Impact of Climate and Land-Use Changes on Water Quality

by

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Factors Controlling the Water Quality

- **Natural sources** (dissolution of minerals and rocks, cation exchange)
- **Anthropogenic sources**
  - **Domestic purposes** (sewages, chemicals, road run off, ...)
  - **Industrial purposes** (cooling water, metallic minerals, toxic sewages, ...)
  - **Agricultural purposes** (fertilizers, pesticides, animal swage, deforestation, ...)

- **Natural sources** (seawater intrusion to aquifers, mixing water)
Multiple Risks

Safe drinking water is essential to the health of American citizens and the economic health of our communities. However, drinking water is vulnerable to contamination from many potential threats. There are programs and activities that, when operated effectively, form a protective web of multiple barriers to ensure the safety of our drinking water. The success of these barriers relies on the involvement and vigilance of local, state, and federal officials, the private sector, public interest groups, and individual citizens.

This page identifies examples of: 1. Surface and groundwater sources of drinking water on farms, 2. Potential threats to those drinking water sources on farms, and 3. The barriers that form the protective web of multiple barriers to health on farms.
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
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

CHALLENGES

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

ADEQUATE METHODS and TOOLS

- Large data set
- Data requirements
- Complex and dynamic interpretation
Study Area: Northern Kelantan Basin

Peninsular Malaysia

Kelantan State

Legend
- Sampling Well
- Lake
- River
- Residential Area
- Railway
- Road
- Kelantan
- Kelantan State

South China Sea

Tumpat

Kota Bharu

Bachok
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%.
- 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.

- 71.8% (around 10783.98 km$^2$) of Kelantan State is covered with forest reserves, which are mainly located in the upstream region.
Northern Kelantan Basin (Land Use Activities)

- Forest & Green Land
- Oil Palm
- Mixed Agriculture
- Paddy
- Rubber
- Built up

Comparison between 1988 and 2011
Northern Kelantan Basin (Land Use Activities)

1988

2011
Hydrogeochemical assessment
Case study: Northern Kelantan Basin

Legend
- Study area
- River
- Major road
- Railway
- Town

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

Developers carry out projects without EIA reports

Massive environmentally degrading activities are rampant. Reality of situation:

STRIPPED BARE
Groundwater monitoring strategies in the study area

101 sampling wells (shallow, intermediate and deep aquifers)

Samples collected from 1989-2014 (twice per year, 25 years)

Analysis of 16 physico-chemical parameters

Number of data

\[(101 \times 25 \times 2 \times 16) = 80,800\]
Data analysis

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

Time series analysis

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

Statistical Analysis
Allow the simultaneous investigation of more than two variables

Factor Analysis/Principal Component Analysis
• To reduce large number of variables to small important variables
• To manage large dataset
• To uncover pattern in variables

Cluster analysis
• To classify of data objects based on the similarity and dissimilarity of variables

t test-ANOVA-MANOVA
• To detect significant differences among mean of variables
• To compare two or more than two groups 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, SO₄.
- F1 indicates strong signature of groundwater salinity, which may attributed by seawater intrusion.

- The first three factors indicating the impact on natural process on groundwater quality
- Factor 4, indicating the impact of anthropogenic activities

<table>
<thead>
<tr>
<th>Variables</th>
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<td>SO₄</td>
<td>0.739</td>
<td>0.002</td>
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<td>0.043</td>
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<tr>
<td>NO₃</td>
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<td>-0.002</td>
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<td>NH₄</td>
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<td>0.200</td>
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<tr>
<td>Fe</td>
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<td>-0.045</td>
<td>0.834</td>
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<tr>
<td>Mn</td>
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<td>0.088</td>
<td>0.831</td>
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<td>Eigenvalue</td>
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<td>1.560</td>
<td>1.429</td>
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<td>Variability (%)</td>
<td>36.026</td>
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<td>10.554</td>
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<tr>
<td>Cumulative (%)</td>
<td>36.026</td>
<td>50.769</td>
<td>61.323</td>
<td>70.073</td>
</tr>
</tbody>
</table>

Four component factors explain 70% of total variance in aquifer
Data interpretation
Hydrochemical classification

Legend
Electrical conductivity (µS/cm)
- < 250
- 250 - 500
- > 500 - 750
- > 750 - 1000
- > 1000

Fig. 5: Spatial distribution of (a) pH, (b) EC, (c) NO$_3$ and (d) Fe in groundwater samples taken from shallow, intermediate and deep aquifer. Sefie (2016)
Data interpretation
Hydrochemical classification

Piper diagram:
- Na-HCO₃ and Ca-HCO₃ 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)

- Malaysia: 5,632,714 ha
- Indonesia: 18,507,771 ha
- Thailand: 1,267,835 ha
- Vietnam: 1,504,547 ha
- Philippines: 761,175 ha
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
Main Objectives

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

Detect and Predict

Reveal
PART I:

Temperal assessment of hydro-chemical facies
**Findings**

**1989**

**Shallow aquifer:** $\text{HCO}_3^->\text{Cl}^->\text{SO}_4^{2-}$ & $\text{Na}^+>\text{Ca}^{2+} \geq \text{Mg}^{2+}$

**Intermediate aquifer:** $\text{Cl}^->\text{HCO}_3^->\text{SO}_4^{2-}$ & $\text{Na}^+>\text{Ca}^{2+}>\text{Mg}^{2+}$

**Deep aquifer:** $\text{HCO}_3^->\text{Cl}^->\text{SO}_4^{2-}$ & $\text{Na}^+>\text{Ca}^{2+} \geq \text{Mg}^{2+}$

**2011**

**Shallow aquifer:** $\text{HCO}_3^->\text{Cl}^->\text{SO}_4^{2-}$ & $\text{Ca}^{2+}>\text{Na}^+>\text{Mg}^{2+}$

**Intermediate aquifer:** $\text{HCO}_3^->\text{Cl}^->\text{SO}_4^{2-}$ & $\text{Na}^+>\text{Mg}^{2+}>\text{Ca}^{2+}$

**Deep aquifer:** $\text{HCO}_3^->\text{Cl}^->\text{SO}_4^{2-}$ & $\text{Ca}^{2+}>\text{Mg}^{2+}>\text{Na}^+$
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
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

EC (µS/cm)

Na (mg/L)

Cl (mg/L)

Kendall’s tau
p-value
Sen’s Slope
Trend

Shallow
Intermediate
Deep

Natural Sources

Natural Sources

Natural Sources

Natural Sources
Findings

**Ca (mg/L)**

- Natural Sources
- Anthropogenic Sources

- **Mg (mg/L)**

- Natural Sources

- Anthropogenic Sources

- **NO₃ (mg/L)**

- Natural Sources

- Anthropogenic Sources

Rapid increased in shallow aquifer
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.
PART III:

Impact of human activities on groundwater quality
Findings

Deforestation

Agricultural Activities

Nitrate leaching

Shallow aquifer

Deep aquifer

Urbanization
Nitrate Concentrations in Northern Kelantan

Why \( \text{NO}_3 \)?

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

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- Component factor 1 (F1) had a strong absolute loading of EC, TDS, Ca, Mg, Na, Cl, SO\(_4\), indicating strong signature of groundwater salinity, which may attributed by seawater intrusion.

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

- Factor 4, indicating the impact of anthropogenic activities – stand alone variable – an indication of anthropogenic input.

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

- Four component factors explain 70% of total variance in aquifer
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.
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

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

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

**Gibbs Ratio (for anion)**

\[
\text{Gibbs Ratio I (for anion)} = \frac{\text{Cl}^-}{\text{Cl}^- + \text{HCO}_3^-}
\]

**Gibbs Ratio (for cation)**

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

**Salinity Hazard (MH)**

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

**Guidelines (WHO, EU, MOH)**

**SAR (Sodium Absorption Ratio)**

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

**Na (%)**

\[
\text{Na} (\%) = \frac{[\text{Na}^+]}{\left( [\text{Ca}^{2+}] + [\text{Mg}^{2+}] + [\text{Na}^+] + [\text{K}^+] \right)} \times 100
\]

**RSC (Relative Sodium Content)**

\[
\text{RSC} = \left( \text{CO}_3^{2-} + \text{HCO}_3^- \right) - \left( \text{Ca}^{2+} + \text{Mg}^{2+} \right)
\]

**KR (Kelly’s Ratio)**

\[
\text{KR} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}}
\]

**PI (Permeability Index)**

\[
\text{PI} = \frac{\left( \text{Na}^+ + \sqrt{\text{HCO}_3^-} \right)}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \times 100
\]
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.
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

Recommendations: For Researcher
For Government and Public

Programme
- Environmental Awareness Camp
- Household Wastes Classification

Acts & Regulation
- To avoid, minimize, or reduce pollutants release

Payment
- Polluter and User Pays Principle

Remediate the Contamination

Economic, Social & Environmental Analysis

Monitoring & Management
- Integrated Water Resources Management
- Integrated Basin Management

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

Responsibility
Re-use
Recycle
Reduce
Waste to energy

CHANGE OUR ATTITUDE
Acknowledgement
THANK YOU

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

(57:17)