SENSITIVITY ANALYSIS OF AN INTEGRATED NUMERICAL FLOW MODEL OUTPUT TO KEY MODEL PARAMETERS USED IN COMMON QUALITATIVE VULNERABILITY ASSESSMENT METHODS

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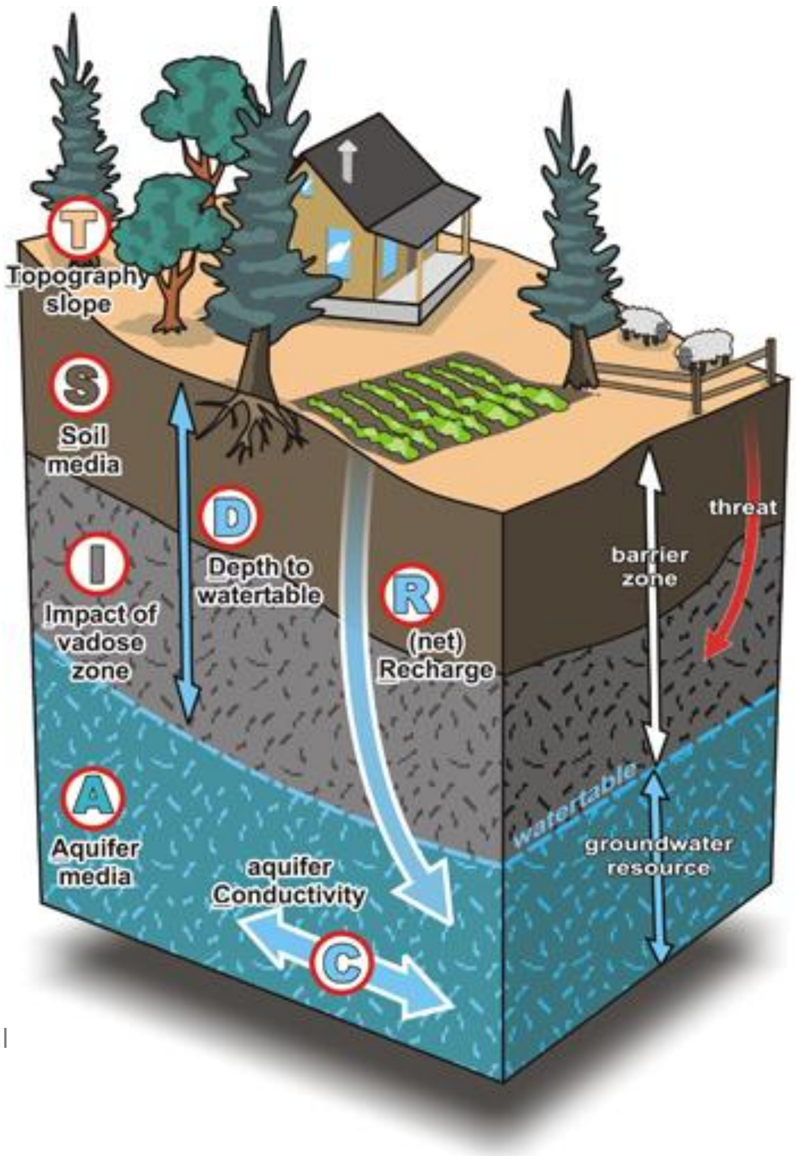
Introduction

Intrinsic groundwater vulnerability



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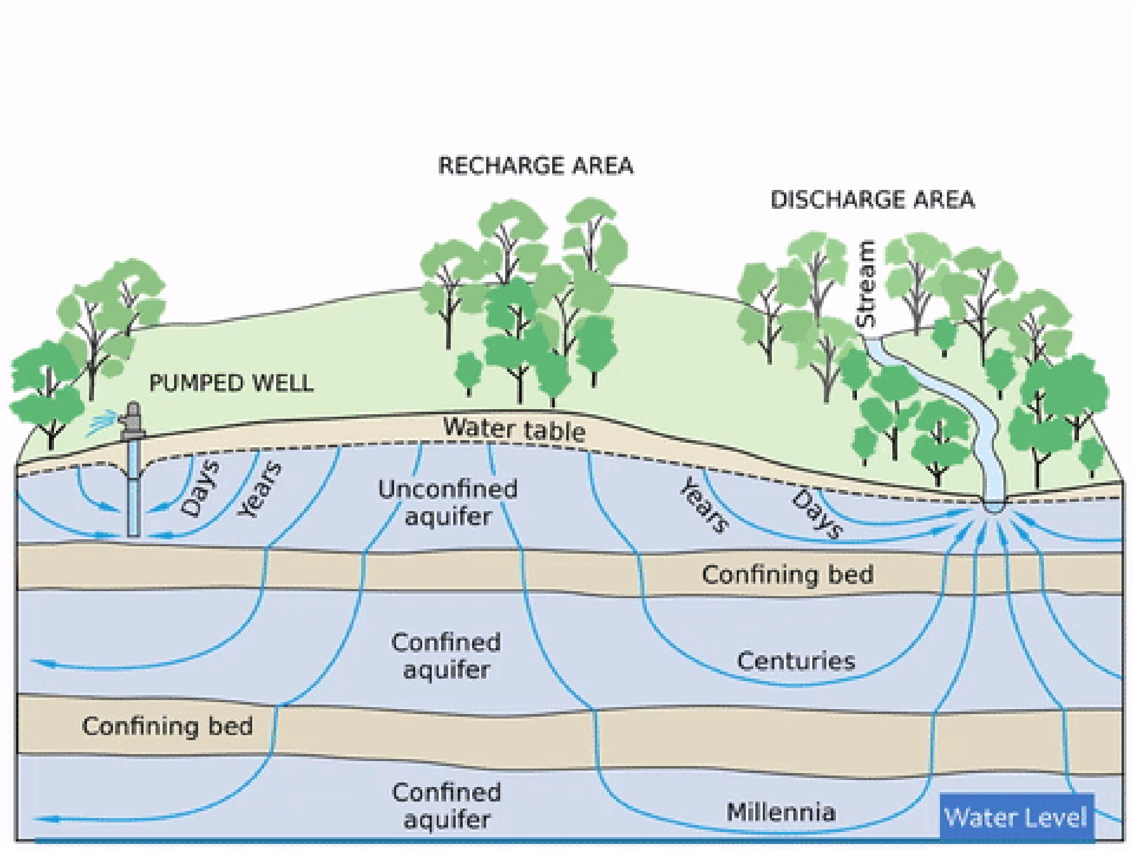
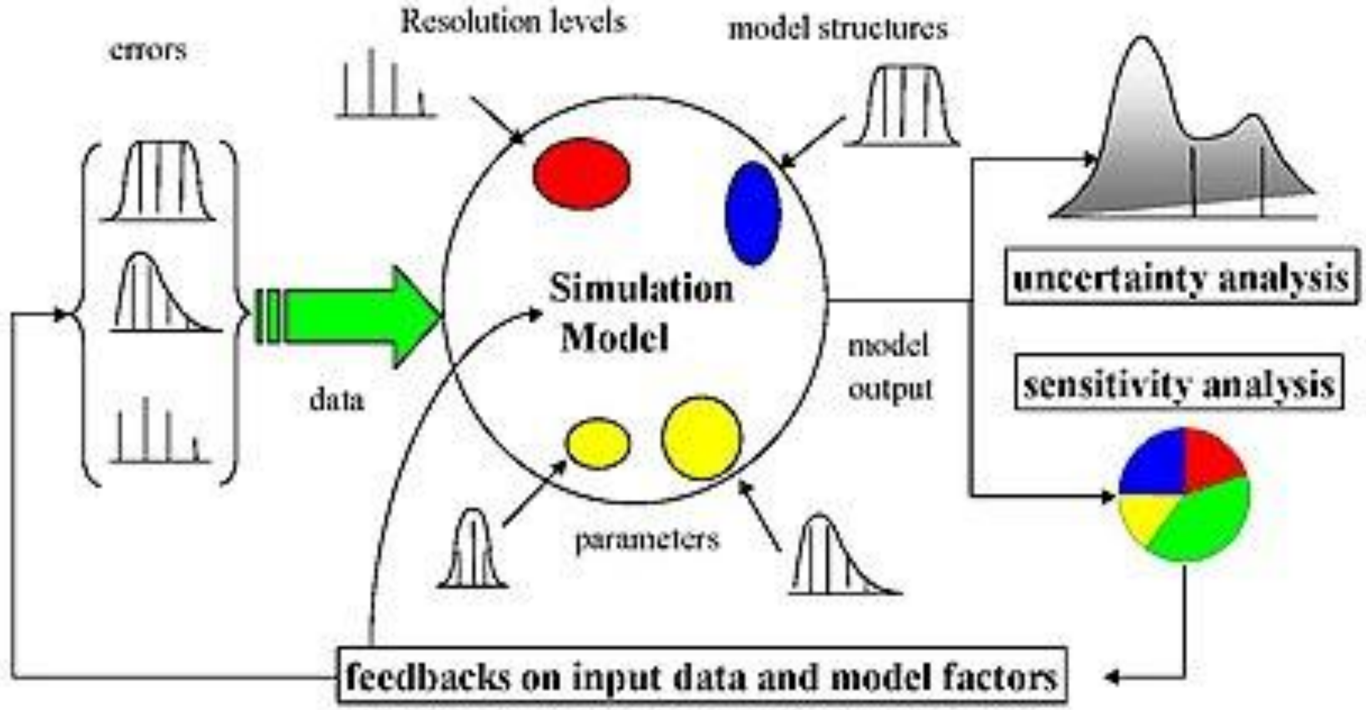
Groundwater Integrated Models



Retrieved from: https://www.hydrosconsult.eu/hydrology/groundwater-modelling/

Sensitivity Analysis



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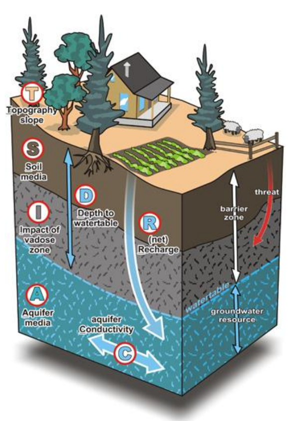
Introduction

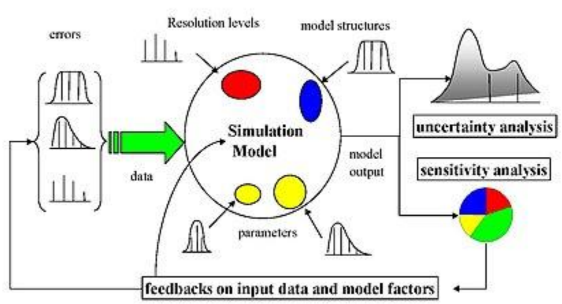
Scope of work

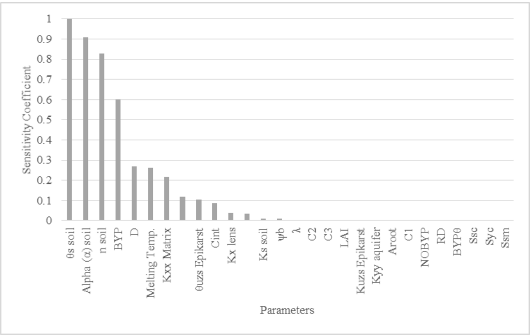
Model Local Sensitivity

Integrated Groundwater Model Simulation in karst → Sensitivity Analysis on Model Parameters → Parameters Weighing and impact on Vulnerability according to the quantified impact of Model parameters on model output

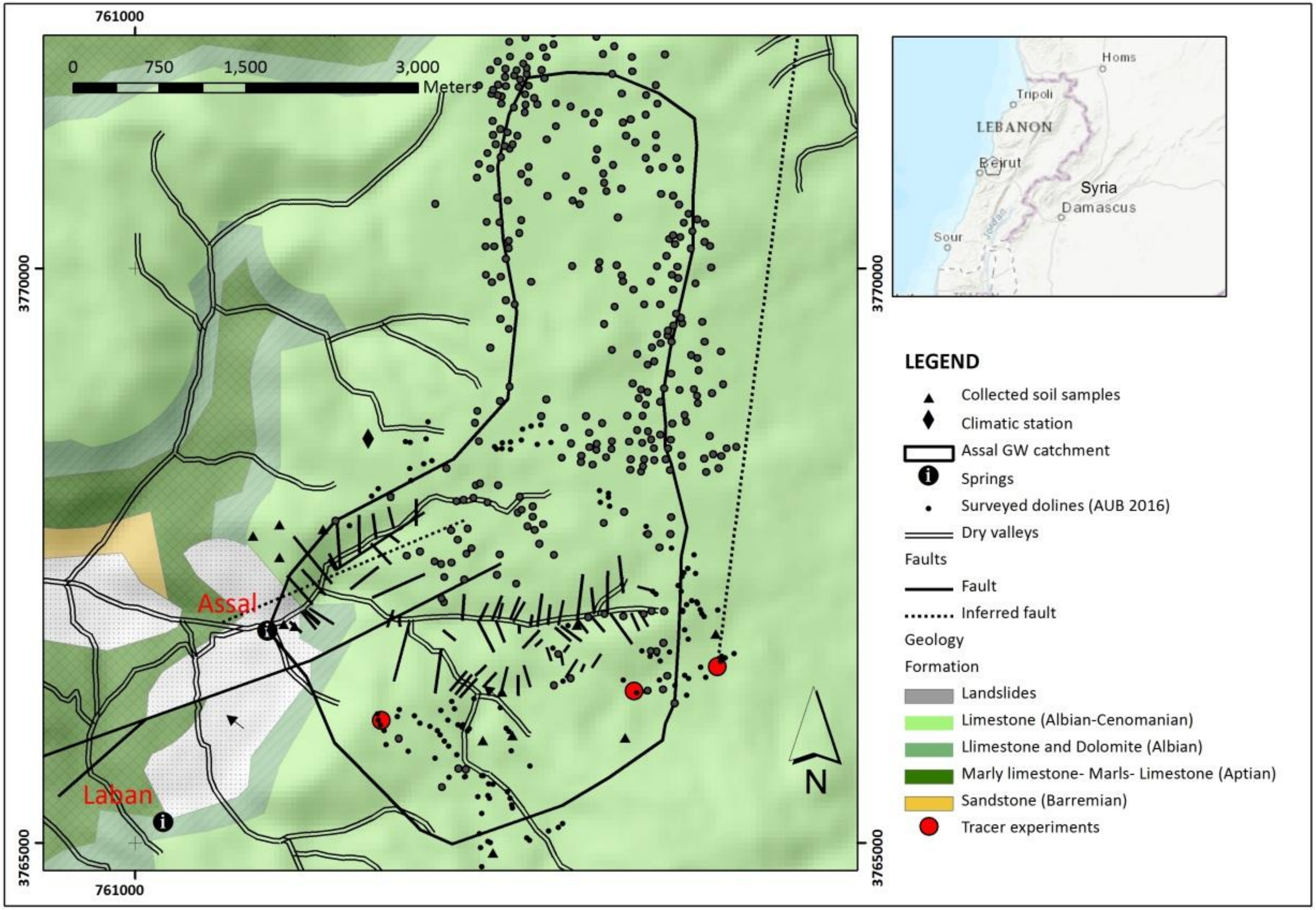
Statistical analysis of model output







Study Area



761000
0
750
1,500
3,000
Meters
3770000
3765000
Assal
Laban
N
Homs
Tripoli
LEBANON
Beirut
Syria
Damascus
Sour
LEGEND
Collected soil samples
Climatic station
Assal GW catchment
Springs
Surveyed dolines (AUB 2016)
Dry valleys
Faults
Fault
Inferred fault
Geology
Formation
Landslides
Limestone (Albian-Cenomanian)
Llimestone and Dolomite (Albian)
Marly limestone- Marls- Limestone (Aptian)
Sandstone (Barremian)
Tracer experiments

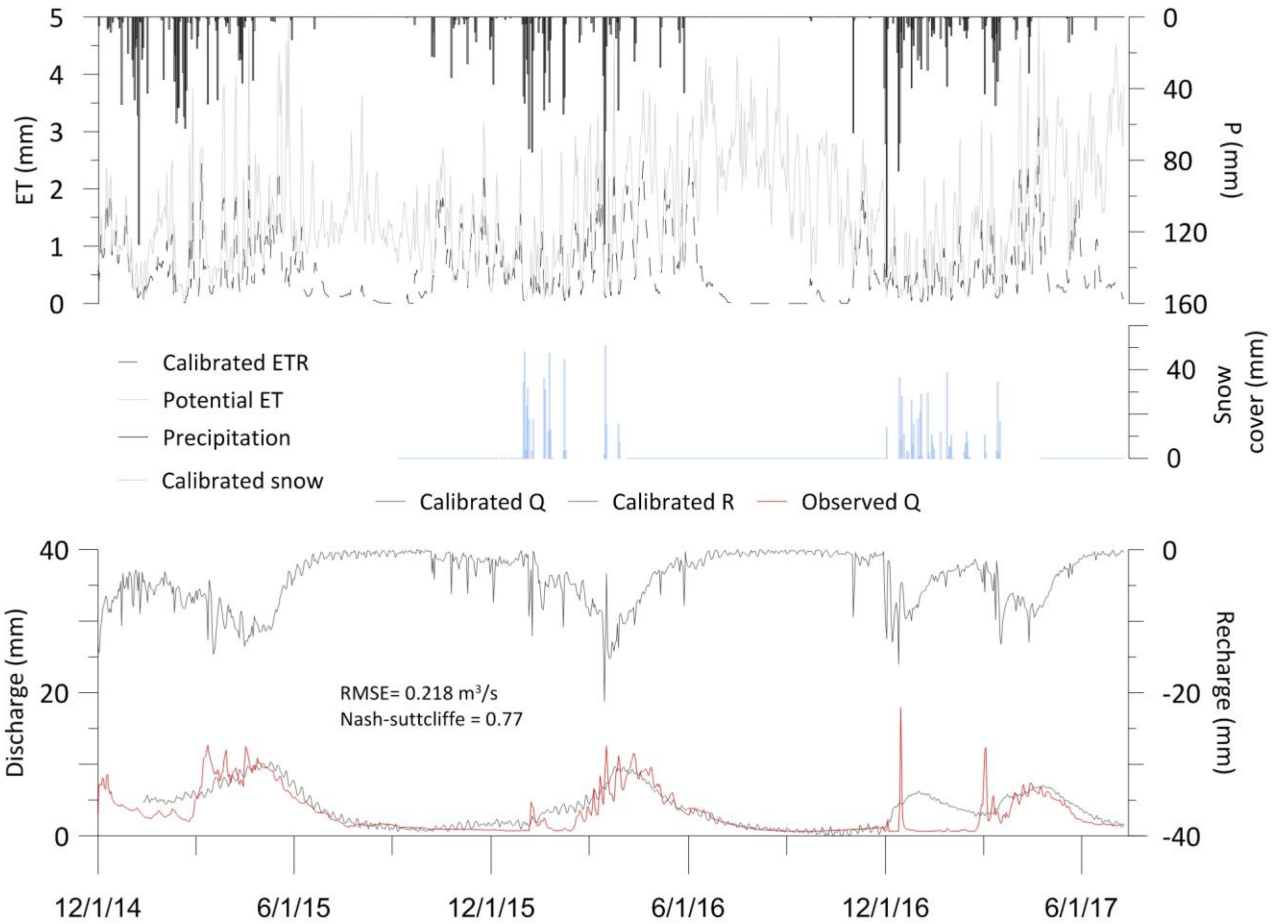
Tools and Methods

1. Integrated flow model
2. Automatic sensitivity analysis
3. Time series manual statistical sensitivity analysis

Tools and Methods

Integrated Flow Model

- Mike She (DHI, 2017) used as numerical engine
- Transient calibrated model (Nash-Sutcliffe=0.77, and RMSE = 0.218 m^3/s)



(Doummar et al., 2018)

Tools and Methods

Selection of parameters Integrated Flow Model

Selection of main parameters for testing and variations in the corresponding karst compartments:

1. Atmosphere (precipitation)
2. Unsaturated zone (lithology, soil, and epikarst)
3. Land use and geomorphological features
4. Karstic features (highly conductive lens and dolines)
5. Saturated zone (lithology)

Tools and Methods

- Local sensitivity analysis
- Central approximation method

$$S_i = \frac{\partial F}{\partial \theta_i}$$

$$\Delta\theta_i = f_c \theta_i$$

$$\Delta\theta_i = f_c(\theta_{i,upper} - \theta_{i,lower})$$

$$S_i = \frac{F(\theta_1, \theta_2, \dots, \theta_i + \Delta\theta_i, \dots, \theta_n) - F(\theta_1, \theta_2, \dots, \theta_i - \Delta\theta_i, \dots, \theta_n)}{2\Delta\theta_i}$$

Where
F is the output measure
θi is the model parameter
Fraction of the parameter interval
Өi,upper and Өi,lower are the specified limits of the parameter

Tools and Methods

Manual Statistical Analysis

Varied parameters from (COP and EPIK)

Manual statistical analysis based on one parameter variation at a time by applying three methods:

1. Preliminary model performance measures
2. Variance-based sensitivity assessment methods
3. Geomorphology qualitative assessment

Tools and Methods

Manual Statistical Analysis

1. Preliminary model performance measures

Performance measure		Selection criteria and ranking	Impact on vulnerability
Residual Mean Square Error (RMSE)	$RMSE = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(S_i - C_i)^2}$	RMSE closer to 0	Integrated sensitivity of the calibrated model in response to parameters variations
Nash Sutcliffe coefficient (E)	$E = 1 - \frac{\Sigma(S_i - C_i)^2}{\Sigma(S_i - \frac{1}{n}(\Sigma S_i))}$	Closer to 1	
Coefficient of determination (R^2)	$R^2 = 1 - \frac{\Sigma(S_i - C_i)^2}{\Sigma(C_i - \overline{C})^2}$	Closer to 1	
Recession Coefficient (α)	$\alpha = \frac{1}{t}\ln\frac{Q_{max}}{Q}$	Closer to calibrated	Sustainable volume available for dilution and aquifer response to upper hydrological compartments
Maximum (Q_t)	Maximum (Q_t)	Closer to calibrated	Sustainable volume available for dilution
Minimum (Q_t)	Minimum (Q_t)		
Mean (Q_t)	Mean (Q_t)		
Kling-Gupta Coefficient (KGE)	$1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$		Model performance and Volume available for dilution

Tools and Methods

Manual Statistical Analysis

2. Variance-based sensitivity analysis methods (Song et al. 2015)

Local Sensitivity Measure	Ranking Criteria	Relationship with groundwater Vulnerability
Discharged Volume (V) $\frac{\sigma^2(Parameters\ Variation)}{\sigma^2(V)}$	Local sensitivity and values of the measures are inversely proportional to parameter sensitivity	Volume available for dilution
Mean Spring Discharge (Qt) $\frac{\sigma^2(Parameters\ Variation)}{\sigma^2(Mean\ (Qt))}$		Sustainable volume available throughout the hydrological year
Sum of Residuals (R) $\frac{\sigma^2(Parameters\ Variation)}{\sigma^2(R)}$		Spring discharge variations that can show groundwater quantities deviations

3. Geomorphology qualitative assessment

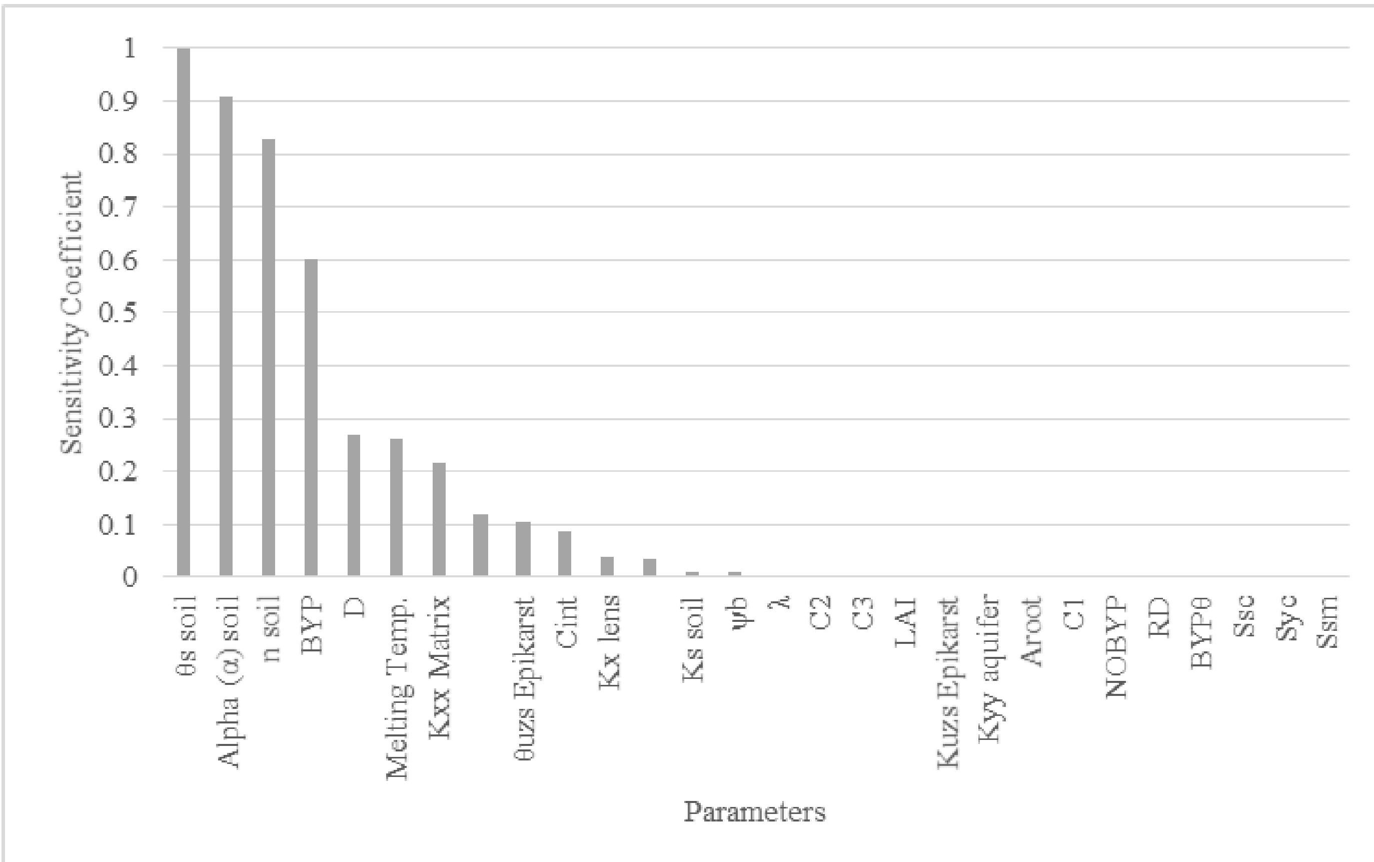
Slope Steepness	Surface Exposed Material
Very Steep (> 35°)	Bare-Rock (Fractured Limestone)
	Doline (Clayey Soil)
Very Gentle (0°-5°)	Bare-Rock (Fractured Limestone)
	Doline (Clayey Soil)

Results and Discussions

1. AUTOCAL results and analysis

2. Time series statistical analysis results
   - Preliminary statistical assessment
   - Variance based methods assessment
   - Geomorphology and slope impact on groundwater vulnerability
   - Modeling-based parameters ranking compared to qualitative methods coefficients

Graphical representation of AUTOCAL outcomes



Results and Discussions

AUTOCAL Results and Analysis

Most Sensitive Parameters:

- Unsaturated zone soil hydraulics (θs soil saturated moisture content, and α and n Van Genuchten water retention curve empirical parameters)
- BYP (bypass portion of net rainfall)

Moderately Sensitive Parameters:

- Climatic Parameters: (Degree Day Coefficient (D) and melting temperature)
- Hydraulic conductivity of the Aquifer and highly conductive lens

Least to none sensitive parameters:

- Vegetation cover
- Epikarst empirical parameters
- Soil hydraulic properties that play a role in fast infiltration other than BYP

Results and Discussions

- Preliminary statistical assessment

RMSE: aquifer Sy (least sensitive 0.11 m^3/s)
KGE: most sensitive (soil thickness, hydraulic conductivity of aquifer and lens)
Discharge related function: bypass did not affect spring discharge trends

- Conclusions

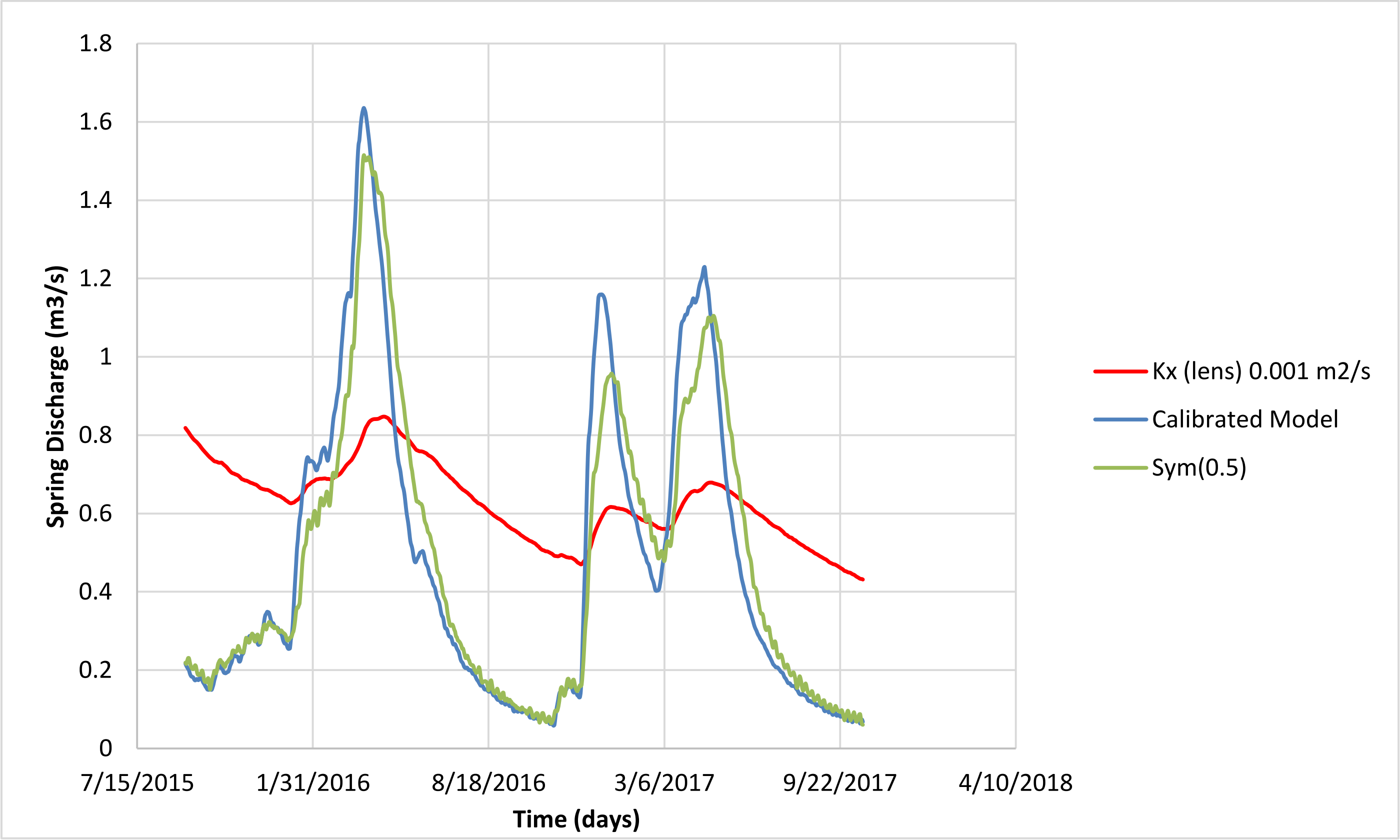
1. Specific yield and saturated moisture content (θs) variations from the calibrated parameter value have increased groundwater vulnerability;
2. Soil thickness is inversely proportional to groundwater vulnerability; and
3. Higher hydraulic conductivity values of the highly conductive zone and the aquifer increase groundwater vulnerability.

Results and Discussions

Time Series Statistical Analysis Results

Preliminary Statistical Assessment

- Preliminary statistical assessment



Results and Discussions

Time Series Statistical Analysis Results
Variance Based Methods Assessment

- Variance based methods assessment

Year 1 (2015-2016)

Objective Function	σ^2(parameter) / σ^2 (Yearly Discharged Volume)	σ^2 (parameter)/ σ^2 ($\sum r$)	σ^2 (parameter)/ σ^2 (Q mean)	Rank
Varied Parameters				
K lens (m/s)	1.86E-05	1.09E-03	2.40E+00	1
Precipitation	2.97E-05	3.00E-05	2.91E+00	2
Saturated moisture content (θs)	8.80E-05	2.11E-07	1.13E+01	3
Log(K aquifer (m/s))	2.30E-02	2.30E-02	2.13E-04	4
Temperature	9.20E-02	8.72E-02	9.02E+03	5
Bypass	1.36E-01	1.36E-01	1.75E+04	6
Soil thickness(m)	1.95E-01	1.95E-01	2.52E+04	7
Specific Yield	2.73E-01	2.73E-01	3.52E+04	8

Results and Discussions

Time Series Statistical Analysis Results
Variance Based Methods Assessment

- Variance based methods assessment

Year 2 (2016-2017)

Objective Function	σ^2 (par)/ σ^2 (Yearly Discharged Volume)	σ^2 (parameter)/ σ^2 (∑r)	σ^2 (parameter)/ σ^2 (Q mean)	Rank
Varied Parameters				
Precipitation	2.97E-05	3.00E-05	2.91E+00	1
Saturated moisture content (θs)	1.34E-04	1.96E-07	2.28E+01	2
K lens (m/s)	3.12E-05	5.31E+00	5.31E+00	3
Log(K aquifer (m/s))	4.11E-02	5.05E-04	5.05E-04	4
Temperature	9.20E-02	8.72E-02	9.02E+03	5
Bypass	1.50E-01	2.56E+04	2.56E+04	6
Soil thickness(m)	4.81E-01	8.20E+04	8.20E+04	7
Specific Yield	2.30E+00	3.93E+05	3.93E+05	8

Results and Discussions

Time Series Statistical Analysis Results
Variance Based Methods Assessment

- Variance based methods assessment

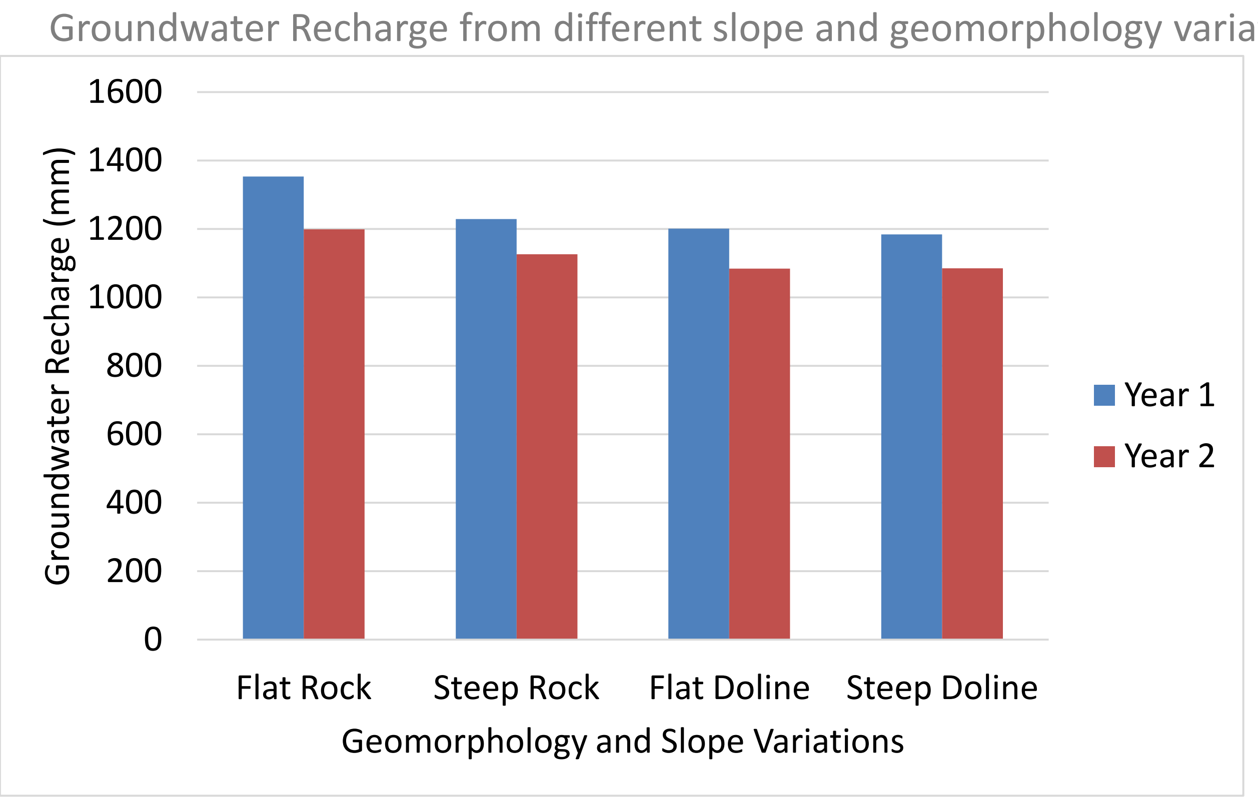
Variance-based Analysis Ranking

Parameter	Rank
Saturated Moisture Content	1
Precipitation	2
Hydraulic Conductivity of Lens	3
Hydraulic Conductivity of Aquifer	4
Temperature	5
Bypass	6
Soil thickness	7
Specific Yield Aquifer	8

Results and Discussions

Time Series Statistical Analysis Results
Geomorphology and Slope Impact on Groundwater Vulnerability

- Geomorphology and slope impact on groundwater vulnerability

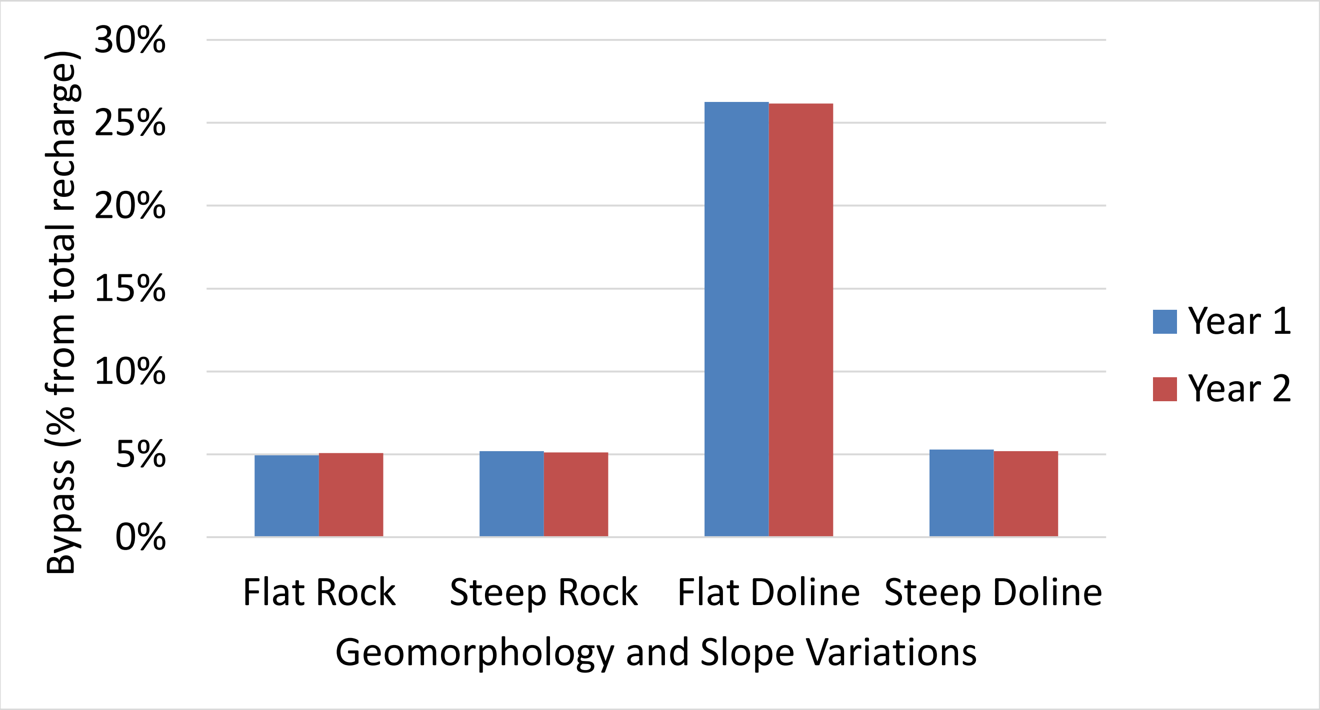


Results and Discussions

Time Series Statistical Analysis Results
Geomorphology and Slope Impact on Groundwater Vulnerability

- Geomorphology and slope impact on groundwater vulnerability

Bypass flow recharge from different slope and geomorphology variations



Conclusions and Recommendations

Conclusions:

A. Ranking of parameters:
   1. Soil hydraulics factors
   2. Climatic factors
   3. Aquifer along with highly conductive lens hydraulic factors

B. Geomorphological features have shown a decent impact on recharge trends and total volume

C. Vegetation cover have shown negligible impact on vulnerability

D. Modeling approach more efficient in terms scale and processes

E. Avoid over estimation of vulnerability classification

Conclusions and Recommendations

Limitations and recommendations:

A. Applying the global sensitivity approach for analysis

B. Conclusion depicted from this work shall be only applied on areas of similar environmental settings

C. Validation of this research's results by applying in other study areas