Vegetation-Erosion Dynamics and Application in China

Zhaoyin Wang
Professor, Dept. of Hydraulic Engineering,
Tsinghua University, China
Chairman, Advisory Council, International Research and Training Center on Erosion and Sedimentation
1. Vegetation-erosion dynamics
Ecological Stresses on vegetation

• The ecological stress is defined as any kind of disturbance on the vegetation, which may change the vegetation cover or affect the vegetation vigor.

• Soil erosion, tectonic motion, landslide, drought, salinization, debris flow, flood, catastrophic wind are the natural stresses.

• Human activities, including agriculture, mining, road construction, trailing, forest recreation, logging and reforestation, exhibit the most direct, and in many cases, the strongest non-natural ecological stresses on the vegetation.
Soil erosion, volcano eruption, and debris flow, impair or destroy vegetation. On the other hand, rill erosion can be controlled by herbaceous vegetation. Debris flow can be partly controlled by wood vegetation.
Resilience of the Vegetation

1. Resilience of the vegetation is defined as inverse of the time needed for vegetation to recover after impaired by stresses and the stresses are removed.

2. If the resilience of a vegetation is zero (in other words, if the vegetation itself can not recover as the stresses retreat), the vegetation is vulnerable. Glacier forest, grass-land on the Qinghai Plateau, vegetation on the Maousu desert are a few examples of vulnerable vegetation.
In south China a vegetation with high resilience quickly restored after a forest fire occurred three years ago.
• Coupled differential equations for vegetation-erosion dynamics

\[
\begin{align*}
\frac{dV}{dt} - aV + cE &= V_\tau \\
\frac{dE}{dt} - dE + fV &= E_\tau
\end{align*}
\]
Mathematical solution of the equations if the stresses are known

$$V = c_1 e^{m_1 t} + c_2 e^{m_2 t} + V_1(t)$$

$$E = c_1 \frac{a - m_1}{c} e^{m_1 t} + c_2 \frac{a - m_2}{c} e^{m_2 t} + E_1(t)$$

$$V_1(t) = e^{m_1 t} \int [e^{-m_1 t} e^{m_2 t} \int e^{-m_2 t} \left( \frac{dV_\tau}{dt} - dV_\tau - cE_\tau \right) dt] dt$$

$$E_1(t) = e^{m_1 t} \int [e^{-m_1 t} e^{m_2 t} \int e^{-m_2 t} \left( \frac{dE_\tau}{dt} - aE_\tau - fV_\tau \right) dt] dt$$
Calculation results - Xiaojiang basin
Anjiagou Watershed on the loess plateau $a=0.001(1/a)$, $c=0.0000018(km^2/a)$, $d=0.01(1/a)$, $f=400(t/(km^2\cdot a^2))$
Application of the differential equations to the Wangjiagou watershed on the loess plateau (east side)
2. Vegetation-erosion chart
Vegetation Erosion Chart

Assume there is no stresses, the vegetation and erosion development follows the homogeneous differential equations:

\[
\begin{align*}
\frac{dV}{dt} - aV + cE &= 0 \\
\frac{dE}{dt} - dE + fV &= 0
\end{align*}
\]
Assume the rate of the variation of $E$ and $V$ equal to zero, i.e. 
$\frac{dV}{dt}=0$ and $\frac{dE}{dt}=0$

we have the two lines

\[ E = \frac{a}{c} V; \quad E = \frac{f}{d} V \]
The vegetation erosion chart for the Xiaojiang Watershed on the Yunnan Plateau

A \[ \left( \begin{array}{c} V' < 0 \\ E' > 0 \end{array} \right) \]

B \[ \left( \begin{array}{c} V' > 0 \\ E' > 0 \end{array} \right) \]

C \[ \left( \begin{array}{c} V' > 0 \\ E' < 0 \end{array} \right) \]
Zone A, $dV/\!\!\!d\!\!\!d < 0$, $dE/\!\!\!d\!\!\!d > 0$. vegetation deteriorating and erosion increasing. The larger is $a/c$, the bigger is the Zone.

Zone B, $dV/\!\!\!d\!\!\!d > 0$, $dE/\!\!\!d\!\!\!d > 0$. Transitional zone.

Zone D, $dV/\!\!\!d\!\!\!d < 0$, $dE/\!\!\!d\!\!\!d < 0$. Transitional zone.

Zone C, $dV/\!\!\!d\!\!\!d > 0$, $dE/\!\!\!d\!\!\!d < 0$. vegetation is developing toward perfect vegetation cover and the erosion rate is decreasing. The larger is the value of f/d, the bigger is the Zone C. For a watershed in this zone, the forest may be logged to a certain extent and the vegetation may recover after a period of time.
Erosion control
Reforestation
Well developed vegetation
Vegetation-erosion chart

Loess Plateau – Anjiagou watershed

A: \( V' < 0 \)  
\( E' > 0 \)  
\( E' = 0 \)

D: \( V' < 0 \)  
\( E' < 0 \)

C: \( V' > 0 \)  
\( E' < 0 \)

V' = 0

Vegetation-erosion chart

Vegetation erosion chart for the Wangjiagou watershed
3. Application of Vegetation-erosion dynamics in China
Rock hills in north China
Loess plateau
Upper and middle Yangtze Basin
Red soil area in south China
Zoning of the loess plateau: I - blown sand dune and Pisha rock hills along the Great wall; II - East zone of gullies and hills; III - West zone of gullies and hills; IV - Gully plateau zone
Vegetation-erosion charts for Zone I (upper left), II (upper right), III (lower left) and IV (lower right).
x-axis is the vegetation cover; and y-axis is the erosion rate per area per year.
Zone I  Blown sand dune and the Great Wall
Zone I  Pisha rock hills (loosely binding rocks)
Zone I  Stabilizing the sand dune by planting straw and dry grasses to form a frame net
Zone I   Reforestation on the blown sand dunes
Zone I Protection against wind and blown sand
Gullies and hills in the loess plateau – Yanhe River basin
Loess Plateau
Gullies and hills in the loess plateau – Yan-an
Gully plateau area in the southeast loess plateau – Near Xi-an
A complex vegetation community with self-restoration capacity has developed in the southeast Loess Plateau.
Vegetation-erosion charts for rock hills in north China (Beijing and Hebei Province) x-axis is the vegetation cover; and y-axis is the erosion rate per area per year.
Rock hills in the Juma River basin to the southwest Beijing
The greened rock hills in the Juma River basin can be well maintained by human management.
Application of vegetation-erosion dynamics in Guangdong Province in south China (subtropical zone)
Vegetation - erosion chart for the red soil area in south China - the Dongjiang watershed in Guangdong Province

The C-zone is large and the E’=0 line is steep, which suggests that reforestation is very effective for erosion control and it is not difficult to move the point into C-zone and the vegetation may develop automatically and quickly.
Reforestation accelerate the vegetation succession in a subtropical area

In the period of 1970-1980, exploitive logging has resulted in serious deforestation in the area. Most of the hills became bare and barren.

In the period of 1981-1984 about 40% of the bared hills were reforested and the erosion rate also reduced by engineering measures. The point in the chart was moved to the C-zone, thence, the vegetation has been developing toward perfect vegetation composed of woods, shrubs, bamboos, liana and grass.

As a comparison, only grass and some shrubs have developed in the neighbor closed hills (no forestation) during the same period of time.
### Vegetation Cover (%)

**Year**
- 1978
- 1983
- 1988
- 1993
- 1998
- 2004

**Legend**
- **Woods**
  - Acacia auriculaeformis
  - Ailanthus altissima
  - Cinnamomum camphora
  - Scheffera actinophylla
  - Sapium discolor
  - Others

- **Herbage**
  - Dicranopteris pedata
  - Melinis minutiflora
  - Miscanthus floridulus
  - Gahnia tristis
  - Scleria hookeriana

- **Shrubs and bamboo**
  - Imperata cylindrica
  - Blechnum orientale
  - Melastoma dodecandrum
  - Setaria viridis
  - Helicteres angustifolia
  - Eremochloa ciliaris
  - Eriachne pallescens
  - Scirpus subcapitatus
  - Bulbostylis barbata
  - Exacum
  - Eleusine indica
  - Eragrostis poaeoides
  - Lycopodium Cernuum
  - Dianella ensifolia
  - Ischaemum barbatum
  - Cymbopogon goeringii
  - Others

- **Liana**
  - Rhododendron simsii
  - Lygodium japonicum
  - Smilax china
  - Zanthoxylum nitidum
  - Fructus Zanthoxyli Planispini
  - Smilax china
  - Rhodomyrtus tomentosa
  - Syzygium jambos
  - Xylosma congestum

**Closed plot (plot 1)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Vegetation Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>0</td>
</tr>
<tr>
<td>1983</td>
<td>0</td>
</tr>
<tr>
<td>1988</td>
<td>0</td>
</tr>
<tr>
<td>1993</td>
<td>10</td>
</tr>
<tr>
<td>1998</td>
<td>20</td>
</tr>
<tr>
<td>2004</td>
<td>30</td>
</tr>
</tbody>
</table>

**Reforested plot (plot 4)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Vegetation Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>0</td>
</tr>
<tr>
<td>1984</td>
<td>0</td>
</tr>
<tr>
<td>1988</td>
<td>10</td>
</tr>
<tr>
<td>1992</td>
<td>20</td>
</tr>
<tr>
<td>1998</td>
<td>30</td>
</tr>
<tr>
<td>2004</td>
<td>40</td>
</tr>
</tbody>
</table>
As a comparison, only grass and some shrubs have developed in the neighbor closed hills (no forestation) during the same period of time.
Conclusions 1

• Vegetation-erosion dynamics and vegetation-erosion chart can be used for prediction of vegetation development and research on effective management strategies.

• The hot and dry valleys can be greened and a vegetation with high resilience may develop if erosion is controlled.

• On the loess plateau the vegetation with self-restoration capacity can develop in the south and east zones. In the west and north zones vegetation may develop by reforestation and erosion control in small watersheds but always needs management.

• In red soil area, the vegetation-erosion chart is the best. The vegetation may quickly restored if it is destroyed by stresses. Moreover, vegetation succession can be accelerated by planting selected wood species and control erosion.
Thank you