Assessing the Current Condition of Damaged Ecosystem - Case Study for Umm Negga Site in the State of Kuwait

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Background

Located in Asia continent

Total area of 17,000 km²

Desert climate

Occasional rainfall
Background

- The world’s largest hydrocarbon spill, and one of the worst environmental disasters in history, occurred as a result of Iraq’s unlawful invasion and occupation of Kuwait in 1990.

- Multiple ecosystems in Kuwait were impacted and contaminated by war activities.
After 20 years?

- **Dry Oil Lakes**
- **Wet Oil Lakes**
- **Tarcrete**
- **Mines and unexploded ordinance**
Human activities

Camping

Overgrazing
Background

• Kuwait was awarded compensation for expenses for future restoration and re-vegetation of damaged terrestrial ecosystems
Study Area
Umm Nigaa

• Considered an open rangeland, which is distant from residential areas.

• The site is used for camping and grazing, as well as, some privet agriculture areas.

• Ministry of Defense in Kuwait established a De-Militarized Zone (DMZ)
Successful Restoration Planning

• The establishment of a successful restoration planning requires:
  1. developing site history which is a critical step in ecology restoration planning since it allows researches to go backward to understand phenomena.
  2. proper ecological site description.

• Erosion is also important for degrades sites since it ultimately degrade physical, chemical, and biological properties of the soil.
Objectives

• Using Spatial analysis and modeling to:

1. Develop site history and assess the impact of land cover change.
2. Estimating potential soil erosion.
Developing site history
Methodology

Data acquisition
- Landsat 7 ETM+ 2002, and 2013 images

Preprocessing
- File extraction, band stacking, study area extraction

Supervised classification
(Mahalanobis Distance method)
- Collect Training Regions of Interest (ROIs) in sand, bare ground, water, wetland, vegetation classes

Accuracy Assessment
- Collect Ground Truth ROIs (50 pixels per class)

Change Detection
- Using Mahalanobis classified images from all five years

Evaluation

Methodology

Developing site history

Change detection for vegetation cover

Results

1988

2%

1991

6%

Umm Nigga 1988

Land_type
- Bareground
- Sand
- Vegetation
- Water
- Wetland

Umm Nigga 1991

Land_Type
- Bareground
- Sand
- Vegetation
- Water
- Wetland
Change detection for vegetation cover

Results

1993
18%

1998
37%

Umm Nigga 1993
Land_Type
- Bareground
- Sand
- Vegetation
- Water
- Wetland

Umm Nigga 1998
Land_Type
- Bareground
- Sand
- Vegetation
- Water
- Wetland
Change detection for vegetation cover

Results

2002

2013

12%

23%
Restored vs DMZ

Results

% vegetation increase

Damaged area

3 5 22 35 2 7

Reference area

0 9 8 40 39 64
Potential Vegetation Production if Fenced and Protected

Results

% vegetation increase

2015: 7
2016: 12
2017: 17
2018: 22
2019: 27
2020: 32
2021: 37
2022: 42
Selecting Reference Area

- According to Soil, Geological properties, and vegetation communities, the study area was classified into 3 unites.
- Each unite contains Damaged and reference site.
Unite 2

Damaged (2)

Reference (2)
Estimate potential soil loss

• Spatial analysis and modeling were using GIS environment were used to estimate potential soil loss.

• There are several methods that were generally used for soil erosion
  1. Water Erosion Prediction Project (WEPP),
  2. Universal Soil Loss Equation Method (USLE),
  3. Erosion Potential Method (EPM)
  4. Modified Pacific South West Inter Agency Committee Method (MPSIAC)
Modified Pacific South West Inter Agency Committee Method (MPSIAC)

- It is designed for arid and semi-arid lands.
- It covers large number of factors.
- The enhanced model is more quantitative than the earlier version and the scoring is more realistic.
## Modified Pacific South West Inter Agency Committee Method (MPSIAC)

<table>
<thead>
<tr>
<th>Effective factors</th>
<th>Equations</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface geology</td>
<td>$Y_1 = X_1$</td>
<td>$X_1 =$Geological erosion index</td>
</tr>
<tr>
<td>Soil</td>
<td>$Y_2 = 16.67X_2$</td>
<td>$X_2 =$Soil erodibility factor</td>
</tr>
<tr>
<td>Climate</td>
<td>$Y_3 = 0.2X_3$</td>
<td>$X_3 =$6-hour rainfall with a 2-year return period</td>
</tr>
<tr>
<td>Runoff</td>
<td>$Y_4 = 0.006R + 10Q_p$</td>
<td>$Q_p =$ annual specific Debi ($m^3/skm^2$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R =$annual of runoff Height ($mm^3$)</td>
</tr>
<tr>
<td>Topography</td>
<td>$Y_5 = 0.33X_5$</td>
<td>$X_5 =$Percentage of the average basin slope</td>
</tr>
<tr>
<td>Vegetation</td>
<td>$Y_6 = 0.2X_6$</td>
<td>$X_6 =$Percentage of land without vegetation</td>
</tr>
<tr>
<td>Land use</td>
<td>$Y_7 = 20 - 0.2X_7$</td>
<td>$X_7 =$Percentage of vegetation cover</td>
</tr>
<tr>
<td>Surface erosion type</td>
<td>$Y_8 = 0.25X_8$</td>
<td>$X_8 =$total surface soil factor scoring in BLM*</td>
</tr>
<tr>
<td>Channel erosion</td>
<td>$Y_9 = 1.67X_9$</td>
<td>$X_9 =$Gully scoring in BLM*</td>
</tr>
</tbody>
</table>
Potential soil erosion

- Factors were combined together to generate the final scoring, which was used in the following equation

\[ Q = 38.77e^{0.0353R} \]

- Where: \( Q_s \) = total sediment yield in m3/km2/yr. \( e = 2.718 \).
Soil erosion results
# Estimated Soil loss

## Results

<table>
<thead>
<tr>
<th>Class</th>
<th>Soil loss (m $^3$/km $^2$/year)</th>
<th>Area_km2</th>
<th>Area %</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>347.81 - 505.41</td>
<td>44.35</td>
<td>18</td>
<td>V.low</td>
</tr>
<tr>
<td>2</td>
<td>505.41 - 593.49</td>
<td>30.47</td>
<td>13</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>593.49 - 700.1</td>
<td>36.68</td>
<td>15</td>
<td>Low-Moderate</td>
</tr>
<tr>
<td>4</td>
<td>700.1 - 890.15</td>
<td>22.85</td>
<td>10</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>890.15 - 1052.39</td>
<td>63.96</td>
<td>27</td>
<td>Moderate-high</td>
</tr>
<tr>
<td>6</td>
<td>1052.39 - 1182.18</td>
<td>37.45</td>
<td>16</td>
<td>High</td>
</tr>
<tr>
<td>7</td>
<td>1182.18- 1529.84</td>
<td>4.52</td>
<td>2</td>
<td>V.high</td>
</tr>
</tbody>
</table>
Model Testing Results

- Bare ground
- Geology
- Surface erosion
- Soil
- Runoff
- Slopes

Erosion Rating vs. Percentage increase graph.
Increasing Vegetation Cover
Results

23% vegetation

37% vegetation
Increasing Vegetation Cover

Results

[Bar chart showing the relationship between soil erosion risk and vegetation cover percentage. The chart indicates a decrease in soil erosion risk as vegetation cover increases.]
MPASIS model vs EMP and USLE

Results

USLE MODEL

• The USLE is the most common used model since it is the most simplistic model for estimating soil erosion.
• This model is described by:
  \[ A = R \times K \times L \times S \times C \times P \]
  1. \( A \) is the average annual soil water loss in tons/ acre/ year,
  2. \( R \) is the rainfall and runoff factor,
  3. \( K \) is the soil erodibility factor,
  4. \( L \times S \) is the slope length-gradient factor, and
  5. \( C \) is the crop/vegetation,
  6. \( P \) is the erosion control practice.
MPASIC model vs EMP and USLE

Results

EMP MODEL

- Estimating soil erosion using EMP model is based on the following four factors which include:

1. $Y$: The coefficient of rock and soil erosion, ranging from 0.25- 2.
2. $X_a$: The land use coefficient, ranging from 0.05- 1.
3. $\Psi$: The coefficient for present erosion type, ranging from 0.1- 1.
4. $I$: Average- land slope in percentage.
MPASIC model vs EMP and USLE

Results
Conclusion

• **Developing a site history** is one of the most useful steps in understanding and assessing damaged ecosystem.

• The results demonstrates the **power of utilizing remote sensing** to determine site history of a desert site for a relatively large area.

• The results document that the effect of **human activities** likely decreased the natural vegetative recovery.

• **Spatial analysis** could answer simple and complex questions, as well as examining the relationship between different spatial data.

• **MPSIAC model** showed the best results for soil erosion compared with other model.
What’s Next

• Conducting fieldwork to determine soil condition.

• Due to the high wind storms it is also important to estimate wind erosion.

• Applying restoration and re-vegetation plan.
THANK YOU
Methods

☐ Supervised Classification

☐ Mahalanobis Distance Method

- Regions of Interest (ROIs) were collected for each of the 5 land-cover types
- The normality assumption of training classes was checked for each class.
- Ground Truth ROIs (for the accuracy assessment) were also created at the same time.
Method

• Accuracy Assessment
  – Training ROIs and Ground Truth ROIs were used to assess the accuracy of Mahalanibus classified images.
  – Overall accuracy and Kappa coefficient were obtained for each classified images.

• Post Classification Change Detection
  – Compared images for two different years at a time (ex. 1988 and 1991)
## Results and Discussion

- **Accuracy Assessment**

<table>
<thead>
<tr>
<th>Classified Image Year</th>
<th>Overall Accuracy</th>
<th>Kappa Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>87.4%</td>
<td>0.7502</td>
</tr>
<tr>
<td>1991</td>
<td>89.6%</td>
<td>0.8700</td>
</tr>
<tr>
<td>1993</td>
<td>91.2%</td>
<td>0.8900</td>
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</tr>
<tr>
<td>2002</td>
<td>86.0%</td>
<td>0.8250</td>
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## Accuracy assessment results

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</tr>
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</table>
Change detection for vegetation cover

Results

35% Vegetation

7% Vegetation
Change detection for vegetation cover

Results

% vegetation increase

Year

Potential Vegetation Production if Fenced and Protected

Results

% vegetation increase

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>7</td>
<td>12</td>
<td>17</td>
<td>22</td>
<td>27</td>
<td>32</td>
<td>37</td>
<td>42</td>
</tr>
</tbody>
</table>

Graph showing the trend with an increasing % vegetation increase from 2015 to 2022.
Runoff Factor

• This factor was generated using Soil Conservation Service Curve Number Equation (SCS-CNE) model.
• Rainfall-runoff relationship was calculated using the following equations:

\[ Q = \frac{(P - I_a)^2}{(P - I_a) + S} \]

• \( Q \) = runoff (in), \( P \) = rainfall (in), \( S \) = potential maximum retention after runoff begins (in) and, \( I_a \) = initial abstraction (in)
• \( S \) is related to the soil and cover conditions of the watershed through the Curve Number (CN). CN has a range of 0 to 100, and \( S \) is related to CN by:

\[ S = \frac{1000}{CN} - 10 \]
Runoff Factor

• The model depends on the runoff curve number (CN).

• the Natural Resource Conservation Service (NRCS) curve number has divided soils into four hydrologic soil groups (HSGs) based on infiltration rates.
MPASIC model vs EMP and USLE

Results

![Erosion class comparison graph]

- V.low
- Low
- Moderate
- High
- V.high

Bar chart showing surface area percentages for different erosion classes.
## Geological factor

<table>
<thead>
<tr>
<th>Geological property</th>
<th>MPSIAC Rating (Y1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeolian sand</td>
<td>8</td>
</tr>
<tr>
<td>Desert floor deposits</td>
<td>6</td>
</tr>
<tr>
<td>Dibdibah formation</td>
<td>5</td>
</tr>
<tr>
<td>Intertidal and Shoaling Sand, silt and Mud</td>
<td>5</td>
</tr>
<tr>
<td>Sabkha deposits</td>
<td>1</td>
</tr>
<tr>
<td>Strand line deposits</td>
<td>2</td>
</tr>
</tbody>
</table>
Soil Factor

- Soil erodability map (K factor) was generated based on RUSLE

\[ k = 2.8 \cdot 10^{-7} \cdot M^{1.14} (1.2 - a) + 4.3 \cdot 10^{-3} (b - 2) + 3.3(c - 3) \]

1. \( M \) is the size of soil particles
2. \( a \) is the percentage of organic matter,
3. \( b \) is soil structure, and
4. \( c \) is the soil drainage class
• climatic factor rating was based on Fourier Index (FI)

\[ \text{FI} = \frac{p^2}{P} \]

• Where \( p \) is the mean monthly rainfall of the wettest month, and \( P \) is the mean annual rainfall

Climate Factor

Rainfall

129 mm (5 inch)
Runoff Factor

• This factor was generated using Soil Conservation Service Curve Number Equation (SCS-CNE) model.

• Rainfall-runoff relationship was calculated using the following equations:

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• \( Q \) = runoff (in), \( P \) = rainfall (in), \( S \) = potential maximum retention after runoff begins (in) and, \( I_a \) = initial abstraction (in)
Topography Factor

\[ \text{LS} = (\text{Flow accumulation} \times \frac{\text{Cell value}}{22.1})^m (0.065 + 0.045 s + 0.0065 s^2) \]

(Wischmeier and Smith 1978)
Land Cover Factor

- Land cover and vegetation cover were rated using MPSIAC equations:
  - $y_6 = 0.2x_6$
  - $y_7 = 20 + 0.2x_7$

Where $X_6$ is bare soil %, and $X_7$ is vegetation cover %.
Surface Erosion Factor

- Surface erosion was rated based on Breau of Land Management (BLM) (Refahi, 2006)
- The location includes two types of erosion, sheet erosion and rill erosion
- Variables that were taken into consideration are land cover, streams, and slopes
- Each erosion type was rated from 0 (low sensitivity) to 15 (high sensitivity)