Prediction of Distribution and Intensity of Hydrocarbon Contamination using GIS

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Abstract

CONTAMINATED INDUSTRIAL PLOTS are commonplace in a modern society. Hydrocarbon contamination has a widespread effect on animals and plants depending on the urban ecosystems and their resources. Despite the history of petroleum use, the research band of the field has been relatively narrow and has concentrated on heavy metal contamination.

The aim of the thesis is to create a simplified method to predict the distribution and intensity of hydrocarbon contaminations that could be utilised by people working in the related industry or by officials.

The prediction of the distribution and intensity of hydrocarbon contamination in the soil using geographic information systems is studied using available public sector remediation reports. A total of 19 reports are inspected and information within them is transferred into a computer software.

The major factor affecting hydrocarbon contamination values is the distance from a contamination point source. Results show there is a possibility to create a simplified prediction model based on a few available factors, such as the distance from the source and the field test results. The accuracy of such a model is sufficient for day-to-day based operations of the industry and officials.

The study suggests that companies and officials working with hydrocarbon contaminated soil should implement in geographic information systems to the planning of contaminated environments. The study recommends greater emphasis on quality control to provide meaningful data for future studies.

Tiivistelmä

PILAANTUNEET MAA-ALUEET OVAT yleinen ongelma nyky-yhteiskunnassa. Hiilivedyillä on haitallinen vaikutus kaupunkiekosysteemien luonnonvaroista riippuvaisiin eläimiin ja kasveihin. Polttonesteiden pitkään jatkuneesta käytöstä huolimatta pilaantuneiden maa-alueiden tieteellinen tutkiminen on pääasiassa keskittynyt raskasmetallien haittavaikutusten tutkintaan.

Tämän lopputyön tarkoitus on luoda yksinkertainen menetelmä hiilivedyillä pilaantuneiden maa-alueiden laajuuden sekä voimakkuuden ennustamiseen. Menetelmän tulee olla myös sellainen, että sitä voisivat käyttää sekä alalla toimivat yritykset että viranomaiset.

Hiilivedyillä pilaantuneen maa-alueen laajuuden ja voimakkuuden ennustamista on tutkittu paikkatietojärjestelmän avulla. Aineistona käytettiin 19:ää julkisen sektorin tilaamaa kunnostusraporttia.

Merkittävin hiilivetysaastumaan vaikuttava tekijä on etäisyys saastuman pistelähteestä. Tulokset osoittavat, että yksinkertaistettu ennustamismenetelmä on mahdollista luoda vain muutaman eri tekijän avulla. Menetelmän tarkkuus on tarpeeksi suuri, jotta sitä voidaan hyödyntää alan jokapäiväisessä työelämässä.

Tutkimuksen perusteella suositellaan, että alalla toimivat yritykset sekä niitä valvovat viranomaiset käyttäisivät paikkatietojärjestelmiä suunnitellessaan hiilivedyillä pilaantuneiden maa-alueiden kunnostamista. Laadunvalvontaa tulisi kehittää enemmän siihen suuntaan, että syntyvä aineisto olisi käyttökelpoista tulevia tutkimuksia varten.

Preface

I WAS INTRODUCED to the field of soil restoration by accident when I noticed the growing interest among the Finnish employers towards people with working experience in the field in question. This happened in the autumn of 2011. As an Environmental Expert intern at a Finnish company specialised in restoration of contaminated soil and run by engineers for engineers, I could not help being exposed to a bit of engineers' type of thinking.

Much of my work were concentrated to sampling on the field, analysing the samples collected and interpreting the research results. After a while I started thinking that there must be a way of integrating some of my knowledge with their expertise to produce something that would be beneficial to both the employees and the employers.

I analysed the steps connected to a restoration project and noticed that the most tedious phase of a project was the planning phase when many kinds of estimates were necessary in order to produce a viable budget, plot future sampling points, and the like.

They say one should seize the day when it arrives. This is my humble attempt to do so.

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Helsinki, Finland

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List of Abbreviations and Methology

DEM - Digital Elevation Model

GIS - Geographic Information Systems

EU - European Union

IDW - Inverse Distance Weighted

ISO 16703:2004 - International Organization for Standardization publication *Soil quality - Determination of content of hydrocarbon in the range* C_{10} *to* C_{40} *by gas chromatography*

LC_{50} - Lethal Concentration, 50%

LiDAR - Light Detection and Ranging

LPG - Liquefied Petroleum Gas

SW-846 - USEPA publication *Methods for Evaluating Solid Waste, Physical/Chemical Methods*

Threshold value - Value after exceeded soil is considered contaminated

TPH - Total Petroleum Hydrocarbon

USEPA - The United States Environmental Protection Agency

WWTP - Wastewater Treatment Plant

Unified Soil Classification System (USCS):
C - Clay
G - Gravel
M - Silt
S - Sand

1 Introduction

1.1.1 Background

UNINTENTIONAL OR INTENTIONAL release of hydrocarbon products into the ecosystems is a problem within various European Union (EU) countries. Between the years 2003 and 2009, altogether 19 petroleum spills of over 100 tonnes occurred within the EU. Out of these six were over 700 tonnes. Although the use of petroleum products has grown by 0.22 percent annually from the year 2000 to 2010[1], the long-term statistics show a declining trend in large scale pipeline and maritime spills.

However, a single spill can still have a major local effect as shown in the 2009 Plaine-de-la-Crau pipeline fracture; as much as 73,000 tonnes of contaminated soil had to be removed to neutralise the effects of between 4,000 and 5,000 tonnes of petroleum. Two-thirds of the excavated soil was transported to a biological treatment centre for processing, the rest was stored.[2] One year after the accident, the company operating the pipeline estimated an expenditure of 50 million euro caused by the leak and 'tens of millions devoted to environmental restoration'.[3]

The European Environment Agency (EEA) estimates there were some 242,000 sites polluted with various contaminants in the EU area in 2006. Another 2,925,000 sites were regarded as active and potentially polluting. These are active sites left unstudied until termination of their operations.[4]

1.1.2 Effects of Hydrocarbons on Organisms

THE USE OF petroleum differs from the use of other hazardous chemicals in the way that its distribution network is highly developed and the product can be purchased without a license or training. However, the LC_{50} of petroleum for aquatic organism has been determined to be as low as 0.62 mg/l. The number indicates a concentration which will kill 50 % of the organisms exposed to it.

Economically important fish and shrimp species seem to be more affected by hydrocarbon contamination than, for example, mussels and starfishes.[5] It has been estimated that one third of the population of juvenile pink salmon (*Oncorhynchus gorbuscha*) was lost the next year after the Exxon Valdez oil spill off the coast of Alaska in 1989[6].

Hydrocarbons can come into contact with organisms either through inhalation, dermal or oral exposure. The lighter fractions have a higher potential to be absorbed by an organism through all means of contact compared to the heavier fractions. Depending on the length of the carbon chain, most of the fractions leave the body through secretion of urine in a few consecutive days. However, some will concentrate to the fatty tissues and take a longer time to leave the organism.[7]

1.1.3 Extraction of Hydrocarbons

THERE ARE TWO commonly used methods to extract unwanted hydrocarbons from polluted soil: mechanical remediation and bioremediation. The first one is a traditional method used in developed countries such as Finland, the United Kingdom and Canada. The contaminated soil is excavated and transported to specialised landfill or a treatment centre with an environmental permit to treat the pollutants.[8,9,10]

The latter technique utilises various micro-organisms to consume the hydrocarbon *in situ*. Bacteria and fungi metabolize and convert the hydrocarbons into carbon dioxide and/or other dead-end products. The particular species of micro-organism must be chosen based on the special needs of the remediation site in question. Much study has been done with the fungi belonging to the genus *Phanerochaete* due to their natural ability to degrate lignin into carbon dioxide. Using micro-organisms is less labour-intensive than excavation as the organisms can be spread by hand by a single person instead of the need to bring an entire excavation crew. However, the operations are limited by several factors regarding the growth and metabolisms of the organism used to convert the hydrocarbons. This kind of limitation, for example, is low outside temperatures that the remediated location might experience in the future of the remediation.[11,12]

1.2 The Situation in Finland

BEFORE THE BEGINNING of the 1970s, there were no contingency plans nor resources in case of a land or maritime petroleum spill within Finnish territory. The situation improved only after The Ministry of Trade and Industry issued sufficient funds to found and equip oil response bases in all major Finnish coastal cities by the end of 1971. The first Finnish manual on how to treat petroleum spills was published in 1970. The costs of the remediation were paid by the regional government.[13] The Environmental Act of 1994 introduced the concept of tort liability in such cases, where the normal operations of a company could result in soil contamination through a spill.[14]

In a 2011 ruling the Finnish Supreme Court deemed the buyer of a contaminated property is not liable to pay for the remediation of the contamined soil, but liability lies with the operator even if the operator had not been the seller of the plot but merely the governing body of a national chain.[15]

The remediation of disused industrial plots was first started in Finland during the 1980s. The SOILI program is intended to target petroleum service stations and was launched as a 10-year program in 1996 by the Finnish Petroleum Federation. However, due to the limited resources and the large number of target sites, a new program, called JASKA, has been launched and is expected to run until the end of 2014.

The program follows the legend of the previous SOILI in its essential parts.[16]

As of December 2012, a total of 1,102 applications for SOILI remediation had been posted to various Finnish Centres for Economic Development, Transport and the Environment. Of these sites, 771 (70 % of all) had been examined and further 383 (35 %) had been remediated.[17]

The Finnish legislation dictates binding threshold and guideline values for the maximum amount of petroleum hydrocarbons in the soil, after which action must be taken in order to remediate the soil before any further use of the land. The threshold value for overall petroleum hydrocarbon fractions (C_{10}-C_{40}) is set to 300 mg/kg.[18] After exceeding the threshold value, soil is considered to be contaminated if it is situated in a residental area. However, risk assesment can be used to evaluate the true risk to the surrounding environment. The various contamination values set by the Finnish legislation are summarised in Table 1.1.

	Threshold	Lower	Higher value
C_5-C_{10}	-	100	500
C_{10}-C_{21}	-	300	1000
C_{21}-C_{40}	-	600	2000
C_{10}-C_{40}	300	-	-

Table 1.1. Threshold, lower and higher guideline values (mg/kg) according to the Finnish legislation for hydrocarbon contamination.

1.3 Hydrocarbons

HYDROCARBONS ARE MOLECULES composed of hydrogen (H) and carbon (C) atoms. All fossil fuels are essentially hydrocarbons with deviating H:C ratios. The crude oil pumped from the ground is called *petroleum*.

Petroleum contains hundreds of different hydrocarbons, which are distilled using various methods to produce substances with different desired properties for different industries.

Lighter hydrocarbon fractions can be manipulated using the Fischer–Tropsch process to produce more complex and heavier hydrocarbons.[19] The most typical crude oil products are presented in Table 1.2.

1.4 Geographic Information Systems

SINCE THE TRANSITION from labour-intensive manual spatial analysis to computer-based analysis, geographic information systems (GIS) have been increasingly used in new field of science. Computer-based GIS was developed in Canada during the 1960s. Its original purpose was to create thematic maps for the govermental organizations.[20]

Geographic information systems can be utilized in any kind of work involving spatial values, such as banking and financial services, military and urban planning.[21] It enables handling a vast amount of different kinds of information at the same time or separately from each other. This translates to time-savings compared to the use of non-GIS techniques and will provide a useful view to the mechanisms behind a trend. The technique is often also used to make risk assessments in the form of probability predictions.

However, e.g. Maguire has critised the use of low resolution data as a base for trend predictions and decision-making.[23]

1.5 Literature Review

THE MIGRATION OF hydrocarbons through the layers of soil has been studied since the end of the 1980s. Abdul identified some of the preferred subsurface migration pathways of leaked petroleum products.[24] However, the interest in using geographic information systems (GIS) in soil contamination study has been focusing on the modelling of heavy metal concentrations in urban environments. Much of recent studies in this field has been done in the People's Republic of China. For example, Li et al. and Lee et al. studied the regional variations of metal contamination using GIS in a highly urbanized area of Hong Kong in 2004 and 2006. They discovered that GIS spatial analysis was a useful tool to examine and evaluate the spread of a contaminant over an area of several kilometers.[25,26]

The 2007 guide published by the European Union's Institute for Environment and Sustainability treats soil pollution as concentrations of heavy metals but makes no direct references to hydrocarbon pollution.[27]

The United States Environmental Protection Agency (USEPA) studied the suitability of the Dexsil® PetroFLAG™ system for measuring total petroleum hydrocarbons (TPH) in contaminated soil.[28] Out of the tested seven field kits, PetroFLAG™ performed well regarding the costs per tested sample and the degree of accuracy when compared to SW-846 (Method 8015B) laboratory results. Regression models for converting PetroFLAG™ sample results to laboratory reference results showed a high square of the correlation coefficient when the samples in question were either contaminated with diesel, weathered diesel

Boiling Point Range (°C)		Product
<30	C_1-C_4	Natural gas (methane, ethane, propane, butane, LPG)
30-200	C_4-C_{12}	Petroleum ether, ligroin, straight-run gasoline
200-300	C_{12}-C_{15}	Kerosene, heating oil
300-400	C_{15}-C_{25}	Gas oil, diesel fuel, lubricating oil, waxes
>400	>C_{25}	Residual oil, asphalt, tar

Table 1.2. Fractions of typical distillation of crude petroleum.[22]

or gasoline in medium-sand, but low when the medium was sandy clay or silty sand and gravel.

Clayton et al. found that most analytical instruments designed to measure the different components of hydrocarbons show a strong linear correlation when the different measurements are plotted against each other.[29]

2 Aim and Objective

THE AIM OF this study is to assess whether it is possible to identify factors contributing to the distribution of hydrocarbons in a soil after a spill using statistical methods, and use the findings to create a GIS model to predict the spread of the contamination and its intensity in any given location with reasonable accuracy.

The need of such a model is unquestionable in the future as more and more contaminated sites come under remediation. The aim is not to create a comprehensive guide to predict contaminations, but to try to create simplified and easy-to-understand methods for the industry.

The questions the study intends to answer are related to a number of quantitive values. How much is the loss in intensity of a hydrocarbon contamination when moving away from a point source? How many factors contribute to the distribution of the contamination?

GIS was a natural choice as a tool as it needs to handle and analyse hundreds of different samples located in hundreds of different locations, often in a single site. The choice also enabled the use of existing data as a starting point for the study.

3 Data and Methods

3.1 General

THE MATERIAL USED in this thesis was extracted from 19 soil remediation project reports posted by the Finnish companies Golder Associates Oy (hereon Golder), FCG Design and Engineering Ltd (hereon FCG) and Ramboll Finland Oy (hereon Ramboll) between the years 2000 and 2012. The remediation project sites are presented in Table 6.1.

The remediation reports were picked from a pre-screened pool of reports in order to remove such reports where no hydrocarbon contamination measurements were available. Remediation reports with less than five sampling points and/or where the highest sampled point had a petroleum hydrocarbon content less than 300 milligrams per kilogram, were also discarded. The projects were distributed unevenly in Southern and Central Finland with the largest hotspot located in the Greater Helsinki metropolitan area. The reports were provided by the City of Helsinki, VR Group Oy and Pöyry Oyj.

The paper sampling maps were digitized using a flatbead scanner and imported to Esri ArcMap 10 software using the Georeferencing tool. Digital maps were imported to the software as they were. Latitude and longitude of individual data points were then read from the program. Each data point was classified based on its location, altitude from the sea level, vertical depth from the surface, the amount of petroleum hydrocarbons per kilogram of sample, grain size, both the horizontal and the shortest possible distance from a possible point source and whether the sample was analysed with a field test kit or by a laboratory.

Point sources were self-identified based on the known location of disused hydrocarbon storage structures, maps and the history of the site. In such cases where no particular point source could be identified, the sample tested for largest hydrocarbon contamination was chosen to present a point source. Remediation projects with more than one point source were divided into separate sub-projects based on their compass directions from the centre of the project site (e.g. "North").

The horizontal distances were determined using the ArcMap's Point Distance tool and measured from the centre of the known point sources. The shortest possible distances were calculated using the Pythagorean theorem using the horizontal distances and the vertical depths.

The soil samples had been collected by trained sampling personnel before or during remediation projects.

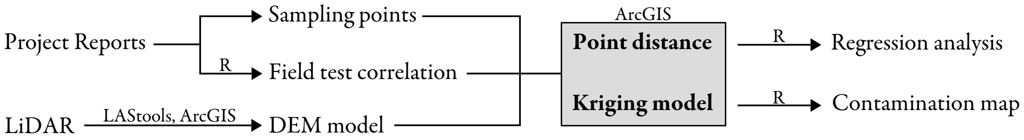
Depending on the project, samples had been collected either using plastic sampling tools or by a subcontractor with a motorised drilling rig under supervision of the sampling personnel. Afterwards the samples were roughly identified based on their estimated grain size. No soil horizon maps were available in any of the remediation projects used.

A total number of 388 field tests were used at the examined projects. 339 of these were PetroFLAG™ and 62 HNU tests. The mean number of field tests used per project was 21.1. Likewise the number of laboratory tests used in the project numbered at 305 tests. The mean number per project was 16.1.

The sampling density was defined by calculating the surface area confined by the sampling points with the Measure an Area tool. The figure was then divided by the number of sampling points. Individual remediation sites were divided into smaller cells. The original sampling density in the studied sites varied from 0.2 to 8.8 points per an are. The median amount was 0.9 points per are.

Historically, two different hydrocarbon field tests have been used in the companies.

Fig. 3.1. A simplied flowchart used as a basis for analysing the projects.



For example, samples taken by FCG between June 1996 and October 2005 were tested using the field test system manufactured by HNU Nordion Ltd Oy.

The system is based on measuring the amount of TPH (C_{10}-C_{40}) on a sample with a color reagent. Its accuracy is limited to approximately 100 mg per kg.[30] Samples taken after October 2005 have been tested using the PetroFLAG™ field test system made by Dexsil® Corporation.

The system uses methanol as a reagent to extract both natural and synthetic hydrocarbons from a soil sample. The extracted fluid is placed on a reader device that gives out the TPH (C_{10}-C_{40}) in milligrams per kg of sample.[31, 32]

It is assumed here that the sampling personnel had been instructed on the proper use of the field test kits based on their user's manuals, but the correction formula for the effect of soil water content when using the PetroFLAG™ system has not been followed.

Likewise, the choice of the PetroFLAG™ analyser response factor, one that is appropriate for the suspected petroleum contaminant at a site, seems to have been often disregarded, and a response factor of seven (for motor oil) is used continuously in the samples tested in the FCG.[33]

The response factor used to analyse a particular sample has not been recorded in any of the available project reports.

The laboratory analyses had been done by three accredited Finnish laboratories, ALS Finland Oy, Novalab Oy and SGS Inspection Services Oy.

ALS uses ISO EN 9377-2 rather than ISO 16703:2004 gas chromatography used by Novalab and SGS as the standard for determinating TPHs. The possible effect or effects of the two different methods on the statistical analyses were ignored due to insufficient data available for a detailed analysis.

Digital elevation models (DEM) were created from light detection and ranging (LiDAR) data supplied free of charge by the National Survey of Finland. The data was imported into ArcGIS via Martin Isenburg's software LAStools. The elevation model was created with ArcGIS's inverse distance weighted (IDW) interpolation algorithm as recommended by Liu et al. 2009.[34] The data has an average of at least 0.5 points per square meter and an elevation accuracy of 15 centimeters or better. The LiDAR data was rendered into DEM using the default IDW settings with a 1 metre grid size.

3.2 Correlation of the Field Results

IT HAS BEEN previously established by USEPA that PetroFLAG™ results show certain bias one way or another when compared to results given by reference laboratories in methods used in the United States of America.[35] However, there were only a single, inadequate reference available on how the PetroFLAG™ results would compare to ISO 16703:2004 results.[36] The relationship between PetroFLAG™ and ISO 16703:2004 analysis results were determined using regression analysis in R-2.15.2 statistical software.

To minimise possible biases, no samples with tested heavy metal contamination were introduced to the sampling. Likewise all samples where the PetroFLAG™ had tested for lower TPHs than the reference were removed as a human error. 17 percent of the original data, which included all the samples where both field and laboratory results were available, had tested for lower TPHs than the reference.

Samples were organised by the amount of hydrocarbons in the sample, the soil texture and the type of petroleum fractions. Multiple recorded soil textures were simplified to two categories: sand and clay. Samples labelled by the sampling personnel as gravel and/or sand were classified as "sand" and samples recorded as silt and/or clay as "clay" according to the classification by VTT Technical Research Centre of Finland.[37] The sample size was 181 analysing pairs. The results are presented in Table 3.1.

The difference between the soil texture and PetroFLAG™ results was statistically significant with a p-value less than 0.05. The relationship in all categories is described most directly by simple linear equations.

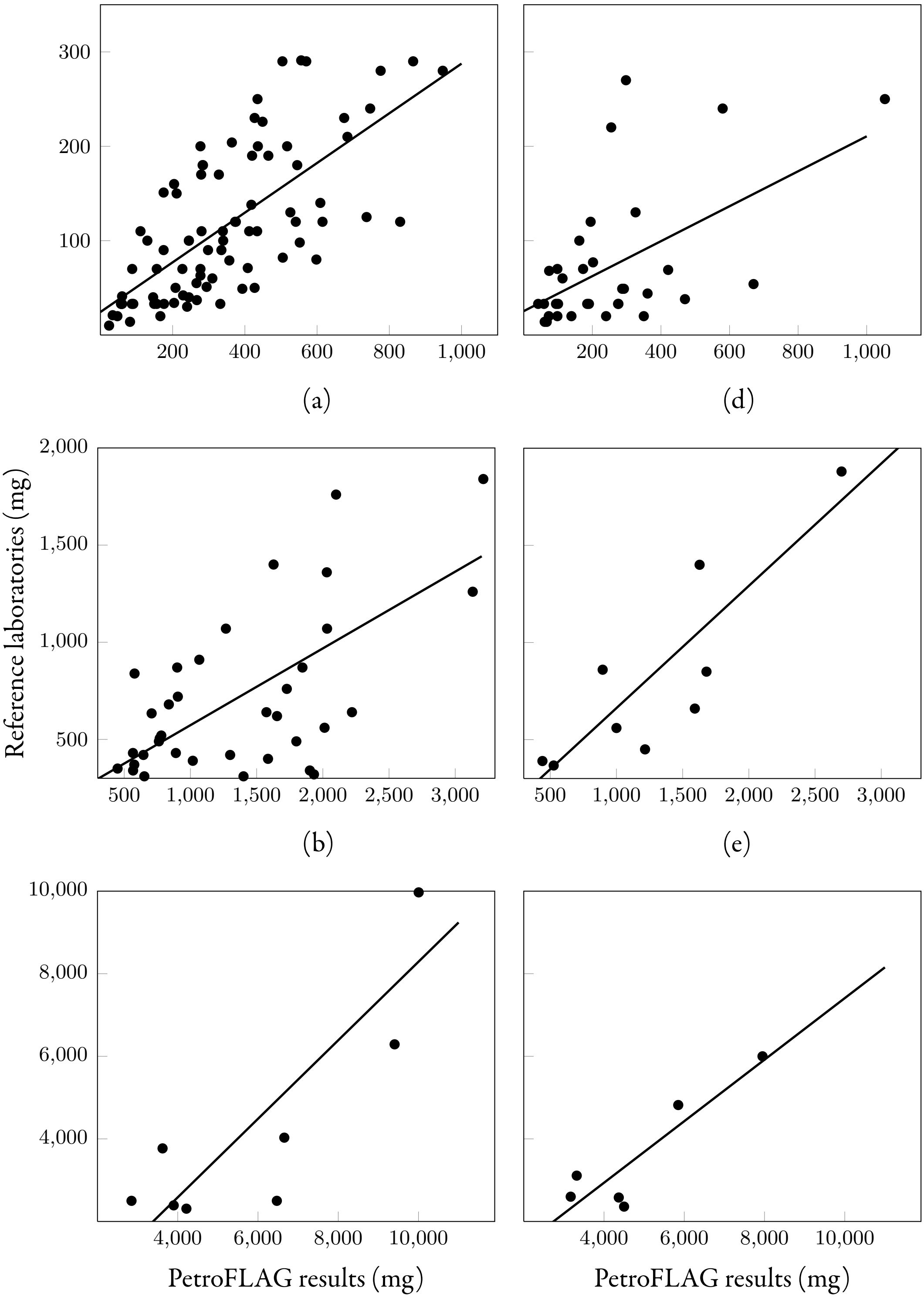
There was no benefit in terms of higher correlation factor when transforming x-axis, y-axis or both axes to natural logarithms for linear regression analysis.

The predictability of the relationship rises with higher contamination values. It can also be observed that the predictability is the lowest with the finest soil texture with no or few contaminants, but rises to par with the coarse results after the amount of contaminants rises over 300 mg.

FOLLOWING PAGE. **Fig 3.2. Distribution of data set points for the correlation analysis. (a) Sand 0-299 mg. (b) Ibid. 300-1999 mg. (c) Ibid. >2000 mg. (d) Clay 0-299 mg. (e) Ibid. 300-2000 mg. (f) Ibid. >2000 mg**

	n	r^2	p-value	
Sand $_{\text{0-299 mg}}$	85	.49	0.000	Y = 0.2632x + 24.3814
Sand $_{\text{300-1999 mg}}$	38	.47	0.000	Y = 0.3951x + 178.1103
Sand $_{\text{>2000 mg}}$	9	.76	0.014	Y = 0.9510x - 1219.6760
Clay $_{\text{0-299 mg}}$	33	.27	0.001	Y = 0.1852x + 25.3583
Clay $_{\text{300-1999 mg}}$	10	.66	0.001	Y = 0.6500x - 33.2600
Clay $_{\text{>2000 mg}}$	6	.76	0.015	Y = 0.7451x - 42.5890

Table 3.1: The relationship between PetroFLAG™ (x) and ISO 16703:2004 (Y) results


300
200
100
200
400
600
800
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1,500
1,000
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Reference laboratories (mg)
500
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2,500
3,000
10,000
8,000
6,000
4,000
4,000
6,000
8,000
10,000
PetroFLAG results (mg)
PetroFLAG results (mg)

(a) (d)

(b) (e)

(c) (f)

4 Results

4.1.1 The Effect of Distance

THE EFFECT OF DISTANCE to the intensity of the soil contamination was analysed using the regression analysis in the R-2.15.2 statistical software. All such sampling points situated higher than the point source as measured from the sea level were exempted from the study. The altitude information was modelled from the LiDAR data with a 0.2 meter contour interval.

The shortest possible distance of the sampling points from a point source varied from 0 to 100 meters, with most of them situated closer than 50 meters from the source. The distances were plotted against the measured and correlated (see Chapter 3.2) soil contamination results for statistical analysis.

The majority out of the 19 remediation sites showed a high degree of correlation between the shortest possible distance and the contamination when fitted into a quadratic equation. In 12 cases out of the 19, between 51 and 98 % of all variation in the contamination could be explained by taking only the variations in the distance from the point source into account.

All sampling sites showed a p-value greater than 0.05 and the square of the correlation coefficient of less than .1 when both contamination and distance scales were converted into logarithmic scales and analysed for regression.

The findings showing the best fits are presented in Table 6.2. It was unexpected to find that all of the equations showed a decreasing soil contamination trend until the values were near or at zero, but increased again for some length of distance. A trend frequently observed was that the contamination sharply dropped after the first tens of meters.

4.1.2 The Effect of Slope

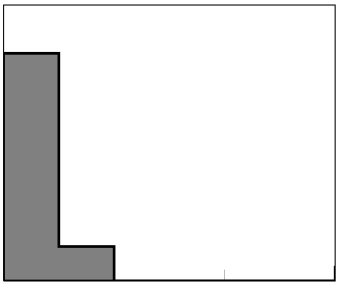
THERE WAS NOT enough surface sampling points to analyse the effects of the slope in relation to the distribution of the contamination.

General observations showed that the contamination immediately below the surface did not follow the 0.2 meter contours created from the LiDAR data.

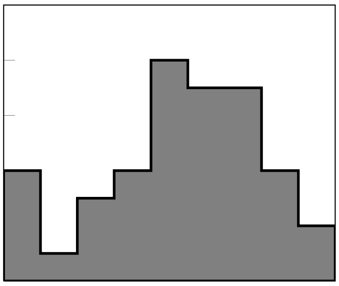
4.2.1 Kriging Interpolation

KRIGING MAPS WERE created from each remediation site to interpolate contamination values between the sampling points. Kriging interpolation was chosen over other available methods mostly based on the available studies on interpolation algorithms as published by, e.g. Wenjiao et al.[38]

Universal Kriging was chosen as the rendering algorithm instead of the Ordinary Kriging due to the observed quadratic trend. The hydrocarbon contamination scales were transformed to logarithms using ArcMap's integrated transformer. The transformed data illustrated more symmetrical histogram than the raw data.

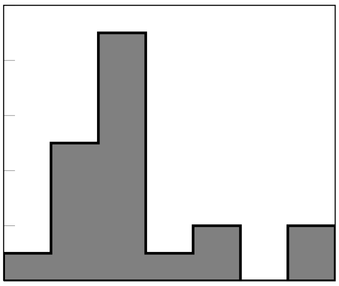


(a)

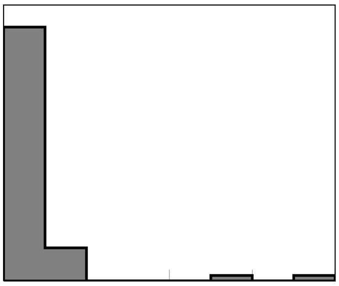


(b)

(c)



(d)



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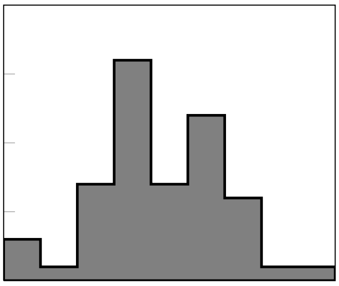

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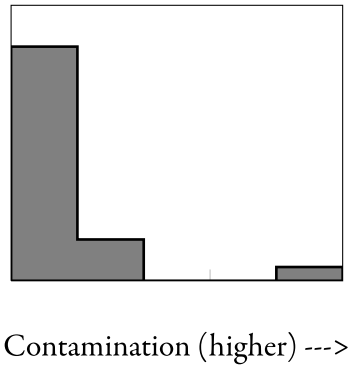
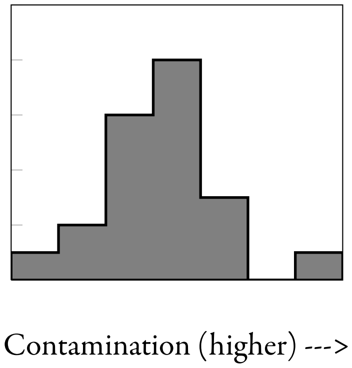


(g)



(h)

PREVIOUS PAGE. **Fig. 4.1. Distribution of hydrocarbon contamination in four remediation sites. (a) & (b) Koulumestari before and after transforming into logarithmic scale. (c) & (d) Kouvola ibid. (e) & (f) Jätkänsaari ibid. (g) & (h) Hermanninranta ibid.**

Maps were rendered in three different scales, 1:250, 1:500 and 1:1500. There was not enough quantative data or the data points were too closely distributed to render an accurate Kriging map for the Höyläämötie, Kiteentie, Kokkola Railway Station, Kukonharju, Muusantori, Ruovedentie, Töölönlahti and Vakkola sites.

The maps showing the respective interpolated maximum contamination values in the rest of the remediation site are presented in the appendix in Fig 6.1.1 - 6.2.3.

The rendered spread patterns of the contaminations are not often circular, but rather oval.

5 Discussion

THE AIM OF this study was to create a process to predict hydrocarbon contamination in the soil with some degree of accuracy. The aim was fulfilled. However, it was acknowledged at the beginning of the study that the data used in this thesis would be insufficient in its accuracy for high-degree accuracy of the distribution of hydrocarbon in the soil. The available data was not created for the study of hydrocarbon distribution in mind but for day-to-day operations of commercial companies.

A major issue was that of lacking documentation in each and every step of the sampling process. As mentioned before, none of the sampling maps used contained clear and accurate coordinates for the sampled soil locations. Here the only option was to use the approximate locations marked on to the sampling maps. When possible, it is the author's opinion that soil samples should be taken right beneath suspected point sources. All additional samples should be taken at the same depth (measured from the sea level) or below as the control sample from the suspected point source.

Regular grid sampling is preferred for Kriging.[39] Minimum surveying costs are naturally preferable in many fields of industry. Hengl and Brus & Heuvelink recommend a strategy where the sampling personnel performs a general survey of the area, and based on the information collected, creates the kriging model. After the locations of the most likely concentrations of contamination have been established, the surveyor proceeds to collect the remaining samples based on the model.[40,41]

The author recommends companies to implement these routines, which would allow the creation of more homogeneous data for research purposes. This requires better understanding of the needs of the research community by the sampling personnel. It may be achieved through greater emphasis on training of the personnel and annual audits of both the personnel and the project reports.

1. Eurostat , 'Consumption of energy', (updated 12 Oct. 2012) <http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy>, accessed 25 November 2012.
2. European Environment Agency (EEA), 'Oil spills', in id., *Mapping the impacts of natural hazards and technological accidents in Europe: An overview of the last decade* (Copenhagen: EEA, 2010) 109.
3. French Ministry for Sustainable Development, Break in a liquid hydrocarbon pipeline; 7 August 2009; Plaine-de-la-Crau, <http://www.aria.developpement-durable.gouv.fr/ressources/fd_36654_plaine_de_la_crau_ang.pdf>, accessed 16 March 2013.
4. EEA, Overview of progress in management of soil contamination in WCE and some SEE countries, (updated 12 Nov. 2009) <http://www.eea.europa.eu/data-and-maps/figures/ds_resolveuid/236B1246-03BA-431D-AD3A-6D3A62F14241>, accessed 29 November 2012.
5. Adam Moles, Sensitivity of ten aquatic species to long-term crude oil exposure, *Bulletin of Environmental Contamination and Toxicology*, 61 (1998): 102-107.
6. Stanley D. Rice, Robert E. Thomas, Ronald Heintz, Alex C. Wertheimer, Michael L. Murphy, Mark G. Carls, Jeffrey W. Short, Adam Moles, 'Synthesis of long-term impacts to pink salmon following the *Exxon Valdez* oil spill: persistence, toxicity, sensitivity, and controversy' (Exxon Valdez Trustee Council): 24.
7. U.S. Department of Health and Human Services, Toxicological Profile for Total Petroleum Hydrocarbons (TPH) (U.S. Department of Health and Human Services, 1999) 104-135.
8. J. Sorvari, R. Antikainen, ML. Kosola, P. Hokkanen, T. Haavisto, Eco-efficiency in contaminated land management in Finland: barriers and development needs, *Journal of Environmental Management*, 5 (2009): 1715-27.
9. The Environment Agency, Dealing with contaminated land in England (Environment Agency, 2002): 8.
10. Eco Canada, Who Will Do the Cleanup? Canadian Labour Requirements for Remediation and Reclamation of Contaminated Sites 2006-2009 (Eco Canada, 2007): 5.
11. G. M. Gadd, Fungi in Bioremediation (Cambridge: Cambridge University Press, 2001): 143-149.
12. Eric. C. Brevik, Lynn C. Burgess, 'Soils and Human Health' (CRC Press, 2013): 99-100.
13. Unto O. Lahtonen, 'Öljyntorjunnan kehitys Suomessa 1968 lähtien 1990-luvulle' [Development of the Oil Spill Response in Finland from 1968 to the 1990s] (Helsinki: Ministry of the Environment, 2004): 70-77
14. Finnish Government, 'Laki ympäristövahinkojen korvaamisesta' [Act on Compensation for Environmental Damage], 1994/737.
15. Ruling of the Finnish Supreme Court [2011] KKO:2011:62
16. Finnish Petroleum Federation, 'The soil remediation programme (soili)', (published online 2012) <http://www.oil.fi/en/federation/soil-remediation-programme-soili>, accessed 18 Nov. 2012
17. 'Soilin historiatietoa' [email to Salla-Riina Hulkkonen], (5 Dec. 2012) <Salla-Riina.Hulkkonen@poyry.com>, accessed 5 Dec. 2012.
18. Finnish Goverment, Government Decree on the Assessment of Soil Contamination and Remediation Needs, 214/2007 English.
19. George A. Olah, Árpád Molnár, Hydrocarbon Chemistry (2nd edn., New Jersey: John Wiley & Sons, 2003): 10.
20. Nick Chrisman, Charting the Unknown: How Computer Mapping at Harvard Became GIS (Esri Press, 2006).
21. Esri, 'What is GIS?', (updated July 2012) <http://www.esri.com/what-is-gis/books>, accessed 6 March 2013.
22. Olah et all. 2003: 10.
23. David Maguire, 'GIS and Science', *GIS Best Practices*, November 2008, 3-8.
24. Abdul S. Abdul, Migration of Petroleum Products Through Sandy Hydrogeologic Systems, *Ground Water*

Monitoring & Remediation, 8/4 (1988): 73-81.

25. Xiangdong Li, Siu-lan Lee, Sze-chung Wong, Wenzhong Shi, Iain Thornton, The study of metal contamination in urban soils of Hong Kong using a GIS-based approach, *Environmental Pollution*, 6 (2004): 113-124.
26. Lee, Siu-lan, Xiangdong Li, Wenzhong Shi, Sharon, Ching-nga Cheung, Thornton, Iain, Metal contamination in urban, suburban, and country park soils of Hong Kong: A study based on GIS and multivariate statistics, *Science of The Total Environment*, 1-3 (2006): 45-61.
27. Tomislav Hengl, A Practical Guide to Geostatistical Mapping of Environmental Variables (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2007): 4.
28. United States Environmental Protection Agency (USEPA), Field Measurement Technologies for Total Petroleum Hydrocarbons in Soil: Dexsil® Corporation PetroFLAG™ System (Washington: Office of Research and Development, 2001).
29. Clayton, J. Clark II., Delfino, Joseph J., 'Correlations between PID and FID Field Analytical Instruments in the Analysis of Soil Contaminated with Diesel Fuel', *Soil and Sediment Contamination*, 12(2) (2003): 156-157.
30. HNU Nordion Oy, 'HNU-kenttätesti' [HNU Field Kit].
31. Dexsil® Corporation, 'PetroFLAG User's Manual', (updated 1 Apr. 2009) <http://www.dexsil.com/uploads/docs/petroflagmanualver.1.rev.1.pdf>, accessed 19 November 2012.
32. K. A. Wright, D. B. Jermstad, 'Evaluation of a Rapid Field Analytical Test Kit for Assessing Hydrocarbon Soil Contamination', Presented at the 'Third International Conference On-Site Analysis' (Jan. 22-25 1996, Houston, TX) <http://www.dexsil.com/uploads/docs/dtr_1502.pdf>, accessed 19 November 2012.
33. Personal communication with Juha Kallio at FCG on 20 Nov. 2012.
34. X. Liu, Z. Zhang, J. Peterson, 'Evaluation of the performance of DEM interpolation algorithms for LiDAR data', in Ostendorf, B., Baldock, P., Bruce, D., Burdett, M. and P. Corcoran (eds.), Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference, Adelaide 2009, Surveying & Spatial Sciences Institute, 771-780.

35 USEPA 2001.

36. Golder Associates, 'Kunnostuksen loppuraportti. Entinen polttonesteiden jakeluasema Mäkelänkatu, 00520 HELSINKI.', remediation report posted to the City of Helsinki, 30 Nov. 2010. The correlation factor in the report had been calculated using Microsoft Excel spreadsheet application without separating the contamination values or the soil texture into separate groups. The square of the correlation coefficient was .28. This is considerably lower than the square of the correlation coefficient of .85 observed in this study.
37. K-H. Korhonen, R. Gardemeister, M. Tammirinne, 'Geotekninen maaluokitus' [Geotechnical soil classification] (Espoo: VTT Technical Research Centre of Finland, 1974) 10.
38. Wenjiao Shi, Jiyuan Liu, Zhengping Du, Yinjun Song, Chuanfa Chen, Tianxiang Yue. Surface modelling of soil pH, *Geoderma*, 1-2 (2009): 113-119.
39. Hengl 2007: 45.
40. Dick J. Brus, Gerard B.M. Heuvelink, Optimization of Sample Patterns for Universal Kriging of Environmental Variables, *Geoderma*, 138 (2007): 94.
41. Hengl 2007.

Name	Last use	Municipality	Company	Year	Field test	Soil composition (percentage of samples)
Hermanninranta	Warehouse	Helsinki	FCG	2007	PetroFLAG™	S (66%), C (17%), M (10%), G (7%)
Höyläämöntie	Car repair shop	Helsinki	Golder	2010	PetroFLAG™	S (75%), M (19%), G (6%)
Jätkäsaari	Harbour	Helsinki	FCG	2009	PetroFLAG™	S (54%), G (46%)
Kauppakuja	Petrol station	Nummi-Pusula	FCG	2001	HNU	C (36%), S (35%), M (26%), G (2%)
Kiteentie	Transformer	Järvenpää	FCG	2012	PetroFLAG™	N/A
Kokkola Railway Station	Railway station	Kokkola	Golder	2009	PetroFLAG™	S (73%), M (27%)
Kouvola Railway Station	Railway station	Kouvola	Golder	2007	PetroFLAG™	S (75%), M (23%), C (2%)
Kotka Railway Station	Railway station	Kotka	FCG	2000	HNU	N/A
Koulumestari	Bus garage	Espoo	FCG	2005	PetroFLAG™	S (37%), C (23%), G (22%), M (18%)
Kukonharju	Car repairs shop	Jokioinen	FCG	2006	PetroFLAG™	G (60%), S (40%)
Muusantori	WWTP	Helsinki	FCG	2005	Laboratory only	S (76%), G (22%), M (2%)
Mäkelänkatu	Petrol station	Helsinki	Golder	2010	PetroFLAG™	S (53%), C (41%), G (6%)
Ruovedentie	Petrol station	Ruovesi	FCG	2001	HNU	S (86%), M (8%), G (6%)
Sorinkatu	Gas plant	Tampere	Golder	2008	PetroFLAG™	S (96%), G (4%)
Töölönlahti	N/A	Helsinki	Ramboll	2012	PetroFLAG™	S (93%), G (6%), C (1%)
Vaasa Railway Station	Railway station	Vaasa	Golder	2007	PetroFLAG™	S (66%), G (17%), C (17%)
Vakkola	Petrol station	Askola	FCG	2012	PetroFLAG™	C (67%), S (33%)
Vallilanlaaksonpuisto	Petrol station	Helsinki	Ramboll	2011	PetroFLAG™	C (37%), S (30%), M (19%), G (14%)
Viilarintie	Bus garage	Helsinki	FCG	2003	HNU	S (58%), M (32%), C (10%)

Table 6.1. Summary of the studied remediation project sites.

	n	r^2	p-value	
Hermanninranta	9	.73	0.009	$0.3332x^2 - 50.3872x + 1970.8072$
Höyläämötie	6	.63	0.106	$12.06x^2 - 850.86x + 11588.23$
Jätkäsaari (North)	8	.78	0.010	$1.951x^2 - 183.015x + 4069.518$
Jätkäsaari (South)	6	.98	0.002	$1.152x^2 - 195.951x + 8852.816$
Kauppakuja	7	.96	0.001	$4.792x^2 - 182.337x + 1624.011$
Kiteentie	6	.02	0.356	$-294.5x + 1696.2$
Kokkola Railway Station	5	.95	0.026	$1.194x^2 - 60.139x + 684.632$
Kouvola Railway Station	13	.89	0.000	$21.31x^2 - 1584.04x + 26311.29$
Kotka Railway Station (West)	12	.34	0.064	$43.51x^2 - 582.76x + 2894.21$
Kotka Railway Station (East)	12	.51	0.016	$31.65x^2 - 609.76x + 3242.75$
Koulumestari	8	.81	0.007	$59.66x^2 - 1176.82x + 5848.57$
Kukonharju	5	.58	0.210	$4.567x^2 - 216.955x + 2626.726$
Muusantori	<5	N/A	N/A	N/A
Mäkelänkatu	7	.85	0.010	$0.7745x^2 - 53.5762x + 1218.4373$
Ruovedentie (North)	<5	N/A	N/A	N/A
Ruovedentie (South)	<5	N/A	N/A	N/A
Sorinkatu	9	.67	0.016	$0.208x^2 - 25.329x + 790.109$
Töölönlahti	8	.28	0.187	$4.374x^2 - 242.240x + 3337.897$
Vaasa Railway Station (West)	7	.14	0.220	$-4.579x + 492.224$
Vaasa Railway Station (East)	7	.00	0.283	$-6.717x + 963.412$
Vakkola	9	.29	0.077	$557.7x - 3809.3$
Vallilanlaaksonpuisto	16	.22	0.078	$0.7885x^2 - 68.8565x + 1644.7075$
Viilarintie	10	.00	0.528	$309.8x + 2132.2$

Table 6.2. Summary of the distance regression analyse.

Fig. 6.1.1. Kriging map from the Hermanninranta site.

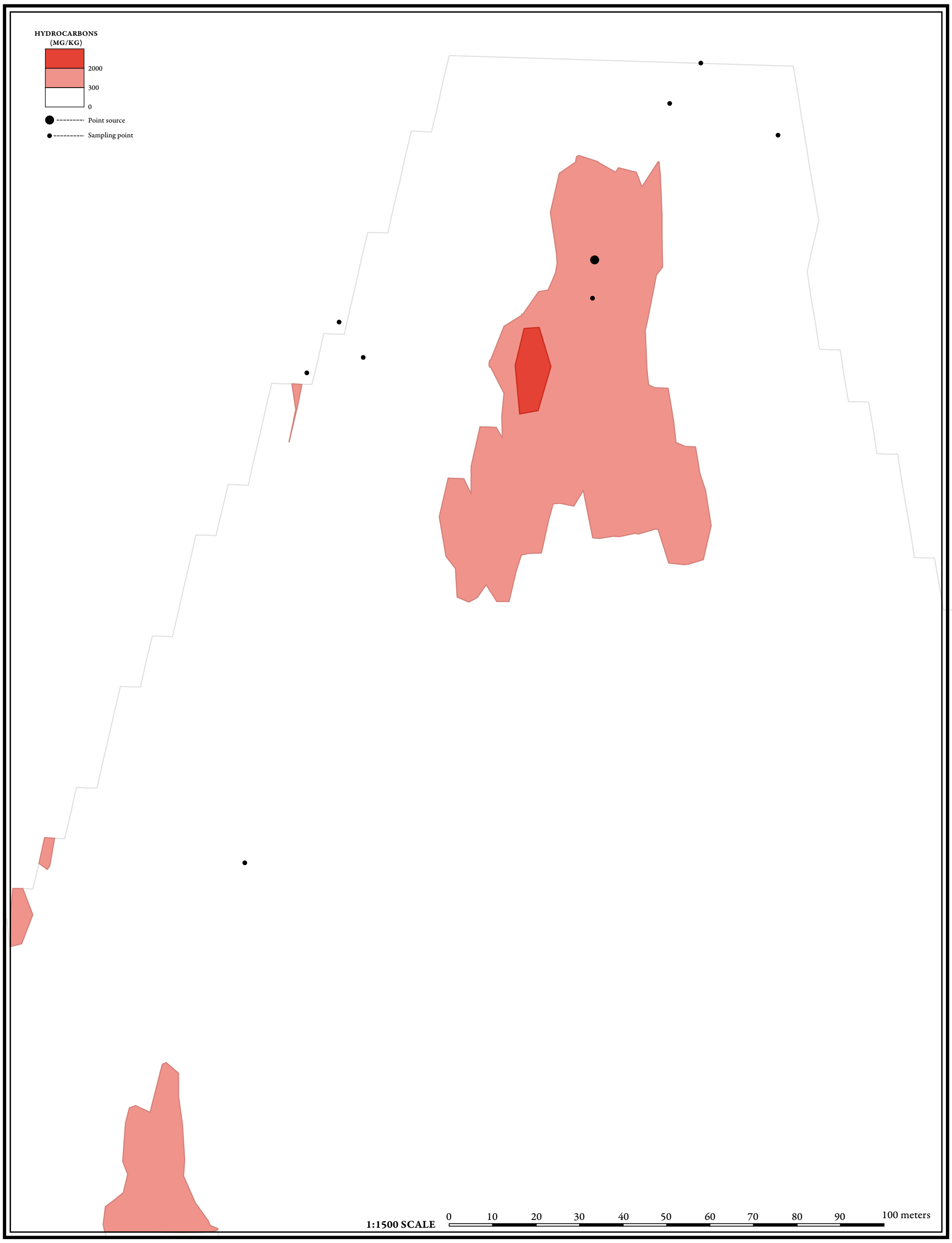


Fig. 6.1.2. Kriging map from the Jätkäsaari (North) site.

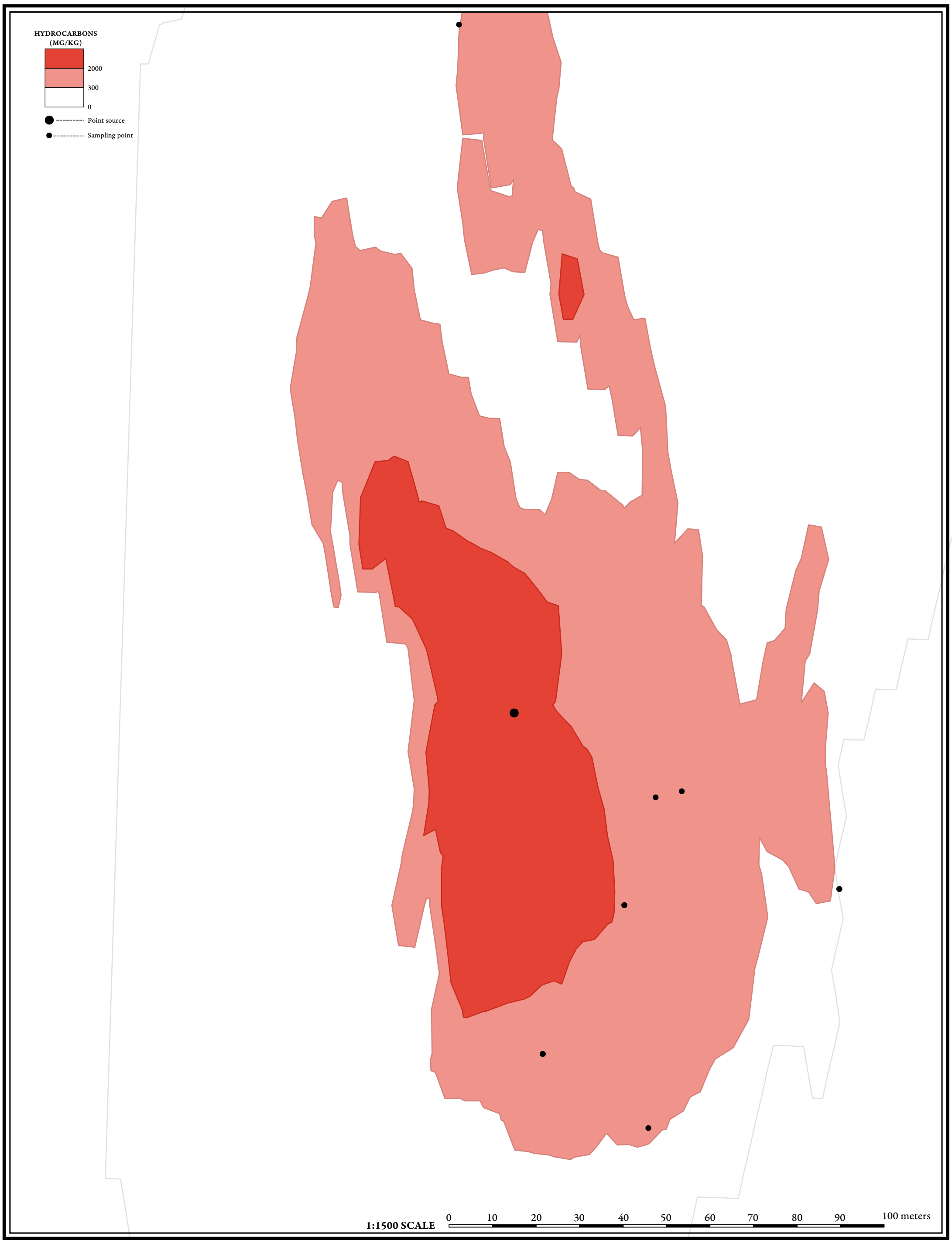


Fig. 6.1.3. Kriging map from the Jätkäsaari (South) site.

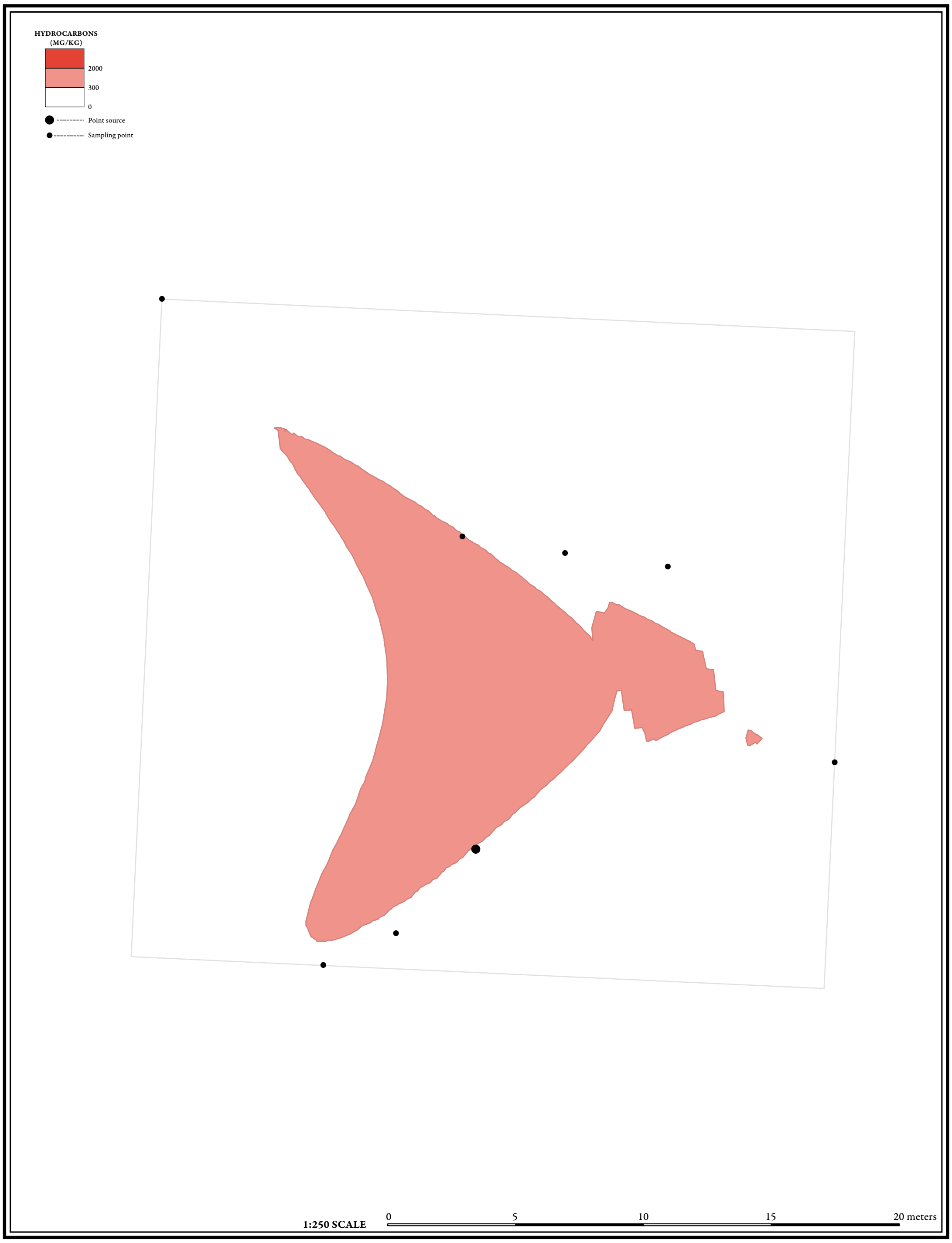


Fig. 6.1.4. Kriging map from the Kauppakuja site.

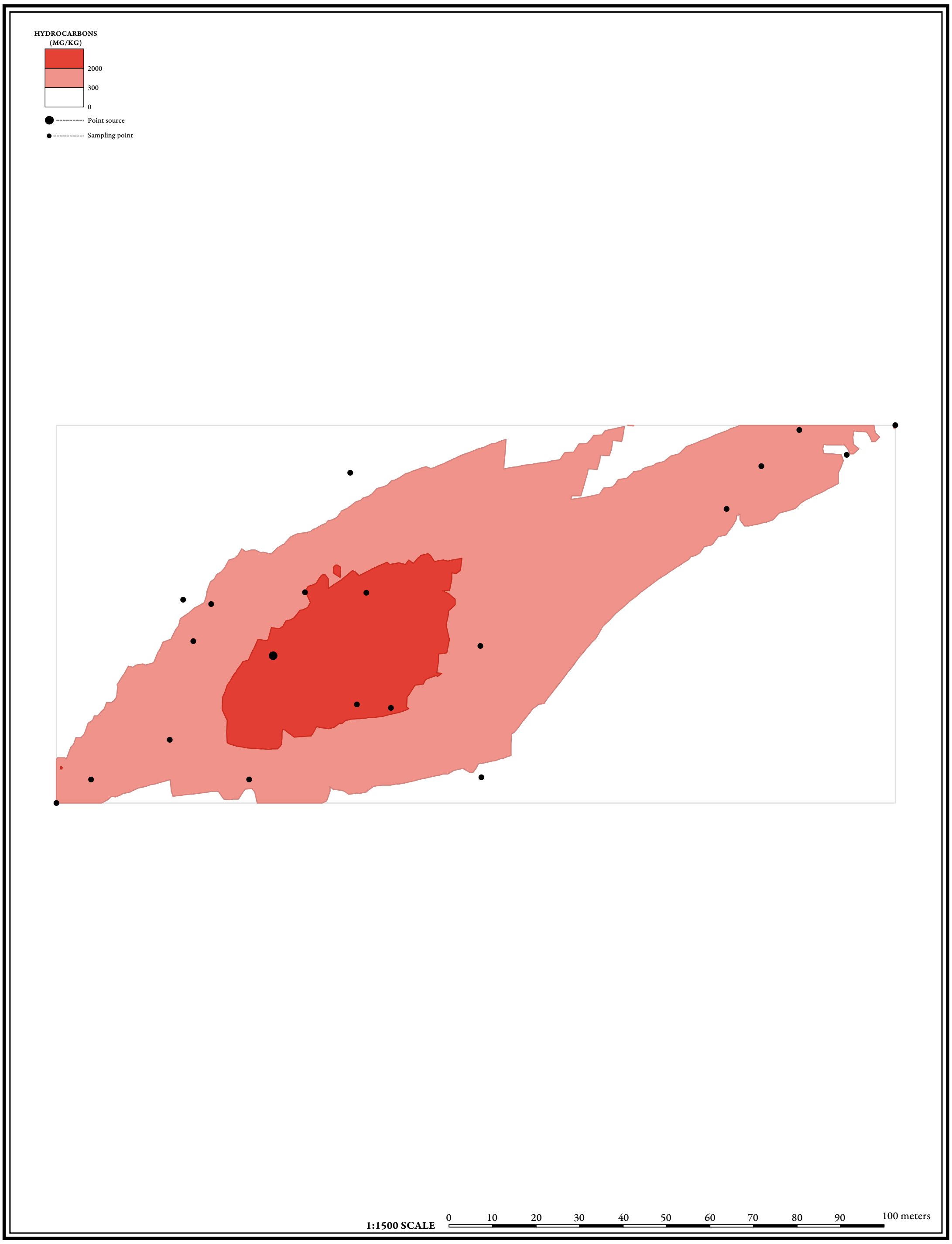


Fig. 6.1.5. Kriging map from the Kouvola Railway Station.

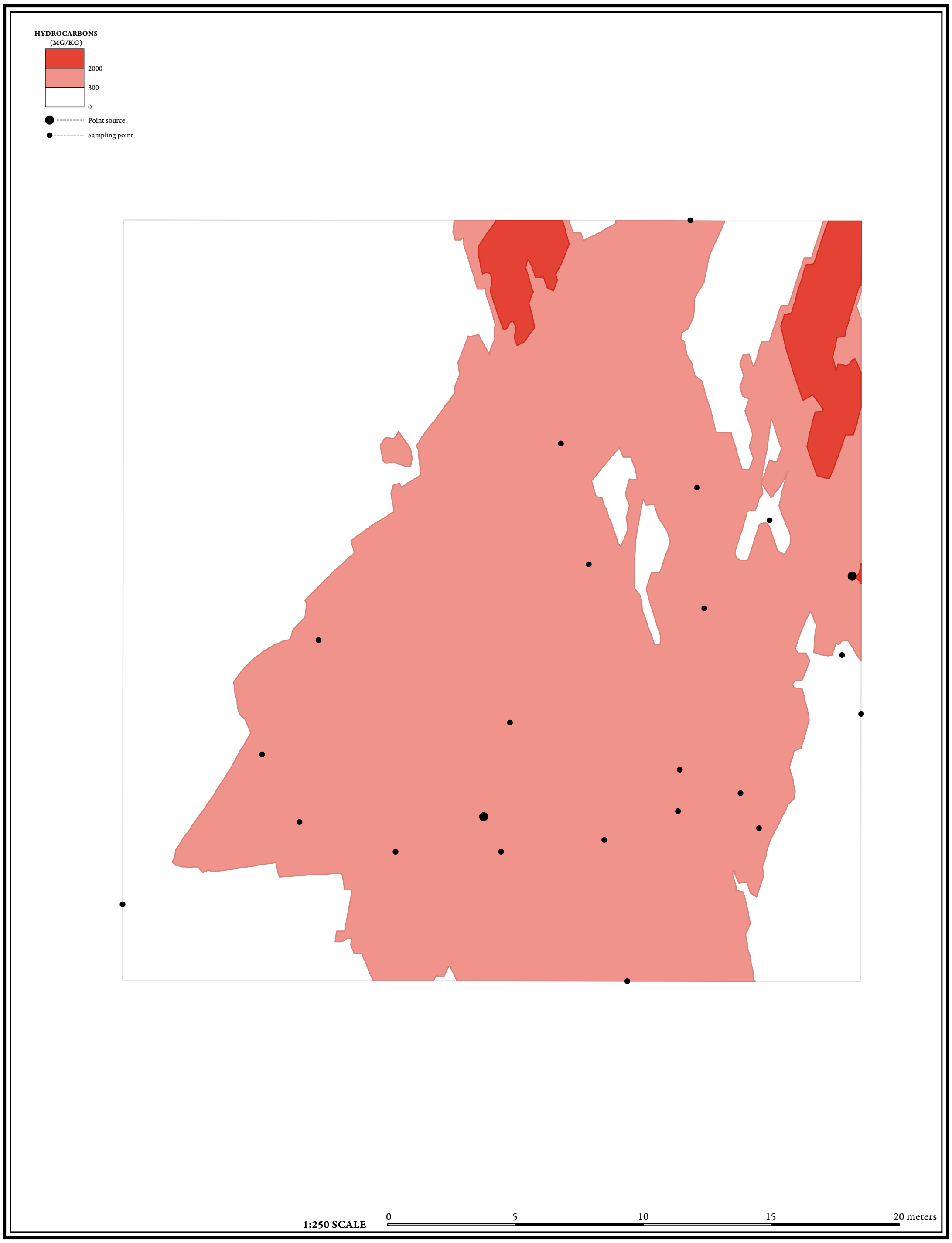


Fig. 6.1.6. Kriging map from the Kotka Railway Station.

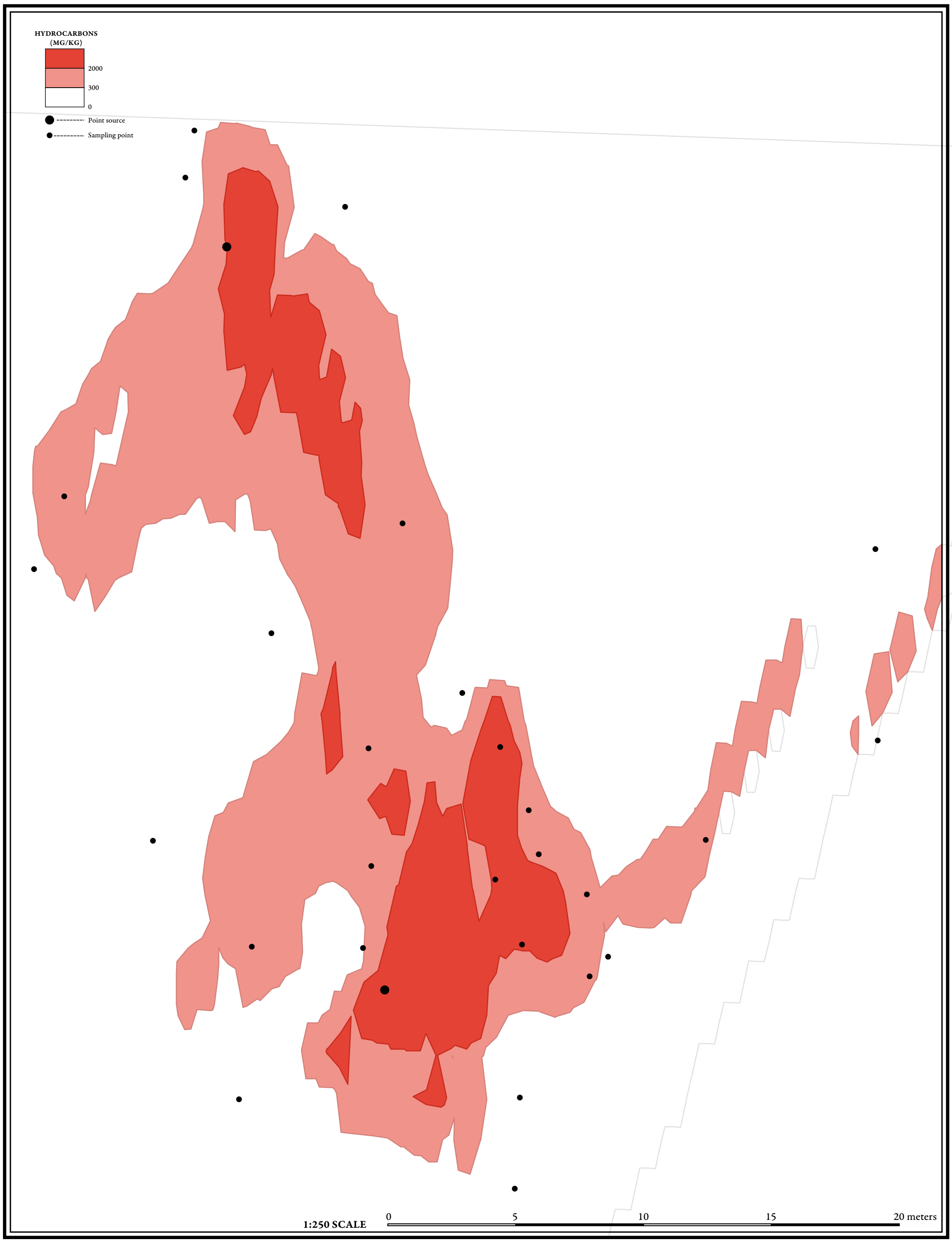


Fig. 6.1.7. Kriging map from the Koulumestari site.

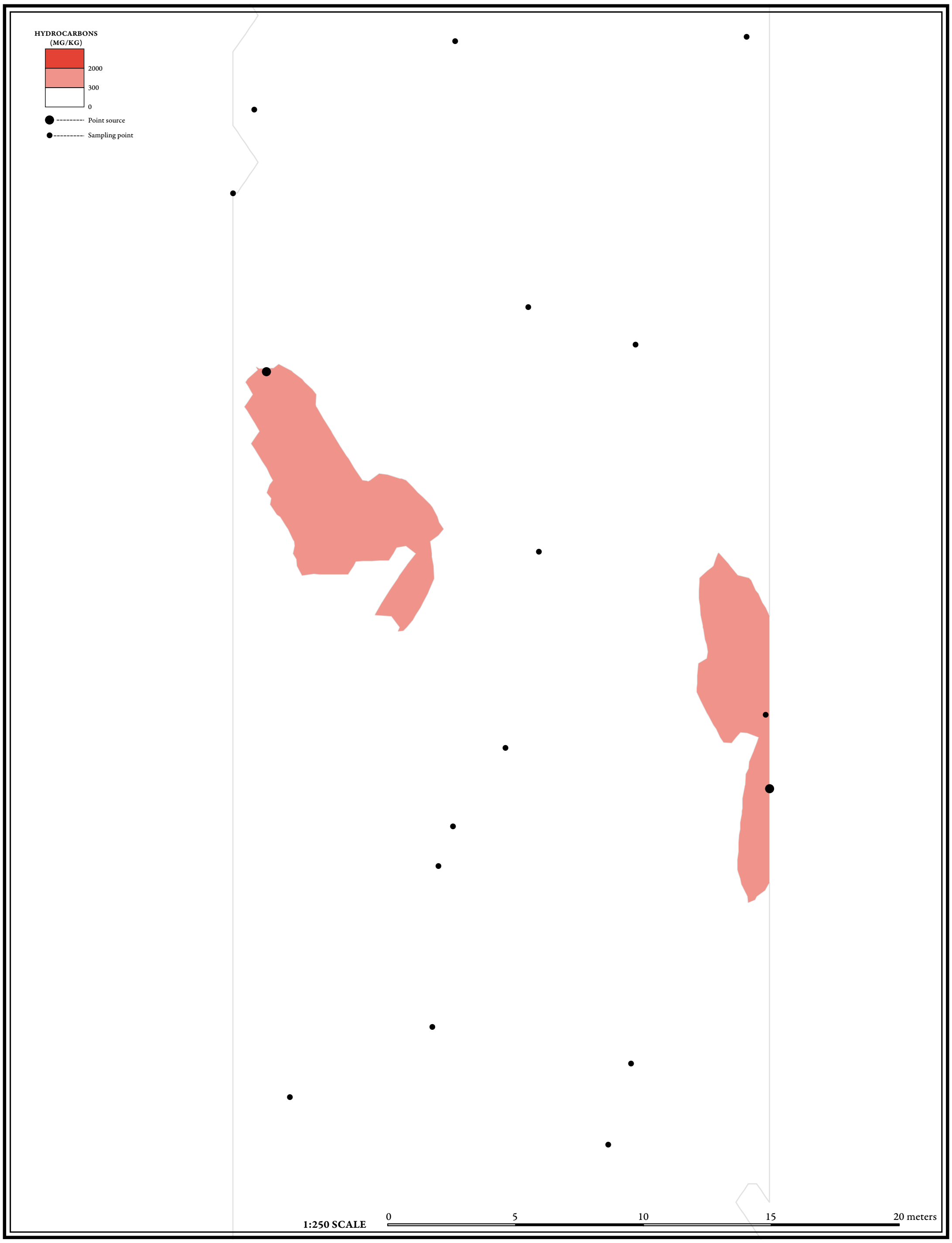


Fig. 6.1.8. Kriging map from the Mäkelänkatu site.

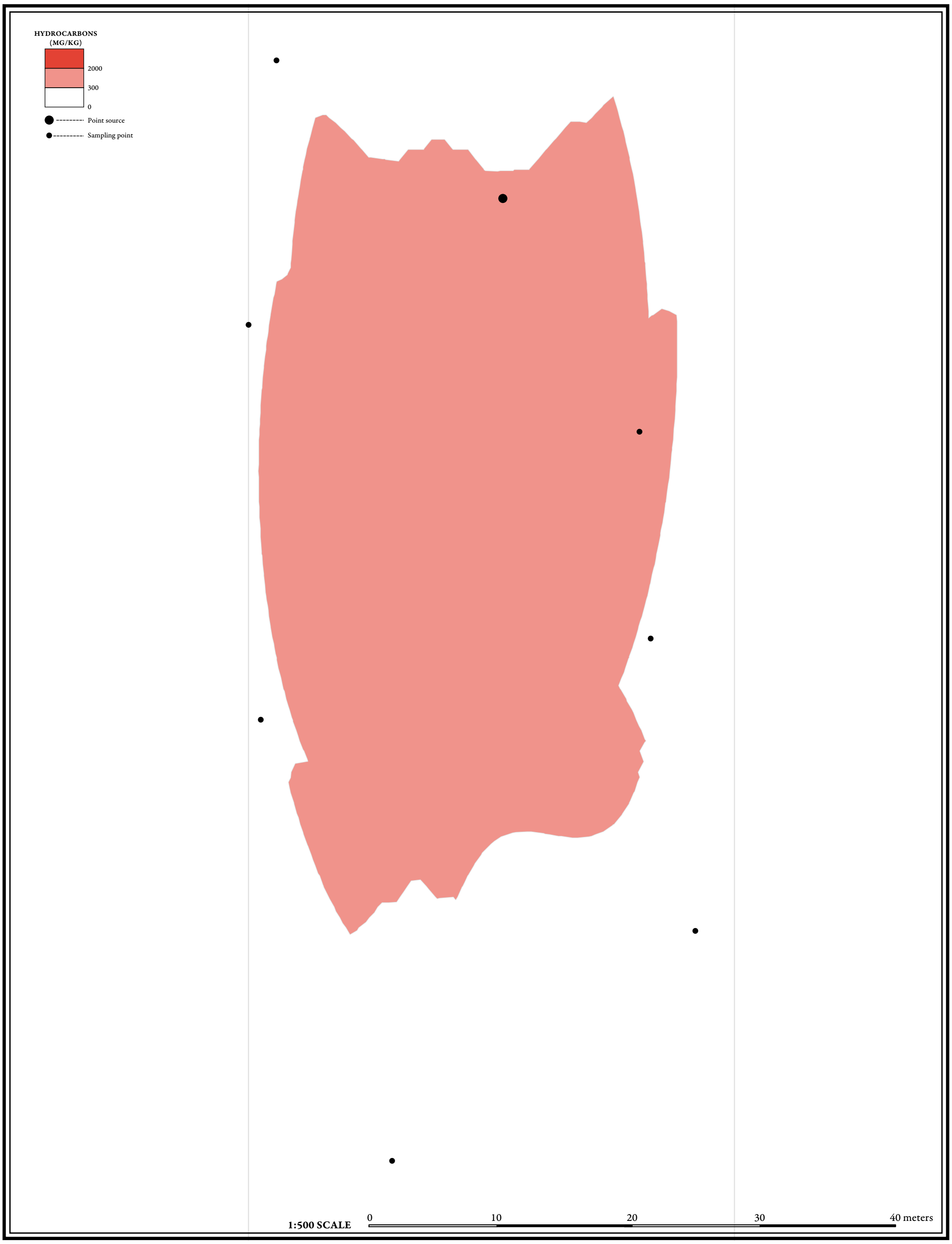


Fig. 6.1.9 Kriging map from the Sorinkatu site.

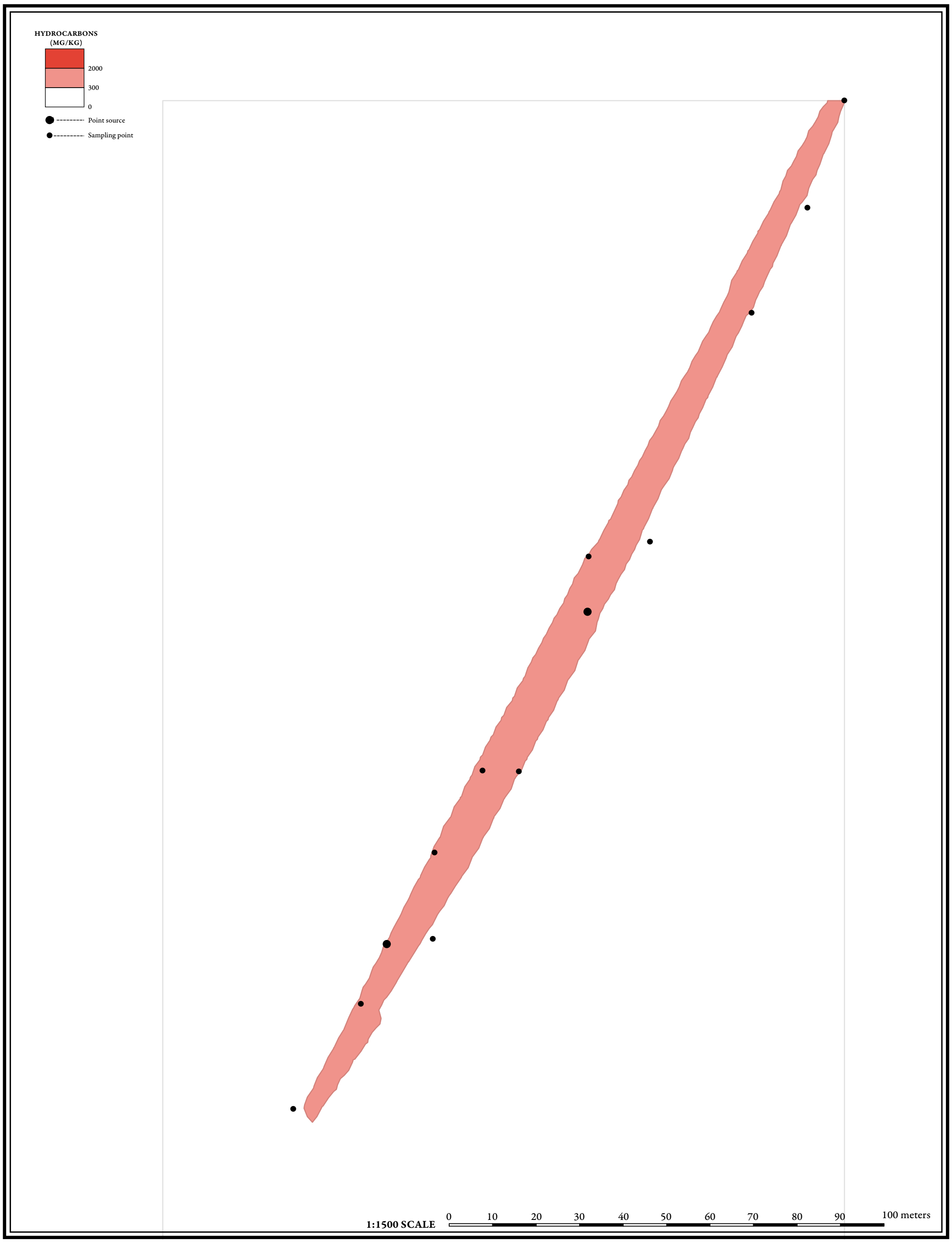


Fig. 6.2.1 Kriging map from the Vaasa Railway Station.

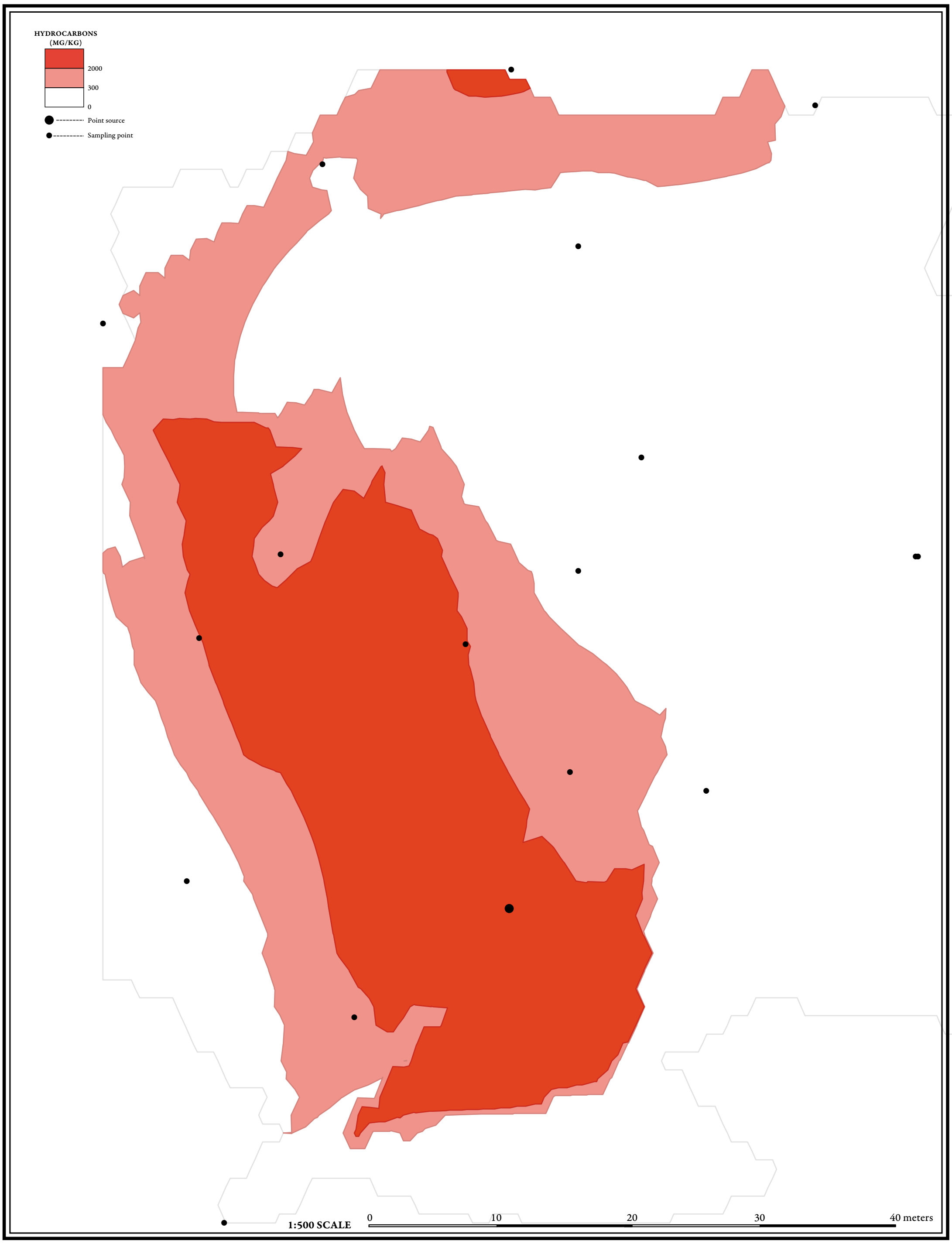


Fig. 6.2.2 Kriging map from the Vallilanlaaksonpuisto site.

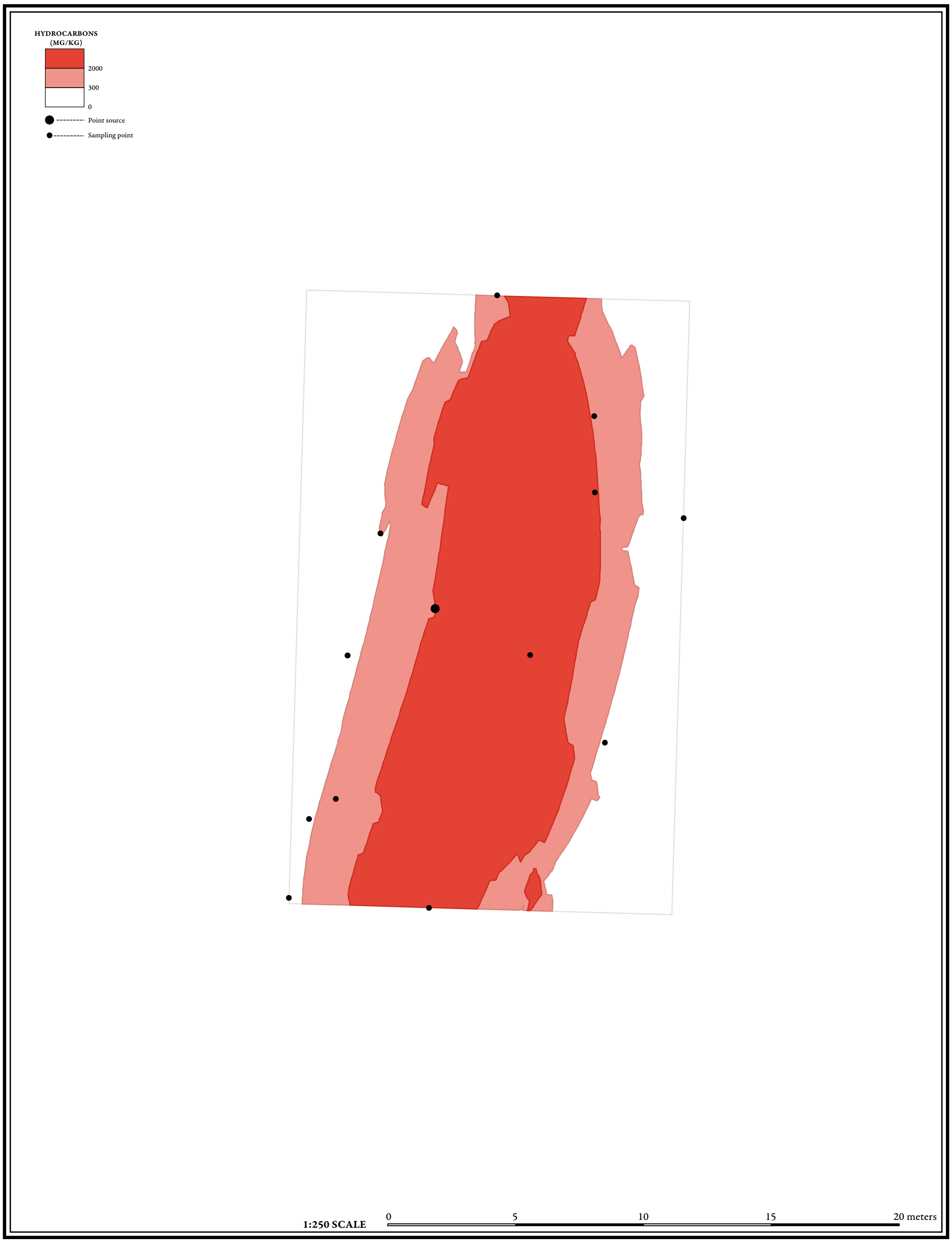


Fig. 6.2.3 Kriging map from the Viilarintie site.

7 Bibliography

Publications

Abdul, Abdul S., 'Migration of Petroleum Products Through Sandy Hydrogeologic Systems', *Ground Water Monitoring & Remediation*, 8/4 (1988).

Brevik, E. C., Burgess, L. C., 'Soils and Human Health' (CRC Press, 2013).

Brus, D., J., Heuvelink, G., B.M., 'Optimization of Sample Patterns for Universal Kriging of Environmental Variables', *Geoderma*, 138 (2007)

Chrisman, N., Charting the Unknown: How Computer Mapping at Harvard Became GIS (Esri Press, 2006).

Clayton, J. Clark II., Delfino, Joseph J., 'Correlations between PID and FID Field Analytical Instruments in the Analysis of Soil Contaminated with Diesel Fuel', *Soil and Sediment Contamination*, 12(2) (2003).

Dexsil Corporation, 'PetroFLAG User's Manual', (updated 1 Apr. 2009) <http://www.dexsil.com/uploads/docs/petroflagmanualver.1.rev.1.pdf>, accessed 19 November 2012.

Eco Canada, Who Will Do the Cleanup? Canadian Labour Requirements for Remediation and Reclamation of Contaminated Sites 2006-2009 (Calgary: Eco Canada, 2007).

The Environment Agency, Dealing with contaminated land in England (Environment Agency, 2002).

Esri, 'What is GIS?', (updated July 2012) <http://www.esri.com/what-is-gis/books>, accessed 6 March 2013.

European Environment Agency (EEA), 'Oil spills', in id., *Mapping the impacts of natural hazards and technological accidents in Europe: An overview of the last decade* (Copenhagen: EEA, 2010).

French Ministry for Sustainable Development, 'Break in a liquid hydrocarbon pipeline; 7 August 2009; Plaine-de-la-Crau',<http://www.aria.developpement-durable.gouv.fr/ressources/fd_36654_plaine_de_la_crau_ang.pdf>, accessed 16 March 2013.

Gadd, G. M., Fungi in Bioremediation (Cambridge: Cambridge University Press, 2001)

Hengl, T., 'A Practical Guide to Geostatistical Mapping of Environmental Variables' (Luxembourg: European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2007).

Lahtonen, U. O., 'Öljyntorjunnan kehitys Suomessa 1968 lähtien 1990-luvulle' [Development of the Oil Spill Response in Finland from 1968 to the 1990s] (Helsinki: Ministry of the Environment, 2004).

Lee, Siu-lan, Xiangdong Li, Wenzhong Shi, Sharon, Ching-nga Cheung, Thornton, Iain, Metal contamination in urban, suburban, and country park soils of Hong Kong: A study based on GIS and multivariate statistics, *Science of The Total Environment*, 1-3 (2006).

Maguire, D., 'GIS and Science', *GIS Best Practices*, November 2008.

Moles, A., 'Sensitivity of ten aquatic species to long-term crude oil exposure', *Bulletin of Environmental Contamination and Toxicology*, 61 (1998).

Olah, George A., Molnár, Árpád, Hydrocarbon Chemistry (2nd edn., New Jersey: John Wiley & Sons, 2003).

Rice, S. D., Thomas, R. E., Heintz, R., Wertheimer, A. C., Murphy, M. L., Carls, M. G., Short, J. W., Moles A., 'Synthesis of long-term impacts to pink salmon following the *Exxon Valdez* oil spill: persistence, toxicity, sensitivity, and controversy' (Exxon Valdez Trustee Council, 1999).

Sorvari, J., Antikainen, R., Kosola ML., Hokkanen, P., Haavisto T., Eco-efficiency in contaminated land management in Finland: barriers and development needs, *Journal of Environmental Management*, 5 (2009).

United States Department of Health and Human Services, Toxicological Profile for Total Petroleum Hydrocarbons (TPH) (U.S. Department of Health and Human Services, 1999).

United States Environmental Protection Agency, Field Measurement Technologies for Total Petroleum Hydrocarbons in Soil: Dexsil® Corporation PetroFLAG™ System (Washington: Office of Research and Development, 2001).

Wenjiao, S., Jiyuan, L., Zhengping, D., Yinjun, S., Chuanfa, C., Tianxiang, Y. Surface modelling of soil pH, *Geoderma*, 1-2 (2009).

Wright, K. A., Jermstad, D. B., 'Evaluation of a Rapid Field Analytical Test Kit for Assessing Hydrocarbon Soil Contamination', Presented at the 'Third International Conference On-Site Analysis' (Jan. 22-25 1996, Houston, TX) <http://www.dexsil.com/uploads/docs/dtr_1502.pdf>, accessed 19 November 2012.

Li, X., Lee, S-l., Wong, S-c., Shi, W., Thornton, I., The study of metal contamination in urban soils of Hong Kong using a GIS-based approach, *Environmental Pollution*, 6 (2004).

Liu, X., Zhang, Z., Peterson, J., 'Evaluation of the performance of DEM interpolation algorithms for LiDAR data', in Ostendorf, B., Baldock, P., Bruce, D., Burdett,

M. and P. Corcoran (eds.), Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference, Adelaide 2009, Surveying & Spatial Sciences Institute.

Manuscripts

Golder Associates Oy, 'Kunnostuksen loppuraportti. Entinen polttonesteiden jakeluasema Mäkelänkatu, 00520 HELSINKI.', report posted to the City of Helsinki, 30 Nov. 2010.

HNU Nordion Oy, 'HNU-kenttätesti' [HNU Field Kit].

Legislation

Finnish Government, 'Laki ympäristövahinkojen korvaamisesta' [Act on Compensation for Environmental Damage], 1994/737.

Ibid., Government Decree on the Assessment of Soil Contamination and Remediation Needs, 214/2007 English.

Ruling of the Finnish Supreme Court [2011] KKO:2011:62.