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Enhancement of groundwater contamination-vulnerability assessment using DLNN method combined with optimized original DRASTIC methods

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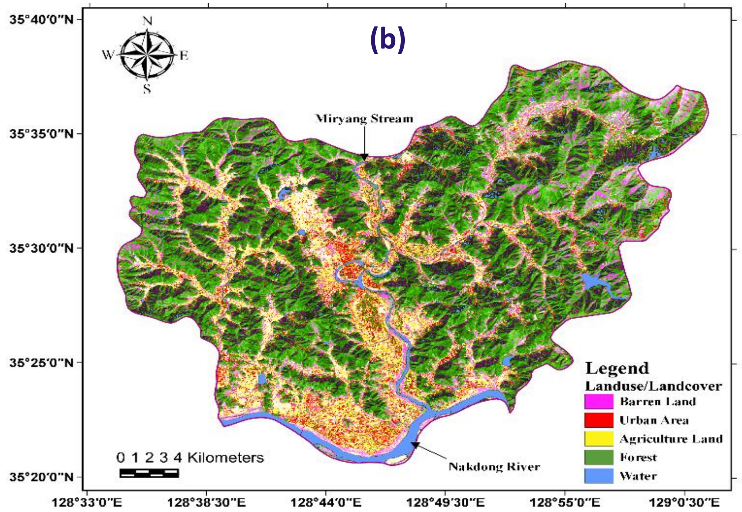
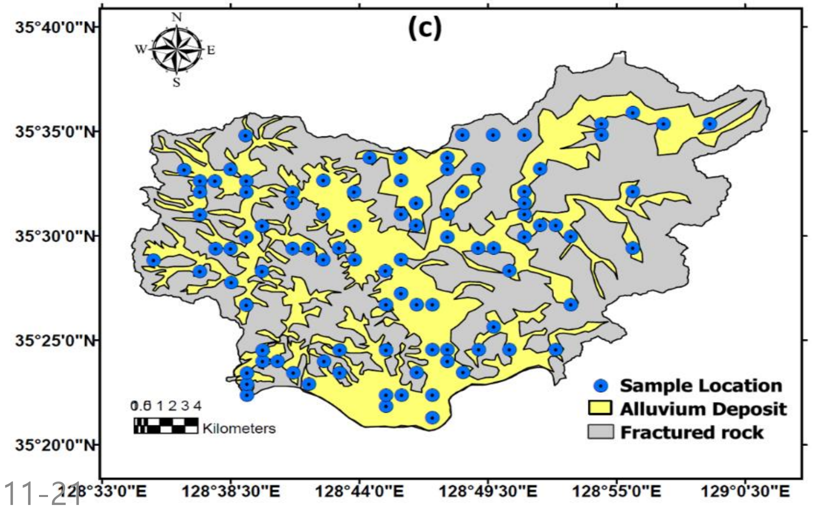
Research Scope

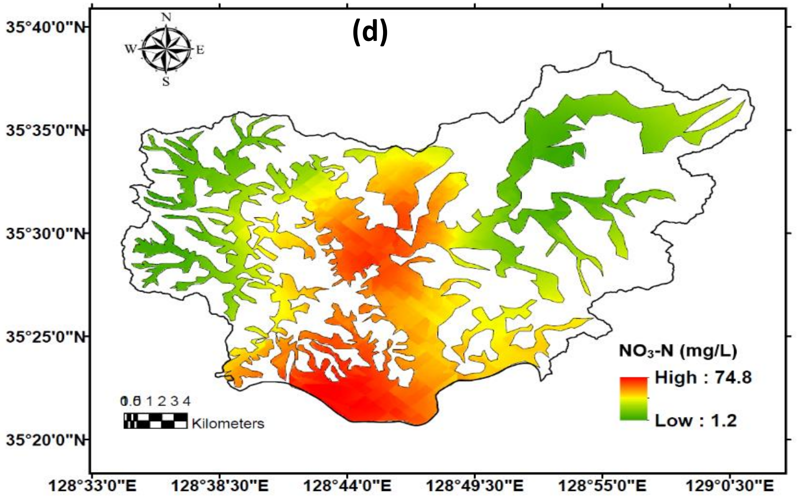
- The reliable assessment of groundwater contamination vulnerability is essential for the conservation and management of groundwater resources.
- Original DRASTIC model (ODM) suffers from the inherited subjectivity, and a lack of robustness to assess groundwater vulnerability.
- Artificial intelligence modeling was combined with optimization algorithms to enhance the assessment of groundwater contamination vulnerability.
- The first strategy-1 used particle swarm optimization (PSO) and differential evolution (DE) algorithms to determine the effective weights of ODM parameters, and to produce new indices of ODVI-PSO and ODVI-DE. For strategy-2, a deep learning neural networks (DLNN) used two indices resulting from strategy-1 as the input data, and adjusted vulnerability indices (AVI) conditioned with NO_3-N values as the output data.
- $AVI_i = \frac{(ODVI)_{avg}}{(NO_3-N)_{avg}} * (NO_3 - N)_i * \frac{1}{\lambda}$

$(ODVI)_{avg}$ is average calculated original DRASTIC vulnerability index, $(NO_3-N)_{avg}$ is average nitrate value, $(NO_3 - N)_i$ is measured nitrate value corresponding to each vulnerability value produced by DRASTIC model. λ is an empirical integer value between 2.0 and 6.0

Study Area



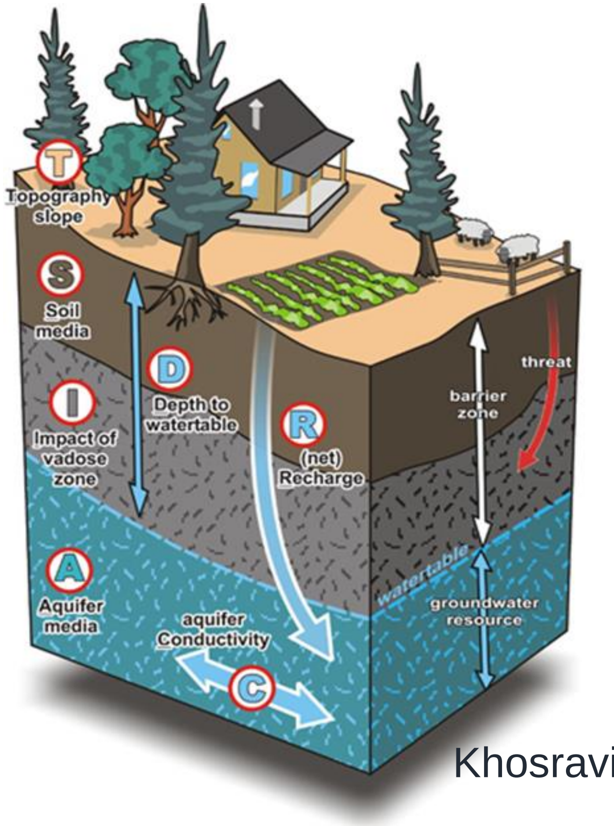




(a) Location map (Miryang City)
(b) Landuse Map
(c) 95 Well sites
(d) NO_3-N concentrations

Original DRASTIC model (ODM)

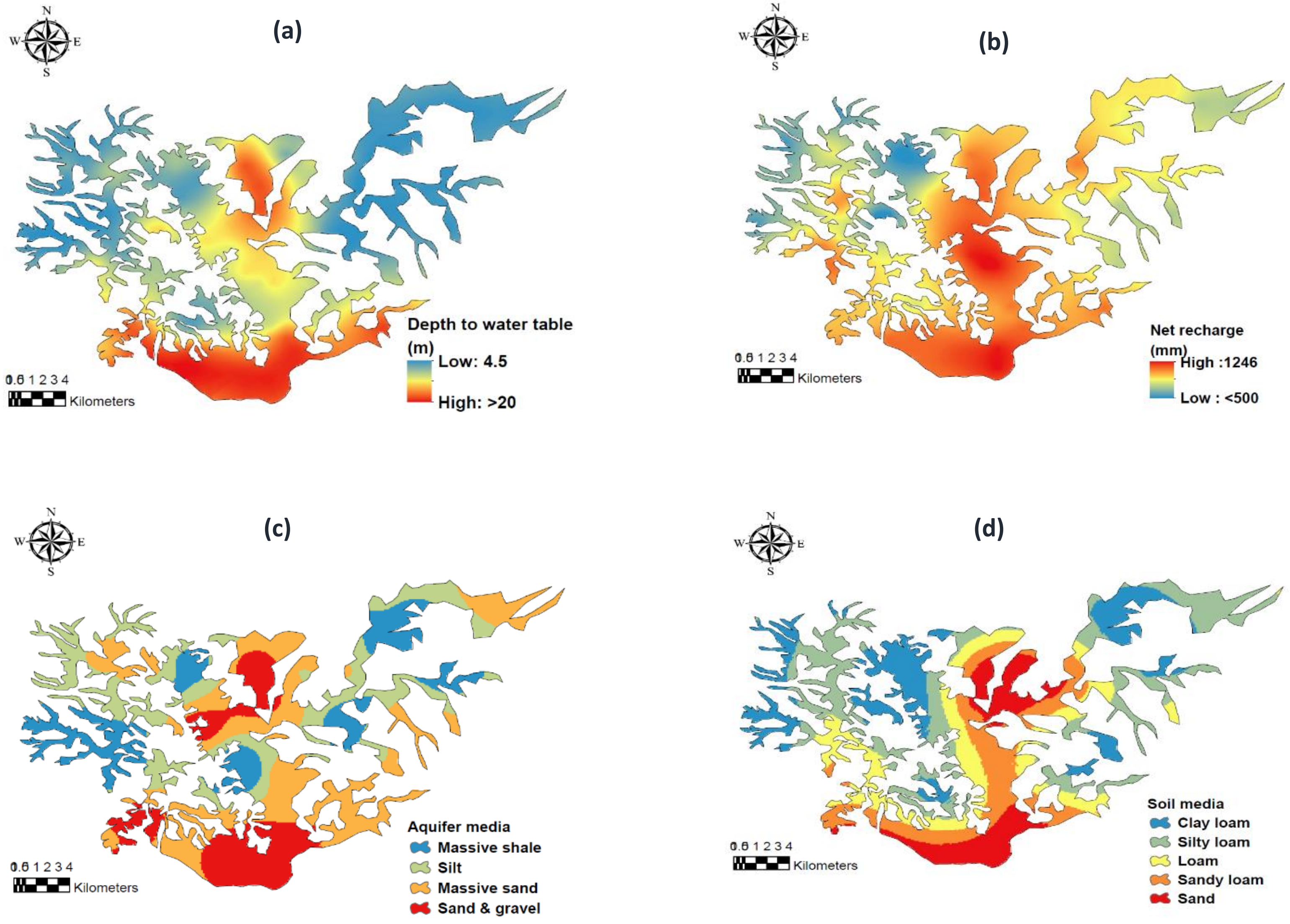
Index	Factor	Description	Relative weight
D	Depth of water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5
R	Net Recharge	Represents the amount of water which penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants.	4
A	Aquifer media	Refers to the consolidated or unconsolidated materials aquifers. The geological characterization is the principle factor that controls the permeability of this zone.	3
S	Soil media	The texture has a significant impact on the amount of recharge that can infiltrate into the ground.	2
T	Topography	Refers to the slope of the land surface. Where slopes are steep, runoff capacity is high, and the potential for pollution to groundwater is lower.	1
I	Impact of vadose Zone	Refers to the saturated zone material properties, which controls the pollutant attenuation processes.	5
C	Hydraulic Conductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminant material within the groundwater system.	3
ID	DRASTIC Vulnerability Index		



Khosravi, et al., 2018

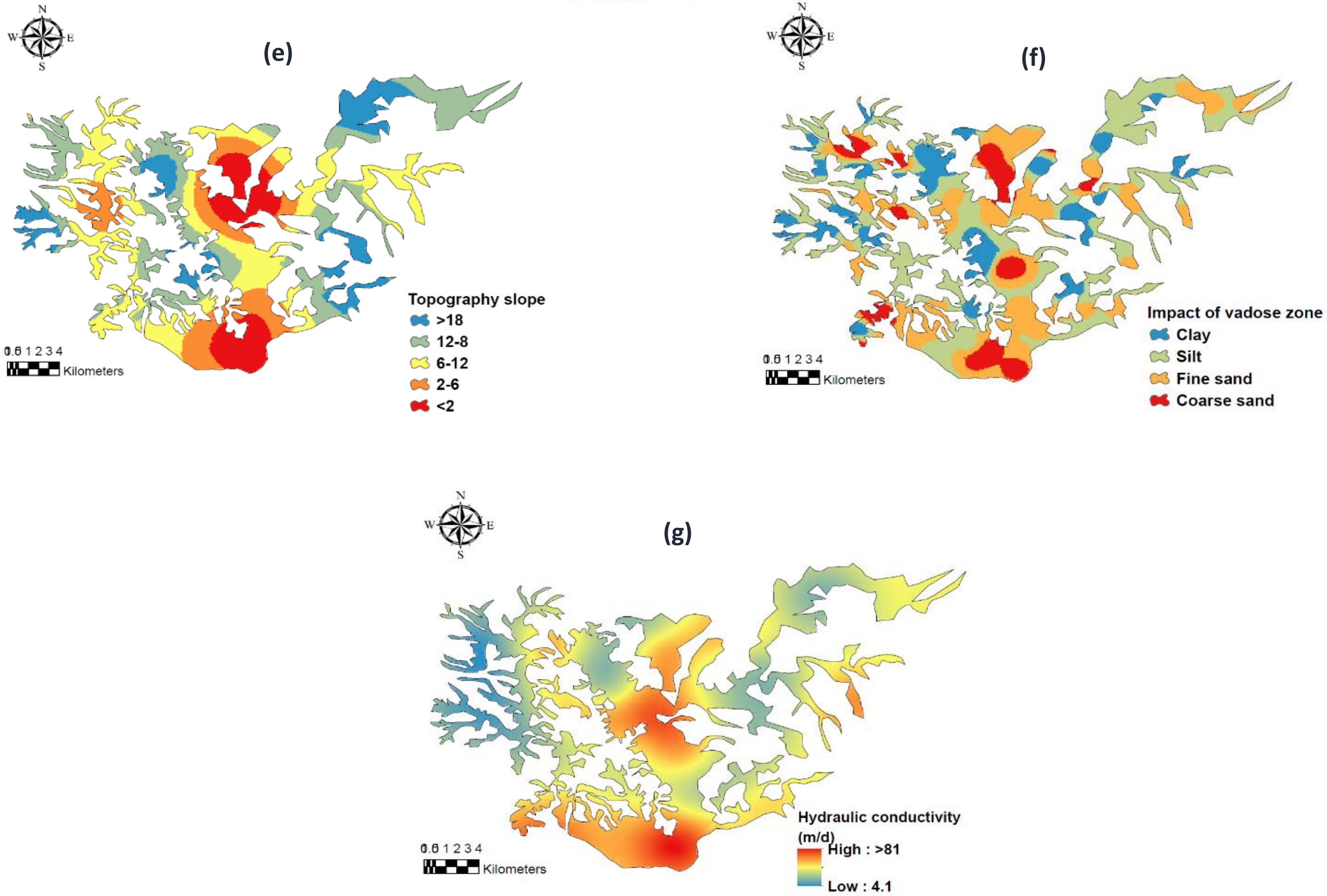
$$ODVI = DwDr + RwRr + AwAr + SwSr + TwTr + IwIr + CwCr \quad (Eq. 1)$$

Thematic maps of DRASTIC factors



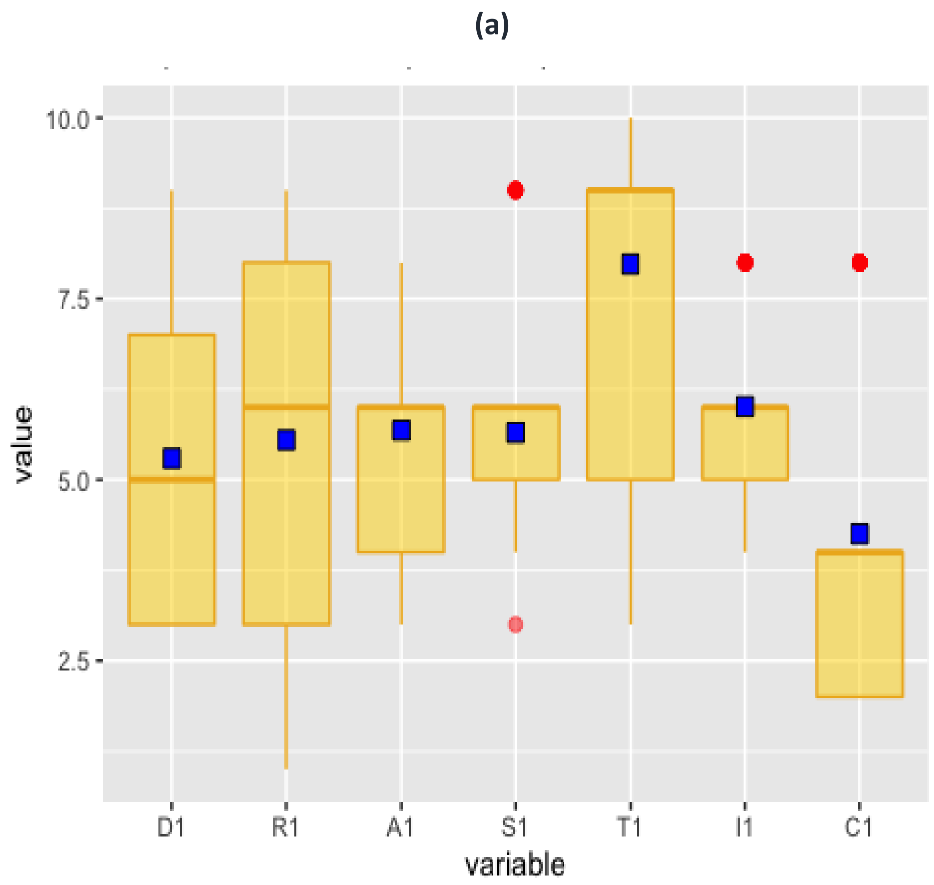
(a) **D**epth to water (b) **R**echarge rate (c) **A**quifer media (d) **S**oil media

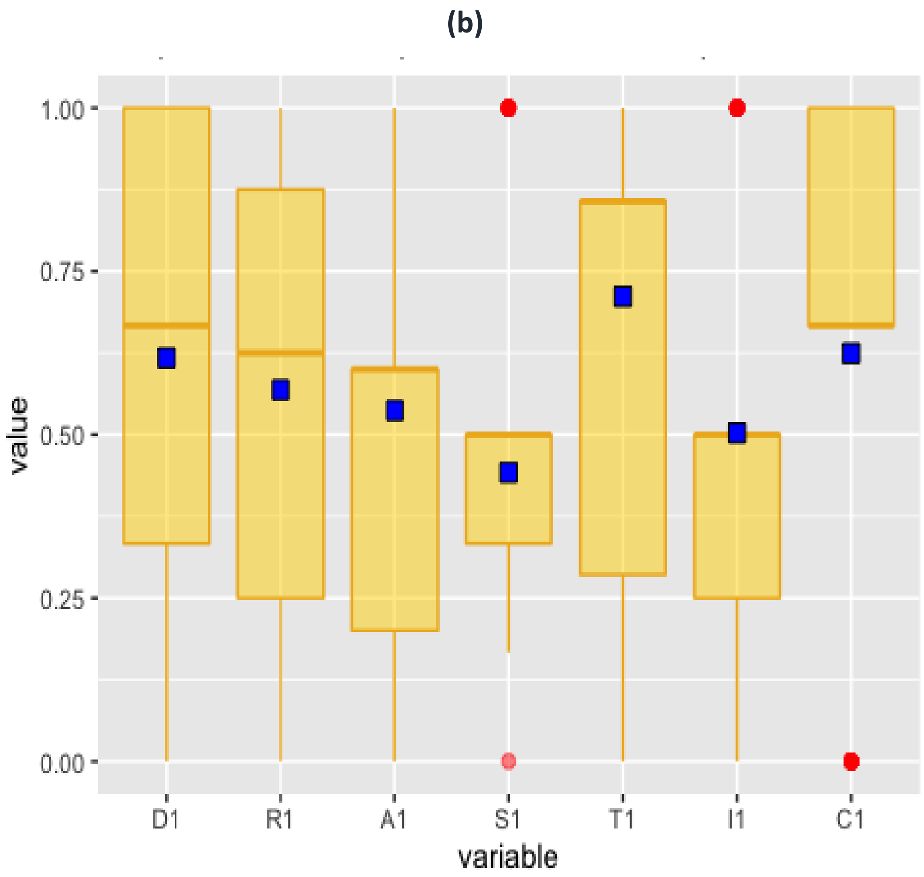
Thematic maps of DRASTIC factors



(e)**T**opographic slope (f) **I**mpact to vadose zone (g) Hydraulic **C**onductivity

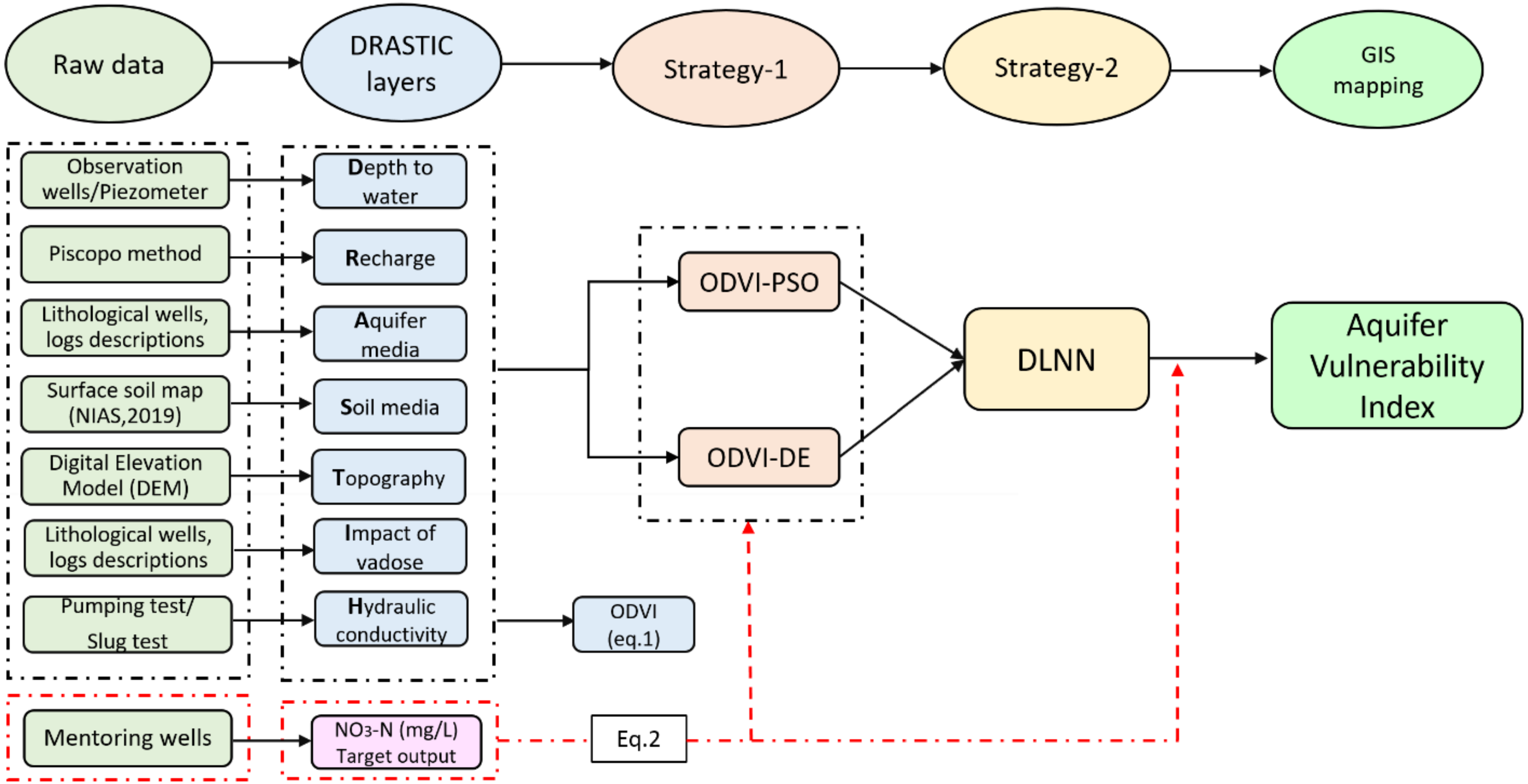
Box plot for rating values of DRASTIC factors





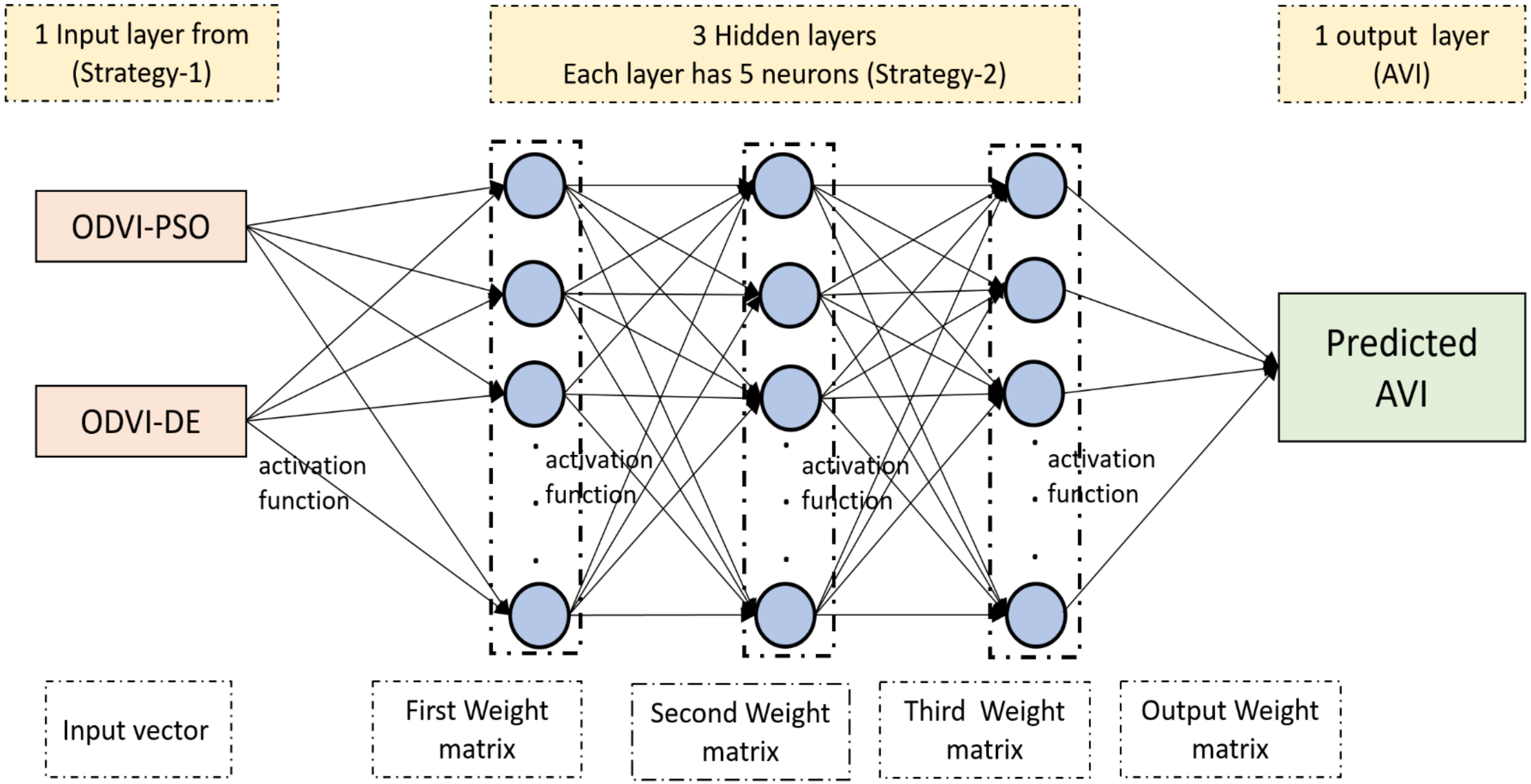
(a) Original rating values, (b) Normalized rating values

Framework of research methodology



ODVI: **O**riginal **D**RASTIC **V**ulnerability **I**ndex; ODVI-PSO: **P**article **S**warm **O**ptimization based on **O**riginal **D**RASTIC **M**odel; ODVI-DE: **D**ifferential **E**volutionary based on **O**riginal **D**RASTIC **M**odel; DLNN**: D**eep **L**earning **N**eural **N**etwork model.

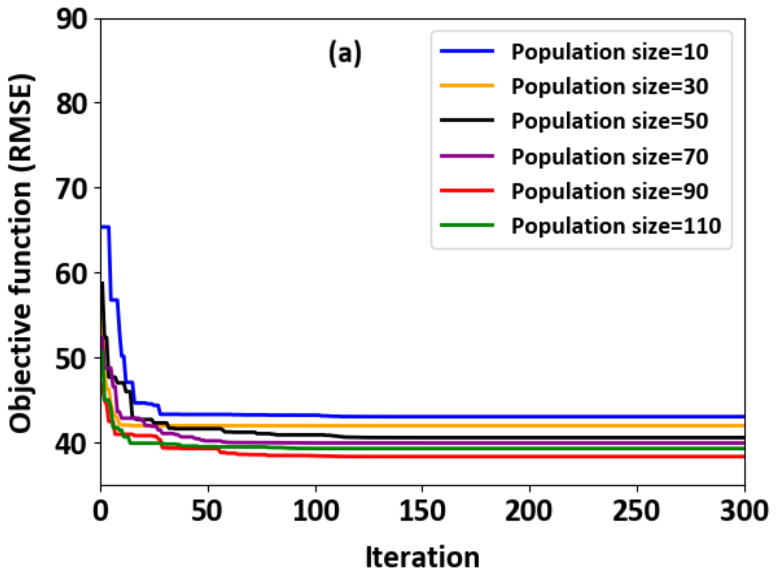
Structure of DLNN model used for the prediction of groundwater vulnerability index (AVI)



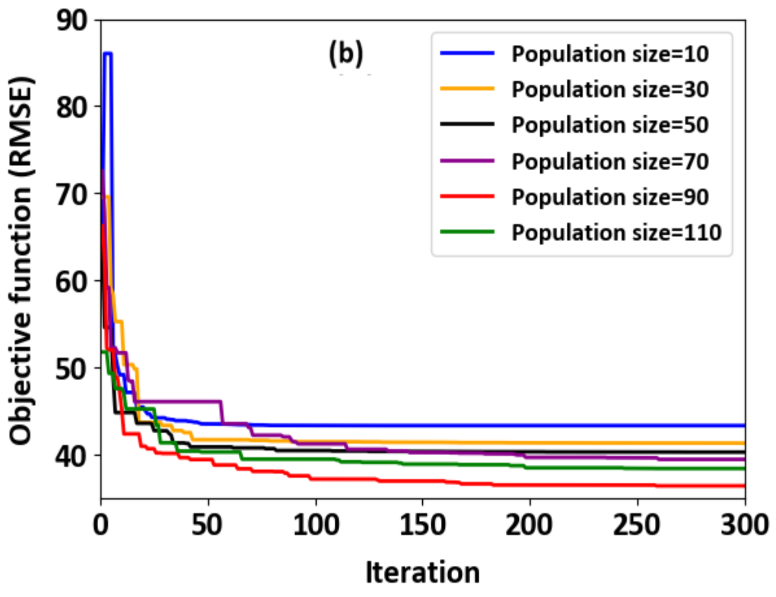
Tune parameters of optimization models

Parameters	PSO	DE
Number of population size	110 (Number of particle agents)	110 (original population size)
Dimension of problem	7 DRASTIC variables	7 DRASTIC variables
Objective function	RMSE	RMSE
Optimal value	Weights for DRASTIC factors	Weights for DRASTIC factors
Tune parameters	α , β=1.3, v=9, ω=1.5	Mutation factor=0.5 Crossover factor=0.4
Iteration number	300	300
Lower and upper bounds	[-1,1]	[-1,1]

Sensitivity analysis on different population size



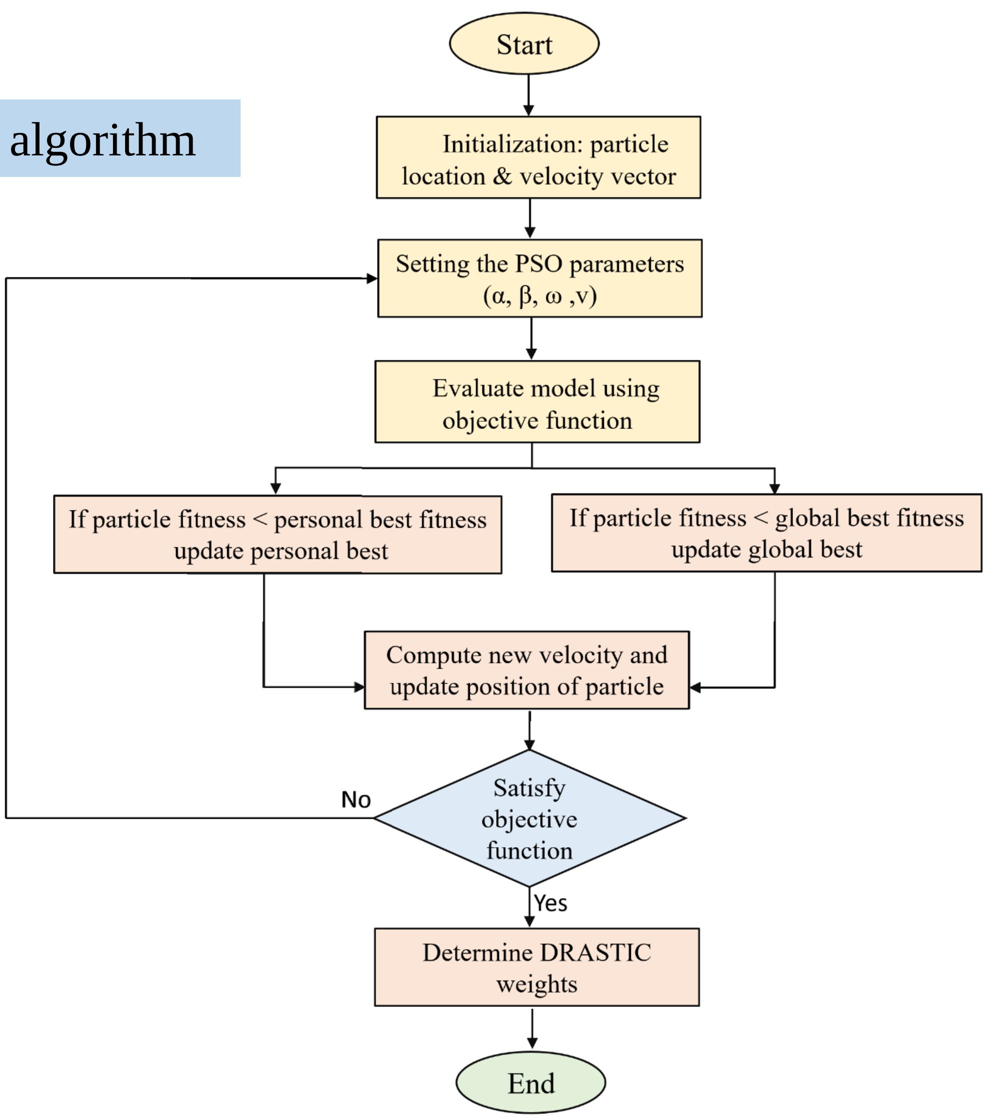
(a) PSO algorithm



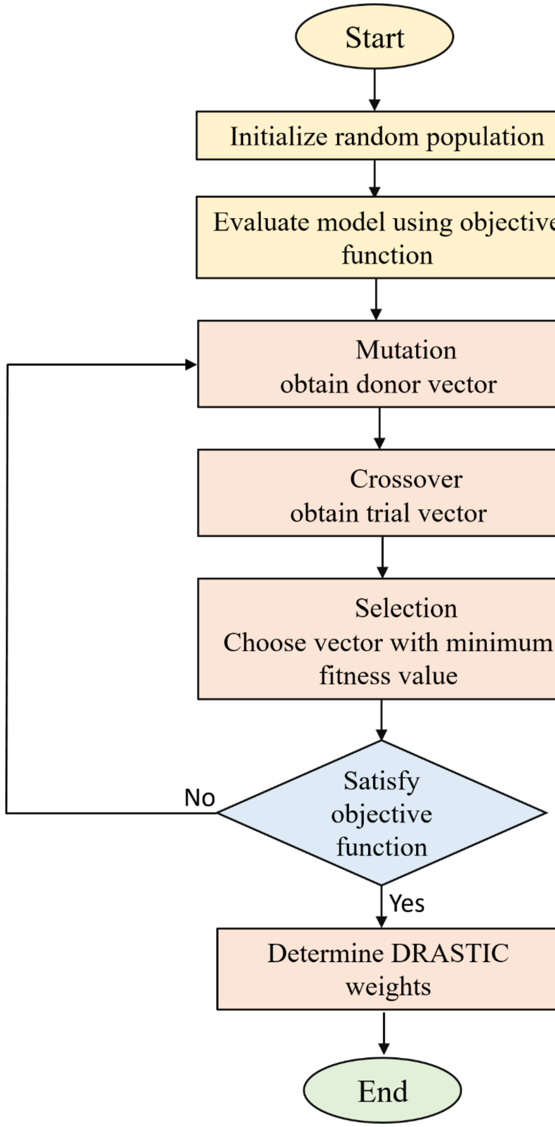
(b) DE algorithm

Determination of DRASTIC weight

PSO algorithm



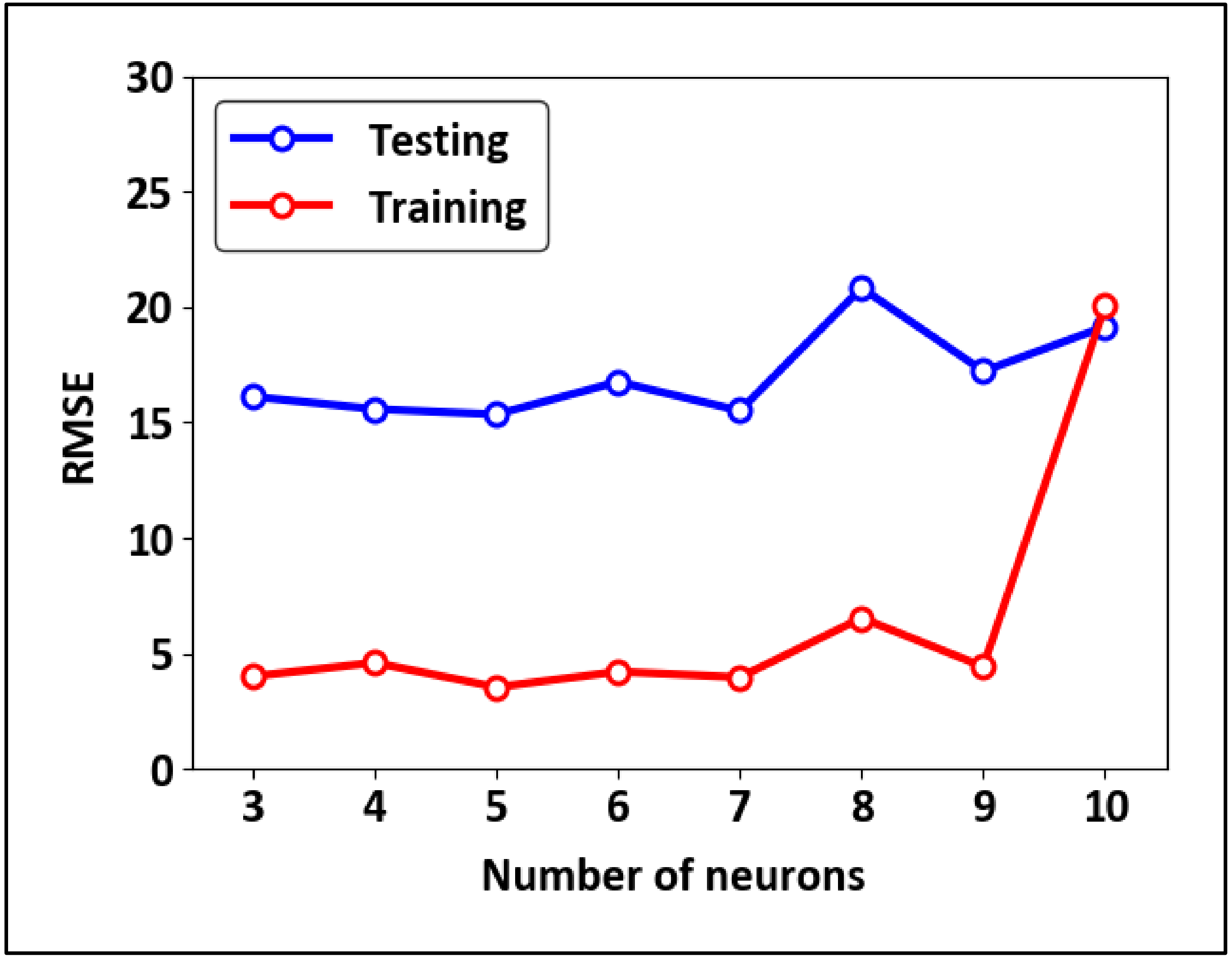
DE algorithm



Original DRASTIC and Optimized weights

Parameters	Original DRASTIC	PSO	DE
Depth to water	5	1.26	1.24
Recharge rate	4	1.15	1.00
Aquifer media	3	1.01	1.62
Soil media	2	1.76	1.16
Topographic slope	1	1.11	1.10
Impact to vadose zone	5	1.84	1.66
Hydraulic conductivity	3	5.00	4.91

Number of neurons in hidden layers of DLNN model

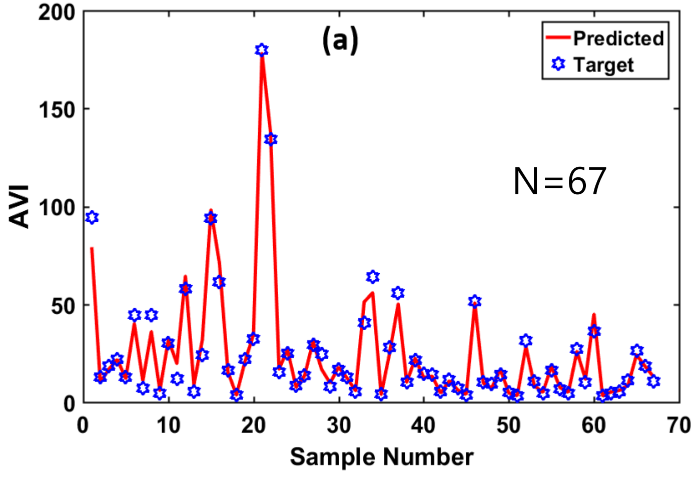


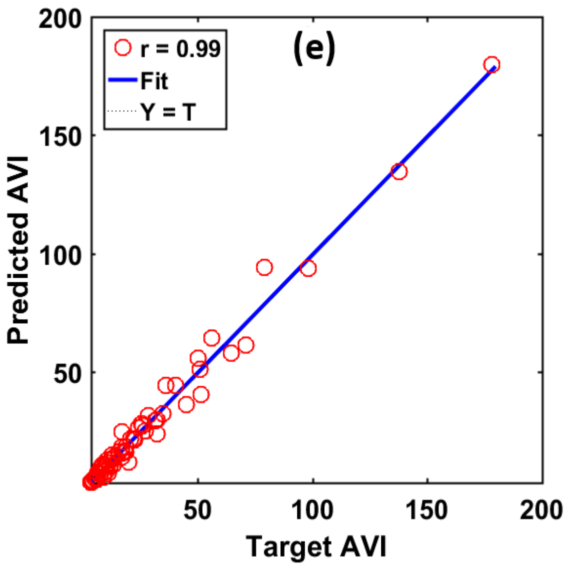
Tune parameters of supervised DLNN model

Parameters	Value
Transfer function	Tansig
Number of hidden layers	3
Number of neurons	5
Learning rate	0.12
Number of iterations	1000
Learning algorithm parameter	0.6
Seed number	3100

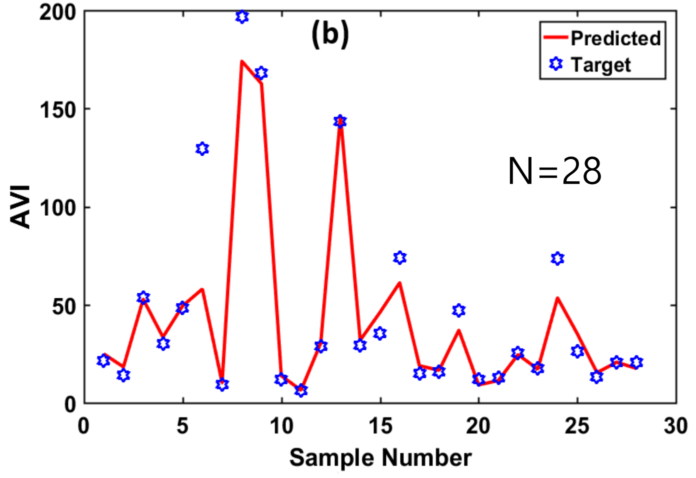
DLNN model (Strategy-2) results

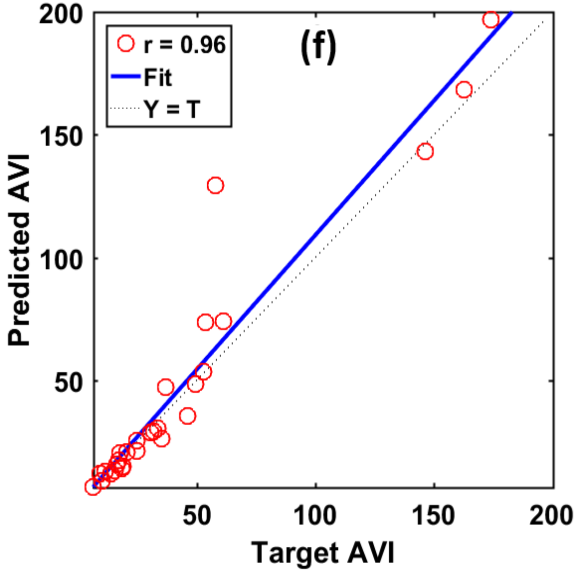
Training Phase



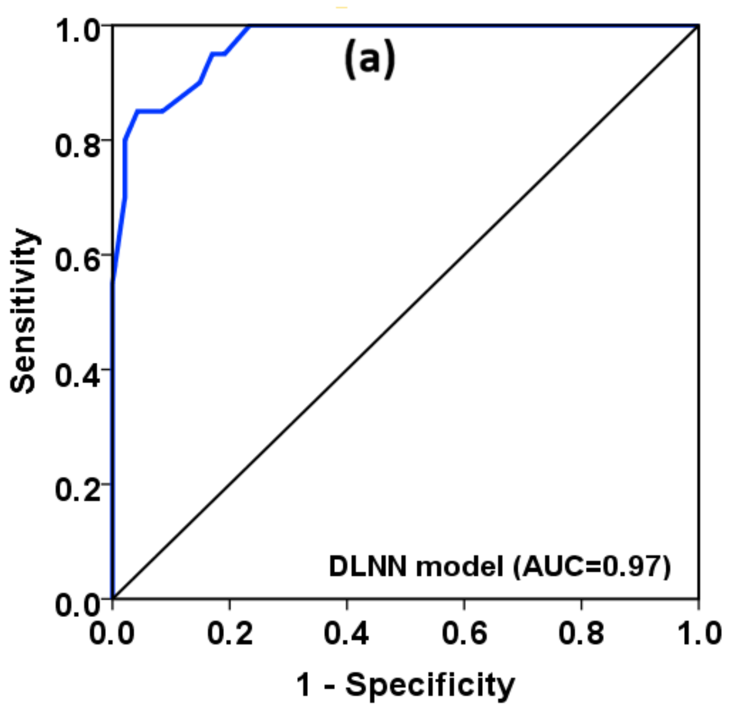


Testing Phase

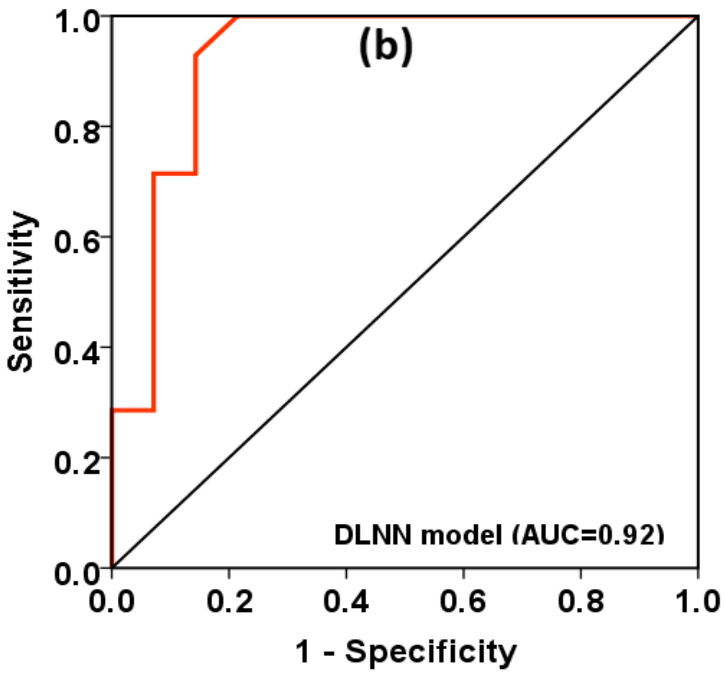




ROC/AUC of DLNN model results



Training Phase

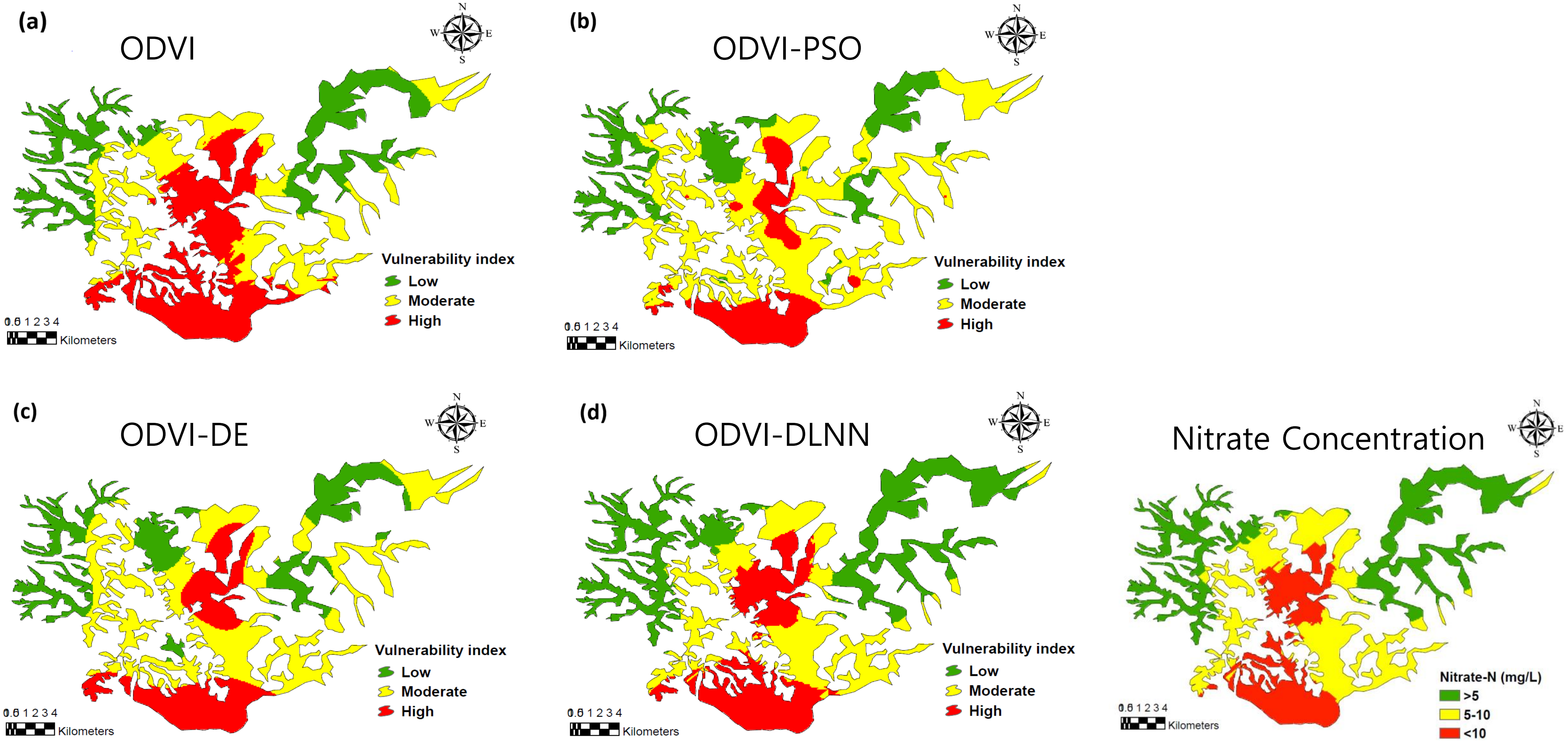


Testing Phase

Correlation coefficients with nitrate and increments of 4 models

Model	Correlation coefficient (γ)	Correlation increment $(r_{model} - r_{ODVI}) / r_{ODVI}$ (%)
ODVI	0.45	0.0 %
ODVI-PSO	0.70	55.6 %
ODVI-DE	0.72	60.0 %
DLNN (Strategy-2)	0.97	115.6 %

Groundwater vulnerability index maps



Class area ratios allocated by 4 models

Model	Class area in percent (%)		
	Low	Moderate	High
ODVI	17.9	15.0	67.1
ODVI-PSO	24.8	43.5	31.7
ODVI-DE	26.8	41.2	32.0
DLNN (Strategy-2)	33.0	24.7	42.3

Conclusions

- Two-strategy-level modeling approach was useful to avoid the shortcomings of the ODM and to increase the accuracy of the final groundwater vulnerability assessment.
- The artificial intelligence DLNN model of strategy-2 produced more accurate results compared to ODVI-DE, OSDVI-PSO, and ODVI index models of strategy-1.
- This research can contribute to the water security of any groundwater contaminated areas through the reliable assessment of two-strategy-level modeling.

Thank you for your attention !!!