Modelling of Environmental and Climatic Problems: Wind and Water Erosion

Zafer Aslan*

Beykent University, Faculty of Science and Literature,
Beykent, Istanbul, Turkey

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* zaslan@beykent.edu.tr

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 presents some results on wind speed simulation and seasonal fuluctuations of water defict for the selected station in different erosion risque 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), Flanagen 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 erositvity 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

$$C_p = P^2_{max} / P \qquad (1)$$

where C_p is the Fournier Index (mm), P_{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 1. Classes of rainfall erosion risk, indexes and soil losses.

Class No	Erosion Risk Class	Fournier Index C_p	Soil Loss (T/ha year)
1	Very Low	<20	<5
2	Low	21-40	5-12
3	Moderate	41-60	12-50
4	Severe	61-80	50-100
5	Very Severe	81-100	100-200
6	Extremely Severe	>100	>200

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:

$$I = P / (T + 10) \tag{2}$$

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:

$$C_w = V^3 \tag{3}$$

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:

$$F(u) = 1 - \exp[-(u/c)^k] \tag{4}$$

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

$$F(u) = dF(u)/du = (k/c)(u/c)^{k-1} \exp[-(u/c)^k] \tag{5}$$

$$F_1(u) = [(F(u) - F_o) / (1 - F_o)] = 1 - \exp[-(u/c)^k] \tag{6}$$

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

$$u = c\{-\ln[1 - (F(u)- F_o) / (1 - F_o)]\}^{1/k} \tag{7}$$

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 calcualted above and given the ratio of maximum to minimum wind speed:

$$u_{rep} = (u_{max} + u_{min}) / 2 \quad (8)$$

$$u_{ratio} = u_{max} / u_{min} \quad (9)$$

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

$$u(I) = u_{rep} + 0.5\,(u_{max} - u_{min}) \cos [2\pi(24 - hr_{max} + I)/24] \quad (10)$$

where hr_{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).

$$AI = P/PE \quad (11)$$

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.

Year	Spring	Erosion Class	Summer	Erosion Risk Class	Autumn	Erosion Class	Winter	Erosion Class	Mean	Erosion Class
1900-1930	20.9	Very Low	10.4	Very Low	54.2	Moderate	78.2	Severe	40.9	Low
1931-1960	30.7	Low	28.5	Low	47.5	Moderate	59.8	Moderate	41.6	Moderate
1961-1998	36.3	Low	24.5	Low	47.0	Moderate	60.7	Severe	42.1	Moderate
1900-1998	33.9	Low	27.1	Low	48.2	Moderate	59.6	Moderate	42.2	Moderate

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, Longtitude: 25° 54´E) between 1997 and 1998, and Ugurlu, Çinaralti 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, Çinaralti 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^3 and theoretical values at all stations in Gökçeada (Tuzla, Ugurlu, Çinaralti and National Station) between 1992-1993, and 1997-1998) is 0.94 with the significant level 1 (confidence limits 0.99) (Figure 1).

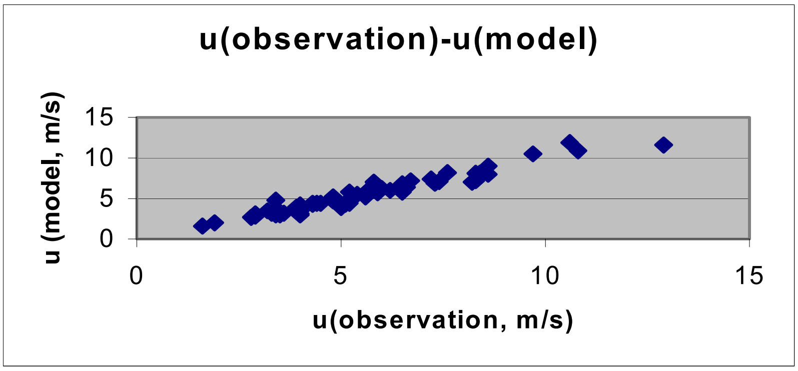

Figure 1. Linear relation between average wind speed values at Gökçeada (Tuzla, Ugurlu, Çinaralti, National Station) between 1992-1993 and 1997-1998.

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