SOIL EROSION INDUCED DEGRADATION OF AGROLANDSCAPES IN UKRAINE: MODELLING, COMPUTATION AND PREDICTION

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**Soil erosion in the world**

Water soil erosion (soil erosion) is a process of washing off, transference and deposition of soils by the drops of rain and surface flow of temporal streams of shower and melted waters.

Process of destruction and transference of soil by wind is named deflation or wind erosion.

As a result of soil erosion the degraded (eroded) soils and gullies are formed.

Soil erosion is one of most widespread and dangerous soil degradation processes in the world.

In accordance with the results of project “Global Assessment Human-Induced Soil Degradation (GLASOD)” of the UN Program on the Environment (UNEP), executed in 1987-1990, more than the milliard ha \((1093.7 \text{ million ha})\) of eroded soils was counted in the world.

Water soil erosion takes the first place among other soil degradation processes – 56 per cent area of all degraded soils. The second place among soil degradation processes occupies deflation. On its stake there is a \(550 \text{ million}\) ha destroyed soils or 28% area of all degraded soils.
As evaluated by FAO, the annual losses of productive soils from erosion in the world approximated 5-7 million ha.

Thus, presently an area of eroded lands in the world occupy 1.2-1.3 milliards ha, that comprises about 10 per cent dry land free of ice. If to take into account the deflated lands, this number increases to 14 per cent.

In separate countries this percent substantially differs from the middle value.

In the USA, where soil erosion was acknowledged as the national calamity, about 9% territory (and 44% cultivated lands) is exposed to erosion.

In China eroded about 20% country area (The Word Factbook, 2003).
### Relative extent of water erosion in Central and Eastern Europe (% of country area)*

<table>
<thead>
<tr>
<th>Country</th>
<th>$W_t$</th>
<th>$W_d$</th>
<th>$W_0$</th>
<th>$W_{we}$</th>
<th>Et</th>
<th>Total</th>
</tr>
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<tr>
<td>Belarus</td>
<td>8.5</td>
<td>0.2</td>
<td>8.7</td>
<td>5.9</td>
<td>14.6</td>
<td></td>
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<td>Bulgaria</td>
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<td>39.8</td>
<td>14.6</td>
<td>54.4</td>
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</tr>
<tr>
<td>Czech</td>
<td>15.1</td>
<td></td>
<td>15.1</td>
<td>3.1</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>Estonia</td>
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<td></td>
<td>3.2</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hungary</td>
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<td></td>
<td>21.2</td>
<td>9.7</td>
<td>30.9</td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
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<td></td>
<td>11.4</td>
<td>1.8</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>Lithuania</td>
<td>10.4</td>
<td>0.4</td>
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<td>3.8</td>
<td>14.6</td>
<td></td>
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<tr>
<td>Moldova</td>
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<td>9.2</td>
<td>1.0</td>
<td>10.2</td>
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<td>4.0</td>
<td>20.8</td>
<td>0.9</td>
<td>21.7</td>
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<tr>
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<td>6.8</td>
<td>11.0</td>
<td>1.8</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>5.4</td>
<td>6.8</td>
<td>12.2</td>
<td>0.6</td>
<td>12.8</td>
<td></td>
</tr>
</tbody>
</table>

Influence of soil erosion on agrolandscapes

Soil erosion is a soil degradation process, but it has negative influence not only on soil cover and, consequently, on quantity and quality of land resources, but also on other components of landscapes – relief, waters (and water resources), vegetable cover and climate. In particular, soil erosion:

- diminishes the most valuable upper part of soil profile, decreasing of humus (soil organic matter) content and nutrients in the soils;
- increases turbidity of river water and worsens of their quality by products of erosive destruction of soils entering rivers;
- carry out sedimentation of reservoirs and waterways (up to disappearance of small rivers);
- decreases absorptive power and moisture-holding capacity of eroded soils, that negatively influences not only on the water regime of soils but also on hydrological regime of territories on the whole;
- reduces power of humus horizon on arable lands and involves in treatment mother rocks, that along with general reductions of humus in the eroded soils conduces to the change of optical brightness and, consequently, the reflecting ability (albedo) of soil cover.

The total and final effect of soil erosion can be marked as the desertification.
Influence of degree of destruction of soils by erosion on their properties in horizon 0-50 cm

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Degree of destruction of soils by erosion</th>
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<tbody>
<tr>
<td></td>
<td>slight</td>
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<tr>
<td>Thickness of soil horizons:</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.5*</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>Humus content</td>
<td>0.95-0.75</td>
</tr>
<tr>
<td>Productivity (of grain)</td>
<td>1.0-0.8</td>
</tr>
<tr>
<td>Moisture-holding capacity</td>
<td>0.98-0.95</td>
</tr>
<tr>
<td>Infiltration capacity</td>
<td>0.85-0.75</td>
</tr>
<tr>
<td>Erodibility</td>
<td>1.3-1.5</td>
</tr>
</tbody>
</table>

*For the 1.0 the values of corresponding parameters for not eroded soils are accepted*
Extreme case of soil erosion on the Loess plateau in China (photo by Li Rui)
Soil erosion in Ukraine

• On January, 1, 2000, in Ukraine was counted 13.9 million ha of eroded agricultural lands, that was 33.2% of their area.

• Taking into account, that agricultural lands in Ukraine occupy about 70% (69.3% on 1.01.2004) the territory, practically its fourth part (23%) is in different degree eroded.

• More than 6 million ha are exposed by wind erosion systematically (14.3% agricultural lands), and in years with dusty storms – up to 20 million ha.

• During a few last decades the area of eroded lands in Ukraine annually was increasing on 80 000-100 000 ha.

• Soil erosion, thus, is most widespread and dangerous soil degradation process in the country. Annual damage only to the agriculture in Ukraine by different estimations equals 5-10 milliard US dollars.
Soil degradation in Ukraine
(by Ukrainian National Scientific Center “Institute of Soil Science and Agrochemistry”)

Soils exposed to water erosion (eroded soils, % of the arable lands)
- Very low (about 1)
- Low (from 1 to 20)
- Moderate (from 20 to 40)
- High (from 40 to 60)
- Very high (above 60)

Degradation of drained lands
- Intense peat cutover and spread of wind erosion
- Secondary swamping

Risk of soils’ overcompaction
- slight
- moderate
- heavy

Humus loss
- low
- medium
- high

Boundaries of nature-agricultural zones
- Zones
- Provinces

Processes of alcalization and salinization
- S

Processes of aluminizing and secondary acidification
- Al

Processes of iron and carbonate accumulation
- Fe, Ca

Soil degradation in Ukraine
Eroded soils (light spots and belts) near Odessa
Surface and gully erosion in Ivanov district of Odessa region
(extra high resolution satellite image from Google Earth web service)
3D view
23.03-24.03.2007. Kherson region (photo by Prof. S.G.Chorny)
The next day after a small rain near-by the south boundary of Odessa (in the distance an approximately 160-170 km)
Intermediate conclusions

Rational use of land and water resources and sustainable development on the whole practically in all regions of Ukraine, but in central and southern its parts especially, is impossible without estimation of modern rates of erosion degradation of landscapes and prediction of them on a prospect, and also without grounds of the system of measures providing prevention of erosion destruction of the soil cover.

It is possible to do only with the use of adequate mathematical model (or models) taking into account all basic natural and economic factors of soil erosion and validated within the territory is being under consideration.

The important value has also the possibility of the model to account the spatial distributing of soil erosion factors, allowing to give estimation of the real distributing of intensity of erosion/deposition within the limits of the examined territory, and the possibility of the model to estimate influence of modern and forthcoming changes in factors of soil erosion, including climate change.
Mathematical models of soil erosion can be parted on two large groups:

- physically based compound dynamic models of erosion/deposition,
- empirical models of soil losses (or soil wash off).
Physically based approach

Limburg soil erosion model (LISEM) (De Roo et al., 1996)

Simplified flowchart of the LISEM model

\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = r(t) - f(t) \]
\[ Q = p R^B \]
\[ \frac{\partial (AC)}{\partial t} + \frac{\partial (QC)}{\partial x} - e(x,t) = q_s(x,t) \]
\[ e = DET + DF \]
Fragment of digital spatial database for Butenya river basin, $F=59\ km^2$
Result of modelling of erosion-deposition process from the shower of 5% probability of appearance, Butenya river basin
Graphs of design rains of 5 and 10 percentage of probability of occurrence (A) and simulated maps of erosion/deposition for the Butenya river basin, caused by design rain 10% (B) and 5% (C) probability of occurrence.
Empirical approach

From the mathematical models of soil erosion, developed in the former Soviet Union, which were recommended and/or used for estimation of erosion losses of soil and planning of soil protective measures within limits of the territory of Ukraine, most theoretically and experimentally grounded there was the model of surface wash off, developed by H.I. Shvebs (1974, 1981).

During the last years on the base of the model of surface wash off by H.I. Shvebs profile (1D) and spatially-distributed (2D) version of soil erosion/deposition model were developed (Svitlychnyi, 1995, 1999; Pjatkova, 2008).

The model belongs to the class of physically-statistical empiric mathematical models of soil erosion of known Universal Soil Loss Equation, USLE (USA).

Unlike other models of this kind, the model developed in Odessa National I.I. Mechnikov University

- is spatially distributed,
- takes into account unstationaryness of process of shower sediment formation,
- allows to predict not only «washing off» but also deposition of alluviums along slope.

As computer program the model are realised with the use of traditional information (TurboPascal) and geoinformation (PCRaster package, Utrecht University) technologies.
Basic equations of mathematical model of erosion/deposition of soils 
(1D version) for warm period of a year

If \( L \leq L_a \):

\[
W(L) = 2.6 \cdot 10^{-6} \left[ 1.5 K_{HM}(L_a) j_R(L_a)L^m(L_a) L_a^{0.5} f_a(L_a) + 
+ K_{HM}(L) f_a(L) j_R(L) L^{1.5} \frac{d(I^m(L))}{dL} + K_{HM}(L) f_a(L) L^m(L) L^{1.5} \frac{d(j_R(L))}{dL} + 
+ K_{HM}(L) j_R(L) I^m(L) L^{1.5} \frac{d(f_a(L))}{dL} + j_R(L) I^m(L) f_a(L) L^{1.5} \frac{d(K_{HM}(L))}{dL} \right],
\]

(1)

if \( L > L_a \)

\[
W(L) = 2.6 \cdot 10^{-6} \left[ 1.5 j_R(L_\Delta)L^m(L_\Delta) L_\Delta^{0.5} K_{HM}(L_\Delta) f_a(L_\Delta) + 
+ K_{HM}(L) f_a(L_\Delta) j_R(L_\Delta) L \frac{d(I^m(L))}{dL} + K_{HM}(L) f_a(L) I^m(L) L \frac{d(j_R(L))}{dL} + 
+ K_{HM}(L) j_R(L) I^m(L) L \frac{d(f_a(L))}{dL} + j_R(L) f_a(L) I^m(L) L \frac{d(K_{HM}(L))}{dL} \right].
\]

(2)
In equations (1) and (2):

\[ W(L) - \text{mean annual rate of soil wash off (t/ha/year) in a distance } L (\text{m}) \text{ from the divide; } \]

\[ L_a - \text{length of zone of growth of sediment formation intensity along a slope (m); } \]

\[ I(L) - \text{function of slope gradient, } \%; \]

\[ j_R(L) - \text{function of relative soil erodibility, dimensionless; } \]

\[ K_{HM}(L) - \text{hydrometeorological factor of shower wash off of soil as function of distance from the divide; } \]

\[ f_a(L) - \text{function of soil protective efficiency of agriculture, dimensionless; } \]

\[ p, n - \text{indexes of degree. } \]
Screen copy of resulting chart of erosion-deposition rate (t/ha/year) by profile (1D) model.
Digital elevation model (A), soil map (B), map of mean annual value of the hydrometeorological factor $K_{HM}$(C) and erosion-deposition map, computed by 2D version of the model (D).
The model is verified using data of observations on experimental runoff plots and slope watersheds located in different parts of the territory of Ukraine, passed wide approbation.

It enables to execute estimation not only modern erosion/sedimentation intensity but also to make quantitative estimation of change of rates of erosion in connection with the changes of climate.
Problem of climate change and soil erosion

Change of annual precipitation during 1894-2007 at Odessa-observatory

\[ P = 0.3864 \times t - 297.82 \]
Change of indices of daily precipitation extremes R20mm (A), RX1day (B) and RX5day (C) for warm period of year during 1900-2007 at Odessa-observatory
Hydrometeorological factor of shower wash off for separate rain (Shvebs, 1974; Shvebs et al., 1993)

\[ k_{HM} = \left[ \sum_{i=1}^{N} (1 + 17.5 A r_i) (r_i - r_{ci})^{2.7} \Delta t_i + \sum_{\xi=1}^{M+1} (1 + 17.5 A r_{\xi}) (r_{\xi} - r_{c\xi})^{2.7} \right]^{2.7} \Delta t_{\xi} \]

\[ r_{cim} = 0.08 + 5.92 \exp \left[ -0.151 \left( B_0 + \sum_{j=1}^{p} \Delta X_j \right) \right] \]

\( r_i \) - intensity of rain during time interval \( i \) from beginning of the rain, for which sediment formation took place;

\( r_{ci} \) – critical intensity of precipitation for the soil, accepted as a standard (ordinary clay non-eroded chernozem);

\( r_{\xi} \) - intensity of precipitation during \( \Delta t_{\xi} \) calculation interval for which \( r_{\xi} < r_{c\xi} \);

\( \lambda \) - coefficient of spatial concentration of slope runoff during of its recession;

\( A \) – coefficient of soil protective efficiency of vegetable cover;

\( N \) – amount of rain intervals with washing off of soil, i.e. of intervals of rain with \( r_i > r_{ci} \);

\( M \) - amount of continuous groups of intervals of rain, for which \( r_{\xi} < r_{c\xi} \).
Summary

1. Soil erosion a result of joint influence of the natural and socio-economic factors, therefore the change of any of them is inevitably caused by the change of intensity and distributions of area of eroded soils, that represents a large ecological and economic problem requiring the adequate decision.

2. From other side, in the conditions of the accelerated increase of area of eroded soils in connection with the modern warming of climate and increase of its instability, soil erosion acts more increasing part in the system of climate-terrestrial-hydrologic interaction.

3. That is why in the regions and countries with the active degradation of soils by erosion, including Ukraine, decision of tasks related to substantiation of the usage of land and water resources, of sustainable development of territories and etc. is impossible without taking into account modern intensity and distribution of soil erosion and prognosis of them on a prospect.

4. The modern regional mathematical models of soil erosion based on researches of the current dynamics and prognosis of changes in the system of climate-terrestrial-hydrologic interaction of the territories are a reliable basis for decision of these tasks.
Thank you very much for your attention!