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Soil Born Dust Release from Polluted Industrial Derelict Land and Deposition in the Ruhr Area (Germany)

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ABSTRACT

In 1997, the Ministry of Environment of Northrhine Westphalia gave order to work out a literature study that gathered the recent point of knowledge regarding the pollutant matters and their spreading in soil born dusts in industrial and urban areas. An important result of the study is that the wind erodibility of *young* industrial soils and substrates is estimated highly, but more investigations have been necessary to get provable facts to judge the possible danger for citizens.

In May 1998, the first instruments for measurements qualifying and quantifying release and deposition of dust have been installed. The station is sited on a plain fallow land (ca. 250 * 600 m) that is more than 25 years out of industrial usage, highly polluted and now almost covered by herbs and up to 8 m high birches. In the west part, there is a circle of cultivated soil surface (vegetationless and loosened) with ca. 8000 m^2 expansion to create "worst case" erosion plain. High Volume Samplers with PM$_{10}$ heads combined with different dust traps with more tasks were installed. The horizontal and vertical distributions of dust particles are measured in consideration of the main wind direction and the urban background pollution. The measurements take place in different distances to the erosion plain. A microclimate station in the area takes all relevant data. That should allow more precise statements regarding the endangering of human health and environment.

The following considerations helped to choose the instruments and their disposition:

- **Younger medical science found out, that the main danger for health is not caused by the whole amount of the suspended dust, but by the amount of PM$_{10}$ (particle matter < 10 µm).**
- **Caused by the high pollution of the source soil, its soil born dusts contain more pollutants and are noxious especially while long-term exposition.**
- **The deposition of polluted soil born dust contaminates the surrounded soils.**

INTRODUCTION

In 1997 the Ministry of Environment of North-Rhine-Westphalia orders to work on a literature study, to determine the state of knowledge regarding the pollutant matters and their spread in soil born dusts in industrial and urban areas. An important result of the study is that the wind erodibility of *young* industrial soils and man made materials, such as abundant hazardous waste sites, is quite likely but more investigations are necessary to get provable facts to judge the possible danger for citizens. The perils of dust release from urban and industrial soils can be:

- The increase of PM$_{10}$ (particle matter < 10 µm). These particles are known as lung-passable and they endanger health even during short-term exposition and independently of their composition (EPA, 1996; EU, 1997).
- The increase of noxious dust in the air, containing cancerous or non-cancerous toxic pollutants. It endangers health as a result of long-term-exposition.
- The degradation of surrounding soils caused by deposition of polluted particles.

Based on the literature study, the Ministry has ordered investigations about quantity and quality of dust release from a polluted former industrial area and the deposition of these dusts. The disposition at the station for dust measurements is chosen to prove measuring techniques and to get results regarding the ways of endangering.

Synopsis of the literature researches

In old traditional urban and industrial areas, soils with man made materials are proportionately widespread. An evaluation of 223 data files from several studies by the Chair of Applied Soil Science (University Essen) about urban-industrial soils, divided into five groups of man made material (1. ashes, 2. slag, 3. coke-coals-tailings, 4. rubbish-bricks, 5. limestone and basalt gravel) showed that:

- In the fine earth fraction the wind-erodible particle sizes (0.02 – 0.63 mm) dominate in all groups of man made material and mixtures of man made and natural soil materials,
- Often a single grain structure can be found,
- Many industrial soils contain a large amount of non-erodible components, like gravel, bricks, slacks and stones. Mckenna, Neumann, and Nickling (1995) show in their investigations, that bigger particles initially cause more erosive air-turbulence, compared to pure sand surfaces. That signifies a higher dust release in the beginning of an erosion process. Later on, the sheltering effect of the non-erodible particles predominates, caused by the growing covering grade.
- The surface drying-up on most of the industrial soils will lead within one day to water contents, which allow wind erosion (Skidmore and Dahl, 1978).

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Urban and industrial soils are often highly polluted with noxious substances. Usually, the smaller the particle size, the higher is the content of noxious substances. Enrichment factors are necessary for calculating the deflation of pollutants with suspended dust. The knowledge about enrichment factors for pollutants in man made materials is low. Regarding the amount of dust release from industrial soils it must be considered, that the agricultural term of the erosion rate (the whole amount of moved soil) is strictly to differentiate from the term of suspended dust rates. Only these suspended particles, which are able to be moved far away from their origin and rise up to human breathing height, are potentially dangerous for human health.

The usage of an area has a high influence on the duration and the amount of suspended dust emissions. It makes sense to separate two types of areas:

Type 1: Fallow land *without* vegetation and human use. The dust release decreases, if vegetation increases. Non-erodible particles on the surface and the formation of surface crusts result in similar effects. For skeleton-rich areas it seems to be acceptable to estimate the share on suspended dust, which can leave an area in a worst-case calculation (Formula 1).

$$Sus\ t \times ha^{-1} = \frac{((L_d \times 102 * T) - G/Gr) \times S}{L_d \times 102 \times T} \quad (1)$$

where Sus t ha^{-1} is the suspended dust mass, L_d is the bulk density of the fine earth (g cm^{-3}), T is the deflation depth (cm), G/Gr = skeleton content on the surface (volume-%), and S is the potential share of fine earth, which can form suspended dust (weights-%).

Example: A skeleton content of 50 vol.-%, a deflation depth of 1 cm between the skeleton, a fine earth bulk density of l g/cm² and a share of the particle size fraction < 0.2 mm of 50 weights-% lead to a possible maximum deflation of 25 t/ha. If more information is known about the pollutant concentration and the pollutant enrichment factors, it will be able to calculate the possible deflation of pollutants.

Type 2: Used areas without vegetation. Almost all fallow lands in urban- industrial areas are used for leisure time activities (e.g. for motocross, playing, walking). By using the land mechanically, fine material will be produced continuously. Soil compaction and structure destruction support soil erodibility (Yuzhang et al., 1994). The highest suspended dust rates by utilisation are found while dry and windy weather conditions (Schäfer et al., 1994). If the land partly sealed, you can observe that on the sealed surfaces displaced particles are easily blown away. They can be moved to the unsealed areas and hit out particles there, even when the thresholds for wind erosive conditions on the unsealed areas are not reached (Yuzhang et al., 1994).

Conception and equipment of the dust measurement station

The station is build up on a plain fallow land (about 250*600 m) of a former chemical factory site. The factory produced lithopone ($BaSO_4$+ZnS)- and other mineral-colours, sulphur acid, sulphate, tar products and sulphur-carbon. The area is more than 25 years out of usage and now nearly covered by herbs and up to 8 m high birches. In the west part, there is a circle of soil surface (vegetationless and loosened) with 100 m diameter (approx. 8000 m²) to create "worst case" erosion plain. Map 1 shows the site and construction-plan of the station for dust measurement. The measuring sites will be described like this e.g.: 150-3-2 = 150 degree over north, 3 meters away from the fringe of the erosion area, 2 cm capture high above the ground. The predominate wind direction is northwest. Tab. 1 illustrates the used traps for measuring the dust precipitation and the dust flux rates. Two High Volume Samplers (Digitel, DHA 80) with inlets for PM_{10} measurement are installed in the central and the 235-3 site. Normally they measure 24 h values. In the case of erosive weather conditions (e.g. wind speed higher than 5 m/s and surface water content lower than 3% weight over a period of 20 minutes), a computer program will change the filters. When these thresholds will fall below or exceed, the filters will be changed again. The surface water content is determined by means of an infrared-reflection photometer. A microclimate station records the wind speed in 3 heights (0.15, 1.5 and 10 m), the wind direction, precipitation, soil and air temperature and global and reflected radiation. Due to the circular erosion plain, it can be expected that between the potential background site (235-3) and the central site is always a field length of 50 m for erosion events.

Properties of the erosion plain

The surface of the erosion plain consists of small-scaled varying mixtures of rubble, sludge, slag, ashes and natural soil materials. In extreme cases, the surface property changes every few centimeters. A sampling grid of 15*15 m was applied to the erosion plain. A composite sample with 30-40 withdrawals was taken from 0-2 cm depth out of every square. A sandy loam texture dominates on the erosion area. The skeleton content is varying between 16-57% weight and consist mainly of bricks. The surface roughness is about 90 mm caused by treating and the bricks. The treating will be repeated every few month to receive a high erodibility. The area loading with inorganic and organic pollutants is high. Map 2 shows the distribution of aqua regia soluble lead and barium in the surface layer. The main emphasis of the high contents occurs at the north fringe on the erosion plain.

First results

In the previous measurement period, the climatological data do not show any period of time, in which a distinct wind erosion event could have taken place. Until today, only periods of few minutes occur (mostly squalls in the front of precipitation's) in which dust from the area could have been released. The following data mainly show properties of urban background dust in the region and local short-range transport processes based on rain splash erosion (in combination with high wind speeds) and maybe also on wind erosion because of local squalls.

PM_{10} – contents and ingredients

The average of the PM_{10} concentration is 33.8 µg m^{-3} (database: 24 h values from June 98 – March 99). At 45 days the concentration has been higher than 50 µg m^{-3} and the maximum has been at 134 µg m⁻³. Table 1 shows the US EPA-limits and the suggested EU-limits for PM_{10}.

Important are those periods, when both PM_{10} collectors show clear differences in the contents and ingredients of PM_{10}. For example in 25th June 98 the daily mean content shows an above-average difference with 38.3 (central site) and 18.9 µg m^{-3} (site 235-3). On this day, the wind velocity reached maximum 8.8 m s^{-1} for 12 minutes (the wind direction was SW), than rainfall followed. Under the assumption that the PM_{10} concentrations were similar during the remaining day, the measured differences could be put down on a period of 12 minutes. To apply the measuring difference only to this period, a mean PM_{10} concentration of 2328 µg m^{-3} can be calculated. Taking a period of 183 min as a basis (start time: wind velocities over 4 m s^{-1}, final time: rainfall start) a mean PM_{10} concentration of 153 µg m^{-3} can be calculated.

The daily mean lead content was measured in the central site with 0.030 (785 mg kg^{-1}) and 0.031 µg m^{-3} (1652 mg kg^{-1}) in the site 235-3. Barium showed contents of 0.024 µg m^{-3} (630 mg kg^{-1}) in the central and 0.013 µg m^{-3} (684 mg kg^{-1}) in the luvside site. The determination of the ingredients is effected by means of CEN/TC 264 N221/WG14N2.

Concerning the 25th June, it is possible that the differences between the PM_{10}-collectors can be regarded to the PM_{10} release from the erosion plain. A couple of days with differences between the collectors cannot be explained at this time.

Dust precipitation

To date the dust precipitation is on all sites below the German annual mean limit value of 0.35 g $(m^2 d)^{-1}$ in the standard measurement height of 150 cm above the ground. The dust precipitation is also measured 2 cm above the ground. The main dust movement take place in the lowest 30 cm of the atmosphere during wind erosion events. Material that is transported in the lowest 1.5 m is not ascertainable with the standard method. In case of the soil degradation caused by deposition of noxious blown out particles the measurement height must be near to soil surface.

The trapped material 2 cm above the ground is clearly more than in 150 cm height (Table 3 Fig. 3). The mass differences between the measurement heights 75 and 150 cm are minimal. They range within the bounds of the standard deviations from duplicate determinations.

The lesser the sites are influenced from vegetation and the better the accessibility to the erosion plain is, the higher are the vertical quotients. The following factors influence these quotients:

1. *The higher the wind velocity, the lower is the catch effectiveness of the Bergerhoff trap.*

Due to the reduced wind velocity near to the surface the effectiveness of the trap increase. Egami & Watson (1989) figure out that the catch effectiveness of cylindrical vessels go against zero regarding particles lower than < 100 µm, if the wind velocity is higher than 7 m s^{-1}. A wind velocity of 1 m s^{-1} causes a catch effectiveness at 60% for particles lower than 100 µm. The higher wind speeds on the central site seem to lead to light lower catch values.

2. *Primarily the height of the vertical quotients is determined by the trapped masses close to the soil surface (Table 3). Near to the soil surface, an important material flux takes place.*

On the sites near the erosion plain, this effect can be caused by wind during dry weather conditions or during wet conditions by rain splash erosion. All sites are surrounded by a fabric of polyethylene at least 150 cm to each side. It is not yet clear, whether this is sufficient to prevent an input of rain splash eroded material during high wind velocities. Herbs and partial birches are growing between the erosion plain and the sites in 100 and 300 m. So, the traps close to the surface on these sites cannot be influenced in a direct way from the erosion plain. The site 235-3 shows a similar quotient in comparison to the sites in 100 and 200 m distance although it is placed direct on the fringe and on the leeside of vegetation – though by the high wind velocities from southwest on the luvside of the erosion plain.

Fig. 1 shows the particle size distribution of the trapped masses from 8 sites in the heights of 2 and 150 cm (samples from Jan 99). The particle sizes maximum is in the coarse silt fraction in the height of 150 cm and near the ground in the fine sand fraction.

The deviations of the particle size distributions close to the surface are clearly higher than at 150 cm. Due to the vegetation between the erosion area and the sites in 100 and 300 m, the fine sand particles cannot be transported from the erosion plain to these sites, otherwise the fine sand fraction must be higher in 150 cm above the ground. So, it is not possible to use the gradients from the sites in 100 and 300 m to calculate the real dust input into the soil. The masses of particles in the collectors near the ground show, that in stands of vegetation a flux of soil material near the surface take place too, which get over a minimum distances of 1.5 m.

The dust ingredients lead and cadmium are mainly under the limit value in the collecting height of 150 cm. In case of barium, there are no threshold values but the contents seem to be extremely high. Further noxious elements are still measured.

Figure 2 illustrates the trend of the quotients (2/150 cm) or the sites 82-25 and 82-100 for the trapped masses, barium and lead. In the trend, the variations of the quotients are rather similar between the sites during the months but the height of the fluctuations is clearly lower in the site 82-100. The amplitude response of barium and lead are contrary to the masses. In comparison, the collecting masses show the highest amplitudes, followed by barium. Lead shows in both sites only for one month, a After this the higher the masses in the collectors are close to the surface are, the lower are the contents of barium and lead, but if the trapped masses near the ground are low the contents of barium and rarer of lead close the soil surface are higher than in 150 cm.

Fig. 3a shows the mean trapped masses (measurement period Jun 98 – Feb 99) in 3 different heights above the ground and different distances to the erosion plain. Fig 3b and 3c illustrates the mean barium and lead contents. The very high content of lead in the trapped material on the site 235-3 is presumable due to the high contents in the erosion plain near these sites (Map 2).

Table 1: Measurement techniques for dust precipitation and dust flux rates.

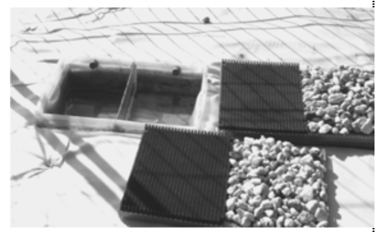
Measurement techniques for dust precipitatio			
Trap type:	Bergerhoff (VDI 2119, Part 2)	Löbner-Liesegang (VDI 2119, Part 3)	KUNSTRA
Description:	Plastic pot (PE soft)	Plastic funnel with plastic bottle	Grid on a two tailed box, one part artificial lawn, one part with silica gravel
Collecting area:	75.4 cm²	452.4 cm²	2 *1117 cm²
Measurement techniques for sediment flux			
Trap type:	SUSTRA (Suspension Sediment Trap) by Janssen & Tetzlaff (1990)	BSNE (Big Spring No 8) by Freyrear (1986) with a rain hut	BOSTRA (Bottle Sediment Trap) by Wilson & Cooke (1980) and Schäfer et al. (1990)
Description:	Possibility to install a scale for continuous dust input measurements	Possibility to measure vertical gradients of dust flux	Possibility to measure vertical gradients of dust flux by high dust concentrations
Collecting area:	19.6 cm²	10 cm²	0.2 cm²

Table 2: US EPA - limits and suggested EU- limits for PM_{10}.

	24 h-Mean [µg/m³]	Annual mean [µg/m³]
US-EPA[1)]	< 150 (> 150 at ≤ 3 d/a)	50
EU[2)]	50 (> 50 at ≤ 35 d/a)	40

[1)] EPA (1990); [2)] EU (1997, step 1 valid till 01.01.2005)
quotient > 1.

Table 3: Vertical gradients of dust precipitation (measurement period June 98 – March 99)

Site	Months	Deposition rate g/(m²d)						
		Height		2 cm / 150 cm				
	[n]	2 cm [$\overline{x}$]	150 cm [$\overline{x}$]	Quotient [$\overline{x}$]	Quotient [x_{min}]	Month [x_{min}]	Quotient [x_{max}]	Month [x_{max}]
235-3	8	0.48	0.09	5.33	1.4	Jun 98	8.6	Feb 99
Central	8	2.40	0.06	40.00	13.7	Aug 98	167,0	Feb 99
82-3	6	1.56	0.11	14.18	3.5	Aug 98	62,0	Feb 99
82-25	8	0.58	0.08	7.25	2.7	Aug 98	15.4	Sep 98
82-100	5	0.46	0.10	4.60	2,0	Jun 98	7.9	Sep 98
82-300	2	0.26	0.07	3.71	3,0	-	4.1	-

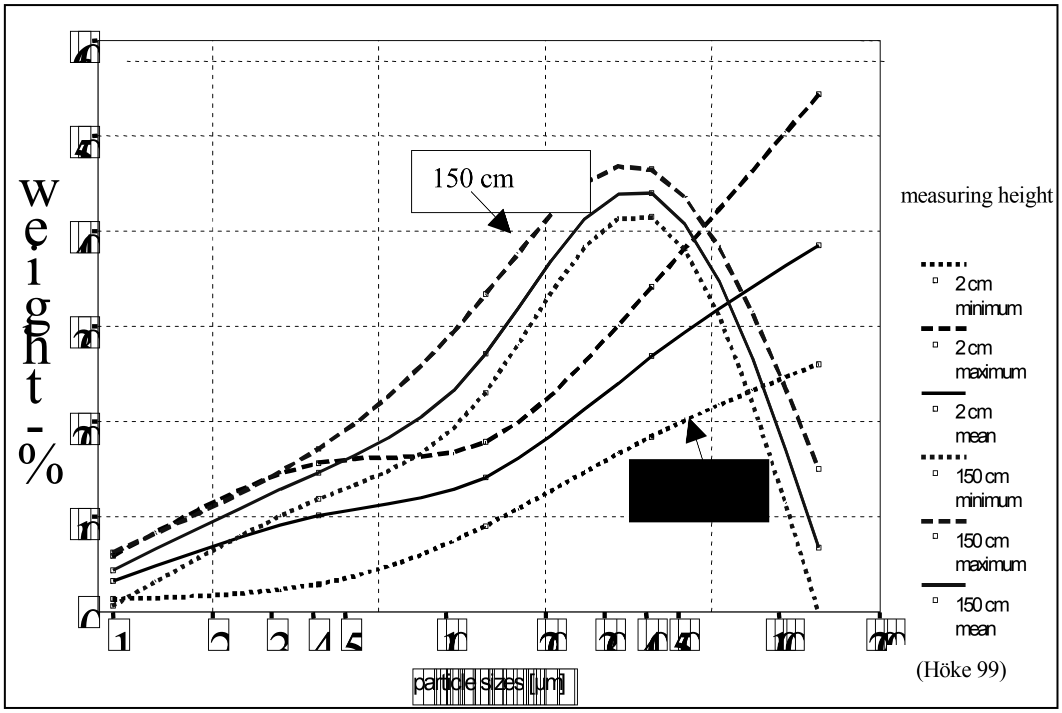


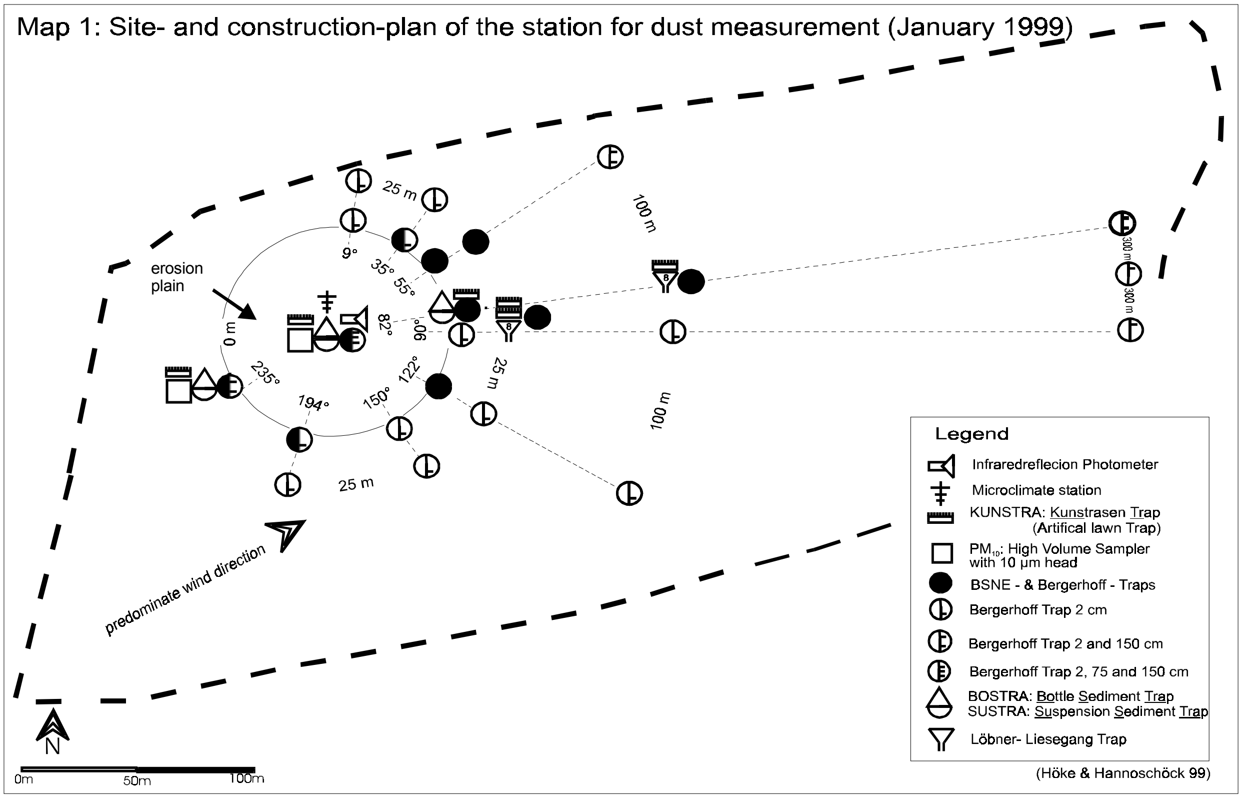
Figure 1: Particle size distribution of the dust precipitation 2 and 150 cm above the ground.

Flux rates

The SUSTRA- and the BSNE traps have collected material in the previous measurement period in spite of the low dust masses. The BSNE traps show vertical gradients in the collected masses. Both traps show clear differences of the trapped masses in comparison to the 235-3, central and the leeside sites, but the values are not yet reasonably evaluated. With the BOSTRA- traps it is not possible to measure low dust concentrations.

SUMMARY AND CONCLUSION

In the previous measurement period there was no periods of time with erosive weather conditions. So, it cannot be said, whether the release of noxious substances by wind is a serious danger under central European climatic conditions. The previous investigations point out, that the measurement of a real dust input in the soil is an important problem on all sites because of rain splash erosion. Collectors, which differ between the dry and wet precipitation, are too expensive for an extensive use.



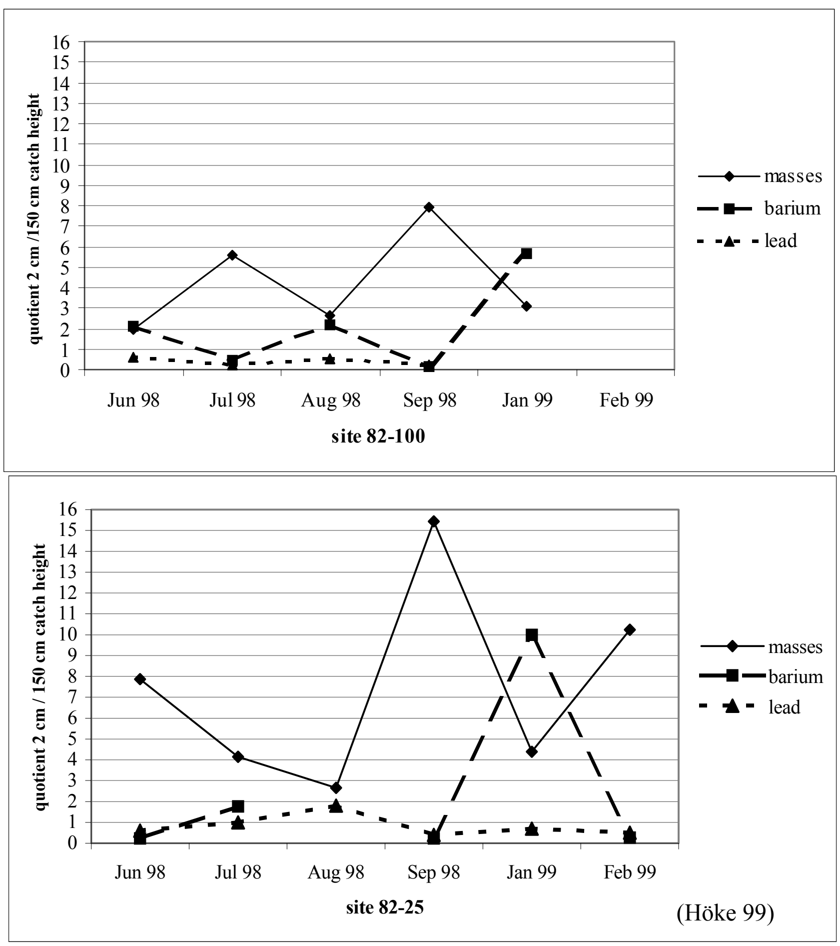
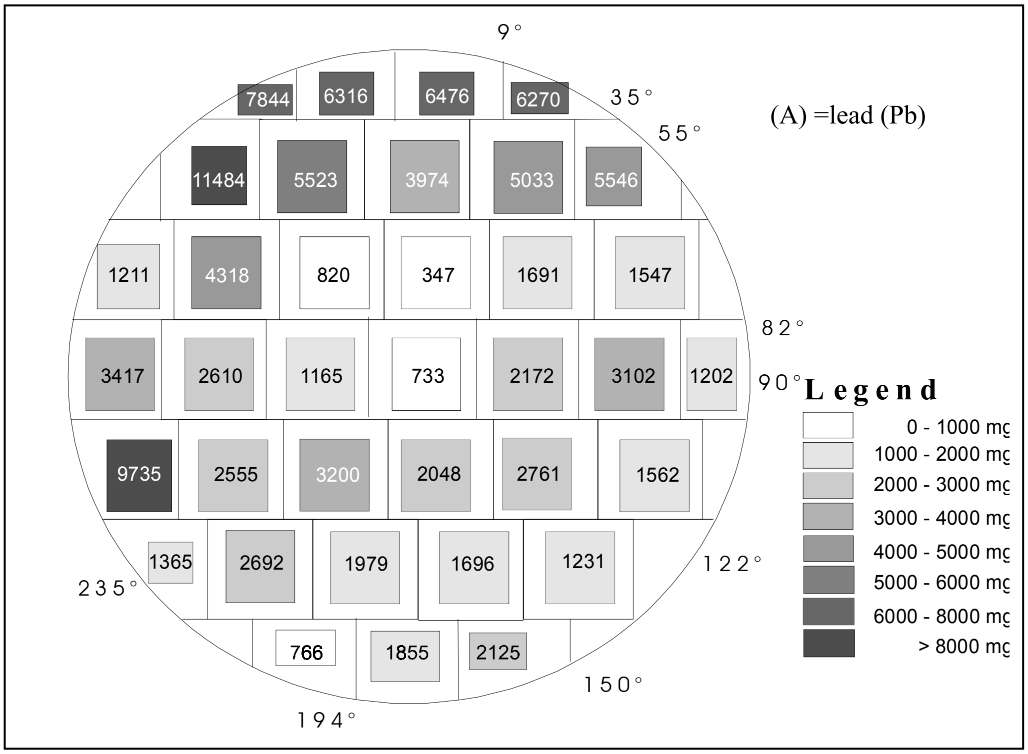
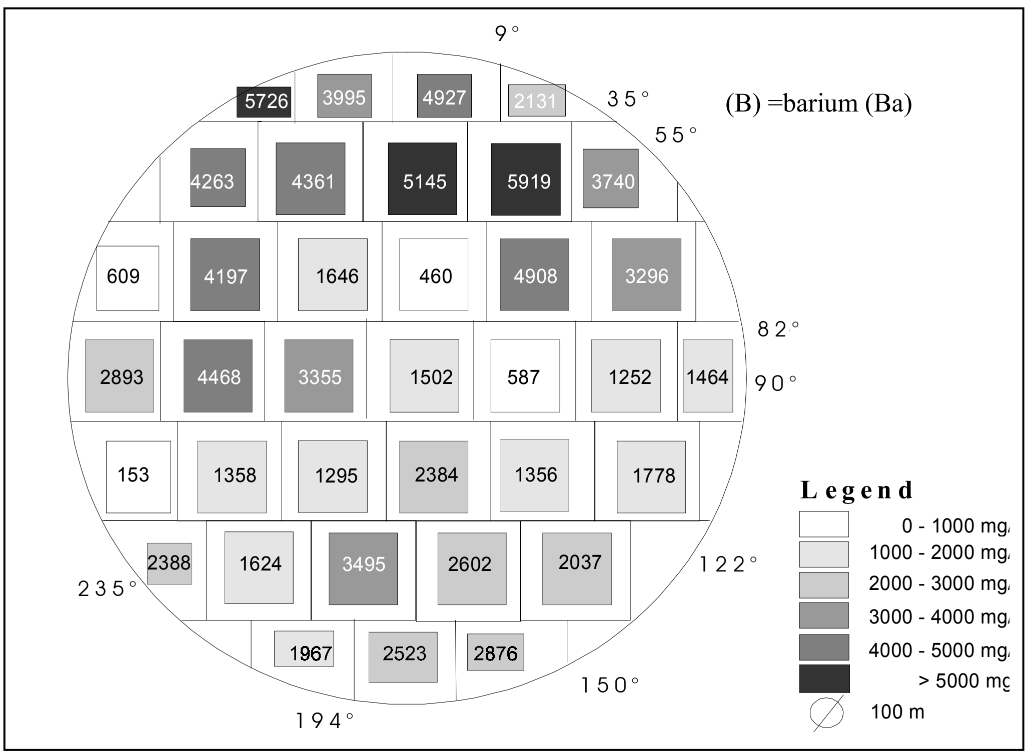


Figure 2: Dust precipitation quotients between 2 and 150 cm catch height for the masses, barium and lead on two sites.

Map 2: Distribution of lead (A) and barium (B) in the surface layer from the erosion plain.





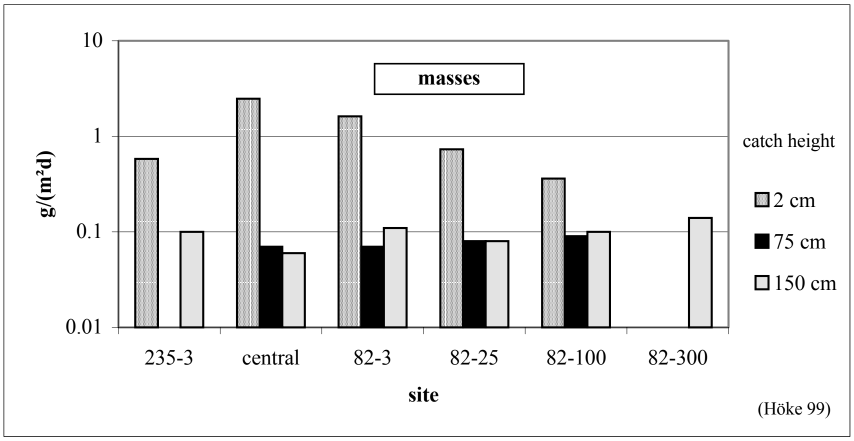


Figure 3a: Mean mass precipitation (Jun 98 – Feb 99) in 3 heights above the ground and in different distances to the erosion plain (Höke 99).

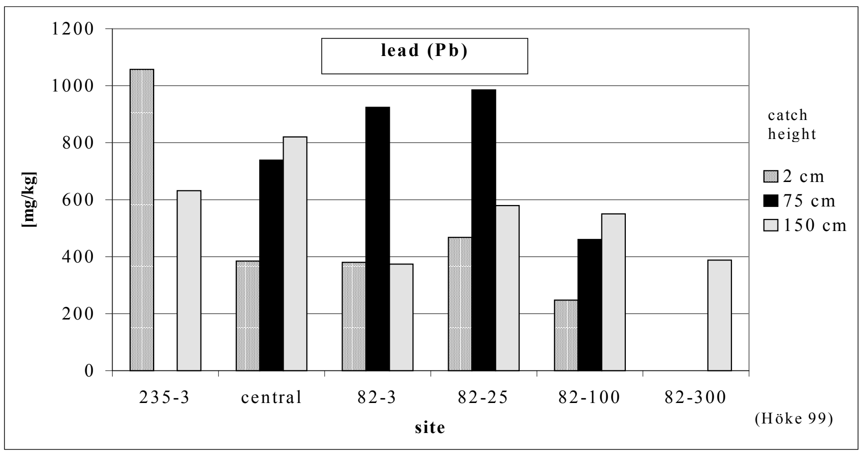


Figure 3b: Mean lead contents (Jun 98 – Feb 99) in 3 heights above the ground and in different distances to the erosion plain.

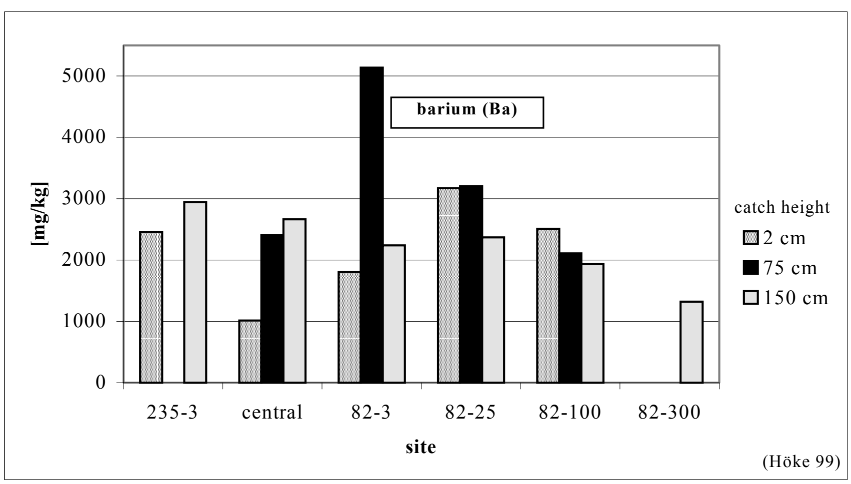


Figure 3c: Mean barium contents (Jun 98 – Feb 99) in 3 heights above the ground and in different distances to the erosion plain.

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