Assessment of Nitrate Discharge to Groundwater from Septic Tanks

The case study of Tehran, Iran

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Rosenberg International Forum on Water Policy

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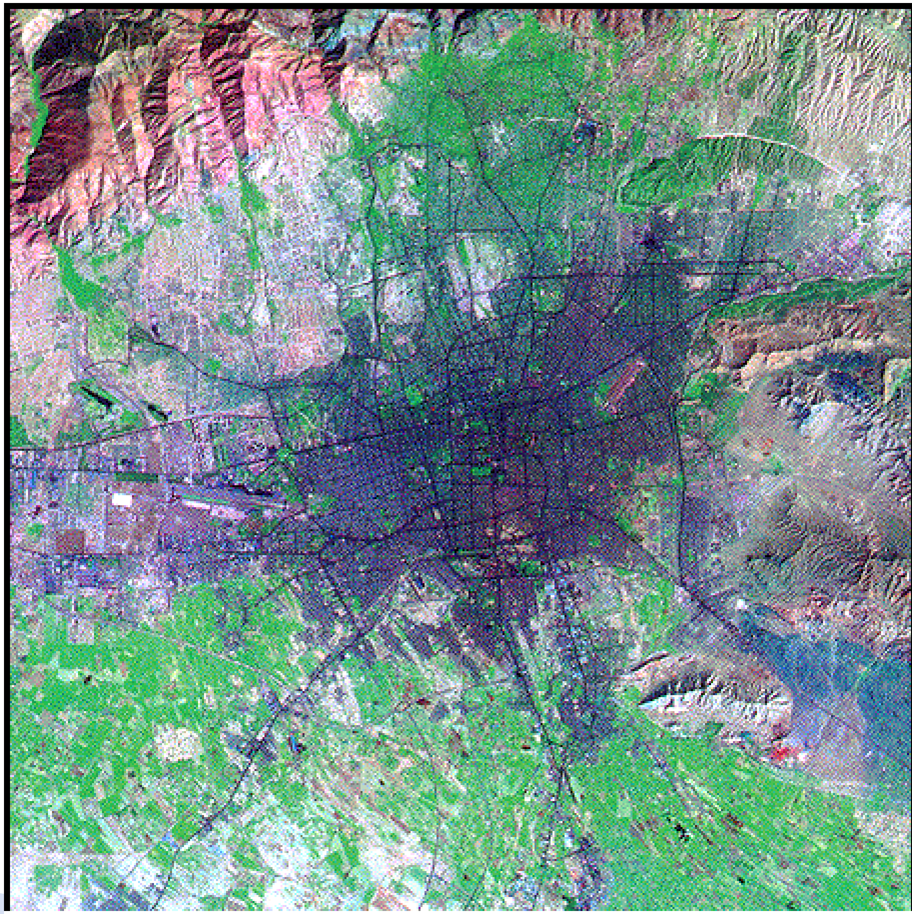
Overview

- Domestic Wastewater discharges through the traditional septic tanks into subsurface

- General View of Teheran
  - Population: 7.2 millions
  - Area: 600 km^2
  - Water Supply:

    40-60% by Groundwater

    60-40% by Surface Resources



Problem

- Although many numerical models have been developed for simulating Nitrogen fate, it is difficult to employ them in large scale due to the limited available field data.

- Considering
  - The scarcity and limitation of the available data,
  - The complexities of the processes, and
  - The largeness of the study area

- **The purpose is,**

  - **to provide a reliable and simple tool for the assessment of Nitrate discharge (or its vulnerability) to groundwater resources in urban area**

Schematic

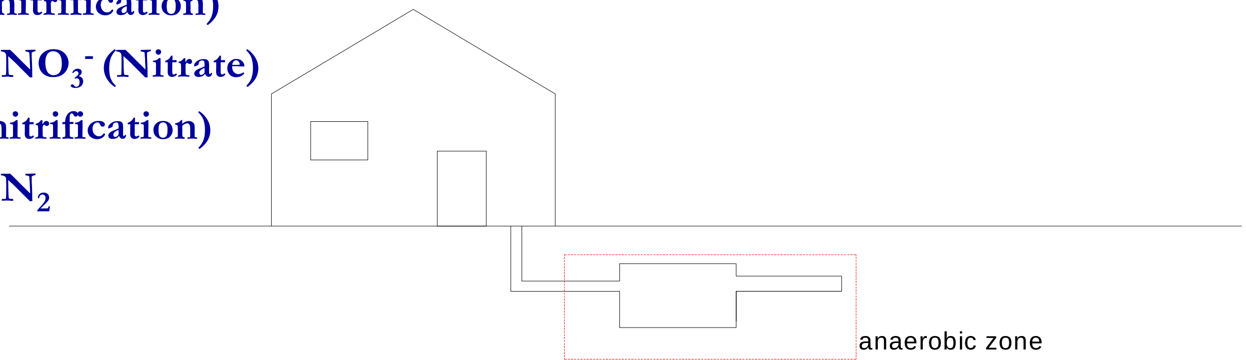
Basic processes of nitrogen compounds in saturated and unsaturated zone

- **Septic Tank**

  Organic N (Urea) to NH_4^+ (ammonium)
- **Unsaturated Zone (nitrification)**

  $NH_4^+ + O_2$ NO_3^- (Nitrate)
- **Saturated Zone (denitrification)**

  $NO_3^- + H^+$ N_2



unsaturated zone

aerobic zone
+
partially anaerobic zone

$$\text{Urea Production: AminoAcids} + H_2O \rightarrow NH_4^+ + \text{Organic Compounds}$$

$$\text{Urea Production:}\ Urea\left[CO\left(NH_3^+\right)_2\right] + H_2O \rightarrow 2NH_4^+ + CO_2$$

$$\text{Nitrification:} NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

$$\text{Denitrification:} 4NO_3^- + 5CH_2O + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O$$

GW Table

saturated zone

anaerobic zone

Methods

- Vulnerability assessment (a modified DRASTIC Method)
- Lumped Parameters Method (LPM)

Nitrogen Sources

- Precipitation (# 1%)

(N: 16 mg/m^2= 9.8 ton/year)

- Wastewater (# 93%)

(N: 30040 mg/m^2=18024 ton/year)

- Parks (# 6%)

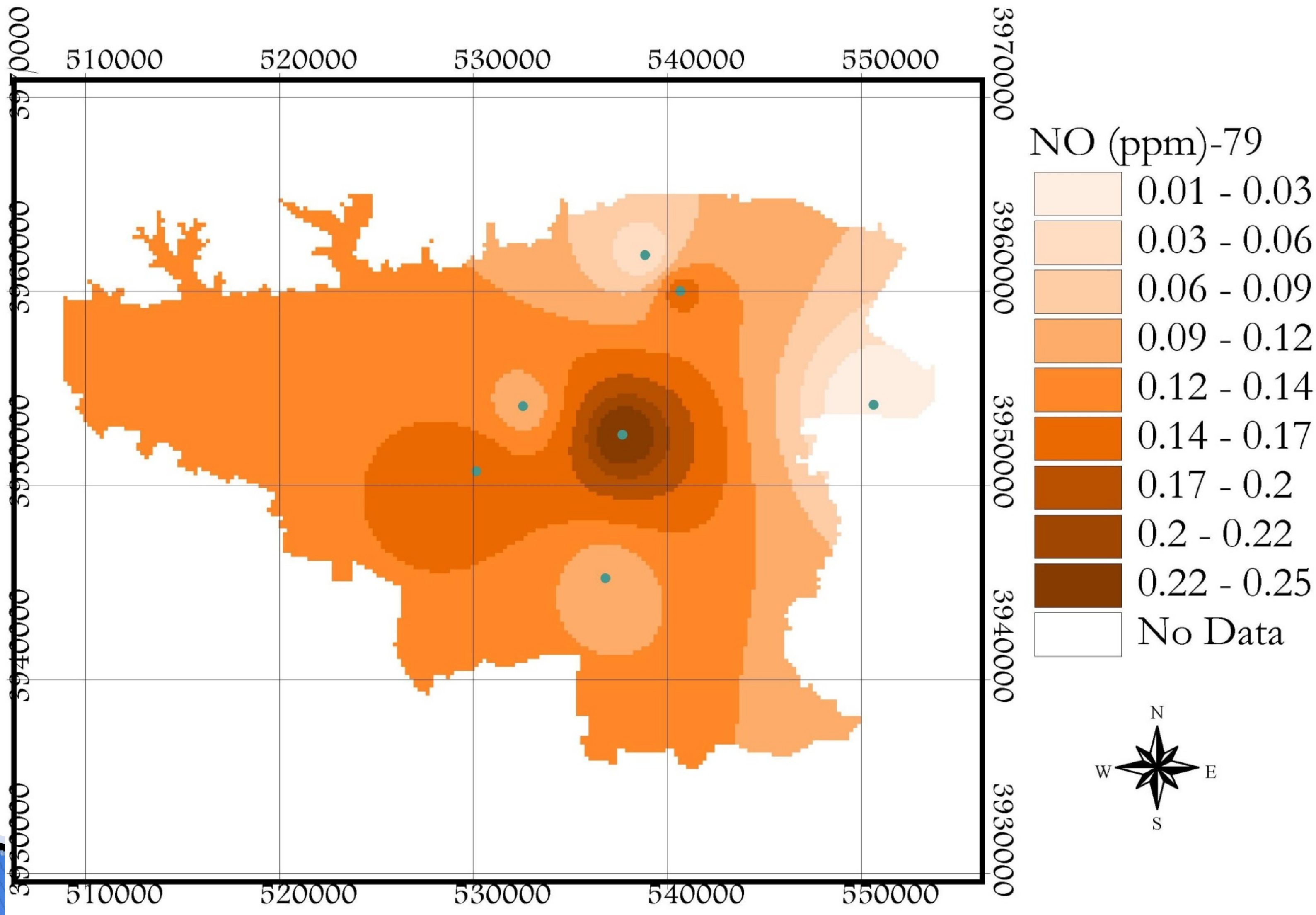
(N: 20 mg/m^2= 1040 ton/year)

Wastewater discharge is the major source of contamination.

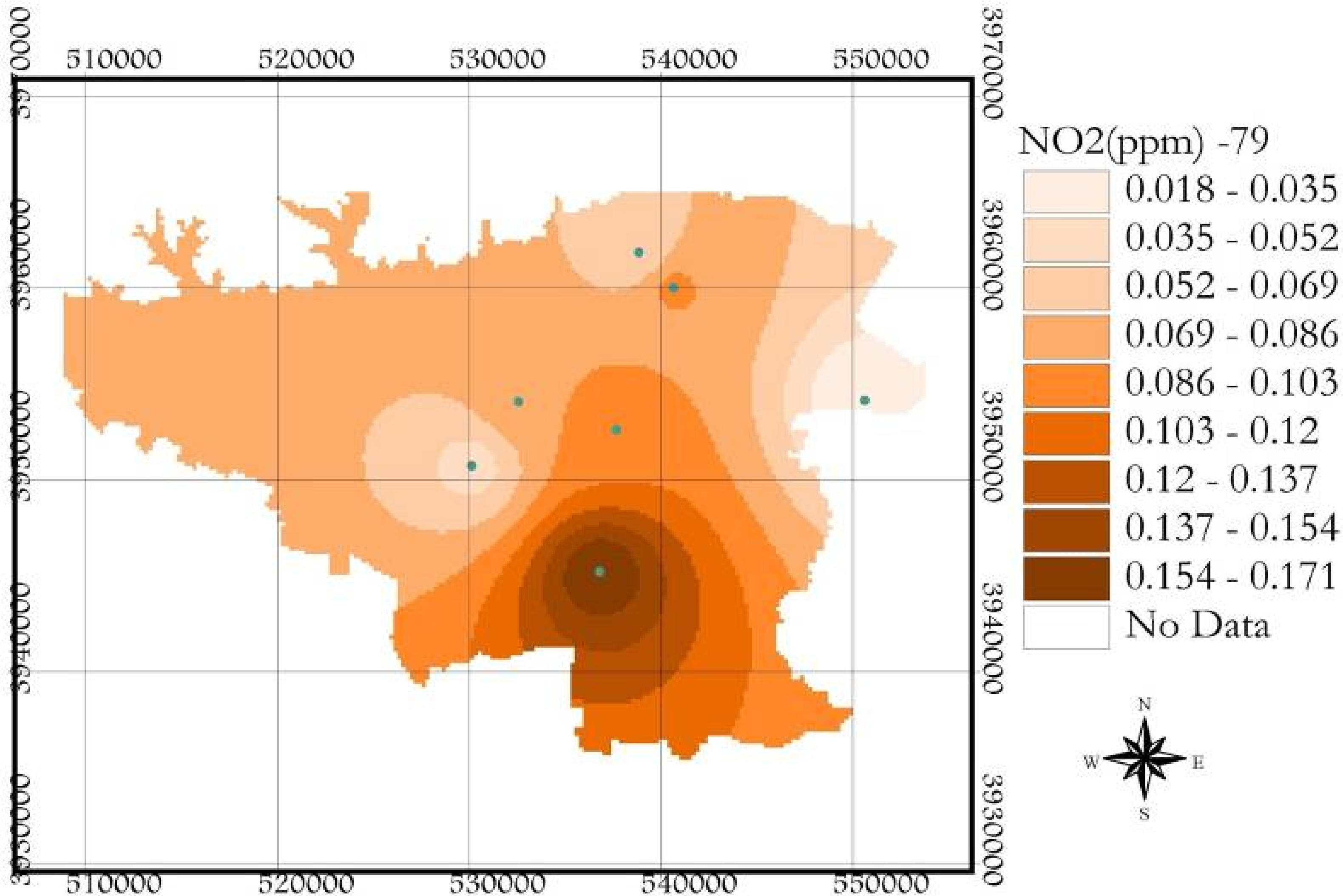
Table 2 Average air N-pollutant concentration in Tehran (ppm) (2000–2001)

Station	X (UTM)	Y (UTM)	NOx	NO_2	NO
Tajrish	538,853	3,961,851	0.0960	0.0487	0.0473
Villa	537,687	3,952,603	0.2931	0.0807	0.2123
Sorkh-Hesar	550,643	3,954,147	0.0220	0.0163	0.0056
Pardisan	532,556	3,954,062	0.1348	0.0728	0.0804
Azadi	530,156	3,950,726	0.1910	0.0409	0.1500
Gholhak	540,668	3,960,011	0.2465	0.0858	0.1565
Bahman	536,813	3,945,206	0.2887	0.1705	0.1219

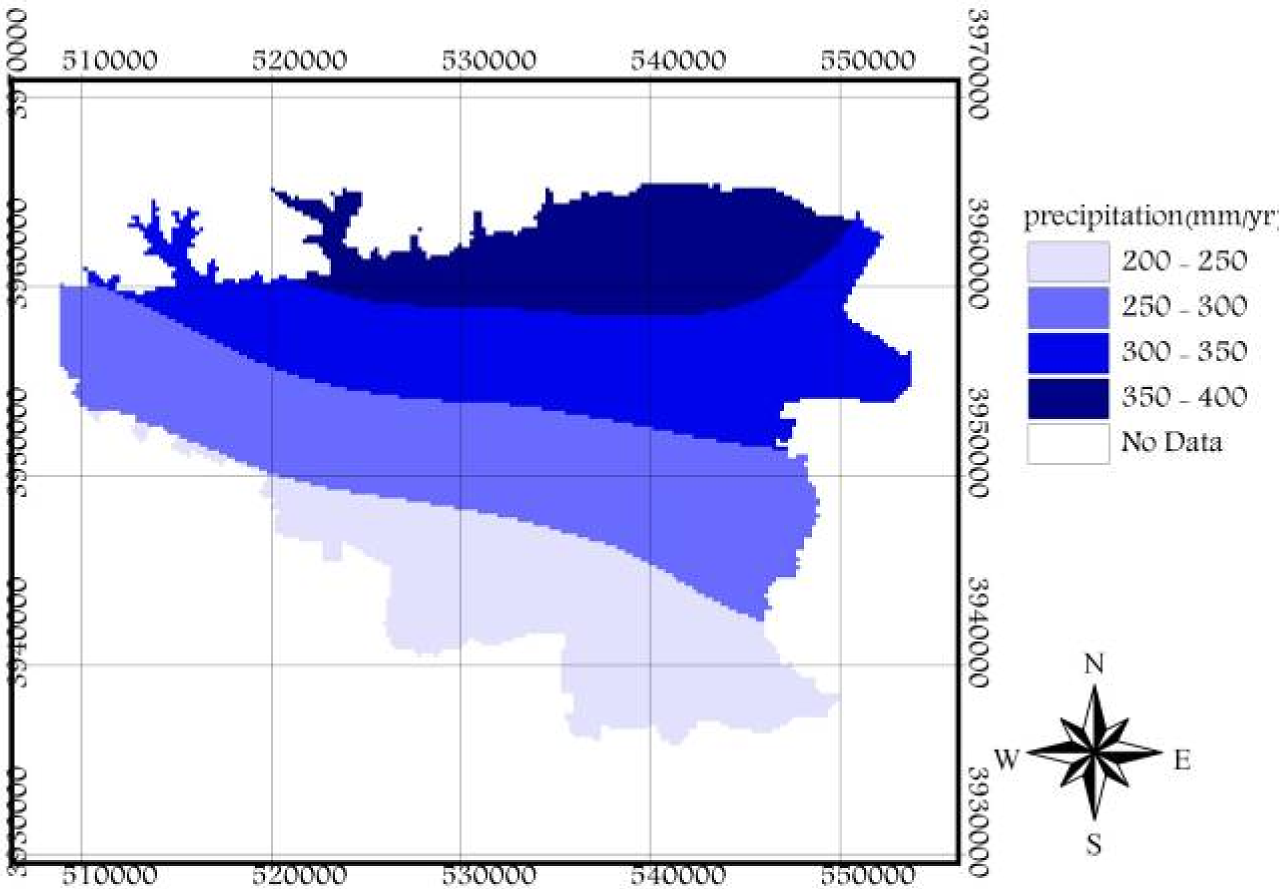
NO Concentration in Air



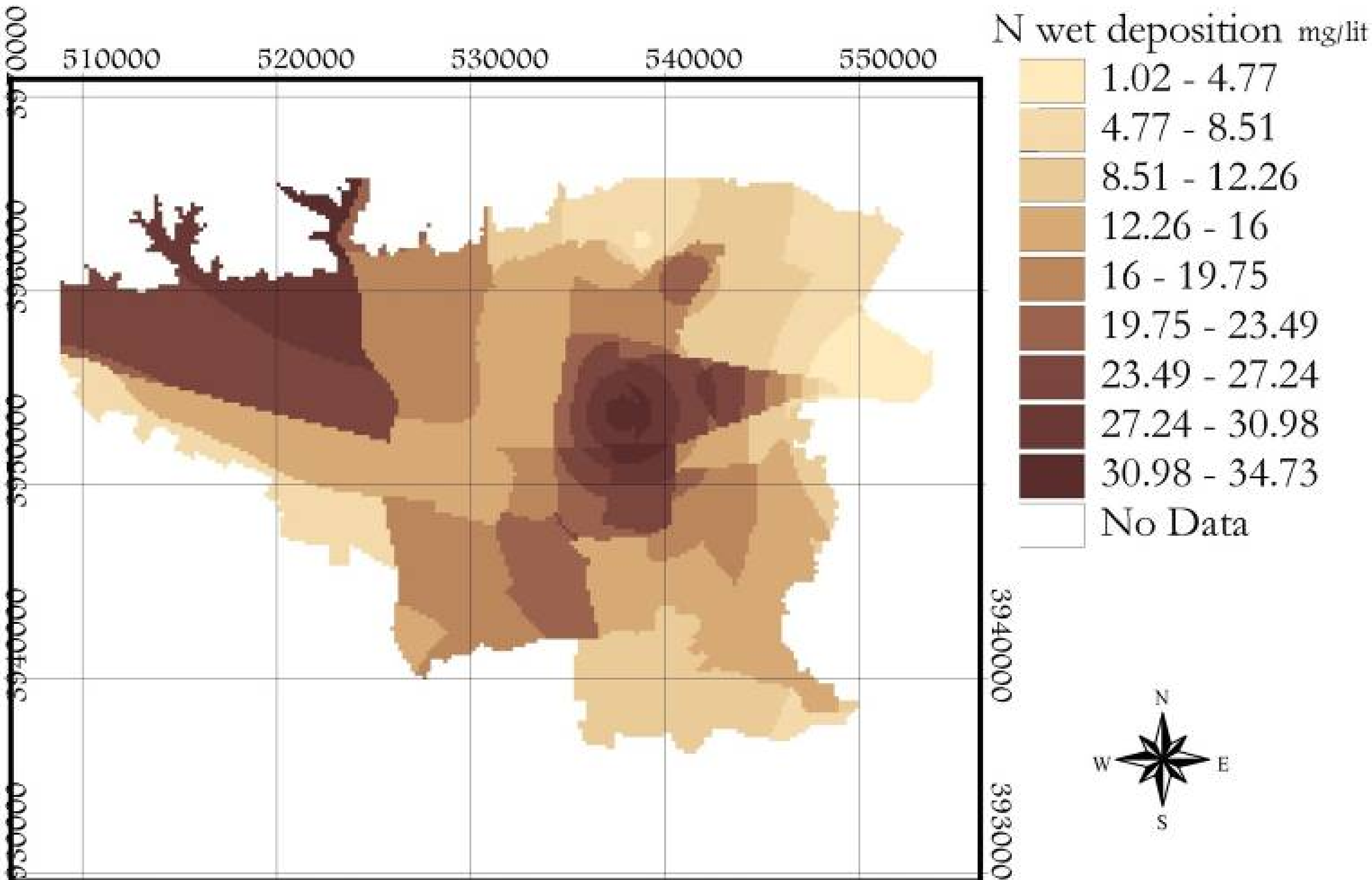
NO_2 Concentration in Air



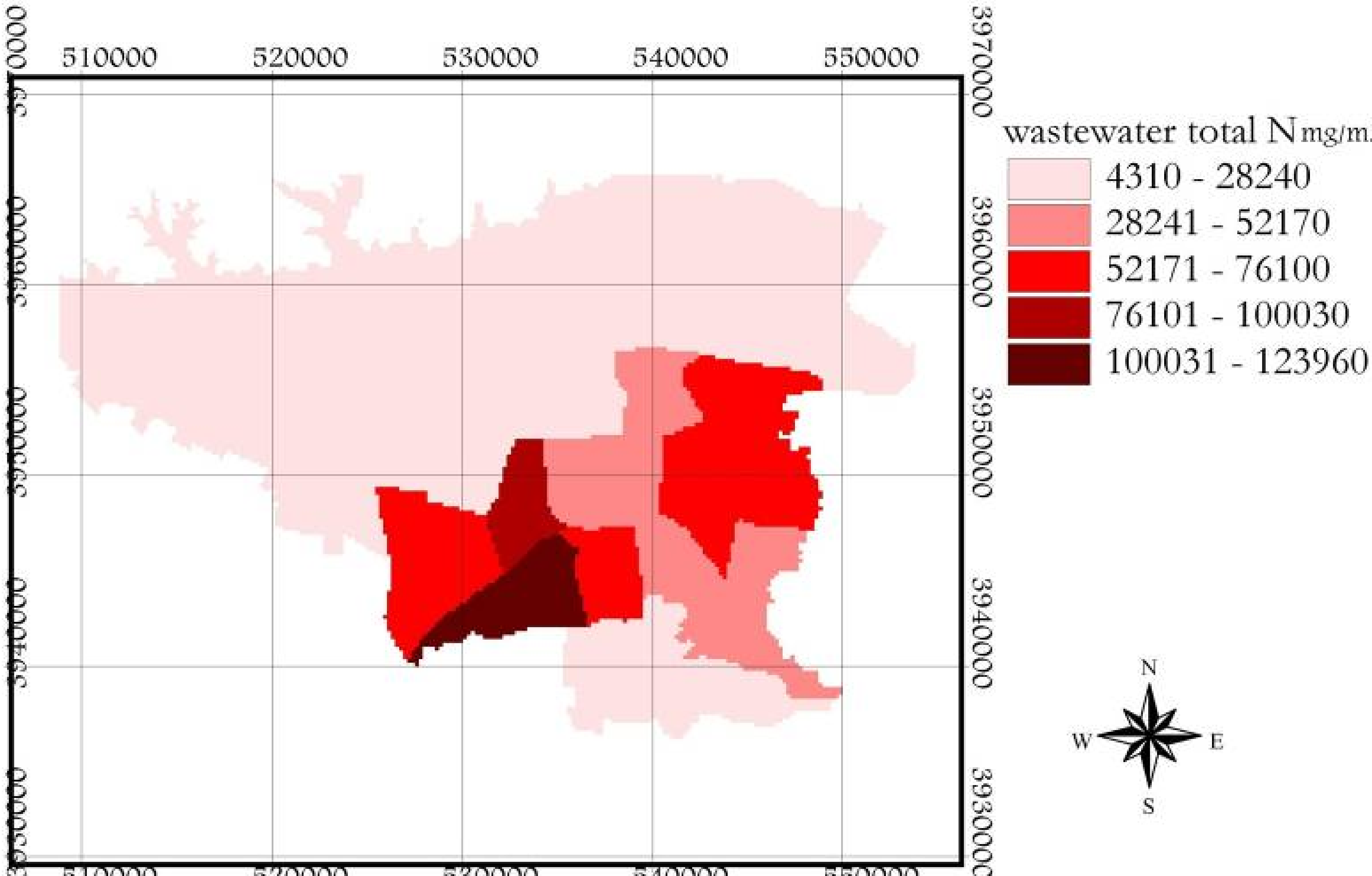
Precipitation



Nitrogen Input Due to Precipitation



Nitrogen Input Due to Wastewater



Wastewater discharge rate in Tehran is estimated about 162 L/day per capita.

DRASTIC

Vulnerability Assessment intrinsic characteristics

D. Depth to water

R. Net Recharge

A. Aquifer Media

S. Soil Media

T. Topography (omitted)

I. Impact of Vadose Zone

C. Hydraulic Conductivity

D.Dw+R.Rw+A .Aw+S.Sw +T.Tw+I.Iw+C.Cw = DRASTIC Index

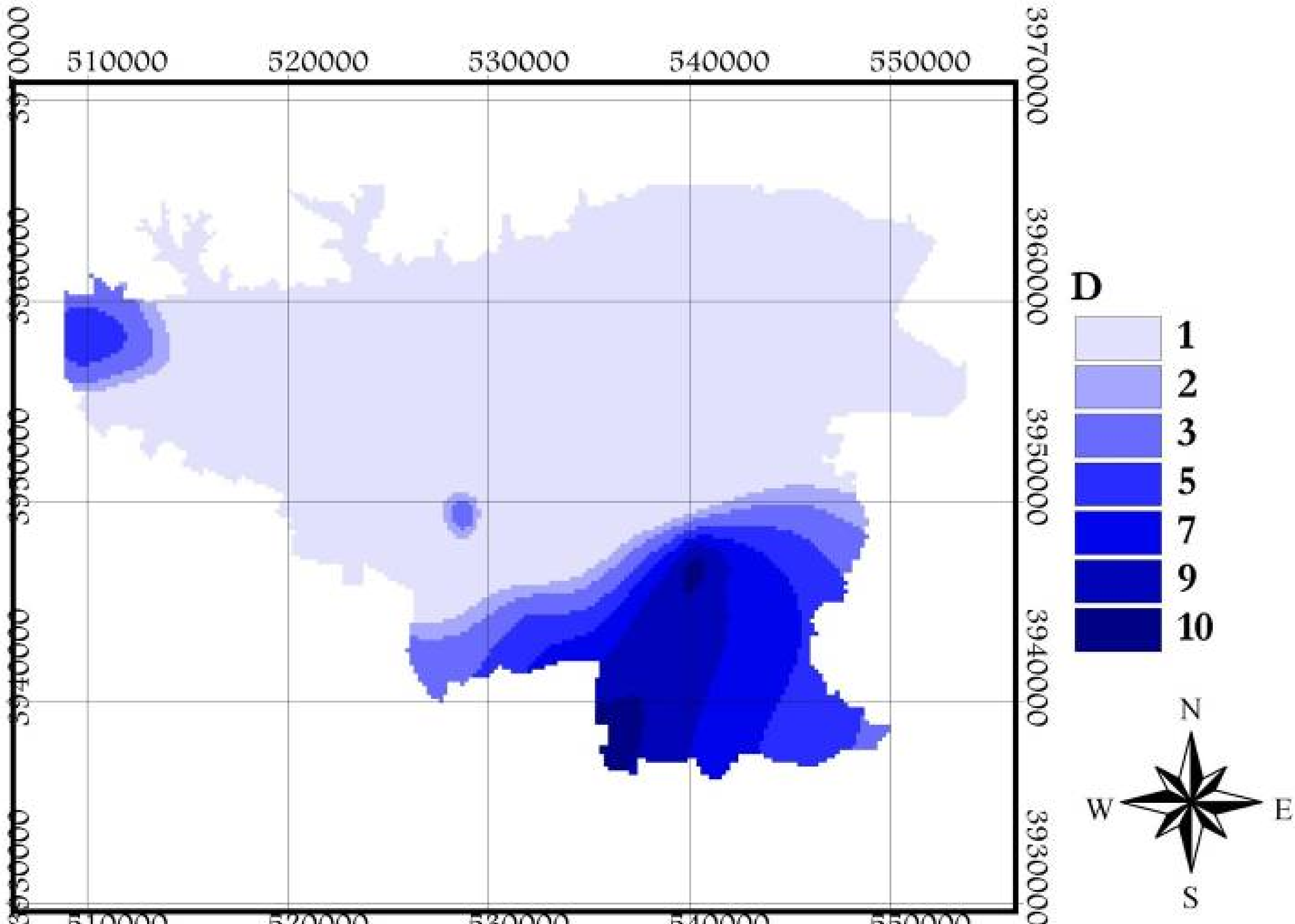
Depth to Water (5)

Range(m)	rating
0-1.5	10
1.5-4.5	9
4.5-9	7
9-15	5
15-23	3
23-30	2
>30	1

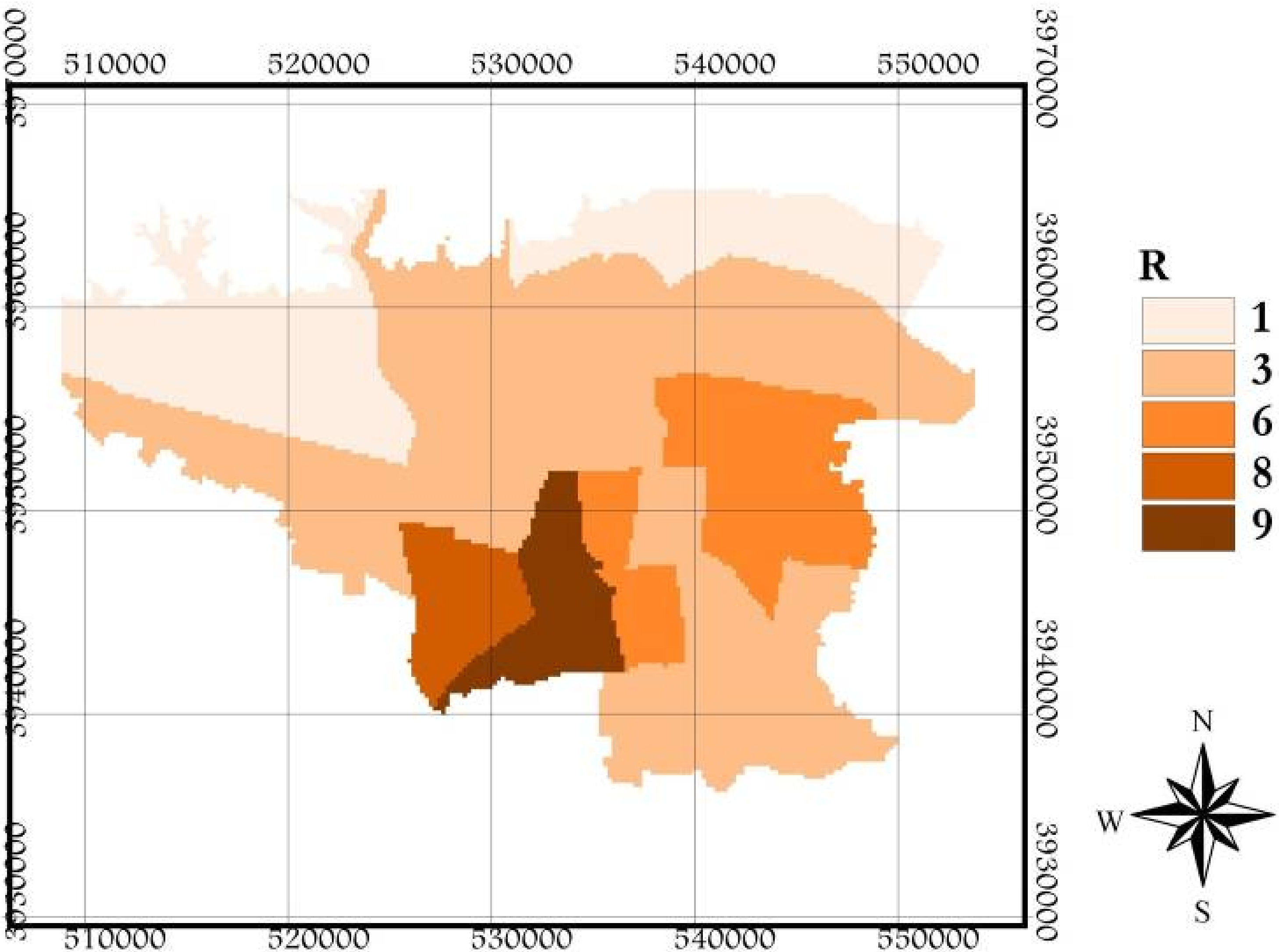
Net Recharge(4)

Range(cm)	Rating
0-5	1
5-10	3
10-18	6
18-25	8
>25	9

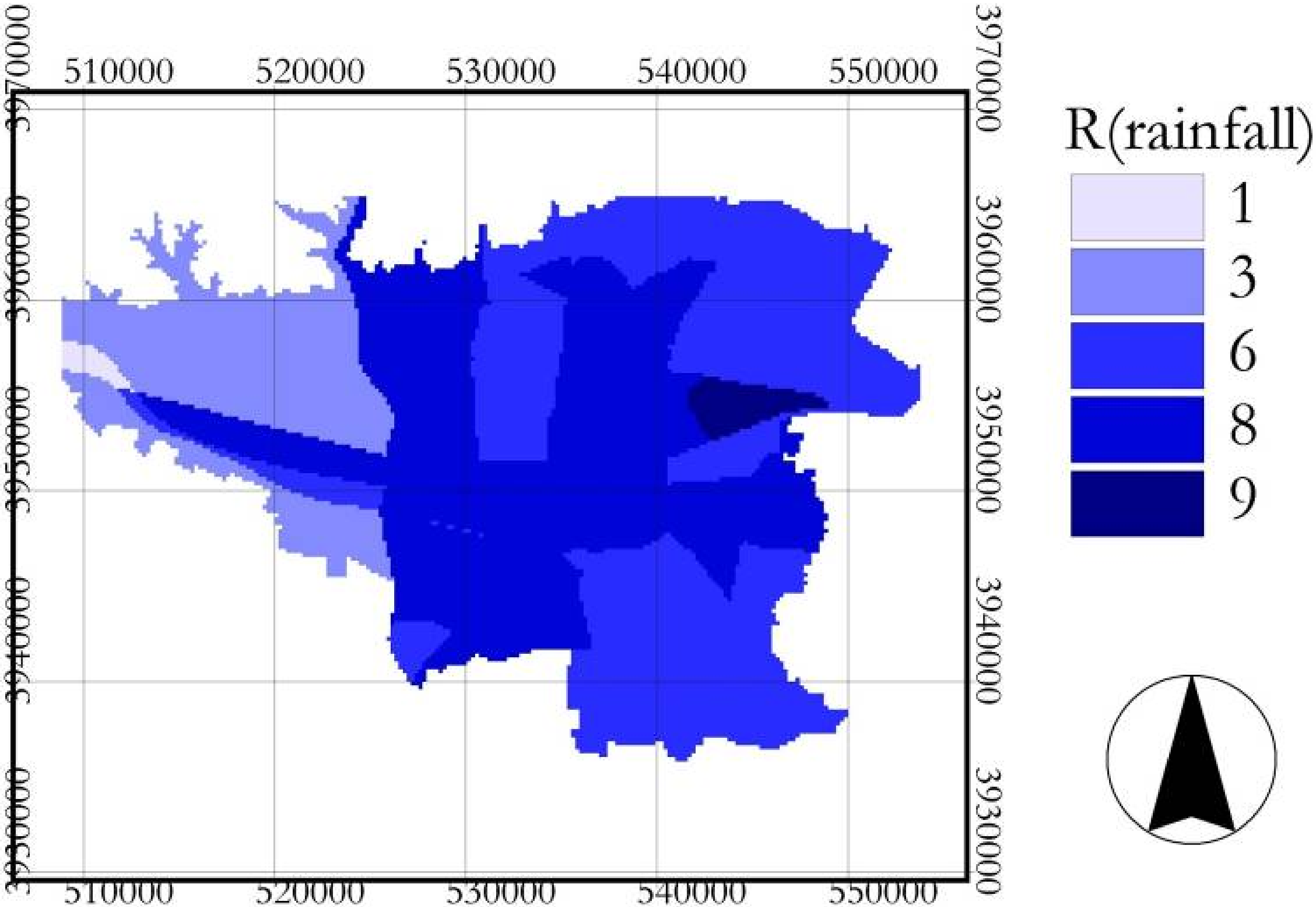
Depth to Water (5)



Net Recharge (Wastewater)(4)



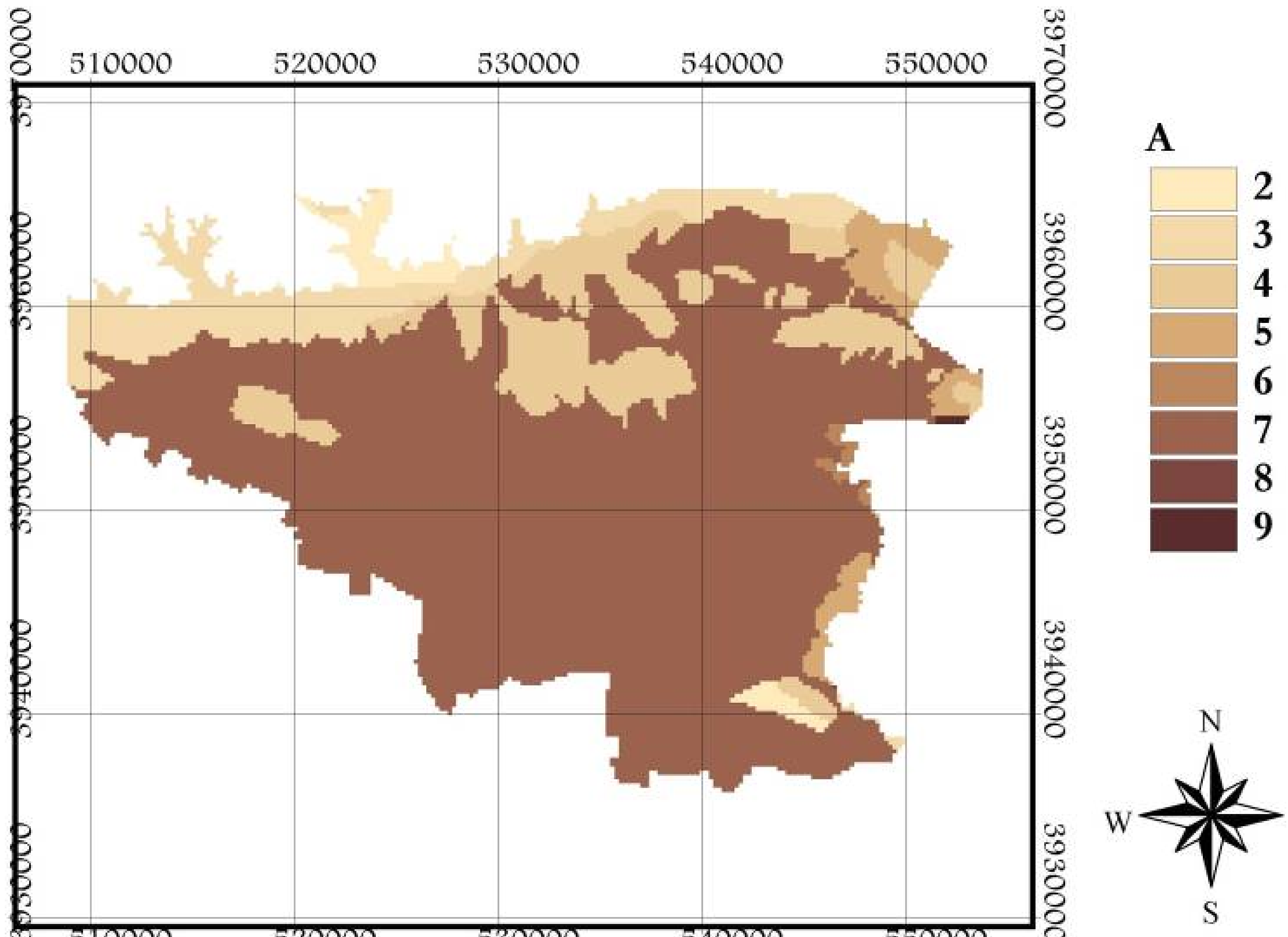
Net Recharge (Precipitation)(4)



Aquifer Media (3)

Range	Rating	Typical Rating
Massive shale	1-3	2
Metamorphic	2-5	3
Weathered Metamorphic	3-5	4
Glacial Till	4-6	5
Limestone	5-9	6
Massive sandstone	4-9	6
Massive limestone	4-9	6
Sand and gravel	4-9	8
Basalt	2-10	9
Karst limestone	9-10	10

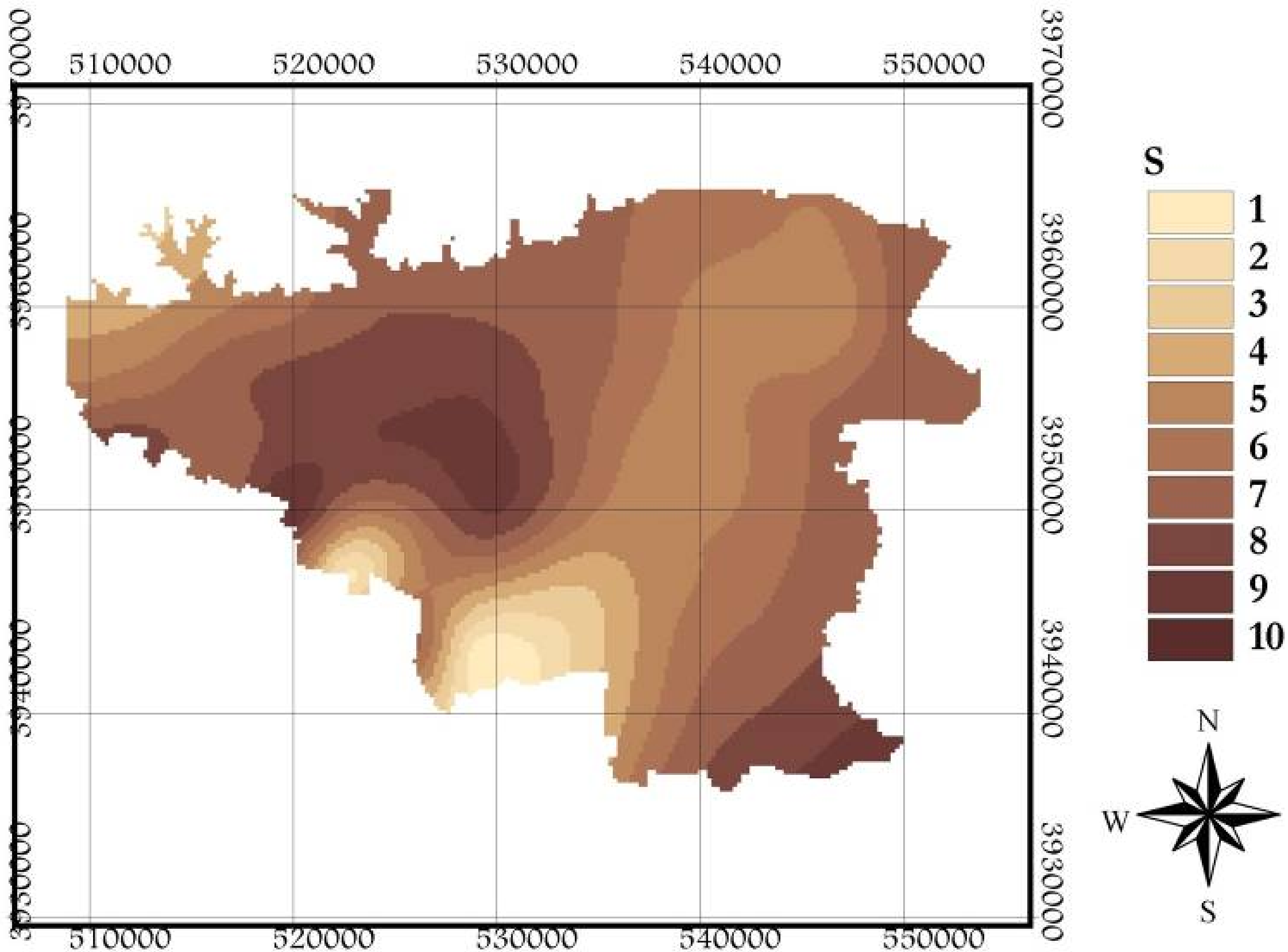
Aquifer Media (3)



Soil Media (2)

Range	Rating
Thin/Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Non-shrinking clay	1

Soil Media (2)



510000
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1
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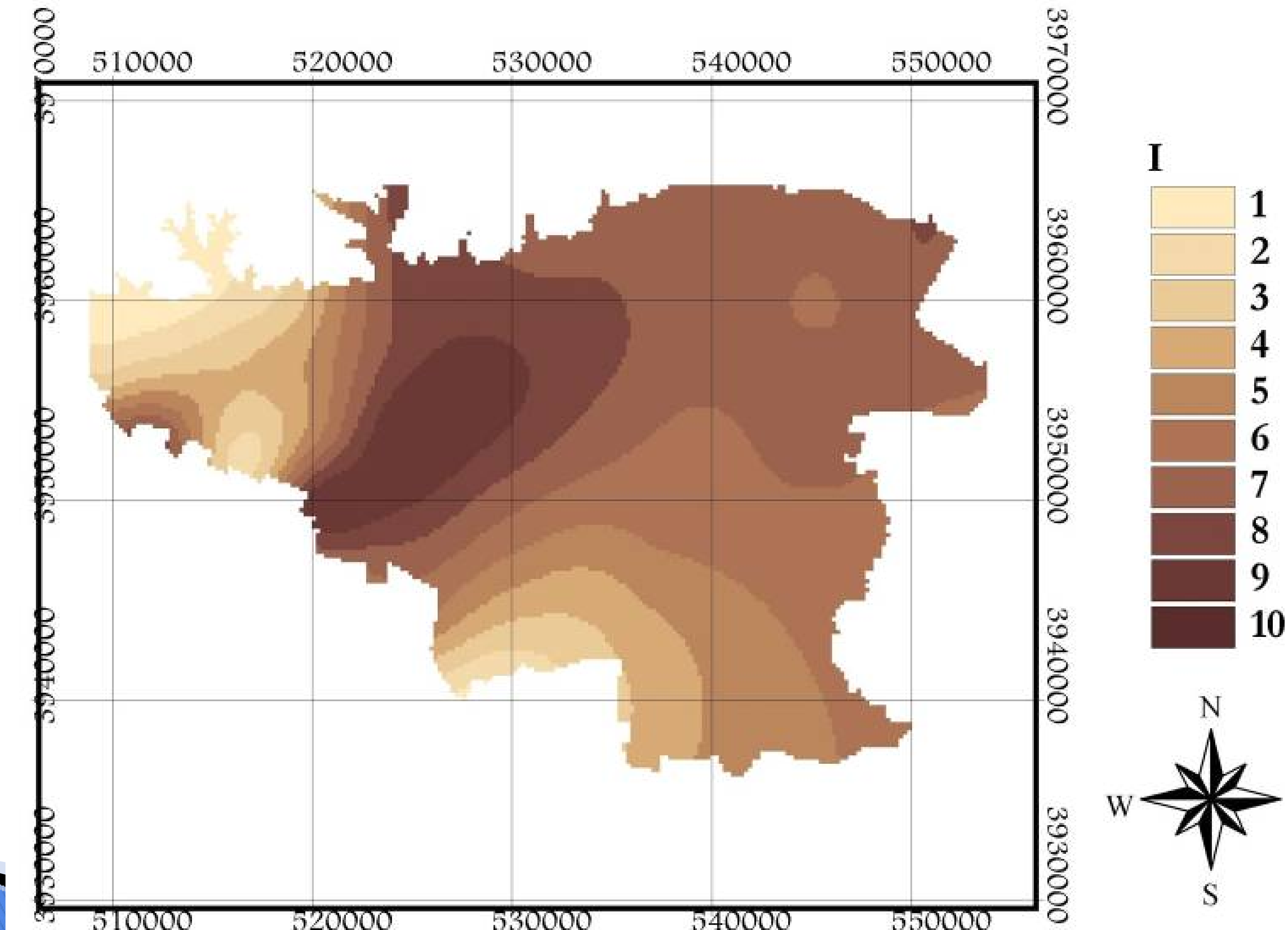
9
10
N
W
S

Impact of vadose zone(1)

Range	Rating	Typical
Confining layer	1	1
Silt/clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded limestone	4-8	6
Sand gravel with clay & silt	4-8	6
Metamorphic	2-8	4
Sand and gravel	6-9	8
Basalt	2-10	9
Karst limestone	8-10	10

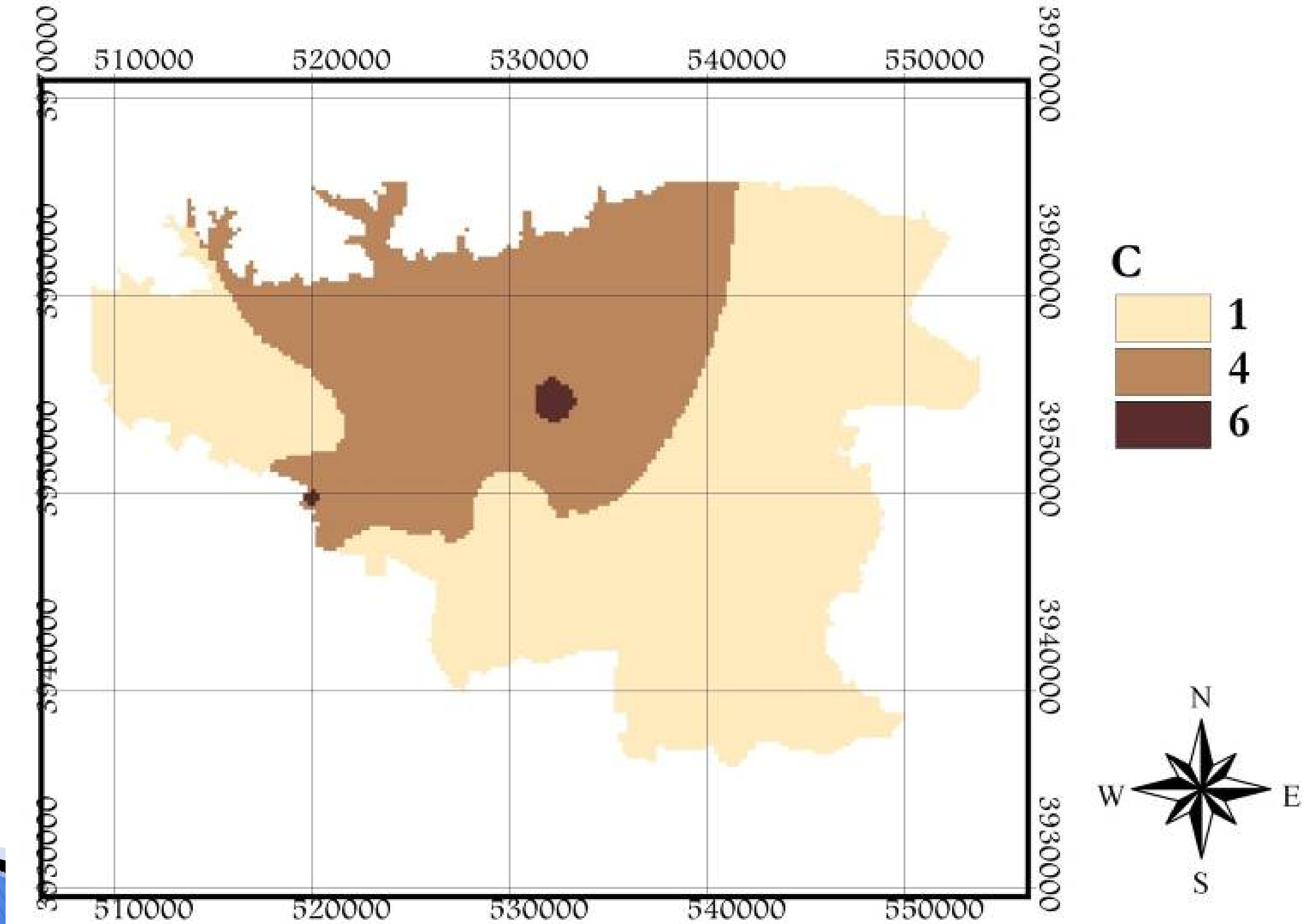
Impact of vadose zone(1)



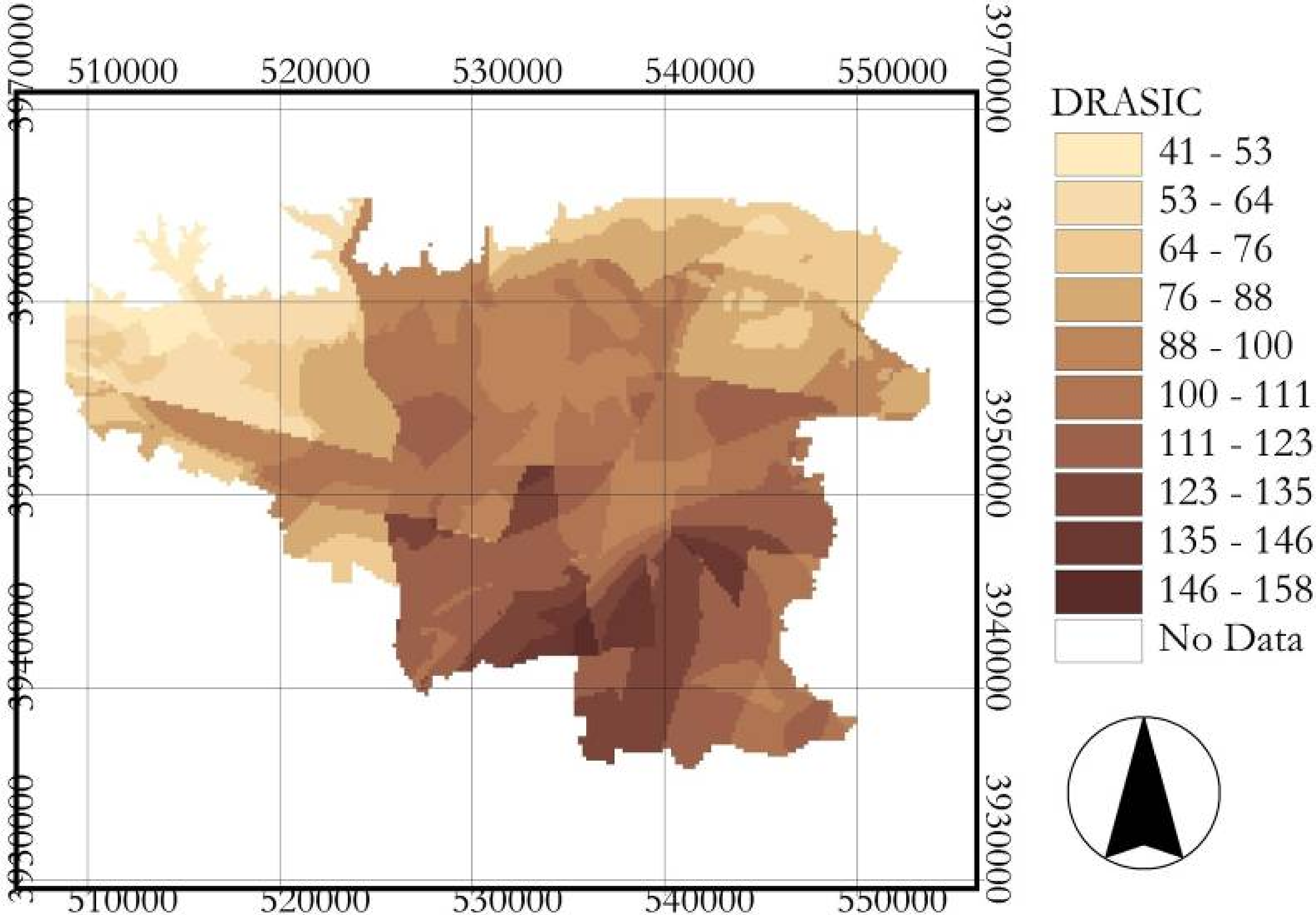
Hydraulic Conductivity (3)

Range(m/day)	Rating
0.04-4	1
4-12	2
12-28	4
28-40	6
40-80	8
>80	10

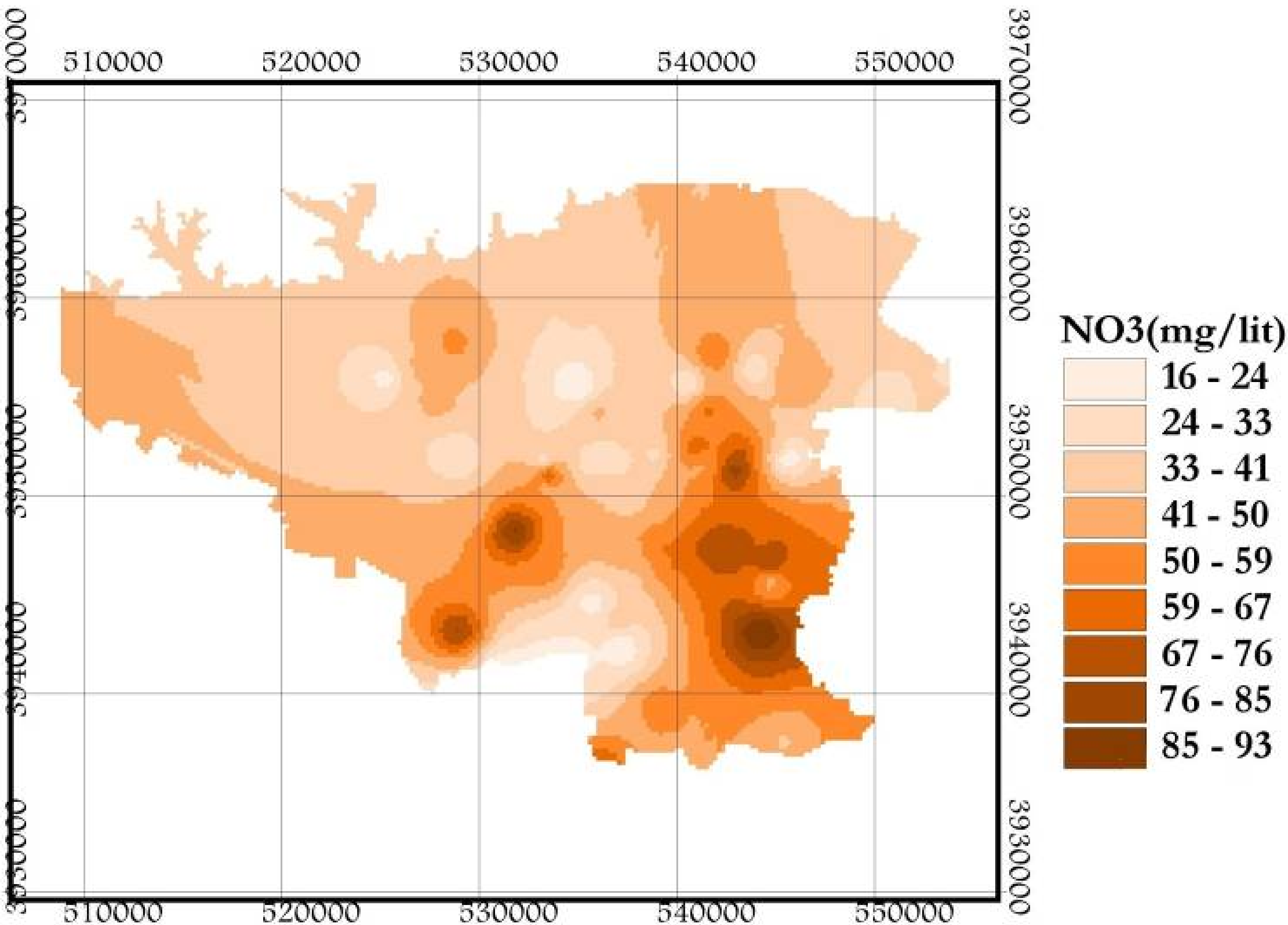
Hydraulic Conductivity (3)



Vulnerability Map



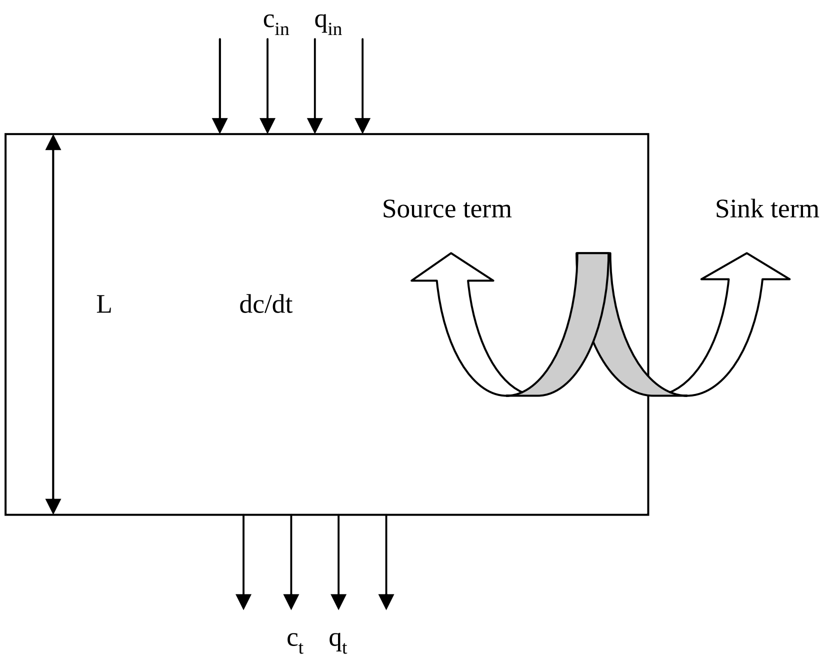
Nitrate Contamination Map



Lumped-Parameters Model (LPM)

Nitrogen Fate Modelling

Model Basis



Mass conservation equation:

$$\frac{\partial(\theta c)}{\partial t} = -\frac{\partial(qc)}{\partial z} \pm (Sink / Source)$$

$$E[\theta] = \frac{1}{L}\int_0^L \theta(z,t)dz \quad E[c] = \frac{1}{L}\int_0^L c(z,t)dz$$

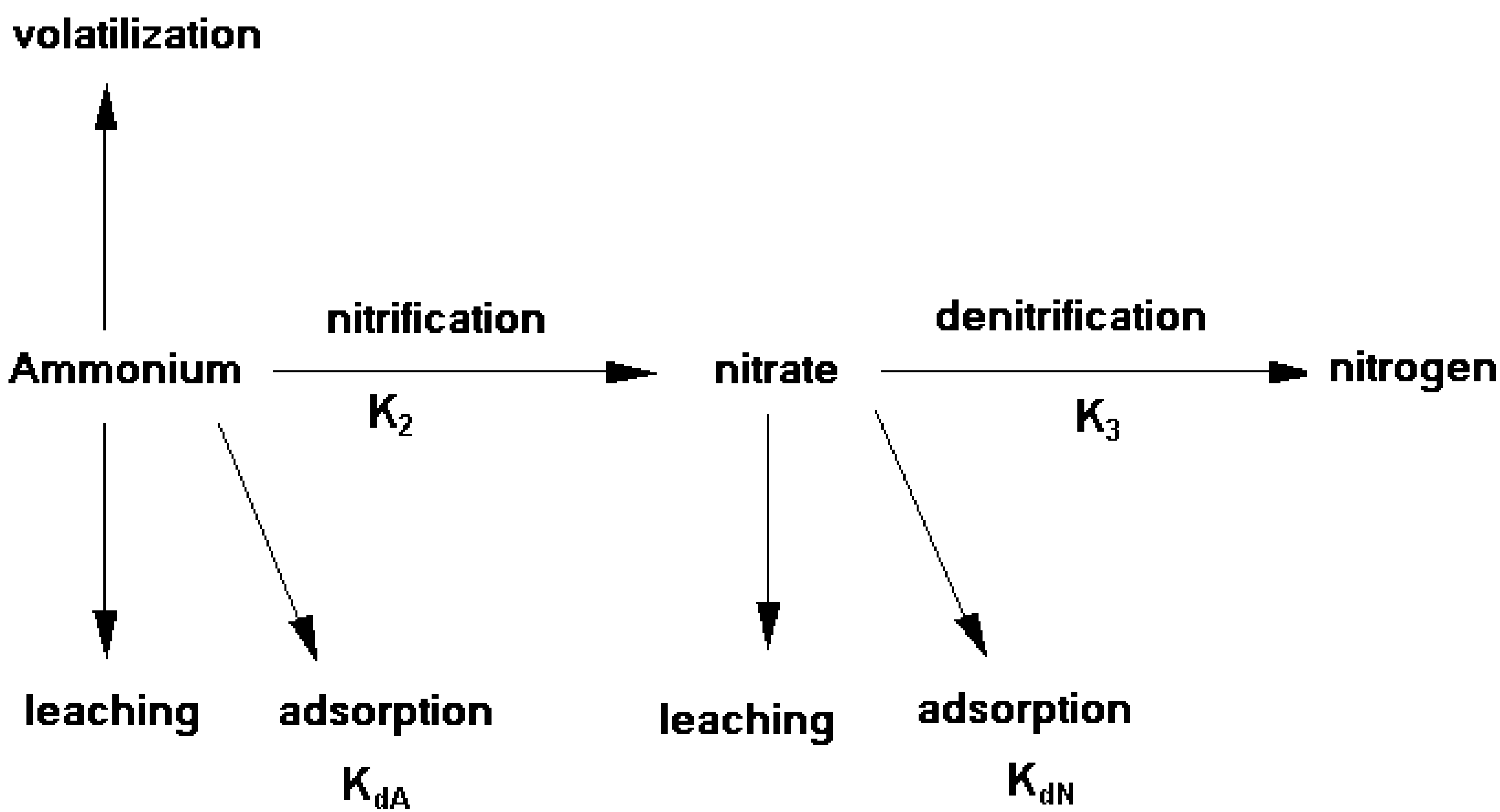
$$E[\theta c] = \frac{1}{L}\int_0^L \theta(z,t)c(z,t)dz$$

$$LE\left[\frac{\partial(\theta c)}{\partial t}\right] = c_{in}q_{in} - c_t q_t \pm \phi$$

- Dispersive fluxes are neglected
- Average concentration of contaminant in soil column is considered
- θ is the soil water content within depth
- q is the water flux
- c is the solute concentration in solution
- z is the depth to groundwater

Nitrogen Fate Modelling

Model Basis



Nitrogen Fate Modelling

Model Basis

Ammonium

$$\left(L\bar{\theta}\right)\frac{dA}{dt}+q_o A=$$

$$q_{in}A_{in}-L\left(\rho_b K_{dA}+\varepsilon K_H\right)\frac{dA}{dt}-k_2\left(L\bar{\theta}A\right)$$

Nitrate

$$\left(L\bar{\theta}\right)\frac{dN}{dt}+q_o N=$$

$$q_{in}N_{in}+k_2\left(L\bar{\theta}A\right)-\left(L\rho_b K_{dN}\right)\frac{dN}{dt}-k_3\left(L\bar{\theta}N\right)$$

Nitrogen Fate Modelling

Model Basis

$$L\left(\bar{\theta} + \rho_b K_{dA} + \varepsilon K_H\right)\frac{d(A)}{dt} + \left(q_{in} + k_2 L\bar{\theta}\right)(A) = q_{in} A_{in}$$

$$\frac{dA}{dt} + \frac{\left(q_{in} + k_2 L\bar{\theta}\right)}{L\left(\bar{\theta} + \rho_b K_{dA} + \varepsilon K_H\right)} A = \frac{q_{in} A_{in}}{L\left(\bar{\theta} + \rho_b K_{dA} + \varepsilon K_H\right)}$$

$$R_{FA} = 1 + \frac{\rho_b K_{dA}}{\bar{\theta}} + \frac{\varepsilon K_H}{\bar{\theta}} \quad , \quad \lambda_2 = \frac{1}{R_{FA}}\left(k_2 + \frac{q_{in}}{L\bar{\theta}}\right)$$

$$\frac{dA}{dt} + \lambda_2 A = \frac{q_{in} A_{in}}{L R_{FA} \bar{\theta}}$$

$$\int_0^t d\left(e^{\lambda_2 t} A\right) = \int_0^t \frac{q_{in} A_{in}}{L R_{FA} \bar{\theta}} e^{\lambda_2 t}\, dt$$

$$e^{\lambda_2 t} A - A_o = \frac{q_{in} A_{in}}{L R_{FA} \bar{\theta} \lambda_2} e^{\lambda_2 t} \Big|_0^t$$

$$A = \frac{q_{in} A_{in}}{L R_{FA} \bar{\theta} \lambda_2}\left(1 - e^{-\lambda_2 t}\right) + A_o e^{-\lambda_2 t}$$

Nitrogen Fate Modelling

Model Basis

$$L\left(\bar{\theta} + \rho_b K_{dN}\right)\frac{dN}{dt} + \left(q_{in} + k_3 L\bar{\theta}\right)N = q_{in}N_{in} + k_2\left(L\bar{\theta}A\right)$$

$$\frac{dN}{dt} + \frac{\left(q_{in} + k_3 L\bar{\theta}\right)}{L\left(\bar{\theta} + \rho_b K_{dN}\right)}N = \frac{q_{in}N_{in}}{L\left(\bar{\theta} + \rho_b K_{dN}\right)} + \frac{k_2\bar{\theta}}{\left(\bar{\theta} + \rho_b K_{dN}\right)}A$$

$$R_{FN} = 1 + \frac{\rho_b K_{dN}}{\bar{\theta}} \quad , \quad \lambda_3 = \frac{1}{R_{FN}}\left(\frac{q_{in}}{L\theta} + k_3\right)$$

$$\frac{dN}{dt} + \lambda_3 N = \frac{q_{in}N_{in}}{LR_{FN}\bar{\theta}} + \frac{k_2}{R_{FN}}A$$

$$\int_0^t d\left(e^{\lambda_3 t}N\right) = \int_0^t \frac{q_{in}N_{in}}{LR_{FN}\bar{\theta}}e^{\lambda_3 t}dt + \frac{k_2}{R_{FN}}\int_0^t\left(\frac{q_{in}A_{in}}{LR_{FA}\bar{\theta}\lambda_2}\left(1 - e^{-\lambda_2 t}\right) + A_o e^{-\lambda_2 t}\right)e^{\lambda_3 t}dt$$

$$e^{\lambda_3 t}N - N_o = \frac{q_{in}N_{in}}{LR_{FN}\bar{\theta}\lambda_3}\left(e^{\lambda_3 t} - 1\right) + \frac{k_2}{R_{FN}}\frac{q_{in}A_{in}}{LR_{FA}\bar{\theta}\lambda_2\lambda_3}\left(e^{\lambda_3 t} - 1\right)$$

$$+ \frac{k_2}{R_{FN}\left(\lambda_3 - \lambda_2\right)}\left(A_o - \frac{q_{in}A_{in}}{LR_{FA}\bar{\theta}\lambda_2}\right)\left(e^{\left(\lambda_3 - \lambda_2\right)t} - 1\right)$$

$$N = \frac{q_{in}}{L\bar{\theta}\lambda_3 R_{FN}}\left(N_{in} + \frac{k_2 A_{in}}{R_{FA}\lambda_2}\right)\left(1 - e^{-\lambda_3 t}\right)$$

$$+ \frac{k_2}{R_{FN}\left(\lambda_3 - \lambda_2\right)}\left(A_o - \frac{q_{in}A_{in}}{LR_{FA}\bar{\theta}\lambda_2}\right)\left(e^{-\lambda_2 t} - e^{-\lambda_3 t}\right) + N_o e^{-\lambda_3 t}$$

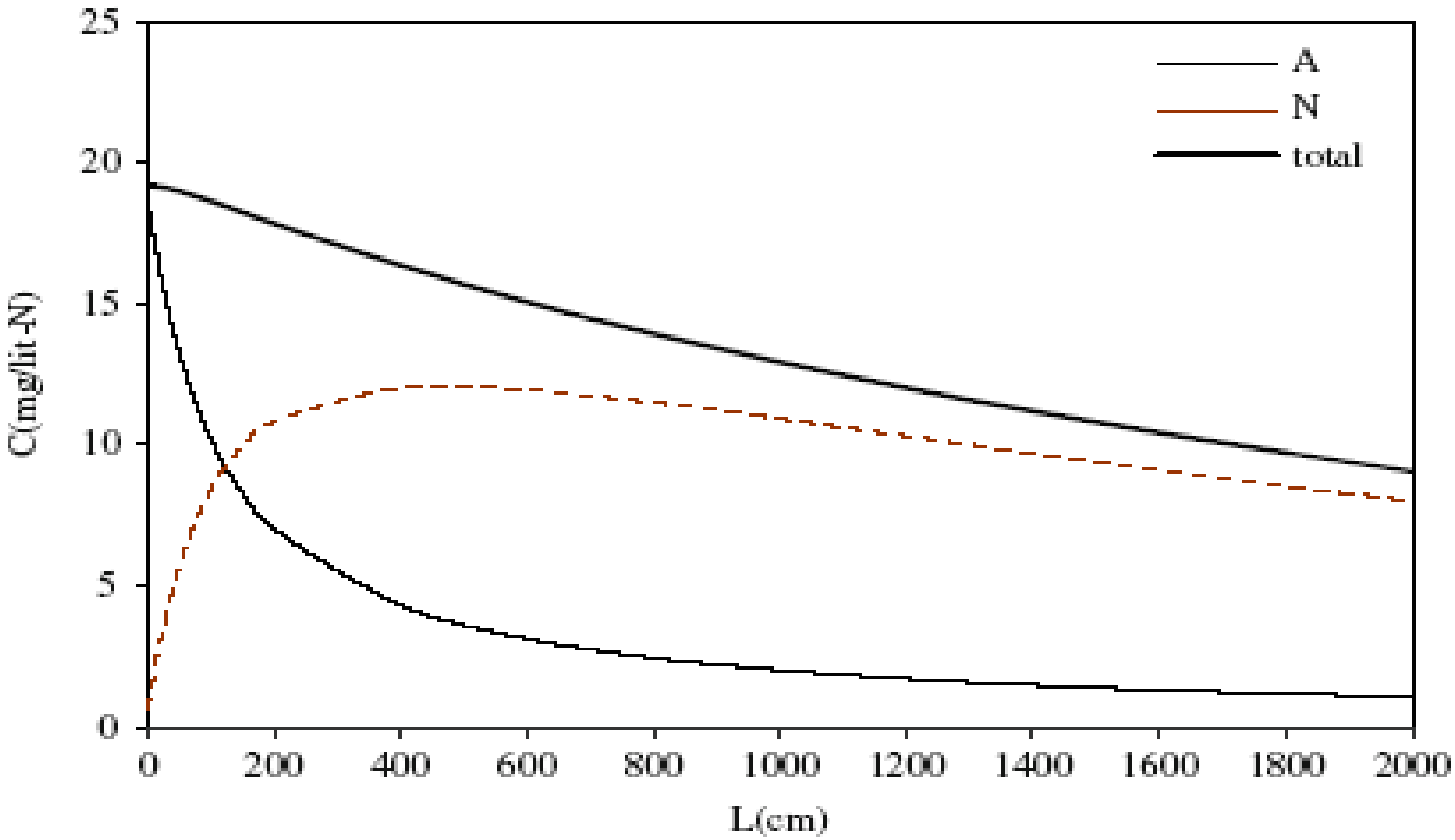
Nitrogen Fate Modelling

Program Run Procedure

- Parameter Calibration
- Selection of Run Points
- Importing Data To GIS
- Map Developing

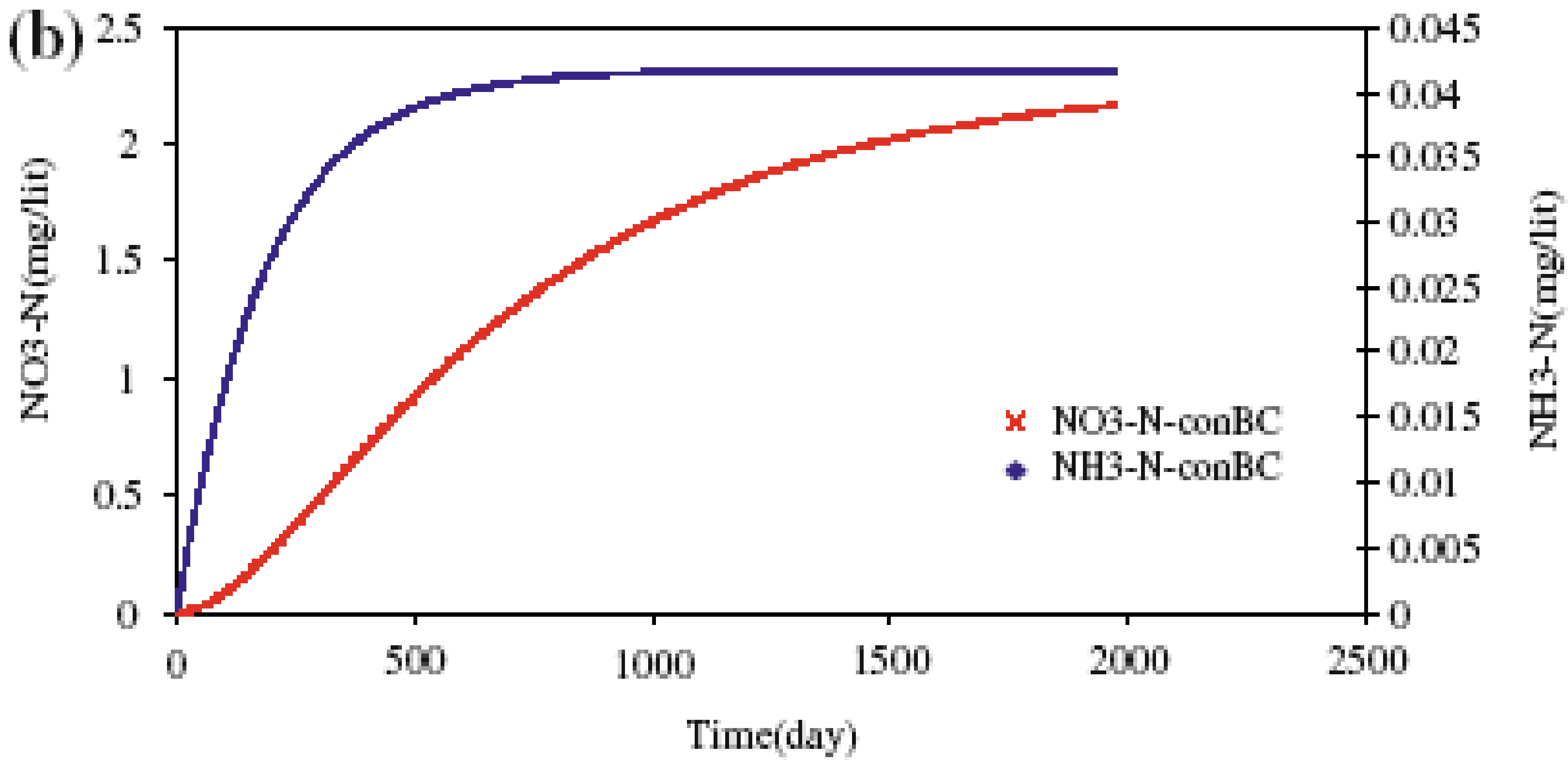
Nitrogen Fate Modelling

Sensitivity Analysis _ Depth



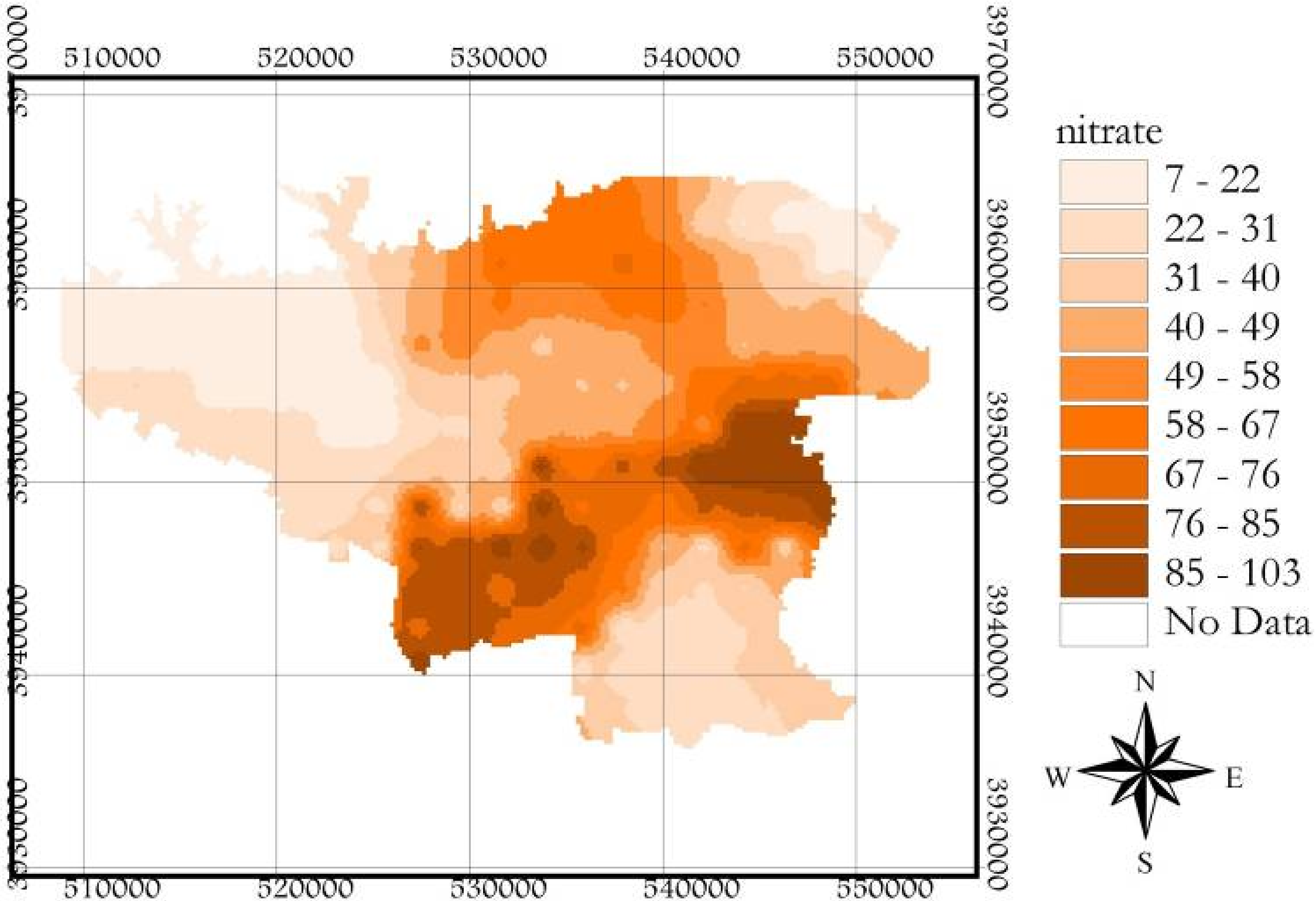
Nitrogen Fate Modelling

Typical breakthrough curve of Nitrate and Ammonium in a soil column

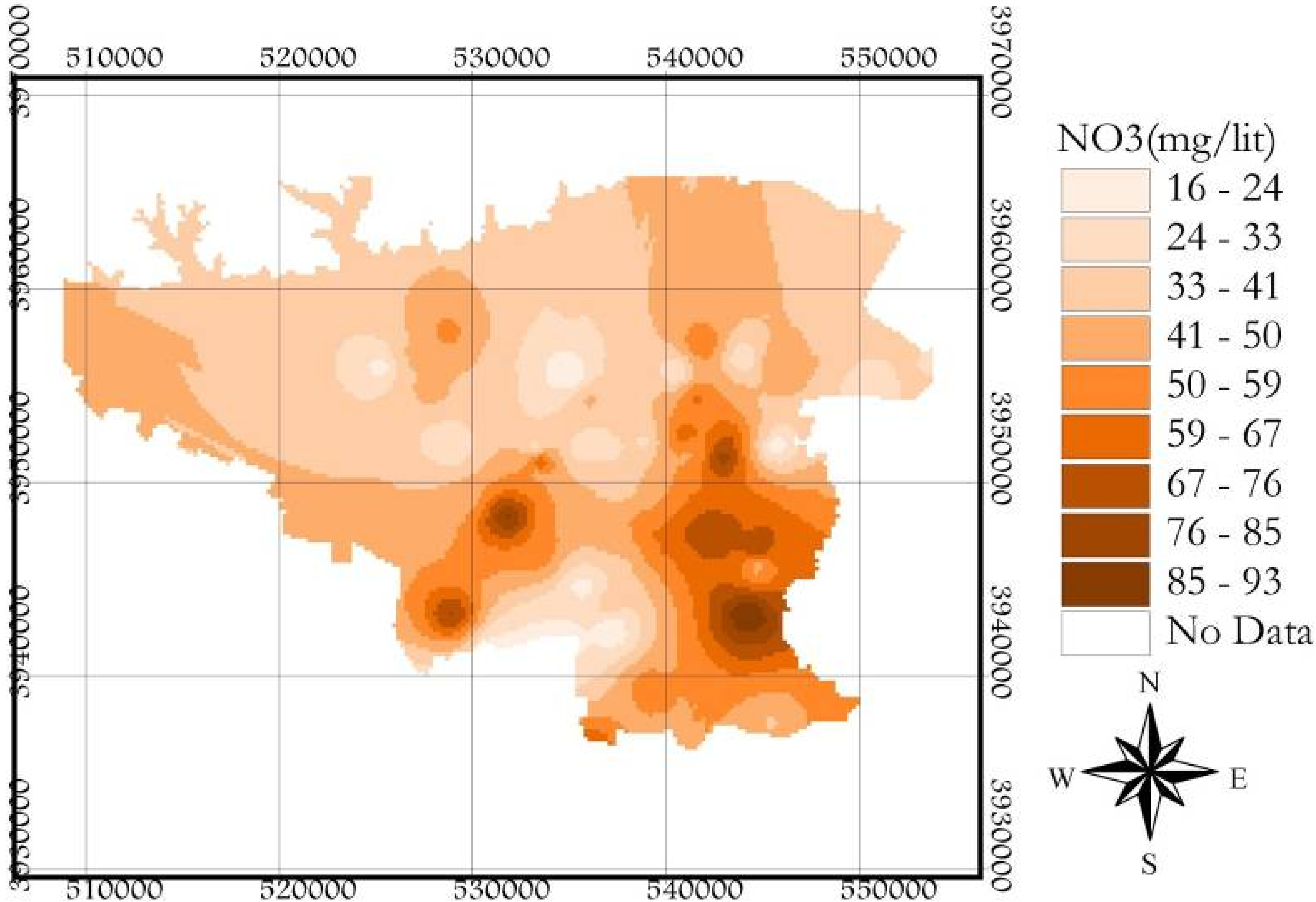


Nitrogen Fate Modelling (LPM)

Result



Total Nitrogen Concentration (Measured)



Summary

•According to mass balance analysis, wastewater discharge from septic tanks is the major Nitrate contamination source in Teheran.

• There is a good correlation between result of modified DRASTIC model and measurements

•Utilizing of LPM model in relation to mass balance method has a sound correlation with measurements

•According to the LPM and Mass Balance, more than 45% of discharged nitrogen will be discharged into groundwater as nitrate

Conclusion

- In south and south-east of Teheran, nitrate concentration in groundwater is very high. More than 55% of Teheran's groundwater resource suffers from nitrate concentration of more than 10 mg/lit(NO_3-N).

- Although, installation of sewage collection system can be very useful for saving groundwater quality but still a long time is needed to recover the quality of groundwater.

Thanks

Nitrogen Fate Modelling

Parameter Calibration

KdA: 3.5-4.5 cm^3/gr

KdN: 0-0.6 cm^3/gr

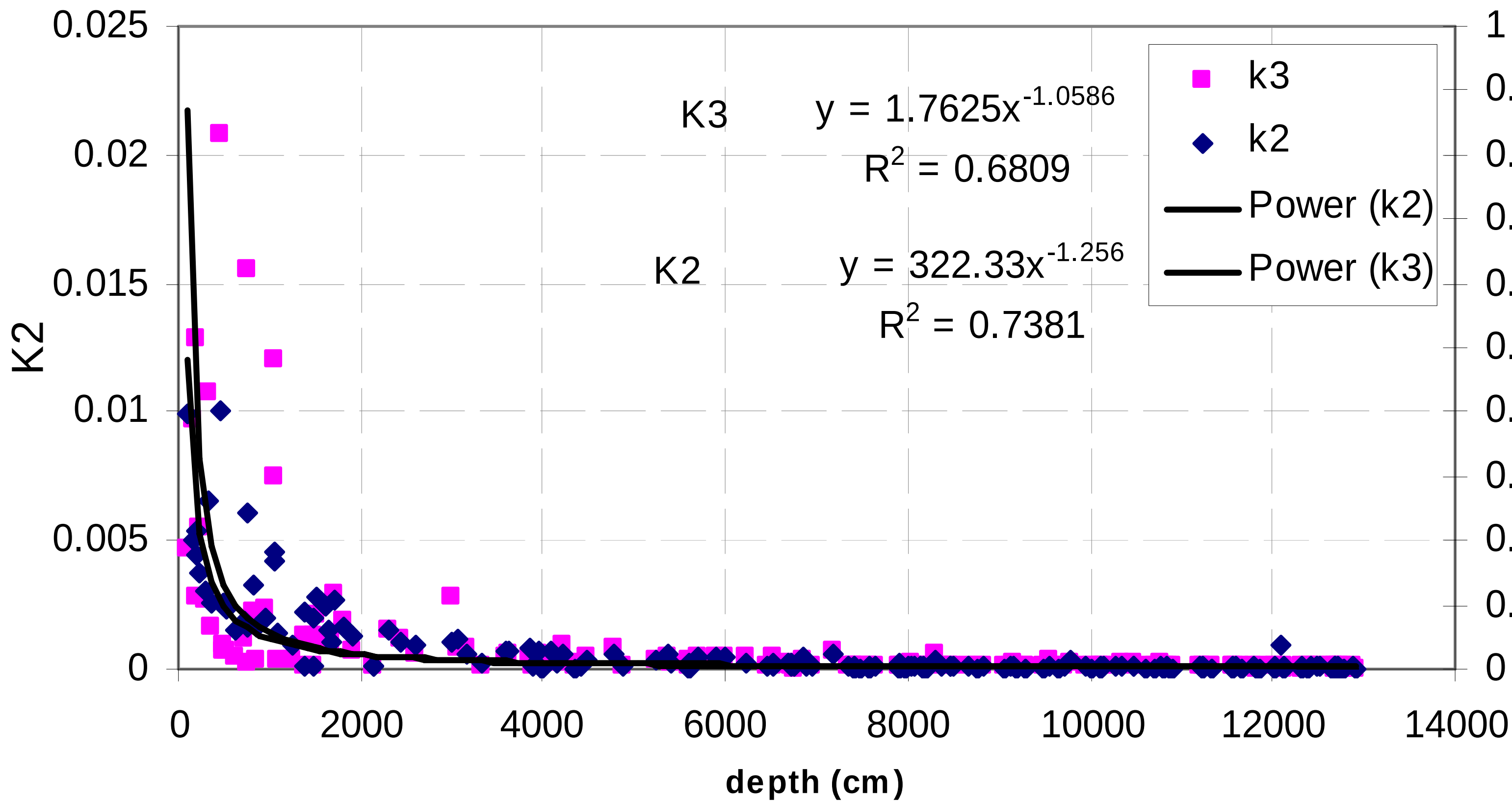
KH: 2

ε :0.15 , θ: 0.45

Reference	$K_2(day^{-1})$	$K_3(day^{-1})$
Wagenet	0.24	0.024
El-Kadi	0.2	0.006
El-Kadi	0.15	0.024
El-Kadi	0.25	0.070

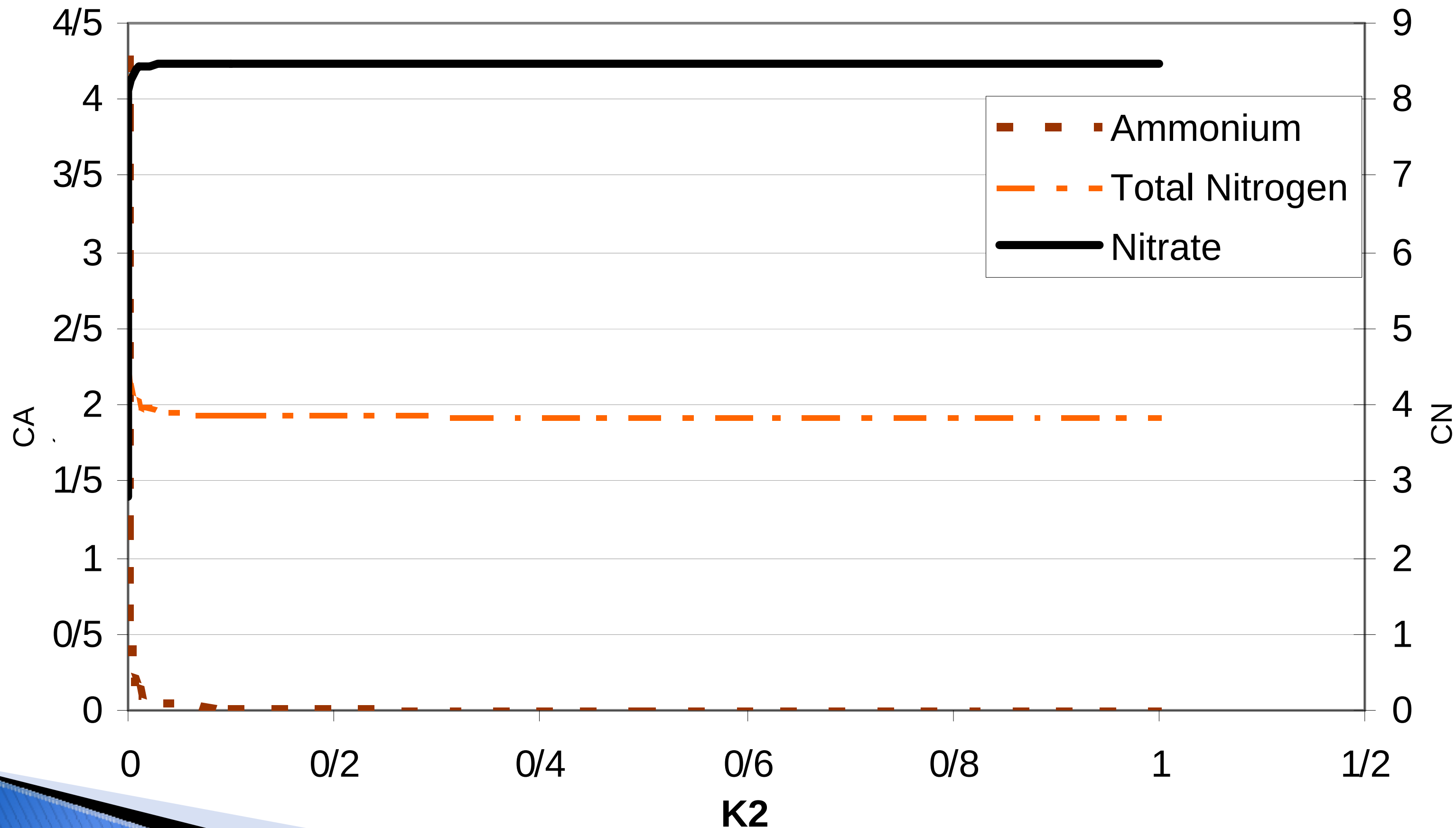
Nitrogen Fate Modelling

Parameter Calibration



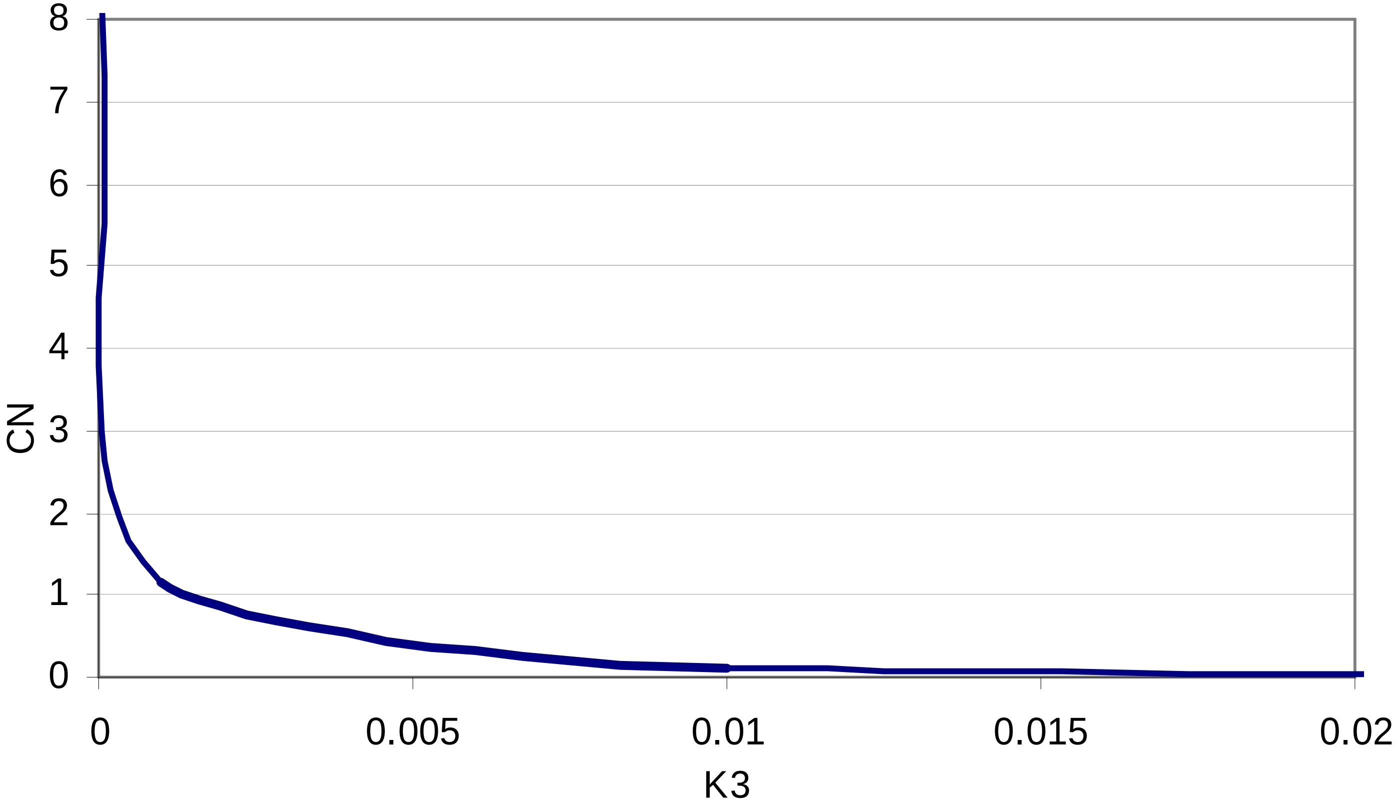
Nitrogen Fate Modelling

Sensitivity Analysis- K_2



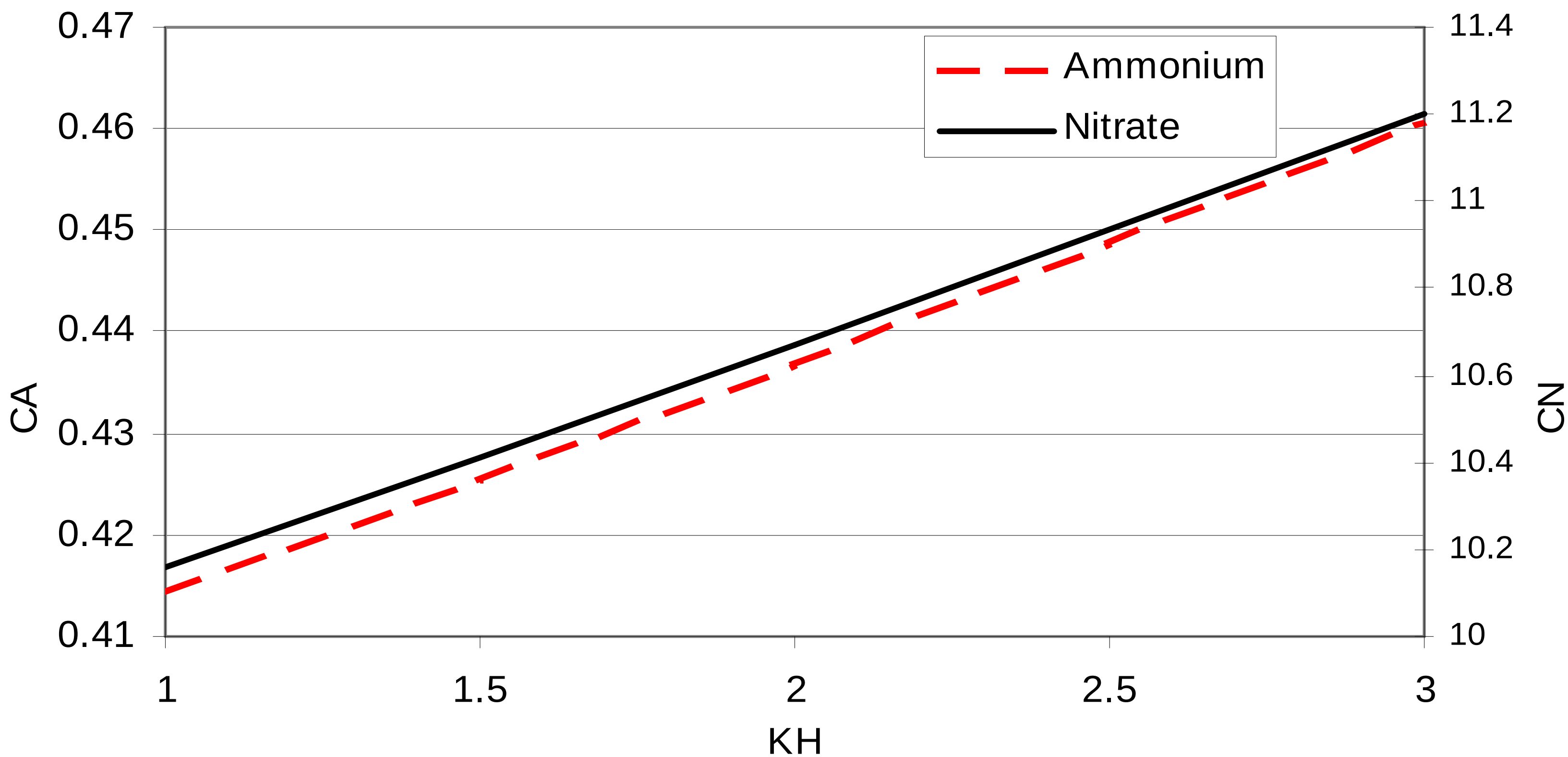
Nitrogen Fate Modelling

Sensitivity Analysis- K_3



Nitrogen Fate Modelling

Sensitivity Analysis- K_H



NO Concentration in Air