	1.00
Localized	0.40

The water balance (WB, mm) component of a cultivated area was calculated as;

$$WB = 100\,(IW + R + CR)\,(1 - SRWI)/(AWC\ DEPL)$$

where R is the amount of rainfall in mm.

The rating of the water balance factor (WBF) was calculated as;

$$WBF = 0.05\,(WB/IREFF)$$

where IREFF is the efficiency of the farm irrigation system.

2- Irrigation Interval Factor:

The frequency of the irrigation events increases the probability of having more excess water available for deep percolation. Hence the effect of irrigation interval factor was calculated as;

$$IIF = (1.03 - 0.0485\ II)\ KR$$

The modifier KR here was used to correct for the effect of the change in surface cover on crop evapotranspiration and hence on irrigation intervals.

3- Soil Conductance Factor:

In order to estimate the capacity of the entire vadose zone that overlies the saturated zone to transmit water, the thickness of the unsaturated zone and its hydraulic conductivity must be determined (Smith and Cassel, 1991; Eimers *et al.*, 2000). Then, conductance ($m^2\ day^{-1}$) of the area considered can be calculated as;

$$CONDCT = A\,K_{HS}/DWT$$

where K_{HS} is the harmonic mean of the saturated hydraulic conductivity of the vadose zone in m/day and *A* is the area to be evaluated in m^2. According to the scale proposed by (Eimers *et al.*, 2000), if the calculated conductance is less than 37 it was given a rating of 0.01. However if it is more than 2.44×10^5 it was given a rating of 1. Between these two limits the rating was calculated as;

$$CONDCTF = 0.11 \log (CONDCT) - 0.386$$

Finally, the deep water percolation index was calculated as the weighted average of the water balance, irrigation interval and conductance factors as follows;

$$DWPI = CF\,(5\,WBF + 2\,IIF + 5\,CONDCTF)/12$$

II. Evaluation of Soil Residual Nitrate Component:

Estimates of the extent of nitrate accumulation from different nitrogen pools in soil require an understanding of the changes in the rates of nitrogen transformation processes and the influences of physical and chemical environmental factors on these biological processes.

Several investigators (Mehran and Tanji, 1974; Hagin and Amberger, 1974; Beek and Frissel, 1973; Misra et al., 1974; Selim and Iskander, 1981; Diezeman et al., 1989; and Wright et al., 1989) have used first-order rate equations to describe transformations of nitrogen. The soil-water content, temperature, pH and aeration have significant effects on nitrogen transformations. The major limitation in the selection of a rate coefficient for nitrification, denitrification, volatilization, mineralization/immobilization, appears to centre on the selection of a value that represents the activity of the microbial populations responsible for these processes.

A. Nitrification Index:

Several researches treated the nitrification process as a single step first order reaction (Rao et al., 1981; Diezman et al., 1989; and Wright et al., 1989). Others (Bhat et al., 1981) considered the nitrification as a single step zero order reaction (from NH_4^+ to NO_3^-). The constant rate of such equations is strongly influenced by various environmental variables. In this model, it was considered that soil moisture, pH and temperature are the major factors affecting the nitrification process in soils.

1- Soil Moisture Factor:

Nitrate production is affected by the water status of the soil. Water loggings limits diffusion of O_2 and, thus, suppress nitrification (Madramootoo and Papodopoulos, 1991). The optimum soil moisture content for nitrification process was found to be equal to 0.8 FC (Myrold, 1998). Therefore, the rating of soil moisture content (THNF) was calculated as follows:

$$THNF = 4.8^{-\alpha\left(\frac{FC}{PWP}\right)}$$

$$\alpha = \begin{cases} \dfrac{(0.8FC - SMC)}{(E - FC)}, & \dfrac{SMC}{FC} \le 0.8 \\ \dfrac{(SMC - 0.8FC)}{(E - FC)}, & \dfrac{SMC}{FC} > 0.8 \end{cases}$$

Where, E is the soil porosity.

2- Soil pH Factor:

A significant correlation between NO_3^- production and pH has been demonstrated by (Morrill and Dawson, 1967; and Dancer et al., 1973). Their results indicated that 3-5 fold increase in nitrification occurred when the soil pH increased from 4.7 to 6.5. The optimum pH range for nitrification was found to be between 7.5 and 8.5.

From the data reported by Dancer et al. (1973), Reddy et al. (1979a) and Bhat et al. (1981), the following relationships for rating the pH factor (PHNF) was obtained:

$$PHNF = \begin{cases} 0.001, & pH \le 4.0 \\ 0.307\ pH - 1.259, & 4.0 < pH < 7.0 \\ 1.000, & 7.0 \le pH < 7.4 \\ 5.367 - 0.599\ pH, & 7.4 \le pH \le 9.0 \end{cases}$$

3- Soil Temperature Factor:

Nitrification is markedly affected by the temperature of the medium (Loehr, 1984; and Paul and Clark, 1989). The optimum temperature for the growth of nitrifers is around 25-30 °C. This process is very slow below 5 °C and above 40 °C. These studies concluded that the nitrification process should occur even at a low temperature. Therefore, the rating of the temperature factor (TEMPNF) on the nitrification process below 27 °C (Myrold, 1998) was calculated as

$$TEMPNF = 1.07^{(T-27)}$$

where T is the soil temperature (°C).

However, at temperature more than 27 °C the rating of this factor was calculated as

$$TEMPNF = 1.07^{(27-T)}$$

The final nitrification index (NTRFI) was calculated as the weighed average of the soil moisture content, soil pH and temperature ratings as follows:

$$NITRFI = (5\,THNF + PHNF + 3\,TEMPNF)/9$$

B. Denitrification Index:

Denitrification is important in soils since it reduces the amount of the nitrate that can be leached to surface and groundwater and because it reduces the amount of nitrogen available for plant growth (Barber, 1995).

For denitrification to occur, denitrifying organisms must be present in an environment favourable for their growth. Soil moisture content, pH, temperature, soil organic matter and N_2-gas losses were found to be the major factors governing denitrification in an ecosystem (Loehr, 1984, Hsieh et al., 1981 and Barber, 1995).

1- Soil Moisture Factor:

The soil moisture content affects microbial activities by influencing oxygen diffusion (Firestone, 1982; and Paul and Clark, 1989). The increase in soil moisture content to a level that interferes with air diffusion progressively increases the denitrification potential. Under field conditions, denitrification is lacking or insignificant at a moisture level less than 60 % of the soil moisture holding capacity (Myrold, 1998). Ryden and Lund (1980) reported that critical moisture tensions at which denitrification occurred in several soils were in the range greater than soil moisture holding capacity to less than saturation. Hence, the rating of the soil moisture factor (THDF) was calculated as follows:

$$THDF = 2.8^{-\beta\left(\frac{E}{FC}\right)}$$

$$\beta = \frac{(E - SMC)}{(E - FC)}$$

2- Soil pH Factor:

Barber (1995) and Loehr (1984) reported a linear relationship between the pH and the rate of denitrification. Optimum denitrification occurs under neutral conditions (pH 6-8) as most denitrifying bacteria grow best near neutrality (Burford and Bremner, 1975; Stanford et al, 1975 and Khan and Moore, 1968). Denitrification becomes slow but may remain significant below pH 5 and is negligible or absent at pH of 4. The following relationship developed by Hagin and Amberger (1974) and modified by Diezman et al.(1989) was used to rate the effect of the pH factor (PHDF) on the denitrification processes.

$$PHDF = \begin{cases} 0.001 & pH < 4.1 \\ 0.129\ pH - 0.527 & 4.1 \le pH < 4.8 \\ 0.84\ pH - 3.942 & 4.8 \le pH < 5.8 \\ 0.032\ pH + 0.745 & 5.8 \le pH < 8.0 \\ 7.00 - 0.755\ pH & 8.0 \le pH < 9.2 \\ 1.414 - 0.143\ pH & 9.2 \le pH \le 9.9 \end{cases}$$

3- Soil Temperature Factor:

Firestone (1982) and Paul and Clark (1989) reported that the rate of denitrification process is directly affected by soil temperature (as microbial activity increases exponentially with increasing temperature according to the Arrhenius equation) and indirectly (as temperature affects O_2 diffusion in water). At temperature less than 15 to 20 °C, a linear rather than an exponential relationship exists between temperature and denitrification potential. The minimum temperature for denitrification in soil is about 5 °C (Cho 1971; Craswell, 1978; and Bailey, 1976) and the maximum value is about 75 °C (Keeney and Follett, 1991). The optimum temperature for the growth of denitrifers is around 25-30°C (Myrold, 1998). Rating the effect of the temperature factor (TEMPDF) on the denitrification processes was similarly calculated as in the nitrification processes.

4- Soil organic matter:

Reddy et al. (1980a) and Bartlett et al. (1979) studied the general relationship between soil organic matter content and denitrification. Their results indicated that denitrification occurs in soils of higher organic matter content and was not measurable in soils with <1% native soil carbon. In this study incorporated a first order reaction for denitrification algorithm that was sensitive to soil organic matter, temperature and moisture which calculated the (SOMDF) as follows:

$$KD = 0.24\ (SOM/\ 0.17 + 0.003)$$

$$DKT = EXP\ (0.07\ T + 2.43\ \log\ (KD))$$

$$DT = II/\ 3$$

$$SOMDF = EXP\ (-0.5\ DKT\ DT)$$

When, DT < 0.6 the SOMDF = 0.001

KD is the rate constant of the denitrification at 35 °C (h^{-1}), DKT is the temperature adjusted rate constant (h^{-1}), SOM is the percent of soil organic matter (%) and DT is the number of days of drainage since the last irrigation.

The denitrification index (DNTRI) was calculated as the weighed average of the soil moisture content, soil pH and temperature as first step:

$$DNITRI = (5\ THDF + PHDF + 3\ TEMPDF + SOMDF)/\ 10$$

5- Degree of saturation:

There are some relationships between the degree of water saturation in soil and nitrogen gas loss. A correction factor of the nitrogen gas losses as a function of degree of saturation (DS) can be calculated as follows Reddy et al. (1980a) and Bartlett et al. (1979):

$$N2GLF = \begin{cases} 0.01 & DS \le 0.78 \\ 1.75\ DS - 1.38 & 0.78 < DS \le 0.9 \\ 8.0\ DS - 7.0 & 0.9 \le DS \le 1.0 \end{cases}$$

The degree of water saturation can be calculated as follows:

$$DS = \frac{SMC}{\left(1.0 - \left(\frac{\rho_b}{2.65}\right)\right)}$$

As a final step, a modified the denitrification index (DNITRI) depending on the nitrogen loss factor can be calculated as follows:

$$MDNITRI = DNITRI\ (1 + N2GLF)$$

C. Volatilization Index:

Temperature, type of N-fertilizer, method of application, soil $CaCO_3$ content, wind speed, soil CEC, soil pH and soil moisture content were considered by several researchers as the most important factors affecting NH_3 volatilization losses from soils (Fenn and Kissel, 1973; Fenn and Kissel, 1974; Fenn, 1975; Fenn and Kissel, 1975; Steenhuis et al., 1976; Reddy et al., 1979b; Steenhuis et al., 1979 and Zia et al, 1999).

1- Soil Temperature Factor:

Srinath and Loehr (1974) reported that increasing the temperature increases the loss of NH_3 through volatilization. They concluded that desorption can occur only at temperatures greater than 3 to 5°C. Steenhuis et al. (1976) reported that the reaction rate was increased by approximately 1.3 to 3.5 folds for each 10°C rise in temperature, when the system temperature changed 0 to 30°C. The effect of the temperature factor on NH_3 volatilization (NH4VTF) was rated according to the following equation:

$$NH4VTF = 0.03\ T$$

If the temperature is less than 5°C this rating is equal to 0.1 while at temperature greater than 30°C the rating is equal to 1.

2-Type of N-Fertilizer Factor:

Several *studies* proved that the NH_4 content of the applied nitrogen fertilizer (inorganic or organic) affects the rate of the nitrogen loses through volatilization (Zia et al., 1999). The rate of *volatilization increases* with increasing the NH_4 contents in the fertilizer. Therefore, the rating of different types of *inorganic* (NFERTF1) and organic (NFERTF2) fertilizers were proposed according to their *contents* of ammonium-nitrogen form and are listed in Table (3).

Table (3): List of different types of inorganic and organic fertilizers and their rating according to their contents of ammonium-nitrogen form.

Type of N-fertilizer	Rating of NFERTF1 factor	Type of organic fertilizer	Rating of NFERTF2 factor
Urea	1.00	Farm M.	0.50
NH4-Form	0.90	Chicken M	1.00
NH4NO3	0.50	Compost	0.05
NO3-Form	0.01	Sewage Sludge	0.70
Slow Release	0.10	Green M	0.01

In some cases, mineral or organic N–fertilizers are separately applied to the soil. But in many cases, both types of fertilizers are applied simultaneously. Hence, an average rating of both mineral and organic fertilizers was calculated as follows:

$$NFERTF = (NFERTF1 + NFERTF2) / 2$$

3- Method of N-Application:

Several researchers demonstrated that much more NH_3 is volatilized from surface application of chemical fertilizers such as urea, sewage sludge and animal manure than from incorporation of these fertilizers or wastes into soil (Terry et al., 1978; Reddy et al., 1979b; Steenhuis et al., 1976, Steenhuis et al., 1979; Zin El-Abedin and Ghaly, 1991 and Zin El-Abedin et al., 1991). Accordingly, the rating of the application method factor for inorganic (MNAPPLF1) and organic (MNAPPLF2) fertilizers are listed in Table (4).

Similarly an average rating of the application methods of organic and inorganic nitrogen fertilizers was calculated as follows.

$$MNAPPLF = (MNAPPLF1 + MNAPPLF2) / 2$$

4- The $CaCO_3$ % Factor:

The presence of calcium carbonate in the soil promotes the conversion of NH_4-form of nitrogen into ammonia (NH_3) and hence its volatilization due to high soil pH and the formation of unstable ammonium carbonate (Fenn and Kissel, 1973; Fenn and Kissel, 1975). Rating the effect of CaCO3 factor on NH_3 volatilization (CACO3F) was calculated as follows;

$$CaCO3F = -0.09 + 0.22\ CC - 0.01\ CC^2$$

When the soil $CaCO_3$ content (CC, %) is less than 0.5% or greater than 10% the CaCO3F equals 0.01 or 1.0, respectively.

Table (4): List of different methods of inorganic and organic fertilizers application and their ratings for NH3 volatilization.

Inorganic fertilizers	MNAPPLF1	Organic fertilizers	MNAPPLF2
Broadcast	1.0	Broadcast	1.0
Incorporatio	0.5	Incorporation	0.5
n.	0.4	Pits	0.05
Bands	0.3		
Pits	0.3*		
Fertigation	0.05**		

* under sprinkler irrigation ** under drip irrigation

5- Wind Speed Factor:

Several studies have indicated that volatilization of NH_3 increased with increasing the wind speed (Watkins *et al.*, 1972 and Vlek and Stumpe 1978). Steenhuis *et al.* (1976) and Steenhuis *et al.* (1979) showed that increasing the air flow rate by a factor of two resulted in reducing the half life for NH_3 loss by approximately the same factor. Watkins *et al.* (1972) observed a little additional loss due to the increased velocity above 33 km h^{-1}. Therefore, the rating of the wind speed factor (WINDF) was calculated in the range of 0.07- 33 km h^{-1} using the following equation:

$$WINDF = 0.44 + 0.016 \log (WIND)$$

At wind speed less than 0.07 km h^{-1} and greater than 33.0 km h^{-1} WINDF is assumed 0.01 and 1.0, respectively.

6- Soil Cation Exchangeable Capacity Factor:

NH_3 Volatilization rate decreases with increasing the cation exchange capacity (CEC) of the soil. This is related to the ability of the soil to retain more NH_4^+ from the soil solution and hence decreases it susceptibility for volatilization. When the CEC of the soil is ≤ 60 $cmol_c$ kg^{-1}, the rating of this factor can be calculated as follows:

$$CECF = 1 - 0.015\, CEC$$

For a soil with CEC greater than 60 $cmol_c$ kg^{-1}, this factor is given a rating of 0.1

7- Soil pH Factor:

Ammonia volatilization is mainly a pH dependent reaction. The influence of pH on NH_3 losses has been clearly demonstrated by several workers (Loftis and Scarsbrook, 1969; Watkins et al., 1972; Hoff et al., 1981; Mills et al., 1974; and Zin El-Abedin 1993). Edwards and Robinson (1969) observed that the maximum NH_3 volatilization from poultry manure was at a pH of 9.0 and a further increase in the pH did not increase NH_3 volatilization. From these studies, the rating of the effect of pH factor on NH_3 volatilization (PHVF) was adapted and formulated in the following equation:

$$PHVF = 0.11\, (pH)^2 - 1.28\, pH + 3.9$$

This equation applies for the pH range (5.0 - 9.5). If the soil pH ≤5.0 or > 9.5, this factor is given a rating of 0.01 or 1.0, respectively.

8- Soil Moisture Factor:

Several studies (Volk, 1966; Ernst and Massey, 1960 and Baligar and Patil, 1968) showed that NH_3 losses increased with increasing the soil moisture content up to the field capacity. In attempting to quantify the relationship between water loss and NH_3 volatilization, Chao and Kroontje (1964) observed that loss of water and NH_3 volatilization from NH_4OH treated soils followed different functions; water loss rate was constant with time whereas NH_3 volatilization rate decreased with time. Accordingly, the following relationships were derived to calculate the rating of the effect of soil moisture on NH_3 volatilization (THVF):

$$THVF = 1 - (3.11 (DV)^3 - 5.41 (DV)^2 + 3.21 DV + 0.051)$$

$$Where\ DV = SMC / E$$

The final nitrogen volatilization index (NH4VI) was calculated as the weighed average of the ratings of the above discussed factors as follows:

$$NH4VI = (5\, NH4VTF + 3\, NFERTF + 4\, MNAPPLF + CaCO3F + 3\, WINDF + 2\, CECF + PHVF + THVF) / 20$$

D. Nitrogen Mineralization/Immobilization Index:

Mineralization, also called ammonification, refers to the biological transformation of organic nitrogen forms into NH_4-from (Myrold, 1998). However, immobilization is the assimilation of mineral soil nitrogen (NO_3 and NH_4-forms) into soil biomass. Both processes are affected by several environmental factors such as soil temperature, moisture, pH, clay content, organic matter content and C/N ratio of the added organic fertilizers (Johnson and Persson, 1982; Paul and Clark, 1989; Foth, 1978; Brady, 1984).

1- Soil Temperature Factor:

Reddy et al. (1979a) and Stanford et al. (1973) reported that the rate of mineralization process doubled with a temperature increase of 10 °C, which yields a temperature correction coefficient of 1.07. Walter et al. (1974) also showed a similar relationship for soil treated with dairy waste with correction coefficient value of 1.13. The rating of the effect of the temperature factor (TEMPMF) on the mineralization/immobilization process for the temperature range 0 - 35 °C was included in the model as follows:

$$TEMPMF = \begin{cases} 1.07^{(T-25)}, & 0 < T \le 25 \\ 1.07^{(25-T)}, & 25 < T \le 35 \\ 0.01, & 0 > T > 35 \end{cases}$$

2- Soil Moisture Factor:

Bhat et al. (1981), Stanford and Epstein (1974), Sindhu and Cornfield (1967) and Reichman, et al.(1966) studied the influence of soil moisture on nitrogen mineralization they concluded that the amount of NH_4^+ produced during incubation increased linearly with volumetric moisture content up to a moisture content corresponding to 0.33 bar tension, above which nitrogen mineralization was decreased. Therefore, the rating of the soil moisture content factor (THMF) was calculated based on the ratio of the soil moisture content (SMC) to the field moisture capacity (FC) as follows:

$$THMF = 1.5^{-\gamma\left(\frac{E}{PWP}\right)}$$

$$\gamma = \begin{cases} \dfrac{0.6FC - SMC}{E - FC}, & \dfrac{SMC}{FC} \le 0.6 \\ \dfrac{SMC - 0.6FC}{E - FC}, & \dfrac{SMC}{FC} > 0..6 \end{cases}$$

3- Soil pH Factor:

The rate of the nitrogen mineralization process is highly affected by the soil pH. However, there are some contradictions about the optimum pH level. Some researchers (Stanford and Smith, 1972 and Dancer et al., 1973) concluded that the rate of ammonification is insensitive to variations in soil pH within the range 4.5 - 8.0. They considered that pH 3.5 is the lower pH limit at which mineralization ceases. On the other hand, Alexander (1977), Frederick and Broadbent (1966), Reddy et al. (1979a), and Diezman et al. (1989) reported that for waste application the optimum pH range is 6.5 to 8.5. They observed that the production of inorganic nitrogen was greater in neutral soils than in acid soils. Accordingly, the rating of the pH factor was as follows:

$$PHMF=\begin{cases}0.0 & pH \le 3.5\\ pH-3.5 & 3.5 < pH < 4.0\\ 0.19\ pH-0.17 & 4.0 \le pH < 6.2\\ 1.0 & 6.2 \le pH < 9.0\\ -0.25\ pH+3.25 & 9.0 \le pH \le 10.0\end{cases}$$

4- Soil C/N ratio Factor:

If the C/N ratio of added organic materials is less than 23, nitrogen mineralization occurs until the ratio reached this value. On the other hand, when this ratio is more than 23, immobilization of mineral nitrogen is assumed to take place until it was reduced to 23 (Myrold., 1998). Harmsen and Kolenbrander (1965), Larson and Schuman (1977) and Paul and Clark (1989) reported that decomposition of agricultural crop residues with 40% carbon and 1.6% nitrogen (C/N ratio of 25) will usually result in no net mineralization or immobilization. The sum of both processes is zero, although they can occur at significant rates. If the C/N ratio (CNR) for the plant is higher than 25, nitrogen will be taken up from the mineral nitrogen pool or degradation will be slowed until the dead soil organic matter, which has a C/N of 10, release more available nitrogen (Reddy et al., 1979a; and Alexander, 1977). Therefore, the rating of the C/N factor (CNRMF) was calculated as follows:

$$CNRMF=\begin{cases}1.0 & , \quad CNR \le 5\\ 1.27-0.06CNR, & 5.0 < CNR < 23\\ 0.01 & , \quad CNR \ge 23\end{cases}$$

5- Soil Clay Content Factor:

Most of the ammonia produced in the soil quickly forms ammonium (NH_4^+). The ammonium ion has a charge of +1 and is available to plants. There are indications that mineralization of organic matter can be enhanced in the presence of soil clay fractions (Myrold, 1998). The following relationship was adapted to rate the effect of the clay percent on mineralization process;

$$CLAYMF=\begin{cases}13.4Y^3-18.9Y^2+9.02Y-0.5, & Y>6.0\\ 0.01 & , \quad Y \le 6.0\end{cases}$$

Where $Y = CLAY/100$.

6- Soil Organic Matter Factor:

The decomposition rate of organic matter can be used as an indirect measurement of nitrogen mineralization. Barber (1979) measured the reduction in soil organic matter content in plots over six year period and found the rate to be 14% per year of the initial nitrogen concentration. Larson et al. (1972), in a similar study, measured organic matter decrease during 11 years and obtained a value of 1.9% per year. Thus, it might be realistically expected that about 2% of the nitrogen in the soil will be mineralized each year (Barber, 1995 and Foth, 1978). Thus, the soil organic matter factor (SOMMF) can be rated by the following equation:

$$SOMMF = SOM/(6462\ SOM + 1.79)$$

The final nitrogen mineralization/immobilization index (MINI) was calculated as the weighed average of the soil temperature, moisture, pH, Clay%, soil organic matter and C/N of the added organic fertilizers Factors as follows;

$$MINI = (4\ TEMPMF+2\ THMF+ PHMF+ 5\ CNRMF + CLAYMF+3\ SOMMF)/16$$

E- Plant Uptake Index:

Several researchers concluded that N-uptake by plants is mainly affected by soil moisture content, soil temperature, rooting depth, soil N-availability and type of N-fertilizer (Ching and Barber, 1979; Warneck and Barber, 1973; Mengel and Barber, 1974 and Myrold, 1998).

1- Soil Temperature Factor:

Ching and Barber (1979) studied the effect of temperature on the nutrient uptake by corn. They found that reducing the temperature to 15 °C, as compared to the optimum at 29 °C, reduced the maximum influx, by one-half and the soil solution buffer power was 1.7. Hence, temperature can have a large effect on all the parameters governing nutrient influx. Accordingly, the effect of soil temperature on the uptake of nitrogen could be rated as follows:

$$TEMPF=\begin{cases}0.01 & T<10\\ 1.07^{(T-29)} & 10 \le T \le 29\\ 1.07^{(29-T)} & 29 < T\end{cases}$$

2- Soil Moisture Factor:

The level of moisture in the soil has a large effect on the effective diffusion coefficient for nutrient diffusion to the root. Warneck and Barber (1972) found that reducing volumetric moisture greatly affected the diffusion of micro-nutrient in the soil. Hence, as soils dry, the rate of nutrient supply to the root decreased, and if this is insufficient to sustain near the maximum influx rates of uptake, the rate of nutrient uptake will decrease. Hence, the rating of the soil moisture factor was calculated based on the values of soil moisture content at field capacity (FC) and welting point (WP) as follows:

$$THUF = 1.7^{-\lambda\left(\frac{E}{WP}\right)}$$

$$\lambda=\begin{cases}\dfrac{(FC-SMC)}{(FC-WP)}, & WP < SMC \le FC\\ \dfrac{(SMC-FC)}{(E-FC)}, & FC < SMC \le E\end{cases}$$

3- Rooting Depth Factor:

The rooting depth and distribution in the soil affect the uptake of NH_4^+ or NO_3^- from the soil. Grass plants tend to have a much lager accumulation of roots in the surface soil layers. Mengel and Barber (1974) observed that for grasses, the root density (cm root cm^{-3} soil) decreased exponentially with increasing depth into the soil. Therefore, the rating of the rooting depth factor on N-uptake considered the relation between the rooting depth of the cultivated crop (RZ, cm) and the depth to the water table (DWT, cm). The crop cover correction factor (KR) was also taken into account since there is a balance between the root systems and the shoots of crops as follows;

$$RZUF = KR\ RZ / DWT$$

4- Soil N-Availability Factor:

Growing plants can make use of mainly the soil mineral nitrogen forms. These forms come from either mineral fertilization or mineralization of organic pools. Organic nitrogen pools include both soil organic matter and applied organic materials (Myrold, 1998). The rate of N-mineralization process depends mainly on the C/N ratio of the applied organic materials.

The amount of mineralized N from soil organic pool (NSOM, kg ha^{-1}) and from applied organic materials (NOM, kg ha^{-1}) can be calculated according to following algorithms:

$$NSOM = (384x10^4\ SOM) /\ CNR$$

$$NOM = 160\ OMAPPR / CNR$$

Where SOM is the soil organic matter content (%) and OMAPPR is the application rate of organic manure (m^3 ha^{-1}). The total mineralizable N (TNOM, kg ha^{-1}) is therefore;

$$TNOM = NSOM + NOM$$

The estimated soil mineral N can be calculated as the sum of total mineralizable N (TNOM, kg ha^{-1}), nitrogen in irrigation water (NIRR, kg ha^{-1}), soil residual nitrogen (RESDN, kg ha^{-1}) and applied mineral N-fertilizer (NAPPR, kg ha^{-1}) as follows;

$$NIRR = (NIRRC\ IW) / 100$$

$$SN = RESDN + NAPPR + TNOM + NIRR$$

Where, NIRRC is the concentration of mineral nitrogen in irrigation water (ppm).

Therefore, the ratio between the crop nitrogen requirements (NREQ, kg ha^{-1}) and the estimated soil mineral N (SN, kg ha^{-1}) was used to rate the effect of soil mineral nitrogen factor on plant uptake as follows;

$$SNUF = 1 - (NREQ / SN)$$

5- Nitrogen Doses Factor:

The efficiency of N-fertilizer use can be increased by splitting the amount of applied fertilizer into more one dose. The more doses applied, the higher efficiency reached and the lower the environmental risk due to leaching (Keeney and Follett, 1991). Accordingly, the ratting of the fertilizer dose effect on N-uptake was calculated as follows;

$$DOSEUF = 1.1 - (1/NDOSE)$$

Where NDOSE is the number of N-application doses.

6- Type of N-fertilizer Factor:

Several studies proved that the type of nitrogen fertilizer (inorganic or organic) affects the rate of the nitrogen uptake. Nitrogen can be present either as NH_4^+ or NO_3. Warneck and Barber (1973) investigated the relative rate of uptake of these two forms by corn and found that there was little different in their rates of absorption. Nitrate is not adsorbed by the soil to any appreciable extent, so it remains almost completely in the soil solution. Hence, the rate of supply of NO_3^- to the root will be relatively faster than NH_4^+. So, this study tried to rate the most fertilizer used depending on the nitrogen ability to be up taken by the plant as in Table (5).

Therefore, the final rating of the fertilizer type factor was calculated as the average of the inorganic fertilizer (NFERTF1) and organic fertilizer (NFERTF2) ratings as follows:

$$NFERTF = (NFERTF1 + NFERTF2) / 2$$

Finally, the nitrogen uptake index was calculated as the weighted averages of the soil temperature, moisture content, rooting depth, nitrogen availability, nitrogen doses and type of nitrogen fertilizer factors as follows;

$$UPTKI = (TEMPUF + 5\ THUF + 3\ RZUF + 5\ SNUF + 2\ DOSEUF + NFERTUF) / 17$$

Table (5): Rating of the effect of fertilizer type on plant N-uptake.

Type of inorganic fertilizer	Rating of NFERTF1 factor	Type of organic fertilizer	Rating of NFERTF2 factor
Urea	0.80	Farm M.	0.80
NH4-Form	0.90	Chicken M	0.70
NH4NO3	0.70	Compost	1.00
NO3-Form	0.50	Sewage Sludge	0.50
Slow Release	1.00	None	0.01

III- Residual Soil Nitrate Risk Indices:

The residual soil nitrate risk index (RSNRI) was calculated using the weighted averages of the nitrification, mineralization, denitrification, volatilization and uptake indices as follows;

$$RSNRI = (NTRFI + MINI + (1- MDNTRFI) + (1- NH4VI) + (1-UPTKI))/5$$

The nitrate leaching risk index (NLRI) evaluates the interaction between the deep water percolation and the residual soil nitrate risk indices was calculated as follows;

$$NLRI = \frac{5\,DWPI + RSNRI}{6}$$

The calculated NLRI index can be then used to rank the agricultural systems into different classes according to their susceptibility of groundwater to pollution with nitrate in agricultural lands. However, the above introduced algorithms need to be integrated in a comprehensive, logic structure to be ready for application and verification.

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الملخص العربى

تصور جديد لتقويم آثار أساليب الإدارة المزرعية والبيئية على النتروجين فى الأراضى الزراعية (النموذج الرياضى مينال)

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يتواصل الإهتمام على المستوى المحلى والعالمى بمشكلة تلوث المياه الجوفية بالكيماويات الزراعية، خاصة الأسمدة النيتروجينية. وهناك العديد من النماذج الرياضية التى تم إنشاؤها لوصف ديناميكية النيتروجين فى البيئة وأثرها على تلوث المياه الجوفية بالنترات المفقودة بالغسيل. ومن المعروف أن هذه النماذج تحتاج إلى كم كبير من البيانات والقياسات التى ترتبط بتقنيات عالية ومعقدة من أجهزة القياس. كما تحتاج خبرة علمية وتقنية عالية لمستخدميها.

لذا تم التفكير فى نموذج رياضى(MEINAL) لتقييم الآثار العديدة والمتداخلة للعوامل الأرضية والبيئية وأساليب الإدارة المزرعية على ديناميكية النيتروجين فى النظام البيئى الزراعى، ومدى احتمال تعرض المياه الجوفية للتلوث بالنترات المفقودة بالغسيل. وقد بنى هذا النموذج على فرض أن العمليات الأساسية التى تتحكم فى مستوى النترات المتبقية بالأرض هى التأزت، عكس التأزت، التطاير، المعدنة/التثبيت وكذلك امتصاص النبات. كما افترض أن التسرب العميق للمياه هو الذى يؤدى إلى غسيل النترات المتبقية بالأرض لتصل إلى المياه الجوفية وتلوثها. وقد افترض فى هذا النموذج أن هذا المكون يتحدد مستواه بالعوامل التى تدخل فى حساب الإتزان المائى للنظام البيئى وكذلك الخواص الهيدرولوكية للأرض. وتم بناء هذا النموذج بطريقة مشابهة لنظم تقييم الأراضىLand Evaluation المتعارف عليها. حيث تم تحديد العوامل التى تؤثر فى كل عملية من العمليات المدروسة. كما تم تحديد الطريقة التى يؤثر بها كل عامل وإعطاؤه قيمة نسبية تتراوح من الصفر إلى الواحد الصحيح حسب قيمته. ومنها تم اشتقاق بعض الدوال الرياضية التى تصف هذه العلاقات. وعند حساب الدليل الخاص بكل عملية أخذ فى الإعتبار الأهمية النسبية للعوامل التى تتحكم فى العملية موضع الإهتمام. حيث أعطى كل عامل قيمة تتراوح ما بين ١- ٥ حسب أهميته النسبية للتحكم فى كل عملية. ومنها تم حساب قيمة الدليل كمتوسط موزون لهذه العمليات.

وفى النهاية يقوم النموذج بحساب دليل خطورة النترات المتبقية بالأرض (RSNRI) ودليل التسرب العميق للمياه (DWPI) واللذان يستخدما فى حساب دليل خطورة التعرض لتلوث المياه الجوفية بالنترات المفقودة بالغسيل (NLRI) بطريقة المتوسط الموزون. هذا وتحتاج المعادلات والعلاقات المستنبطة من هذه الدراسة إلى صياغتها فى صورة برنامج تطبيقى ذو بناء منطقى متكامل يأخذ فى الإعتبار التداخل بين العوامل المدروسة. وهذا يتيح لنا القيام بعملية التقييم الشاملة لهذا النموذج الرياضى.