Fine-Particle Emission Potential From Overflowing Areas of the Tarim River

Xinhu Li, Guanglong Feng, Chengyi Zhao, and Zehao Zheng

Abstract: Fine particulates less than 2.5 μm (PM2.5) or 10 μm (PM10) are often emitted from river bank or other alluvial lands to the atmosphere during dry and windy seasons worldwide, which contribute to land degradation and poor air quality. Investigation of PM2.5 and PM10 emission potential could contribute to the development of mitigation strategy and better land management practices. In the low-precipitation zone (<100 mm annual precipitation) of the Tarim Basin in western China, wind erosion and fugitive dust emission are recognized problems on the oasis. There is limited information, however, regarding wind erosion on river overflow areas, areas of temporal flooding, in the Tarim Basin. The objectives of this study were to characterize PM2.5 and PM10 emission potential and wind erosion potential of soils along the Tarim River. The results of particle analysis revealed that most soils (28 soils) were silt loam in the overflowing area of the Tarim River; few (12 soils) soils were sandy loam. The soils had low clay and high silt contents. Soil particles greater than 840 μm (nonerodible soil particles) were not found by sieving all soil samples. Contents of PM2.5 and PM10 ranged from 1.6 to 30.4% and 4.5 to 78.6%. These high percentages of fine soil particulates suggest that mitigation of soil wind erosion and fine-particle emission is important in protecting air quality in the region. The highest content (44.9%) of saltation-size particles (100- to 500-μm diameter) was found in the lower reaches of the river, followed by the middle reaches (14.6%) and then the upper reaches (11.7%) of the river. The highest content of suspension particles (<100-μm diameter) was observed for soils in the middle reaches (13.1%), followed by the upper reaches (11.2%) and the lower reaches (7.1%).

Key Words: Wind erosion, PM2.5, PM10, soil particle size distribution, river overflowing area, Tarim River

(*Soil Sci* 2013;178: 556–567)

Fugitive dust is a frequent product of wind erosion (Gillette, 1977) and is often the most visible evidence of soil wind erosion downwind from actively eroding fields. Aeolian erosion and dust production are major environmental concerns because atmospheric particulate matter impacts the regulation of surface temperature (Overpeck et al., 1996), air quality (Husar et al., 2001), and human health (Schwartz, 1994).

Atmospheric dust influences climate by altering the Earth's radiation/energy balance (Tegen and Lacis, 1996). The potential of wind erosion is the highest in arid and semiarid regions (Feng et al., 2011). Soil and mineral particles with a diameter less than 60 μm are especially important to air quality because they contain significant amounts of soil nutrients (Zobeck and Fryrear, 1986) and contaminants (Pye, 1987), and they are capable of long-range transport. Of particular concern are those particles with a mean aerodynamic diameter of less than or equal to 10 μm (PM10) and 2.5 μm (PM2.5), which are stringently regulated by environmental regulation agencies such as the US Environmental Protection Agency (USEPA) and the Ministry of Environmental Protection of the People's Republic of China as air pollutants.

Meteorological statistic analyses of sand-dust events in some important source regions of China revealed that the frequencies of sand-dust events were not always significantly correlated with the synoptic and climatic parameters (Hu et al., 2001; Wang et al., 2004b; Qian et al., 2007). This has led scientists to consider the influence of other factors while studying the meteorological causes of sand-dust events. The size distribution and stability of soil aggregates have a major influence on wind erodibility of soils (Tatarko, 2001). Soil grain size is a fundamental property of sediment particles that plays a major role in various processes among which sand drift and soil movement are of special interest for the environment of the arid and semiarid regions (Labiadh et al., 2011). Dry sieving and use of a laser particle sizer are methods better adapted to retrieving the size distribution of the soil aggregates with the minimum of disturbances. Particle size distribution data are widely available for soils worldwide; it would be advantageous to estimate factors influencing wind erodibility from those data (Chandler, 2005).

Briefly, silt particles are light and porous enough to be carried away by wind erosive forces (Madden et al., 2010). Jackson (1975) concluded that PM10 potential is highly correlated to soil texture, as determined by the pipette method and sieving. Because of the greater amounts of fine particles, clayey soils have a higher potential to emit PM10 than sandy soils. Chandler et al. (2002) hypothesized that PM10 potential would increase with progressively finer textured soil but then decrease as greater aggregate stability from increases in clay and organic matter begins to outweigh increases in the total number of particles less than 10 μm in diameter in the soil. Madden et al. (2010) reported that there was a significant correlation between the ratio of percentage of silt to percentage of clay and PM10 concentration.

In northern China, the frequency of dust storms increased as the expansion of land desertification increased rapidly from 2,100 km^2 $year^{-1}$ between 1976 and 1988 to 3,600 km^2 $year^{-1}$ between 1988 and 2000 (Wang et al., 2004a). Zhang et al. (1997) estimated that approximately 800 Tg of Chinese desert dust is lifted into the atmosphere annually based on estimates of atmospheric dust deposition in five Asian and Pacific regions. In contrast, simulations using the USEPA model (Xuan et al., 2000) concluded that 43 Tg of Chinese desert dust is emitted into the atmosphere annually.

Global dust emissions play a significant role in global climate cycles (Arimoto et al., 2006; Goudie and Middleton, 2006)

State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, China.
Address for correspondence: Dr. Guanglong Feng, USDA-ARS, P. O. BOX 5367, 810 Highway 12 East, Mississippi State, MS 39762, USA. E-mail: gary.feng@ars.usda.gov
Financial Disclosures/Conflicts of Interest: *This research was supported by the National Natural Science Foundation of China (Grant No. 41171019), the One Hundred Talented Researchers Program of Chinese Academy of Sciences, and Foundation of Chinese Academy of Sciences (Grant No. XBBS201207).*
Received June 4, 2013.
Accepted for publication October 16, 2013.
Copyright © 2014 by Lippincott Williams & Wilkins
ISSN: 0038-075X
DOI: 10.1097/SS.0000000000000019

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

and become part of deep ocean sediments (Duce et al., 1980; Duce and Tindale, 1991). Tarim Basin, as one of the world's primary areas of potential dust source in the world, emitted large quantities of dust that were carried by winds over large areas of Asia and across the Pacific to North America (Husar et al., 2001; Yu et al., 2012).

Areas within source regions that provide ideal conditions for dust generation include dry lake beds (Reheis, 2006; Blank et al., 1999), open deserts (Qian et al., 2007), fallow farm fields and other disturbed land (Zobeck and Fryrear, 1986; Stout and Zobeck, 1996), and unpaved roadways and building sites (Chow and Watson, 1997); however, little attention has been paid to alluvial sediments along rivers. Planned or regulated overflow flooding has been applied as an important measure for river rehabilitation and reversing ecosystem degradation (Wuetrich, 1996). River overflow flooding plays an important role in maintaining spatial heterogeneity in plant community composition and structure in arid floodplain landscape (Blom and Voesenek, 1996). River overflow flooding could also contribute to changes in soil surface particle distribution and vegetation cover in the Tarim Basin, which flows across the Taklimakan Desert. The river overflowing region had an area of approximately 3,000 to 5,000 km^2, which is a type of very important and unique landscape (Fig. 1). Except for the natural flooding overflow, there were 52 ecology gates for planned overflow in the Tarim River (Fig. 1B). The planned overflow plays an important role for the maintenance of plant cover beside the Tarim River.

There were some lakes or ponds in the arid and semiarid regions; some of them were desiccated because of strong evaporation and lack of recharge. The lakes become desiccated, leaving large areas of bare ground prone to becoming potential dust sources. Dry lake beds can provide much smaller particles (e.g., <10 μm) during wind erosion than sand deserts and the Gobi but are effectively "point sources" when compared with deserts (Yue et al., 2004; Yang et al., 2008). The river overflow area in arid regions had a similar process to dry lake on the hydrologic and sedimentologic interactions that may sustain dust production. Reynolds et al. (2007) reported that many factors affect the potential of dust emission from playas. The factors considered included relations among hydrologic characteristics, thickness of the capillary-fringe zone, and playa-surface characteristics, with respect to wet and dry playas. Similar situation exists in river overflow area of arid region. Soils in the river overflow area could also be a potential dust source. Therefore, it is necessary to investigate the potential of wind erosion in the region.

The objective of this study was to determine the potential of PM2.5 and PM10 emission and wind erosion of soils at the different sections of the Tarim River overflow area.

MATERIALS AND METHODS

The studied areas are located along the Tarim River (Table 1; Fig. 2). The Tarim River is located in Xinjiang Uygur Autonomous Region, China. It is the largest inland river in China and lies in the Tarim River Basin with an area of 1.22 million km^2. The annual precipitation varies in the range of 20 to 50 mm; in contrast, the annual potential evaporation is as high as 2,500 to 3,000 mm. Tarim River has an overall length of 1,321 km. In the arid desert climate, desert shrubs and semishrubs are dominant, whereas

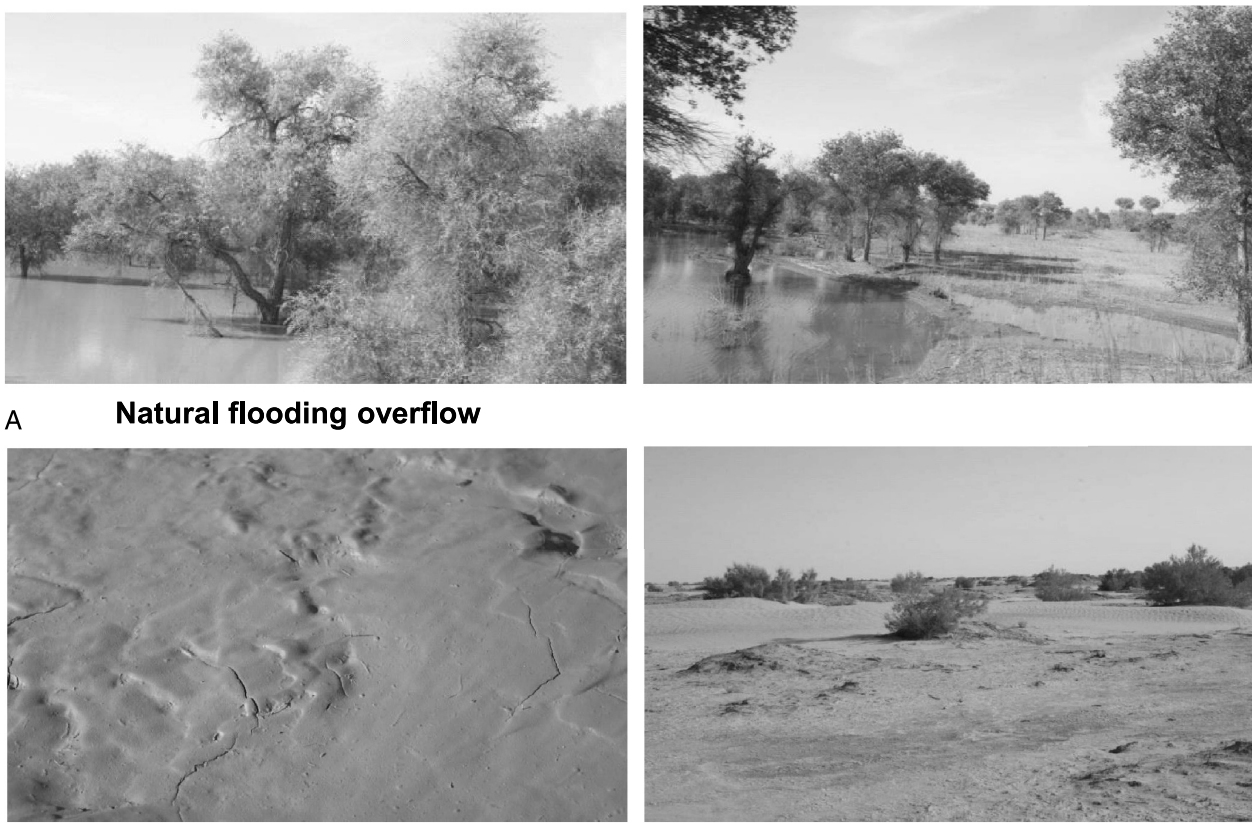

FIG. 1. River overflow in the Tarim River Basin.

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

TABLE 1. Location of Soil Samples

No.	Samples[a]	Latitude	Longitude	No.	Samples	Latitude	Longitude
1	A1	80°57′01″	40°29′24″	27	B8	84°13′47″	41°10′37″
2	A2	81°48′46″	40°44′30″	28	B9	84°12′35″	41°09′16″
3	A3	80°53′50″	40°25′10″	29	B10	84°15′01″	41°05′52″
4	A4	80°53′50″	40°25′10″	30	B11	84°15′01″	41°05′52″
5	A5	80°53′50″	40°25′10″	31	B12	84°14′56″	41°01′28″
6	A6	81°30′54″	40°44′19″	32	B13	84°14′56″	41°01′25″
7	A7	81°57′40″	41°28′03″	33	B14	84°14′49″	40°57′07″
8	A8	81°57′41″	41°27′58″	34	B15	84°14′49″	40°57′05″
9	A9	81°57′40″	41°28′03″	35	B16	84°16′58″	40°50′00″
10	A10	82°02′28″	41°22′51″	36	B17	85°32′41″	40°59′29″
11	A11	82°02′29″	41°22′56″	37	B18	85°32′38″	40°59′34″
12	A12	82°02′29″	41°22′55″	38	B19	85°32′42″	40°59′30″
13	A13	82°48′38″	41°01′17″	39	B20	85°32′34″	41°59′28″
14	A14	82°47′33″	41°00′33″	40	B21	85°32′43″	40°59′33″
15	A15	82°47′22″	41°00′29″	41	B22	85°32′43″	40°59′33″
16	A16	82°46′10″	40°59′45″	42	B23	86°6′16″	41°07′12″
17	A17	82°46′20″	40°59′26″	43	B24	86°6′12″	40°07′19″
18	A18	82°46′19″	40°59′26″	44	C1	87°56′24″	40°25′51″
19	A19	82°45′51″	40°58′52″	45	C2	87°56′23″	40°24′37″
20	B1	84°11′21″	41°17′00″	46	C3	87°56′20″	40°24′03″
21	B2	84°11′22″	41°17′00″	47	C4	87°56′23″	40°24′37″
22	B3	84°11′22″	41°17′00″	48	C5	87°56′23″	40°24′37″
23	B4	84°12′8″	41°13′55″	49	C6	87°56′23″	40°24′37″
24	B5	84°12′13″	41°13′59″	50	C7	87°56′23″	40°25′49″
25	B6	84°13′45″	41°10′41″	51	C8	87°56′23″	40°25′49″
26	B7	84°13′47″	41°10′38″				

[a]The A represents the soil samples in the upper reach, the B represents those in the middle reach, the C in the lower reach. The upper reach from A1 to A19, the middle reach from B1 to B24, and the lower reach form C1 to C8.

large herbaceous plants, shrubs, and trees grow on the floodplains and low terraces along both riversides (Xu et al., 2009). Woodlands are dominated by *Populus euphratica*; major shrubs include *Tamarix* species, *Lycium ruthenicum*, *Halimodendron halodendron*, and so on, and herbs are mainly composed of *Phragmites australis*, *Apocynum venetum*, *Alhagi sparsifolia*, *Karelinia caspica*, *Glycyrrhiza inflata*, and so on.

Soil sample sites were selected along the Tarim River, from the upper reaches to the lower reaches of the river. The 51 soils were collected from the upper 5-cm layer of the soil profile using a flat shovel. Approximately 2 kg of soil sample was taken at each site from the river about 0.15 to 30 km. There were 19 soil samples in the upper reaches, 24 soil samples in the middle reaches, and eight soil samples in the lower reaches. The soil samples were air-dried and hand sieved through a 2-mm sieve to remove large aggregates, stone, and plant residue. Large aggregates were mechanically fractured to facilitate passage through the 2-mm sieve. Soil passing through the 2-mm sieve was used for soil particle size analysis. Particle size distributions were measured using a Malvern Mastersizer S laser diffractometer (Malvern Instrument, Malvern, England) that measures volume percent of particles in 100 size classes from 0.02 to 2,000 μm. Soil samples were pretreated before analysis using sodium acetate to dissolve carbonates and hydrogen peroxide to oxidize organic matter. Samples were rinsed with deionized water and centrifuged, and excess supernatant was decanted. Each sample was dispersed with sodium hexametaphosphate by agitation for 16 h and analyzed in a deionized water suspension with no sonication.

Soil texture were described with clay (<2 μm), silt (2–50 μm), very fine sand (50–100 μm), and fine to coarse sand (100–2,000 μm) following the taxonomy of the US Department of Agriculture.

RESULTS AND DISCUSSION

A total of 51 samples were analyzed in this study of the soils along the Tarim River. The soil texture is indicated in Table 2, Table 3, and Fig. 2. Twenty-eight soils, which account for 52% of soil samples, were silt loam. These soils were found from the upper reaches to the middle reaches of the Tarim River. Twelve soils were classified as sandy loam and were located to the middle reaches of the river. In addition, there were five loam soils, five silt soils, and three loam sandy soils. The content of clay in those soils ranged from 1.3% to 24.5%, indicating that the soils had a low content of clay in the studied area. Especially for the lower reaches, the content of clay ranged from only 1.3 to 16.5%, whereas the content of sand ranged from 55.1 and 86.9%, indicating that the soils from the lower reaches had the lowest content of clay and the highest content of sand in the Tarim River overflow area. The sand/clay distribution could result from the fact that the lower reaches of the river dried up at a high frequency (Tursun et al., 2009), resulting in the fine

 © 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

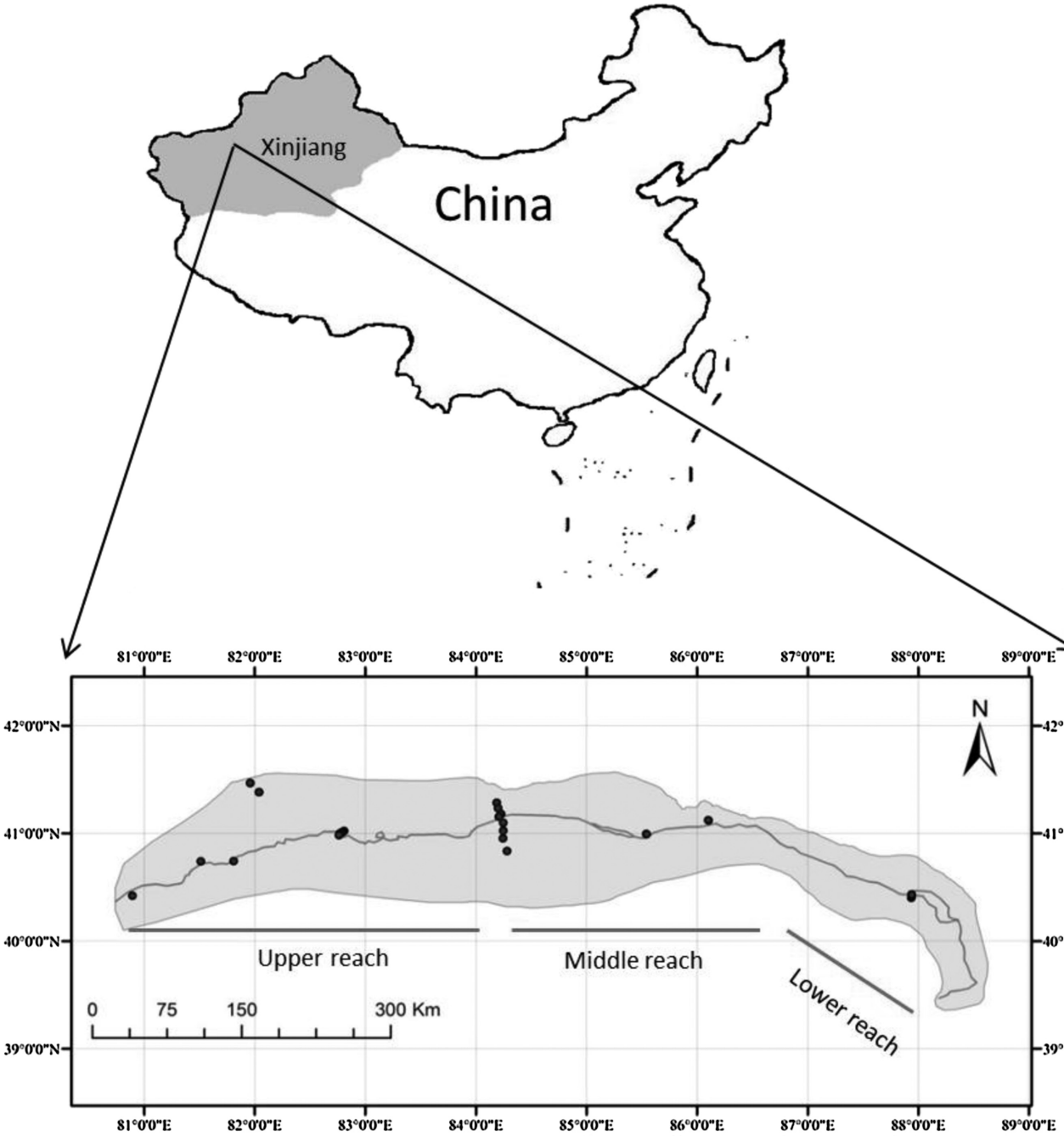

FIG. 2. Sampling sites within the river overflow of the Tarim River.

particles of soils being blown away because of severe wind erosion (Chen et al., 2011).

The D50, D84, and D99 mean diameter particles represent the 50th, the 84th, and 99th percentile of the particle size distribution, respectively, as measured by volume. The D50 and D84 ranged from 4.5 to 124.8 μm and from 12.4 to 210.9 μm. The D99 ranged from 494.1 to 246.4 μm, indicating that the soil particles were fine in the study area. The soil sample (C2, 87° 56′23″, 40°24′37″) had the largest D50 and D84 values in the lower reaches of the river. The lower reaches had a range of 68.1 to 390.2 μm (D99); the middle reaches, from 87.7 to 450.5 μm; and the upper reaches, from 141.1 to 494.2 μm, indicating that the soil particles were finer in the middle reaches and the upper reaches and were coarser in the lower reaches. There were significant differences ($P < 0.05$) in D99 (represents the 99th percentile of the particle size distribution) between the lower reaches and the upper reaches, middle reaches (Table 3). The soil particle size of the lower reaches was significantly coarser than the upper reaches and the middle reaches. The middle reaches and the upper reaches ranged from 224.72 to 450.53 μm and from 222.29 to 390.28 μm. The particle size distributions for D99 in the middle reaches and the upper reaches were similar.

The soil particles greater than 840 μm in diameter are generally considered not to be erodible by wind (Chepil, 1942). Particles

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

TABLE 2. Soil Particle Size Distribution (%) and Texture of Soils

No.	Samples	Clay[a]	Silt	Very Fine Sand	Fine to Coarse Sand	Texture[b]	No.	Samples	Clay[a]	Silt	Very Fine Sand	Fine to Coarse Sand	Texture[b]
1	A1	6.6	60.0	22.5	10.9	SiL	27	B8	10.0	74.4	11.5	4.1	SiL
2	A2	5.5	50.2	29.9	14.4	SiL	28	B9	5.8	51.7	28.4	14.1	SiL
3	A3	2.2	38.9	27.1	31.8	L	29	B10	5.8	51.7	28.4	14.1	SiL
4	A4	1.6	34.0	35.3	29.0	L	30	B11	24.5	71.9	3.1	0.5	SiL
5	A5	2.3	40.7	29.0	28.0	L	31	B12	13.4	67.4	14.9	4.4	SiL
6	A6	2.9	25.8	39.0	32.3	SL	32	B13	8.9	58.8	23.6	8.7	SiL
7	A7	12.0	81.7	5.2	1.1	Si	33	B14	18.8	75.0	4.8	1.4	SiL
8	A8	12.0	81.7	5.2	1.1	Si	34	B15	13.8	78.6	5.8	1.7	SiL
9	A9	16.6	81.1	1.5	0.8	Si	35	B16	16.4	80.6	2.3	0.7	SiL
10	A10	8.6	52.7	29.3	9.5	SiL	36	B17	4.7	35.7	32.5	27.1	SL
11	A11	15.0	79.2	4.9	0.9	Si	37	B18	4.0	36.7	31.2	28.1	SL
12	A12	11.2	80.1	6.2	2.6	Si	38	B19	4.1	35.5	34.6	25.8	SL
13	A13	21.7	72.1	4.6	1.7	SiL	39	B20	4.7	45.1	31.3	18.9	SL
14	A14	4.6	54.7	27.8	12.8	SiL	40	B21	5.1	37.3	33.8	23.7	SL
15	A15	6.6	69.2	19.8	4.4	SiL	41	B22	4.3	39.1	32.8	23.9	SL
16	A16	6.2	54.0	26.9	12.9	SiL	42	B23	1.3	11.8	22.9	64.0	LS
17	A17	18.6	71.8	5.9	3.6	SiL	43	B24	1.3	11.8	22.9	64.0	LS
18	A18	15.8	81.9	2.2	0.2	SiL	44	C1	3.2	38.2	36.0	22.6	SL
19	A19	6.7	53.8	24.3	15.2	SiL	45	C2	7.5	45.1	29.2	18.1	L
20	B1	18.6	63.5	7.8	10.1	SiL	46	C3	4.1	30.5	35.9	29.5	SL
21	B2	16.3	70.2	9.9	3.6	SiL	47	C4	5.2	48.9	31.5	14.4	L
22	B3	14.2	72.6	11.4	1.8	SiL	48	C5	16.5	67.0	12.1	4.4	SiL
23	B4	13.7	56.8	21.8	7.7	SiL	49	C6	2.8	29.0	43.5	24.8	SL
24	B5	13.7	56.8	21.8	7.7	SiL	50	C7	3.8	36.2	35.4	24.5	SL
25	B6	14.6	78.6	6.1	0.7	SiL	51	C8	3.6	39.3	36.7	20.5	SL
26	B7	13.6	71.5	11.7	3.2	SiL							

[a]Very fine sand, 50 to 100 μm; fine to coarse sand, 100 to 2,000 μm; Silt, 2 to 50 μm; Clay, less than 2 μm.
[b]L, loam; LS, loam sandy; Si, silt; SiL, silt loam; SL, sandy loam.

© 2014 Lippincott Williams & Wilkins
Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

TABLE 3. Mean Diameter by Volume From D (50th Percentile) to D (99th Percentile)

No.	Samples	D(50)	D(84)	D(99)	No.	Samples	D(50)	D(84)	D(99)
1	A1	30.90	83.40	326.15	27	B8	13.97	49.34	156.72
2	A2	44.01	94.92	295.58	28	B9	41.41	94.97	355.21
3	A3	65.32	145.47	277.57	29	B10	41.41	94.97	355.21
4	A4	68.02	132.97	377.79	30	B11	4.49	12.35	87.84
5	A5	60.22	137.24	358.22	31	B12	12.31	57.60	135.53
6	A6	75.41	137.21	390.28	32	B13	28.00	78.78	154.88
7	A7	11.84	31.10	102.29	33	B14	6.64	23.25	101.10
8	A8	11.84	31.10	102.29	34	B15	8.12	28.08	116.47
9	A9	7.05	19.39	70.37	35	B16	8.21	20.60	87.67
10	A10	35.33	84.04	147.64	36	B17	63.38	127.51	249.84
11	A11	9.85	28.77	89.10	37	B18	63.05	131.01	349.97
12	A12	10.45	29.42	126.16	38	B19	63.30	124.21	450.53
13	A13	6.08	22.51	123.59	39	B20	50.33	107.66	221.40
14	A14	41.15	89.49	291.81	40	B21	59.92	118.92	386.33
15	A15	26.97	62.96	153.83	41	B22	58.91	120.98	438.12
16	A16	37.79	91.44	176.73	42	B23	40.00	101.42	406.70
17	A17	7.83	30.82	386.01	43	B24	124.81	210.89	334.69
18	A18	8.78	21.80	68.11	44	C1	60.28	116.02	382.13
19	A19	35.83	97.99	360.08	45	C2	46.53	106.08	449.11
20	B1	6.86	64.57	204.02	46	C3	69.58	133.79	439.49
21	B2	8.91	41.16	135.49	47	C4	45.80	96.03	399.58
22	B3	9.26	41.43	134.94	48	C5	7.83	51.52	141.08
23	B4	18.42	75.69	148.41	49	C6	67.99	118.78	447.44
24	B5	18.42	75.69	148.41	50	C7	62.342	121.093	494.239
25	B6	10.59	31.82	99.96	51	C8	58.562	110.057	196.51
26	B7	12.66	47.62	134.03					

more than 840 μm were not found in the 51 soil samples. In fact, most soil particles were not greater than 400 μm in diameter (Fig. 3). Dong and Li (1998) studied wind erodibility of Aeolian sand as affected by its grain size and found that sand of 90 μm was the most susceptible to wind erosion in the northern part of Taklimakan Desert. The percentage of 90-μm particles varied from 0.2 to 7.6% (Fig. 4). The mean value was 3.6%, indicating that the study region had moderate potential of wind erosion.

Chepil (1955) observed a negative relationship between erosion in a wind tunnel and the percentage of clay contained in the soil. Soils containing 20 to 35% clay were least erodible. Coarse-textured soils often lack sufficient amounts of silt and clay to bind individual sand particles together or they may form weakly cemented clods that are readily broken down and eroded. There were two soil samples (A13 and B11) that contained 21.6 and 24.6% clay, respectively, but they only accounted for 3.9% of soil samples. As previously mentioned, a high potential of wind erosion was found in the entire overflow area along the river.

Saltation is primarily responsible for redistribution of surface soil within the ecosystem, therefore, affecting vegetation and soils on a local scale (Larney et al., 1998; Okin et al., 2006; Li et al., 2007). Mirzamostafa et al. (1998) performed separate calculations for erosion of soil by suspension and saltation processes, both of which they predicted from dispersed soil analysis. It is logical to predict suspension size material (<100 μm) for Aeolian soils separately from saltation-size material (100–840 μm). The content of saltation-size material ranged from 0.2 to 64.0% of the individual soil samples, with a mean value of 14.43% in the studied region. It could be concluded that the river overflow area had a moderately high potential for saltation. The content of saltation-size particles had a range of 0.2 to 32.3% with a mean value of 11.7% in the upper reaches, a range of 0.5% to 64.0% with a mean value of 14.55% in the middle reaches, and a range of 5.7% to 80.0% with a mean value of 44.9% in the lower reaches. The overflow area of the lower reaches had the highest potential of saltation-size particles, followed by the upper reaches; the middle reaches had the lowest potential of saltation-size particles.

The content of suspension-size material (<100 μm) had a range from 36.1 to 99.80% and mean value of 85.6% in the entire study region, indicating that the potential suspension emission is likely high in the overflow area of the Tarim River. There was a range from 67.7 to 99.8% and a mean value of 88.3% in the upper reaches. There was a range of 36.1 to 99.5% and a mean value of 86.9% in the middle reaches. In the lower reaches, the content of particles less than 100 μm had a range of 70.5 to 95.6% and a mean value of 80.1%. The upper reaches had the highest potential suspension emission, the middle reaches had mid potential, and the lower reaches had the lowest potential for suspension emission.

The results of the particle size revealed that the less than 60-μm particle content of soils ranged from 14.8 to 98.2%, and the mean value was 66.6%. There were 39 samples (D50) containing a mean size less than 60 μm, indicating that more than 89% of the samples within the 50th percentile of the particle size distribution (Table 3) could contribute to poor air quality and that the studied area is a significant dust source in the Tarim Basin. The upper reaches ranged from 33.6 to 98.3% with a mean value of 73.6%, the middle reaches ranged from

© 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

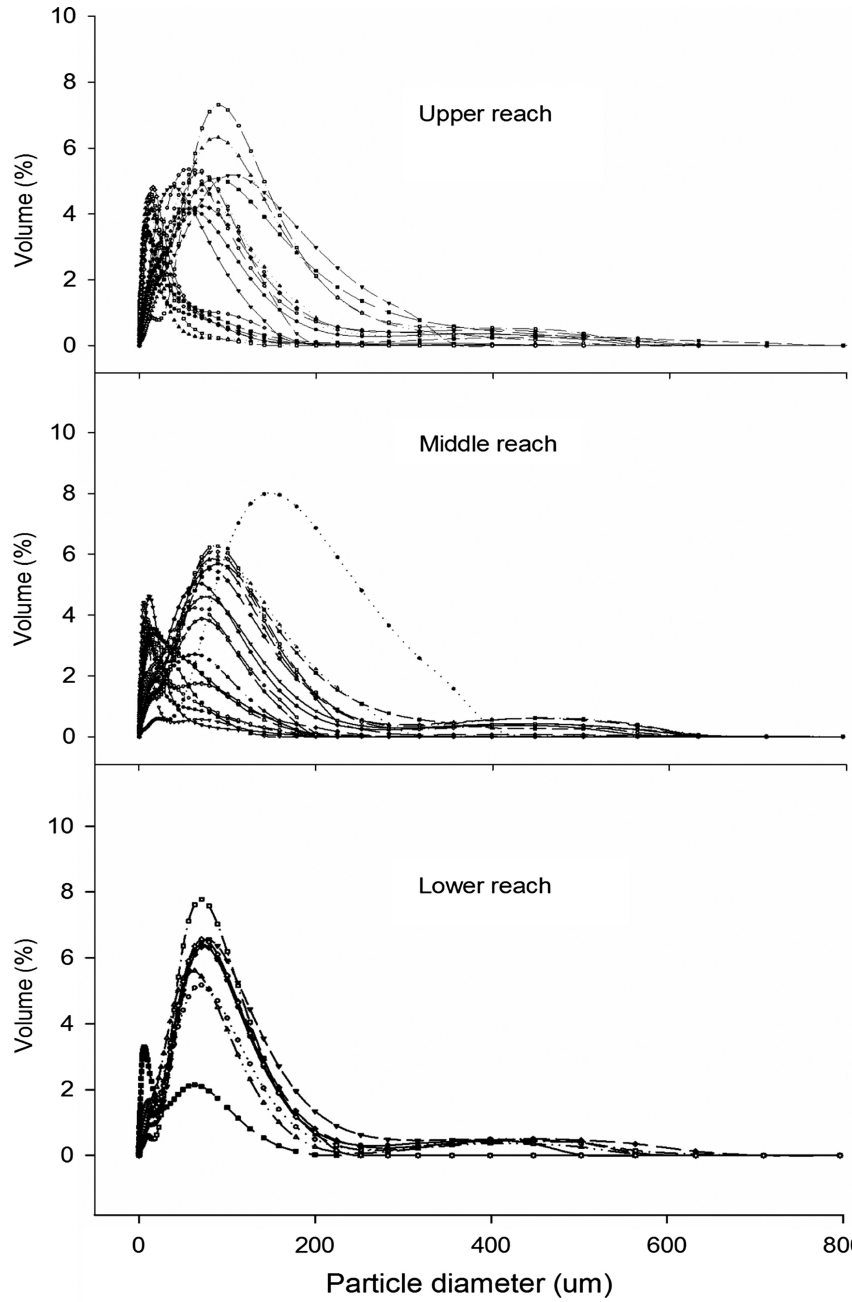

FIG. 3. Particle size distribution of soils.

14.8 to 97.6% with a mean value of 70.8%, and the lower reaches ranged from 38.1 to 85.6% with a mean value of 52.4%, indicating that the less than 60-μm particle content of soils was high in the entire Tarim River main stream. Especially for the upper reach, the soils have the highest content of particles less than 60 μm. There were eight samples (50% of the total) that had content of particles less than 60 μm more than 90%. This suggests that the upper reaches of the overflow area of the Tarim River could make a great potential contribution to poor air quality.

The soil particles less than 60 μm contain significant amounts of soil nutrients (Zobeck and Fryrear, 1986), which can be transported over a relatively long distance (D'odorico and Porporato, 2006). Therefore, it is necessary to measure dust control, and mitigation of poor air quality should be considered in the region for preventing degradation of both soil and air quality.

In one study, particles in suspension had diameters ranging from 0.25 to 16 μm, with mean diameters of 2.2 μm, in dust storms (Lu, 2004). In our soil samples, the content of soil particles in the range of 0.25 to 16 μm ranged from 6.2 to 88.75% (Fig. 5), and the mean value was 41.3%, suggesting a substantial potential for suspension during dust storms in the river overflow area. Li et al. (2008) reported that the soils in the transitional zone between oasis and desert in the Taklimakan Desert were a major dust source, particularly in the Tarim Basin.

 © 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

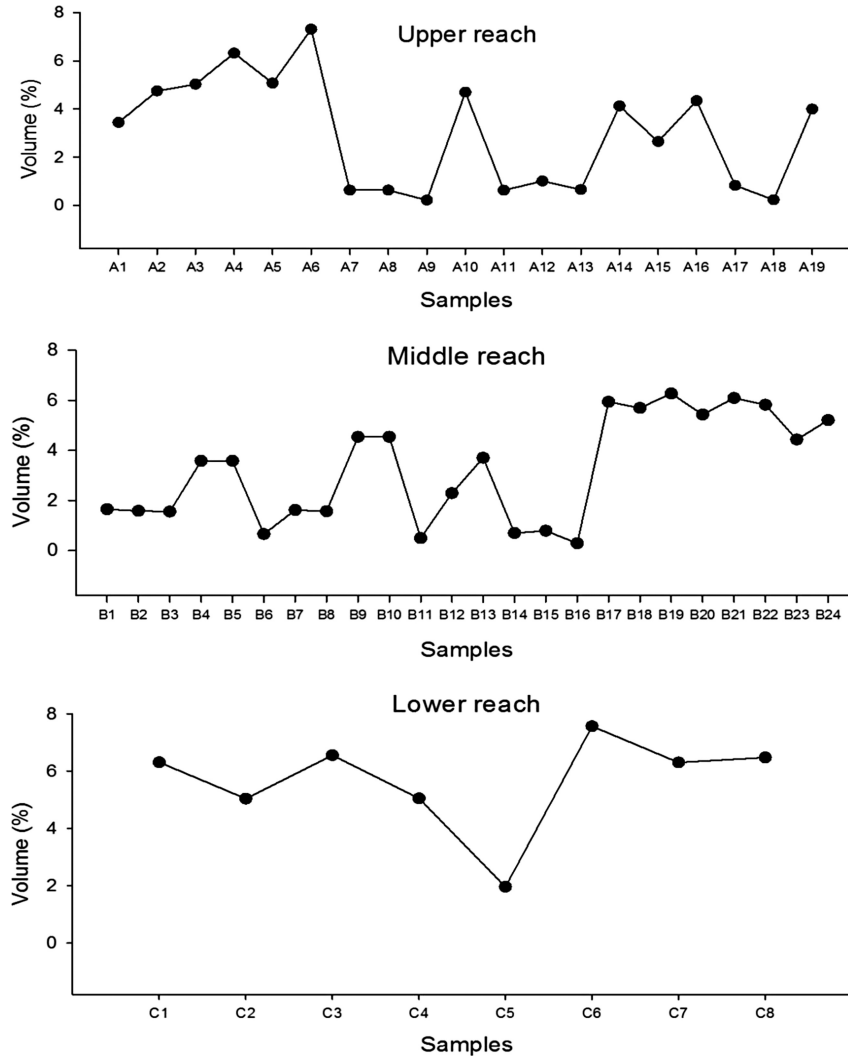

FIG. 4. Content of particles in 90-μm diameter of soils at different sections within the overflow area of the Tarim River.

Our research provides additional evidence to support this conclusion. In the study region, the middle reaches had the highest potential contribution to dust storms, followed by the upper reaches; the lower reaches had lowest contribution. These results are consistent with results obtained for the suspension-size particles less than 100 μm.

Of particular concern are those particles with a mean aerodynamic diameter less than or equal to 2.5 μm (PM2.5) and 10 μm (PM10), which are stringently regulated by the Chinese Ministry of Environment Protection as air pollutants. Table 4 shows that PM2.5 and PM10 content of the 51 soils ranged from 1.6 to 30.4% and 4.5 to 78.6%, respectively. Similarly, a mastersizer was also used in the United States to conduct dispersed soil particle size analysis in an effort to determine potential emission of PM2.5 and PM10 for soils located in the highly erodible regions (Chandler et al., 2002; Feng et al., 2011). Chandler et al. (2002) reported that soils on the Columbia Plateau and Texas contain 19 to 38% and 16% of PM10, respectively. Feng et al. (2011) reported that five sandy and silt loam soils in Washington State contain 11 to 20% of PM2.5 and 17 to 39% of PM10, which indicates that PM2.5 and PM10 content of soils along the Tarim River were 30% more and two times higher than soils in the dust sources of the United States, respectively.

Table 4 shows that there were large differences in both PM2.5 and PM10 among these soils. The PM 2.5 and PM10 mean values were 11.5 and 32%, which indicate that most soils contain high percentages of PM2.5 and PM10. The ratio of PM2.5/PM10 ranged from 0.25 to 0.42, and the mean value was 0.36. These results reveal that there is a high emission potential of PM2.5 and PM10 in the overflow area of the Tarim River. Table 4 shows that there were differences among the three reaches of the river. The middle reach of the river had the highest content of PM2.5 and PM10, followed by the upper reach, with the lower reach having the lowest content of PM2.5 and PM10. The USEPA (1990) has started developing National Ambient Air Quality Standards for particulates between PM2.5 and PM10 (PM10-2.5). In this study area, PM10-2.5 varied from 2.9 to 48.2%, with a mean value of 19.6%. The content of very fine particulates ranged from 4.4 to 40.4% in the upper reach, ranged from 12.6 to 48.2% in the middle reach, and from 2.9 to 14.2% in the lower reach. Similarly, the highest content of very fine particulates was

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

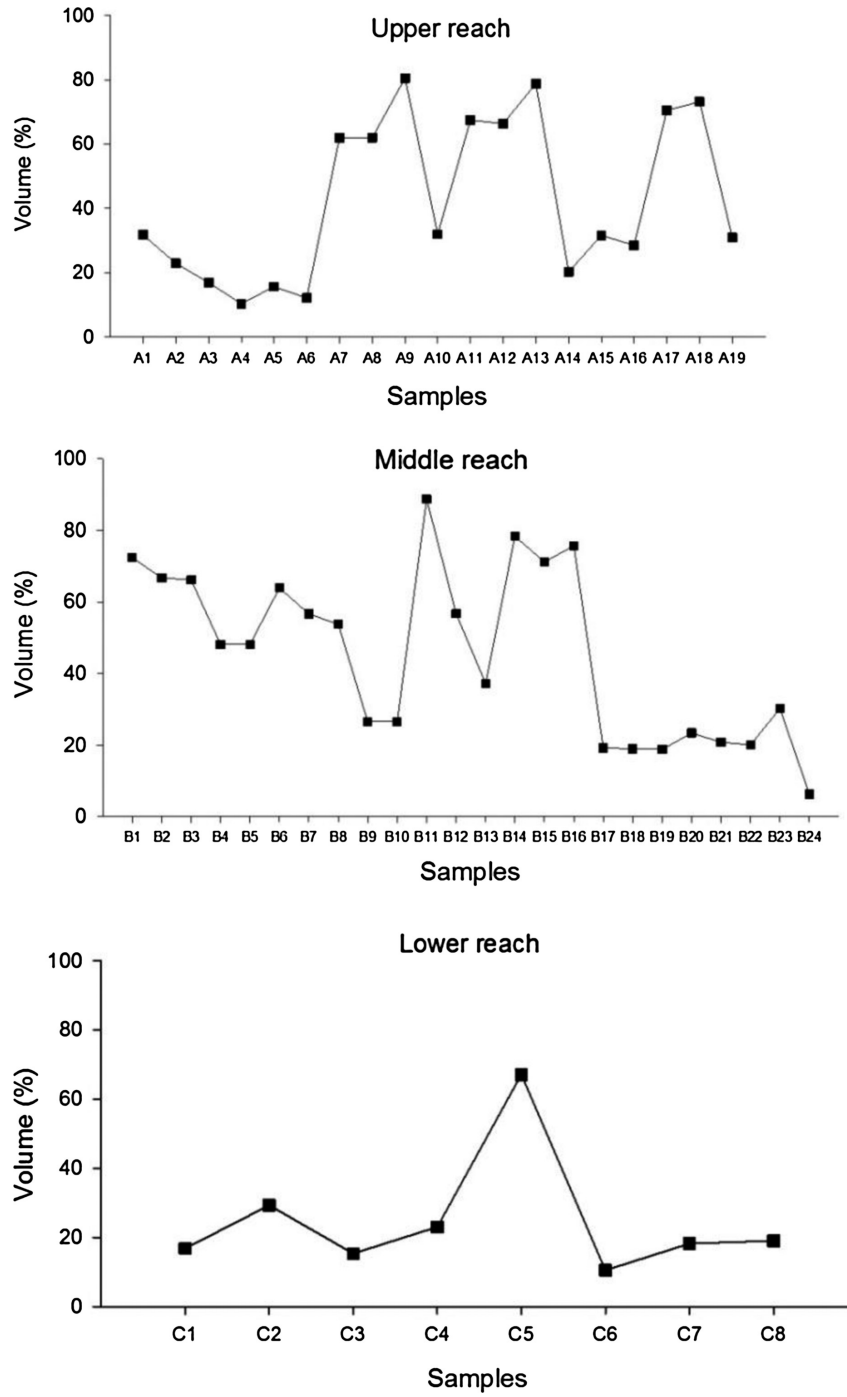

FIG. 5. Content of particles in 0.25- to 16-μm diameter of soils at different sections within the overflow area of the Tarim River.

found in the river's middle reach. Wind erosion may create air quality concerns at both local and regional scales because of long-range transport of fine and very fine particulates lifted into the atmosphere.

The contribution of fine particulates contained in flood-deposited sediment to windblown dust should be taken into consideration in river overflow areas. Shen et al. (2006) reported that the Tarim River flooded 1.74 times every year during the period from 1951 to 2000. Flood peaks greater than 800 m^3/s occurred in almost every year from 2000 to 2006 and those greater than 1,000 m^3/s occurred in 6 of these 7 years (Chen et al., 2011). In addition, the annual water-borne sediment discharge was 1.376×10^7 t in the middle reach of the Tarim River (Xia, 1998). Hu et al. (2005) reported that the flood-suspended load particle diameter ranged from 2 to 50 μm in the Tarim River; the D50 ranged from 11 to 41 μm in the upper reach, and the mean D50 was 31 μm in the middle reach. Most particles of the flood-suspended load were highly erodible. Frequent river flooding contributed to accumulation of a high percentage of fine particles. After drying, those silt loamy soils are susceptible

 © 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

TABLE 4. PM2.5 and PM10 Percentage of Soils

No.	Samples	PM2.5	PM10	No.	Samples	PM2.5	PM10
1	A1	7.87	22.35	27	B8	12.61	40.40
2	A2	6.52	16.61	28	B9	6.98	19.62
3	A3	2.68	10.82	29	B10	6.98	19.62
4	A4	1.95	6.36	30	B11	30.39	78.63
5	A5	2.78	10.16	31	B12	16.23	44.61
6	A6	3.47	8.85	32	B13	10.65	28.23
7	A7	14.55	43.52	33	B14	23.45	65.41
8	A8	14.55	43.52	34	B15	17.57	57.06
9	A9	20.69	63.68	35	B16	19.73	57.72
10	A10	10.13	24.68	36	B17	5.63	14.46
11	A11	18.23	51.13	37	B18	4.77	13.66
12	A12	13.92	48.38	38	B19	4.95	13.86
13	A13	26.44	66.83	39	B20	5.62	16.70
14	A14	5.38	13.77	40	B21	6.12	15.71
15	A15	7.67	20.81	41	B22	5.13	14.62
16	A16	7.53	20.73	42	B23	8.33	22.52
17	A17	22.34	57.43	43	B24	1.56	4.46
18	A18	19.16	55.01	44	C1	3.87	11.73
19	A19	8.06	22.48	45	C2	8.92	22.67
20	B1	22.99	61.29	46	C3	4.82	11.59
21	B2	19.99	53.87	47	C4	6.24	17.03
22	B3	17.64	52.48	48	C5	20.58	56.71
23	B4	16.68	40.10	49	C6	3.31	8.21
24	B5	16.68	40.10	50	C7	4.62	13.37
25	B6	17.96	49.90	51	C8	4.37	13.65
26	B7	16.72	44.40				

to wind erosion. Therefore, the river floods contributed to high levels of fine particles. Much of the dust by wind erosion in the region may be the result of river sedimentation.

In a previous study, Li et al. (2009) found that the mass percentage of medium sand (250–500 μm) significantly increased to 37.96% after two windy seasons in the northern Chihuahuan Desert. On the other hand, soil particles in the range of 50 to 125 μm (very fine sand) declined significantly from 15.01 to 13.55%. Similarly, significant decreases in the percentage of soil particles with diameters less than 50 μm (silt and clay) were found during this period. Silt particles are sufficiently light and powdery to be transported by wind-erosive forces. In terms of our research results, the lower reach of the river had the largest grain size. Two possible explanations for this observation are as follows. First, the lower reach of the Tarim River did not carry as much water and there were fewer natural flooding and planned overflow flooding events. Chen et al. (2011) reported that since the beginning of the 1990s, desiccation occurred on the lower reach of the Tarim River because of the high intensity of water resource utilization in the upper reach of the river basin. Tursun et al. (2009) also noted that, because of the irrational water-land resources use and biological resources exploitation in the past 50 years, the lower reaches of nearly 363 km from the DaXiHaiZi reservoir had been dry for 30 years. The decreased occurrence of floods and river overflow could not provide more fine particles. A second probable reason was winnowing by wind erosion. Wind erosion and desertification have been enhanced, and the biodiversity has been severely damaged in the lower reach of the Tarim River (Chen et al., 2011). Feng et al. (2001) reported that, between 1958 and 1987, the rate of land desertification area was increased by 30.0% and, within this area, the rate of land desertification area was increased by 13.7, 30.1, and 35.3% in the upper, middle, and lower reaches, respectively. Chen et al. (2006) also reported that the environmental quality was severely degraded in the lower reach. The lack of water led to decreased vegetation cover, with the resulting increase in wind erosion and the loss of soil fine particles. Strong wind erosion and the shortage of water flow resulted in more soils with coarser particles in the lower reach. This explanation also suggests why there were more saltation-size particles and fewer suspension-size particles.

It is noted that particles, not aggregate size, were measured in this study. Chepil (1942, 1962) developed a rotary sieve and dry sieving procedure for measurement of dry aggregate size distribution. This method was adopted in soil wind erosion research. However, the rotary sieve is out of date and not readily available to research. In contrast, mastersizer, as a new technology using laser diffraction, can rapidly analyze particle size of a large number of soils (Zobeck, 2004). To some extent, particle size analysis has the advantage to estimate factors influencing wind erodibility (Chandler, 2005). The mastersizer requires dispersing soils before measurement. Although dispersed soil particle size distribution, in general, is higher than nondispersed dry aggregate size distribution, the particle size analysis could represent the most potential of soil fine-particle emission. The soils on the overflow areas are located in an extremely dry area, the Taklimakan Desert, in an arid region; those soils contain much lower organic matter. There is likely little opportunity for aggregate formation. Thus, dispersed soil analysis may portray surface conditions along the river.

CONCLUSIONS

Fifty-one soil samples were taken from the upper 5-cm layer of the soil profile in the overflow area of the Tarim River. Analysis of the soil particle size distribution indicated that the texture of most soils was silt loam and these soils were mainly located in the upper reach to the middle reach of the Tarim River. The soil particles were finer in the middle reach and the upper reach, with coarser particles predominant in the lower reach.

The river overflow area is one of the major dust sources in the Tarim Basin, where dust storms frequently occur. It was also found that the river overflow area was one of the major PM2.5 and PM10 emission sources in the Tarim Basin. The highest content of saltation-size particles was found in the overflow area of the lower reach, followed by the upper reach and the middle reach. In contrast, high percentages of suspension-size particles were found in the upper and middle reaches. River floods could result in additions of fine particles to these overflow areas, and considerable dust may be generated from river sediments by the erosive forces of wind. Therefore, mitigation of soil wind erosion and fine-particle emission should be considered in the region.

REFERENCES

Arimoto R., Y. J. Kim, Y. P. Kim, P. K. Quinn, T. S. Bates, T. L. Anderson, S. Gong, I. Uno, M. Chin, B. J. Huebert, A. D. Clarke, Y. Shinozuka, R. J. Weber, J. R. Anderson, S. A. Guazzotti, R. C. Sullivan, D. A. Sodeman, A. Prather, and I. N. Sokolik. 2006. Characterization of Asian dust during ACE-Asia. Glob. Planet Change. 52:23–56.

Blank R. R., J. A. Young, and F. L. Allen. 1999. Aeolian dust in a saline playa environment, Nevada, USA. J. Arid Environ. 41:365–381.

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Blom C. W. P. M., and L. A. C. J. Voesenek. 1996. Overflowing: the survival strategies of plants. Trends Ecol. Evol. 11:290–295.

Chandler D. G., K. E. Saxton, J. Kjelgaard, and A. J. Busacca. 2002. A technique to measure fine-dust emission potentials during wind erosion. Soil Sci. Soc. Am. J. 66:1127–1133.

Chandler D. G. 2005. Predicting wind erodibility of Locssial soils in the Pacific Northwest by particle sizing. Arid Land Res. Manag. 19:13–27.

Chen Y. N., H. Zilliacus, W. H. Li, H. F. Zhang, and Y. P. Chen. 2006. Ground-water level affects plant species diversity along the lower reaches of the Tarim River, Western China. J. Arid Environ. 66:231–246.

Chen Y. N., Z. X. Ye, and Y. J. Shen. 2011. Desiccation of the Tarim River, Xinjiang, China, and mitigation strategy. Quat. Int. 244:264–271.

Chepil W. S. 1942. Measurement of wind erosiveness of soils by dry sieving procedure. Sci. Agric. (Ottawa). 23:154–160.

Chepil W. S. 1955. Factors that influence clod structure and erodibility of soil by wind: IV. Sand, silt and clay. Soil Sci. 80:155–162.

Chepil W. S. 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc. 26:4–6.

Chow J. C., and J. G. Watson. 1997. Fugitive Dust and Other Source Contribution to PM10 in Nevada's Las Vegas Valley: Volume II Final Report. DRI Document No. 4039.2F1, prepared for the Clark County Department of Comprehensive Planning, Las Vegas, NV, by the Desert Research Institute, Reno, NV.

D'odorico P., and A. Porporato. 2006. Dryland Ecohydrology. Springer, The Netherlands.

Dong Z. B., and Z. S. Li. 1998. Wind erodibility of Aeolian sand as influenced by grain-size parameters. J. Soil Erosion Water Conserv. 4:1–12.

Duce R. A., C. K. Unni, B. J. Ray, J. M. Prospero, and J. T. Merrill. 1980. Long-range atmospheric transport of soil dust from Asia to the Tropical North Pacific: temporal variability. Science 209:1522–1524.

Duce R. A., and N. W. Tindale. 1991. Chemistry and biology of iron and other trace metals. Limnol Oceanogr. 36:1715–1726.

Feng G. L., S. Brenton, and W. Laura. 2011. Fine particle emission potential from loam soils in a semiarid region. Soil Sci. Soc. Am. J. 75:2262–2270.

Feng Q., K. N. Endo. and G. D. Cheng. 2001. Towards sustainable development of the environmentally degraded arid rivers of China—a case study from Tarim River. Environ. Geol. 41:229–238.

Gillette D. A. 1977. Fine particulate emissions due to wind erosion. Trans. ASAE. 20:890–897.

Goudie A. S., and N. J. Middleton. 2006. Desert Dust in the Global System. Springer, New York, NY.

Hu L. Q., J. D. Xia, and C. Q. Sang. 2001. Analysis of satellite images of strong sandstorm in Xinjiang. Arid Land Geogr. 24:30–32.

Hu C. H, Y. G. Wang, and Q. C. Guo. 2005. Fluvial Process and Regulation of the Main Stem Tarim River. Science Press, Beijing, China.

Husar R. B., D. M. Tratt, B. A. Schichtel, S. R. Falke, F. Li, D. Jaffe, S. Gasso, T. Gill, N. S. Laulainen, F. Lu, M. C. Reheis, Y. Chun, D. Westphal, B. N. Holben, C. Gueymard, I. McKendry, N. Kuring, G. C. Feldman, C. McClain, R. J. Frouin, J. Merrill, D. DuBois, F. Vignola, T. Murayama, S. Nickovic, W. E. Wilson, K. Sassen, N. Sugimoto, and W. C. Malm. 2001. Asian dust events of April 1998. J. Geophys. Res. 106:317–330.

Jackson M. L. 1975. Soil Chemical Analysis Advanced Course, 2nd ed. M. L. Jackson, Madison, WI.

Tursun K., T. Manisahan, G. H. Han, and S. Li. 2009. Analysis on impact factors of land desertification in lower reaches of Tarim River in past 50 years. J. Desert Res. 29:1029–1034.

Labiadh M., G. Bergametti, B. Attoui, and S. Sekrafi. 2011. Particle size distributions of South Tunisian soils erodible by wind. Geodin. Acta 24:37–47.

Larney F. J., M. S. Bullock, H. H. Janzen, B. H. Ellert, and E. S. Olson. 1998. Wind erosion effects on nutrient redistribution and soil productivity. J. Soil Water Conserv. 53:133–140

Li J., G. S. Okin, L. Alvarez, and H. Epstein. 2007. Quantitative effects of vegetation cover on wind erosion and soil nutrient loss in a desert grassland of southern New Mexico, USA, Biogeochemistry. 85:317–332.

Li J., G. S. Okin, and E. H. Epstein. 2009. Effects of enhanced wind erosion on surface soil texture and characteristics of windblown sediments. J. Geophys. Res. 114:1–8.

Li S. K., M. Lu, K. R. Wang, and X. Wang. 2008. Soil erosion of the main ground surface types influences on formation of dust storm in South Xinjiang. Sciential Agri. Sinica. 41:3158–3167.

Lu M. 2004. Formation cause and control of sandstorm in China. Sciential Agricultura Sinica. 35:440–446.

Madden N. M., R. J. Southard, and P. J. Mitchell. 2010. Soil water and particle size distribution influence laboratory-generated PM10. Atmos. Environ. 44:745–752.

Mirzamostafa N., L. J. Hagen, L. R. Stone, and E. L. Skidmore. 1998. Soil aggregate and texture effects on suspension components from wind erosion. Soil Sci. Soc. Am. J. 62(5):1351–1361.

Okin G. S., D. A. Gillette, and J. E. Herrick. 2006. Multi-scale controls on consequences of aeolian processes in landscape change in arid and semi-arid environments. J. Arid Environ. 65:253–275.

Overpeck J., D. Anderson, S. Trumbore, and W. Prell. 1996. The southwest Indian monsoon over the last 18,000 years. Clim. Dynam. 12:213–225.

Pye K. 1987. Aeolian Dust and Dust Deposits. Academic Press, New York, NY, 334.

Qian Y. B., Z. N. Wu, Q. Yang, L. Y. Zhang, and X. Y. Wang. 2007. Ground-surface conditions of sand-dust event occurrences in the southern Junggar Basin of Xinjiang. China J. Arid Environ. 70:49–62.

Reheis M. C. 2006. 16-year record of aeolian dust in Southern Nevada and California, USA: controls on dust generation and accumulation. J. Arid Environ. 67:487–520.

Reynolds R. L., J. Yount, M. Reheis, H. Goldstein, P. ChavezJr., R. Fulton, J. Whitney, C. Fuller, and R. M. Forester. 2007. Dust emission from wet and dry playas in the Mojave Desert, USA. Earth Surf. Process. Landforms 32:1811–1827.

Schwartz J. 1994. Air pollution and daily mortality: a review and meta-analysis. Environ. Res. 64:36–52.

Shen Y. P., S. D. Wang, G. Y. Wang, C. Shao, and W. Y. Mao. 2006. Response of glacier flash flood to global warming in Tarim River Basin. Adv. Clim. Change Res. 2:32–35.

Stout J. E., and T. M. Zobeck. 1996. The Wolfforth field experiment: a wind erosion study. Soil Sci. 161:616–632.

Tatarko J. 2001. Soil aggregation and wind erosion: processes and measurements. Ann. Arid Zone. 40:251–263.

Tegen I., and A. A. Lacis. 1996. Modeling of particle size distribution and its influence on the radioactive properties of mineral dust aerosol. J. Geophys. Res. 101:19237–19244.

US Environmental Protection Agency. 1990. Clean Air Act Amendments of 1990, Detailed Summary of Titles, Title 1-Provisions for Attainment and Maintenance of National Ambient Air Quality Standards-Ozone, Carbon Monoxide, and PM10 Nonattainment Provisions. Washington, DC, USEPA, pp. 24–28.

Wang T., W. Wu, X. Xue, Q. Sun, and G. Chen. 2004a. Study of special distribution of sandy desertification in North China in recent 10 years. Sci. China (D). 47:78–88.

Wang X., Z. Dong, J. Zhang, and L. Liu. 2004b. Modern dust storms in China: an overview. J. Arid Environ. 58:559–574.

Wuetrich B. 1996. Deliberate flood renews habitats. Science. 272:344–345.

Xia D. K. 1998. Channel change and sediment movement in Tarim River. Hydrology 6:42–46.

 © 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

Xuan J., G. L. Liu, and K. Du. 2000. Dust emission inventory in northern China. Atmos Environ. 34:4565–4570.

Xu H. L., M. Ye, and J. M. Li. 2009. The ecological characteristics of the riparian vegetation affected by river overflowing disturbance in the lower Tarim River. Environ. Geol. 58:1749–1755.

Yang L. R., L. P. Yue, and Z. P Li. 2008. The influence of dry lakebeds, degraded sandy grasslands and abandoned farmland in the arid inlands of northern China on the grain size distribution of East Asian aeolian dust. Environ. Geol. 53:1767–1775.

Yu H. B., L. A. Remer, M. Chin, H. S. Bian, Q. Tan, T. Yuan, and Y. Zhang. 2012. Aerosols from overseas rival domestic emissions over North America. Science 337:566–568.

Yue L. P., L. R. Yang, Z. P. Li, M. Wang, W. J. Zhang, and H. G. Nie. 2004. Grain-size distribution of the sediments of dry lake-bed in the northwest of China and sand-dust weather in the East Asia. Acta Sediment. Sinica. 22:325–331.

Zhang X. Y., R. Arimoto, and Z. S. An. 1997. Dust emission from Chinese desert sources linked to variations in atmospheric circulation. J. Geophys. Res. 102:28041–28047.

Zobeck T. M., and D. W. Fryrear. 1986. Chemical and physical characteristics of windblown sediment. II. Chemical characteristics and total soil and nutrient discharge. Trans. ASAE. 29:1037–1041.

Zobeck T. M. 2004. Rapid particle size analyses using laser diffraction. Appl. Eng. Agric. 20(5):633–639.

© 2014 Lippincott Williams & Wilkins

Copyright © 2014 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.