Modelling of Environmental and Climatic Problems: Wind and Water Erosion

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Abstract

Magnitude of wind and water erosion mainly depend on wind velocity, rainfall rate, slope and soil characteristics. The main purpose of this lecture is to define the role of small, meso and large scale phenomena (local and synoptic fluctuations) on water and wind erosion. These lecture notes present some results on wind speed simulation and seasonal fluctuations of water deficit for the selected station in different erosion risk and transition regions of Turkey.
INTRODUCTION

In order to simulate the process of soil erosion by wind, wind speed and it’s characteristics are considered, (Skidmore, 1986, 1995, 2000a, 2000b). Prediction of wind speed and direction is extremely difficult. Raindrops, water and soil type play an important role on soil erosion, flood, landslides etc. The reason of soil erosion is mainly caused by the impact of raindrops on the soil surface and its flow between rills and in channels down slope. It also causes landslides on steep slopes. The erosivity effect of raindrops depends on the energy of a rainstorm, Pla Sentis (1998), Flanagan and Livingston (1995) and Gabriels (1993). Monthly rainfall data were used to compute rainfall erosivity indices for various stations in Ghana, (Oduro-Afriye, 1996). Temporal and spatial variation of rainfall erosivity and climatic factor of wind erosion are investigated in Turkey, Aslan, (1997), Tulunay et al., (2002), Aslan et al., (2002). Higher values of Fournier Index are observed in the North-eastern Black Sea, the Southern Aegean Sea and Mediterranean Sea Regions. This manuscript also presents some results on wind and water erosion characteristics at the Northwestern part of Turkey (Gökçeada).

METHODOLOGY

Rainfall Erosivity Factor and Water Erosion

Rainfall and runoff erosivity factors are defined by considering the results of field measurements. The Fournier Index described as a climatic index is defined by Odura-Afriye (1996) as

\[ C_p = \frac{P_{\text{max}}^2}{P} \]  

(1)

where \( C_p \) is the Fournier Index (mm), \( P_{\text{max}} \) the rainfall amount in the wettest month and \( P \) the annual precipitation (mm).

Table 1 shows classes of rainfall erosion risk based on the Rainfall Erosivity Index. \( C_p \) values above 60 show severe to extremely severe erosion risk in average climatic conditions, Odura-Afriye (1996).

<table>
<thead>
<tr>
<th>Class No</th>
<th>Erosion Risk Class</th>
<th>Fournier Index ( C_p )</th>
<th>Soil Loss (T/ha year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very Low</td>
<td>&lt;20</td>
<td>&lt;5</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>21-40</td>
<td>5-12</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>41-60</td>
<td>12-50</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>61-80</td>
<td>50-100</td>
</tr>
<tr>
<td>5</td>
<td>Very Severe</td>
<td>81-100</td>
<td>100-200</td>
</tr>
<tr>
<td>6</td>
<td>Extremely Severe</td>
<td>&gt;100</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>
Soil Moisture Prediction

Soil moisture over the western Turkey (in Istanbul) basin has been evaluated for long-term data by using De Martonne’s Index I (Piervitali et al., 1999). The index is given by the following equation:

\[ I = \frac{P}{(T + 10)} \]  

(2)

where \( P \) is the total yearly precipitation (mm) and \( T \) the mean yearly temperature (°C). Index values more than 30 correspond to the humid areas where time adjusted irrigation was necessary.

Wind Erosion (Climatic Factor)

Wind erosion index is also defined as climatic factor \( C_w \). It is a function of horizontal wind speed as given below:

\[ C_w = V^3 \]  

(3)

Erosion risk classes based on mean wind speed values have been studied by Aslan (1997) and Aslan et al., (2002).

Determination of Daily Wind Speed

The cumulative Weibull distribution function \( F(u) \) and probability density function \( f(u) \) are defined by Skidmore (1986) and (1995) as below:

\[ F(u) = 1 - \exp \left[-\frac{(u/c)^k}{(u/c)^k}\right] \]  

(4)

where \( u \) is wind speed, \( k \) the shape parameter (dimensionless) and \( c \) the scale parameter (m/s).

\[ F(u) = \frac{dF(u)}{du} = \frac{(k/c)(u/c)^{k-1}\exp\left[-\frac{(u/c)^k}{(u/c)^k}\right]}{(u/c)^k} \]  

(5)

\[ F_1(u) = \left[\frac{(F(u) - F_o)}{(1 - F_o)}\right] = 1 - \exp\left[-\frac{(u/c)^k}{(u/c)^k}\right] \]  

(6)

where \( F_1(u) \) is the cumulative distribution with the calm periods eliminated, and \( F_o \) the frequency of the calm periods. The dependent variable is wind speed \( u \) given by

\[ u = c\left\{\ln\left[1 - \frac{(F(u) - F_o)}{(1 - F_o)}\right]\right\}^{1/k} \]  

(7)

The program draws a random number, \( 0.0 < RN < 1.0 \) which is assigned to \( F(u) \), and subtracted from it the frequency of calm periods \( F_o \).
**Determination of Sub-daily Wind Speed**

Program reads from the wind data-base the ratio of maximum to minimum mean hourly wind speed and the hour of maximum wind speed for the location and month under consideration. Calculate the maximum and minimum wind speed for the day based on the representative wind speed as calculated above and given the ratio of maximum to minimum wind speed:

\[ u_{\text{rep}} = \frac{u_{\text{max}} + u_{\text{min}}}{2} \]  
\[ u_{\text{ratio}} = \frac{u_{\text{max}}}{u_{\text{min}}} \]

where \( u_{\text{rep}} \) is the daily mean representative wind speed as calculated from Eq. (8) and \( u_{\text{ratio}} \) the ratio of daily maximum \( u_{\text{max}} \) to daily minimum \( u_{\text{min}} \) wind speed. Wind speed for any hour of the day \( u(I) \) can be simulated from

\[ u(I) = u_{\text{rep}} + 0.5 \left( u_{\text{max}} - u_{\text{min}} \right) \cos \left[ 2\pi \left( 24 - h_{\text{max}} + I \right)/24 \right] \]

where \( h_{\text{max}} \) is the hour of the day when wind speed is maximum and \( I \) the index for hour of day.

**Aridity Index**

Aridity index AI is given by the following equation (Türkes. 1999; Aslan and Tokgözlü, 2000).

\[ AI = \frac{P}{PE} \]

where \( P \) is the annual total precipitation (mm) and \( PE \) the potential evaporation (mm). Aridity Index values for arid and dry sub-humid areas have been ranged between 0.05 and 0.65.

**ANALYSIS**

**Analysis of Rain-Erosivity**

Time variation of regional average annual total precipitation values in Turkey shows a increasing trend between 1900-1998. Erosivity values determined for overall over Turkey (average value) show severe erosion risk in winter. Table 2 gives some statistical characteristics of annual regional total precipitation and FI values based on the “Climate, Impacts LINK Project” (Giorgi and Francisco, 2000; New et al., 1999, 2000; Aslan et al., 2002).
Table 2. Seasonal variation of erosivity (Fournier Index) and erosion risk class in Turkey.

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring Erosion Class</th>
<th>Summer Erosion Risk Class</th>
<th>Autumn Erosion Class</th>
<th>Winter Erosion Class</th>
<th>Mean Erosion Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900-1930</td>
<td>20.9 Very Low</td>
<td>16.4 Very Low</td>
<td>54.2 Moderate</td>
<td>78.2 Severe</td>
<td>40.9 Low</td>
</tr>
<tr>
<td>1931-1960</td>
<td>30.7 Low</td>
<td>28.5 Low</td>
<td>47.5 Moderate</td>
<td>59.8 Moderate</td>
<td>41.6 Moderate</td>
</tr>
<tr>
<td>1961-1998</td>
<td>36.3 Low</td>
<td>24.5 Low</td>
<td>47.0 Moderate</td>
<td>60.7 Severe</td>
<td>42.1 Moderate</td>
</tr>
<tr>
<td>1900-1998</td>
<td>33.9 Low</td>
<td>27.1 Low</td>
<td>48.2 Moderate</td>
<td>59.6 Moderate</td>
<td>42.2 Moderate</td>
</tr>
</tbody>
</table>

Analysis of Wind Speed and Erosion

Data used in this study is hourly wind speed measurements from an automatic wind recording system mounted in Gökçeada (Tuzburnu, Altitude: 34m msl, Latitude: 40° 11’N, Longitude: 25° 54’E) between 1997 and 1998, and Ugurlu, Çinaraltı and National Station between 1992-1993, 1997-1998). To define water erosion at the study area, monthly and annual rainfall rate values based on long term observations are analysed.

When the other wind speed values are considered at Ugurlu, Çinaraltı and National Station between 1992-1993, the linear regression coefficient \( r \) between wind speed observations \( u \) and theoretical values is 0.97 with the significant level 1 (confidence limits 0.99). The linear regression coefficient \( r \) between wind speed observations \( u \) and theoretical values at all stations in Gökçeada (Tuzla, Ugurlu, Çinaraltı and National Station) between 1992-1993, and 1997-1998) is 0.94 with the significant level 1 (confidence limits 0.99) (Figure 1).

![Figure 1. Linear relation between average wind speed values at Gökçeada (Tuzla, Ugurlu, Çinaraltı, National Station) between 1992-1993 and 1997-1998.](image-url)
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REFERENCES


