1 INTRODUCTION

1.1 History

From the beginning of the Industrial Revolution the river Meuse has been used as a drain for industrial waste.
During the 19th century the waste was not only liquid but also contained solid waste like coaldust, slag and other mine garbage. This waste came mainly from the industrial areas concentrated around Liège (figure 1.2). In this period very little was known about the harmful effects of these pollutants, so the various industries dumped great quantities of waste into the Meuse.
At present cities and industries almost only discharge partially purified waste products in the Meuse. This effluent still contains heavy metals, salts and organic compounds.
The bulk of the heavy metal pollution originates from polluted riverbanks and spoil heaps that are eroded into and transported by the river Meuse and its tributaries. The waste from the metal industries, which has been dumped for all these years and adsorbed by mud and ground particles, has dispersed throughout the complete river system of the Meuse.
The eroded polluted mud and silt that the river transports is then again deposited on the riverbanks and floodplain of the Meuse. These areas are only inundated at high discharges, which are frequent but irregular, and can cover areas that are at least 1 km wide (see photos appendix 3). The amount of fluviatile deposits (rivermuds with a high heavy metal concentration) is dependent on sedimentation processes. It has been proved that the sedimentation of polluted silt has been going on for about 350 years and it is interesting to compare the difference between the study area shape in 1866 and its shape now (Kuijper, 1867) (see appendix 2).

1.2 Area Description

The study area is situated west of the city Stein and south of the village Urmond in South-Limburg, the Netherlands. The area is about 5 km^2 and it is almost totally inundated when the discharge of the Meuse is high (1,500-2,000 m^3/s). The land is mainly used for pasture and to a lesser degree for crops. The roads are almost only situated on dikes and the two villages in the area Meers and Maasband are build on higher grounds. Industrial activities in the area consist of one still functioning pit in the southern part of the area and a purification plant of DSM in the west near the Julianakanaal. Figure 1.1 is a survey of the buildings, industrial areas and important infrastructural works in the study area and the direct surroundings. Figure 1.2 is a survey of the most important cities, mining and industrial areas of South-Limburg and the direct surroundings in Belgium and Germany.

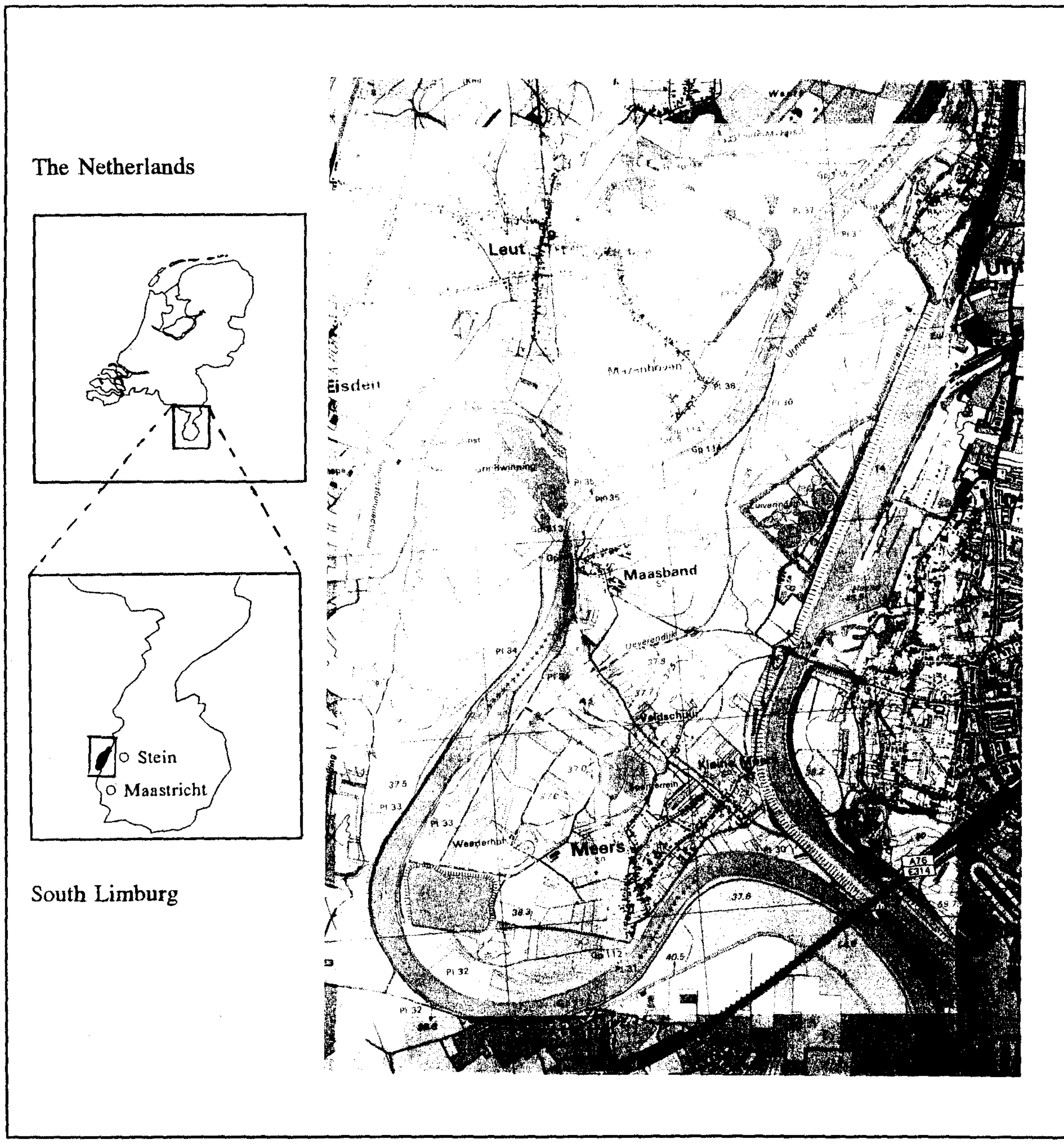

Figure 1.1 Study area

1.3 Problem definition

The areas which are inundated by the Meuse can contain high concentrations of heavy metals. The often serious pollution of those grounds with heavy metals can restrict the sort of landuse. Using crops from those grounds by adults or children can lead to a potential health risk. This report was written to predict those potential risk-areas for the complete Meuse valley.

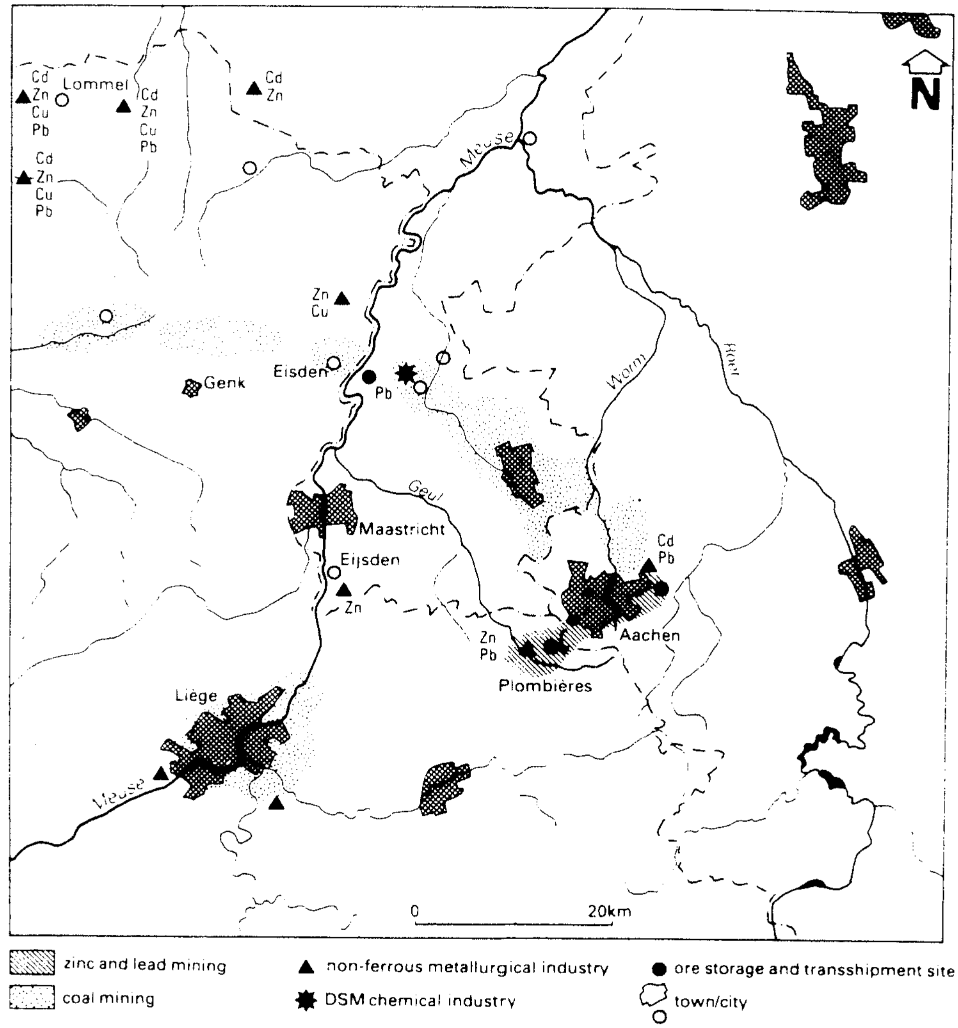

Figure 1.2 **Direct surroundings of the study area**

Goals are stated as follows:

This inquiry has the primary goal to predict the amount and spatial variability of heavy metal-pollution occurring in the inundated grounds of the complete Meuse valley. To realize this, a method has to be designed to map the polluted areas. This method has to have a reasonable quality without making unacceptable costs. In this inquiry it is tried to find a quick standardized method with help of GIS and geostatistics.

A second goal is to predict the actual risks for adults and children when they use crops from areas with high or even toxic heavy metal concentrations. Analysis with computer-programs are used to predict that risk.

2 WORKING METHOD IN FIELD AND LAB

2.1 Introduction

The procedure that was followed can be generally subdivided into three aspects:
1 - actual fieldwork, data collection (§ 2.1)
2 - lab-analysis (§ 2.2)
3 - processing of data and the interpretation of the results (chapter 4 & 5)
In total there were 164 samples collected (see figure 2.1).

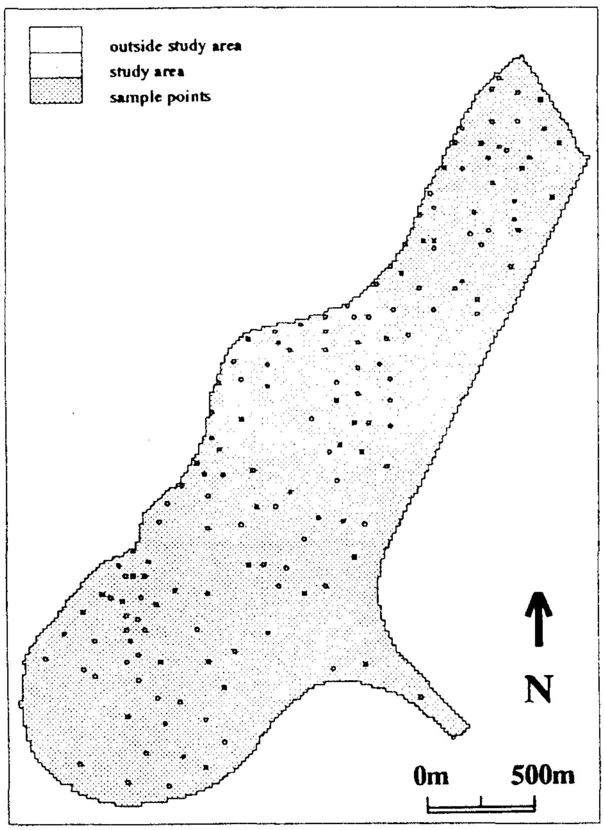

Figure 2.1 Distribution of the sample points

The first part was done in the summer of 1990 in the months may and september, and took a total of six weeks.
The lab analysis was done in november 1990 and took about two weeks.
The data-processing was done in october 1991 - january 1992 and november 1992 - march 1993.

2.2 Fieldwork

The main goals set before the beginning of the actual fieldwork were the obtaining of:

- a precise map containing altitudes
- a table with the concentrations of 4 heavy metals (Cu, Cd, Zn, Pb) at least 175 points, equally spread over the entire area
- a landuse map
- a geomorphologic map (especially with dikes and depressions)

To gain some insight in the area, the landuse-map was made first. This was done by bike which is the best and quickest way to map areas with a scale like the investigated area. There was differentiated between the following landuses:

Agriculture, subdivided in:
- Meadowland (Ah)
- Beets (Ab)
- Grain (Ag)
- Maize (Am)
- Potatoes (Aa)

Pasture (W)

Fruit growing, subdivided in:
- Low fruit trees (Fl)
- High fruit trees (Fh)
- Fruit trees in pasture (FW)

Woods (B)

Vegetable garden/horticulture (Tb)

Other Areas (villages, sports field etc)

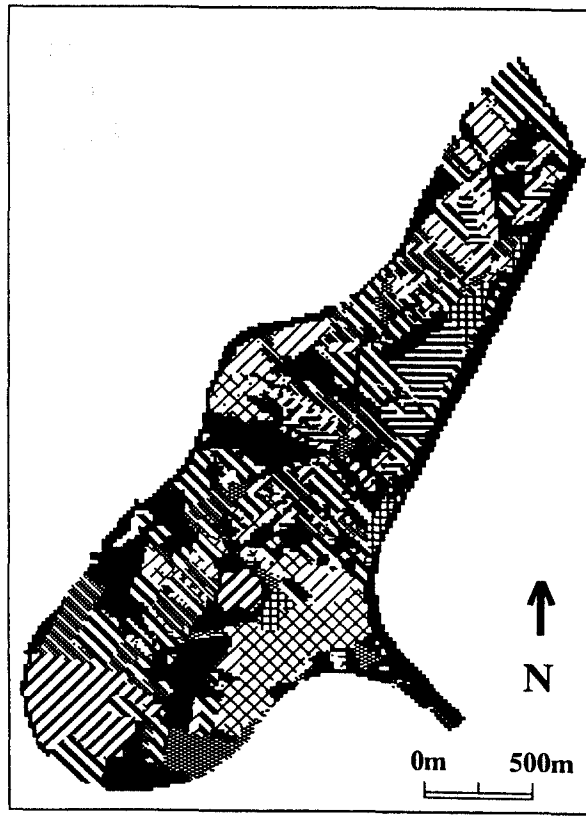

Figure 2.2 Landuse map of the study area

Special attention was given to the vegetable gardens. Good mapping of them was necessary in connection with the potential/actual exposure to humans, eating from their own vegetable gardens.
The landuse-mapping was also done to see if there would be some relations with the the heavy metal concentrations that were measured in the particularly areas.

The making of the geomorphological map was done at the same time. Important for the investigation was the occurrence of dikes and depressions (usually old river-channels) because they determined the watercourses, which on their turn are the determining factor for the deposition of polluted silt and mud. The occurrence of sand and gravel-pits was also important because they sometimes functioned as a watercourse for other areas.

The next step was to obtain the altitudes of approximately 250 points in the area to get a good altitude-map. Especially the dikes and depressions were measured extensively and

special attention was given to the lowest points on the dikes because they function as bottlenecks to the incoming water. The water must first pass these bottlenecks before inundating the larger area behind it.
A topological map of the Netherlands (1:10,000), which already consisted of a large number of altitudes, was used as a base. The known altitudes were starting points for obtaining new values.
The work was done with a levelling instrument (for measuring altitudes) and a three meter high levelling-staff. The area generally declines from 40 to 32 meter +NAP from south to north over a length of 5 km., so just some deep depressions gave some trouble measuring. The measuring usually was done in series of 3-7, starting at a point where the altitude was known. In areas with a lot of relief, more measurements were done, and vice versa.

The last aspect of the fieldwork consisted of the collection of soil samples. More samples were taken from frequently inundated areas because variation was expected to be higher there.
To create a map showing the places where a sample was to be taken the raw RWS inundation-frequency-map dating from 1977 (appendix 4) was corrected using the newly made altitude map and geomorphological map. Four inundation classes were recognized. The first class (most inundated) was sampled most:
1st cl. - sampled on random stratified raster of 100 m.
2nd cl. - sampled on random stratified raster of 150 m.
3rd cl. - sampled on random stratified raster of 250 m.
4th cl. - sampled on random stratified raster of 500 m.
A map of the area containing the new flooding frequency classes was gridded in respectively 100, 150, 250 and 500 m. With an ordinary pocket calculator random values for x- and y-axis were calculated. This resulted in a random-stratified network-map which functioned as the guide for sampling.
The actual collection of ground samples was done by taking a small amount of ground at approximately 10 cm. depth at 10 places lying in a radius of 10 meters. This resulted in a sample of approximately 2-3 kg. per site. A total of 164 samples were taken. These also included 4 representative spots were every 30 cm. was sampled down to a depth of 120 cm.
This was done to gain some insight into the vertical profile of the different inundation frequency classes. Usually samples were taken on salient points in the landscape such as depressions or elevated points.
Because of the (semi-)random character of the sample-taking the corresponding landuse of the visited points was not known beforehand. The special interest in vegetable gardens, which usually are very small, was however neglected in this way. That is why some extra points were located in vegetable gardens.

While taking the samples some other features were noted:
- colour throughout the profile (1.40 meters)
- lime content throughout the profile
- texture throughout the profile
- coaldust and slag throughout the profile
- geomorphologic features at the sample point

Distinguished were (for exact descriptions of the distinctions see Berendsen, 1987):

Texture	Colour	Lime content
loamy sand (LS)	dark grey	<0.5%
sandy loam (SL)	grey	0.5-1.5%
Loam (L)	dark brown	>1.5%
Silt Loam (SiL)	middle brown	
Silt (Si)	light brown	
Sandy Clay Loam (SCL)		
Clay Loam (CL)		
Silty Clay Loam (SiCL)		
Sandy Clay (SC)		
Silty Clay (SiC)		
Clay (C)		

2.3 Lab-analysis

The values for the four heavy metals were obtained by using the standard-procedure at the physical geography-lab of the University of Utrecht. A total of 184 samples were analyzed. Of those 184 (164 + 5*4 depth) samples, four sample-points consisted of four samples taken every 30 cm. down to 120 cm.

The first two characteristics that were determined are:
* moisture content
* the amount of organic material

Both values were used to determine the heavy metal concentration of the sample.
The moisture content is obtained by weighing out 5.000-10.000 gram of soil, placing this for 24 hours in a stove at a temperature of 105 °C. The sample is then weighed again and the following formulas are used to calculate the loss of moisture:

$$\text{moisture content (\%)} = \frac{g'}{(g-g')} * 100$$

$$\text{moisture correction} = \frac{100}{100 + \text{moisture content (\%)}}$$

where: g = weighed out soil
g' = difference between samples before and after 24 hours in the oven

The moisture correction factor (ranging between 0-1) is used to obtain the correct weight of samples for the calculation of the heavy metal concentration.
The amount of organic material present in samples is determined with a similar method. First the sample (5.000-10.000 gram) is weighed. It is then placed in an oven at 850 °C for four hours. The loss of organic material is calculated by:

$$\text{organic-material loss (\%)} = \frac{(G*v) - G'}{(G*v)} * 100$$

where: G = initial weighed amount of ground
G' = weight of sample after it has been in the stove

v = moisture correction
Both methods are widely used and fairly simple.

The concentration of heavy metals is determined with a test that uses 25% nitric acid (HNO_3).
First 1 gram of the sample is put into a teflon capsule and 8 ml. 25% HNO_3 is added. The teflon capsule is then heated to 100 °C for 2 hours. The sample is then checked to ensure that the moisture loss is kept within a range of 1-2%. After cooling, 32 ml. of distilled water is added to the sample. This combination is centrifuged for 15 minutes and the atomic absorption spectroscopy-method is used to obtain the concentrations of lead, copper, cadmium and zinc in the effluent.
The principle of adsorption- and emission spectroscopy is to use high temperatures to separate elements into atoms so that the atoms can the be counted.