Calibration of RWEQ in a patchy landscape; a first step towards a regional scale wind erosion model

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Abstract

Despite the fact that wind erosion seriously affects the sustainable use of land in a large part of the world, no validated wind erosion model that predicts windblown mass transport on a regional scale exists. Vegetation has the potential to decrease soil loss by wind erosion through the protection of the soil surface, through the reduction of wind speed and through the entrapment of saltating particles. Simulation of wind erosion process will differ at regional scale from field scale and as a result it will represent by different parameters. These parameters include vegetation cover, wind barriers, soil surface roughness and some other soil properties. The interaction of wind erosion with vegetation is the best example of a process that changes from plot to regional scale. The objective of this research was to make a starting point for a regional scale wind erosion model by establishing relations between the intensity of windblown mass transport and vegetation cover in a patchy landscape in Syria.

Measurements on windblown mass transport were executed at 9 different land uses (and thus vegetation cover) in agricultural stabilization zones 4 and 5 in Khansser valley, Syria. At each plot 16 MWAC (Modified Wilson and Cooke) sediment catchers were installed and wind speed was recorded with five-minute intervals. The RWEQ (Revised Wind Erosion Equation) was translated into the dynamic modelling language of PCRaster and applied to determine the relations between vegetation density and pattern and intensity of mass transport.

The results of this application showed that RWEQ in PCRaster (RiP) gave acceptable predictions for the uniform fields without incoming sediment sources. So, the predicted and observed results are in the same magnitude. However RiP needs more calibration to improve its prediction of the spatial variation of the windblown mass transport. With completing the calibration process, RiP will have the potential to form the basis of a regional scale wind erosion model.

Key words: **Wind erosion, RWEQ, scale, Syria, vegetation pattern, vegetation cover**

Introduction

Wind erosion is a dominant problem for both the environment and humanity in arid and semi-arid regions of our planet (Stroosnijder, 2007). In these regions, 24 % of all cultivated and 41 % of all pastoral fields suffer from moderate to severe land degradation due to wind erosion (Rozanov, 1990). Causing nutrient losses from soil surface, wind erosion decreases soil productivity (Visser and Sterk, 2007) and has negative effects on human health due to the harmful effects of dust particles on the respiratory system (Copeland et al., 2009). Climate factors interacting with soil properties and land management act upon wind erosion (Zobeck et al., 2000). The land management has an essential effect on the vegetation cover which is the most important protective factor of soil surface against erosive winds (Zhou et al., 2008). Through the covering of the soil surface, the reducing of wind speed at soil surface and the slowing down the movement of saltating particles, vegetation has the potential to decrease the windblown mass transport

(Leenders et al., 2005). The density and the distribution of vegetation determine its effectiveness in reducing the windblown materials. Leenders et al. (2006) studied the effect of woody vegetation in decreasing windblown sediment. They indicated that the ideal management of vegetation elements in a field is interrelations between the number of vegetation elements, the area covered with silhouettes and the type of the vegetation elements. Studying wind erosion and understanding the processes are reliable steps in dealing with wind erosion hazards and devastation. A large number of researches on wind erosion have been carried out on the point (e.g. Spaan and van den Abeele, 1991), the field (e.g. Hagen, 2004) and recently on the village scale (Visser and Sterk, 2007). However, land managers and decision makers need regional scale predictions of wind erosion to prepare future plans of land uses and prepare for the hazards of regional wind erosion (Feng and Sharratt, 2007).

The prediction of wind erosion at a regional scale is an essential tool for land policy makers for future land use planning in order to minimize the wind erosion hazard (Visser and Sterk, 2007). Current regional scale models are lack validated and because of the doubts about their prediction, their results are not taken seriously by policy makers (Van Rompaey and Govers, 2002) . The development of a regional scale models from the basis of a validated field scale models could be a solution to this problem. However, as in most environmental phenomena, also in wind erosion, most processes at the larger scale differ from those at the smaller scales (Zobeck et al., 2000). Thus, small scale models are not directly applicable at larger scales (Seyfried and Wilcox, 1995). Upscaling of models from field to regional scale was successfully applied in hydrology (Merz et al., 2009). However, upscaling in wind erosion research is so far not applied. That is because of difficulties of collecting data required for validation of regional scale wind erosion models (Visser, 2004; Zobeck et al., 2000). Through the process of upscaling a field based model towards a regional scale model, data requirements are reduced, the needed time and expenditures for data collection are decreased and errors resulting from the use of average regional scale values as input parameters are avoided (Gaunt et al., 1997; Smith, 1999). Finally, developing regional models based on validated field scale models leads to a more reliable output of the derivative models.

Before initiating model upscaling, it's essential to get the model sufficiently calibrated and validated. Depending only on validated field scale models the regional scale models can be derived (Blöschl, 1995). So, specific relations among the model parameters and the outputs of the field scale model should be studied carefully before using this model for upscalling purpose.

The objective of this research was to make a starting point for a regional scale wind erosion model through the establishment of relations between the intensity of windblown mass transport and vegetation cover and distribution in a patchy landscape in Syria. In this research, the RWEQ wind erosion model was calibrated and validated to be used later as a base for the developing of the regional scale wind erosion model.

Materials and method

Khanasser valley is situated between Al Hass and Shbeith mountains southeast of Aleppo city, Syria. At an altitude of 350 m asl, the valley is rather flat. Annual rainfall ranges from 150 to 250 mm and the rainy season starts in October and ends in May (Masri et al., 2003). According to annual rainfall, Syria can be divided into 5 stability zones (ICARDA, 2005). In stability zone 4, the annual rainfall is 200 -250 mm and the land use is dry farming (mainly cereals). In stability zone 5, the annual rainfall is less than 200 mm and cultivation is forbidden. This research was carried out in stable zone 4 and 5 in Khanasser valley.

Wind in the dry season (from June to September) comes mainly from directions ranging from south to west and the monthly average of wind speed fluctuates from 3.5 ms^{-1} in the south to 4.4

ms^{-1} in the north (Bruggeman et al., 2010). The daily average wind speed can exceed 10 ms^{-1} (Masri et al., 2003). Wind erosion is one of the most dominant degradation problems threading not only agricultural and livestock activities but also the settlement in this region (Thomas and Turkelboom, 2008).

This research was carried out using a "portable" plot approach, as such it was possible to measure at many locations with the available equipment. Measurements were carried out on a total of 9 plots. For most plots no non-eroding border was present at a sort distance. Therefore eroded materials could blow easily into and out of the plot. Table 1 presents land use, zone, soil type and vegetation type at each site.

A set up of 16 MWAC catchers placed in a regular grid with an interval of 20 m in a plot of 60 x 60 m was chosen at every site. This instrument set up allowed the measurement of changes in wind-blown mass transport at the borders of different land units; and provided a transect of mass fluxes regardless of the wind direction. Total mass transport was calculated by sampling the mass flux at 5 heights (0.10, 0.30, 50, 0.75 and 1.00 m) and applying the approach of Sterk and Raats (1996) for the calculation of mass transport (kgm^{-1}).

At every site a full climate station was installed. To determine the duration of saltation events and the initiation of the mass flux a saltiphone (Spaan and van den Abeele, 1991) was used. Wind speed ($m\ s^{-1}$) was measured by 5 anemometers attached to a holder bar at the heights of 0.40, 1, 1.88, 3.00 and 4.00 m. A wind vane, placed at height of 2.00 m, was used to record the wind direction. Air temperature and the relative humidity was measured at a height of 2.00 m. All sensors were connected to a CR1000 data logger, recording data on basis of 5 minute intervals.

Translation of RWEQ into PCRaster

In its original format, RWEQ (Fryrear, 1998) doesn't provide the required flexibility for this research to use inputs that represent the distribution of some parameters over the study area (for further information on RWEQ see the manual: Fryear, 1998). Moreover, the time step in the original version was (1-15 days) and the model simulates data for this period using CLIGEN. To be able to analyze the effect of vegetation density on windblown mass transport and its spatial distribution, a model should allow input of maps representing vegetation cover and soil roughness. The big advantage of RWEQ is that the model is relatively simple and uses a limited amount of input data which makes the model more easy to scale up, compared to more complex physically based models. To allow the input of spatial variable parameters and to use the advances of RWEQ, it was decided to translate RWEQ into the dynamic modeling language of PCRaster. This modeling language has a wide range of spatial and non-spatial database in inputs and outputs of dynamic models (Karssenberg and De Jong, 2005). Karssenberg (2006) successfully used PCRaster in upscalling saturated conductivity for Hortonian runoff modeling from point to plot scale.

Apart from the translation of RWEQ, some adaptations have been made to the original version of the model. One important change is the spatial distribution of the mass transport using the LDDs (local drain direction) application of PCRaster to allow the sediment to "flow" with the main wind directions. Furthermore, the time steps are divided in 4 periods a day from 12h – 18h, from 18h -24h, from 24h -06h and finally from 06h – 12h. And the weather factor (WF) was simulated for each time step separately. The erodible factor, soil crust factor, soil roughness factor and combined crop factor were calculated depending on field observation.

Table 1. Zone, crop, texture and land use of wind erosion measurement plots in the Khansser valley, Syria

Name	Zone	Crop	Soil [*1]	Land use
Serdah A	4	Wheat	Clay-Loam	Harvested field with partially grazing; standing silhouette
Serdah C	4	Camion	Clay-Loam	Harvested field with Intensive grazing, no standing silhouette,
Mugherat A[*2]	4	Wheat with Atriplex	Sandy-Loam	Harvested field with Intensive grazing, no standing silhouette, shrubs of Atriplex
Mugherat NA	4	Wheat	Sandy-Loam	Harvested field with Intensive grazing, no standing silhouette,
Umm Mail	4	Barley	Clay-Loam	Harvested field with Intensive grazing, no standing silhouette,
Adami agri	4	Wheat	Silt-Loam	Harvested field without grazing
Adami WA	5	Atriplea reserve	Sandy-Loam	Reserve area with Atriplex with partial grazing, high density Atriplex
Adami Gazelle	5	Atriplex reserve	Silt-Loam	Reserve area with Atriplex with partial grazing,
Rangeland Dami R	5	Bare	Silt-Loam	Range land without any vegetation cover

*1 After soil texture was determined by hydrometers method the soil type was determined using Soil Texture Calculator (NRCS, 2010)

*2This field is a combination of farming and Atriplex-reserve tested by ICARDA to combine Atriplex with farming to reduce the effect of erosive wind on the soil surface

Results and discussion

Windblown mass fluxes were measured at 6 plots in the stability zone 4 and at 3 plots in stability zone 5 in Khansser valley, Syria in 2009. Generally, the average wind speed during measurement periods ranged from 2.3 to 8.77 ms^{-1} with maximum wind velocity of 11.54 ms^{-1} at Serdah A measurement plot. The main wind direction was WSW/SSW with some exceptional events in which the main wind direction was ENE/SSE/ ESE. The highest measured mass flux was in the rangeland area in stable zone 5 (68.43 kg m^{-1}), a field with hardly any cover. Here we only present the calibration of Umm Mail to be able to fully describe the calibration process.

Figure 1 gives an overview of the location of MWACs, the land use and the surrounding area of the measurement plot of Umm Mail. Table 2 presents the input parameters of RWEQ for this plot. Table 3 summarizes the calibration parameters and the range of values used for the calibration.

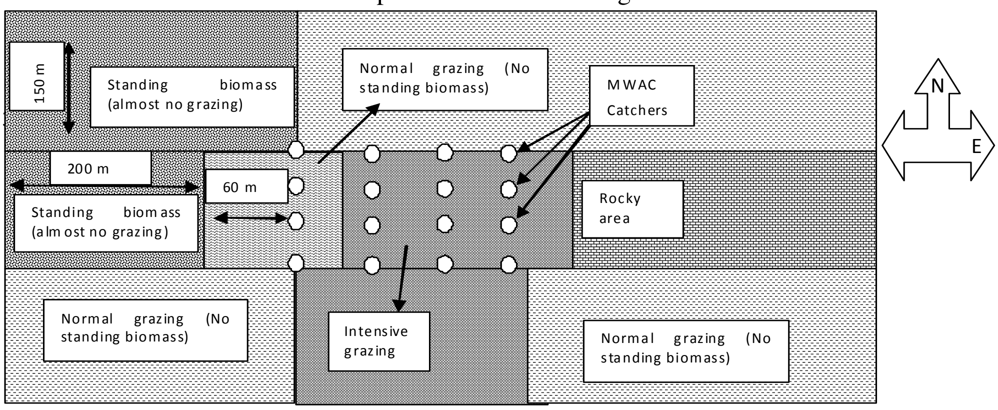

Figure 1. Description of land use inside and around the measurement plot of Umm Mail, Khansser valley, Syria.

Table 2. The main input parameters of RWEQ for the plot of Umm Mail

Factors	Input parameters	Parameter values
Weather factor (Change every time step)	Wind speed (ms^{-1})	3.00-7.00
	Wind direction (degrees)	170-290
	Temperature (degree Celsius)	23-38
	Solar radiation (Cal/cm^2)	155.00
Soil and erodible factor (Depending on field observation)	Continent of Organic matter (%)	1.30-1.6
	Continent of clay (%)	22-26
	Continent of sand (%)	33-45
	Soil moisture (%)	1.0-4.0
Roughness and crust factor (Depending on field observation)	Plough ridge spacing (cm)	35-40
	Plough ridge height (cm)	8-10
	soil roughness (chain method)	1.2-3.5
Vegetation/residues factor (Depending on field observation)	Covered surface (%)	2-6
	Height of vegetation or silhouette (cm)	3-5

Table 3. Calibration parameters for RWEQ in PCRaster (RiP) and the range of calibration

Calibrated factors/parameters	Original value	Range of calibration
Erodible factor (*EF*)	29.09	20-150
Crop canopy (*CC*)	5.614	0.10-6.00
Soil roughness (*SR*)	0.124	0.009-0.150
Critical field length (*S*)	0.3711	0.10-0.400

RWEQ in PCRaster (RiP) results

Figure 2 shows the relation between the measured and predicted mass flux for the measurement plot of Umm Mail at 3 wind events.

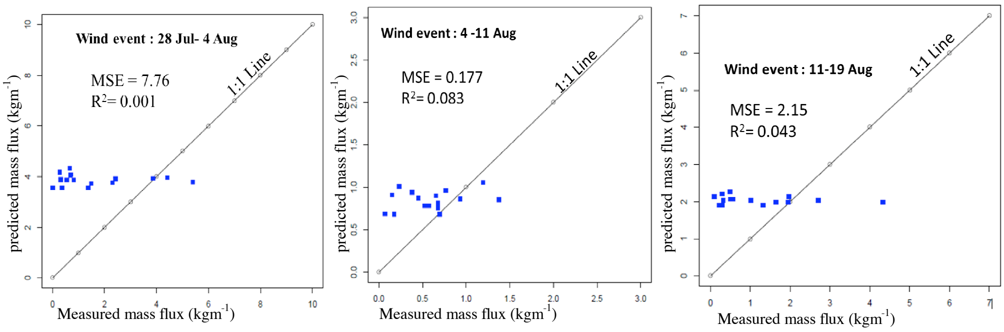

Figure 2. Measured mass flux ($kg.m^{-1}$) at the location of 16 catchers versus the RiP-predicted values at these locations for 3 wind events at Umm Mail measurement plot.

From Fig 2, it can be noticed that for the 3 wind events at the Umm Mail plot different values of measured and modeled mass fluxes were recorded. These differences from one event to another can be related mainly to the variation of the wind speeds during the 3 events. When comparing the

observed and predicted mass flux for each event, in general term, the model gave acceptable results for the total windblown mass flux comparing with the observations. That can be proved by the values of mean squired errors (MSE) which was low for the 3 wind events (7.76 for the event of 28 Jul – 4 Aug, 0.17 for the event of 4-11 Aug and 2.15 for the event of 11-19 Aug). That indicated that the model has the potential to predict the total windblown mass flux. However, looking to the spatial variation of the total mass flux, it can be concluded that the model failed to predict the spatial variation observed in the 16 catchers. This inexact prediction of spatial variation of total mass flux resulted in low values of the squared correlation (R^2) (0.001 for the event of 28 Jul – 4 Aug, 0.083 for the event of 4-11 Aug and 0.043 for the event of 11-19 Aug). A possible reason for this lack of spatial variation in the calculated output is the large distance of the non-eroding boundary at this site. As a result to model assumes that mass transport has reached it maximum transport capacity. Another possible reason is the difference in detail between the point measurements and the calculations of average mass transport in the grid. The measurements are sensitive for small, local changes in e.g. roughness of vegetation cover, whereas the model uses average input values over a grid of 10 x 10 m.
The fact that the model has the capacity to predict mass transport within the correct order, shows that the model can be used for the upscaling. To improve the prediction of changes in mass transport with changing land use the requires further calibration and adjustment.

Conclusion

There is no doubt that there is imperative need for a regional scale wind erosion model. In the current research a first step toward this model was done. RWEQ model was rewritten as a RiP model which was tested against ground data collected from 9 measurement plots in Khansser valley, Syria. RiP was calibrated for few parameters to improve its prediction to the windblown mass transport. The elementary results showed that the model prediction is falling in the same magnitude of the observation. The model still needs more calibration to predict precisely the spatial variation of the total mass flux over the region of this research.

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