AGRICULTURE • INNOVATION • LIFE

Impact of Climate and Land-Use Changes on Water Quality

by

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SEAMEO SEARCA

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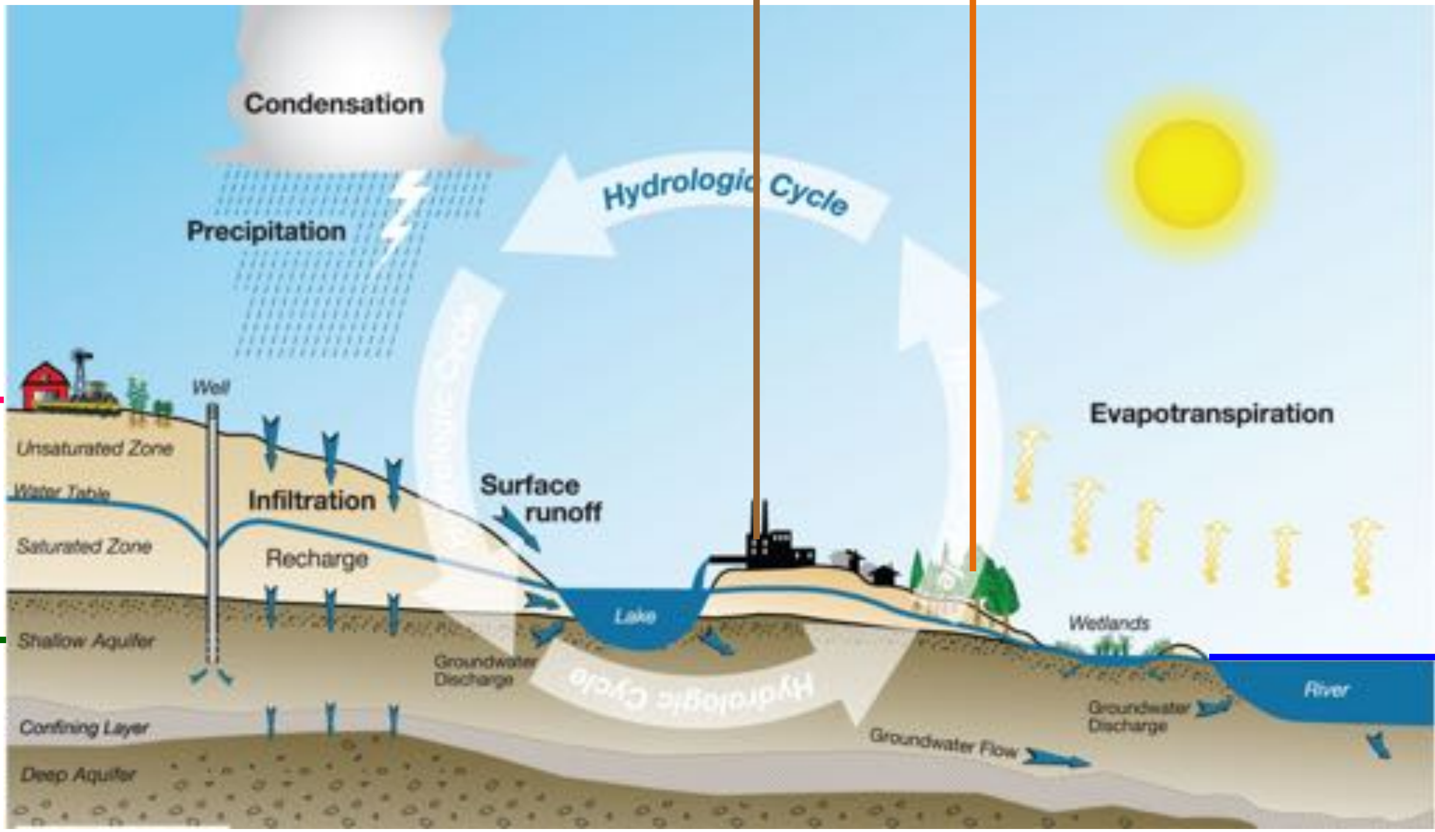
Factors Controlling the Water Quality

Anthropogenic sources
Industrial purposes
(cooling water, metallic minerals, toxic sewages, …)

Anthropogenic sources
Agricultural purposes
(fertilizers, pesticides, animal swage, deforestation, …)

Anthropogenic sources
Domestic purposes
(sewages, chemicals, road run off, …)

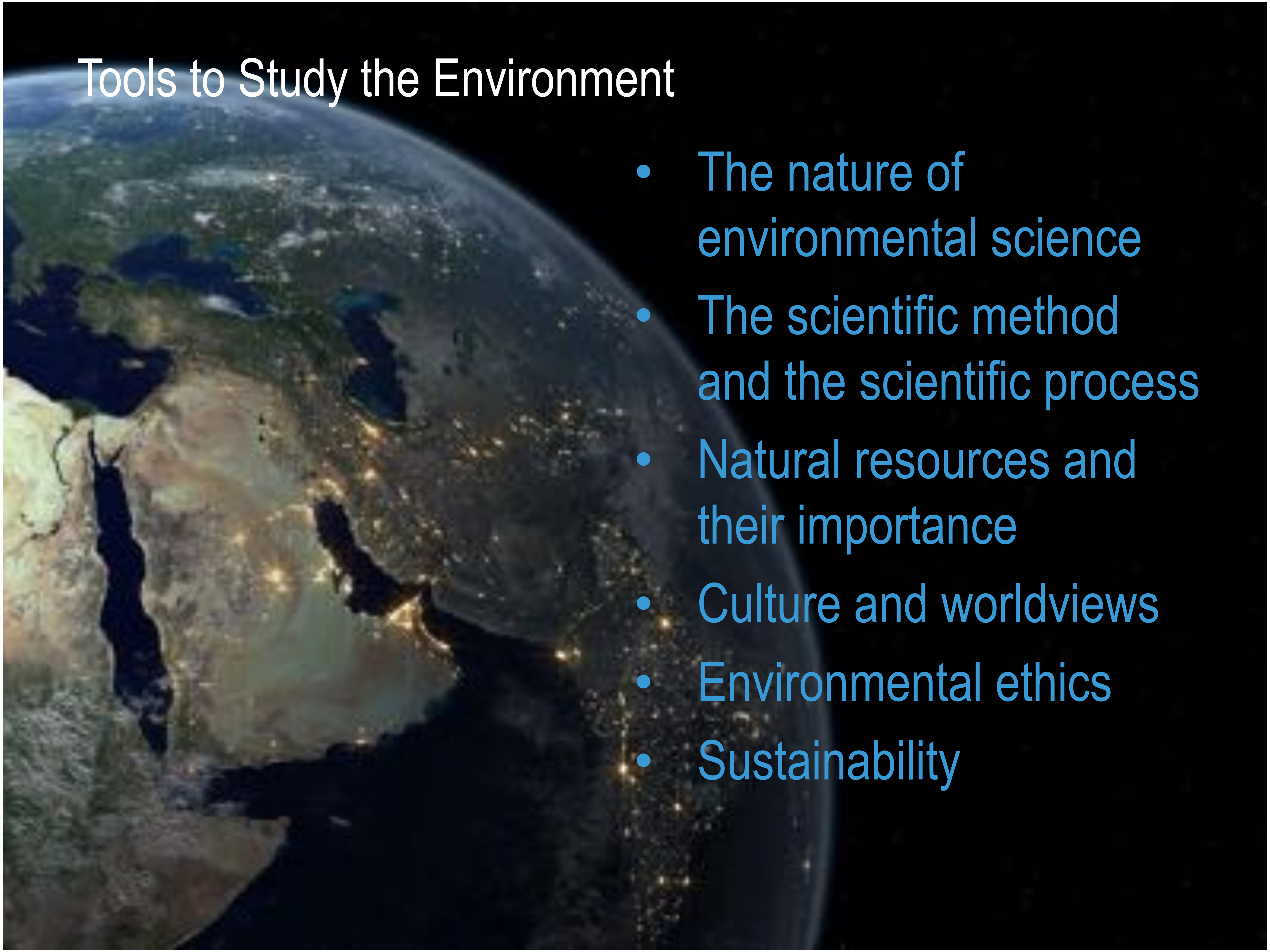


Natural sources
(dissolution of minerals and rocks, cation exchange)

Natural sources
(seawater intrusion to aquifers, mixing water)

Multiple Risks

Tools to Study the Environment



- The nature of environmental science
- The scientific method and the scientific process
- Natural resources and their importance
- Culture and worldviews
- Environmental ethics
- Sustainability

Environmental Assessment

Baseline conditions	Effects Assessment	Mitigation	Residual effects	Significance determination
Existing environment	Environmental effects	Environmental mitigation	Residual and cumulative environmental effects	Significance of adverse environmental effects

Hydrochemical Assessment

Step 1:
Select vulnerable area

Step 2:
Implement monitoring strategies

- Number of samples
- Sampling frequency
- Sampling time
- Sampling location

Step 3:
Samples collection, storage, transfer

- On site analysis
- Sample preservation

Step 4:
Laboratory analysis, QA/QC

Step 5:
Data analysis and modelling

- Statistical analysis
- Hydrochemical calculation and modelling

Step 6:
Results interpretation

Common Problems in Hydrochemistry Studies

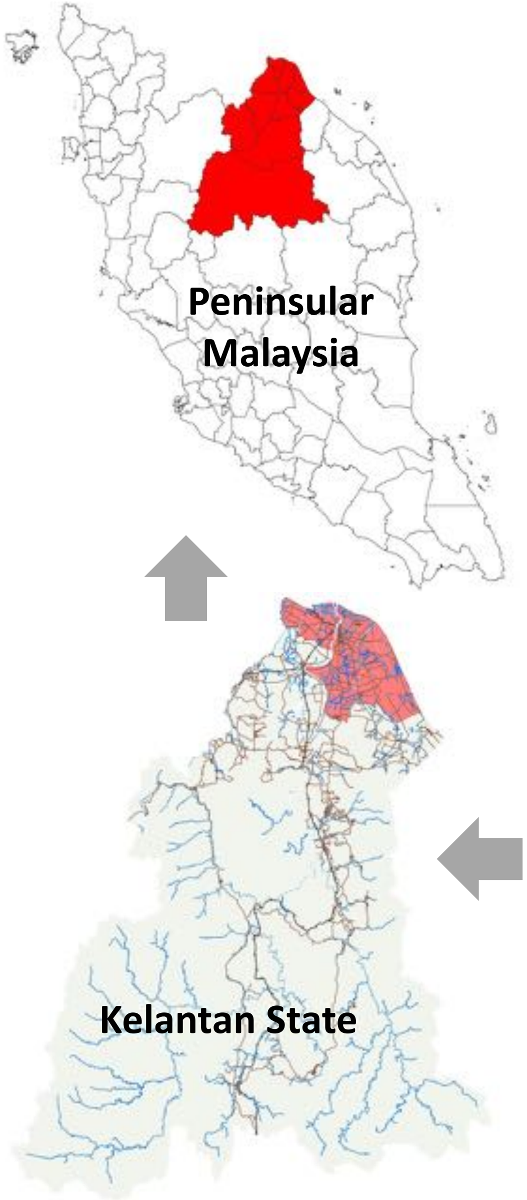
ADEQUATE METHODS and TOOLS

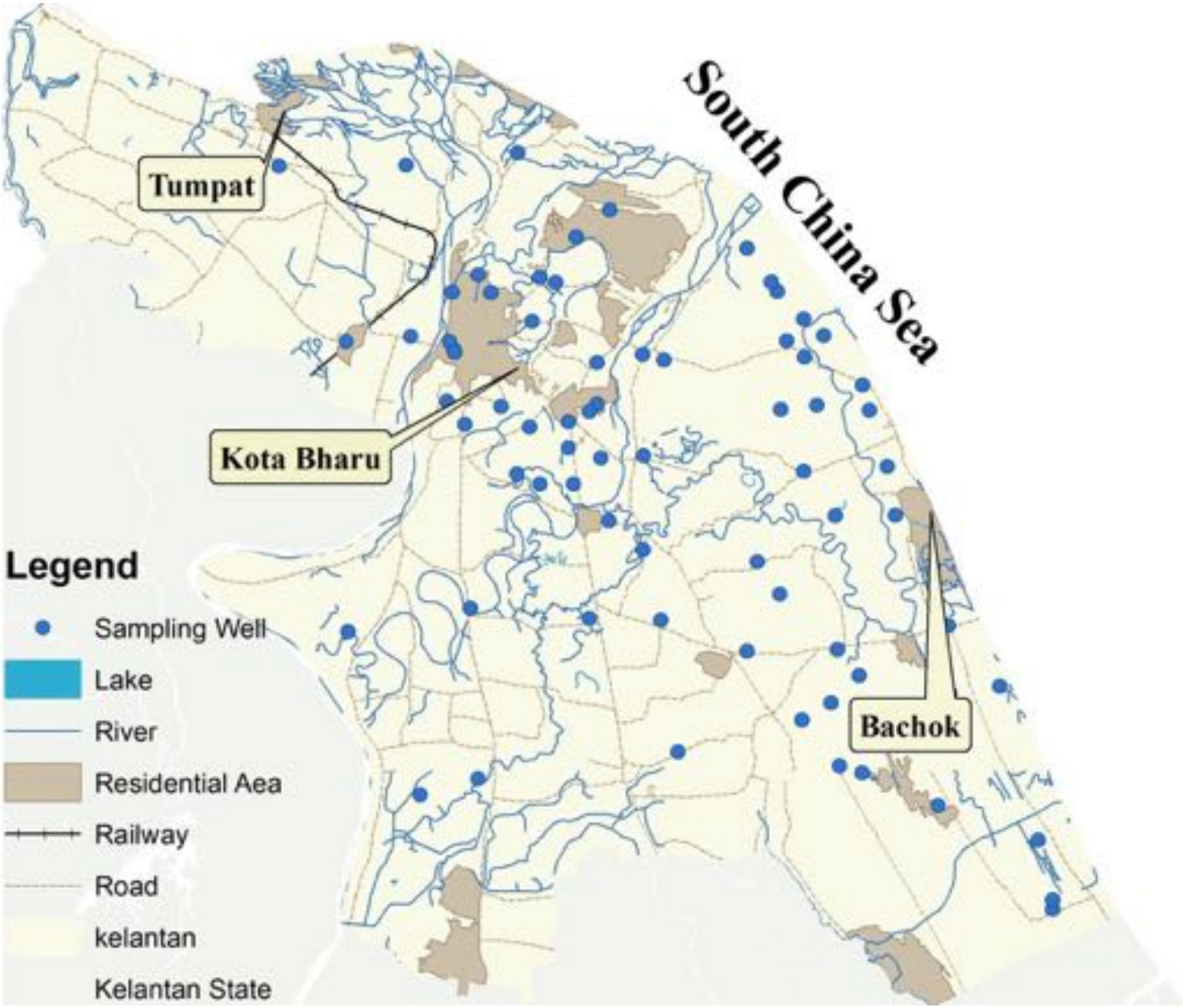
CHALLENGES

- Complex cause-effect relationships
- Spatio-temporal dimension
- Up-scaling processes to basin scale
- Missing data (if depends on secondary data)

- Large data set
- Data requirements
- Complex and dynamic interpretation

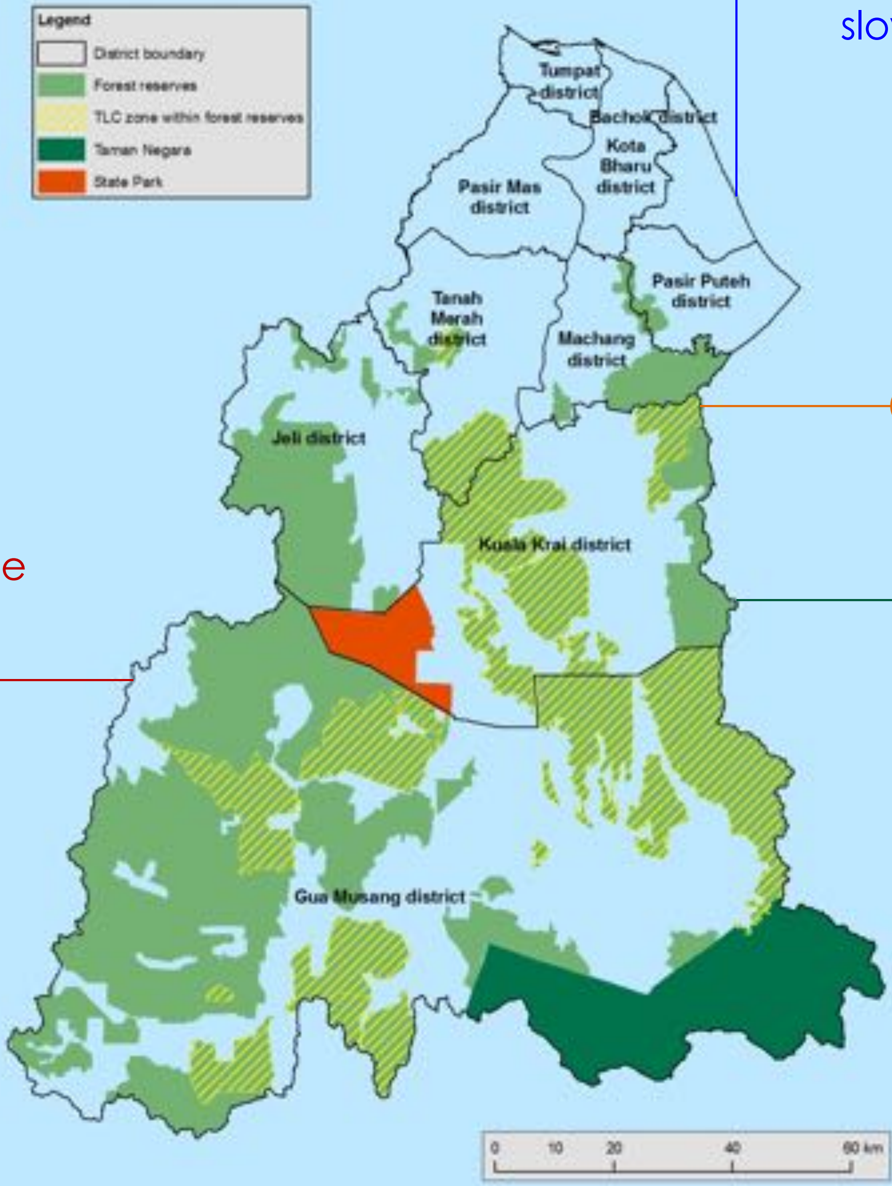
Study Area: Northern Kelantan Basin





Example of hydrogeochemical assessment
Case study: Northern Kelantan Basin

- From 1970s to 1990s land use change was progressive with 7% growth, the growth slowed in the 1990s to 1.4%.



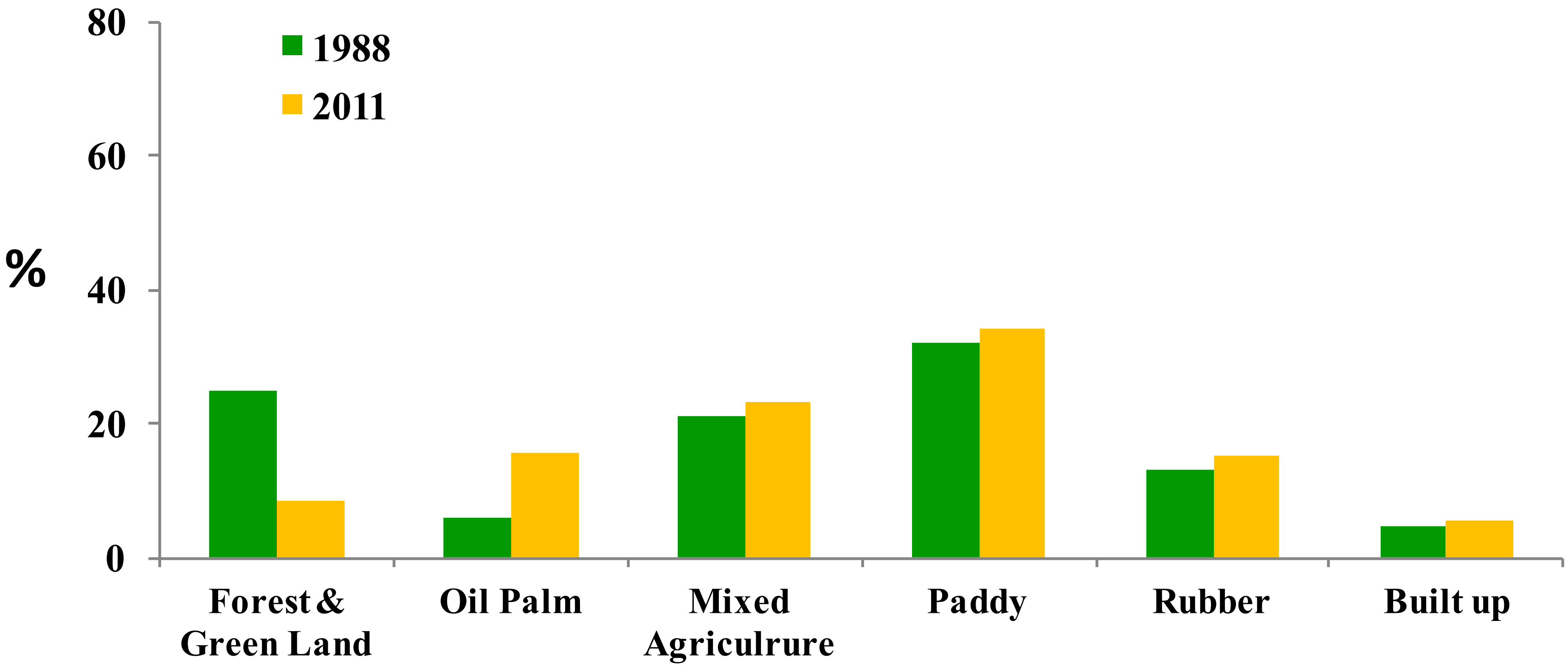
- 71.8% (around 10783.98 km^2) of Kelantan State is covered with forest reserves, which are mainly located in the upstream region

- Approximately 70% of potable water is derived from groundwater sources

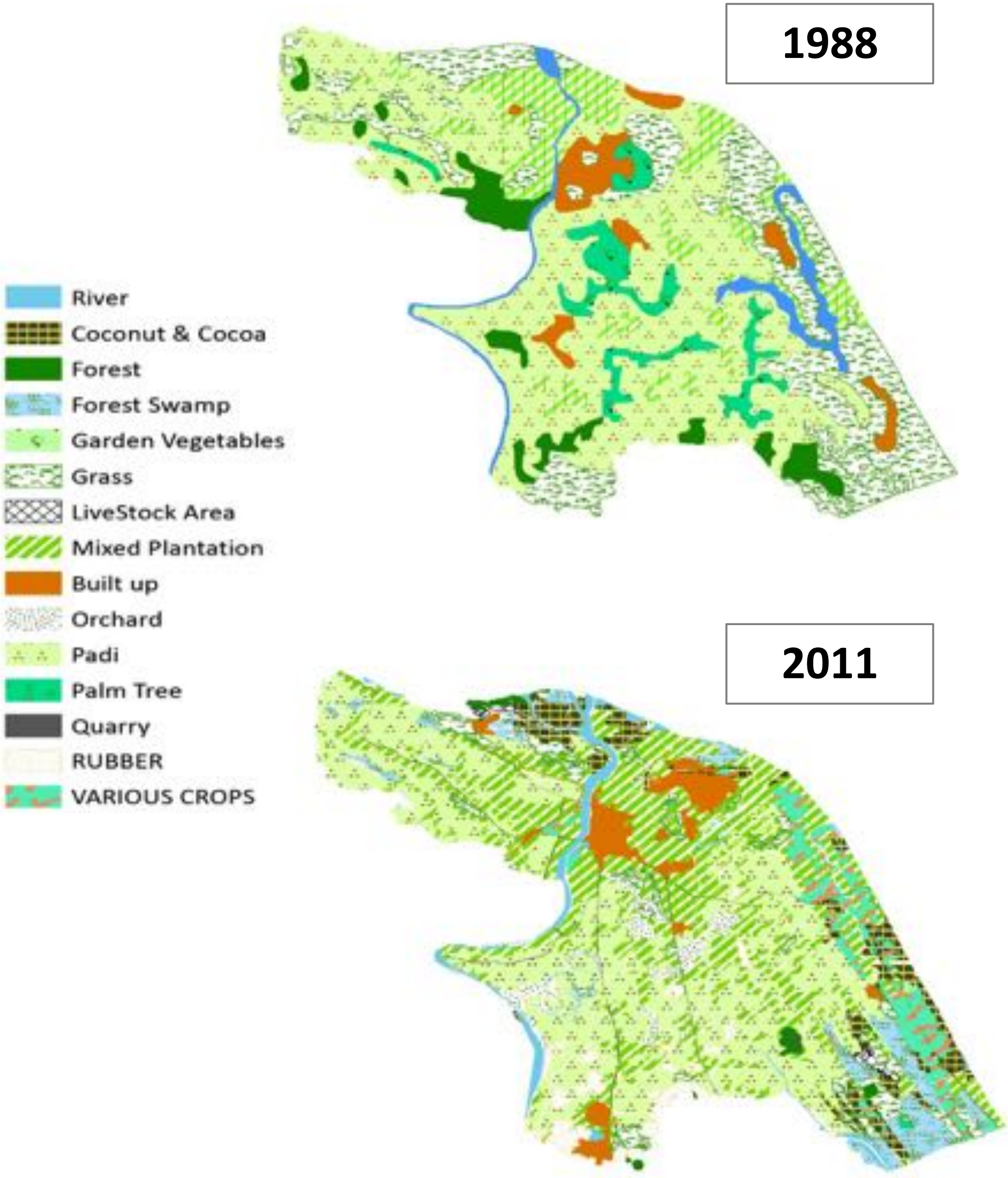
- Kelantan population increased from 1,174,000 (1990) to 1,718,000 (2015)

- Near 80% of the population concentrated in Northern Kelantan

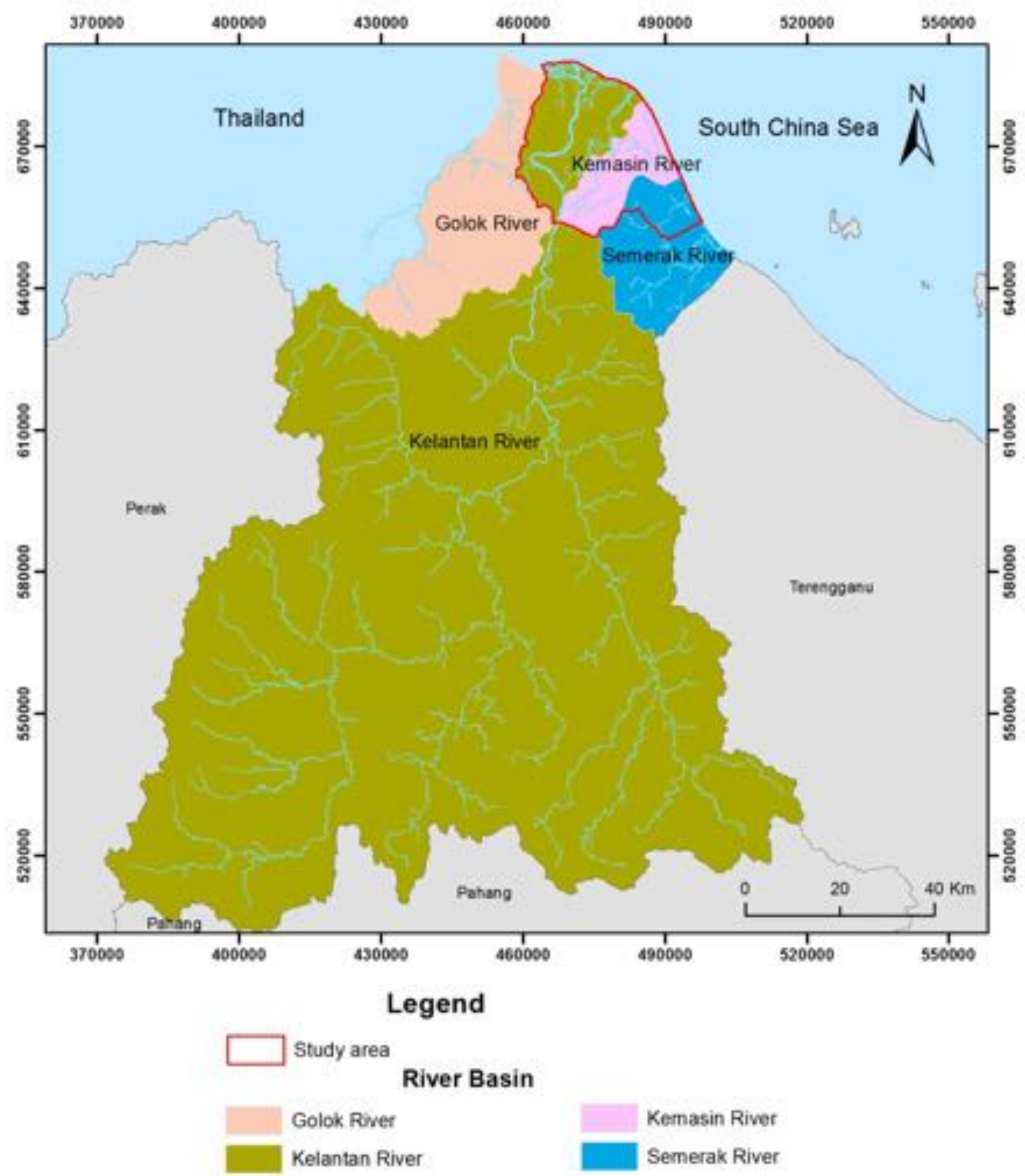
Northern Kelantan Basin (Land Use Activities)

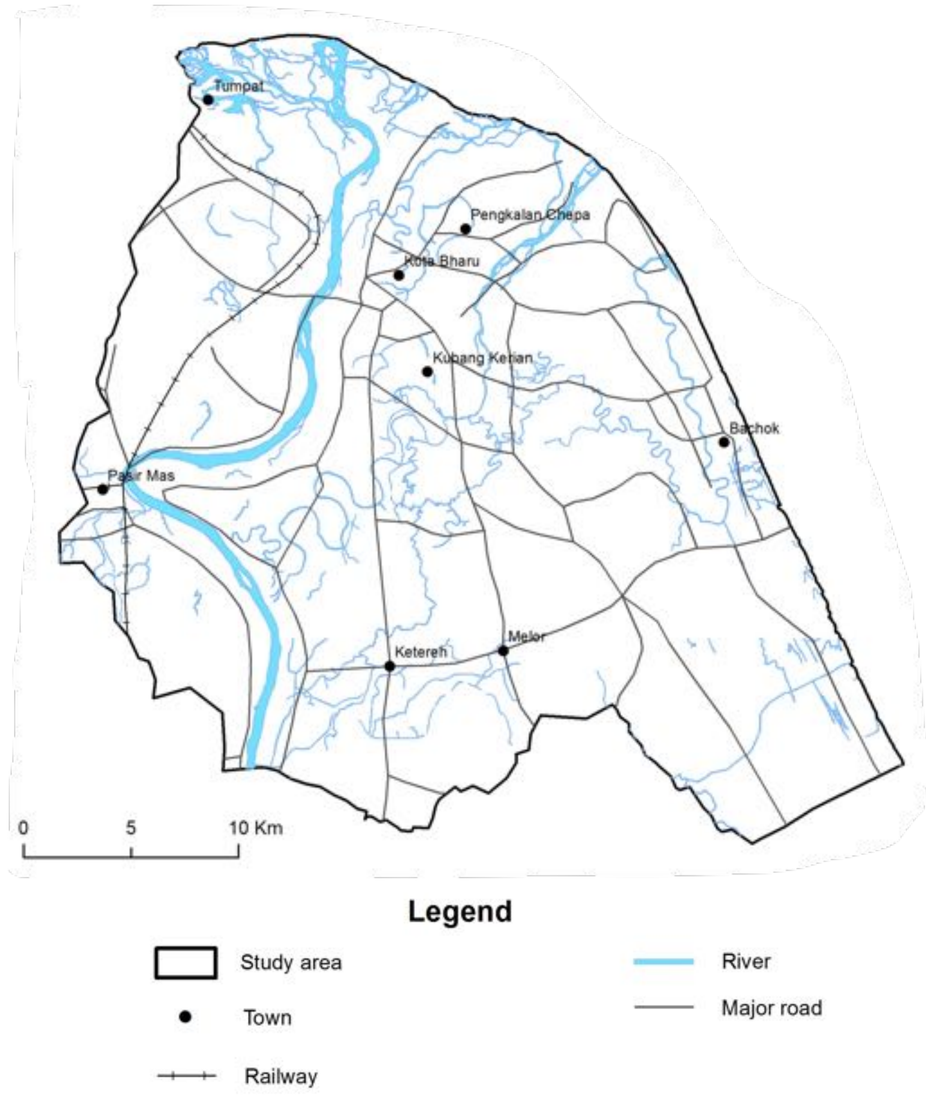


Northern Kelantan Basin (Land Use Activities)



Hydrogeochemical assessment
Case study: Northern Kelantan Basin

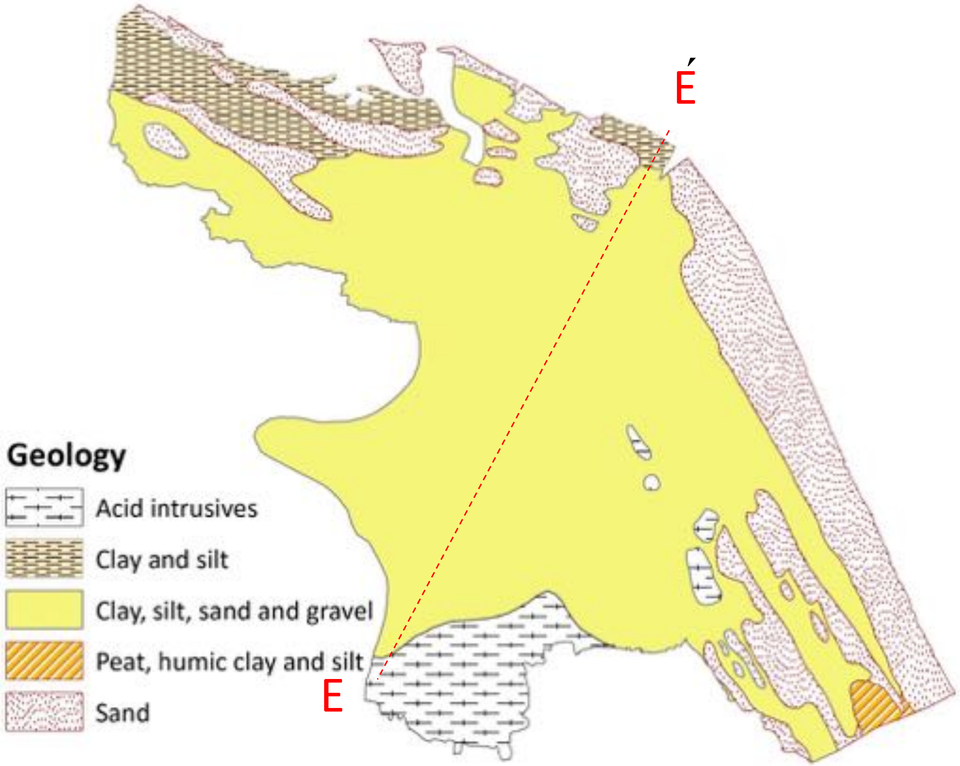




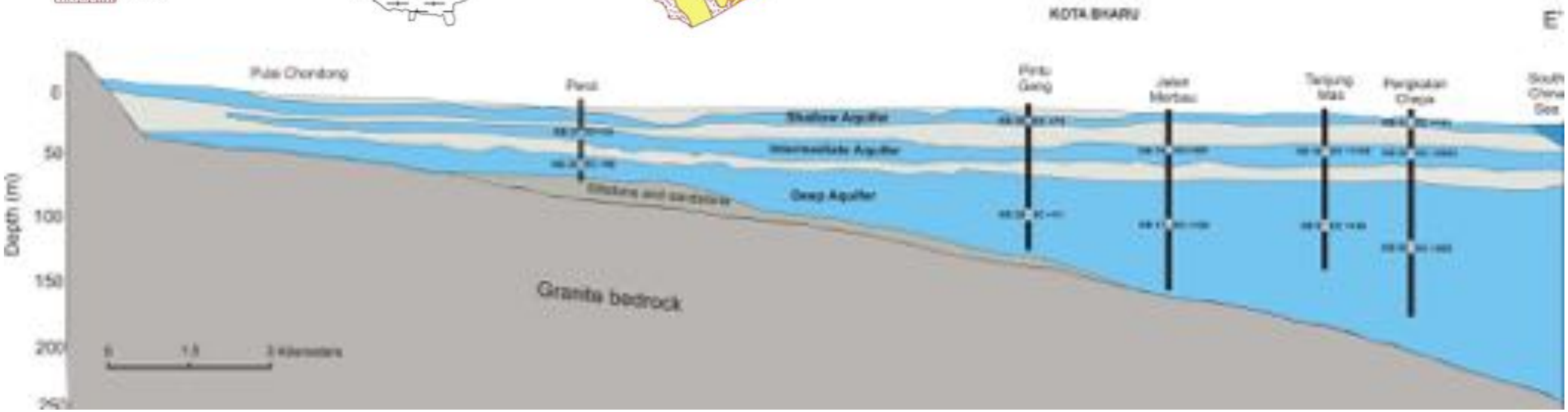
Sefie (2016)

Hydrogeochemical assessment

Case study: Northern Kelantan Basin

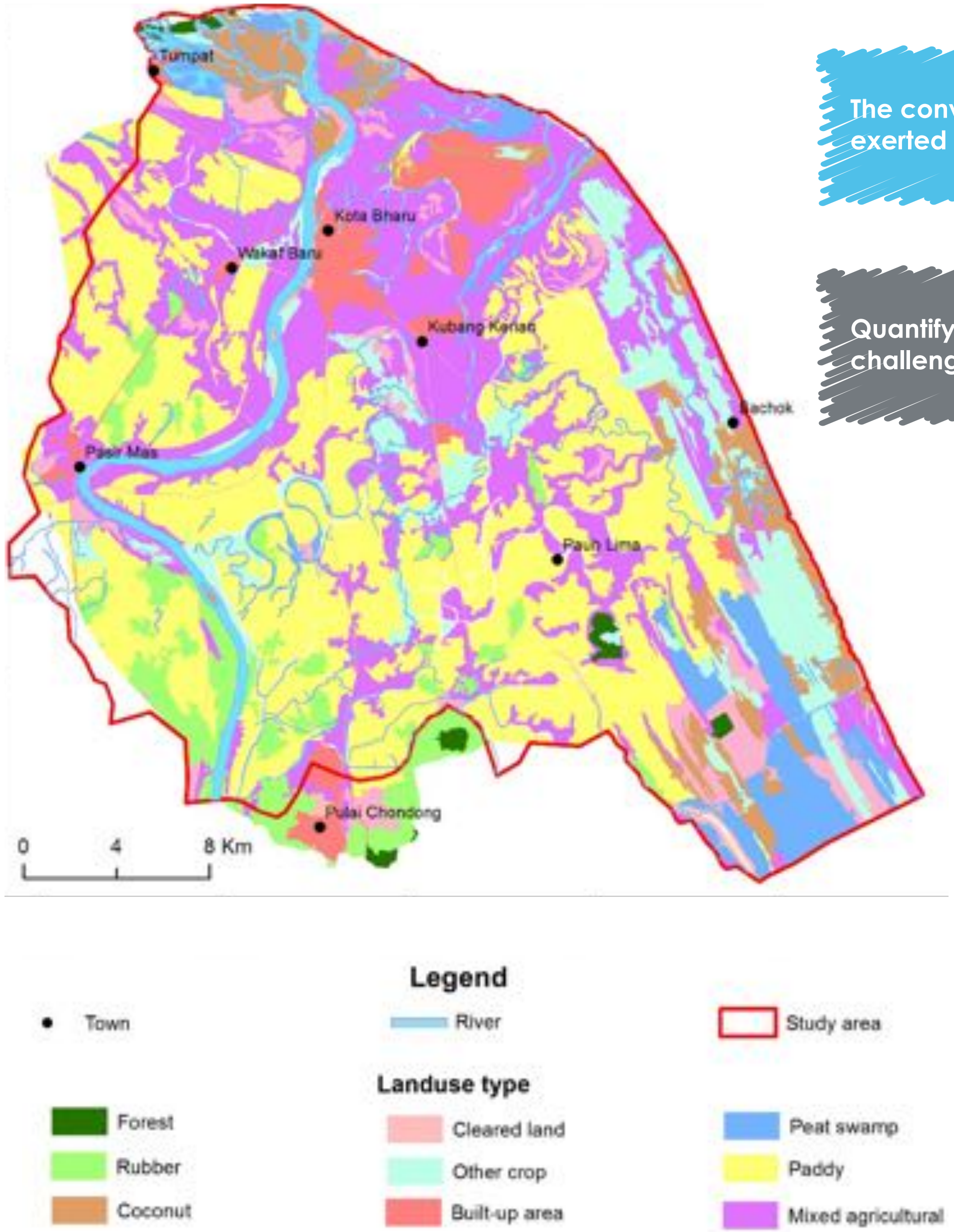


The groundwater in the intermediate aquifer up to an average distance 6 km from the coastline is affected by the fossil seawater, which probably trapped during the sedimentation.



Hydrogeochemical assessment

Case study: Northern Kelantan Basin



The conversions of forests and green lands to urban and farmland as have exerted significant changes on the terrestrial ecosystems.

Quantifying how these changes can affect the quality of water resources is still a challenge for hydrologists.

14 face rap over land clearings

LOJING PROJECT: Developers carry out projects without EIA reports

HARIZ MOHD
KUALA LUMPUR

FOURTEEN errant developers have so far been taken to court for flouting environmental rules in Lojing, Kelantan.

Natural Resources and Environment Minister Datuk Seri Douglas Uggah Embas said the developers — nine of whom had carried out projects without submitting Environmental Impact Assessment (EIA) reports — had to be taken to task for damaging the environment.

He said the environment authorities found that massive damage had been done to the rich flora and fauna in the Lojing area because of unlawful land development work.

"Of the 14 cases, nine developers had failed to come up with EIA reports while the other five had EIA reports, but had failed to follow its mitigation plans.

"We are monitoring the situation and will not hesitate to take action against any other developer who fails to adhere to the law," he told the *New Straits Times* yesterday.

Uggah was commenting on rampant land clearing activities in Lojing, which neighbours the famous tourism spot of Cameron High-

ESTABLISHED 1845

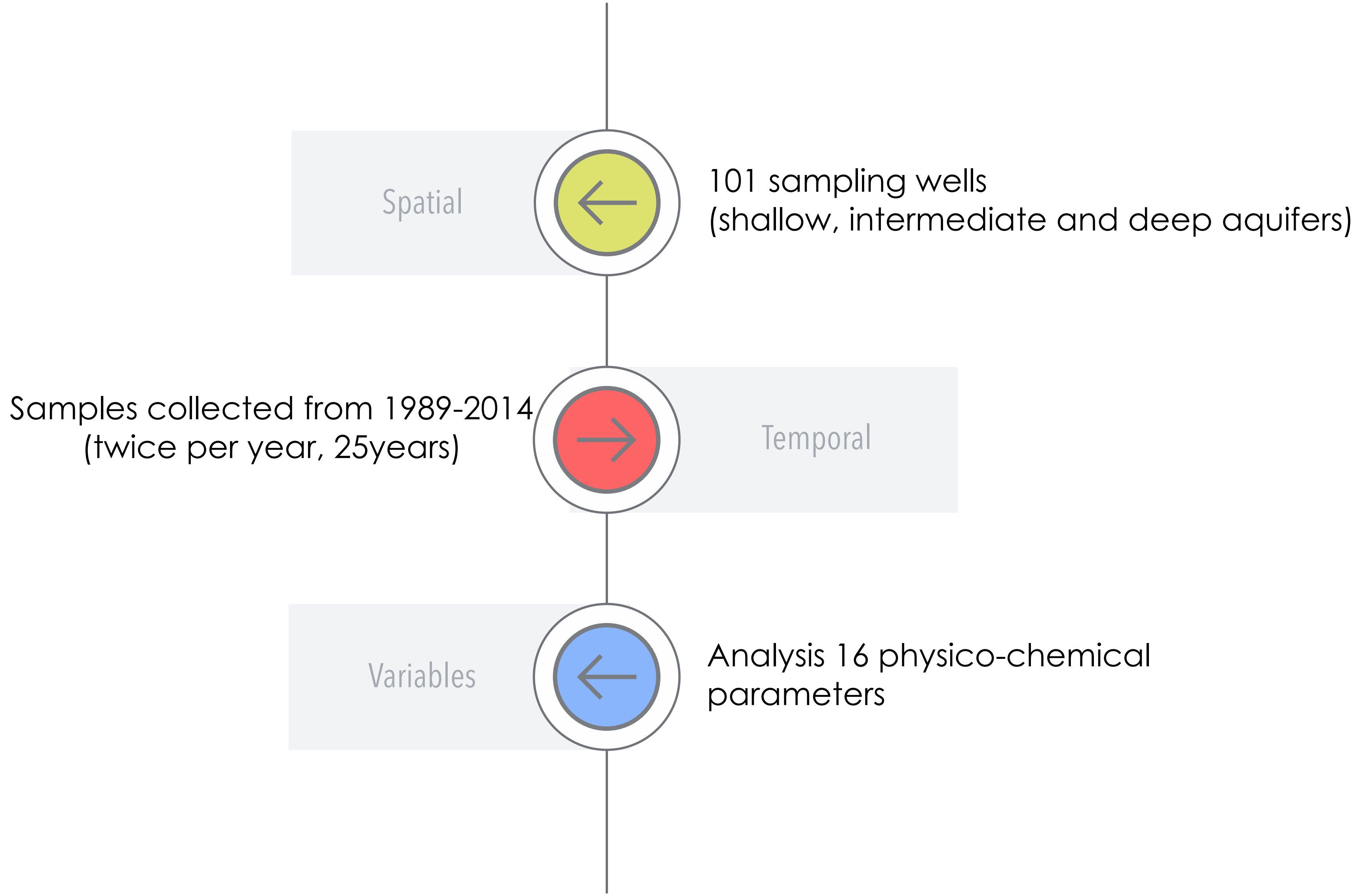
LOJING PLUNDERED: Massive environmental degradation as Kelantan government denies reality of situation, writes *Sharanjit Singh*

STRIPPED BARE

- State exco member insists there is no logging in the area because 'there is no timber left there'
- Plans drawn up for townships in an area where the rivers are the colour of 'teh tarik'
- NGOs demand transparency from state government

→ REPORTS ON PAGES 4 & 5

Groundwater monitoring strategies in the study area



Number of data

(101*25*2*16)= 80,800

Data analysis

- To reduce large number of variables to small important variables
- To mange large dataset
- To uncover pattern in variables

Factor Analysis/Principal Component Analysis

- To detect variation of variables over a period of time
- To analysis time data to characteristics of the data
- To predict future values based on previously observed values

Time series analysis

Statistical Analysis
Allow the simultaneous investigation of more than two variables

t test-ANOVA-MANOVA

- To detect significant differences among mean of variables
- To compare two or more than two groups of variables

Regression Analysis

- To estimate the relationship between the independent and dependent variables
- To determine the effect of independent variables on depend variable
- To predict the value of depend variable based on independent variables

Cluster analysis

- To classify of data objects based on the similarity and dissimilarity of variables

Data Analysis: Example of factor analysis
Hydrochemical investigation in the study area

- The first factor usually represents the most important process that controls hydrochemistry of groundwater

- Component factor 1 (F1) had a strong absolute loading of EC, TDS, Ca, Mg, Na, Cl, SO_4.
- F1 indicates strong signature of groundwater salinity, which may attributed by seawater intrusion.

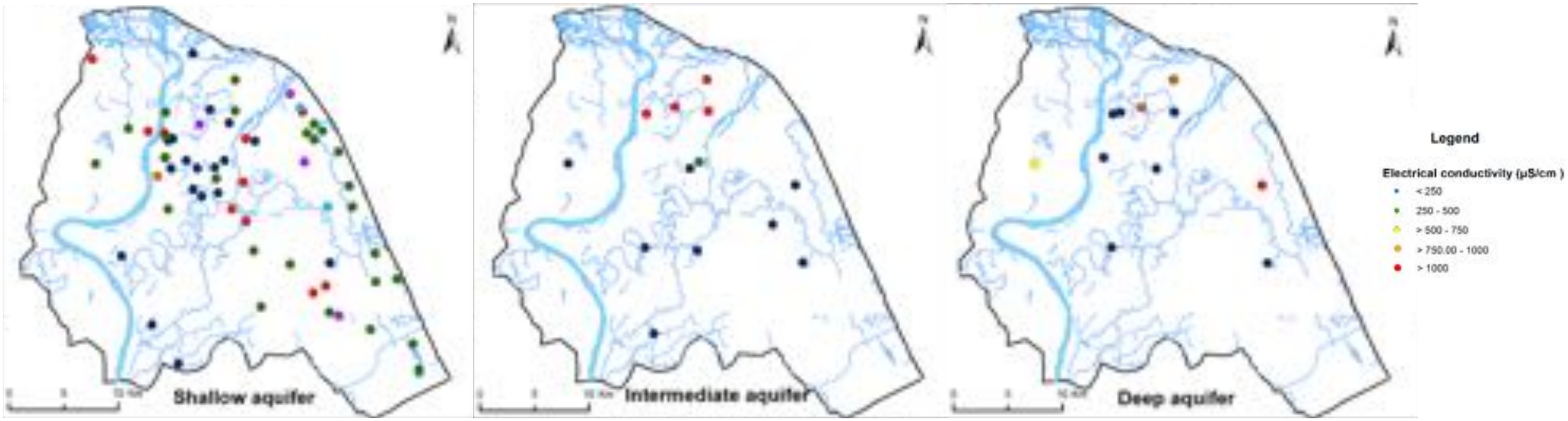
Variables	VF1	VF2	VF3	VF4
pH	0.057	**0.697**	-0.111	-0.198
EC	**0.888**	0.360	0.121	0.151
TDS	**0.889**	0.345	0.128	0.111
Ca	**0.671**	0.494	0.102	0.101
Mg	**0.782**	0.370	0.182	0.054
Na	**0.912**	-0.040	0.029	0.019
Cl	**0.902**	-0.180	0.021	-0.016
SO_4	**0.739**	0.002	0.007	0.141
K	0.509	0.299	0.199	0.489
CO_3	0.072	**0.652**	-0.056	0.098
HCO_3	0.495	**0.727**	0.161	0.043
NO_3	0.142	-0.029	-0.002	**0.846**
NH_4	0.030	0.098	0.200	-0.483
Fe	0.175	-0.045	**0.834**	-0.047
Mn	0.079	0.088	**0.831**	0.049
Eigenvalue	6.418	1.560	1.429	1.104
Variability (%)	36.026	14.743	10.554	8.749
Cumulative (%)	36.026	50.769	61.323	70.073

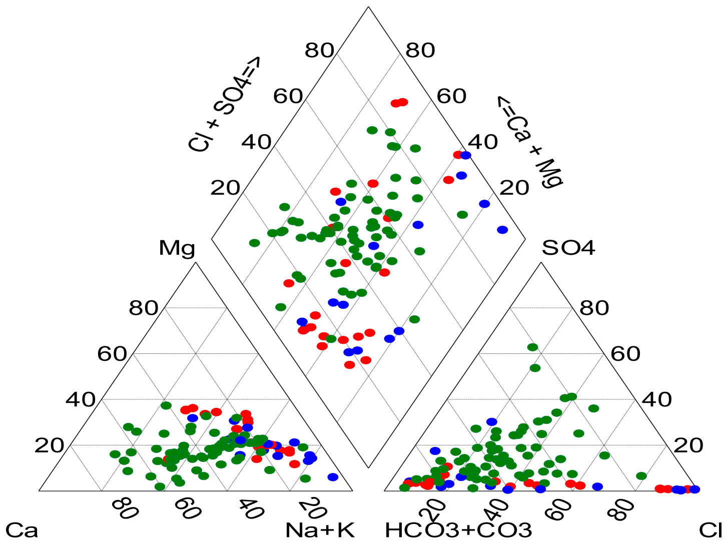
- Factor 4, indicating the impact of anthropogenic activities

- The first three factors Indicating the impact on natural process on groundwater quality

Four component factors explain 70% of total variance in aquifer

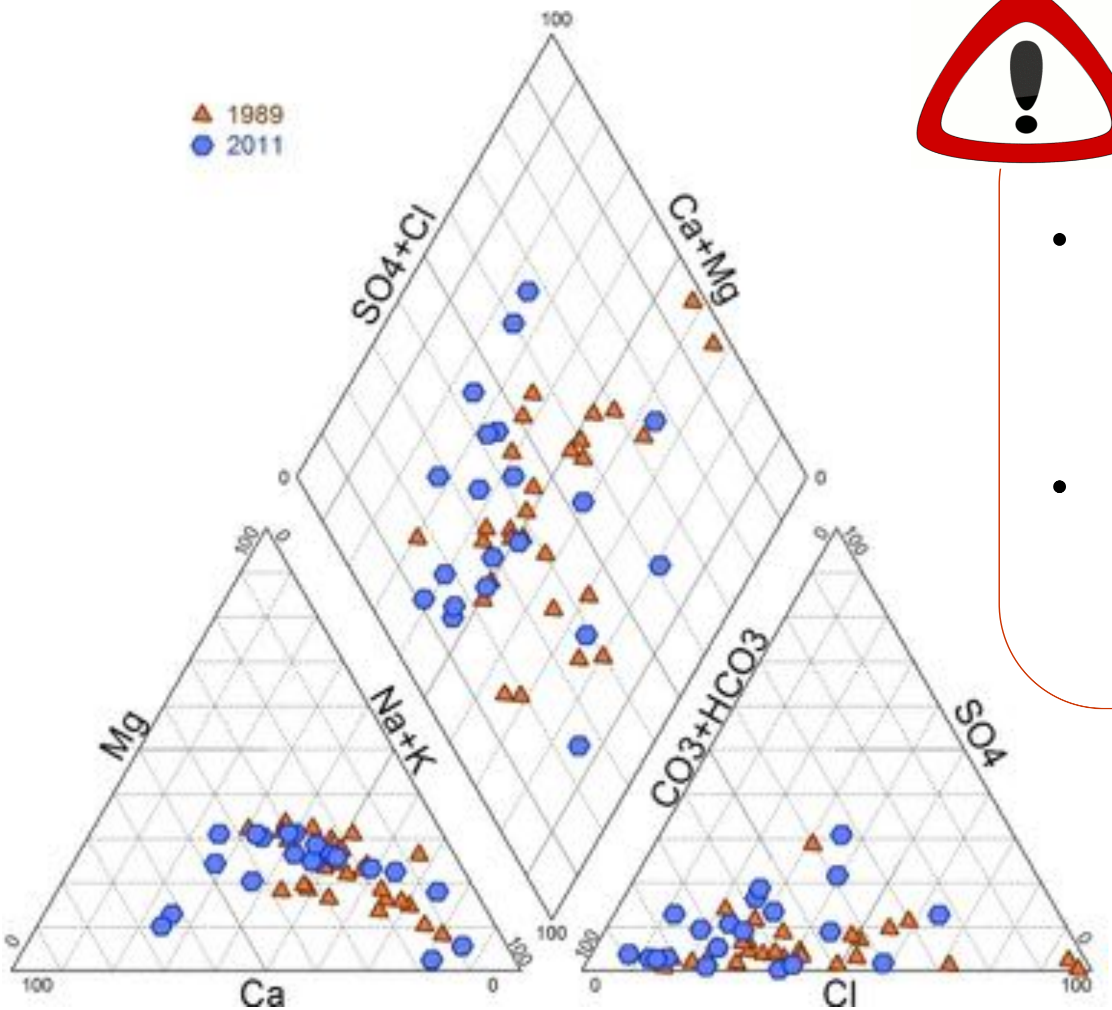
Data interpretation
Hydrochemical classification





Sefie (2016)

Data interpretation
Hydrochemical classification

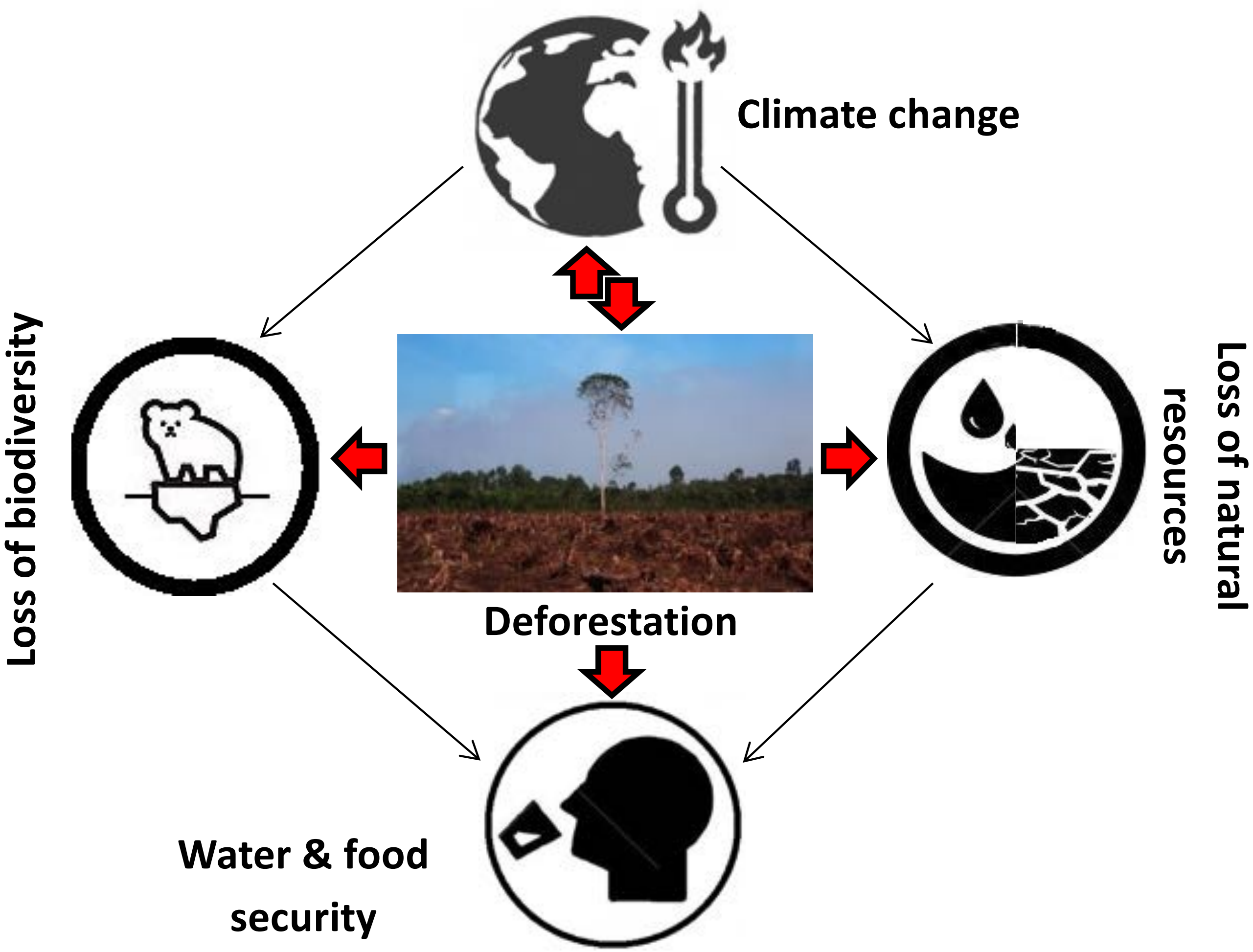


Piper diagram:

- Na-HCO_3 and Ca-HCO_3 are main groundwater type in both years, which means groundwater facies did not show significant changes
- two samples in 1989, which indicated Na-Cl type, which can be represented saline water intrusion to fresh water

Global Environmental Change

- Population growth, changing climate, and rapid urbanization increase demand for food, irrigation water and agricultural lands.
- The agricultural lands is expending rapidly through conversion of forest and wetlands.



Deforestation in South-East Asia (2001-2014)

Impacts of Climate Change in South-East Asia

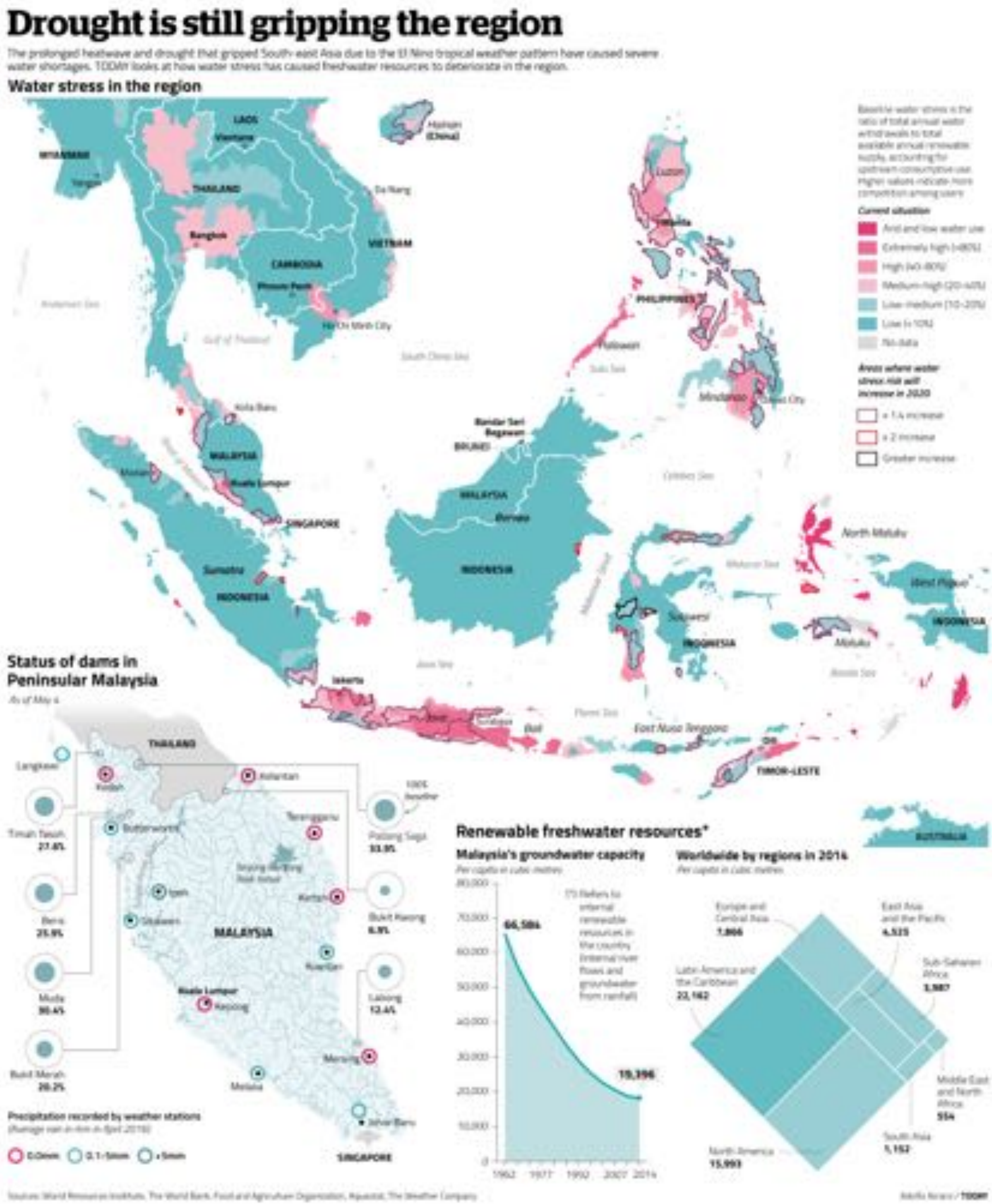
Impacts of Climate Change on Water Resources

Detecting, quantifying, and predicting how these changes can affect the water resources is still a challenge for hydrologists.

River

Lake

Groundwater



Drought is still gripping the region
The prolonged heatwave and drought that gripped South-east Asia due to the El Nino tropical weather pattern have caused severe water shortages. TODAY looks at how water stress has caused freshwater resources to deteriorate in the region.
Water stress in the region
LAOS
MYANMAR
THAILAND
Bangkok
CAMBODIA
VIETNAM
PHILIPPINES
Luzon
Manila
Mindanao
MALAYSIA
Kuala Lumpur
SINGAPORE
BRUNEI
MALAYSIA
Borneo
INDONESIA
Sumatra
INDONESIA
Sulawesi
North Maluku
West Papua
Jakarta
Java
Bali
East Nusa Tenggara
TIMOR-LESTE
AUSTRALIA
Status of dams in Peninsular Malaysia
THAILAND
MALAYSIA
Kelantan
Terengganu
Ipoh
Kuantan
Kuala Lumpur
Melaka
Johor Baru
SINGAPORE
Timah Tasoh
Beris
Muda
Bukit Merah
Padang Saga
Bukit Kwong
Labong
Precipitation recorded by weather stations
Renewable freshwater resources*
Malaysia's groundwater capacity
Worldwide by regions in 2014
66,584
19,396
1962
2014
Europe and Central Asia
East Asia and the Pacific
Sub-Saharan Africa
Latin America and the Caribbean
Middle East and North Africa
South Asia
North America

Arranz (2017)

Main Objectives

Detect and Predict

Reveal

To detect and predict the impact of land use and climate changes on groundwater quality

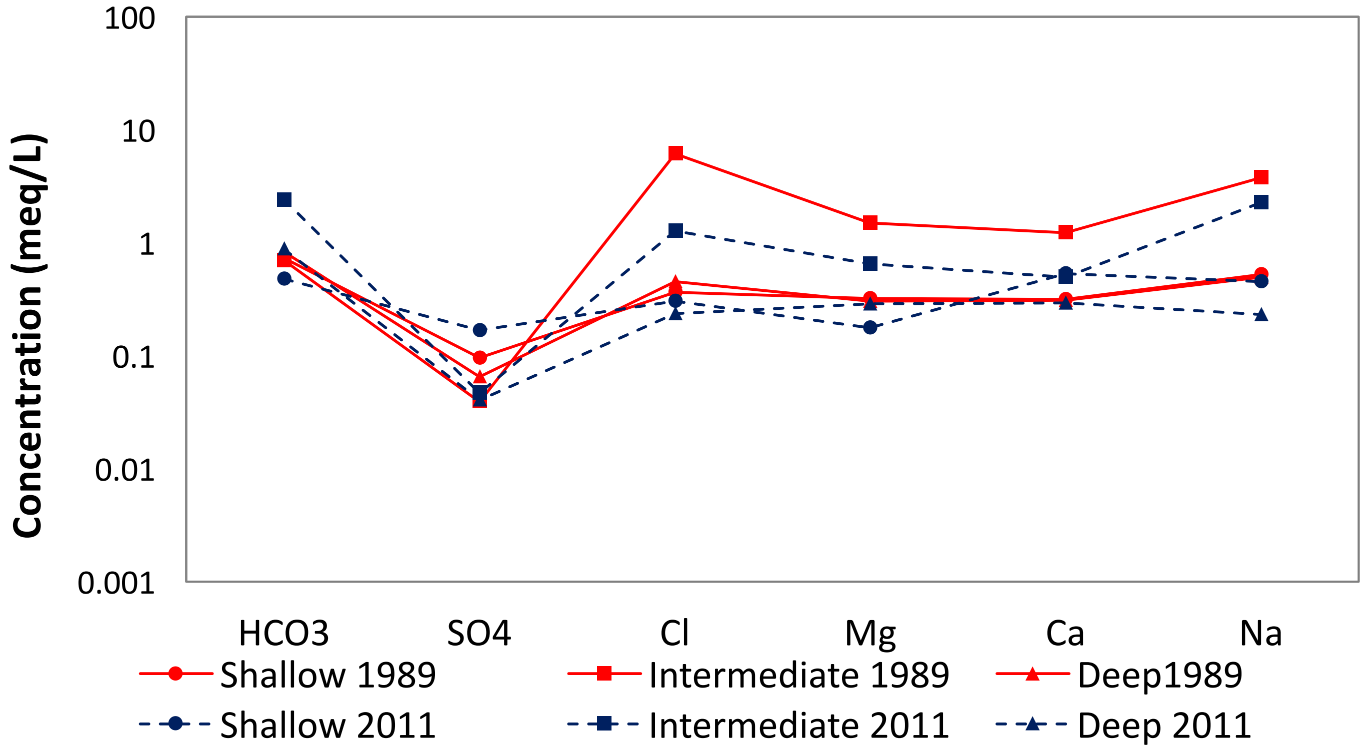
- To detect and characterize groundwater hydrochemistry type variations
- To identify groundwater quality trends
- To detect and quantify the impact of human activities on groundwater quality
- To predict the groundwater quality variations

Findings

PART I:

Temporal assessment of hydro-chemical facies

Findings



1989

Shallow aquifer: HCO^{3-}>Cl^{-}>SO_4^{2-} & Na^{+}> Ca^{2+} ≥ Mg^{2+}

Intermediate aquifer: Cl^{-}>HCO_3^{-}>SO_4^{2-} & Na^{+}> Ca^{2+}>Mg^{2+}

Deep aquifer: HCO^{3-}>Cl^{-}>SO_4^{2-} & Na^{+}> Ca^{2+} ≥ Mg^{2+}

2011

Shallow aquifer: HCO^{3-}>Cl^{-}>SO_4^{2-} & Ca^{2+}> Na^{+}>Mg^{2+}

Intermediate aquifer: HCO_3^{-}>Cl^{-}>SO_4^{2-} & Na^{+}> Mg^{2+}>Ca^{2+}

Deep aquifer: HCO^{3-}>Cl^{-}>SO_4^{2-} & Ca^{2+}> Mg^{2+}>Na^{+}

Findings

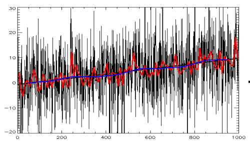
PART II:

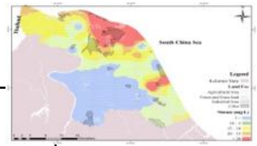
Detection of groundwater quality trends

Findings

Impact of climate and land use changes on water quality for agriculture

Detection





Time series Analysis

- Trend analysis

Geospatial technique

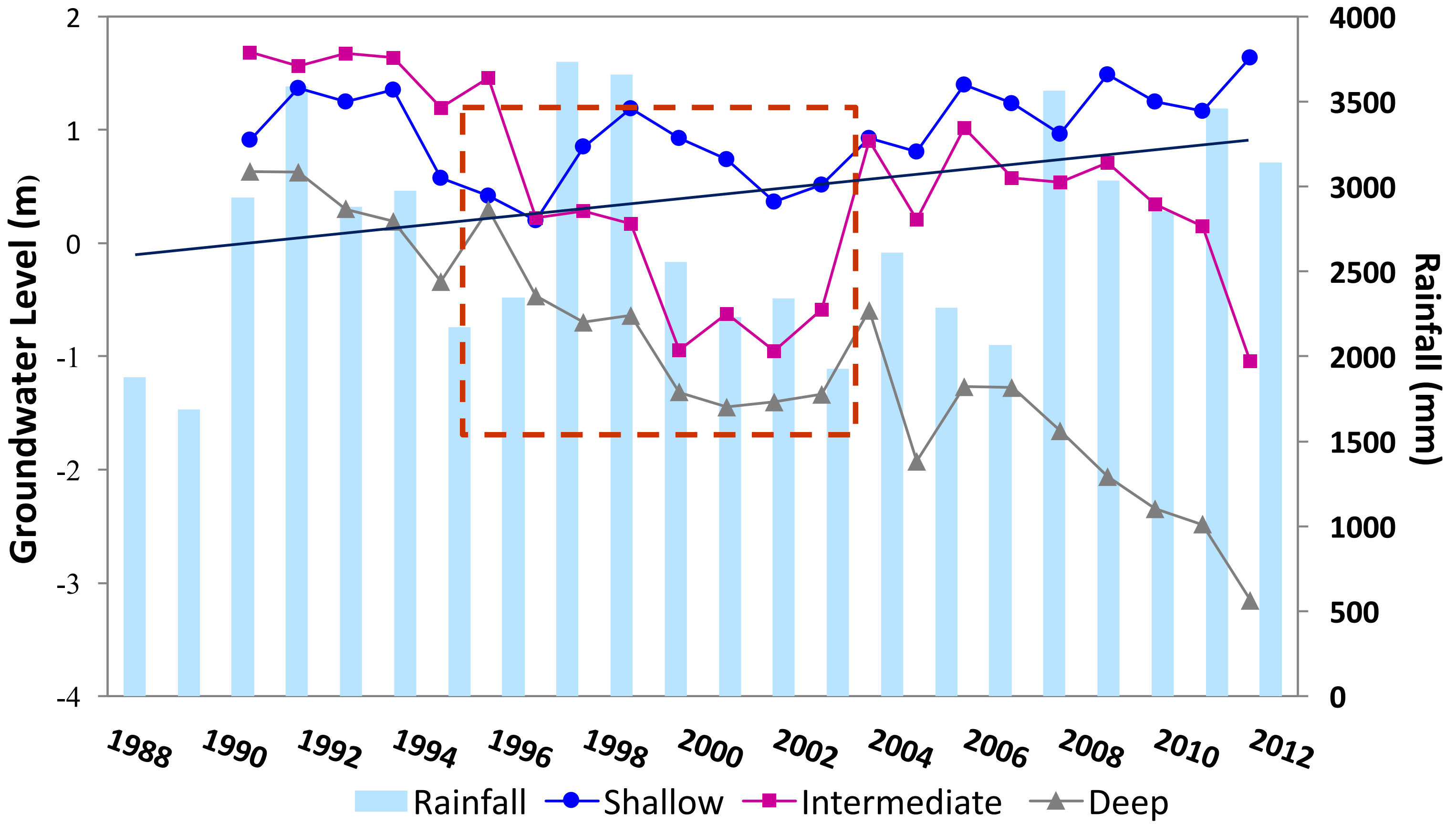
- Inverse Distance Modelling

Prediction

Time series prediction modelling

- ARIMA

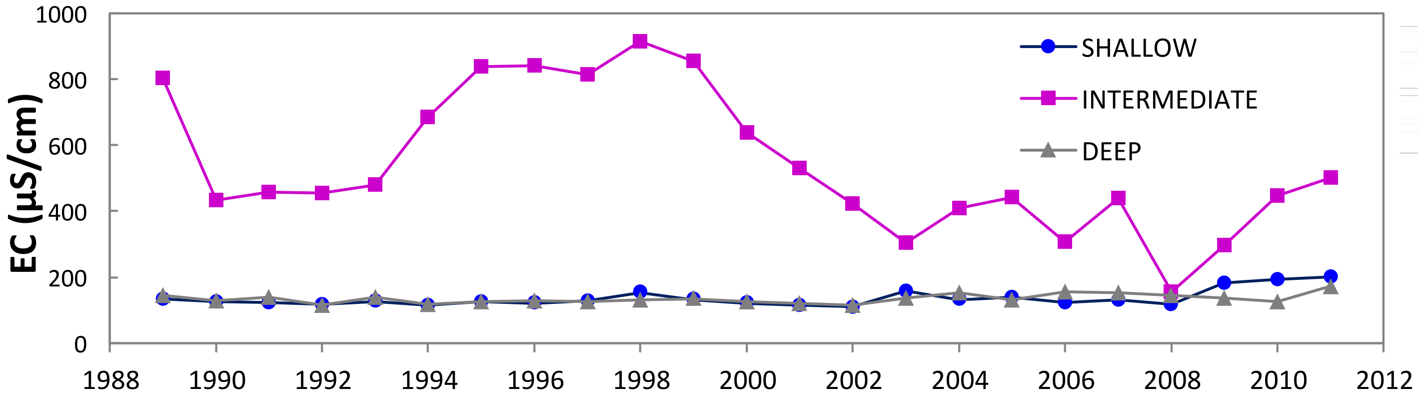
Findings



Groundwater abstraction was 36.37 million liters per day in 1981, increased to 57 MLD in 1990, and raised rapidly to 184.35 MLD in 1993 with implementation of 72 new wells in the study area, which cause the groundwater level decreased sharply from 1995 until 2003 in the intermediate aquifer.

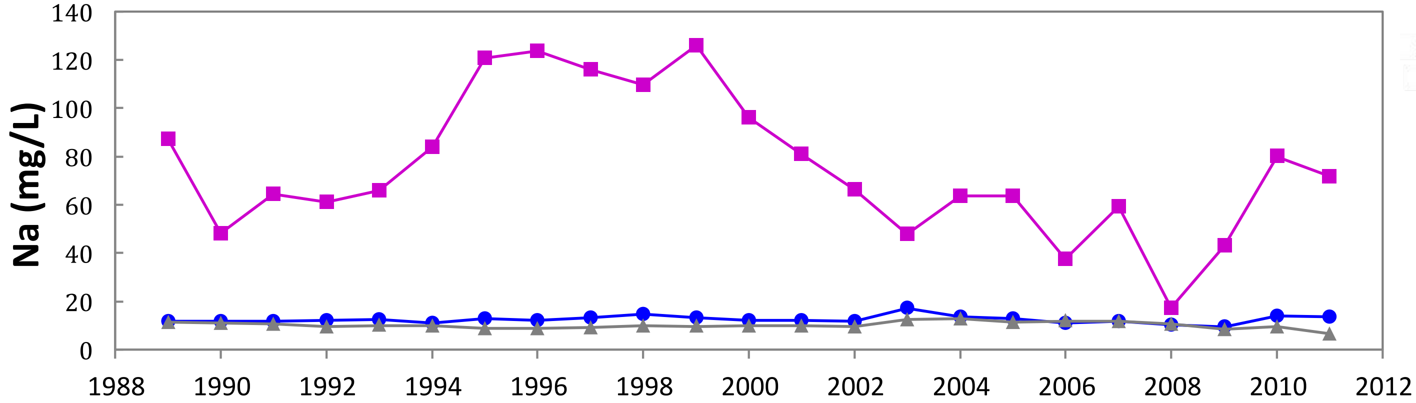
The average of rainfall data is 2580mm from 1991 to 2007, however, the average of rainfall is 3210mm from 2008 to 2012, which shows increase in precipitation in area.

Findings



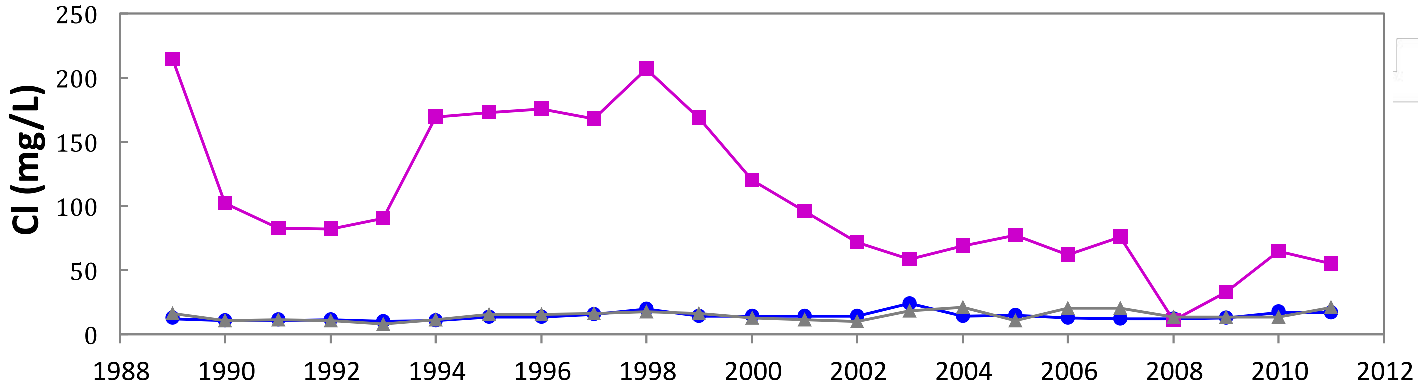
	Shallow	Intermediate	Deep
Kendall's tau	0.277	-0.304	0.249
p-value	0.068	0.044	0.103
Sen's Slope	1.068	-13.712	0.824
Trend	No-Trend	Decreasing	No-Trend

Natural Sources



	Shallow	Intermediate	Deep
Kendall's tau	0.071	-0.257	-0.048
p-value	0.653	0.092	0.771
Sen's Slope	0.025	-1.596	-0.013
Trend	No-Trend	No-Trend	No-Trend

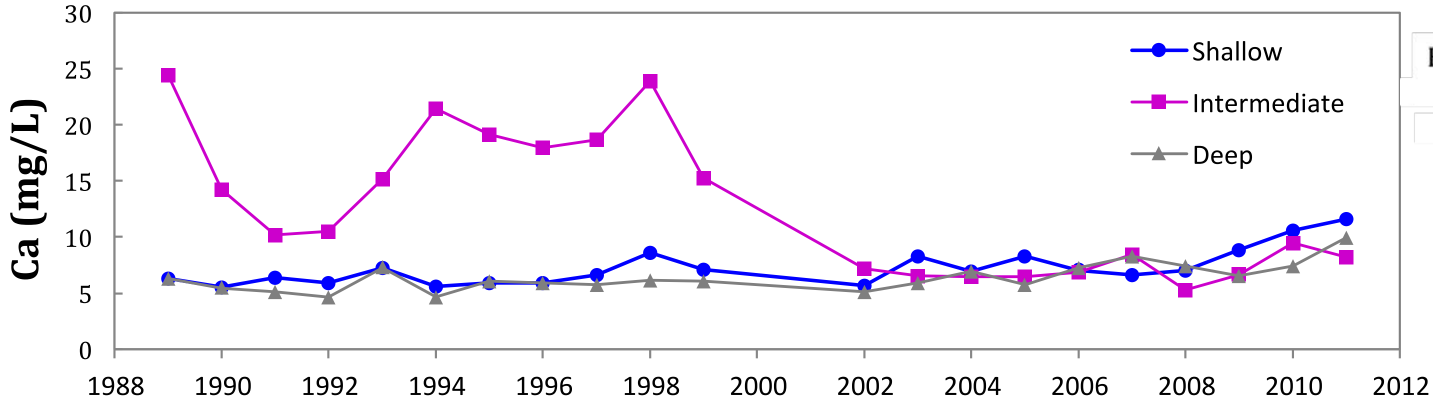
Natural Sources



	Shallow	Intermediate	Deep
Kendall's tau	0.325	-0.549	0.325
p-value	0.032	0.000	0.032
Sen's Slope	0.148	-5.540	0.104
Trend	Increasing	Decreasing	Increasing

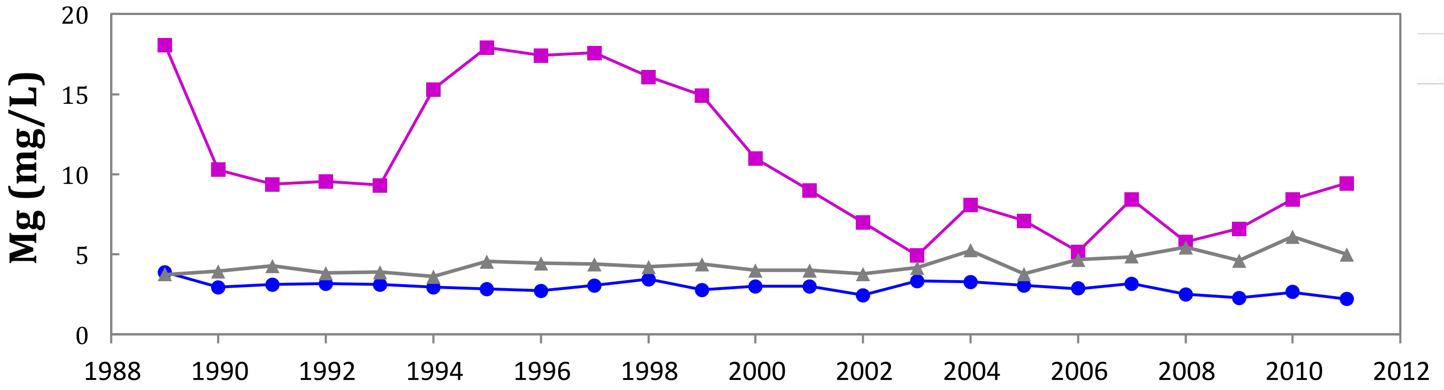
Natural Sources

Findings



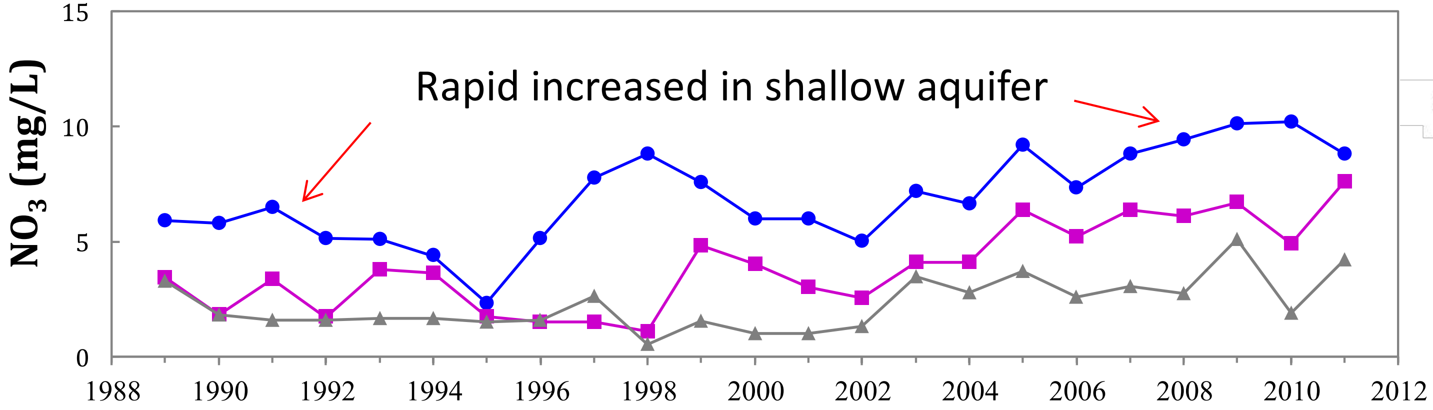
	Shallow	Intermediate	Deep
Kendall's tau	0.495	-0.419	0.448
p-value	0.001	0.008	0.004
Sen's Slope	0.151	-0.602	0.147
Trend	Increasing	Decreasing	Increasing

Natural Sources



	Shallow	Intermediate	Deep
Kendall's tau	-0.341	-0.470	0.444
p-value	0.025	0.001	0.003
Sen's Slope	-0.03	-0.369	0.053
Trend	Decreasing	Decreasing	Increasing

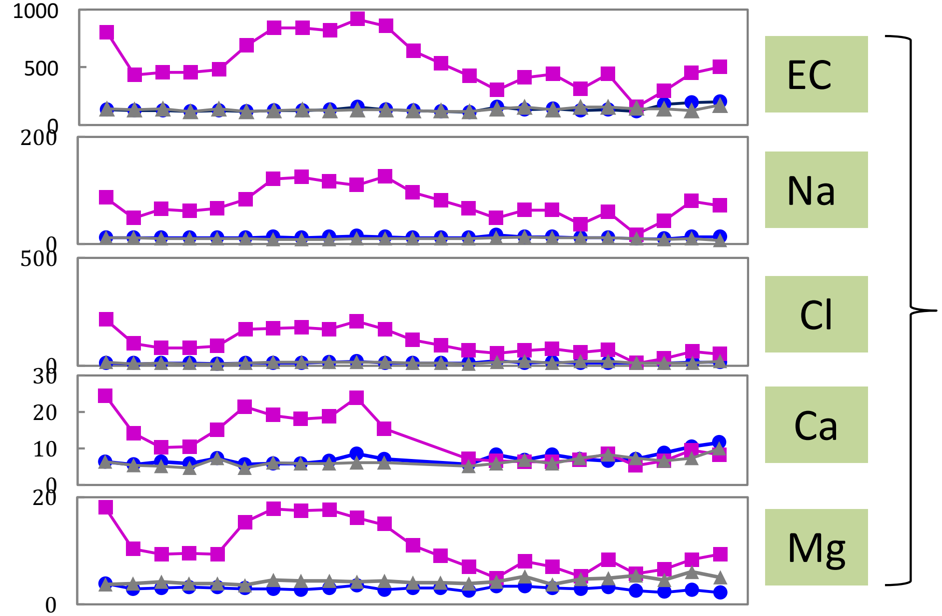
Natural Sources



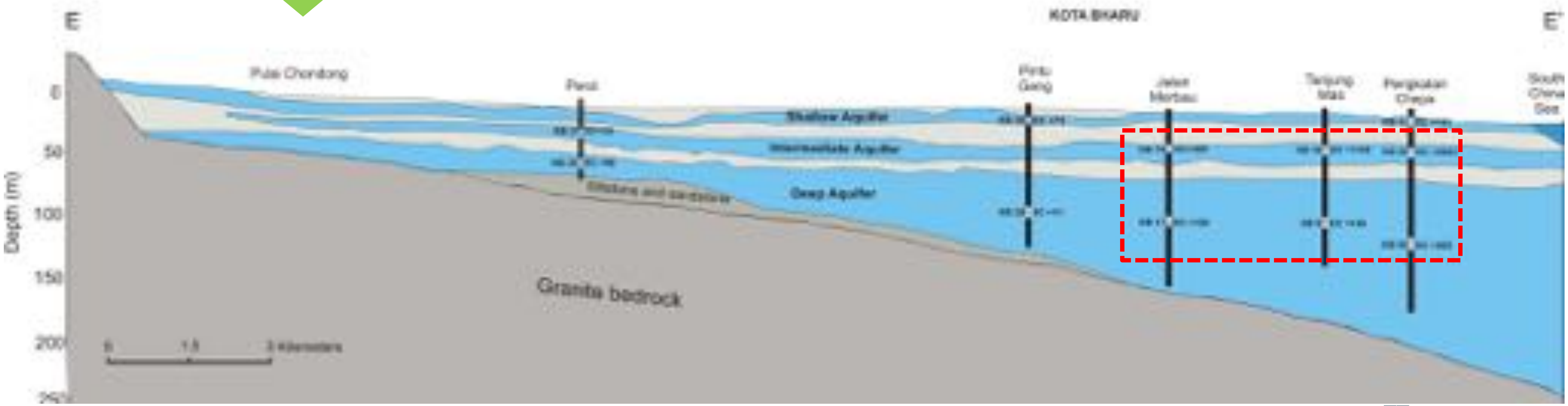
	Shallow	Intermediate	Deep
Kendall's tau	0.560	0.323	0.253
p-value	0.000	0.061	0.096
Sen's Slope	0.253	0.082	0.074
Trend	Increasing	No-Trend	No-Trend

Anthropogenic Sources

Findings



The patterns of long-term EC, Na, Cl, Mg, and Ca values in intermediate aquifer confirm the findings by Haryono (1995); Samsudin et al. (2008), which suggested that the brackish water of the second aquifer is ancient seawater that may have been trapped during the deposition of the sediments.

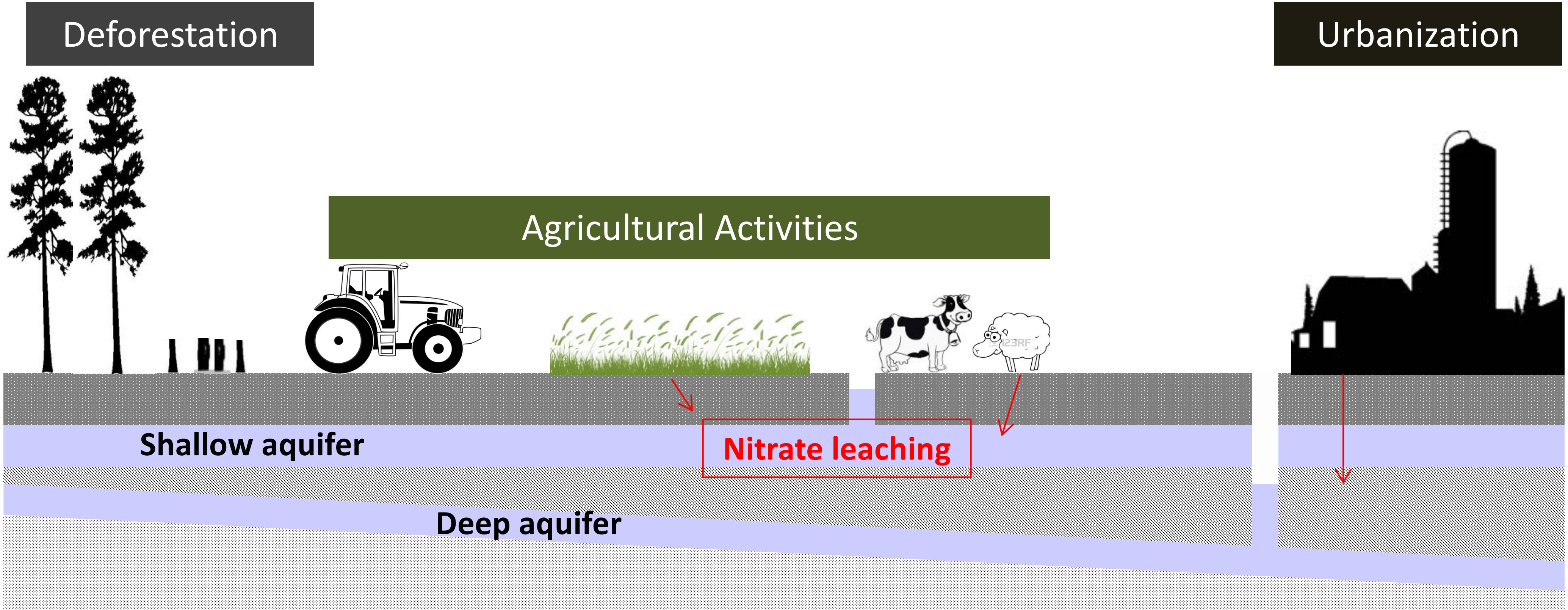


Findings

PART III:

Impact of human activities on groundwater quality

Findings


Deforestation
Urbanization
Agricultural Activities
Shallow aquifer
Nitrate leaching
Deep aquifer

Nitrate Concentrations in Northern Kelantan

Why NO_3?

- Nitrate concentrations can be applied as an indicator to trace the link between land use changes and groundwater quality.

- The first factor usually represents the most important process that controls hydrochemistry of groundwater

- Component factor 1 (F1) had a strong absolute loading of EC, TDS, Ca, Mg, Na, Cl, SO_4.
- F1 indicates strong signature of groundwater salinity, which may attributed by seawater intrusion.

Variables	VF1	VF2	VF3	VF4
pH	0.057	**0.697**	-0.111	-0.198
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- Factor 4, indicating the impact of anthropogenic activities

- The first three factors Indicating the impact on natural process on groundwater quality

Four component factors explain 70% of total variance in aquifer

- Stand alone variable – an indication of anthropogenic input

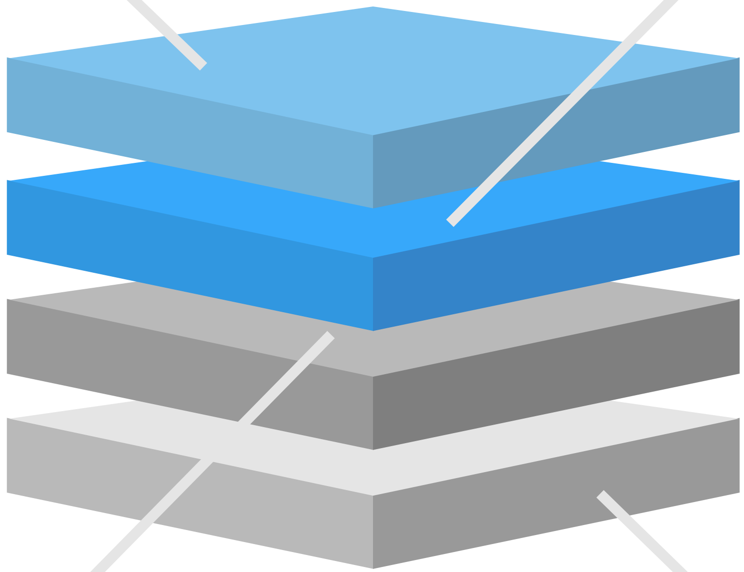
Methodology

1. Nitrate Data

The regional groundwater samples were collected from 1989 to 2014, from 101 sampling wells, including shallow aquifer (64 wells), intermediate aquifer (14 wells) and deep aquifer (23 wells), from residential, industrial and agricultural areas

2. Time Series Analysis

To elucidate the relationship between previous observed values with predicted future values



3. Trend Analysis

The Mann-Kendall test is the most common trend test in hydro-meteorological studies.

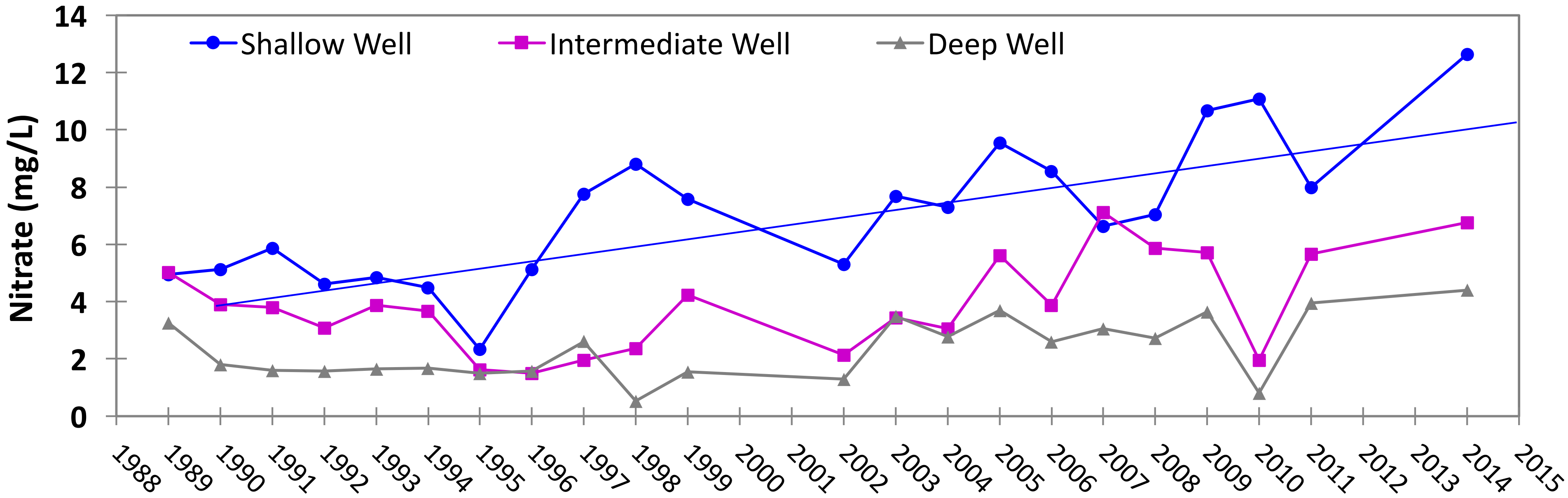
To estimated trends using the Theil and Sen's median slope estimator for specific time periods by the percentage changes over the mean

4. Predicting Model

ARIMA modeling to predict future values based on the observation from several past years observations

In this study, the ARIMA model is applied to predict the nitrate concentration in the groundwater for the period 2015-2030

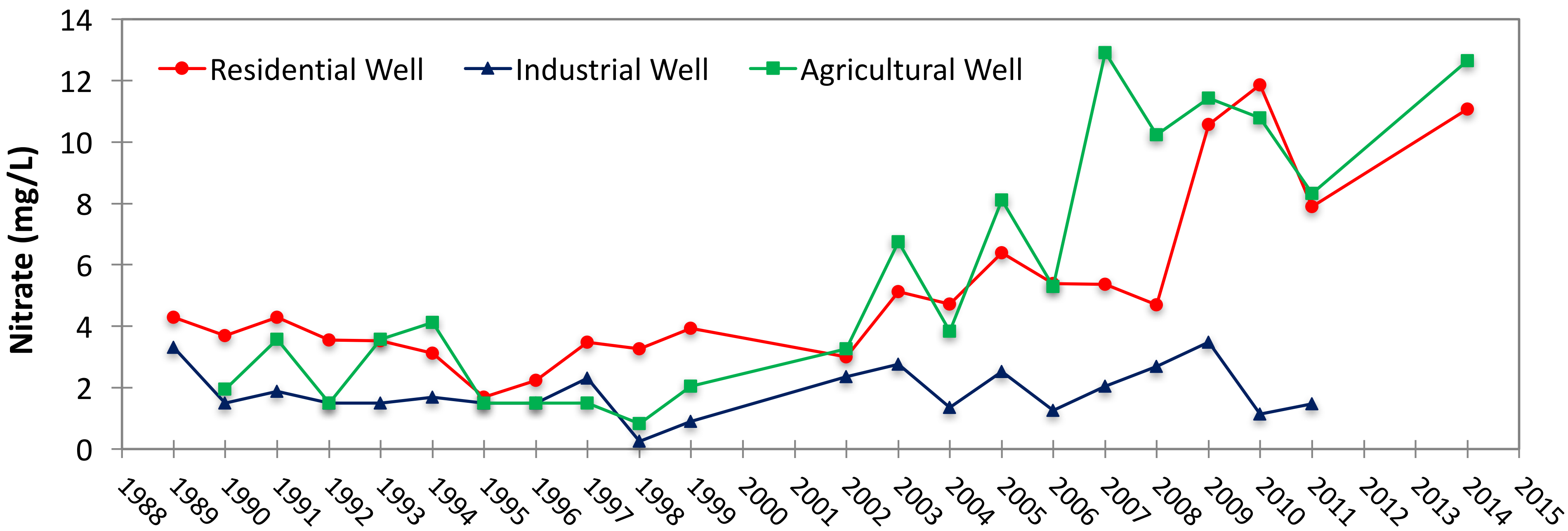
Findings



Present study reveal a significant increasing trend of nitrate concentration in the shallow aquifer from 1989-2014

Although the intermediate aquifer shows a higher concentration of nitrate compared to the deep aquifer, the nitrate concentrations do not have meaningful trends over 25 years of observations

Findings



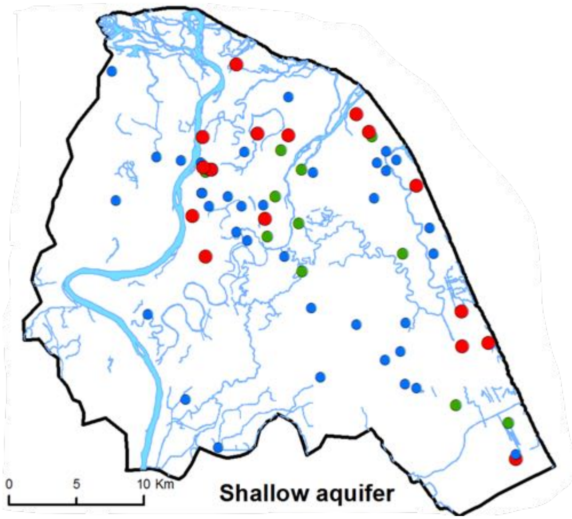
The significant increasing trend of nitrate concentration in the **residential wells** (P value, 0.001<0.05) from 1989 to 2014.

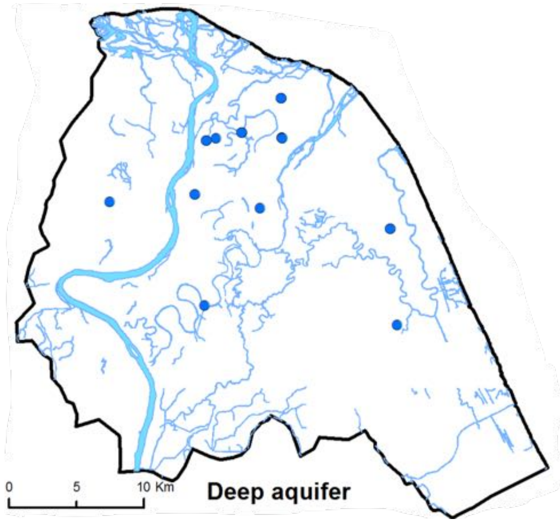
The significant increasing trend of nitrate concentration in the **agricultural wells** (P value, 0.000<0.05) from 1989 to 2014.

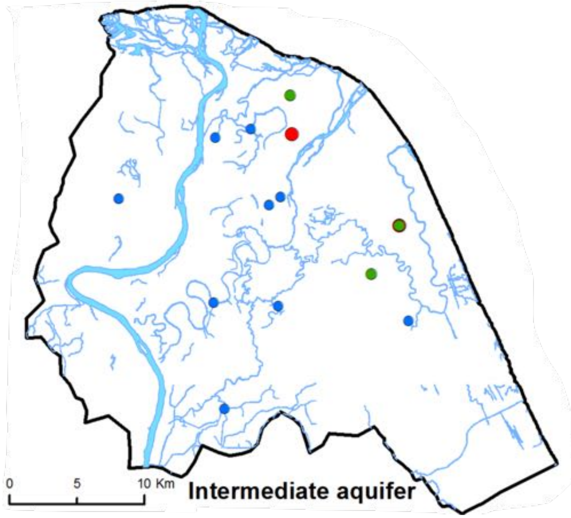
There is no any significant trend (P value, 0.955>0.05) in the time series data for the nitrate concentration in **industrial wells** from 1989 to 2014

Nitrate Concentrations in Northern Kelantan

2014
Nitrate Concentrations







Legend

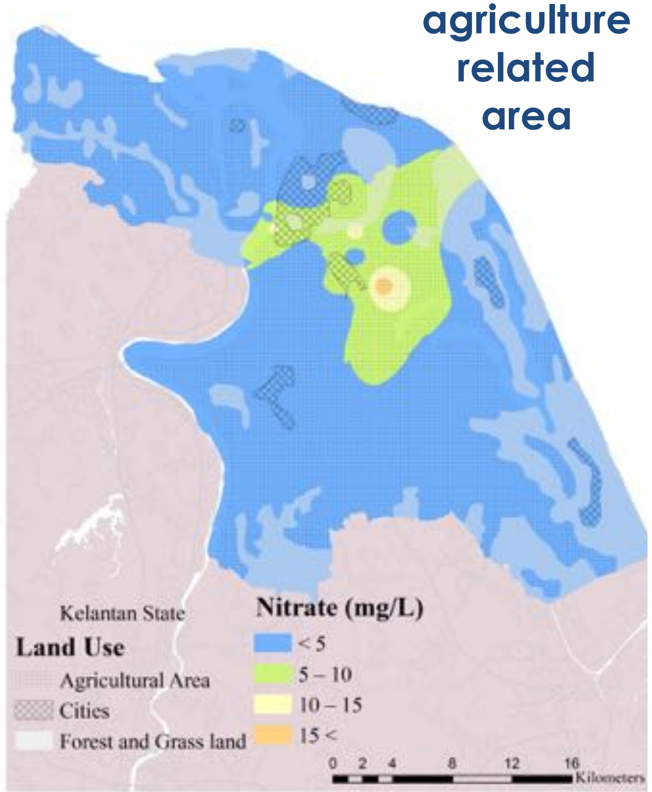
Nitrate (mg/L)

- < 5.00
- 5.00 - 10.00
- > 10.00

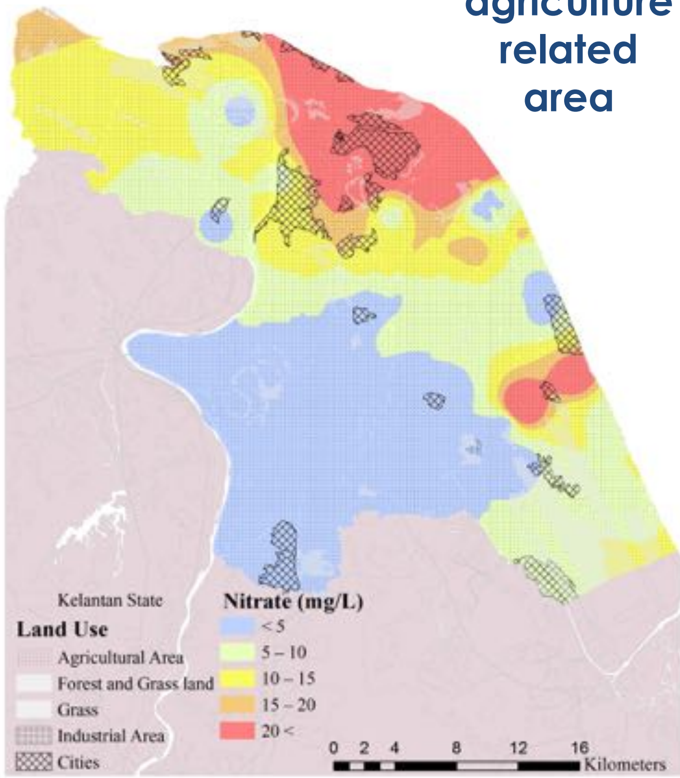
Findings




71% agriculture related area



86% agriculture related area






2014

99% of the study area (847 km²) showed nitrate concentrations **less** than 10 mg/L

2014

38% of the study area (316 km²) showed nitrate concentrations **higher** than 10 mg/L

Findings

PART IV:

Prediction modelling of nitrate contamination from agricultural activities

Findings

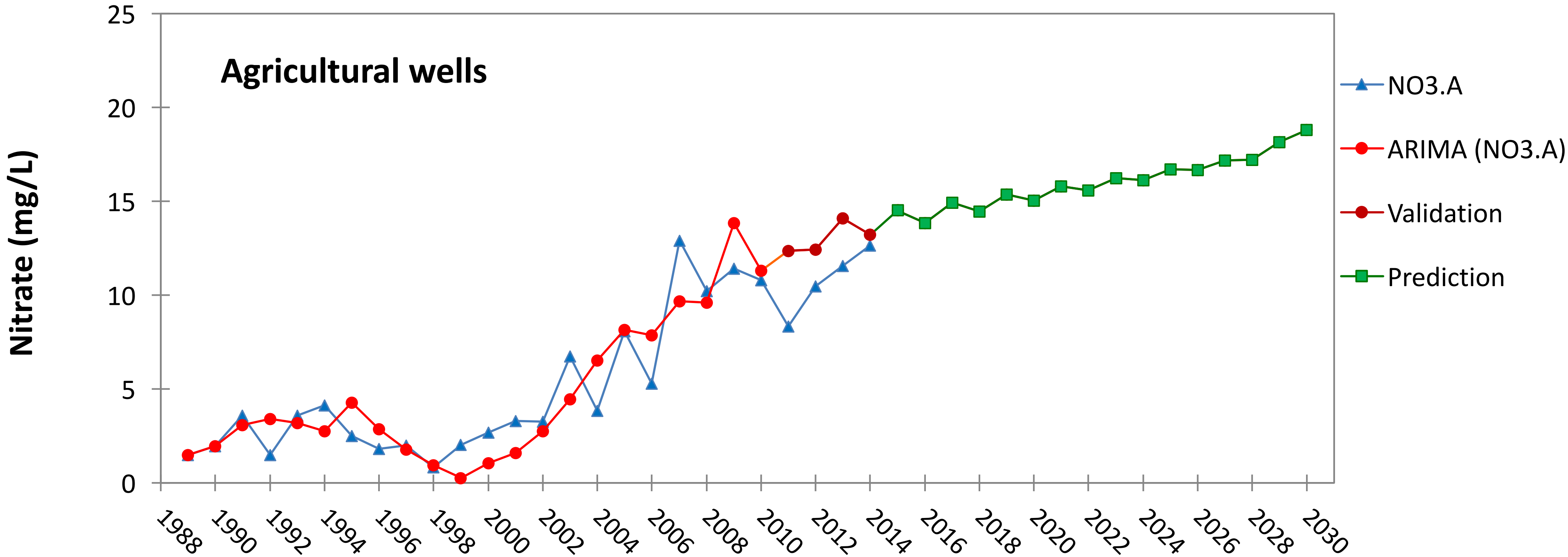
Prediction Modelling

One of the most common methods for modelling and predicting of time series data is ARIMA model

Several hydro meteorological studies applied ARIMA modeling to predict future values based on the observation from several past years observations

It is based on a combination of autoregressive (AR), integrated (I), and moving average (MA) parts which are presented as ARIMA (p, d, q), respectively

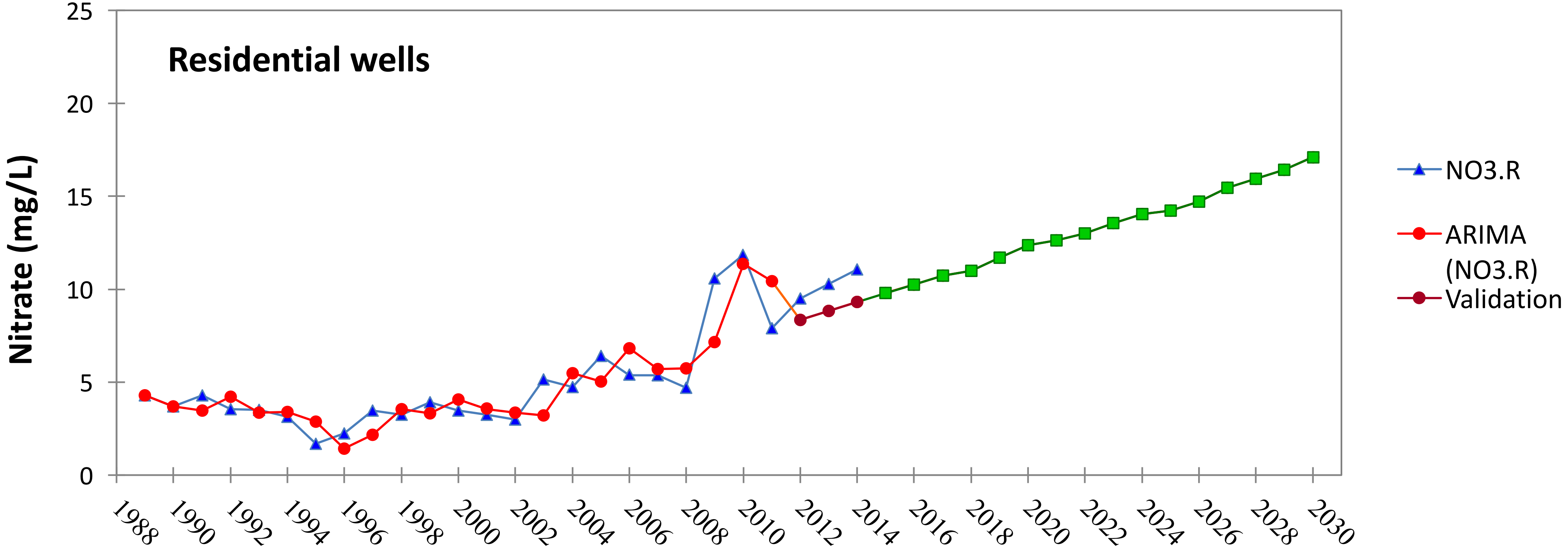
Findings



- The perfect prediction model is (1,2,2)
- Model correlation is 0.88
- The model shows lowest RMSE, MAPE, and MAE
- The residuals are normal and independent

- Nitrate contamination would increase from 13.64 mg/L in 2014 to approximately 18.8 mg/L in 2030
- The annual growth rate of nitrate contamination from 1989 to 2014 was 8.1%, which would be decreased to 2.64% from 2015 to 2030

Findings



- The perfect prediction model is (2,2,2)
- Model correlation is 0.86
- The model shows lowest RMSE, MAPE, and MAE
- The residuals are normal and independent

- the nitrate contamination also would increase from 11.08 mg/L in 2014 to 17.1 mg/L in 2030
- The annual growth rate of nitrate contamination was 3.89 from 1989 to 2014, which was predicted to be stable (with 3.9% annual growth) from 2014 to 2030

Suitability Usage

Indices

Guidelines (WHO, EU, MOH)

$$\text{Gibbs Ratio I (for anion)} = \frac{Cl^-}{(Cl^- + HCO_3^-)}$$

$$\text{Gibbs Ratio II (for cation)} = \frac{Na^+ + K^+}{(Na^+ + K^+ + Ca^{2+})}$$

$$MH = \frac{[Mg^{2+}]}{[Ca^{2+}] + [Mg^{2+}]} \times 100$$

$$SAR = \frac{[Na^+]}{\sqrt{\frac{1}{2}([Ca^{2+}] + [Mg^{2+}])}}$$

$$Na\,(\%) = \frac{[Na^+]}{([Ca^{2+}] + [Mg^{2+}] + [Na^+] + [K^+])} \times 100$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

$$PI = \frac{\left(Na^+ + \sqrt{HCO_3^-}\right)}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$$

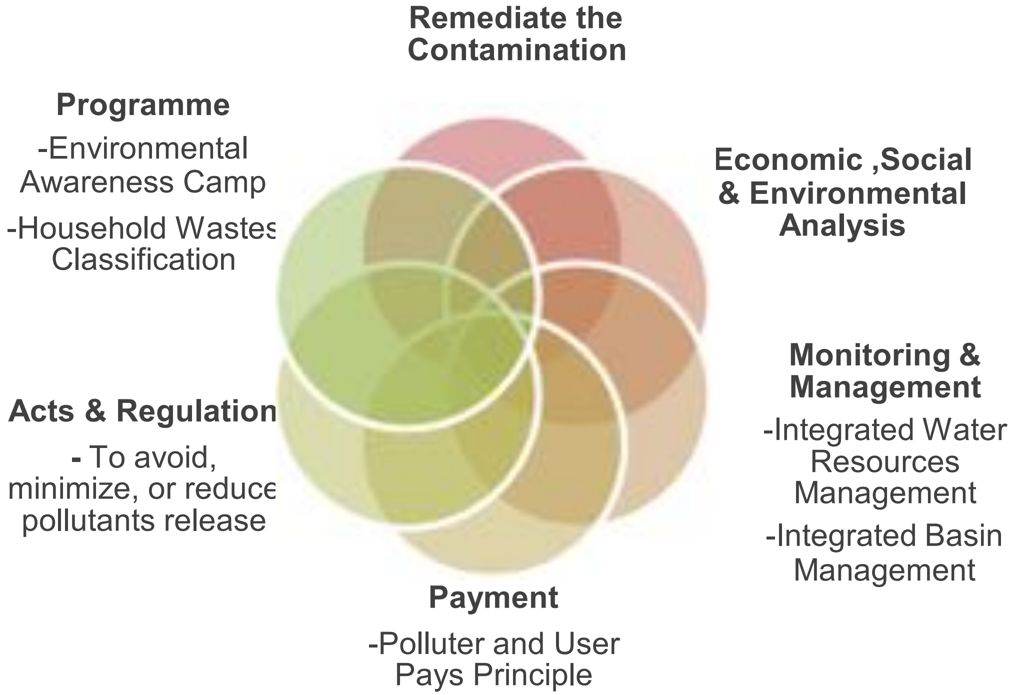
Conclusion

- Deforestation and agricultural expansion are assumed to have significant impact on groundwater quality.
- The forests and green lands show an annual decrease of rate about 4.5% from 1989 to 2014.
- Nitrate concentration shows an annual increase of around 3.74% in the shallow aquifers from 1989 to 2014.
- Twenty-five years of record data for the groundwater quality clearly reveal the negative impact of human activities arising from the increase in nutrients, sewage, and chemical fertilizers into the environment.
- This study predicts an increasing annual trend of around 2.27% and 3.9% in agricultural and residential wells.

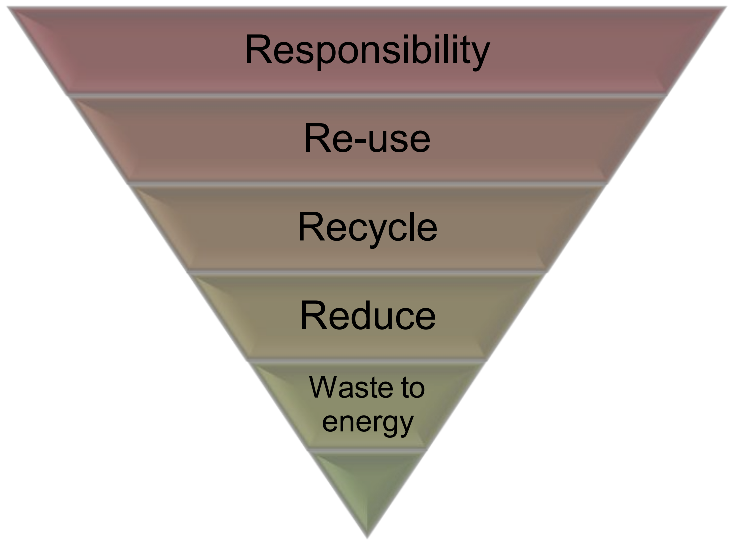
Recommendations: For Researcher

- Increase the frequency of sampling
- Continuous monitoring of various pollution variables with more comprehensive data
- Application of comprehensive aqueous thermodynamic modelling to study pollutant water-sediment interaction
- Identification of point source and non-point source pollutant
- A more thorough analysis of water, sediments and biological samples
- Analysis of hydrological processes with combination of hydrogeological and hydrochemical properties
- Analysis of organic variables, soil characteristics and climate influence on river pollution status
- Application of isotopic fingerprints in complement with the environmental forensics approach

For Government and Public



~The only way to solve the pollution crisis is if everybody, consumers and producers alike, urgently takes responsibility for reducing waste~



CHANGE OUR ATTITUDE

Acknowledgement

THANK YOU

"We have made clear to you the signs; perhaps you will understand."

(57:17)

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