A new wind-erosion sampler for monitoring dust-storm events in the Indian Thar Desert

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Removal of soil particles by wind is an active land-degradation process in the Indian Thar Desert. To compute the soil loss due to wind erosion, eroded aeolian masses are mostly collected by samplers, which are available with different designs at desert areas of the world. In the Indian Thar Desert, dust catcher in the design of Bagnold sampler was generally used to collect eroded masses at different heights from the surface, but this had a few drawbacks. Keeping in mind the constraints of the existing sampler, a new wind-erosion sampler was designed, fabricated, tested and installed in the Indian Thar Desert at Jaisalmer. This erosion sampler has the ability to adjust its orifice towards the wind direction and thus is capable of collecting aeolian masses from any direction. With this sampler, eroded aeolian masses were collected and analysed during several dust-storm events and periodic wind-erosion events during June–September 2009. Computation of mass flux ($ML^{-2}T^{-1}$) and soil loss from the collected aeolian mass data successfully captured the intensity of dust-storm/wind-erosion events and their variation within a season. Therefore, the new erosion sampler may be used as a tool to monitor and assess dust-storm events in the Indian Thar Desert.

Keywords: Dust storm, mass–height profile, soil loss, wind-erosion sampler.

DESERTIFICATION is affecting the livelihood of millions of poor people, in the dry lands, which occupy nearly 41% of the earth's land area and are home to more than two billion people in the world[1]. Global climate change may exacerbate the desertification process due to increase in evapotranspiration and a likely decrease in rainfall in drylands, which may increase the severity of wind-erosion events, a dominant land-degradation process in these regions. In India, 13.5% of the total geographical area is affected by wind erosion, a major portion of which lies in the Indian Thar Desert comprising the western part of Rajasthan, northern part of Gujarat, and some parts of Punjab and Haryana[2]. Under future climate-change scenarios, wind erosion from the Indian Thar Desert plays a key role in regional climate change. During wind-erosion events, nutrient-rich dust consisting of minute soil particles, commonly known as particulate matter (PM), gets eroded from desert surface and is deposited on roads, canals, industrial areas and residential areas, causing several problems to normal life[3,4]. These aeolian sediments not only create problems through deposition at unwanted places, but are also the reason for health hazards in the form of respirable suspended PM in the atmosphere[5]. During severe wind-erosion events, wind-eroded particles are being transported through the atmosphere over long distances and in some cases such a type of dust transport is inter-continental[6,7]. According to several weather-prediction models, global temperature is showing a rising trend, and under such situations wind-erosion events might be much more severe. Therefore, wind-erosion events and their impact on the arid environment of Indian Thar Desert and adjoining areas need to be assessed periodically.

Aeolian sediment load to the atmosphere generated during wind-erosion events is generally quantified through different types of sampling devices, which are known as samplers, traps, catchers or collectors. Among wind-erosion samplers, the most popular one is the Big Spring Number Eight (BSNE) sampler[8]. Another popular sampler is the Modified Wilson and Cook (MWAC) sampler[9]. Other than these two samplers, several indigenously manufactured ones, e.g. suspended sediment trap (SUSTRA), Pollate Catcher (PULCA) and Saltiphone, Cox sand catcher are available in different arid regions of the world[10]. In the Indian Thar Desert, dust catcher in the design of Bagnold sampler has been used since long time for collecting the eroded soil mass from wind-erosion events, but this has a few drawbacks[11,12]. First, the installed dust catcher is fixed type and does not rotate along with the wind direction. Secondly, it is more suitable for collecting suspension flow. Thirdly, the top of the sampler is open and hence suspended soil particles may be deposited in the collector other than eroded soil particles generated due to wind-erosion events. The BSNE sampler has a collection efficiency of > 90% for particles of size greater than 0.84 mm, but it is less efficient for collecting fine particles, which could be due to the presence of a fine-sized mesh on top of the sampler through which particles may exit. Moreover, soils of the Indian Thar Desert are comparatively rich in fine-sized soil

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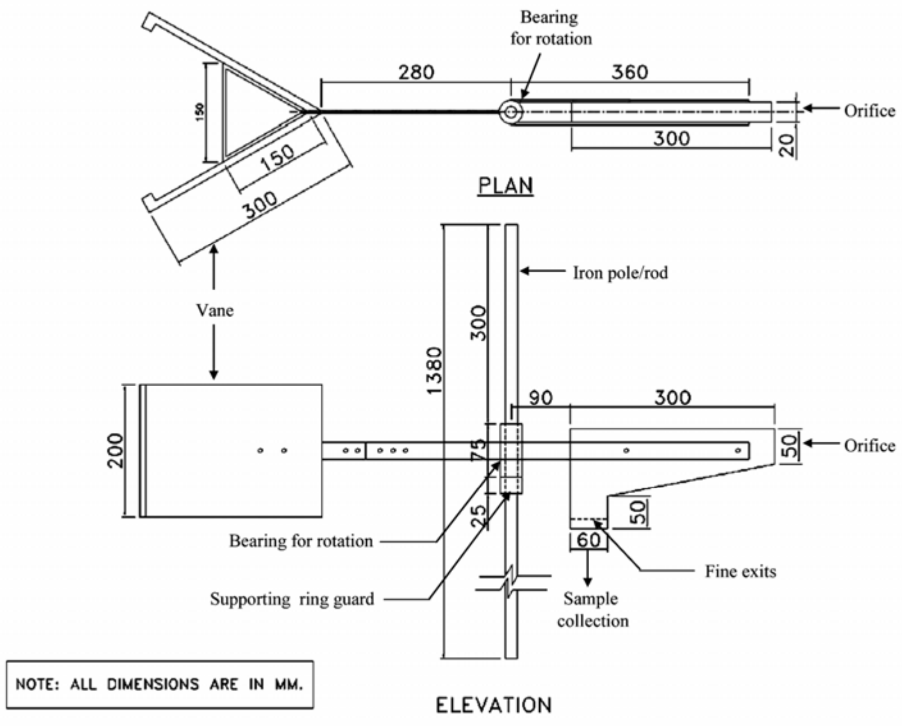

Figure 1. Proposed new wind-erosion sampler.

particles than other deserts of the world[13]. Satellite monitoring of severe dust-storm events also revealed that minute dust particles eroded from this region create a blanket of dust haze over western India and the Indo-Gangetic plains[14,15]. Therefore, it is essential to monitor and assess the wind-erosion events in the Indian Thar Desert. For this purpose a more efficient wind-erosion sampler is needed. Keeping in mind the constraints of the already available dust catchers and the present requirement, we aimed to develop a new wind-erosion sampler for collecting wind-eroded soil mass in the Indian Thar Desert.

Design and installation

Design

The new wind-erosion sampler has been designed in such a way that it can collect eroded particles from any direction (Figure 1). For this purpose a vane has been attached at the back. The orifice of the sampler is 2 cm wide and 5 cm in height. To include aerodynamic features, the cross-sectional area of the sampler from its orifice shows an increasing trend along its length. Such a design of the sampler enables it to work on the Bernoulli's principle. In principle, high-velocity wind loses its force after entering the sampler through the orifice and the particles carried along with it get deposited into the collector by gravity. For dissipating the internal high pressure of the sampler, two fine exits have been designed on both sides of the sampler. The removable collector is fixed at the bottom end of the sampler to collect the eroded mass that has entered it. A ball-bearing system is kept between the sampling area and the vane of the sampler for its free rotation in a pole. The bearing system was fixed after identifying the centre of gravity of the sampler in order to reduce the friction between the bearing and the iron pole. To enable the sampler to collect wind-eroded aeolian mass at several heights, arrangements were made to fix a number of samplers in a single pole at the desired heights.

Major features

The new erosion sampler has the ability to adjust its orifice towards the wind direction, which is also a feature of the BSNE sampler and many other available samplers outside India. However, in India dust catcher has been used since the last three decades and it is fixed type and thus is not able to rotate its orifice towards the wind direction. The proposed wind-erosion sampler has overcome the major constraints of the previously available dust catcher in India. Besides these, a few characteristic features of the proposed erosion sampler are listed below:

(i) The top of the sampler is closed and therefore prevents the deposition of fine suspended particles during calm atmospheric condition after a wind-erosion event.

(ii) The sampler does not require a rain hood and is able to collect eroded soil particles during dust-storm events associated with rainfall.

(iii) It is cheap to fabricate and one can construct a single assembly with five samplers with about Rs 8000.

(iv) The vertical gap of the sampler from the centre of the orifice to the bottommost part of the vane is 10 cm. Therefore, it is able to collect eroded soil particles starting from 10 cm height from the surface to any desired height.

(v) It is more suitable to study the wind erosion in the form of suspension flow and some portion of saltation flow, but not for surface creep.

Installation and field experiment

The sampler was initially tested at research farm sites of the Central Arid Zone Research Institute (CAZRI), Jaisalmer, during windy days. To test the collection efficiency of the sampler, a known quantity of soil was blown in the atmosphere at 5 m windward distance from the sampler and the blowed soil mass was collected and recorded. The rotation of the sampler was also checked at different wind speeds measured using a cup anemometer of the meteorological observatory of the regional research station of CAZRI at Jaisalmer, fixed at a standard height of 3 m from the ground surface. The measured wind speed at 3 m height was logarithmically related with wind speed at 2 m height, which is the maximum height of collecting samples with the new wind-erosion sampler in the field. Initial field testing of the sampler on windy days with removal of a known quantity of soil from the surface revealed a collection efficiency of 85–90%, which is comparable with the collection efficiency of the most popular BSNE sampler. Moreover, the sampler rotated freely towards the wind direction even with mild wind speed (5–10 km h^{-1}), measured at 3 m height from the surface and thus confirmed that the new sampler was able to collect eroded mass during mild wind-erosion events also.

After initial field testing, the sampler was installed at a controlled grazing rangeland site of the farm of CAZRI at Jaisalmer dominated with *Lasiurus sindicus* (sewan) grass (Figure 2). Density of sewan grass at the field site was 8000–9000 tussocks ha^{-1}. Grazing in the field site was controlled by allowing cattle to browse sewan grass to a height of 10–15 cm from the desert surface. Due to scanty annual rainfall (73.6 mm) in 2009, sewan grass had not sprouted and hence surface roughness in the form of vegetation was less. Other than grasses, a few shrub bushes of *Zizyphus mortiana*, *Propospis juliflora*, *Calotropis procera*, *Aerva persica*, etc. with maximum canopy height of 3 m were sparsely distributed at the field site. Soils of the field site are defined as Typic Torripsamments[16]. Sand content (0.02–2 mm) of soils was more than 80–85%. Soil depth was restricted to 60–70 cm with calcite concretion below it. Dried tussocks of sewan grass provided a partial barrier to wind-erosion events through their soil-binding capacity and therefore soils surrounding the tussocks were less eroded compared to the inter-tussock area, which resulted in uneven surface at the field site. The sampler was placed at the centre of a circular field with radius of around 150 m and having non-eroding boundaries at the periphery. Four samplers were fixed on an iron pole at 0.25, 0.75, 1.25 and 2.00 m height from the surface. Polythene bags were fixed on the sampler as indicated in Figure 2. The collected eroded masses were recorded after each dust-storm event, as well as periodically. Mass-fluxes of aeolian sediments were fitted in a power-decay mass–height profile (eq. (1))[11], which was found to be the best model for the Indian Thar Desert.

$$q(z) = az^{b}, \qquad (1)$$

where q is the mass flux ($ML^{-2}\,T^{-1}$) of aeolian sediments at height $z(L)$ from the surface and a and b are empirical constants of the equation. Total aeolian mass transport rate ($ML^{-1}T^{-1}$) was computed through integration of eq. (1) with lower limit of $z = 0.25$ m to upper limit of $z = 2$ m. However, to calculate the approximate estimate of total soil loss the lower and upper limits of z were taken as 0.01 m and 2 m respectively.

For initial assessment of the potential environmental impact of dust-storm events, particle size distribution and soil organic carbon (SOC) content of the collected aeolian mass during a single dust-storm event on 15 June 2009 were determined. Particle size distribution was determined by international pipette method[17] and SOC content was determined using the Walkley and Black method[18].

Figure 2. The new wind-erosion sampler installed at the field site of Jaisalmer station of CAZRI located in the Indian Thar Desert.

Table 1. Dust-storm events and periodical observations on wind erosion in Jaisalmer region of the Indian Thar Desert during June–September 2009 for which aeolian masses were collected by the new wind-erosion sampler

	Date and time (dd/mm/yy and hh : mm)			Mean daily meteorological parameters				
Observations	From	To	Duration	T_{max} (°C)	T_{min} (°C)	RH (%)	Rain (mm)	Wind speed (km h^{-1})
Dust-storm events (DSE)								
DSE-1	15/06/09 (16 : 00)	15/06/09 (16 : 30)	30 min				1.8	
DSE-2	17/06/09 (20 : 00)	17/06/09 (20 : 20)	20 min				6.2	
DSE-3	24/06/09 (16 : 00)	24/06/09 (16 : 15)	15 min				5.4	
DSE-4	09/07/09 (20 : 00)	09/07/09 (20 : 25)	25 min				3.0	
DSE-5	14/07/09 (19 : 30)	14/07/09 (19 : 45)	15 min				6.0	
Periodical observation on wind erosion (POWE)								
POWE-1	25/06/09	02/07/09	7 days	40.31	27.00	52.19	–	8.72
POWE-2	15/07/09	30/07/09	16 days	37.19	25.81	64.84	8.60	14.39
POWE-3	31/07/09	18/08/09	19 days	37.15	24.75	58.93		17.42
POWE-4	19/08/09	03/09/09	15 days	37.39	24.64	65.89	10.20	12.20
POWE-5	04/09/09	23/09/09	20 days	38.82	22.76	62.71	–	14.12

Results and discussion

Dust-storm events and periodical observations on wind erosion

The new wind-erosion sampler successfully collected eroded aeolian masses during several dust-storm events and wind-erosion events during June–September 2009 (Table 1). It may be noted that meteorological parameters during the dust-storm events are not mentioned in Table 1 because of unavailability of fine-resolution weather data. The most severe dust storm of 2009 was observed on 15 June, which was also one of the most severe dust storms over the last two decades. Wind speed during this dust-storm event was 50–55 km h^{-1}; it started at 4 : 00 pm and lasted for around half an hour. The second most severe dust-storm event of 2009 occurred on 17 June, just two days after the first severe dust storm of the year. The severity of the second dust-storm event in terms of soil loss was comparatively less because of the previous-day rainfall event (15.2 mm), which resulted in the formation of fragile soil aggregates on the desert surface and prevented erosion of loose sands. Besides these two events, another three dust-storm events on 24 June, 9 July and 14 July 2009 were recorded and the corresponding aeolian masses were collected. It was characteristically observed that most of the dust-storm events were of short duration (15–30 min) and occurred in the evening. Another characteristic feature of these dust-storm events was that most of them were associated with drizzling at their dissipating stage. Significant amount of eroded masses was also collected periodically during June–September 2009, which mostly occurred due to sudden occurrence of gusty wind and associated erosion over small scale. All these periodic observations were also recorded and presented in Table 1 with their duration.

Mass–height profile of eroded soil

Fitting parameters of power decay mass–height profile (eq. (1)) of collected aeolian masses at different heights during severe dust-storm events and periodical observations are given in Table 2. The R^2 values from Table 2 indicate that data on eroded mass at different heights were well-fitted in the power decay mass–height profile, which was also reported earlier as the best for the Indian Thar Desert condition[11]. It was also observed that eroded mass data from severe dust-storm events fitted better than those collected during mild dust-storm events.

Parameter a of the power decay mass–height profile indicates the aeolian mass flux, q at a height of 1 m from the surface. Therefore, parameter a indirectly indicates the comparative severity among several dust-storm events. Parameter b indicates how aeolian mass flux changes with height from the surface. More the magnitude of b, steeper will be the mass–height profile curve, and more will be the difference in q between near-surface and 2 m height from the surface. Thus, parameter b indirectly indicates the contribution of suspension (occurs above 30 cm from the surface) and saltation process (occurs within 30 cm layer from the surface) in the eroded mass for a wind-erosion event. Both these parameters are expected to vary with weather parameters and land-surface characteristics, which are temporally highly variable and therefore parameters a and b are expected to vary within a season. Moreover, if the measurements are done over a similar land surface, then these parameters will indicate the effect of weather parameters. Significant variation in weather parameters was observed during June–September 2009, and thus both the parameters a and b varied across different observation periods. Land-surface characteristics were mainly controlled by the presence of sewan grass and associated hummocks at the experimental site. Due to lack of sufficient rainfall in 2009, growth of this

Table 2. Fitting parameters of power decay mass–height profile of wind-eroded mass flux and the associated soil loss at Jaisalmer region of Indian Thar Desert during 2009

Observations	Wind-erosion events (dd/mm/yy)	Parameter (*a*)*	Parameter (*b*)	Fitting R^2	Soil loss in suspension mode of erosion (kg ha^{-1})
Dust-storm events					
DSE-1	15/06/09	89.933	–1.095	0.99	389
DSE-2	17/06/09	94.303	–0.788	0.93	246
DSE-3	24/06/09	8.606	–1.111	0.85	19
DSE-4	09/07/09	26.730	–1.683	0.99	128
DSE-5	14/07/09	8.224	–0.773	0.91	16
Periodical observation on wind erosion					
POWE-1	25/06/09–02/07/09	27.586	–0.321	0.55	23
POWE-2	15/07/09–30/07/09	61.510	–1.801	0.94	203
POWE-3	31/07/09–18/08/09	61.510	–1.892	0.99	255
POWE-4	19/08/09–03/09/09	26.691	–0.464	0.59	49
POWE-5	04/09/09–23/09/09	12.108	–1.334	0.98	39

*Parameter *a* of the power decay model indicates aeolian mass flux at 1 m height from the surface. Here, unit of *a* is g m^{-2} min^{-1} for dust-storm events and g m^{-2} day^{-1} for periodic observations of wind-erosion events.

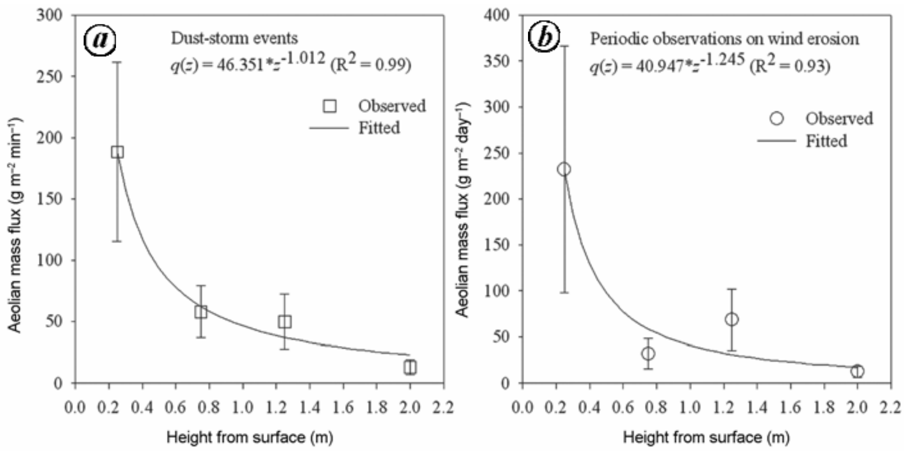

Figure 3. Mass–height profile of wind-eroded aeolian masses of (***a***) dust-storm events and (***b***) periodic observations on wind-erosion events in the Indian Thar Desert at Jaisalmer during June–September 2009.

grass species was limited and therefore variation of surface characteristics along the observation periods was less. Soil moisture is another land-surface characteristic, which varied across the observation periods and thus contributed to the variation of parameters *a* and *b*. From Table 2, it can be seen that parameter *a* is the highest for the dust storm on 15 June 2009, which may be considered as the most severe dust-storm event. The same dust-storm event was earlier suggested as most severe dust storm of 2009 based on observations in the field.

The mass–height profile curves during dust-storm events and periodical observations of wind erosion are presented in Figure 3. The figure shows how aeolian mass flux reduces with height above the surface. It was also observed that variation of observed mass flux at the lowermost sampling height (0.25 m) was more than those observed for higher sampling heights. On an average, mass flux at 1 m height, as indicated by parameter *a*, was 46.351 g m^{-2} min^{-1} during dust-storm events, whereas it was 40.947 g m^{-2} day^{-1} during periodical observations on wind erosion from June to September 2009. Magnitude of parameter *b* was comparatively higher during periodical observations on wind erosion than during dust-storm events. This indirectly indicates that eroded mass fluxes were more differentiated with height during periodical observations on wind erosion than during dust-storm events. From Figure 3, it may be observed that mass flux at 0.75 and 1.25 m height from the surface was almost similar and more specifically for periodical observations on wind erosion. However, mass–height data in power decay model showed good fitting with $R^2 = 0.99$ for dust-storm events and 0.93 for periodical observations on wind erosion. Fitting of data by excluding the mass flux data of 0.75 or 1.25 m height resulted in an even better fit. Therefore, it may be concluded that aeolian mass flux reduces with height from the surface during wind-erosion events in the Indian Thar Desert.

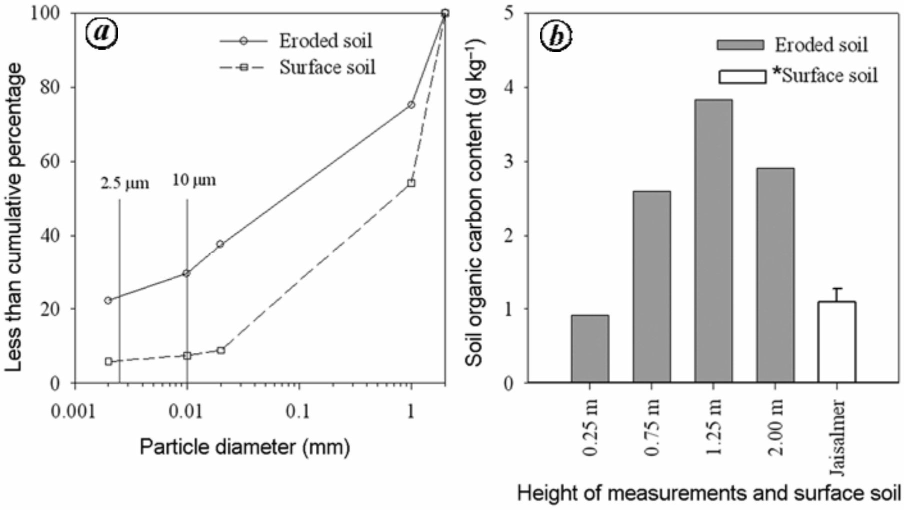

Figure 4. Particle size distribution and soil organic carbon content of eroded soils during the dust-storm event on 15 June 2009 and the same for surface soil in the Indian Thar Desert at Jaisalmer. *Soil organic carbon content of surface soil of Jaisalmer District was calculated based on soil series data published by NBSS&LUP, Nagpur[16].

Soil loss due to wind erosion

Total mass transport rate ($ML^{-1} T^{-1}$) was computed by integrating the power decay model as described in eq. (1) from 0.25 to 2 m height from the surface. The calculated mass transport rate was converted to soil loss (kg ha^{-1}), and is presented in Table 2. The data in Table 2 indicate soil loss mostly through suspension mode. To obtain a true estimate of total soil loss, the eroded soil mass needs to be collected and measured in all three modes of erosion: suspension, saltation and surface creep. In the present study, mass flux data were collected at 0.25–2 m layer from the surface, where mostly suspension mode of erosion occurs. However, to obtain an approximate total soil loss, power decay mass–height profile was extrapolated near the surface ($z = 0.01$ m) to include the contribution of surface creep and saltation.

Computed soil loss in suspension mode during dust-storm events revealed a maximum soil loss of 389 kg ha^{-1} during the dust-storm event on 15 June 2009, which only lasted for 30 min. However, extrapolation of power decay model resulted in total soil loss of 1166 kg ha^{-1} during the same dust-storm event. On an average, the soil loss rate during dust-storm events of 2009 was found to be 17 kg ha^{-1} min^{-1}. Periodical observations on eroded soil mass revealed an average soil loss rate of 25 kg ha^{-1} day^{-1}. Cumulative soil loss in suspension mode during middle of June to end of September 2009 was 1.36 t ha^{-1}, whereas total soil loss was 12.02 t ha^{-1}. It was also found that almost half of this total soil loss occurred during five dust-storm events of the year. It is clear from the above data that a major portion of soil loss during wind-erosion events may have occurred below 0.25 m height from the surface. Hence, measurements of soil loss below 0.25 m height through surface creep sampler and combining these data with mass-flux data obtained from the new wind-erosion sampler will lead to more accurate computation of soil loss. Recently, a free-rotating surface creep sampler was fabricated, which is in the process of installation at the same rangeland site where the new wind-erosion sampler has been installed.

Potential threats of eroded soil on environment

Eroded soil mass, commonly known as dust, emitted during wind-erosion events over desert areas throughout the world, remains in the atmosphere for a long time as suspended particles. The suspended particulate matter (SPM) mixes with other minute particles of the atmosphere, e.g. carbon soot, smoke, salts, etc. and produces a blanket of haze, known as aerosols. Aerosols have both direct and indirect effects on net radiative forcing and therefore play a key role in climate change. Moreover, SPM in the atmosphere has an adverse effect on respiratory and cardiovascular activity of people and thus is considered as a health hazard.

Particle size analysis of collected aeolian samples during the dust-storm event of 15 June 2009 showed that PM having size less than 10 μm (PM_{10}) was 30% in the eroded aeolian mass, whereas the same for the desert surface was only 7.5%. Particle size distribution of eroded soil along with the same for the surface soil is presented in Figure 4 *a*. It clearly reveals that fine-sized particles are more in the eroded soils than on the land surface and therefore have a greater role in aerosol load in the atmosphere.

SOC content of eroded aeolian mass during the dust-storm event on 15 June 2009 was on an average 2.6 g kg^{-1} and was highest in eroded soils collected at 1.25 m height from surface (Figure 4 *b*). On the contrary, average SOC content of surface soil at Jaisalmer is 1.1 g kg^{-1}, which is the average SOC content of surface horizons for six major soil series of Jaisalmer District published by National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur[16]. These data indicate that a major portion of the SOC pool may be lost through a single and short-duration dust-storm event. For example, total SOC loss during the dust-storm event on 15 June 2009 was calculated to be 3 kg ha^{-1}.

Future needs

The new wind-erosion sampler could be used as a tool to monitor the desertification process in the Indian Thar Desert and its impact on global climate change. To utilize its full potential further research efforts are needed. First, collection efficiency of the sampler needs to be fully tested in a wind-tunnel system. Secondly, a surface creep sampler needs to be associated with the new sampler assembly to collect eroded soil mass in the near to surface layers (0–10 cm). Thirdly, the wind-erosion sampler assembly needs to be multiplicated for assessing different land-use systems of the Indian Thar Desert in terms of their contribution to dust load in the atmosphere, so that suitable measures may be taken in future. Fourthly, high-resolution weather data during dust-storm events need to be generated for correlating the eroded soil-mass data with meteorological parameters or indices and for detailed process-based modelling of wind-erosion events.

Summary and conclusion

A new wind-erosion sampler has been designed, fabricated, tested and installed in the Indian Thar Desert at Jaisalmer. The new sampler is able to rotate along the wind direction and thus able to collect eroded aeolian masses from any direction. The newly designed sampler has successfully collected aeolian masses during several dust-storm events in 2009 at a rangeland site of Jaisalmer. Computation of soil loss from collected mass-flux data showed an average soil loss rate of 17 kg ha^{-1} min^{-1} during the dust-storm events and 25 kg ha^{-1} day^{-1} during June–September. Particle size distribution of eroded soil during a severe dust-storm event revealed a PM_{10} concentration of 30%, whereas it was only 7% on the ground surface. SOC content of eroded aeolian mass was also higher (2.6 g kg^{-1}) than the average SOC content of the surface soil (1.1 g kg^{-1}) at Jaisalmer. Thus, the new wind-erosion sampler may be a useful tool to monitor dust-storm events in the Indian Thar Desert and to assess their impacts on the environment.

1. Millenium Ecosystem Assessment, Ecosystems and human well-being: Desertification synthesis. World Resources Institute, Washington, DC, 2005.
2. Santra, P., Mertia, R. S. and Narain, P., Spatial pattern of wind-erosion in western Rajasthan. In *Geoinformatics Application for Sustainable Development* (eds Singh, A. K. *et al.*), Water Technology Centre, IARI, New Delhi, 2004, pp. 239–243.
3. Mertia, R. S., Prasad, R., Gajja, B. L., Samra, J. S. and Narain, P., Impact of shelterbelts in arid region of western Rajasthan. Central Arid Zone Research Institute, Jodhpur, 2006.
4. Santra, P., Mertia, R. S. and Narain, P., Land degradation through wind-erosion in Thar Desert – Issues and research priorities. *Indian J. Soil Conserv.*, 2006, **34**(3), 214–220.
5. Santra, P. and Mertia, R. S., Air pollution through particulate matter and its impact on human health. *Sci. Rep.*, 2006, 28–29.
6. Singh, R. P., Satellite monitoring of dust and its impact on natural resources and climate change. In Proceedings of Abstracts of International Conference on Nurturing Arid Zones for People and the Environment: Issues and Agenda for 21st century. CAZRI, Jodhpur, 2009, p. 11.
7. Deepsikha, S., Sateesh, S. K. and Srinivasan, J., Dust aerosol over Asia and adjacent continents retrieved using METEOSAT infrared radiance, Part I: sources and regional distribution. *Ann. Geophys.*, 2006, **24**, 37–61.
8. Fryrear, D. W., A field dust sampler. *J. Soil Water Conserv.*, 1986, **41**, 117–120.
9. Wilson, S. J. and Cook, R. U., Wind erosion. In *Soil Erosion* (eds Kirkby, M. J. and Morgan, R. P. C.), Wiley, Chichester, 1980, pp. 217–251.
10. Goossens D., Offer, Z. and London, G., Wind tunnel and field calibration of five aeolian sand traps. *Geomorphology*, 2000, **35**(3–4), 233–252.
11. Mertia, R. S., Santra, P., Kandpal, B. K. and Prasad, R., Mass–height profile and total mass transport of wind-eroded aeolian sediments from rangelands of Indian Thar desert. *Aeolian Res.*, 2009, doi:10.1016/j.aeolia.2010.04.002.
12. Mann, H. S., Characterization and properties of dune and associated soils. In *Sand Dune Stabilization, Shelterbelts and Afforestation in Dry Zones* (FAO Conservation Guide), Food and Agricultural Organisation of the United Nations, Rome, 1985, pp. 125–132.
13. Dhir, R. P., Characterization and properties of dune and associated soils. In *Sand Dune Stabilization, Shelterbelts and Afforestation in Dry Zones* (FAO Conservation Guide), Food and Agricultural Organisation of the United Nations, Rome, 1985, pp. 41–49.
14. El-Askary, H., Gautam, R. and Kafatos, M., Monitoring of dust-storms over Indo-Gangetic basin. *Indian J. Remote Sensing*, 2004, **32**(2), 121–124.
15. Krishna Moorthy, K., Suresh Babu, S., Satheesh, S. K., Srinivasan, J. and Dutt, C. B. S., Dust absorption over the ‘Great Indian Desert’ inferred using ground-based and satellite remote sensing. *J. Geophys. Res.*, 2007, **112**, D09206.
16. Shyampura, R. L., Singh, S. K., Singh, R. S., Jain, B. L. and Gajbhiye, K. S., *Soil Series of Rajasthan*, NBSS&LUP, Nagpur, 2002, p. 329.
17. Gee, G. W. and Bauder, J. W., Particle size analysis. In *Methods of Soil Analysis, Part 1, Agronomy Monograph No. 9* (ed. Klute, A.), ASA and SSSA, Madison, WI, 1986, pp. 383–412.
18. Walkley, A. J. and Black, I. A., An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, 1934, **37**, 29–38.

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