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Implementation of Swedish Risk Assessment Guidelines in Kodaikanal, India

A Study of Mercury Contamination in an Area Near a Former Thermometer Factory

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ABSTRACT

Implementation of Swedish Risk Assessment Guidelines in Kodaikanal, India.
A Study of Mercury Contamination in an Area Near a Former Thermometer Factory
Carin Hayer and Anna Lindholm

The aim of the project was to make a detailed risk assessment using Swedish guidelines for a factory site in Kodaikanal, South India, and a nearby village called Vellagavi. The study areas were chosen due to previous records of mercury contamination on the factory site and a possible spread to Vellagavi. A comparison between Indian and Swedish guidelines for risk assessment of contaminated areas was performed. The purposes of comparing the two systems were to locate if there were any differences in the legislation, or guidelines, and to find ways of improving the processes. The project also included an evaluation of possible remedial actions that could reverse or prevent environmental damage that might be caused by the former factory. Methods used for the project were literature studies, semi-structured interviews and surveys.

The results from the risk assessment were that the Swedish Computer Program for Calculation Site Specific Guideline (CPCGV), with some adjustments, could be used in order to calculate site specific guideline values for mercury concentrations on sites similar to Swedish conditions, such as climate. The site specific guideline values in soil ranged from 0.1-2.4 mg/kg. An Indian court decision had stated that a guideline value of 20 mg/kg should be used for remediation at the factory site. The result from the forward dose calculation showed that when a soil contains 20 mg/kg, the tolerable daily intake of mercury would be exceeded, and therefore pose a risk to human health.

The comparison of legislation systems between India and Sweden showed several differences. India does not have any legislation relating directly to polluted soil. Risk assessments in India commonly rely on several different international standards even though the standards are not regulated by law.

The results from the remedial evaluation showed that there were several possible remediation methods that could be used on the factory site. Limited remedial actions were suggested for Vellagavi since there were no measurements taken on site. Preferably, remediation should take place at the source of the contamination, i.e. the factory site.

Keywords: *Mercury contamination, Thermometer Factory Kodaikanal, Risk Assessment in Sweden, Risk assessment in India, Environmental Legislation, Remediation Methods, Sustainable Development Goals.*

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REFERAT

Implementering av svenska riskbedömningsriktlinjer i Kodaikanal, Indien.
En studie av kvicksilverförorening i ett område nära en tidigare aktiv termometerfabrik.
Carin Hayer och Anna Lindholm

Det övergripande målet med projektet var att genomföra en detaljerad riskbedömning för en fabriksplats i Kodaikanal, södra Indien, samt för en närliggande by, Vellagavi. Tidigare genomförda mätningar uppvisade förhöjda halter av kvicksilver i området, varför det ansågs vara ett lämpligt område för studien. Studien innehöll en jämförelse av riktlinjer för riskbedömningar för förorenad mark mellan Indien och Sverige där syftet var att identifiera skillnader i lagstiftning och riktlinjer samt lokalisera eventuella förbättringsmöjligheter. Studien innefattades även av en åtgärdsutredning för fabriksplatsen och Vellagavi, vars syfte var att utreda vilka åtgärder som skulle kunna minska risken för fortsatt miljöförstöring eller återställa området. Metoderna som användes i studien var litteraturstudier, semi-strukturerade intervjuer och en enkätundersökning.

Resultatet från riskbedömningen visade att beräkningsverktyget för platsspecifika riktvärden från Naturvårdsverket kunde användas på platser som liknar Sverige klimatmässigt, efter att diverse justeringar hade gjorts. Beräkningsverktyget användes för att ta fram ett platsspecifikt gränsvärde för kvicksilverkoncentrationen i marken. Det framtagna platsspecifika gränsvärdet för koncentrationen kvicksilver i jord varierade mellan 0,1-2,4 mg/kg. Ett beslut utfärdat av indisk domstol angav att fabriksplatsen skulle saneras så att kvicksilverkoncentationen i marken inte skulle överskrida 20 mg/kg. Resultatet från den här studien visade att den nivån av förorening i marken skulle innebära att det tolerabla dagliga intaget av kvicksilver skulle överskridas.

En jämförelse av de juridiska systemen som anknöt till förorenad jord i Indien respektive Sverige visade på flertalet skillnader mellan länderna. Indien har ingen lagstiftning som speficikt reglerar förorenad jord medan det i Sverige regleras av Miljöbalken. Riskbedömningar i Indien baserades ofta på internationella standarder, med det fanns ingen lagstifting som reglerade vilka standarder som skulle användas.

Resultatet från åtgärdsutredningen var att det fanns flera olika åtgärdsmetoder som skulle kunna användas för att sanera fabriksplatsen. Åtgärdsutredningen för Vellagavi var begränsad eftersom det inte fanns tillräckligt mycket mätdata för området. Företrädesvis bör saneringsåtgärderna vidtas vid föroreningskällan, vilket i detta fall är fabriksplatsen.

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PREFACE

This thesis was made as a completion of the Master's Programme in Environmental and Water Engineering at Uppsala University.

The idea and original design of the study were crafted by the authors due to an interest in what impacts contaminated sites can have on the human health and the environment. Also, it was brought to our attention that a previously active thermometer factory in Kodaikanal might had caused mercury contamination on the factory site and in its surrounding areas. Thanks to the scholarship programme Minor Field Studies, funded by Swedish International Development Cooperation Agency (SIDA), the project was possible to conduct. The scholarship gave us the chance to travel to Kodaikanal, India, where the organisation Palni Hills Conservation Council assisted in carrying out the field study.

Due to the outbreak of COVID-19, the field study part of the project had to be cut short, and none of the planned field measurements could be conducted. With help from the academic supervisor, Professor Dan Berggren Kleja of the Department of Soil and Environment at Swedish University of Agricultural Sciences, the direction of the report was changed and the report that is seen today took form.

The project was divided into three parts. The first part was a risk assessment, which was conducted by both project participants. The second part was an individual focus, performed by Carin Hayer, which examined how risk assessments were implemented in India compared to Sweden. The third part was another individual focus, performed by Anna Lindholm, which evaluated different remediation methods that could be applied to the study area.

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We would also like to thank all the members of the Indian organisation Palni Hills Conservation Council (PHCC) for welcoming us to Kodaikanal and helping us in our research. Also, or showing us the breathtaking scenery around Palni Hills. May all your work for environmental issues in the area be successful and rewarding. We would like to give special thanks to Anna at PHCC who helped and supported us through our field work, invited us to dinner, walked with us to Vellagavi and arranged for us to stay there over night. It was an unforgettable experience and we will be forever grateful for your support. We would also like to give special thanks to Antony, whose translation skills and local knowledge of the area made the interviews in this project possible.

We would also like to give our warmest thanks to Pramila and her family (both the two- and four legged ones). She took really good care of us during the whole stay and made absolutely fantastic food.

Thank you, or as we learned in Tamil: நன்றி

POPULÄRVETENSKAPLIG SAMMANFATTNING

Hur stort hot utgör en förhöjd kvicksilverhalt i marken och vad kan göras för att förbättra situationen?

I den vackra bergskedjan i södra Indien finns en stad som heter Kodaikanal. Strax utanför Kodaikanal fanns en termometerfabrik som var i drift i nästan 30 år, tills det uppmärksammades att det hade läckt ut kvicksilver i området från trasiga termometrar. Fabriken stängdes ner år 2001 på grund av kvicksilverutsläppen och än idag finns stora mängder kvicksilver kvar i marken på området.

Företaget som ägde termometerfabriken, Hindustan Unilever Limited (HUL), har tidigare gjort en utredning för att ta fram ett gränsvärde för kvicksilverhalten i marken som de ansåg vara tillräckligt låg för att inte orsaka någon skada på vare sig människor eller miljö. Detta värde var 20 mg kvicksilver per kg jord (mg/kg) och godkändes av indisk domstol. I denna studie undersöktes vad den rekommenderade halten skulle bli om ett svenskt tillvägagångssätt hade använts. Resultatet i den här studien för rekommenderad kvicksilverhalt i jord blev 0,1-2,4 mg/kg. Det farligaste med kvicksilver är att andas in det, men det hade inte HUL inkluderat i sina beräkningar i samma utsträckning som det brukar göras i Sverige. En av anledningarna till att HUL:s gränsvärde blev mycket högre var antagligen för att de inte tog lika stor hänsyn till just inandningen av kvicksilver i sin utredning. I studien kunde det även konstateras att det bestämda gränsvärdet på 20 mg/kg skulle utgöra en hälsorisk för personer som vistas på området.

Bara ett stenkast bort från fabriksområdet ligger den lilla, idylliska byn Vellagavi. Byn ligger på en bergsrygg och går endast att nå till fots. Eftersom kvicksilver kan röra sig med luften finns en risk att det miljö- och hälsofarliga ämnet har nått byn under alla de år som fabriken var aktiv. Denna studie visade att invånarna i Vellagavi framförallt riskerade att få hälsoproblem till följd av kvicksilverexponering under lång tid. För att ta reda på mer om hur mycket kvicksilver faktiskt som har färdats från fabriken ner till Vellagavi behövs fältmätningar.

En riskbedömning görs om ett område misstänks vara förorenat för att utreda vilka risker som föroreningen innebär. I denna studie gjordes även en undersökning av hur processen för riskbedömning såg ut i Indien jämfört med Sverige. I Indien finns det inga lagar som täcker just förorenad jord och än så länge finns det inte heller några nationella riktlinjer för hur en riskbedömning ska genomföras. Däremot brukar den indiska riskbedömningen följa internationella standarder, vilka liknar den svenska processen. Det finns pågående projekt för att hitta potentiellt förorenade områden i Indien och för att skapa riktlinjer till riskbedömningar.

För att försöka minska de risker som en kvicksilverförorening innebär, så undersöktes vilka saneringsmetoder som skulle kunna fungera på fabriksplatsen och i Vellagavi. I studien kunde det konstateras att vissa saneringsmetoder inte fungerar för kvicksilver eftersom det är en ganska speciell metall, men det fanns ändå flera olika saneringsmetoder som kunde användas. Vilka saneringsförslag som väljs beror på hur förorenat området är, vilka ekonomiska förutsättningar som finns och hur mycket naturen får påverkas. Gemensamt för de saneringsförslag som utreddes i studien var att problemet bör åtgärdas vid utsläppskällan, i detta fall på fabriksplatsen, istället för att sanera omkringliggande områden.

CONTENTS

LIST OF ABBREVIATIONS AND DEFINITIONS

Background Level: The concentration of pollutant that would be found in the nature, without any anthropological impact.

Baseline Alternative: The remedial alternative where no remedial action will be taken on the contaminated site.

BAT-alternative: The remedial alternative where the Best Available Technology is applied to the contaminated site.

Cash Crop: A crop that is intended to be sold, rater then to be used for personal consumption by the grower.

Conceptual Model: A visual model used for identifying the contamination situation.

CPCB: Central Pollution Control Board, in India.

CPCGV: Computer Program for Calculation of Guideline Values. An Excel-based computer program used for calculating site specific guideline values, provided by Swedish Environmental Protection Agency.

DNAPL: Dense Non-Aqueous Phase Liquid, i.e. a liquid that is denser than water and is immiscible in water.

Environmental Guideline Value: The concentration of contaminants in soil that can be present without having any negative effects on the environment.

EQS: Environmental Quality Standards. Legally binding policy values that sets the maximum allowable concentration for a substance in different media.

ERM: A company called Environmental Resources Management Australia Pty Ltd that performed a risk assessment for the factory site in Kodaikanal.

Excavation: Removing contaminated soil from a site.

Fairness Cream: A skin cream used for making the skin less dark in colour, also called skin whitening cream.

Forward Dose Calculation: A method using the concentration of contaminant in different media in order to calculate the total exposure to humans.

Guideline Value for Health Effects: The concentration of contaminants in soil that can be present without having any negative effects on human health.

HUL: Hindustan Unilever Limited. The company that owned the thermometer factory.

HLL: Hindustan Lever Limited, who changed their company name to Hindustan Unilever Limited (HUL) in 2007. It was the company that owned the thermometer factory.

HQ: Hazard Quotients. Calculated by dividing the Mean Daily Intake by the Tolerable Daily intake.

IMPCSI project: A project for “Inventory and Mapping of Probably Contaminated Sites in India”.

KM: Sensitive land use (in Swedish: Känslig Mark).

Kodaikanal: A city in Southern India, located around 2 000 meters above sea level.

MARL: Maximum Allowable Risk Level. If MARL=1, the mean daily intake is not allowed to exceed the tolerable daily intake.

Max-alternative: The remedial alternative where the maximum remediation if performed. Several remedial actions can be combined in order to maximise the remedial outcome.

MDI: Mean Daily Intake of a substance.

Methylmercury: Mercury in an organic form that is highly toxic.

MKM: Less sensitive land use (in Swedish: Mindre Känslig Markanvändning).

Model Parameter: Parameters connected to the internal configuration of a model, making it a part of the essence of a model.

Pesticide: A substance used for protecting agricultural plants by pest control.

Protection Target: Receptors of concern during a risk assessment. It could for example be residents in an area or a lake.

Phytoremediation: Remediation method using plants' uptake of contaminant.

Remediation: One, or several action(s) taken on a contaminated site in order to reduce the concentration of contaminant(s).

Response Level: If the level of contaminant exceeds the response level, the site is considered to be contaminated and a response needs to be taken.

RfC: Reference concentration. The total acceptable daily dose of an airborne toxic substance.

Screening Level: If the contaminant in the soil is below the screening level, the area is assumed to be "not contaminated". If the level of contaminant exceeds the screening level, the site is probably contaminated and there is a need for further investigations.

SEPA: Swedish Environmental Protection Agency.

Single Exposure Pathway Concentration: The allowable concentration of contaminant in soil based on the exposure from a single pathway.

Site Specific Guideline Value: A tolerable concentration of pollutant on a specific site.

Skin Whitening Cream: A skin cream used for making the colour of the skin lighter, also called fairness cream.

SPCB: State Pollution Control Board.

Supervisory Authority: An authority that is in charge of supervising that rules and regulations are followed.

TDI: Tolerable Daily Intake of a substance without risking harm, both on short- and long-time basis.

Vellagavi: A small town, outside Kodaikanal.

1 INTRODUCTION

Kodaikanal is a scenic hill station located in South India. There are many beautiful places in the area of Kodaikanal, India, and the richness in biodiversity is unique and important to protect. The biodiversity should be a priority in order to guarantee a sustainable environment for present and future generations. Therefore, the need of taking care of the environment is of importance for sustainable socio-economic aspects, industrial development and most of all biodiversity.

Hindustan Unilever Limited (HUL) operated a thermometer factory in Kodaikanal until 2001, when it was closed due to reports of possible misconduct, brought forth by Greenpeace and local NGO:s (Unilever n.d.; Greenpeace 2010). It was discovered that management failure had led to non-acceptable storage and disposal of broken thermometers (Hunter 2016). The factory released several tons of mercury spill during decades of operating. The consequences of the mercury spill could not only lead to short term effects, such as human exposure and soil contamination, but also to long term effects due to the increased concentrations in the surrounding areas. Only about 2 km as the crow flies from the factory site in Kodaikanal lies a small village called Vellagavi. The village can only be reached by foot and the walk from Kodaikanal takes around 3 hours due to only one existing steep path. Vellagavi is located near the former factory and could be a potential target for contamination issues since the village lies in the same catchment area as the factory site.

The project was conducted in collaboration with an Indian organisation, Palni Hills Conservation Council (PHCC) and was aligned with several of the 17 Sustainable Development Goals stated by the UN. Primarily the goals 6, 14 and 15, but also the goals 3, 11 and 12 were included in the project (see Figure 1).

Figure 1: The 17 Sustainable Development Goals presented by the UN.

The goals 6, 14 and 15 were mostly integrated in the aim of conducting the risk assessment and evaluating the environmental consequences of the mercury contamination in the Kodaikanal area. The 3rd goal was a matter of human health, since high concentrations of mercury can generate serious health problems that might not even be treatable. The goals 11 and 12 were integrated in the project through investigations of previous and future land use for the factory site and the importance of sustainable industrial production. The importance of sustainable production becomes even more palpable when the industry is placed adjacent to, or even in, a city. The consequences of non-sustainable production were examined in this project, since the factory site has been contaminated for decades.

1.1 WHAT IS MERCURY?

Mercury is a metal and an element that occurs naturally in small amounts in the environment. The metal is used in several industrial components, and previously in amalgam for dental filling. Mercury was also used in thermometers, such as the ones produced in Kodaikanal, due to its property of expanding evenly relative to temperature (Canada Environment and Climate Change 2009). Mercury have a low boiling point which make it fluid in room temperature. The fluid could also vaporise, making inhalation of mercury vapour possible (Royal Society of Chemistry n.d.). Mercury exposure can cause health problems and environmental damage due to its toxicity. Accumulation of mercury in biomass is a risk caused by all formations of mercury since it can oxidise and be reduced into hazardous forms (Park 2011). The solubility and bioavailability of mercury in soil is pH-dependent. Methylmercury is a toxic form of mercury that is highly bioavailable and accumulates in biomass. It is shown that mercury can be prolonged in the atmosphere for up to two years, making it difficult to locate specific unknown pollution sources (USGS n.d.). Therefore, when assessing mercury contamination it is important to have a precautionary approach in order not to risk any health and environmental damage.

2 AIM AND RESEARCH QUESTIONS

A report from 2015 concluded that the factory site in Kodaikanal continuously releases mercury into the environment and therefore serves as a reservoir of mercury (Community Environmental Monitoring 2015). This led to concentrations above background level in the surrounding areas. Therefore, it is important to perform a detailed and independent assessment of mercury contamination in the area.

This project was divided into three parts: a risk assessment, an implementation analysis of risk assessments in India compared to Sweden and an evaluation of remediation methods. The risk assessment part was conducted by both project participants, and was followed by individual extended foci.

2.1 RISK ASSESSMENT

The aim of the project was to make a detailed risk assessment using the Swedish guideline model for a factory site in Kodaikanal and a nearby village called Vellagavi. The study areas were chosen due to previous records of contamination in Kodaikanal and a possible spread to Vellagavi. The research questions for the risk assessment were:

- How can the Swedish risk assessment tool, Computer Program for Calculation of Guideline Values, be used in an environmental risk assessment of the mercury contaminated sites in the Kodaikanal area?
- How does the concentration of mercury in soil pose a risk to the environment and human health in the Kodaikanal area?

2.2 EXTENDED FOCI

2.2.1 RISK ASSESSMENT IMPLEMENTATIONS

The aim of the first extended focus was to make a comparison between the use and regulations of risk assessment for contaminated soils in India and Sweden. The laws relating to contaminated soil for both countries were examined to find similarities and dissimilarities between the countries' approaches. The purpose of comparing the two countries' systems was to locate if there were any gaps in the legislation, or guidelines, and to find ways to improve the process. The research question was:

- What are the differences and similarities for implementing environmental risk assessment in India compared to Sweden?

2.2.2 REMEDIATION METHODS

Based on the results of the risk assessment, a remedial analysis was made to examine possible remediation methods for the factory site and Vellagavi. The aim of the second extended focus was to evaluate possible remedial alternatives in order to reverse or prevent environmental damage that might be caused by the former factory's activities. The research question was:

- What remediation methods can be applied on the factory site and in Vellagavi to reduce risks imposed by mercury on environment and human health?

3 BACKGROUND

The background of the project is presented below, in the order: mercury, the mercury problem in Kodaikanal and its surroundings, risk assessment, legislation and remediation methods.

3.1 MERCURY - PROPERTIES AND EXPOSURE

Mercury is a metal that occurs naturally in small amounts in the environment, such as in air, water and soil. The commonly used background level for mercury in soil is 0.1 mg mercury per kg soil (SEPA 2009a). It can occur naturally in three forms: organic, inorganic, and elemental (Hunter 2016). Mercury behaves like a dense non-aqueous phase liquid, DNAPL (Park 2011). Studies have shown that since the industrial revolution, the concentration of mercury in biomass have increased. This indicates that anthropological activities are causing elevated mercury concentrations, where industrial activities are considered to be the main source. Mercury have been used in thermometers due to its property of expanding evenly relative to temperature. Disposal or release of mercury can be an anthropogenic source of mercury pollution (Canada Environment and Climate Change 2009).

Some forms of mercury can be bioavailable, which is dangerous for humans and ecosystems (Bernhoft 2012). When bioavailable, it can accumulate in the food chain, which leads to much of the human exposure generally comes from food, e.g. fish. The concentration of mercury in the food chain accumulates due to the poor degradability, leading to increased concentrations in biomass (Krishna, Jyothirmayi and Madhusudhana Rao 2014). In addition to the bio-accumulation, a more acute exposure can arise from inhalation of mercury vapour which is directly linked to human malady. Some forms of mercury can target the brain function, which can have fatal consequences. It could also be distributed throughout the body with little degradation. A low long-time exposure could be dangerous to all living things and therefore it is important to protect the environment from non-naturally occurring mercury and prevent future exposure problems (Bernhoft 2012).

Since the chemical properties makes it possible for mercury to be found in air, it makes the pollutant mobile and able to spread over great distances. It is shown that mercury can be prolonged in the atmosphere for up to two years, making it difficult to locate specific pollution sources (USGS n.d.). Mercury can be bound to particles that are present in the air. Finer particles, with a size less than PM_{10}, are associated with a higher amount of mercury compared to larger particles (Moreno et al. 2005; Xu et al. 2013). Human exposure to mercury can occur when particles of contaminated soils are inhaled.

The amount of mercury in the soil can have an impact on the amount of mercury found in crop roots. A study found that a positive linear correlation could be found between the concentration of mercury in the soil and the concentration in the roots of maize and wheat (Niu et al. 2011). If the concentration of mercury in the air reaches high levels it can result in elevated levels of the substance in crop roots. The study also found that an increase in concentration of mercury in the air leads to higher levels in the foliage of maize and wheat, whereas the effect on the mercury levels in crop seeds from air and soil was insignificant. Increasing concentrations of mercury can also occur due to the use of pesticides. When growing sugar cane, a fungicide containing organomercury can be used to treat pineapple disease (Turull et al. 2018). Sugarcane is commonly grown in agro-climatic zone 4, which includes Tamil Nadu (Department of Agriculture & Cooperation and Farmers Welfare 2018). Different chemicals can have an impact on in what form mercury will exist. Methyliodide, a fumigant used for pest control, can react with photodegraded mercury, and lead to the formation of methylmercury (Cochran and Ross 2017).

Mercury is also used in cosmetic products that possess a skin whitening effect, where the skin's melanin production is reduced by the inorganic mercury, therefore giving a whitening effect (Al-Saleh 2016). Usage of skin whitening creams containing mercurychloride has shown increased mercury levels in the user's skin and urine (Palmer, Godwin and McKinney 2000). Even though the use of mercury in cosmetic creams is illegal in India, a study from the Centre for Science and Environment found that 44 % of the examined skin whitening creams contained mercury (Sahu, Saxena and Johnson 2014).

3.2 SITE DESCRIPTION

Kodaikanal municipality is located in the state Tamil Nadu, in the south of India, and has an elevation of around 2 100 meter above sea level (Government of Tamil Nadu 2020). The yearly rainfall in Kodaikanal is approximately 1 700 mm/year (Sujatha and Sridhar 2017). The geology in the area mostly consist of charnockite and pink granites (Bagyaraj et al. 2013). The parent rock in the area experience heavy weathering due to the intense rainfall - laterite and lithomograpic clays is therefore commonly found in Kodaikanal (ibid.).

The town Kodaikanal was founded in 1845 (Encyclopaedia Britannica n.d.). An artificial lake was constructed near the city centre and is now one of the main tourist attractions for Indian tourists. Kodaikanal is a hill station that gets its main source of income from tourism. Right outside the town, in 1986, the company Hindustan Lever Limited (HLL, later called HUL) acquired a factory in Kodaikanal to produce thermometers (see Figure 2).

Figure 2: A map of Kodaikanal area, including approximate locations of the factory site and Vellagavi. The map was provided by Google Maps, and some adjustments were made.

The factory was previously owned and operated by Chesebrough Pond's. The factory was closed in 2001, after Greenpeace and Palni Hills Conservation Council had filed a report for contamination and inappropriate storage of broken thermometers (Greenpeace 2010). Many of the previous studies of the area have focused on the northern side of the mountain, since it is more exploited to tourists and residents. The factory site is placed on a southward slope and by ocular inspection and previous measurements it could be assumed that elevated concentrations of mercury could be found on the southern side. On the Southern side of the mountain, there is a village called Vellagavi. Vellagavi is situated about 2 km from the factory site in Kodaikanal (see Figure 2). The village can only be reached by foot, which takes about 3 hours. The village consist of approximately 30 houses. The main income for the inhabitants come from growing cash crops that is grown on farmland located close to the village. An overview of the village and its surroundings can be seen in Figure Figure 3.

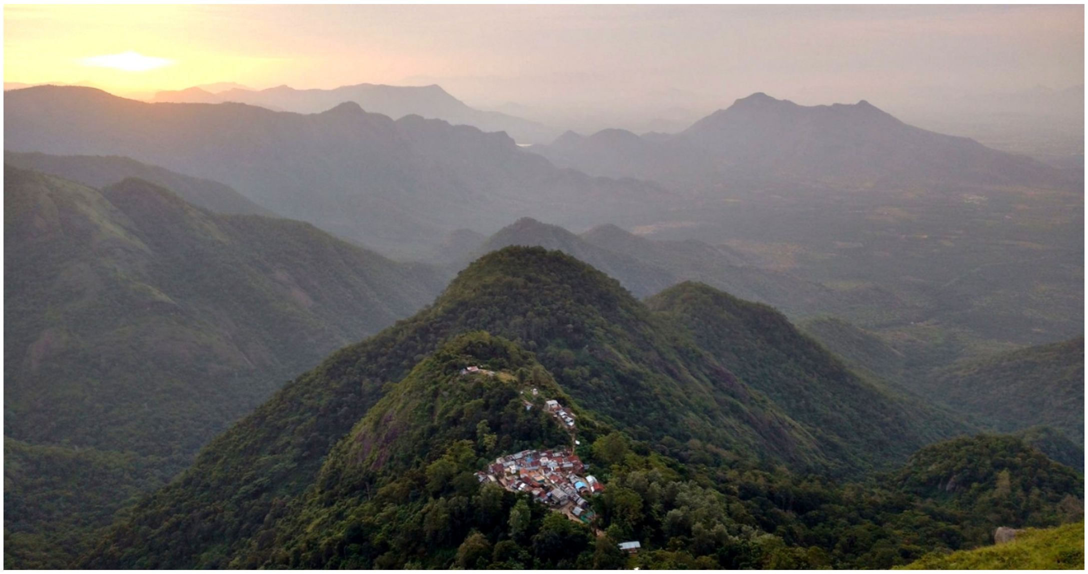


Figure 3: A picture of the village Vellagavi. Source: Manish Kumar.

As mentioned previously, mercury can spread through different kinds of media, and travel long distances. It is possible that mercury released from the factory has been deposed in Vellagavi. The potential pathways for mercury transport and exposure are presented in Figure 4.

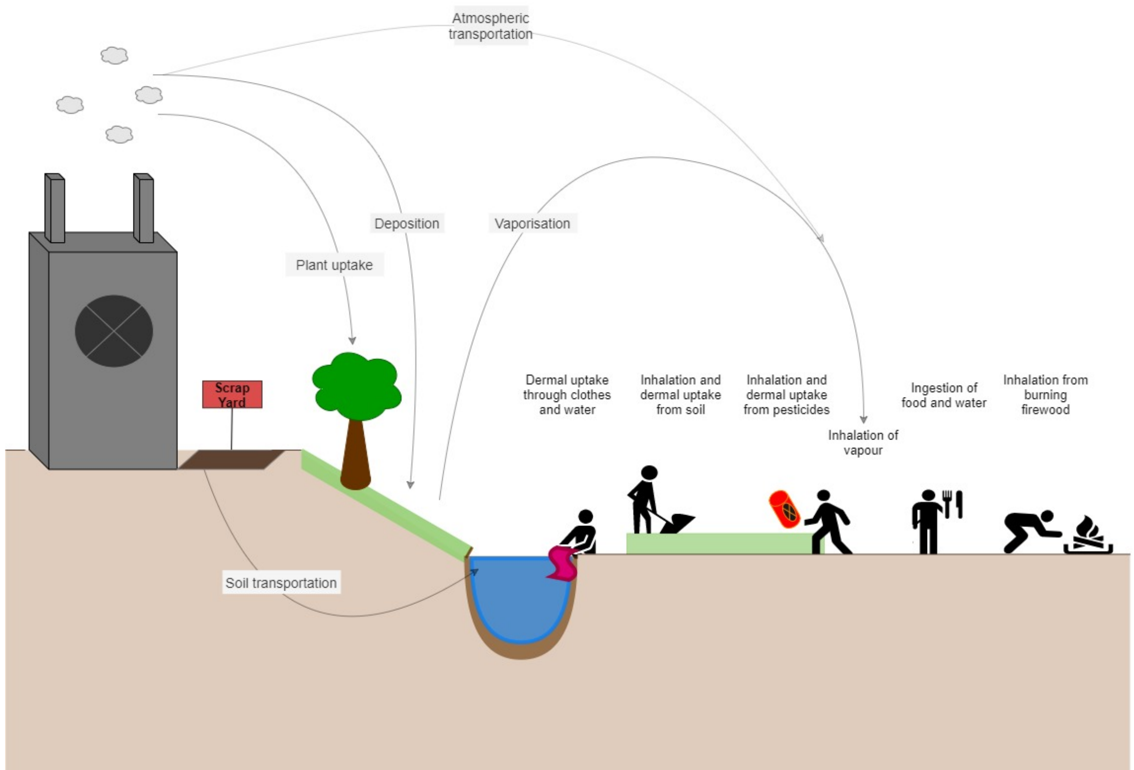


Figure 4: An overview of mercury transportation in nature and the potential exposure pathways for the inhabitants of Vellagavi. The arrows represents the different possible flows of mercury.

3.3 RISK ASSESSMENT

The aim of a risk assessment is to estimate the risks of a contaminated area and how the risks needs and/or can be reduced in order to prevent long-term and short-term negative effects on environment, health and natural resources. When studying and evaluating contaminated sites, the procedure of a risk assessment can be used. An area is defined as contaminated if the concentration exceeds the background level. A risk assessment is a tool for providing information about risks and necessary measures in a contaminated area. The Swedish Environmental Protection Agency (SEPA) provides a model for risk assessment of contaminated areas, called Computer Program for Calculation of Guideline Values (SEPA 2010).

The risk assessment is a part of the process of determining what remediation methods that are required in order to stop or reverse the negative environmental impact. The risk assessment is used as a basis for an extensive process of remedial evaluation, risk evaluation and providing quantifiable measures of action. Different countries have different approaches to conducting risk assessments. In Sweden, two types of risk assessments are commonly used: the basic- or detailed risk assessment. The basic risk assessment is used to evaluate if there is a risk of environmental consequences, by comparing the measured concentrations to generic guideline values. The detailed risk assessment is used when the contamination situation is extensive or complicated, or when many objects are polluted. If guideline values and limit values are missing or the uncertainties of risks are too big, the detailed risk assessment is needed. The Swedish risk assessment methodology is usually iterative and divided into the following parts: Problem Description, Exposure- and Effect Assessment and Risk Characterisation. (ibid.)

Problem Description and Conceptual Model

In the initial phase of conducting a risk assessment, the problem is described and then a conceptual model is created in order to examine the situation and to provide information about what data that is needed. Guidelines for a conceptual model of risk assessments is provided by SEPA. The conceptual model corresponds to the problem formulation, pollution analysis, identified guideline values, exposure pathways, dispersion analysis and the load in the area. When compiling the results, it is important to explain the quantitative results and what main objects that are important for the evaluation and the conclusions of risk reduction. The local conditions determine the type of tests and information that needs to be collected. In order to withhold a transparent process, the whole chain of handling the lab tests is important to include in the risk assessment. A plan of quality analysis is a requirement to properly evaluate uncertainties and deviations. (SEPA 2010)

Exposure- and Effect Assessment

In the exposure analysis, the information about different concentrations is summed up to be used for exposure estimation. In a risk assessment, there are several choices that must be made, transparently and well-motivated. In the more environmentally exposed areas (e.g. nature reserves), the protection of soil and water should be extensive since it might be sensitive to exploitation. More exposed areas, e.g. industrial sites, usually leads to degraded land use, but the area should still be able to provide the necessary ecological activities. Also, animals should be able to temporarily stay in the area without being exposed to life threatening risks due to pollution. As a parallel to the exposure assessment, an effect assessment is made. The effect assessment refers to examine what concentration of contaminant in soil where the exposure could pose a risk. The concentration values produced in the effect assessments does not provide information about where or how the contamination spreads and cannot be used for calculating the effects of remedial actions. However, the values can be used for calculating the threat of exposure based on data and models. In a detailed risk assessment, toxicological and eco-toxicological data can be needed due to studies of more complex systems or lack of existing guideline values. (ibid.)

Risk Characterisation

Another step in the risk assessment is to estimate the amount of pollution that the protection targets are exposed to, which later can be used to determine the site specific guideline value. The amount of contaminant in a media or its dispersion could be estimated by measurements or mathematical and statistical models, with carefully thought-through assumptions that should not lead to over- or under estimating the effects. In a detailed risk assessment for complex systems, it is preferable to combine measurements and mathematical models. Repeated measurements provide more reliable results and can indicate trends, variation and deviation. SEPA provides information about national data of background- and reference values. (ibid.)

3.3.1 COMPUTER PROGRAM FOR CALCULATION OF GUIDELINE VALUES

The Computer Program for Calculation of Guideline Values (CPCGV) is an Excel-based program used for deciding site specific guideline values. CPCGV was designed by SEPA and is accessible to the public. The program can provide calculations for two general scenarios: sensitive land use (KM - Känslig Markanvändning) and less sensitive land use (MKM - Mindre Känslig Markanvändning). An example of KM is residential areas and for MKM is factory sites. The characteristically related values for these land uses are prefilled in the model. The program also allows the user to create unique scenarios, in order to match site specific conditions at the investigated site. There are three main parts of the program: Guidance in creating a conceptual model, Calculations of site specific guideline values for contaminated soil and The content of pollutant in different media based on the soil content. (SEPA 2009b)

CPCGV uses three different types of parameters: scenario parameters, substance parameters and model parameters. Scenario parameters are used for adapting the model to site specific conditions, e.g. human exposure time. Substance parameters are connected to specific contaminants on the site, such as chemical data. Model parameters, e.g. particle count in air and the breathing capacity of a child, are rarely changed since these are fundamental parts of CPCGV. If any model parameter is changed, there needs to be clear and relevant reasons for doing so. (ibid.).

The result from running the program is a value for each exposure pathway, called Single Exposure Pathway Concentration (SEPC). The SPEC for each pathway (e.g. inhalation of vapour) represents the acceptable contamination concentration in the soil as if that was the only exposure pathway present. The term "acceptable contamination concentration" refers to the highest concentration where the long time exposure does not pose a risk for the protection target. The exposure pathway with the lowest concentration value decides the site specific guideline value. Each substance has a background level of concentration in the CPCGV. The resulting guideline value can never be lower than the background value. If so, the value gets adjusted to match the background level. The model also account for short time exposure and acute toxic effects. The procedure of inserting concentrations from all exposure pathways from the conceptual model in order to receive information about the maximum allowed concentration in soil is called backward dose calculation. By inserting the concentration of the contaminant in soil the CPCGV, the model can also calculate the concentration of contaminant in different media. (SEPA 2009b)

3.3.2 UNCERTAINTIES IN RISK ASSESSMENTS

There are several uncertainties that can occur during a risk assessment and it is important to transparently present how the uncertainties are being dealt with during the assessment. Conceptual uncertainties can occur due to wrongly formulated problems and models, which can be caused by inadequate analysed data, e.g. what pollution that is relevant or the exposure pathways. The model uncertainties can occur due to simplifications, rounding up or down, or lack of knowledge when using mathematical models to calculate dispersion, exposure and transport etc. Uncertainties in data can occur due to flaws in testing, test results, measurement methods and/or measurement errors. Variability contributes to uncertainties in a risk assessment, since it is connected to the natural variation in systems, e.g. temperature, precipitation and soil properties or if parameters are time dependant. The natural variation in individual exposure (soil intake, sensibility to pollution or body mass) can affect the evaluation of risk assessment. Uncertainties in model parameters are connected to the parameters used in the conceptual model, which all have an inherent variability and uncertainty. Therefore, the choice of model affects the usage of parameters and further on, the model uncertainty is strongly related to the choice of parameters. When dealing with uncertainties it is important to be transparent and present the results by including the uncertainties. There are several ways to decrease the uncertainties, by e.g. sensitivity or sensibility analysis. (SEPA 2009a)

3.4 IMPLEMENTATION OF RISK ASSESSMENT

In this section, the fundamental environmental laws connected to soil pollution for both Sweden and India will be presented. The processes for identification and classification of polluted area and guideline values will be presented for the two countries. This information is a foundation for the extended focus of implementation of risk assessments.

3.4.1 ENVIRONMENTAL LEGISLATION IN SWEDEN

Contaminated areas are legally regulated by Chapter 10 in the Swedish Environmental Code (SFS 2020:75). The definition used for pollution damage is pollution that causes damage and inconvenience for either human health or the environment. The media covered for pollution damage are land, water, groundwater, buildings and facilities. Air pollution is not covered in the term pollution damage, but damage caused by air exhaust on other media, e.g. soil, is included in the law (Regeringskansliet 2006). Therefore, a company can be held accountable if environmental damage arises from air exhaust stemming from their activities.

3.4.2 IDENTIFICATION AND CLASSIFICATION OF POLLUTED AREAS IN SWEDEN

The County Administrative Boards in Sweden work with identifying areas that might suffer from soil pollution. The work done by the County Administrative Boards to identify polluted areas was mainly conducted from 1990s until the end of 2015 (SGI 2018). Since it is assumed by SEPA that most of the polluted areas in Sweden are now found, the main focus is on verifying that the areas actually are polluted and to initiate remediation (SEPA 2020). Identification of possible polluted areas is also conducted by other governmental bodies, like the Swedish Transport Administration and the Geological Survey of Sweden. The identification is based on what type of industry that have been conducted in the area and the potential pollution risk that is related to the industry. SEPA provides a list with different lines of business that have been divided into four risk classification groups. The list also consists of a guide for which pollutants that is common for each type of industry.

After the identification step, a screening process is initiated. The purpose of the screening process is to assign the potentially polluted area in a risk category. The screening process is divided into two phases:

1. Orientation Study
   The orientation study mainly relies on combining already available information that can be derived from maps or archives with site visits.

2. General Survey
   In the general survey a geomap over the area is created and sampling is conducted on the site. The survey also contains information about the quality of the investigation.

Both phases result in reports containing a summary, an evaluation and a classification of the risk category. The risk categories are numbered, raging from 1, meaning "very high risk", to 4, meaning "low risk". Areas prioritised for further inquiry are usually placed the risk categories 1 or 2. All of the areas that are identified as possible places for pollution is gathered in a national database. (SGI 2018)

3.4.3 GUIDELINE VALUES IN SWEDEN

Generic guideline values for polluted soils are provided by SEPA. If the amount of a pollutant in the soil is below the generic guideline value the human- and environmental risk is on an acceptable level (Naturvårdsverket n.d.). The generic guideline values are not legaly binding (Inglezakis and Menegaki 2016).

Depending on the area's land use, two different generic guideline values are available: One for sensitive land use (KM) and one for less sensitive land use (MKM) (see Table 1). The guideline value for KM is limited by the exposure pathway: inhalation of vapour and intake of plants. The guideline value for MKM is limited by the exposure pathway inhalation of vapour.

Table 1: Generic guideline values for mercury provided by SEPA

	Sensitive Land Use [mg/kg]	**Less Sensitive Land Use [mg/kg]**
Mercury	0.25	2.5

3.4.4 ENVIRONMENTAL LEGISLATION IN INDIA

India have different laws regulating environmental pollution depending on the effected medium. There is no legislation aimed directly at contaminated soil. For pollution of water bodies the Water (Prevention and Control of Pollution) Act is applied. For air pollution the Air Act (Prevention and Control of Pollution) is applied (Reynaers and Nandeshwar 2020). There is also an Environmental Protection act (EP act) that gives the Central government several means to handle environmental pollution. The Central government has the authority to decide which institution that should perform the assessment for a potentially polluted site. The EP act allows the Central government, Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB) to use accredited private agencies and parties for site assessments. The EP act also contains specific guidelines on how measurements should be taken during a site assessment (Tyag 2013). The EP act, in combination with the Water and Air act, gives the enforcing agencies the permission to enter sites to conduct sampling and assessment, if deemed necessary. Under the EP act there are several different policies and rules. The Hazardous Wastes (Management And Handling) Rules (HW rules) are one example of this.

3.4.5 IDENTIFICATION AND CLASSIFICATION OF POLLUTED AREAS IN INDIA

A project for "Inventory and Mapping of Probably Contaminated Sites in India" (IMPCSI), requested by the Ministry of Environment and Forest and performed by a consortium, is currently active. Different criteria are used for identifying probably contaminated sites. The criteria are based on if the site have been subjected to any potentially harmful:

- industry types.

- industrial processes.

- hazardous waste generation.
- or other type of anthropogenic contaminant.

3.4.6 GUIDELINE VALUES IN INDIA

The guideline values used in India mostly rely on different international standards. The Indian guideline values are divided into two categories: screening- and response levels. If the concentration of contaminant in the soil is below the screening level, the area is assumed to be “not contaminated”. If the level of contaminant exceeds the screening level, the site is probably contaminated and further investigations are needed. If the level of contaminant exceeds the response level, the site is considered to be contaminated and a response needs to be taken. The proposed Indian response levels for soil is the same as the Dutch levels and the screening levels are the same as used in Canada. The limiting exposure pathway for the Canadian screening levels for mercury is ingestion of soil for the land uses: agriculture, residential/parkland, commercial and industrial. For an industrial site, it is the environmental aspect that is the limiting factor. The guidelines values for mercury (inorganic) proposed in India is displayed in Table 2. The same guideline values are presented in the guidelines provided by the Ministry of Environment and Forest and in the IMPCSI project (Ministry of Environment and Forests 2015a; Ministry of Environment, Forest and Climate Change 2015).

Table 2: Indian guideline values for mercury

	Screening Levels [mg/kg]				**Response Level [mg/kg]**
	Agricultural	**Residential/ Parkland**	**Commercial**	**Industrial**	
Mercury	6.6	6.6	24	50	36

3.5 REMEDIATION

The aim of remediation is to reduce or eliminate unacceptable risks in a contaminated area, e.g. water, land or buildings. In remediation projects, health- and environmental risks in contaminated areas should be assessed in a short term and a long term perspective (SEPA 2009a). It is also important to make sure to protect surface water and groundwater since contaminated water could lead to hazardous consequences for human health and biodiversity. In the Swedish Environmental Goals, it is specified that future generations should have access to clean water and the ecosystems in water should be sustainable and healthy. The dispersion from contaminated areas should not lead to increased amount of contamination in other areas. Good ecological- and chemical status and non-contaminated sediments in lakes are important for long-term sustainable environment. The function of the ecosystem should also be considered, since it is of importance for future usage. Remedial actions need to be cost effective and suitable for each project. The remedial process according to the Swedish standard contains the following steps:

1. Formulation of remedial goals
2. Investigation and studies
3. Risk assessment
4. Evaluation of remedial alternatives
5. Selection of remedial alternatives
6. Quantifying remedial objectives

The second extended focus was to make an evaluation of remedial alternatives and the process of the evaluation is presented below.

3.5.1 EVALUATION OF REMEDIAL ALTERNATIVES

The aim of evaluating remedial alternatives is to examine different remediation methods that can be applicable to the contaminated area (SEPA 2009a). In this process and the next (selection of remedial alternatives) different alternatives will be evaluated in order to present alternatives that are relevant according to the specific remediation project. The different alternatives are being compared to a list of criteria, such as legislation, environmental impact, costs and general interests. The choice of remedial alternatives is based on the evaluation- and selection phases where a compilation of advantages and disadvantages for each remedial alternative is presented. The process of evaluation is the following:

1. Identifying relevant remedial alternatives
2. Initial analysis of remedial alternatives
3. Detailed analysis of remedial alternatives
4. Compilation of acceptable remedial alternatives

Identifying Relevant Remedial Alternatives
When identifying relevant remedial alternatives, there are some important aspects to take into consideration. The remedial alternatives should reduce the health and environmental risks in such a way that the technical and economical aspects are reasonable. The remedial actions can either reduce or eliminate the contamination on the site, which can be made in two ways: reduction of contamination source, or protective remedial action. The first way aims for a reduction of the concentration of contaminant on the site. The second way aims to limit the contaminant from spreading to its surroundings. The remedial alternatives should be designed to only be executed once. The aim is to eliminate any maintenance during and after remediation, but some maintenance during a short period of time can be required. Using technologies that are energy saving is desirable, as well as applying Best Available Technology (BAT). The damage in the area caused by the remedial action should not exceed the damage caused by the contamination. The remedial action should not restrict future land use in an unreasonable way. The evaluation should, at least, include a baseline alternative and potential candidates for a BAT-alternative and a max-alternative. The baseline alternative is when no remedial action on the contaminated site is taken. The BAT-alternative should be effective, reasonably expensive and make sure that the contaminated areas are restored within reasonable amount of time. The max-alternative is when the maximum remedial action being taken. In the max-alternative, several remedial actions can be combined in order to maximise the remediation since this alternative usually is included in complicated remediation projects. The cost of the max-alternative is included in the evaluation, but not rated in any way. (ibid.)

The remedial alternatives are being prioritised depending on the contamination situation. SEPA recommends to first and foremost choose remedial alternatives that reduces the source of contamination almost completely, even though an important aspect is to reduce the levels of contamination to an acceptable level. There are guidelines on how to approach different contaminants depending on the situation. The effectiveness of the measure in the long run should be taken into account, since changes in e.g. temperature, groundwater levels or precipitation can affect the remedial action's effectiveness. (ibid.)

Initial Analysis of Remedial Alternatives
In the initial analysis of alternatives, different alternatives are being compared in accordance with four evaluation criteria: fulfilling the remedial goals, corresponding to the stakeholders interest and funding, being technically feasible and achieving expected results. In each step of the process of evaluating remedial alternatives, some alternatives can be eliminated for not fulfilling a criterion. Each remedial alternative should include information about the volume or area of remediation and what demands that have been stated for the technical solutions in order to make comparisons for selecting remedial alternatives. (ibid.)

Detailed Analysis of Remedial Alternatives
Based on the initial analysis of alternatives, the analysis proceeds to evaluate the remaining alternatives more. The analysis should include costs, risks and disruptions. In the cost analysis, all costs should be included. The risks that are evaluated should be based on the results from the risk assessment. The analysis of disruptions focuses on emissions, noise, water demand, pollution etc. This part of the process requires a lot of resources and knowledge. (ibid.).

Compilation of Acceptable Remedial Alternatives

The results from previous steps should be compiled and presented, even the alternatives that have previously been eliminated, to make the process transparent. Every alternative should include documentation of the action, such as what action and in what way the action will be performed. The documentation should also include information about expected effects and consequences, the difficulties and risks, what safety measurements needed and of course the uncertainties related to the action. (SEPA 2009a)

4 METHODOLOGY

Several methods were used in order to conduct the project and the methods will be presented in this chapter. The methods used in this project are divided into the project's three parts.

4.1 RISK ASSESSMENT

This project followed the structure of a detailed risk assessment with standard set guidelines, provided by SEPA. In order to make a detailed risk assessment, the collecting of information was primarily from literature studies, surveys and interviews.

The literature studies used for the risk assessment provided information about what chemical parameters that were needed for the detailed risk assessment and the parameters connected to the survey. For the risk assessment, the following words were used for searching: *mercury contamination in water, dispersion model, risk assessment, mercury risk assessment, mercury poisoning, thermometer factory in Kodaikanal*

For conducting of the risk assessment, a conceptual model was created to understand the situation of contamination. The parameters needed for the risk assessment were identified and collected in order to decide what to include in the survey and the interviews (see Chapters 4.1.3 and 4.1.4). The survey was conducted in Vellagavi and focused on collecting information about the parameters needed for the risk assessment (see the survey in Appendix B.1). An ocular inspection of the study areas gave information about location, topography and vegetation for both factory site and for Vellagavi. The interviews focused on the farmers' use of pesticides for their crops and were conducted in a farming area near Kodaikanal. The interviews was used to locate if there were sources of mercury exposure that did not originate from the contaminated study area. SEPA's calculation tool was used to evaluate the site specific guideline value for both the factory site and for the village Vellagavi. A forward dose calculation was made in order to evaluate how the court-decided site specific guideline value could affect human health.

4.1.1 CONCEPTUAL MODEL

A conceptual model for workers on the factory site was created, where both health- and environmental aspects were included. Another conceptual model for the inhabitants of Vellagavi was created in order to get a better understanding of the contamination situation in the small village near the former factory. The models were based on the exposure pathways that SEPA included in their guidelines for risk assessment and complemented by the exposure pathways that were discovered during the survey and interviews (SEPA 2010). The conceptual model for the forward dose calculation was based on above mentioned guidelines from SEPA and other identified exposure pathways that were identified during the survey and interviews. The visual result for each conceptual model was created in a tool called *draw.io*.

4.1.2 PARAMETER COLLECTION

The site specific guideline values were calculated with the CPCGV. In this chapter, the collection of parameters used in the calculation model is further explained. All concentrations and guideline values in this report will be mentioned as mg/kg, referring to mg mercury per kg soil. When conducting the risk assessment some of the parameters were collected from different sources. The parameter values that were used for both factory site and Vellagavi are displayed in Table 3. The sources of the parameters used for factory site and Vellagavi are presented separately in Tables 4 - 5.

Table 3: The parameters needed for the risk assessment conducted at the factory site and Vellagavi related to the source of information

Parameter	Source
Fraction of organic carbon	Literature studies
Particles in the air	Literature studies
Average life expectancy	Literature studies
Fraction dissolved/mobile organic carbon	SEPA standard
Dry density	SEPA standard
Soil moisture level	SEPA standard
Fraction pore air	SEPA standard
Air circulation in buildings	SEPA standard
Depth to contamination	SEPA standard

For the risk assessment made on the factory site, the Swedish standard values for less sensitive land uses (MKM) were used, since it was an industrial area. The assumption was that the factory site will continue to be used for industrial purposes. The parameters used in the risk assessment for the factory site are presented in Table 4.

Table 4: The parameters needed for the risk assessment conducted on the factory site related to the source of information

Parameter	Source
Time spent indoors and outdoors	SEPA standard for less sensitive land use
Exposure time	SEPA standard for less sensitive land use
Area	Literature studies
Air volume in buildings	SEPA standard for less sensitive land use
Area under building	SEPA standard for less sensitive land use
Recharge	Literature studies, comparing three sites
Stream flow rate	Multi value analysis

For the risk assessment made on Vellagavi, the Swedish standard values for sensitive land uses (KM) were used, since it was a residential area. The number of inhabitants were determined approximately by asking people in the village. In Vellagavi, five different houses were visited during the survey. These houses provided information for the size determination of buildings in the area. The length, width and height of each room in the houses was estimated by eye and noted on the survey paper. The house sizes were used for determining the median air volume indoors and the base area of the buildings. In Vellagavi, the atmospheric transportation of mercury from the factory site to Vellagavi was excluded (see Figure 4 in Chapter 3.2). This was due to the model used in the project focused on the exposure that stemmed from the soil. The parameters used for Vellagavi are presented in Table 5.

Table 5: The parameters needed for the risk assessment conducted in Vellagavi related to the source of information

Parameter	Source
Time spent indoors and outdoors	Survey
Exposure time	SEPA standard for sensitive land use & Survey
Area	Google Maps
Air volume in buildings	Survey
Area under building	Survey
Consumption of plants	SEPA standard for sensitive land use
Fraction consumed plants grown in the area	SEPA standard for sensitive land use & Survey

4.1.3 SURVEY

The aim of the survey was to examine living habits that were connected to the exposure- and health parameters in the risk assessment. A well designed survey question is brief, where the general principle is that a survey question should have no more than 20 words or include more than three commas. Long questions tends to be more complex and they have a higher tendency to confuse the respondent. In order to make a question easy to understand, it is important to ask for only one thing at the time. (Iarossi 2006)

To receive the information about the residents in the area that was required to conduct risk assessment, a survey was carried out in Vellagavi. The survey was conducted during mid-day in Vellagavi. The selection of inhabitants included in the survey was based on the families that were not working in the fields at the moment of the survey. All survey questions were asked during the same day due to the need of having a translator present. Six families were surveyed, where one of the surveyed persons was younger than seven years. A total of 18 persons answered the survey questions. Only answers from people that were residents in Vellagavi were used in the evaluation of the survey.

Two translators helped with carrying out the survey. One of the translators was a native Tamil speaker who lived right outside the village. The second translator was a native of Germany who had lived in India for decades. The survey questions were designed to be easily understood and to provide short answers. This led to that both translators, regardless of fluency in Tamil, could ask the questions and translate the answers.

4.1.4 FARMERS' INTERVIEWS

The aim of the farmers' interviews was to examine the farming culture and to include the results from the interviews in the risk assessment in order to estimate the exposure risks from crops. The farmers' interviews were carried out in a farming community, Pallangi, located in close proximity to Kodaikanal. A PHCC member acted as a translator since the farmers only spoke Tamil. In total three farmers were interviewed. The questionnaire for local farmers was carried out in order to investigate mercury pathways within the agricultural system. The questions were:

- Where is the water for irrigation collected?
- What type of crop is grown?
- Where is the crop sold?
- Are pesticides used? What kind? How frequently?

A further inquiry was made for each pesticide that was reported during the farmers' interviews. The goal of the inquiry was to determine if any of the pesticides that were used by the farmers contained mercury or methyliodine. Depending on the available information about each pesticide, different strategies were used to retrieve the chemical composition. For the pesticides where the containers had been presented during the interview, the labels on the containers where inspected to retrieve information about the content. For the pesticides that did not have available containers, the manufactures website were visited to retrieve a list of content.

4.1.5 UNCERTAINTY ANALYSIS OF FACTORY SITE

An uncertainty analysis was made for some of the parameters that were used in the risk assessment of the factory site. The analysis was based in changing one parameter at the time to study that parameters influence on the site specific guideline value. The parameters that were changed in CPCGV for the factory site were recharge and flow rate. Recharge in this report refers to the groundwater formation within the study area. The flow rate refers to the water flows in Levinge stream that runs below the factory (see Figure 2). The uncertainty analysis was divided into two parts: human health and environment. The analysis was based on a conceptual model for workers on the factory site, using the settings for MKM as a base in CPCGV.

Recharge

An uncertainty analysis of the recharge's influence on the guideline value was made, since there was no information of recharge on the factory site. In order to collect information about recharge, studies of other locations were compared to the site properties at Kodaikanal. The two areas compared to Kodaikanal were Ruatoria and Hyderabad. Ruatoria, New Zealand, is an area that has similar yearly precipitation to Kodaikanal. Ruatoria and Kodaikanal also have similar temperature patterns, even though an offset between the two locations exists due to them being in different hemispheres (see Figure 5).

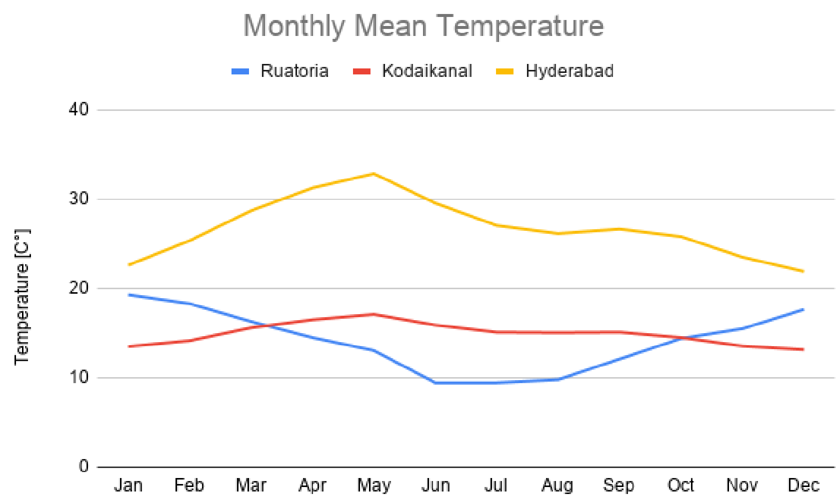


Figure 5: Average monthly Temperature for Kodaikanal (Indian Institute of Tropical Meteorology 2020a), Hyderabad (Indian Institute of Tropical Meteorology 2020b) and Ruatoria (MetService n.d.)

Hyderabad, India, is a city located around 800 km from Kodaikanal. Both areas are dominated by a sandy clay loam soil. The temperature for the area is displayed in Figure 5. Hyderabad has less precipitation and a considerably higher temperature. A higher temperature leads to higher evaporation and less water reaching the groundwater. Therefore, the recharge in Hyderabad is probably lower than the recharge in Kodaikanal. The percentages of precipitation to recharge for Hyderabad and Ruatoria are presented in Table 6.

Table 6: Compilation of precipitation, evaporation, recharge and the ratio between precipitation and recharge of three different cities

Location	**Precipitation [mm/year]**	**Recharge [mm/year]**	**Precipitation to Recharge [%]**	**Reference**
Ruatoria	$1.8 \cdot 10^3$	$6.9 \cdot 10^2$ *	39 **	(Roderick and Farquhar 2005)
Hyderabad	$8.0 \cdot 10^2$	$1.1 \cdot 10^2$	14 **	(Athavale and Murti 1980)
Kodaikanal	$1.7 \cdot 10^3$	-	-	(Sujatha and Sridhar 2017)

* Calculated from *Precipitation - Recharge*, assuming no runoff.
** Calculated from $\frac{Recharge}{Precipitation}$

The factory site is partly located on a plateau and partly on a steep slope. Because of the slope in combination with a rain pattern that consists of intensive rain showers, the area might experience a high level of surface runoff. The different levels of recharges used were: 5, 100, 210, 390, 580 mm/year. The SEPA calculation tool uses 5 mm/year as the lowest possible recharge and that value was used in order to represent a scenario where all precipitation becomes surface runoff. One scenario was that all precipitation percolated, hence no surface runoff occurred at the factory site, even though it was unlikely due to the sloping surroundings and the high-intensive rainfall. Despite this, a scenario with no surface runoff was used to evaluate the impact that a changed recharge pattern would have. The recharge value of 100 mm/year was the Swedish standard value for MKM and was therefore included in the calculations. The values 210 mm/year and 580 mm/year were based on the studies in Hyderabad and Ruatoria and were calculated by multiplying the total precipitation in Kodaikanal with each studies' percentage of precipitation to recharge. The value 390 mm/year was included in the scenario analysis since it was between the two values stemming from Ruatoria and Hyderabad to create a greater spread of values for the uncertainty analysis.

Flow Rate
The flow in the Levinge stream, which is a stream adjacent to the factory, varies during the year due to the monsoon season. The big seasonal variation in flow in combination with a lack of data made it difficult to determine the flow rate. Therefore, a wide range of possible flow rates was used for the analysis. The minimum value for reaching the alarm level in the calculation tool was 0.032 m^3 /s and the maximum value was 5 m^3 /s. The used values were evenly distributed during the interval. The calculation model's default value of 0.03171 m^3 /s was included.

Combining Recharge and Flow Rate
By combining the flow rate and recharge at the factory site, different scenarios were created. This was made in order to determine the parameters' influence on the guideline value. The different recharges and flow rates were combined in order to produce scenarios conservative scenarios and less restricting scenarios. Extreme scenarios, e.g. very recharge combined with high flow rate, were also produced in order to examine the highest obtained guideline value from CPCGV.

4.1.6 UNCERTAINTY ANALYSIS OF VELLAGAVI

An uncertainty analysis was made in the same way for Vellagavi as for the factory by changing one parameter at the time. For the uncertainty analysis of Vellagavi, three parameters were used: the amount of indoor air that exchanges during a day, the intake of locally produced crops/plants and the time spent indoors. The procedure was based on a conceptual model for the inhabitants in Vellagavi.

Exchange of Indoor Air
The parameter of air exchange was connected to the ventilation possibilities in the houses. In Sweden, the lower limit of air exchange is 12 times per day. Since the standard of the houses were a bit different in Vellagavi, compared to Sweden, the air exchange might be different. Because of the uncertainties, several air exchange values were used, starting from 12 times/day and up to the CPCGV's alarm level of 100 times/day. The value of 12 times/day was used in the other simulated scenarios, referring to a precautionary approach.

Fraction of Consumed Locally Grown Plants
The consumption rate used in the uncertainty analysis of this parameter was varied between 10 % to 90 %. The term "locally" was referring to the area that were adjacent to the city centre of Vellagavi. This parameter was related to the level of self-sufficiency and the spread of consumption rate was made in order to evaluate different possible scenarios. The rate of growing crops for self-consumption can fluctuate rather quickly since the farmland in the area already is available and agriculture practises is commonly known. For the analysis of the effect of a changed ratio of self-consumption of locally grown vegetables were set to the following values: 0.1, 0.4, 0.5 and 0.9. The investigated values were chosen to get a spread of scenarios depending on the ratio of consumed plants that is locally grown. A consumption rate of 0.1 was used in the other simulated scenarios.

Time Spent Indoors
The parameter of time spent indoors was varied between 10 % and 100 % in order to evaluate this parameter's influence on the site specific guideline value. 100 % time spent indoors was used in the other simulated scenarios, since it should be possible to spend all time indoors.

4.1.7 FORWARD DOSE CALCULATION

As a part of answering the second research question for the risk assessment part, a forward dose calculation was conducted on the factory site. A forward dose calculation provided the total exposure of the substance on a protection target. A report from 2006 stated that residences were planned to be built on the factory site (Hindustan Lever Limited 2006). Therefore, the mercury exposure to humans was evaluated, with the guideline value of 20 mg/kg in the soil (as stated in the court decision). The calculation was used in order to evaluate if the court-decided guideline value would pose a threat to future residents. The equations for the forward calculations were based on a Canadian handbook (Minister of National Health and Welfare 1995). Assumptions used in CPCGV were applied on the calculations. The equations can be found in Chapter 5.7. All calculations were made for both adults and children. The parameters, that were adjusted in order to suite to the site specific conditions, were related to ingestion, inhalation and dermal uptake.

4.2 IMPLEMENTATION OF RISK ASSESSMENTS

The literature used in this part of the project was mainly reports published by governmental agencies or companies. To get an insight of how risk assessments were conducted in India, email interviews were conducted with people working with practical knowledge about Indian risk assessments. To locate individuals working with risk assessments in India LinkedIn was used. The search word "Contaminated Soil Risk Assessment" was paired with the location set to "India". A contact request was sent to individuals that on their CV stated to have worked with risk assessments for contaminated soil. The contact request where accompanied by a 300 word message briefly explaining the study and the aspiration to ask questions about risk assessments in India, the message can be found in Appendix C. From the total numbers of contacted persons, two had the correct background and were willing to answer questions. The interviews where conducted trough direct messaging at LinkedIn.

One interview was conducted with an Administrative official at the Swedish county government to acquire information about implementing practises of risk assessment in Sweden. The interview was held as a video meeting. Information was also recovered from follow up conversation via written communication.

4.3 REMEDIAL EVALUATION

The evaluation of remedial alternatives followed the suggested assessment procedure from SEPA and evaluated potential remedial alternatives for both the factory site and Vellagavi (SEPA 2009a). The evaluation was primarily based on literature studies and followed the procedure presented in Chapter 3.5.1. The identification of remedial alternatives was based on previous known remedial actions that could work on mercury contaminated sites. A website called *Åtgärdsportalen* was used to identify possible remedial actions, using literature studies as a complement. An initial analysis of the identified remedial alternatives was made.

The cost estimation made in the remediation part of the project was very rough and based on that all soil at the whole factory site were supposed to be remediated, to a contamination depth of 0.35 m. The estimation was made in order to approximate the magnitude of the costs, not the absolute value. The cost estimation was based on American studies and methods, hence cannot be directly translated into Indian values, since there are differences in economics between the two countries.

The results from the remedial evaluation were based on the results from the risk assessment made in this project, which indicated a need of remediation. Literature studies for this part of the project were mainly based on platforms such as Google Scholar, Scopus, Researchgate and the online library of Uppsala University. The following words were used for searching: *remediation mercury, mercury measurements, phytoremediation, mercury uptake plants, mercury in mushrooms*

5 RESULTS OF RISK ASSESSMENT

In this chapter, the results from the survey, interviews and the risk assessment will be presented. In Chapter 6, there will be discussions of the risk assessment results. The results and discussions for the extended foci will be presented in Chapters 7 and 8.

5.1 SURVEY

The results from the survey conducted in Vellagavi were mainly the following (see Appendix B.2 for a more thoroughly description):

- Men spent most of the time outdoors and women spent most of the time indoors.
- The main crops grown in Vellagavi were "cash crops" that the inhabitants sold at the Kodaikanal Sunday Market.
- They bought almost all of their food at the Kodaikanal Sunday Market.
- The water used in Vellagavi mainly came from a well located several kilometres from Vellagavi.

After the survey, some follow-up questions were asked to some PHCC members. The water in the well originated from another well below an area called Vattakanal and the water was transported through pipes down to Vellagavi. The water source was not considered to be threatened by mercury contamination from the factory site. [1] The river below Vellagavi was not used for washing clothes since it was difficult to reach. [2] The results from the survey were used for calculating the site specific guideline values for Vellagavi.

5.2 FARMERS' INTERVIEWS

The results from the farmers' interviews conducted in Pallangi, Kodaikanal were (see Appendix A for more thorough answers):

- Most farming areas were placed on the north side of the mountain (the opposite side of the mountain relative to the factory site). Therefore, the risk of contamination from the factory is low.
- Most farmers delivered their crops to the Kodaikanal Sunday Market.
- Pesticides were used in the area.
- The pesticides presented in this report were not found to contain any mercury (see Table 7).

[1] Mr. Bala, Secretary, PHCC, Personal communication, 09/04/2020
[2] Annette Baumann, Member, PHCC, Personal communication, 19/04/2020

Table 7: Pesticides used by the interviewed farmers and their chemical components, where the dash represents that no information was found

Pesticide	Active ingredient/s	Does is contain:		Reference
		Mercury	Methyl iodide	
Indofil Z-78	Zinc ethylene Bis Dithiocarbamate	Probably not	Probably not	Package label
Tarzan Rite	Triazophos	Probably not	Probably not	Package label
Folio gold	Chlorothalonil, metalaxyl-M	No	No	(Syngenta 2016)
Dithane M45	Mancozeb	No	No	(Dow AgroSciences n.d.)
Nuvacron	Monocrotophos	Probably not	Probably not	Package label
Condap	-	-	-	-
Carset	-	-	-	-
Power win	-	-	-	-
X-TRA power	-	-	-	-

To determine if the pesticides contained mercury or methyliodide, labels on the packages were used in combination with online searching for a complete table of content for each product. Only one farmer agreed to show the packages for the pesticides. The pesticides presented by the farmer were: Indofil Z 78, Tarzan Rite, Nuvacron, Power win and X-tra power. The packages for Power win and X-tra power did not have any table of content nor information about the active ingredient. No information of the two pesticides could be found online. Therefore, no analysis could be made on the chemical compounds. For the pesticides Condap and Carset no information could be found online. There were no indicators that either of the two pesticides contained mercury or methyliodine. The pesticides that had a complete list of ingredients and did not report any mercury-related ingredients are marked as “No”, while pesticides with a partial list of ingredients are marked as “Probably not” in Table 7. Pesticides used by farmers did probably not consist of mercury related ingredients. Therefore, the exposure pathway from pesticides were eliminated from the exposure calculations.

5.3 LITERATURE VALUES FOR RISK ASSESSMENT

In order to calculate the site specific guideline value for mercury in soil for the factory site and for Vellagavi, literature values for the parameters were collected. The calculation was based on the CPCGV and was used in the risk assessment.

The value of particles in the air used in the model was based on air quality measurements in Ooty, which is another hill-station in the Western Ghats that shares many similarities with Kodaikanal. The average PM2.5 level in Ooty was 24 μg /m^3 during the period 28-07-2019 to 07-03-2020 (World Air Map n.d.). The data of fraction of organic carbon was collected from a previous study, conducted in collaboration with the PHCC (Beardsley-Schoonmaker 2011). The fraction organic carbon was measured in four places around Kodaikanal. It was assumed that the soil parameters in Vellagavi were similar to the ones in Kodaikanal. The median value of the four measurements, which gave a fraction of organic carbon of 0.0146 kg/kg, were used in CPCGV.

In order to calculate air circulation in houses the volume of the houses in Vellagavi were estimated by ocular inspection during the survey. The largest house visited during the survey also accounted for the largest house in the village. This house was considered an outlier since all other houses in the village were noticeably smaller. Hence, the largest house was excluded from the data set of house volume.

The parameters in the risk assessment that were collected are presented in Table 8.

Table 8: Parameters used for the risk assessment in Vellagavi and the factory site. The missing values in the table were not relevant for the calculations at the specific sites and therefore not presented in the table

Parameter	Factory Site	Vellagavi	Unit	Reference
Fraction of organic carbon	$1.4 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$	kg/kg	(Beardsley-Schoonmaker 2011)
Particles in the air	25	25	μg/m^3	(Plume Labs n.d.)
Average life expectancy	69	69	years	(World Bank 2018)
Fraction dissolved/mobile organic carbon	$3.0 \cdot 10^{-6}$	$3.0 \cdot 10^{-6}$	kg/dm^3	(SEPA 2009b)
Dry density	1.5	1.5	kg/dm^3	(SEPA 2009b)
Soil moisture level	0.32	0.32	dm^3/dm^3	(SEPA 2009b)
Fraction pore air	$8.0 \cdot 10^{-2}$	$8.0 \cdot 10^{-2}$	dm^3/dm^3	(SEPA 2009b)
Air circulation in buildings	12	12	/day	(SEPA 2009b)
Depth to contamination	0.35	0.35	m	(SEPA 2009b)
Hydraulic conductivity	$1.0 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$	m/s	(SEPA 2009b)
Hydraulic gradient	$3.0 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	m/m	(SEPA 2009b)
Thickness of the aquifer	10	10	m	(SEPA 2009b)
Fraction of time spent indoors	1.0	1.0		(SEPA 2009b)
Exposure time - Intake of polluted soil	$2.0 \cdot 10^{2*}$ / 60^{**}	$3.65 \cdot 10^2$	days/year	(SEPA 2009b)
Exposure time - Dermal contact with soil	90^* / 60^{**}	$3.65 \cdot 10^2$	days/year	(SEPA 2009b)
Exposure time - Inhalation of dust	$2.0 \cdot 10^{2*}$ / 60^{**}	$3.65 \cdot 10^2$	days/year	(SEPA 2009b)
Exposure time - Inhalation of vapour	$2.0 \cdot 10^{2*}$ / 60^{**}	$3.65 \cdot 10^2$	days/year	(SEPA 2009b)
Area	$8.5 \cdot 10^4$	-	m^2	(Hindustan Lever Limited 2006)
Air volume in buildings	$2.4 \cdot 10^2$	18	m^3	(SEPA 2009b) Results from the survey
Area under building	$1.0 \cdot 10^2$	9	m^2	(SEPA 2009b) Results from the survey
Recharge	$1.0 \cdot 10^2$	-	mm/year	(SEPA 2009b)
Stream flow rate	$3.2 \cdot 10^{-2}$	-	m^3/s	(SEPA 2009b)
Consumption of plants	-	0.25	kg/day	(SEPA 2009b)
Fraction consumed plants grown in the area	-	0.10		(SEPA 2009b)

* Value used for adults.
** Value used for children.

5.4 UNCERTAINTY ANALYSIS OF FACTORY SITE

In order to examine different scenarios and to make an analysis of uncertainties, several parameters were changed one by one. The reason for the chosen parameter values can be found in Section 4.1.5. The focus for the factory site was the environmental aspects, due to the lack of information related to human health, such as air volume in buildings. A previous report that determined the site specific guideline value at the factory site had disregarded all environmental effects (Hindustan Lever Limited 2006). Therefore, it seemed important to investigate the environmental impact on the guideline value. The protection targets for the environmental part of the assessment at the factory site were surface water (Levinge stream), terrestrial ecosystems and groundwater.

5.4.1 CONCEPTUAL MODEL FOR FACTORY SITE

The identified exposure pathways for potential workers working on the factory site were compiled into a conceptual model, presented in Figure 6.

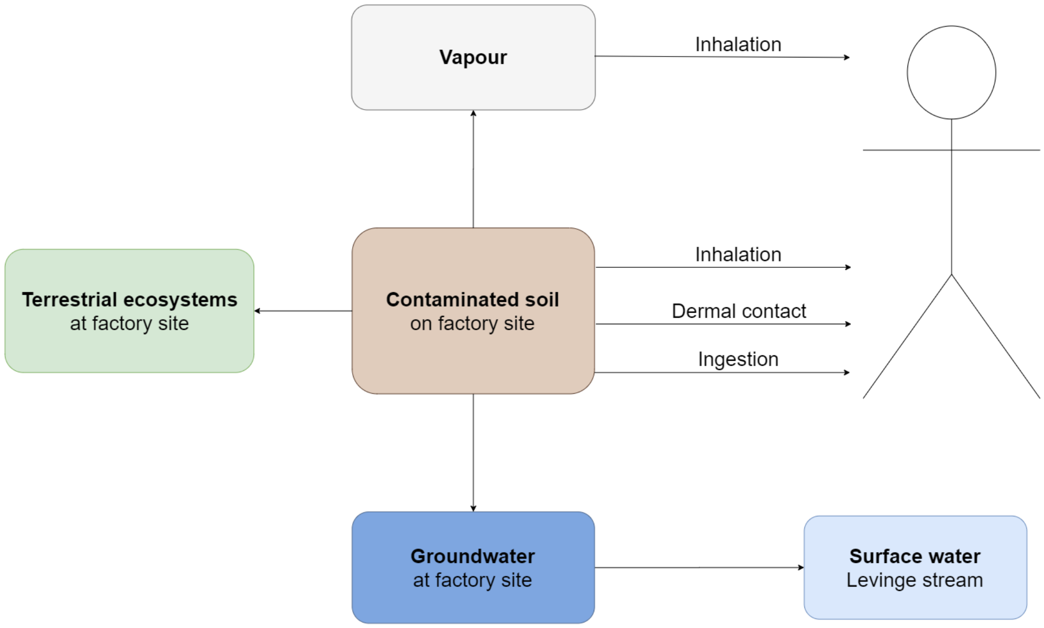


Figure 6: A conceptual model of the pathways for mercury exposure from the contaminated soil to humans working on the factory site and for the three environmental protection targets: terrestrial ecosystem, groundwater and the Levinge stream.

The identified exposure pathways for the factory site were the same exposure pathways that were recommended by SEPA for less sensitive land use. The protection target for human health was assumed to be people working in the area. The exposure pathway for ingesting plants grown on the site was not considered, since no one was assumed to have a vegetable garden at their workplace.

5.4.2 GUIDELINE VALUE FOR HEALTH EFFECTS

In this scenario it was assumed that people (adults) were working at the factory and would spend 200 days at the factory site. The SEPA values for MKM were used as a foundation for the calculations. The exact parameter values for the factory site are presented in Table 8. By using the CPCGV, the result for the health based guideline value was obtained (see Table 9).

Table 9: Single exposure pathway concentration and guideline values for health based mercury exposure. The health guideline values were not affected by any change of recharge or flow rate

Single Exposure Pathway Concentration [mg/kg]					Health Guideline Value for Long Time Exposure [mg/kg]	Guideline Value for Health Effects [mg/kg]
Inhalation of Soil Particles	**Dermal Exposure to Soil/Dust**	**Inhalation of Dust**	**Inhalation of Vapour**	**Ingestion of Plants**		
52	$1.0 \cdot 10^3$	$1.2 \cdot 10^4$	2.5	-	2.4	2.4

Recharge and flow rate did not affect the health based guideline values since those parameters were not included in the health-related calculations. If the groundwater would have been used as drinking water, the health based guideline value would have been dependant on the recharge. As mentioned previously, the result reflected a scenario where the factory site continues to be used as a factory. The result did not reflect a suitable guideline value for a residential area.

5.4.3 ENVIRONMENTAL GUIDELINE VALUE

In order to calculate the environmental guideline value for the factory site, two parameters were used in the uncertainty analysis: recharge and flow rate. Recharge was defined as the groundwater recharge on the factory site, whereas the flow rate was based on the water flows in the river below the factory. Protection of groundwater and surface water were important protection targets in the environmental risk assessment. The environmental guideline value represents the amount of mercury in soil that does not pose a risk for the environment, e.g. water, soil, plants, biodiversity etc.

Recharge
For the uncertainty analysis of possible recharges on the factory site, the environmental guideline values were calculated for different recharge values (see Table 10).

Table 10: The accepted single exposure pathway concentration of mercury in soil and the environmental guideline values for different exposure pathways, depending on the range of possible recharge values. The italic value indicates the standard value used in CPCGV

Recharge [mm/year]	Protection of Ground Ecosystems [mg/kg]	Protection of Groundwater [mg/kg]	Protection of Surface Water [mg/kg]	Environmental Guideline Value [mg/kg]
5.0	10	11	1.4	1.4
$1.0 \cdot 10^2$	10	0.83	$7.1 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$
$2.1 \cdot 10^2$	10	0.55	$3.0 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$
$3.9 \cdot 10^2$	10	0.44	$2.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
$5.8 \cdot 10^2$	10	0.39	$1.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-2}$

A change in the level of recharge affected both protection of groundwater and protection of surface water. The limiting guideline value was protection of surface water in all scenarios. The effect the recharge had on the guideline value was greater at lower recharge values. This points to the importance of making measurements of recharge. Even at a recharge rate of 100 mm/year the guideline value was below the background level of 0.1 mg/kg of mercury.

Flow Rate
An uncertainty analysis of the flow rate's influence on the guideline value was conducted. To locate the threshold value that resulted in protection of groundwater being the limiting factor for the guideline value, the flow rate of 0.4 m^3/s was included. The guideline values for environmental and human exposure are presented in Table 11.

Table 11: The accepted single exposure pathway concentration of mercury in soil and the environmental guideline values for different exposure pathways, depending on the range of possible flow rate values. The italic value indicates the standard value used in CPCGV

Flow Rate [m^3/s]	Protection of Ground Ecosystems [mg/kg]	Protection of Groundwater [mg/kg]	Protection of Surface Water [mg/kg]	Environmental Guideline Value [mg/kg]
$3.2 \cdot 10^{-2}$	10	0.83	$7.1 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$
0.10	10	0.83	0.22	0.22
0.40	10	0.83	0.89	0.83
1.0	10	0.83	2.2	0.83
3.0	10	0.83	6.7	0.83
5.0	10	0.83	11	0.83

Recharge and Flow Rate
The recharge and flow rate values that resulted in the lowest guideline value were combined to produce a scenario for the most conservative guideline value (see the last row in Table 12). The recharge and flow rate values that resulted in the highest guideline value were combined to produce a scenario with the least restricting guideline value (see the

first row in Table 12). The least and most conservative guideline values were not probable since the two parameters were positively correlated, due to their dependence on precipitation. To test a more likely scenario, a high recharge was combined with a high flow rate. A low recharge was combined with a low flow rate for examining a scenario with less precipitation. The results are shown in Table 12.

Table 12: The accepted single exposure pathway concentration of mercury in soil and the environmental guideline values for different exposure pathways, depending on the range of possible combinations between recharge- and flow rate values

Recharge [mm/year]	Flow Rate [m^3/s]	Protection of Ground Ecosystems [mg/kg]	Protection of Groundwater [mg/kg]	Protection of Surface Water [mg/kg]	Environmental Guideline Value [mg/kg]
5.0	5.0	5.0	11	$2.3 \cdot 10^2$	5.0
5.0	$3.2 \cdot 10^{-2}$	5.0	18	1.4	1.4
$1.0 \cdot 10^2$	0.10	5,0	1.1	0.22	0.22
$2.1 \cdot 10^2$	1	5.0	0.58	1.1	0.58
$3.9 \cdot 10^2$	3.0	5.0	0.39	1.7	0.39
$5.8 \cdot 10^2$	5.0	5.0	0.31	1.9	0.31
$5.8 \cdot 10^2$	$1.0 \cdot 10^{-4}$	5.0	0.39	$3.8 \cdot 10^{-5}$	$3.8 \cdot 10^{-5}$

To summarise, the site specific guideline values for the factory site ranged between 0.1 - 2.4 mg/kg, for the less sensitive land use, when both environmental and human impacts were considered. For the environmental analysis, the limiting exposure pathway varied between protection of surface water and protection of groundwater depending on the values used for recharge and flow rate. The limiting value for health effect came from the exposure pathway for long time exposure.

5.5 UNCERTAINTY ANALYSIS OF VELLAGAVI

In order to examine different scenarios and to make an uncertainty analysis, the following parameters were used: the amount of indoor air that exchanges during a day, the intake of locally produced crops/plants and the time spent indoors. The reason for the chosen parameter values can be found in Section 4.1.6. The uncertainty analysis in Vellagavi was only conducted for humans as a protection target, focusing on health aspects. The environmental aspects were not examined due to a lack of information. The settings for KM was used as a base in CPCGV.

5.5.1 CONCEPTUAL MODEL FOR VELLAGAVI

The identified exposure pathways for the inhabitants of Vellagavi was compiled into a conceptual model, presented in Figure 7.

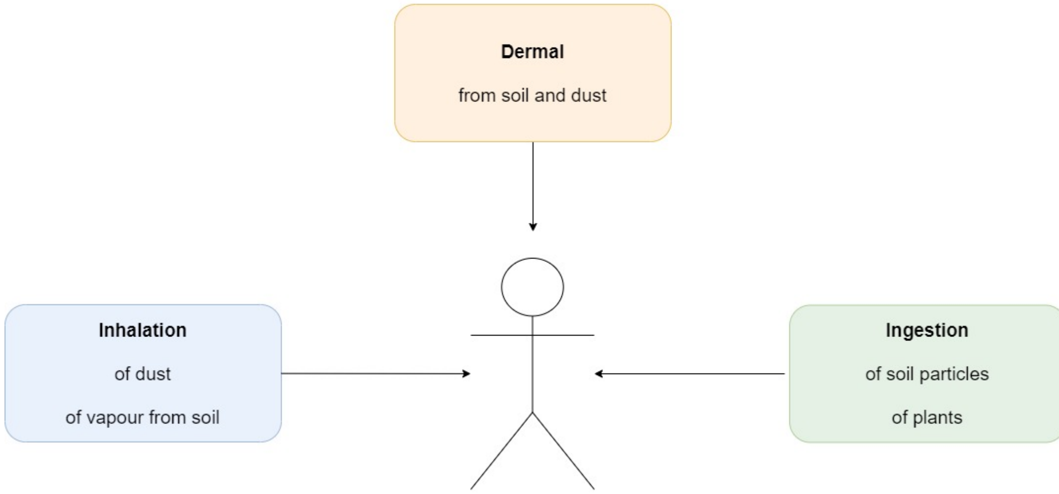


Figure 7: A conceptual model for mercury exposure pathways to humans in Vellagavi.

The conceptual model was used to indicate the exposure pathways that were in included in the calculation for a health based site specific guideline value. All exposure pathways originated from the contaminated site. During this analysis, the contaminated site referred to the village Vellagavi. It was assumed that mercury had travelled from the factory to the village, where the deposition of mercury have contaminated the soil in Vellagavi. Exposure from external sources of mercury does not effect the result from the CPCGV and therefore the site specific values generated in this analysis.

The conceptual model for Vellagavi included several exposure pathways. Mercury uptake can bind to trees and plants, which later on can be used as firewood when cooking or plants for eating. This can be considered as a source of mercury exposure. The exposure pathway through burning contaminated firewood was not included in the conceptual model due to the lack of data. Ingestion of plants stemming from the area was included in the conceptual model.

Mercury can also be transported through deposition and soil transport into adjacent waters. If using that water it can lead to mercury exposure. Since the survey did not indicate that any contact with surface water in the area occurred, the exposure pathway was not included in the conceptual model.

5.5.2 GUIDELINE VALUE FOR HEALTH EFFECTS

Exchange of Indoor Air

In the uncertainty analysis of the parameter exchange of indoor air, a range of health based guideline values of mercury exposure were obtained. The valued ranged between an air exchange at 12 times/day that was the Swedish standard and up to 100 times/day that was the alarm level in CPCGV. The result from the analysis is presented in Table 13.

Table 13: The accepted single exposure pathway concentration of mercury in soil and the health guideline values for different exposure pathways, depending on the air exchange scenarios. The italic value indicates the standard value used in CPCGV

Air Exchange [times/day]	Single Exposure Pathway Concentration [mg/kg]					Health Guideline Value for Long Time Exposure [mg/kg]	Guideline Value for Health Effects [mg/kg]
	Inhalation of Soil Particles	Dermal Exposure of Soil/Dust	Inhalation of Dust	Inhalation of Vapour	Ingestion of Plants		
12	5.8	69	$1.8 \cdot 10^3$	0.34	0.76	0.22	0.22
18	5.8	69	$1.8 \cdot 10^3$	0.51	0.76	0.29	0.29
24	5.8	69	$1.8 \cdot 10^3$	0.68	0.76	0.34	0.34
50	5.8	69	$1.8 \cdot 10^3$	1.4	0.76	0.45	0.45
75	5.8	69	$1.8 \cdot 10^3$	2.1	0.76	0.51	0.51
$1.0 \cdot 10^2$	5.8	69	$1.8 \cdot 10^3$	2.8	0.76	0.54	0.54

Fraction of Consumed Locally Grown Plants
The crops grown in Vellagavi was mainly cash crops that was sold at either the market in Kodaikanal or in the plains. The result from the survey showed that the diet of the inhabitants of Vellagavi mainly relied on vegetables produced in other areas. The villagers in Vellagavi did consume their own produce that they were not able to sell at the market. Therefore, a consumption rate of locally grown plants was estimated to 0.1 (10 %) which was used in the other simulated scenarios. The result from different fractions of local plant consumption is shown in Table 14.

Table 14: The accepted single exposure pathway concentration of mercury in soil and the health guideline values for different exposure pathways, depending on the consumed fraction of locally grown plants. The italic value indicates the standard value used in CPCGV

Consumed Locally Grown Plants	Single Exposure Pathway Concentration [mg/kg]					Health Guideline Value for Long Time Exposure [mg/kg]	Guideline Value for Health Effects [mg/kg]
	Inhalation of Soil Particles	Dermal Exposure to Soil/Dust	Inhalation of Dust	Inhalation of Vapour	Ingestion of Plants		
0.10	5.8	69	$2.1 \cdot 10^3$	0.34	0.76	0.22	0.22
0.40	5.8	69	$2.1 \cdot 10^3$	0.34	0.19	0.12	0.12
0.50	5.8	69	$2.1 \cdot 10^3$	0.34	0.15	0.10	0.10
0.90	5.8	69	$2.1 \cdot 10^3$	0.34	$8.5 \cdot 10^{-2}$	$6.7 \cdot 10^{-2}$	$6.7 \cdot 10^{-2}$

Time Spent Indoors
Time spent indoors was referring to the amount of time that the inhabitants spent indoors. From the survey it was clear that the difference between men and women were significant. The men were mostly in the field when women, in contrast, were mostly at the house. Only a few hours a day did the women leave their houses for getting water and collecting fire wood. In the report the value of 1, e.g. 100 %, of time spent indoors was used in the other simulated scenarios. This was due to the fact that the inhabitants should be able to stay at home for a full day without being exposed to dangerous levels of mercury, referring to a precautionary principle. The health based guideline value for the different scenarios are presented in Table 15.

Table 15: The accepted single exposure pathway concentration of mercury in soil and the health guideline values for different exposure pathways, depending on the amount of time spent indoors. The italic value indicates the standard value used in CPCGV

Fraction of Time Spent Indoors	**Single Exposure Pathway Concentration [mg/kg]**					**Health Guideline Value for Long Time Exposure [mg/kg]**	**Guideline Value for Health Effects [mg/kg]**
	Inhalation of Soil Particles	**Dermal Exposure to Soil/Dust**	**Inhalation of Dust**	**Inhalation of Vapour**	**Ingestion of Plants**		
0.1	5.8	69	$1.8 \cdot 10^3$	3.3	0.76	0.55	0.55
0.5	5.8	69	$1.8 \cdot 10^3$	0.67	0.76	0.33	0.33
0.8	5.8	69	$1.8 \cdot 10^3$	0.42	0.76	0.26	0.26
0.9	5.8	69	$1.8 \cdot 10^3$	0.38	0.76	0.24	0.24
1	5.8	69	$1.8 \cdot 10^3$	0.34	0.76	0.22	0.22

The guideline values for soil, based on health aspects, ranged from background level (0.1 mg/kg) to 0.55 mg/kg. The percentage of consumption of locally grown plants was the only parameter that could lead to a guideline value that was below the background level. Long time exposure was the limiting exposure pathway in all cases.

5.6 OTHER EXPOSURE PATHWAYS

The Swedish CPCGV have a limited number of possible exposure pathways and only accounts for exposure that originates from the contaminated area. Therefore, it was investigated if there are other possible exposure pathways, both originating from the contaminated area and from outside sources, that might have an effect.

When searching for other possible exposure pathways, it seemed like the use of skin whitening creams were a potential source of mercury exposure. During the field study, it became clear that skin whitening creams were used in India. According to the survey performed in Vellagavi, no one in the village were using skin whitening creams in a daily skin care routine, but the younger generation and people in bigger villages and cities might be using them. When visiting regular grocery stores there were skin whitening creams for sale. The only skin whitening cream that was examined in this report was found to contain mercury as an ingredient to lighten the skin. It was the skin whitening cream “Fair and Lovely” and it contained 0.1 mg mercury per kg cream, which is a considerable amount of the TDI. The use of skin whitening creams might have an impact on the results from the risk assessment, since this exposure pathway is not included in the model.

Burning contaminated wood might also be considered as a possible exposure pathway, since the answers from the survey showed that inhabitants of Vellagavi collects their firewood used for cooking in the nearby areas. Plant uptake of mercury is possible and therefore, there might be a risk of mercury exposure when burning the wood indoors. It was not possible to conduct any measurements on the contamination risk from burning firewood and therefore it was not included as an exposure pathway in the calculations. For future studies, it would be interesting to investigate the exposure from burning contaminated wood.

5.7 FORWARD DOSE CALCULATION

For the forward dose calculation, the mercury concentration in the soil was set to 20 mg/kg, since it was decided in an Indian court as the limit value for remedial actions for future land use. A scenario where residential houses were built on the factory site was used in order to calculate the total exposure for a potential future resident in the area. The constructed houses were assumed to be built in accordance with Swedish standards. Therefore, the dimensions of the houses, thickness of houses foundations and air exchange were all set to be equal to the SEPA standard values for KM used in CPCGV. The contamination depth in soil was assumed to be 0.35 m, the same value that was used in the backward calculations.

5.7.1 CONCEPTUAL MODEL FOR FORWARD DOSE CALCULATION

In order to identify the mercury exposure pathways for potential residential living on the factory site, a conceptual model was created and used for the forward dose calculation (see Figure 8).

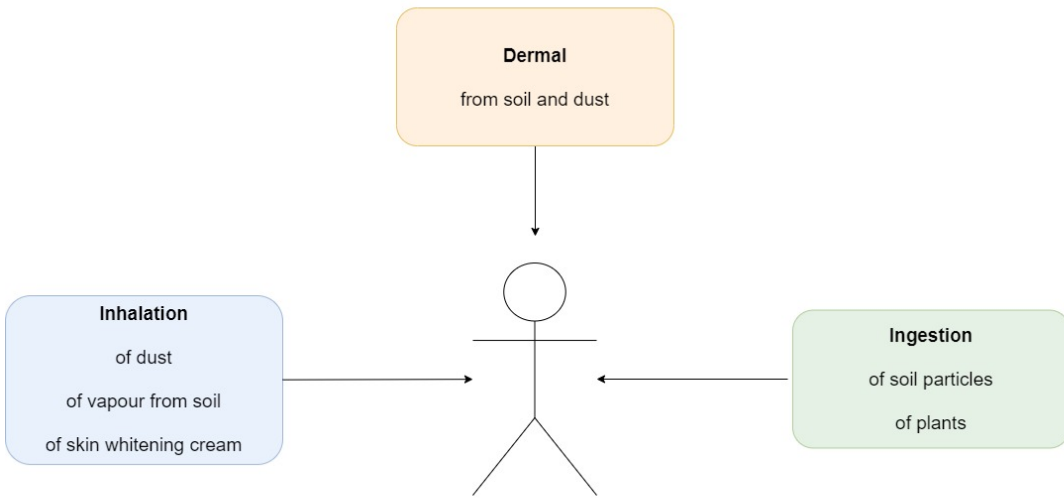


Figure 8: A conceptual model for mercury exposure pathways to people living on the factory site. The conceptual model was used for the forward dose calculation.

The difference in this conceptual model, compared to the ones used for the uncertainty analysis for factory site and Vellagavi, was the exposure from skin whitening creams. Some of the skin whitening creams contains mercury and since there was a widespread use of the creams in India, this exposure pathway was included in the conceptual model for the forward dose calculation.

5.7.2 EQUATIONS AND PARAMETERS

For the calculation of the intake from ingestion of locally grown plants (see Equation (1)) and ingestion of soil (see Equation (2)), methylmercury and elemental mercury were considered. It was assumed that the soil consisted of 0.15 % methylmercury and the remaining mercury was assumed to be elemental mercury. Parameter definitions and values for Equations (1)-(6) are given in Table 16. The choice of taking different forms of mercury into account during the oral intake was due to methylmercury having a higher bioavailability in the digestion system then other forms of mercury.

$$\begin{aligned} \text{Hg from Ingestion of Plants} = {} & \frac{C_{root} \cdot R_{con\_plant} \cdot F_{plant\_grow} \cdot F_{root} \cdot F_{bio\_in\_MeHg} \cdot F_{MeHg}}{BW} \\ & + \frac{C_{leaf} \cdot R_{con\_plant} \cdot F_{plant\_grow} \cdot (1 - F_{root}) \cdot F_{bio\_in\_MeHg} \cdot (1 - F_{MeHg})}{BW} \\ & + \frac{C_{root} \cdot R_{con\_plant} \cdot F_{plant\_grow} \cdot F_{root} \cdot F_{bio\_in\_Hg} \cdot F_{Hg}}{BW} \\ & + \frac{C_{leaf} \cdot R_{con\_plant} \cdot F_{plant\_grow} \cdot (1 - F_{root}) \cdot F_{bio\_in\_Hg} \cdot (1 - F_{Hg})}{BW} \end{aligned} \tag{1}$$

$$\text{Hg from Ingestion of Soil} = \frac{C_{soil} \cdot R_{soil} \cdot F_{bio\_in\_MeHg} \cdot F_{MeHg}}{BW} + \frac{C_{soil} \cdot R_{soil} \cdot F_{bio\_in\_Hg} \cdot (1 - F_{MeHg})}{BW} \tag{2}$$

For inhalation, the calculations were based on 100 % of the time spent indoors, since it is was subject of maximum exposure and the exposure should not pose a threat if spending all the time indoors. In the forward dose calculation, the time spent indoors was connected to the parameter of soil vapour from indoor air. The inhalation exposure pathway consisted of three sub-pathways: soil vapour, inhalation of dust (mercury containing dust) and inhalation of vapour from skin whitening creams. For the lung retention parameter (inhalation of dust), the SEPA standard value of 75 % was used, which reflected the amount of mercury that was absorbed and withhold by the lungs in relation to the total intake of mercury contaminated air. Equations (3)-(5) were used for calculating the exposure pathway of inhalation.

$$\text{Hg from Inhalation of Soil Vapour} = \frac{C_{in\_air} \cdot F_{lung} \cdot R_{lung}}{BW} \tag{3}$$

$$\text{Hg from Inhalation of Dust} = \frac{C_{soil} \cdot C_{part} \cdot F_{site\_dust} \cdot F_{lung} \cdot R_{lung}}{BW} \tag{4}$$

$$\text{Hg from Inhalation of Vapour from Skin Whitening Cream} = \frac{C_{bedr} \cdot F_{lung} \cdot R_{lung}}{BW} \tag{5}$$

For dermal exposure, the exposure from contaminated soil and the use of skin whitening cream were calculated (see Equation (6)). The mercury uptake through skin was 0.01%, in accordance with the value provided by SEPA (Kemakta Konsult AB 2016).

$$\text{Hg from Dermal Exposure} = \frac{C_{soil} \cdot R_{soil\_exp} \cdot R_{skin\_exp} \cdot F_{skin\_exp}}{BW} \tag{6}$$

The parameter values that were used in the forward dose calculation are presented in Table 16.

Table 16: The values used for each parameter during the forward calculations

Parameter	Denotation	Value	Unit	Reference
		Ingestion		
Concentration Hg in root vegetables	C_{root}	$8.6 \cdot 10^{-3}$	kg/kg	CPCGV*
Concentration Hg in leafy vegetables	C_{leaf}	$2.2 \cdot 10^{-3}$	kg/kg	CPCGV*
Amount consumed plants, Adults/Children	$R_{con\_plant\_a}$	0.40 / 0.25	kg/day	(SEPA 2009b)
Fraction of plants consumed plants grown on site	F_{plant_grow}	10	%	(SEPA 2009b)
Fraction of consumed root vegetables	F_{root}	50	%	(SEPA 2009b)
Factor for absorption of ingested MeHg	$F_{bio\_in\_MeHg}$	90	%	(SEPA 2009c)
Factor for absorption of ingested Hg	$F_{bio\_in\_Hg}$	$1.0 \cdot 10^{-2}$	%	(SEPA 2009c)
Fraction MeHg out of Tot-Hg	F_{MeHg}	0.15	%	(ERM 2007)
Body weight, Adults/Children	BW	70 / 15	kg	(SEPA 2009b)
Concentration of Hg in soil	C_{soil}	20	mg/kg	(HUL 2017)
Amount consumed soil, Adults/Children	R_{soil}	50 / 120	mg/day	(SEPA 2009b)
		Inhalation		
Concentration of Hg in indoor air	$C_{in_a ir}$	$2.4 \cdot 10^{-3}$	mg/m^3	CPCGV*
Lung retention	F_{lung}	75	%	(SEPA 2009b)
Lung volume, Adults/Children	R_{lung}	20 / 7.6	m^3/day	(SEPA 2009b)
Amount of soil particles in air	C_{part}	$2.4 \cdot 10^{-7}$	kg/m^3	(World Air Map n.d.)
Fraction of dust originating from the polluted site	F_{site_dust}	50	%	(SEPA 2009b)
Concentration Hg in bedroom air	C_{bedr}	$4.3 \cdot 10^{-3}$	mg/m^3	(Copan et al. 2012)
		Dermal		
Skin exposure to contaminated soil	R_{soil_exp}	2.0	kg/m^2	(SEPA 2009b)
Amount exposed skin, Adults/Children	R_{skin_exp}	0.30 / 0.20	m^2	(SEPA 2009b)
Fraction of Hg absorption from dermal exposure	F_{skin_exp}	$1.0 \cdot 10^{-2}$	%	(SEPA 2009c)

* From the tab "Halter" within CPCGV

5.7.3 RESULT OF FORWARD DOSE CALCULATION

All exposure pathways (Equations (1) - (6)) were summarised in order to calculate the exposure from soil containing 20 mg/kg, as decided in court, to the site specific guideline value (HUL 2018). To evaluate if the decided concentration in soil poses a threat to people if they would live on the factory site in the future, a forward dose calculation was made. The results are presented in Figure 9.

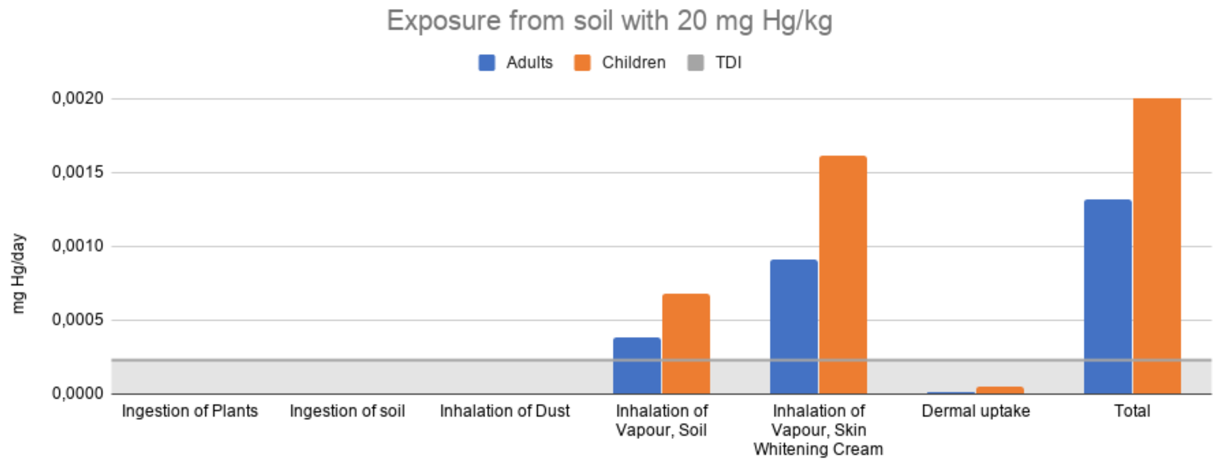


Figure 9: The exposure from different exposure path for one person during one day, including TDI for a 70 kg adult and 15 kg child.

The total exposure exceeded the TDI values for both children and adults when all exposure pathways were summarised (see Figure 9). Both the exposure from inhalation of skin whitening creams and of mercury vapour stemming from the soil exceeded the TDI-value for the factory site.

In this scenario, only 10 % of the consumed food was considered grown on the site. This percentage could be different depending on the level of own-grown food. Fish was not included in the diet, leading to less exposure of mercury, since mercury has the capacity to accumulate in biomass. Based on the interviews, the exposure of mercury through pesticides were excluded from the forward dose calculations since the pesticides that were used in the Kodaikanal area did probably not contain any mercury.

6 DISCUSSION OF RISK ASSESSMENT

6.1 SURVEY

The survey was conducted in the small village of Vellagavi, about 2 km from the factory site. There were not many people speaking English, which led to the choice of using a translator. It is not preferable to use a translator for surveys since it increases the risk of the misunderstandings of questions. In this case, the survey would not have been possible to conduct without the translator.

Depending on the type of agency that carries out a survey, the same questions can get different responses. When governmental agencies conduct surveys about sensitive issues, for example corruption, under-reporting is a problem (Iarossi 2006). At the same time it has been shown that when a governmental agency asks about non-sensitive questions, the result has a higher data accuracy than if the same questions where asked by a private firm. Therefore, it is important to consider what effects the position of the organisation that conducts the interview has on the results.

The choice of conducting a semi-structured survey method was probably the best fitted for the situation, since the method allowed us and the translator to interpret the questions and answers without loosing the essence of the question. Of course, the use of a translator always brings an aspect of uncertainty which should be taken into consideration when analysing and using the results. We were not familiar with the villagers from before, in contrary to the translator. This led to the translator being able to expand the questions and answers in order to make the survey understandable for everyone involved. This was helpful when conducting a survey in an (to us) unknown language. Some of the survey questions were removed after discussions with the translators, since the questions were not relevant for Vellagavi. One example is the question “Do you own a cow? If so, is the milk consumed in the household?”. No one in the village owned a cow. Keeping the irrelevant questions only risked taking focus away from the more important questions. All removed questions are presented in Appendix B.1 together with explanations of why they were removed.

Overall, the answers for living patterns, food culture and house construction in the village were very homogeneous. The translators confirmed that the answers from the surveyed people accurately represented the village as a whole. All answers from the survey can be found in Appendix B.2.

6.2 FARMERS’ INTERVIEWS

The chosen method for the farmers’ interviews was also semi-structured. It was probably a good choice of method since it provided some space for discussions and follow-up questions. The interview was shortened to around ten questions in order to reduce the time needed for each interview, due to fact that the farmers were busy and participated at the expense of their time for work. The most essential question did remain and the results were still relevant for the study.

The results from the farmers interviews showed that none of the pesticides used by the interviewed farmers where found to contain mercury. This result should be treated with caution since there was several sources for potential errors.

- Only three farmers were interviewed
  Since the field work had to be cancelled halfway through the project, only a fraction of the planned interviews were conducted. The practice of three farmers is to few to make a well based assumption about the pesticide use in the entire area.

- All farms where located in the same area
  The farms where all located next to each other in Pallangi. A wider spread of farms located in different farming communities would have provided more information about the pesticide use.

- There was some negative connotation surrounding the use of pesticides
  The use of conventional or organic farming is an issue that is currently very active. The NGO that provided help with translating the interviews is known in the area to promote organic farming. Therefore, the farmers might have been reluctant to admit using non-organic pesticides. Only one of the farmers agreed to show the packages of pesticides he used, but the main reason for this is believed to be that it was the only farm with close access to pesticides in field, where the interviews were conducted.

- Miscommunication during the translation
  All interviews where conducted with the essential help of a translator, whose mother tongue was Tamil. Since the translator did not have formal education regarding translation and did not speak perfect English, some nuances in the questions and answers might have been lost in translation.

- Not all pesticides were found during further research
  Some of the pesticides mentioned during the interviews could not be found on the internet afterwards. For two pesticides, Power win and X-TRA power, this could be the result of very generic names. It could also be if the pesticides were produced in a small scale. The two other pesticides that could not be located digitally was: Condap and Carset. The reason could be the same, that the pesticides only is produced in small scales. It could also be a result from misspelled pesticide names since no confirmation with a name on package could be made.

- Not all ingredients in each pesticide could be located
  Some of the pesticides did not present all ingredients on the packages or on the internet, therefore there are some uncertainties of the remaining ingredients. From the literature studies if was found that if mercury was not the main active ingredient then the pesticides probably did not contain mercury at all.

The low numbers of interviews and the close proximity of the farms could have led to uncertainties in the results, but the reliability of the results were increased by asking a person with knowledge of local farming practices. The results from the interviews were in line with what the person with local knowledge told.

The results indicated that pesticides containing mercury were not used, or only used in limited quantities, in the area. A shop that used to sell pesticides, but now only sell seeds, did not know of any pesticides to be sold that contained mercury. Due to difficulties with language the questions might have been misunderstood, since pesticides containing mercury was available to be purchased from an online store (KilPlayPesticides n.d.). Despite this, the use of mercury in pesticides is prohibited by law in India, with the exception of Methoxy Ethyl Mercury Chloride (MEMC) (Burger Chakraborty et al. 2013). MEMC is a legal seed treatment for, among others, potatoes (ibid.). Therefore, the concern of mercury in pesticides could be a source of contamination was not without ground. It would be interesting for future studies to examine the concentration of mercury in soil in the agricultural areas of Kodaikanal, and maybe other heavy metals, since it produces much food that is delivered to the Kodaikanal Sunday Market. To get a more thorough understanding about the use of mercury in the agricultural landscape of Kodaikanal further studies are necessary.

6.3 THE RISK ASSESSMENT PROCEDURE

It was more data missing than what would have been desired when conducting the risk assessment in accordance with the Swedish guidelines. Despite that, the overall calculations and results were indicators of the contamination situation in Kodaikanal. When conducting the risk assessment, there were parameters that did not exist for the specific site. The parameters used ended up being a combination of SEPA's standard values, literature values and estimated values. The choices of literature values were based on sites having similar conditions to Kodaikanal, with respect to specific aspects, such as precipitation. Those values were considered to be the best available approximation.

In order to adjust the model to Kodaikanal and Vellagavi, model parameters were changed. The changed parameters were: average life expectancy and amount of soil particles in air. The average life expectancy was lower in India, compared to Sweden, which led to less years of exposure. This could have led to a higher guideline value, compared to the Swedish standard for life expectancy. The amount of soil particles in the air was assumed to be higher in Kodaikanal than the Swedish standard for the parameter. A larger amount of particles in the air should lead to a higher rate of inhalation of contaminated particles and increasing exposure. Therefore, a higher amount of soil particles in air, compared to the Swedish standard, should lead to a lower guideline value.

It explicitly says in the handbook from SEPA that model parameters should not be changed unless the user has great knowledge about the parameters influence on the result. Changing the model parameters affects the essence of the model. Therefore, a more in-depth uncertainty analysis of the changed model parameters could be a next step in the investigation.

6.4 UNCERTAINTY ANALYSIS OF FACTORY SITE

For the uncertainty analysis of the factory site, both environmental and health aspects were examined. The two parameters used in the uncertainty analysis for factory site were recharge at the factory site and flow rate in Levinge stream.

6.4.1 GUIDELINE VALUES FOR HEALTH EFFECTS

The assumption of time spent on factory site was partly based on the SEPA's standard set of values for MKM. But the time spent on the site might differ since the factory is not active anymore. However, from the field study it was clear that people were working on the factory site, even though it probably was due to remedial actions being taken. If the factory site in the future would be used for other industrial activities the concentration of mercury in the soil should not pose a threat to the human health. Therefore, it was relevant to examine the health effects from the mercury contaminated site.

The lack of information about parameters affecting the human health exposure led to that only parameters effecting the environmental guideline value were varied. The two parameters, recharge and flow rate, did not have any effect on calculations related to human health. In this scenario, it was assumed that the area's groundwater was not used as drinking water. If the groundwater was to be consumed, it should be included as a source for human exposure. There were two wells at the factory site that were probably not used, hence not included in the calculations made in this project. If using the groundwater it would mean that the recharge would be having an effect on human health.

When using the CPCGV to calculate the guideline value for health effects, it resulted in long time exposure being the limiting exposure pathway. The difference between the received value for inhalation of vapour (2.5 mg/kg) and value for long time exposure (2.4 mg/kg) was small. Because of the uncertainties that could have affected the input parameters, there was no ground to claim that the value for long time exposure was indefinitely lower. Since the two exposure pathways were of the same order of magnitude, either one could be the limiting factor.

6.4.2 ENVIRONMENTAL GUIDELINE VALUES

When considering the dilution factor in comparison with the amount of infiltrated water, the area of the contaminated site plays an important role. The model's dilution factor was influenced by the area used. The dilution factor has a linear dependence on the amount of infiltrated water in the investigated area (Stockholms stad 2019). In this case, a larger area means that a larger volume of water passes through the contaminated soil, which leads to a lower dilution factor. When increasing the area from 2 500 m^2 (SEPA standard) to 85 000 m^2 (area of factory site), the dilution factor became more than 33 times lower. The alarm level for the CPCGV was at 500 m for both width and length of the examined area. This indicated that the model should be suitable for handling large areas, since the factory's area was smaller than the alarm level for CPCGV. The need of having a big area could be related to the results from the uncertainty analysis, where the site specific guideline value became noticeably low. The low guideline values could be an indication of that large industrial sites with a high infiltration rate are sensitive to contamination. Since no measurements were performed on this factory site it was difficult to estimate how much of the factory's total area that had elevated levels of mercury.

The calculations of k_d-values, which is the relation between the amount of pollutant in water and in solid phase, are usually mathematically simplified even though the real process is quite complicated (Fanger et al. 2006). CPCGV's default k_d-value was 300 l/kg, which was used in this report (SEPA 2016). When deciding upon a k_d-value, a lower value should be used if an interval is presented, since the leaching of contaminant otherwise could be under-estimated when looking at the long term aspects. The values decided by SEPA could be considered conservative and precautionary and therefore useful when the risk should not be under-estimated (Fanger et al. 2006). Important to notice is that the evaluation made by SEPA did not conduct and evaluate any experiments on the properties of leaching of mercury. Therefore, the k_d-value used in CPCGV should be examined closer. It was also noticed in the evaluation from SEPA that the results of the k_d-value of the different metals that were studied differed much. There is usually a positive correlation between the k_d-value and pH (ibid.). Therefore, the pH-value is important to know when using the CPCGV, in order to adjust the k_d-value to an appropriate level. In this study, the pH-value was not available for the factory site. A sensitivity analysis of k_d- and pH-values might had been a possible way of examining the parameters' influence on the guideline value.

To estimate the recharge, a multi value analysis was made. The results from the analysis were based on the studies of Hyderabad and Ruatoria. The reasons for choosing the two studies can be found in Chapter 5.4. From the results of the two studies applied on Kodaikanal, a recharge value ranging from 210 mm/year to 580 mm/year was considered probable. The CPCGV have an alarm level for recharge values exceeding 400 mm/year, which means that the model is still functional, but sends a message to the user that the value is above normal. There is higher precipitation in Kodaikanal compared to Sweden, but the evapotranspiration is higher in Kodaikanal too. It is highly possible that the precipitation, and therefore also the recharge, for Kodaikanal lies outside the Swedish norms. A problem arising from this could be that the model might not be suited to deal with high water flows. The site specific guideline value varied depending on the recharge. A small recharge of 5 mm/year resulted in an environmental guideline value of 1.4 mg/kg. A high recharge of 580 mm/year produced an environmental guideline value of 0.012 mg/kg. The guideline value cannot be lower than the background level for mercury in soil, which was 0.1 mg/kg. In that case, the guideline value was set to 0.1 mg/kg when the recharge was 580 mm/year. The entire area of the factory site was included in the calculation of recharge. It is possible that the recharge only happened within a limited area of the factory site, where the ground was plane, and not in the steeper parts. A closer investigation of the factory site must be conducted to make conclusions of the recharge situation.

The recharge that was used in the uncertainty analysis for different flow rates affected the produced site specific guideline values. Since the recharge values were uncertain, the achieved guideline values from the flow rate analysis also carried uncertainties. The analysis of the resulting guideline values therefore focused on the trend of how a changed flow rate would affect the site specific guideline value, rather than the actual flow. A lower flow rate led to a lower guideline value, with the protection of surface water as the limiting protection target. The flow rate in the Levinge stream could be assumed to vary with the precipitation rate, leading to different flow rates during a year depending on the monsoon season. Using a recharge of 100 mm/year, the background level was reached when the stream's flow rate exceeded 0.4 m^3/s, with the protection of groundwater as the limiting protection target. The protection of surface water was the limiting protection target when the flow rate was equal or less than 0.4 m^3/s and the recharge was set to 100 mm/year.

A way to handle the uncertainties connected to choosing recharge levels and flow rates, a calculation for different combinations between recharge and flow rate was conducted. When the lowest possible flow rate was combined with the highest recharge level it produced a conservative result. This scenario assumed that a large portion of the precipitation either percolated or evaporated, since high surface runoff should result in higher flow rates. For this scenario it resulted in an environmental guideline value of 0.000038 mg/kg, which was lower than the background level. The combined health and environmental guideline value for this scenario was set to 0.1 mg/kg, since a guideline value cannot be below the background level. An opposite scenario, with high flow rate and low recharge, was created to obtain the highest possible guideline value. The environmental guideline value for this scenario was 5 mg/kg. This resulted in the health guideline value of 2.4 mg/kg being the limiting protection target. Neither scenarios with high recharge and low flow rate, nor low recharge and high flow rate were probable. To replicate scenarios that was considered more probable for the factory site, combinations between recharge and flow rate were used in the calculations. There was no knowledge of what would be considered a "high value" (or low) at the factory site. Therefore, values from the higher end of the examined spectra for recharge were combined with values from the higher end of the examined spectra for flow rate. And vice versa. This might not match what might be considered as "high" values for the conditions in Kodaikanal. Therefore, the exact values produced in the analysis should be considered with caution. The generated guideline values from the combinations of recharge and flow rate, excluding the extremely low and high ones, ranged between 0.31 and 0.58 mg/kg. It was difficult to draw any clear conclusions from the result, other than it is important to measure recharge for the factory site and flow rate for the Levinge stream when conducting a risk assessment for the factory site.

The tables provided in Chapter 5.4 could be used as templates when the parameter values are measured in order to conduct a risk assessment with less uncertainties. If the difference between the assumed flow rate (0.0032 m^3/s) or recharge (100 mm/day) and the measured value would be significant, the site specific guideline values should be recalculated.

6.5 UNCERTAINTY ANALYSIS OF VELLAGAVI

For the uncertainty analysis of Vellagavi, three parameters were varied: exchange of indoor air, fraction of consumed locally grown plants and time spent indoors. The environmental values in this report could not be validated with current data, since the fieldwork had to be cancelled due to the outbreak of COVID-19 before any measurements could be made. So therefore, the main focus for Vellagavi was on human health. If the measurements planned for the project would have been possible to conduct, then there would have been results for mercury concentration in soil, water, sediments and crops in Vellagavi. In that way, it would have been possible to evaluate if there is a contamination problem in Vellagavi and to make an environmental evaluation of site specific guideline values.

The mercury that is currently present in Vellagavi's soil was considered to stem from previous exhaust from the factory that have been deposed in Vellagavi. The mercury in the soil in Vellagavi can re-enter to the air and therefore pose a risk of mercury exposure. In the calculated scenario, all inhalation of mercury vapour was assumed to come from the mercury that had re-entered the air from the soil in Vellagavi. This means that the calculated scenarios did not account for any extra mercury vapour that currently travels from the factory site to Vellagavi. Since it can be assumed that the inhalation of mercury from outside sources is higher than average, the site specific guideline value for Vellagavi might have to be more conservative than the output from the calculation model in order to not risk any negative consequences caused by mercury exposure.

Since there are no measurements for the air exchange indoors, the values used in the calculations were hypothetical. When combining the exchange of air with the time spent indoors, there might be days where these two parameters are not in favour for the mercury exposure, but even during these days it should not be any risk of negative health effects. The houses in Vellagavi are open and not well-isolated, unlike in Sweden, and the inhabitants usually cook their food on open fire indoors. The indoor fires leads to local low pressures making the air travelling upwards, driving in air from the the outside. On one hand, this could argue for greater exchange of air indoors than only 12 times a day. On the other hand, the outdoor temperatures are high and therefore the temperature gradient might not be as high as it would have been in Sweden when making an "indoor fire". Since the actual value of air exchange was not known in this case the lowest value of 12 times per day was used, referring to a precautionary approach. The long time exposure was limiting for all air exchange levels. The exposure from ingestion of plants was in the same order of magnitude as the long time exposure. For low exchange of indoor air values, the exposure from inhalation of vapour also was within the same order of magnitude.

When the consumption of plants by the inhabitants in Vellagavi consisted of 50 % locally grown plants the health based guideline value for long term exposure reached 0.1 mg/kg, which is also the background value for mercury. To clean the soil beyond the point of natural occurring mercury level would not be possible, both from an economical and a technical aspect. A more in-depth discussion about possible remediation methods can be found in Chapter 8. A higher self-sufficiency regarding food in Vellagavi could be problematic because of its immense effect it has on the level of exposure, and in result the guideline value for the area. A change in the fraction of consumed plants that stems from the area affected the health risk based guideline value. A ratio of consuming 10 % locally grown plants was estimated to reflect the current situation. But since most of the inhabitants earn their livelihood by farming, a rapid increase of self-produced consumption was possible. The result showed that the health based guideline value was affected by the amount of consumed locally grown plants. An increase in consumption of 10 % to 90 % led to a three times lower guideline value for health effects. Therefore, changed consumption patterns should be taken into consideration.

There was a significant difference between the two genders in the village when studying the time spent indoors. Women spent almost all day indoors, while men spend most of the time outdoors, both day- and night time. Therefore, the choice of the women's living patterns were chosen, since more time indoors leads to a higher mercury exposure. Yet again, the health guideline value for long time exposure was the limiting factor. For more than 50 % of the time spent indoors, the exposure from inhalation of vapour was in the same order of magnitude as the long time exposure.

The site specific guideline values calculated for Vellagavi ranged from the background level (0.1 mg/kg) to 0.55 mg/kg. All of the varied parameters were considered sensitive and the general pattern showed that protection of health was important. Even low concentrations of mercury in soil had an impact on the human health. The result showed that it is important to further examine the actual concentration and exposure in Vellagavi since the guideline values were low.

6.6 OTHER EXPOSURE PATHWAYS

During the survey no residents of Vellagavi reported that they used skin whitening cream. All of the people that was included in the survey was either over 40 or under 12. A discussion stemming from the question about skin whitening cream brought to light that some of the younger generation might be using skin whitening creams. It is believed that the use still is very limited, even among the younger population, due to the limited economic status for the villagers. If the village of Vellagavi is to receive more tourism in the future the funds available to villagers will likely increase. Skin whitening creams are of easy access since it is available in stores in Kodaikanal, especially a skin whitening cream named "Fair & Lovely" was observed in several stores. The skin whitening cream "Fair & Lovely" was banned in 2019 by the European Union due to it containing mercury (0.1 mg/kg) (European Commission n.d.). In the future, there is a risk that the increase of economic means for the villagers in Vellagavi leads to a higher mercury exposure due to the use of skin whitening creams.

Mercury in pesticides were excluded in the forward dose calculation since the interview result showed that the pesticides that were mentioned in this report did probably not contain any mercury. No other exposure pathways were identified during the field work.

The mercury uptake from fish is generally known to be high and therefore can be a source for mercury exposure. Fish was not included in the study as an exposure pathway since it was not included in the diet of the villagers. If the diet of the villagers changes in the future and fish is consumed, the decision of excluding fish has to be revised. If the consumption of fish increases, the exposure from outside sources of mercury will increase.

6.7 FORWARD DOSE CALCULATION

In order to evaluate if it would be suitable to use the current factory site as a residential area, a forward dose calculation was made. The chosen concentration of mercury in soil for the forward dose calculation was 20 mg/kg, which was the remediation value that was set in court. HUL was obligated to remediate the area to that value and therefore it will be the maximum concentration in soil on the factory site when the remedial actions are finished. The results in Chapter 5.7 showed that the total mercury exposure exceeded the Swedish TDI-value for both children and adults. Having a mercury concentration of 20 mg/kg in the soil, the daily exposure of mercury could exceed the TDI for humans if the factory site will be used for residential purposes. Even if the exposure pathway from inhalation of skin whitening cream was disregarded, the exposure from mercury vapour stemming from the contaminated soil exceeded the TDI. Such high concentration as 20 mg/kg mercury in the soil could pose a threat to human health.

The dermal uptake of mercury was set to the standard value from SEPA's calculation tool. The value was based of dermal uptake from Cadmium (Cd) and multiplied with a factor 10 to correct for uncertainties, in accordance with the SEPA's guidelines. In order to make more accurate assessments in the future, individual values for dermal uptake of metals should be included in the SEPA calculation tool. The properties of mercury differs from other metals and therefore, it is reasonable to think that mercury also have other dermal uptake than other metals.

The time spent indoors was set to 1 (=100 %). The reason for this choice was the same as for the calculations in the risk assessment for Vellagavi: it should be possible to spend all time indoors without it being dangerous. For the lung retention parameter, the standard value from SEPA was used. The mercury uptake in lungs was difficult to estimate since there were no studies found on the subject. Therefore, the SEPA standard value of 70 % was used. As for the particle inhalation of air, it was estimated that 50 % of the particles in air came from the contaminated site. This estimation was based on the standard set of values from SEPA. On one hand, one could argue that the particle inhalation would be high in the area since the contamination situation was palpable. On the other hand, the fraction of particles stemming from the contaminated soil might possibly be the same as in the SEPA model. This, because of the estimated amount of mercury stemming from the contaminated soil would behave in the same ways in Sweden as for the factory site.

The use of skin whitening creams affects the amount of mercury at home and the exposure to a whole family (Copan et al. 2015). The use of skin whitening creams can affect the amount of inhaled mercury, since skin whitening creams containing mercury can emit vapour that can be inhaled. The dermal uptake of mercury in the creams was considered negligible compared to the inhalation of vapour and was therefore excluded from the conceptual model. Therefore, it is important to include the use of skin whitening creams in the risk assessment and the forward dose calculations. In this report, no questions about the use of skin whitening creams were asked to residents in Kodaikanal, only residents in Vellagavi, so there is no accurate information about any possible use of skin whitening cream. However, reports have shown that the skin whitening creams are used by approximately half of the Indian women and skin whitening creams occupies over 60 % of the Indian skincare market (Jose and Ray 2018 ; Glenn 2008). It could also be observed that local stores in Kodaikanal sold skin whitening creams by the brand “Fair & Lovely”, so there was an access to skin whitening creams for the inhabitants of Kodaikanal. Therefore, it is important to include this exposure pathway in the forward dose calculation. The pathway does not exist in the SEPA calculation tool since it does not originate from the contaminated soil.

Since no residential buildings were constructed on the site before this study, it was difficult to make a correct estimation for the buildings' properties. In this report it was assumed that the future properties would follow the Swedish building standards. The air volume for the building was assumed to be 240 m^3. This could be compared to the estimated air volume for buildings in Vellagavi was 18 m^3. A bigger air volume would mean a lower concentration of mercury in indoor air. If HUL decides to use the area a for residential buildings, it is important to perform a forward dose calculation that considers the properties of the building. If there are plans of building residential areas on the factory site that uses the wells on the factory site for providing water, then the wells should be thoroughly investigated to guarantee that the well water is not contaminated. In the calculated scenario, it was assumed that no drinking water was taken from the site, including the wells. If the water wells are supposed to be used for drinking or other purposes, this exposure pathway should be included in future risk assessment.

The forward dose calculation showed that the court decided site specific guideline value of 20 mg/kg is not sufficient. The mercury exposure from inhalation of vapour alone exceeded the Swedish TDI by far. The exposure pathway from skin whitening creams was also shown to have a noticeable effect. The factory site should not be used for residential purposes since it will pose a threat to human health. It is important to consider that the exposure from sources outside of the contaminated site might already exceed the TDI, leading to the amount of exposure from the contaminant stemming from the site must be even lower than 20 %. The value of 20 % stems from what percentage of the TDI of mercury (suggested by SEPA) that can originate from the contaminated site. Further investigations on this area is needed to make a more solid evaluation.

6.8 APPLICABILITY OF THE CPCGV MODEL

The CPCGV have maximum and minimum values for parameters, a parameter value outside those levels results in a warning. Since the climate in India is different from Sweden some parameters might be outside the Swedish standard. This does not pose a problem for the calculated values but brings down the user friendliness. The purpose of warning levels is to communicate to the user that the value is out of the ordinary, to retain the integrity of this feature in an Indian setting new warning levels needs to be crafted.

The model parameters in the CPCGV is generally not supposed to be altered. To customise the model to better represent the conditions in India, alteration was required. This could have led to that some of the calculations conducted within the model might be poorly calibrated for the other set of model parameters, even though no such thing was discovered in this study. Before putting the CPCGV to use in India, there is a need for further investigations of what calculations the changed model parameters affects. A positive aspect of using the CPCGV was that many parameters were possible to change, which makes the model more adjustable to specific situations.

The bioavailability for mercury might differ from what was used in this report, since it depends on several factors, such as pH, temperature, and adsorption. A more detailed study would be required to evaluate only the bioavailability, which was not possible to fit in this project. Other parameters that is incorporated in the calculations within the CPCGV could be greatly affected by the deviation from the Swedish standards. One example of such parameter is Henry's constant. Henry's constant expresses the ratio of a compound that is present in air, compared to water, at a specific temperature (Ashok and Morrison 2007). Since the temperatures for India differs greatly from Sweden this could have an impact on the results. It could also be problematic to use CPCGV in India since the country has several climate zones. A version for CPCGV in India would therefore require a more extensive set of options to regulate temperature depending parameters and its effects on calculations.

The result from the CPCGV could not be compared with any values from a process that is known to be accurate. It is therefore difficult to give a conclusive answer to if the CPCGV truly can provide accurate result for an Indian site. The result from the theoretical analysis indicated that the model has a great flexibility and that it, with small adjustments, can be useful in India.

The CPCGV was used to calculate the spread of contaminant to the protection targets groundwater and surface water. The computer model made basic assumptions about the spread of contaminant and is commonly used as a screening method to see if the spread of contaminant can pose a risk (SGI 2018). The way of simplifying the calculations of the spread of contaminant was unrelated to if the model was used in Sweden or in India. However, it was a limitation of the applicability of the CPCGV in general. For cases were the spread of contaminant have impact on the result, there is a need to use calculation models that can calculate the spread of contaminant more accurately. In this report, it was shown that both groundwater and surface water could be limiting protection targets for the site specific guideline value. Further investigations are therefore required for the factory site with a model tailored to examine the spread of a contaminant.

7 RESULTS AND DISCUSSION OF RISK ASSESSMENT IMPLEMENTATIONS

This section will provide results and discussion for the extended focus of implementation of environmental risk assessments. The research question answered in this section is:

What are the differences and similarities for implementation of environmental risk assessment in India compared to Sweden?

Since the legal system is the foundation for implementation of risk assessments, the section will start by covering both countries' approaches to environmental legislation. This will be followed by a comparison between the processes of identifying and classifying polluted areas. The initiating process for risk assessments and the used guideline values for both countries are covered. To get an insight into how a risk assessment was performed in India and how it compares to Sweden, an actual example of an Indian risk assessment was used for a comparison to Swedish guidelines. The Indian risk assessment used in the comparison determined the site specific guideline values for the factory site in Kodaikanal. The Indian risk assessment was chosen since it was performed on the factory site, which is the same as the rest of the report focuses on. The section will also include how a more standardised approach to risk assessments can be achieved.

7.1 IMPLEMENTATION OF ENVIRONMENTAL RISK ASSESSMENT

In this section, the processes of identification and classification of possibly polluted soils in India and Sweden will be further explored. Comparisons between the two countries' approaches of initiating risk assessments and using guideline values will be made.

7.1.1 ENVIRONMENTAL LEGISLATION

In Sweden, contaminated soil is regulated by the Swedish Environmental Code (SFS 2020:75). In India, no legislation specifically regulates contaminated soil. For cases related to contaminated soil, the used legislation is the Environmental Protection (EP) Act, the Water act, Hazardous Waste (HW) rules and case law (Reynaers and Nandeshwar 2020). There is a need for legal tools focusing specifically on contaminated soil. The Indian government has shown an endeavour to increase the legal aspects for contaminated soil. This can be assumed from the policy development , for example the renewal of rules for hazardous waste in 2016 (G.S.R No. 395 (E)). There are also several projects aiming to create standardised protocols for the implementation of laws, like the IMPCSI project (COWI 2015). A report from 2014 found that there are four main challenges for implementation of environmental legislation in India: "a lack of financial resources, a shortage of staff, a lack of standardized protocols, and a lack of legal authority" (ELI 2014).

In some cases, the enforcing agency in India do have some specific legal authority. The enforcing agencies have legally stated rights to enter "any place" to conduct sampling and assessment, if deemed necessary. The SPCB can also use something called a Show Cause Notice (SCN). After a SCN is issued, the company have approximately 15-30 days to proclaim their reasons of why a criminal prosecution should not be instigated. If the company cannot provide sufficient proof, the SPCB can cut the companies supply of electricity and/or water. (Kaushik and Tavinder 2020)

For over 30 years the practise of economic compensation to persons effected by an accident arising from a company's hazardous activities have existed in Indian case law (ibid.). This indicated that the legal system has experience with handling liability from accidents related to pollution, even though the system focused on human health rather than environmental protection. In more recent environmental legislation, the precautionary approach and the polluter pay principle are included (e.g. Nation Green Tribune Act 2010) (ibid.). This is a clear stride towards a more environmentally sustainable legislation in India.

7.1.2 IDENTIFICATION AND CLASSIFICATION OF POLLUTED AREAS

In Sweden, county governments have conducted an inventory of possibly contaminated areas. SEPA states that most of the possibly contaminated areas in Sweden were located by the year 2015 (SEPA 2020). County governments are currently working with risk classifications of the possibly contaminated areas. [3]

In September 2013 the Indian IMPCSI project had located 320 sites that were potentially contaminated. In 2018, Sweden had 80 000 sites that were categorised as potentially contaminated (SGI 2018). This indicates that there is still a large number of unknown sites that are potentially contaminated in India.

Compared to Sweden, India has a bigger set of obstacles when it comes to mapping contaminated areas. Just the shear area of India makes the task to map the entire country difficult. India also struggles with vastly different problems than Sweden, such as poverty and water provision, leading to more of the governmental focus lies on providing basic needs for its citizens. There is also a lack of knowledge about conducting risk assessment since the procedure is relatively uncommon and is often conducted by international consultants.[4] Therefore, an implementation of stricter environmental law calls for more education within the environmental field.

A guideline document from the Indian Ministry of Environment and Forests suggest a classification system for possibly contaminated areas (Ministry of Environment and Forests 2015b). To prioritise between possibly contaminated sites, India uses a system where different parameters are scored based on severity. The majority of the parameters are valued to a score between 0 and 10, a higher score indicates greater risks. The parameters considered are (ibid.):

- Source concentration
- Quantity of source
- Toxicity factor
- Mobility factor
- Containment
- Attenuation
- Land use at the site
- Population at risk
- Sensitivity of receptor
- Groundwater system at risk
- Surface water at risk
- Sensitive ecosystems

The parameters' scores are based on data and/or assumptions. The guideline for the scoring system is to use the worst case scenario for all assumptions (ibid.). The proposed Indian system accounts for twelve different parameters connected to the source, pathway and receptor. The classification system for contaminated sites, suggested by the Indian Ministry of Environment and Forests, is ambitious. The system might be too advanced to efficiently locate areas with possible contamination since it accounts for many parameters.

The Indian IMPCSI project has other criteria to provide a classification for possibly polluted area. As mentioned in the background, the criterion are if the site have been subjected to any potentially harmful:

- industry types.
- industrial processes.

[3] Frida Gällstedt, Administrative official, County government of Gävleborg, Personal communication, 05/06/2020
[4] Vidya Sundaram, Principal Consultant - Team & Operations Lead at Arcadis, 01/05/2020

- hazardous waste generation.
- or other type of anthropogenic contaminant.

In Sweden the classification of a contaminated site is solely based on the type of industry that has been present in the area. A positive aspect with Sweden's down scaled system is that it is simple to categorise different sites since the system is based on only one parameter. This approach relies on the availability of old documents declaring what industries that have been present at the examined area. The approach might be problematic to implement in India since it requires documentation that might not exist. A first step for India could be to focus on restricting present and future spills from active corporation activities by implementing stricter environmental laws. A stricter environmental legislation would limit the current and future contamination of areas. Since the resources are limited, the main priority for India would be to limit any active situation that poses a risk of polluting soil. Ideally, the work with identifying and categorising potentially polluted areas can be carried out simultaneity.

The classification suggested by the IMPCSI project is fairly close to the system used in Sweden. This means that the suggestion from the IMPCSI project would reap the benefit from having a simple system but at the same time covering a lot of possible reasons for soil pollution.

7.1.3 GUIDELINE VALUES

Sweden uses a system where the generic guideline values are based on the area's land use. The use is divided into two categories: sensitive land use (MK) and less sensitive land use (MKM).

India has proposed to use the practice of screening- and response levels (a schematic view for the interpretation of screening- and response level can be seen in Figure 10). If a site has levels of contaminants exceeding the response level the area is immediately identified as contaminated. The response level used in India comes from rules for hazardous waste (G.S.R No. 395 (E)). This means that restrictions set for hazardous waste are used directly on contaminated soil. Since hazardous waste generally has different properties than soil, using the same concentration values for hazardous waste and soil might not be appropriate.

Figure 10: A schematic figure for how screening- and response levels should be interpreted. Since there are different screening levels depending on the land use, the label "screening level" in the figure refers to the screening level with the lowest value.

The Swedish methodology does not include a response level. It consists of guideline values for sensitive- and less sensitive land use that can be seen as screening levels. The methodology has a greater reliance on conducting site specific assessment to achieve a guideline value. India could benefit from using the approach of more individualised site specific assessments. The differences in climate and geological properties between different parts of the country are greater in India than in Sweden. Therefore, it is important that the assessments are based on site specific properties.

The screening levels from the guideline provided by the Ministry of Environment and Forests are based on Canadian standards. In the guidelines, there are more land use categories and each category have a different guideline value (Ministry of Environment and Forests 2015a). The categories are: Agricultural, Residential/Parkland, Commercial and Industrial. Agricultural use has the strictest guideline value and Industrial has the highest allowed level. The proposed Indian screening- and response level(s) for mercury are presented together with the Swedish generic guideline values in

Figure 11.

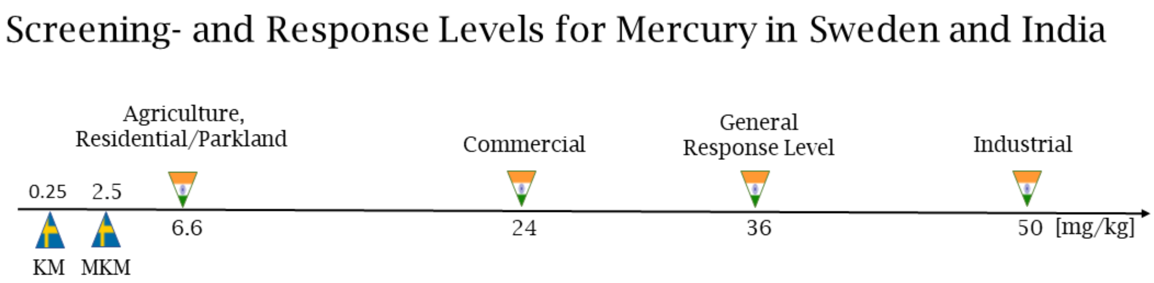
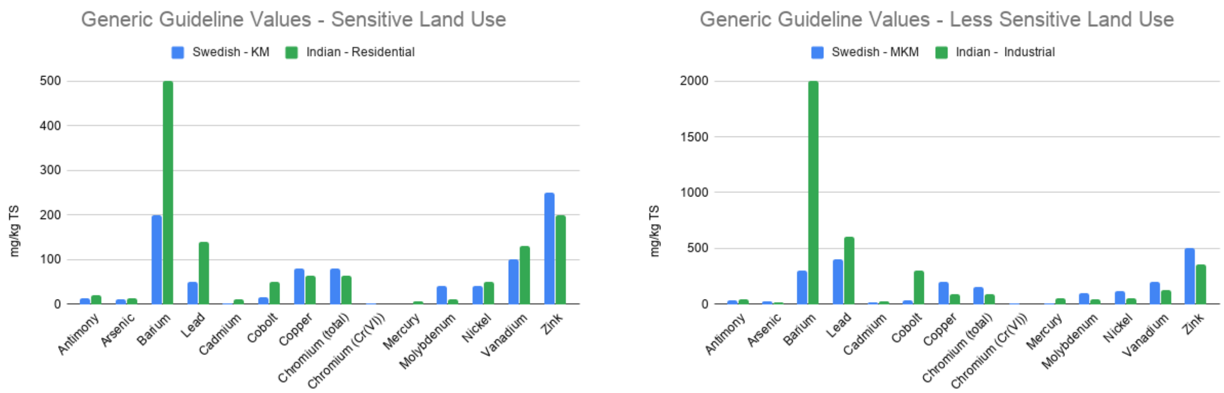


Figure 11: The Swedish guideline values for sensitive land use (KM) and less sensitive land use (MKM) in relation to the Indian screening- and response levels for different land uses.

In Figure 11 it can clearly be seen that the generic guideline values in Sweden are more conservative than in India. The term KM is used in cases where the quality of the soil does not limit the use of the area and that a person could permanently stay on the site for its entire lifetime. Residential areas fall within the categories for KM. MKM is generally used for areas where humans only spend a limited time in, e.g. offices or industrial areas (SEPA 2009b). The guideline value for industrial land in India is 20 times higher than the Swedish guideline value for MKM. The Indian guideline value for residential areas is more than 26 times higher than the corresponding Swedish value for KM.

As mentioned previously, the proposed Indian screening levels is taken from the Canadian screening levels. The Canadian risk assessment model takes the same exposure pathways into consideration as Sweden. The limiting exposure pathway for the Canadian screening levels for mercury is “soil ingestion” for all land uses, except industrial (Canadian Council of Ministers of the Environment 1999a). For an industrial site, the environmental aspect is the limiting factor. This could be compared with the limiting factors for the Swedish generic guideline values. For KM, the health based exposure pathways from inhalation of vapour and ingestion of plants are limiting (Kemakta Konsult AB 2016). For MKM, the health based exposure pathway from inhalation of vapour is limiting. The Canadian method to calculate screening levels is very similar to the Swedish method to calculate generic guideline values. It is therefore difficult to see any obvious reasons for the differences in the values. One reason could be that the Canadian model uses a lower value (0.1%) for fraction of organic carbon in the soil (Canadian Council of Ministers of the Environment 1999b). The organic carbon fraction in soil used for the Swedish generic guideline values is 2%. A lower fraction of organic carbon could lead to an under-estimation of the risk a certain substance poses (SEPA 2010).

It is important to note that the evaluated guideline- and screening levels were for mercury. To see if the screening levels in India generally was higher than the Swedish ones, several different elements were compared. The 15 first elements in the Swedish list for generic guideline value were chosen for the comparison. The Swedish generic guideline values for sensitive areas were compared to the Indian screening levels for residential areas in Figure 12a. The Swedish generic guideline levels for less sensitive areas was compared to the Indian screening levels for industrial areas in Figure 12b.



(a) The Swedish guideline levels for sensitive land use compared to the The Indian screening value for industrial use.

(b) The Swedish guideline levels for less sensitive land use compared to the The Indian screening value for industrial use.

Figure 12: A comparison between Swedish guideline values in blue and Indian screening levels in green. Note that the scales are different for the two figures.

From Figure 12a it can be seen that Sweden have more conservative values for 9 out of the 15 substances for sensitive land use. Figure 12b shows that Sweden have a more conservative value for 5 out of the 15 substances for less sensitive land use. So, despite the major difference for guideline levels for mercury, not all elements follow the same trend.

Sweden's more conservative guideline values for mercury have the advantage of minimising the risk polluted soil might pose for human health and terrestrial ecosystems. A too low guideline value might lead to a disproportionately large use of resources for remediation purposes compared to the gains of the actions. Having the generic guideline value as a initial value, to see if further investigations are required, reduces the risk for unnecessary use of resources (Naturvårdsverket n.d.). This is how both the Swedish generic guideline values and the proposed Indian screening levels are used. A site specific guideline value is then generated for the site, and then used for formulating remedial goals.

A positive aspect of the categories of India's screening levels is that the category names are largely self-explanatory. The screening level for industrial use is called "Industrial". Compared to Sweden, where the screening levels are classified as sensitive- or less sensitive land use. The Swedish names are more diffuse and the person handling the risk assessment has to have knowledge about the subject. Having more explicit naming of the generic guideline levels categories could result in a more transparent process, since a wider audience can understand the process.

7.1.4 INITIATION OF RISK ASSESSMENTS

In India, there are no defined reasons for when a risk assessment is required.[5] Risk assessments are usually initiated by multinational corporations due to the risk to get a bad reputation if action is not taken towards a pollution.[6] One common reason for a risk assessment to be initiated is if there is someone either files a complaint with the local pollution control or a Public Interest Litigation is filed to the local authorities. [7] This is confirmed by the case with the thermometer factory in Kodaikanal. Greenpeace and a local NGO — Palni Hills Conservation Council (PHCC) — found contaminated waste dumped behind the factory walls and reported it to authorities. The company still denies dumping contaminated waste on the factory site. Despite the denial, the activity at the factory was ended after the suspicions of malpractice was reported. During the following couple of years there were several different studies conducted at the site, one of them being the report containing site specific guideline values that was performed by the company Environmental Resources Management (ERM). The ERM report will be used for further analysis in the Chapter 7.2. The case of the thermometer factory in Kodaikanal is one example of how public attention can lead to initiating a risk assessment for polluted soil.

[5] Vidya Sundaram, Principal Consultant - Team & Operations Lead at Arcadis, 01/05/2020

[6] Suyash Misra, Technical Discipline Leader - Environment Business Line, Arcadis, Personal Communication, 22/04/2020

[7] See footnote 5

In Sweden, there are a couple of reasons for initiating a risk assessment. One is that the Supervisory Authority wants more information about an area. Common procedure is that the Supervisory Authority requires a risk assessment if a potentially contaminating activity have been performed on the site. [8] A risk assessment can also be initiated by a company if the company plans on selling the area and has to know if remedial actions needs to be taken.[9] In Sweden, there are also private companies that initiate risk assessments. One example is the non-profit company SPIMFAB that consists of Swedish Institute of Petroleum and Bio Fuels and several fuel companies. The company was active from 1997 to 2014 and worked with risk assessments and remediations of old petrol stations (Spimfab 2014).

7.2 RISK ASSESSMENT CONDUCTED BY ERM IN COMPARISON WITH SWEDISH GUIDELINES

To evaluate how risk assessments are performed in practice in India, an Indian risk assessment report for the factory site was analysed. Since generating site specific guideline values was the step performed in present report, the same step was chosen for the comparison between the Indian and Swedish procedure. The report used in the comparison was called "Former HLL Mercury Thermometer Factory, Kodaikanal, Tamil Nadu, India: Site Specific Target Levels" and was performed by Environmental Resources Management Australia Pty Ltd (ERM) (Hindustan Lever Limited 2006). The report will be referred to as "ERM report" in following sections. The ERM report was commissioned by Hindustan Level Limited (ibid.).

In the ERM report for site specific guideline values, the steps of the assessment were similar to general methodology used in Swedish risk assessment. The four steps in the process are presented in Table 17.

Table 17: The translated names for the four parts included in a Swedish risk assessment and the name of the main parts of the ERM report.

Swedish Standards	HUL risk assessment
Problem description	Issues identification
Effect assessment	Hazard assessment
Exposure assessment	Exposure assessment
Risk characterisation	Risk characterisation

As seen in Table 17, the steps in the ERM report for site specific guideline values matches the recommend steps in a Swedish risk assessment. The ERM report was based guidelines from the U.S. and Australia. The American guidelines that were presented in the report came from a document called "Guide for Risk Based Corrective Action Applied at Petroleum Release Sites" and the Australian guidelines stemmed from a document called "Environmental Health Risk Assessment Guidelines for Assessing Human Health and Ageing". This was another indication that international aspects are commonly incorporated in Indian risk assessments. Sweden have guidelines that are very general and applies for several different types of contaminated sites and type of contaminants. Since the ERM report follows guidelines that specifically applies to petroleum release sites, the guidelines used might be too specific. Since no access to the American guidelines were possible, this could not be investigated further.

7.2.1 ISSUES IDENTIFICATION

The potential exposure pathways relating to human health that was taken to account during the risk assessment performed by ERM at the factory site were:

[8] Frida Gällstedt, Administrative official, County government of Gävleborg, Personal communication, 06/05/2020
[9] See footnote 8

- Inhalation of dust, outdoors.
- Inhalation of dust, indoors.
- Ingestion of soil.
- Dermal contact with soil.
- Ingestion of locally grown vegetables.

All the exposure pathways presented in the ERM report were included in the Swedish risk assessment guidelines. The Swedish guidelines also account for inhalation of vapour and ingestion of water. Since there was no drinking water source on the factory site, the pathway of ingestion of water was not relevant. The ERM report includes measurements from a previous study of soil vapour on the factory site. The soil vapour study showed values ranging from below the detection limit at 0.002 μg/m^3 up to 13 μg/m^3. The highest soil vapour value came from a hot spot on the factory site containing high concentrations of mercury on the site (200 mg/kg to 500 mg/kg). In the ERM report it was assumed that remedial actions will be taken on the the hot spots, and therefore any levels of mercury vapour from the hot spots could be disregarded in the risk assessment. To base a risk assessment of possible future remediation practices would not be legitimate according to Swedish guidelines for risk assessments. A Swedish risk assessment would have to account for the pollution that is currently present and from that create a remediation plan. After the remediation is finished, a follow up investigation should be made. According to the Swedish model, it is not correct to assume that the remediation will be successful, since the remedial action can fail and then the high concentrations would still present in the soil. [10] This assumption resulted in that the remaining soil vapour values of mercury was below the recommended air quality guideline values from WHO, U.S. Environmental Protection Agency and the Agency for Toxic Substances and Disease Registry in U.S. Therefore, the pathway of inhalation exposure from vapour was eliminated from the ERM report since all mercury vapour measurements where below the presented air quality guidelines.

The Swedish approach to risk assessments allows 20 % of the the TDI to stem from the contaminated area. The reasoning for removing the exposure from inhalation of vapour in the ERM report was due to the measured values of mercury in vapour was below three air quality guidelines. The amount of mercury that comes from the exposure to mercury vapour might be below the guideline values, but in combination with other exposure pathways it could exceed the amount of exposure allowed from the contaminated area.

The risk assessment carried out in this report have showed that the exposure from inhalation of vapour was one of the limiting pathways for the site specific guideline value at the factory site. It can therefore be assumed that it is very important to take into account the exposure stemming from inhalation of mercury vapour. Since the amount of inhaled mercury is an important parameter, it is positive that the actual amount has been measured at the site. Despite this, the conclusions drawn by ERM from the measurements were not in line with the Swedish guidelines. The amount of gaseous mercury in the air varies during the year. The choice of season and time during the day to conduct measurements could have an impact on the results. The measurements referred to in the ERM report were conducted during April. In Kodaikanal the amount of atmospheric total mercury peaks during the summer months (Karthik et al. 2017). Therefore, there is a low risk that the mercury vapour values used in the ERM report were understated due to the choice of time when measurements were conducted.

The ERM report stated that the factory site is proposed to be used as a residential area and/or for recreational purposes. The potential receptors that were included in the report were:

- Future residents
  Residents that spend time both outdoors and indoors in the area. It is assumed that the future residents will have the opportunity to have their own kitchen gardens in the area.
- Recreational users
  People that occasionally visits the recreational outdoor area within the site.

[10] Frida Gällstedt, Administrative official, County government of Gävleborg, Personal communication, 06/05/2020

The ERM report only focuses on potential receptor: humans. It do not take into account for terrestrial ecosystems, groundwater or surface water as potential receptors. The ERM report states that two wells and surface water is present on the site. In a risk assessment following the Swedish guidelines potential receptors for the environment should be included [11]. The ERM report contained no discussion about the the decision to only regard humans as potential receptors. In this project, a multi value analysis was conducted to produce site specific guideline values for the factory site. The environmental guideline value was the limiting value for all but one input value (see Chapter 5.4). The only scenario where the health guideline value was limiting was when the flow rate was high and the recharge was low. The result from this report shows that the environmental receptors are important to include in a risk assessment.

The ERM report states that children (ages 0-6) were the most sensitive potential receptor. ERM stated that all residents and recreational users were considered to be children (ages 0-6) in the conducted calculations due to having a precautionary approach. The definition of children was the same as in the Swedish risk assessment methodology. A difference was that the Swedish method accounts for both adults and children. In CPCGV both the exposure time for children and adults can be varied.

7.2.2 HAZARD ASSESSMENT

In this section, in the ERM report, the values used for the dose-response calculations were presented. The Reference Concentrating (RfC) and Tolerable Daily Intake (TDI) used in the ERM report are presented in Table 18 along with the Swedish default values.

Table 18: Tolerable Daily Intake (TDI) that accounts for oral intake and Reference Concentration (RfC) that accounts for inhalation used in the ERM report presented next to the Swedish equivalents

	TDI	**Unit**	**RfC**	**Unit**
Values used in ERM report*	$3.0 \cdot 10^{-4}$	mg/kg-day	$8.6 \cdot 10^{-3}$	mg/kg-day
**Swedish standard ** **	$2.3 \cdot 10^{-4}$	mg/kg-day	$2.0 \cdot 10^{-4}$	mg/m^3

* 25 % of the dose is allowed to ail from the contaminated area
** 20 % of the dose is allowed to ail from the contaminated area

One difference in the ERM report's approach compared to the Swedish standard was that 25 % of the intake could come from the polluted area. This was a higher percentage compared to Sweden where 20 % was allowed to come from the polluted area. This would mean that the TDI in the ERM report had to be slightly lower to match the Swedish TDI. Instead the values used in the ERM Report was higher than the Swedish TDI. The unit for RfC was different between the ERM report and the Swedish standard, which made a comparison between the two values difficult.

The hazard assessment in the ERM report contained a hazard identification as wells as a dose-response assessment. The chapter for hazard identification in the ERM report had a section about the toxicological profile for elemental mercury, e.g. biological availability and absorption patterns. The information was general, and no connection to the site specific conditions was made. The ERM report's section called Hazard Assessment contained the same information as the section called Effect Assessment in a risk assessment following the Swedish guidelines.

7.2.3 EXPOSURE ASSESSMENT

For the exposure assessment, the ERM report used a statistical software (Crystal Ball, v. 7.2.2) to simulate human behaviour and to calculate potential exposure from each exposure pathway. Probability distributions used in the ERM report came from a Contaminated Land Exposure Assessment model (CLEA) created by UK's department for Environment, Food and Rural Affairs.

The ERM report used an approach where some parameters were described by probability distribution functions. These parameters were: body weight, soil ingestion, skin surface, outdoor inhalation rate, indoor inhalation rate, root vegetable ingestion rate, non-root vegetable ingestion rate (see Table 19).

[11] Frida Gällstedt, Administrative official, County government of Gävleborg, Personal communication, 05/06/2020

Table 19: Parameter assumptions from the ERM Reports probability distribution functions alongside the Swedish standard implemented in CPCGV

Parameter	**ERM Report**			**SEPA Standard for Sensitive Land Use**		**Unit**
	Min. Value	**Max. Value**	**Mean Value**	**Children**	**Adults**	
Body weight	7.4	20	14	15 *	70	kg
Soil ingestion	$1.0 \cdot 10^2$	$1.0 \cdot 10^2$	$1.0 \cdot 10^2$	-	-	mg/kg-day
Skin surface	$3.8 \cdot 10^2$	$8.0 \cdot 10^2$	$6.2 \cdot 10^2$			cm^2
Outdoor inhalation rate	5.3	15	10	7.2	20	m^2/day
Indoor inhalation rate	2.0	5.4	3.8	7.2	20	m^2/day
Root vegetable ingestion rate	0.62	1.3	1	0.83**	0.29 **	g/kg-bw/day
Non-root vegetable ingestion rate	0.29	0.32	0.32	0.83***	0.83 ***	g/kg-bw/day

* The weight of 10 kg is used for calculations of acute toxic risk for small children
** Calculated by multiplying the total consumed plants (0.25 & 0.4) with the fraction root-vegetables (0.5) and then divided by body weight (15 & 70)
*** Calculated by multiplying the total consumed plants (0.25 & 0.4) with the fraction leaf and stalk vegetables (0.5) and then divided by body weight (15 & 70)

The human behaviour assumptions made in the ERM report are showed in comparison with the standard SEPA values for the same parameters in Table 20.

Table 20: Values used for human behaviour assumptions in ERM report and the corresponding standard value in CPCGV.

Parameter	**ERM Report Residents**	**SEPA Standard for Sensitive Land Use**		**Unit**
		Children	**Adults**	
Exposure frequency to site	$3.50 \cdot 10^2$	$3.65 \cdot 10^2$	$3.65 \cdot 10^2$	days/year
Fraction of skin exposed to soil	20	20	30	%
Soil skin adherence	0.50	0.20	0.20	mg/cm^2
Exposure frequency to surface soil	$1.8 \cdot 10^2$	$1.2 \cdot 10^2$	$1.2 \cdot 10^2$	days/year
Fraction of time spent indoors	92* / 88**	$1.0 \cdot 10^2$	$1.0 \cdot 10^2$	%
Fraction of time spent outdoors	8.0* / 13**	0.0	0.0	%
Fraction consumed plants grown on site	10	10	10	%

* The value used for children between 0 and 1.
** The value used for children between 1 and 6.

The human behaviour assumptions made in the ERM report had several similarities with the standard values from the Swedish standard for KM. The assumptions for fraction of skin exposed to soil and fraction consumed plants that are grown on the site were the same. There were slight differences in the amount of days in a year people were expected to be present on the site. The exposure frequency to site, a term used in the ERM report, was interpreted as equivalent to the term Exposure to Inhalation of Vapour/Dust in the Swedish CPCGV. The Swedish model accounted for 15 more days of exposure each year than in the ERM report. But the exposure frequency to surface soil was in turn 60 days shorter in the Swedish model than in the ERM report. Both systems assumed that the majority of the time was spent inside the house.

7.2.4 RISK CHARACTERISATION

To reach a site specific guideline value for the factory site, ERM used an approach based on Maximum Allowable Risk Level (MARL) and Hazard Quotients (HQs). A HQ is the Mean Daily Intake (MDI) divided by the Tolerable Daily intake (TDI). The report set HQ ≤ 1 as the acceptable level. All exposure pathways showed HQ-values below 1 and therefore it was assumed that no further investigation was needed. The site specific guideline value was calculated by dividing the MARL, set to 1, with the sum of HQs for all pathways. The guideline value was also multiplied by an arbitrary soil concentration, set to 1. This resulted in that the site specific guideline value was equal to the TDI divided with the MDI.

ERM used a forward approach to calculate the site specific guideline value. As mentioned in previously in the report, in a forward dose calculation the concentration of contaminant in the soil is measured, then the size of the exposure is calculated. The Swedish CPCGV uses a backward approach to calculating site specific guideline values. The computer program provides an acceptable level of contaminant in the soil so that the exposure do not exceed the acceptable exposure level. The CPCGV contains a feature that allows the user to enter the concentration of pollution in soil to calculate the concentration of pollutant in pore air, pore water, groundwater, surface water, indoor air and outdoor. This feature mainly exists so the user can compare measurements on the site with the values given by the model (Axelström, Back and Carling 2001). As shown in this report, the feature can also be used in performing a forward dose calculation for a contaminated site, although that use is not recommended by SEPA.

A positive aspect with using a forward dose calculation is that it accounts for the conditions that actually is present on the site. It is based in the actual circumstances that is on the site, rather than what the circumstances could be. Backward calculations have a more long-term approach to risk assessments. The result from a backward calculation gives acceptable guideline values for a site so that no risk arises on a long term perspective (100-1000 years) (Back and Nilsen 2012). Both methods therefore have positive and negative aspects, and different site characteristics might require different approaches.

Backward calculations are traditionally used in Swedish risk assessments (ibid.). The Swedish guidelines do include information about performing backward- as well as forward dose calculations (SEPA 2010). The approach of forward dose calculation is also used as a standard within the area for environmental medicine in Sweden (ibid.). This indicated that the more frequent use of backward calculations for risk assessments in Sweden is not due to the lack of knowledge about forward dose calculations. It could indicate that Sweden gives more significance to the long term risks, and therefore uses an approach that mainly accounts for future risks. The positive aspect of this is that the guideline values usually are more conservative. The negative aspect of conservative values is that they might be too conservative. Remedial actions can have high resource costs, e.g. energy and economic. A too conservative value can therefore lead to a waste of resources without providing a safer environment for the users. With this as background, it is important that the appropriate method for risk assessment is used for each specific site. To make it easier for the risk assessor to choose an appropriate method, the approach of both forward and backward calculations should be included in the CPCGV. The potential to develop the CPCGV, so that it includes a feature were forward dose calculations can be performed, is high.

It is important to note that the ERM report were from 2006. The practises and methods for conducting risk assessments in India have probably evolved since then. The ERM report was chosen mostly due to pedagogic reasons, since it is performed on the factory site which the rest of the report focuses on. A more in-depth evaluation of risk assessment practices in India could be performed by investigating a larger number of and more recent risk assessment reports.

7.3 STANDARDISATION

In previous sections, it has been shown that the implementation of risk assessments in India and Sweden have several differences. The issue of soil pollution is something that every country struggles with. Therefore, it is important to use all the knowledge available to make sure to minimise the harm from polluted areas. A way of combining all the information that is available is for different countries to work together to reach an international standard for risk assessments.

The International Organization for Standardization (ISO) is developing a standard for impact assessment for soil quality. The name of the umbrella project is ISO/TC 190/SC 7. The umbrella project consists of 38 published standards and 3 standards under development. Some examples of the published documents are standards for: "Conceptual Site Models for Potentially Contaminated Sites", "Guidance on the Determination of Background Values" and "Characterization of Soil with Respect to Human Exposure". It also contains standards for sampling relating to contaminated soils. The project has 20 countries as participating members and 10 countries as observing members. Sweden is one of the participating members in the project, while India is not. (ISO n.d.)

With an increasing globalisation and the rise of multinational corporations, the need for unified international standards are essential. The work by ISO for an international standard for impact assessment for soil quality is a positive effort to reach a more unified international standard. A way for India to integrate more comprehensive guidelines for the work related to risk assessment is to join the work for an ISO standard within impact assessment.

7.4 CONCLUSIVE THOUGHTS

In this section a summary of the findings from the analysis of risk assessment implementation in the two countries and the case study of the actual Indian risk assessment report is presented.

7.4.1 RISK ASSESSMENT IMPLEMENTATIONS

There were major differences in environmental legislation for contaminated areas between India and Sweden. India did not have any specific legislation covering soil pollution but implements response levels from legislation concerning hazardous waste. There is ongoing work in India to craft guidelines within risk assessments and soil remediation. The proposed screening level for mercury in India was far higher than the Swedish generic guideline value. An analysis of other elements showed that it was not possible to make a general assumption about which of the two countries that had more conservative generic guideline values.

India have also initiated a project to identify possibly polluted areas. Sweden have already claimed to have found the majority of possibly polluted areas within the country. The approach used in Sweden relied on a simple classification system. The project to identify possibly polluted areas have been successful in Sweden since all possibly polluted sites have been identified. This is an indication that a simple classification system can be beneficial.

The process of initiating a risk assessment in India have a much greater reliance on public attention. In Sweden the initiation of risk assessment is driven by a supervisory authority.

7.4.2 RISK ASSESSMENT CONDUCTED BY ERM IN COMPARISON WITH SWEDISH GUIDELINES

The comparison was performed on one report assessing site specific guideline values in India. It is not possible to draw any widespread conclusions about how risk assessments are generally conducted in India from a single report. The report could still provide some indication on how site specific guideline values are calculated in India.

In general, the ERM report followed the same structure as the Swedish guidelines for conducting site specific guideline values. One major difference was that the ERM report did not account for environmental aspects. The parameter values used for tolerable daily intake and human behaviour assumptions only showed slight variations between the two countries. The ERM report did not account for the exposure pathway from inhalation of vapour. The reasoning by ERM that remediation will be performed for hot spots, and that measured values from above the hot spots can be disregarded, would not have been made in a risk assessment following the Swedish guidelines. ERM also used a forward dose calculation approach while backward calculation approach is more common in Sweden. All in all, the ERM approach shows great similarities with the Swedish approach but the few differences that exists have a major impact on the resulting site specific guideline values.

8 RESULTS AND DISCUSSION OF REMEDIATION METHODS

The former thermometer factory has been shut down since 2001 and the site is being cleaned from mercury after a court decision in 2016. On the factory site, there have been measurements taken that showed high levels of mercury in soil and surrounding water and sediments. It is of great importance to take action to prevent the continuous spread of mercury to surrounding areas. In the nearby small village, Vellagavi, the inhabitants were concerned about the contamination issues and many told, during the interviews, that the crops were declining due to mercury contamination.[12] However, the the effect on crops from mercury will not be a part of this report. There was no clear evidence of mercury related reasons for the decline in crops and a further investigation exceeds the scope of this study.

For the research question for the second extended focus to be answered, the factory site and the village of Vellagavi were examined individually. The research question for the second extended focus was: *What remediation methods can be applied on the factory site and in Vellagavi to reduce risks imposed by mercury on environment and human health?*

According to the risk assessment for the factory site made in this project, the site specific guideline value was lower for the less sensitive land use (MKM) (see Chapter 5) than the guideline value decided in court for the factory site (HUL 2018). The method that was used for evaluating remedial alternatives in this project was in accordance with SEPA's recommendations for the evaluation procedure (SEPA 2009a). The evaluation of remedial actions depended on the results from the risk assessment (see Chapter 5). Since mercury cannot be degraded, the possible actions are either to separate mercury from soil or to immobilise it in soil (Xu 2013). The risk assessment in this project reached a maximum site specific guideline value for MKM of 2.4 mg/kg and in contrast to the court decided 20 mg/kg (HUL 2018). The differences of discussed remedial alternatives in this project, compared to the report from HUL that was used for the court decision, led to that other remedial actions being evaluated in this project. The potential remediation methods taken on a contaminated site can be divided into two actions: in situ and ex situ (Svenska Geotekniska Föreningen 2019). In situ refers to the actions taken are made on site. Ex situ means that the remedial action is made on a different place, e.g. removing contaminated soil to a safe place where it can be cleaned.

8.1 DATA AND VALIDATION

The remedial evaluation was not complete since data from the factory site and Vellagavi were missing. Only a few parameters related to soil characteristics could be presented in the analysis, since there were no previous records of such parameters. For example, the pH value would have been important to include in the evaluation but was not possible to measure. If the soil properties had been measured, the remediation analysis could have been made more thorough. The parameters needed in order to conduct the initial evaluation of remedial alternatives are presented in Table 21.

Table 21: Parameters needed for conducting an initial evaluation. "n.i." means that no information was available

Parameter	Source of Information
Groundwater table	n.i.
Groundwater pressure	n.i.
Potential flow directions	Field Study
Water flow	n.i.
Sedimentation and redox relations in water areas	n.i.
Depth to bedrock	n.i.
Fraction of contaminant in different media, matrix, and particle size distribution	n.i.
Amount of contaminant in water	HUL
Potential requirement of drainage	n.i.
Characterisation of the soil's, sediment's and mountain's physical properties	Some information from HUL

[12] Annette Baumann, Member, Palni Hill Conservation Council, 2020

Even though there are many parameters missing, an initial analysis of remedial alternatives was relevant in this project in order to examine remedial options for the mercury contaminated site. The risk assessment and remedial evaluation were compared to the information presented in the risk assessment made by HUL. For Vellagavi, no data has been collected before and therefore it would have been interesting to evaluate what effects the factory's emissions might have had on its surroundings.

For the detailed analysis of the remedial alternatives more extensive information would be needed, e.g. fraction of organic matter, inhomogenises, leaching, matrix characterisation of the contaminated site and a potential preparation of the contaminated site for disposal facilities (SEPA 2009a).

8.2 EVALUATION OF REMEDIAL ALTERNATIVES FOR FACTORY SITE

A study from 2015 showed that the soil beside the factory site was contaminated (Community Environmental Monitoring 2015). Therefore, there should be an incentive to perform remediation on the site, so that no further spreading of contaminant occurs. The remedial alternatives should focus on cleaning the soil, since soil represents most of the factory site and still holds contaminant. For the remedial evaluation of the factory site, a baseline alternative and potential candidates for max- and BAT-alternatives were presented. There was not enough data to decide upon a BAT- and max-alternative in this project. Therefore, the possible alternatives was evaluated, but not rated. In the cost calculations of the alternatives, an approximate area of 85 000 m^2 was used for the factory site (ERM 2007). The contamination depth was 0.35, in accordance with the SEPA standard. This gave a total soil volume of 29 750 m^3 that was used for estimating the remediation costs for the factory site.

8.2.1 BASELINE ALTERNATIVE

As mentioned in the background, the baseline alternative is when no remedial action is taken. In the baseline alternative for the factory site, the concentration of mercury in soil would decrease over time. There would be a constant leaching of mercury into air and the surroundings. Since the factory now is closed there will be no more accumulation of mercury. Over time, the concentration of mercury at the factory site will decrease in such way that it is no longer harmful for its environment. Since there were too high concentrations in the nearby soil in 2015 there might be a risk that the levels of mercury will be too high many years to come and continue to contaminate surrounding areas, such as the nearby village Vellagavi and surrounding forests. If the baseline alternative is chosen, then there should be constant supervision of mercury concentration on site and at its surroundings in order to quickly detect if the levels of mercury would increase or not decrease as anticipated. Since there are people living adjacent to the former factory, there should be measurements taken there also and it should be important to inform the neighbours of the factory if the levels of mercury exceeds the acceptable levels. If so, then HUL should offer the neighbours compensation proportional to the effects of contamination. It could be difficult to predict whether the concentration in the soil will decrease to acceptable levels within 5 years, 10 years or maybe 50 years since it vaporises over time. Mercury does not disappear; it just converts or transports to other locations. There have been decreasing trends of mercury concentration in the soil from 2001, when the factory was closed, until 2015 when a previous investigation was conducted. Therefore, it can be reasonably assumed that the concentration will decrease over time. There have been discussions of building residential houses on the factory site. If so, it is of great importance to examine the soil and to take enough remedial actions in order for the site to not be hazardous for the future residents. The baseline alternative might not be preferable, regardless of land use.

8.2.2 PHYTOEXTRACTION

A remedial alternative for the factory site could be phytoextraction, which is a kind of phytoremediation method. The method of phytoextraction is an in situ method that uses the uptake of heavy metals in plants in order to harvest the plants, hence removing plants and mercury from the site (Renberg n.d.; Napoli et al. 2019). For mercury, the phytoextraction technology is effective since when the plants have absorbed the mercury, the plants will be removed from the site and treated to not re-contaminate the area (Derakhshan Nejad, Jung and Kim 2018). Phytoremediation is considered to replace the more traditional remediation methods such as soil removal or soil washing, since it removes the same amount of mercury but have less impact on soil and biodiversity (Heaton et al. 1998). Removal of mercury will be done by harvesting the plants to prevent that the contamination returns to the soil (Greipsson 2011). After harvest, the contaminated plants can either be composted or incinerated and then be sorted as hazardous waste on a landfill (Svenska Geotekniska Föreningen 2020).

There are several plants to choose from when deciding upon the remedial alternative. When determining what kind of plant that should be used in this specific case, a botanist should be consulted, since the species in the area might differ a lot from what grows in Sweden. The plants should preferably have the following properties:

- Thrive on the site, but not be invasive.
- Be efficient for mercury uptake and resistant to high concentrations of mercury in soil.
- Improve soil structure.
- Manage weekly, monthly, or annual harvesting.

Except from the choice of plant(s), there can be microbes included in the plants that convert toxic mercury into less toxic forms (Derakhshan Nejad, Jung and Kim 2018). Therefore, an enhanced mercury uptake in plants can be achieved by using genetically modified microbes in plants (Heaton et al. 1998). This is an in situ phytoremediation method whose main purpose is to use selected plants that are modified with a bacterial gene that converts the toxic Hg(II) into the less toxic form, Hg(0) by using redox reactions. It has also been shown that it converts methylmercury into a less toxic form in similar ways. The enhanced metal uptake is usually used when the concentration in soil exceeds the capacity of the plants' uptake (Napoli et al. 2019). A plant's potential heavy metal uptake is usually described as the translocation factor (TF). TF indicates the ability of the plant to translocate mercury from the soil to the leaves. If TF ≥ 1 it is indicated that the plant have great capacity of translocate the mercury (Lominchar, Sierra and Millán 2015). A study showed that the plant *Cyrtomium macrophyllum* had a translocation factor of 2.62, which indicated great possibilities of mercury uptake (Xun et al. 2017). The mercury uptake was still effective for concentrations as high as 500 mg/kg. Potential plants that can be used for the phytoextraction method on the factory site are presented in Table 22.

Table 22: Plants used for phytoextraction in other studies and that can be applied in this project

Species	**Media**	**Advantages**	**Disadvantages**	**Source**
Cyrtomium macrophyllum	Soil	High Hg-tolerance Effective Hg-uptake	Not guaranteed to thrive on site	(Xun et al. 2017)
Jatropha curcas	Soil	High Hg-tolerance Effective Hg-uptake. The plant can be used for bio-diesel fuel	Might be invasive	(Marrugo-Negrete et al. 2015)
Arabidopsis thaliana	Soil	High potential of Hg-uptake when modified	Requires bacterial-genetically modification	(Kiyono et al. 2013) (Heaton et al. 1998)
Nicotiana tabacum	Soil	Effective Hg-uptake Resistant to high levels of Hg Possible genetic modification	More efficient for air cleaning	(Heaton et al. 1998)
Lactarius (Mushrooms)	Soil	Effective Hg-uptake	Not found in the area	(Falandysz 2017)

The cost was difficult to estimate since there was a complex contamination situation and the cost depended strongly on the choice of phytoremedial method. An American study showed through a cost-benefit calculation that phytoremediation costs around 38 $ per m^3 soil for phytoremediation performed during a two year period (Wan, Lei and Chen 2016). Using the volume of 29 750 m^3 generated a total cost for phytoremediation of approximately 1 130 000 $. It was also reported that the cost of phytoremediation was lower than the of other remediation methods (ibid.). The company, HUL, will suffer from financial loss due to remediation costs (harvesting), and that the land will not be used for anything until the remediation is completed. This cost was not included in the cost analysis.

The environmental consequences for choosing phytoremediation could be primarily the decreasing mercury concentration in the soil and improved soil structure due to perennial plants. Depending on choice of phytoremediation method it might lead to increased biodiversity unless an invasive species is utilised which inflicts with the existing ecosystem. Since Kodaikanal and its surroundings have problems with the invasive species Eucalyptus and Acaia[13], using these two species for phytoremedial actions are not recommended. These species are not widely used for phytoremediation, but since the invasive problem in Kodaikanal is so obvious, these plants should be excluded from the evaluation.

A compilation of advantages and disadvantages of phytoextraction are presented in Table 23.

Table 23: A compilation of advantages and disadvantages of the remedial method of phytoextraction

Phytoextraction	
Advantages	**Disadvantages**
Low energy and resource demand	Time consuming
Removal of mercury is effective	Continuous harvesting
The choice of plants used for phytoremediation can be customised to the specific areas depending on what thrives on site	Need of post-processing harvested plants
Low yearly costs	Technology under development
Remediation reach of up to 75 cm in the soil, which suits the selected area in this project	

The efficiency of the phytoextraction is under evaluation and the method is still tested in pilot projects. The efficiency of mercury uptake is also strongly dependant on what species that are used, the soil chemistry and several other aspects that affects the bioaccumulation. A priority must be to decrease the source of contamination and to make sure that the site is clean enough for not being considered hazardous. This remediation method is time consuming, which can have impact on the ecological and economical evaluation. However, it is the most sensitive action for soil remediation, which is good from an environmental perspective. Minimal impact on the soil would be preferable, as well as the decreasing concentration of mercury. If the remediation takes too long time, then the exposure of mercury to the protection targets is prolonged, which poses a risk. When mercury accumulates in the phytoremediation plants, it can be collected by harvesting. Depending on the concentration of mercury in the plants they can be composted or incinerated. Either way, it is important to evaluate the extraction of mercury from the plants and how to handle the mercury that has been collected in the plants. The evaluation showed that phytoremediation would be a possible option when using plants that can accumulate mercury, even though the more exact choice of plant(s) used for phytoremediation should be examined more closely if this remediation method was chosen.

[13] Mark Antrobus, President, Palni Hills Conservation Council, 2020

8.2.3 THERMAL DESORPTION AND PHYTOREMEDIATION

Another potential alternative for remediation at the factory site could be to combine thermal desorption with phytoremediation. The thermal desorption would lower the concentration of mercury in soil. If mercury remains in the soil after thermal desorption, then it could be combined with phytoremediation. The remedial technology of thermal desorption is based on heating soil containing mercury in order for the contaminant to volatilise and leave the soil (Derakhshan Nejad, Jung and Kim 2018). Steam, microwaves, and infrared radiation can be used for heating the soil combined with vacuum extraction. This method can remove up to 99 % of the mercury in the soil and takes about 1 hour if soil is heated up to 550 ^oC (ibid.). The effectiveness of the method depends on the vaporisation of mercury, which in turn depends on applied temperature, soil composition and the redox conditions on the site (Park 2011). Also, if the mercury is bound to other soil components it can affect the efficiency of thermal remediation (Park, Katz and Liljestrand 2015). The method of thermal remediation is effective even for mercury in other formations, such as HgO, HgS, $HgCl_2$ (Wang et al. 2020). The disadvantage of this method is the high energy demand required if the soil is heated to over 500 ^oC. The energy demand is not in line with the recommendations from SEPA, who suggested energy efficient methods (SEPA 2009a). However, the method is very efficient even for high concentrations (Navarro et al. 2013). In order to decide upon thermal desorption, there are several soil characteristics that need to be clarified, such as soil moisture, heat capacity, particle size etc. If the soil moisture is too high ($\geq$ 20 %), the cost and energy demand for only drying the soil in order to commence the remediation will be high (GeoEngineer 2013).

The total cost for the remediation method of thermal desorption, without specifying what technology that was used, ranged from 3 600 000-5 400 000 $ (Otto and Bajpai 2007). Important to know is that these costs were based on compiled studies from the year of 1995, leading to a probability of outdated costs for the method.

The environmental consequences for this alternative could on one hand generate fast removal of mercury in the soil leading to less risk of mercury poisoning. On the other hand, it will have negative ecological consequences due to the heating of soil into unnatural temperatures, affecting the biological systems in the soil. The compilation of advantages and disadvantages of thermal desorption are presented in Table 24 and the compilation of phytoremediation is the same as presented in Chapter 8.2.2.

Table 24: Compilation of advantages and disadvantages of the general thermal desorption remediation method

Thermal Desorption	
Advantages	**Disadvantages**
The method is effective for mercury contaminated soil	High energy demand
The amount of heat can be customised to the specific contaminant in order to not over-consume energy	Important to supervise the volatilising of mercury
Can achieve target treatment temperatures above the boiling point of water	Affecting ecosystem since the soil is heated to unnatural temperatures
Works on many different kinds of soils	It takes time to cool down the soil into normal temperatures, which might have a negative effect on local ecosystems
Can operate near other buildings without affecting them	Might be size limiting for in situ remediation
It has been used worldwide since the 1980	

A kind of thermal desorption is Thermal Conducting Heating (TCH) which is applicable on many different pollution scenarios, e.g. dioxins, pesticides and mercury (TerraTherm n.d.). TCH is based on leading heat through e.g. iron rods placed in the ground that heats up the contaminated soil to a target treatment temperature. Depending on the contaminant's volatile ability the temperature is adjusted accordingly. The heating procedure is combined with a vapour cap that collects the mercury gas. The area of heating is limited to the possibility to collect the volatilised mercury and the mechanical and physical resources of the heating. There are different varieties of TCH. One of them is an in situ method called Steam Enhanced Extraction (SEE) which can be applied to sites with difficult conditions, e.g. rapid groundwater flow. SEE is suitable for remediation of larger contaminated areas and for high contamination levels. This is the case for the factory site, which makes it a possible remedial alternative of thermal desorption. Mercury can bind to soil particles and stay in the soil, making a heating method possible for remediation (Cascade Environmental n.d.). Electrical Resistance Heating (ERH) is another TCH-method that can be applied to soil and groundwater for in situ remediation. It uses the techniques of sending current through the soil moisture and then the resistance in the soil produces heat. The installation of the rods can be made by horizontal or angular drilling techniques. ERH is suitable for addressing VOCs, CVOCs and NAPLs (United States Environmental Protection Agency 2020).

The ERH method could be an alternative for the factory site in order to remediate the soil. The cost of ERH was estimated by USEPA to 42-92 $\$/m^3$. If all soil were to be remediated, a volume of 29 750 m^3, the total cost would approach 1 250 000-2 737 000 $. This technology has been used on several contaminated site before and is well-tested, but there is a limited amount of vendors that offers the technology. (ibid.)

There is also a method using a heating blanket and it can be used for remediation of hot spots (GeoEngineer 2013). From a report made by ERM it was shown that the factory site had several mercury contaminated hot spots (ERM 2007). The blanket can cover an area of 15 m^2 and heat the soil to a depth of 0.9 m, which is deeper than necessary at the factory site. By using the blanket on selected areas, such as the hot spots, the concentration could be decreased.

Combining remediation methods can usually be effective for complex contaminated sites where limited previous success of remedial action. Therefore, using TCH (e.g. ERH) on the larger contaminated areas combined with the thermal blanket for the hot spots and phytoremediation as a complement for the remaining mercury contamination could be considered as an alternative.

8.2.4 EXCAVATION AND SOIL CLEANING

Excavation in combination with soil washing could be a remedial alternative for the factory site. There are primarily two versions for the excavation method: remove the soil for cleaning purposes and then put the cleaned soil back on site or remove the soil to a landfill and insert new soil. For both methods, there might be a need of pre-treatment to make the soil match the requirements from the ones taking care of the soil (Federal Remediation Technologies Roundtable n.d.).

For the alternative of removing the soil and transporting it to a landfill, the soil might need to be cleaned before disposal, depending on the amount of mercury in the soil and local regulations for contaminated soil in landfills (ibid.). How much of the mercury that risks being volatilised when excavating should also be evaluated. The mercury that previously had been bound to the soil might be released when the excavation commences. Overall, the excavation and off-site disposal is a relatively simple and by far the most well tested process.

The excavation of 20,000 tons of contaminated soil was estimated to take about 2 months (ibid.). A soil volume of 29 750 m^3 was used. An approximate weight of 1 500 kg for 1 m^3 soil generated a total of 44 625 ton soil (Målnsätra Gård n.d.). According to the time estimation, this would take about 4-5 months, if all soil on the factory site was removed within the depth of 0.35 m. The concentration of mercury in the soil of the factory site was unevenly distributed in hot spots. Therefore, the hot spots probably require pre-treatment before removing the soil. The cost estimation for excavation and disposal on landfill, excluding pre-treatment, was 270-460 $ per ton removed soil. If all soil were removed from site it would cost about 12 050 000-20 530 000 $. The estimated costs were based on an American calculation that included excavation, transportation, and disposal at a disposal facility, for an American case. This was a rough estimation since the cost probably differs between the U.S and India. The cost of potential pre-treatment was not included in the estimation. A suggestion of pre-treatment, especially for the hot spots on the factory site, could be chemical immobilisation in order for mercury not to vaporise when excavated and transported. Since mercury could be volatile, this is an important aspect to take into consideration when deciding upon what pre-treatment method to use.

The aspects affecting the total cost of the excavation depends on several reasons (Federal Remediation Technologies Roundtable n.d.). The aspects that should be taking into consideration are:

- The amount of contaminated soil.
- The amount of soil tests needed in order to determine the depth, soil properties and spread of the contamination.
- The need of pre-treatment.
- The availability of machines, able to transport hazardous waste without polluting its surroundings.
- Distance from contaminated site to the nearest landfill or cleaning facility.

Excavation combined with the chemical remediation method of soil washing can be made both in situ and ex situ. The in situ method usually includes chemical leaching which is based on adding chemical(s) in order to mobilise mercury in the soil, making it easier to remove (Derakhshan Nejad, Jung and Kim 2018; He et al. 2015). The aim of mobilise mercury is to form soluble mercury complexes, such as HgI_4^{2-}, to make the removal easier. A study has shown that adding 0.1 M hydrochloric acid to mercury contaminated soil is effective for contaminant removal up to 80-90 % (Alghanmi et al. 2015). The cost for soil washing, or chemical mobilisation, ranged from 1 420 000-33 200 000 $, based on previous studies. The upper range was based on a pilot project which was more expensive than the full-scales projects (Otto and Bajpai 2007). There was one study that could provide the total cost for a soil washing project, which was 7 700 000 $. The cost per year was not specified in any of the cases.

Excavation can also be combined with thermal desorption, where the thermal desorption is used as a soil cleaning method. The excavated soil can be cleaned both in situ and ex situ depending on where the thermal desorption equipment is placed. The vapour can be collected and treated in an off gas treatment unit, which is a sort of equipment used for collecting the vaporised mercury. Depending on the extent of the contaminated soil, the cost of ex situ thermal desorption for soil cleaning purposes was about 150-200 $ / ton. For large remediation project it is often desirable to use in situ remediation to cut down transportation costs. For the factory site, around 44 625 ton soil was estimated to be excavated. This would lead to a cost of 6 700 000 $ to 8 925 000 $. (GeoEngineer 2013)

The environmental consequences for the excavation and soil cleaning alternative could be that removing soil might affect the soil ecosystem negatively. Plants and trees that are removed from site in order to make the excavation easier can lead to leaching of mercury and other chemicals, if present. The excavation can also lead to more mercury being released into air that was previously bound to the soil. If the protection of ground ecosystems is important to the site, then the excavated soil needs to be replaced with soil that promotes biological growth, since microorganisms have been removed from the site when the soil was excavated (Svenska Geotekniska Föreningen 2019). A compilation of the advantages and disadvantages are presented in Table 25.

Table 25: Compilation of advantages and disadvantages when using the remedial action of excavation combined with a soil cleaning method

Excavation and Soil Cleaning		
Method	**Advantages**	**Disadvantages**
Excavation and landfill	All contaminant in soil will be removed Not the most expensive method	Mercury could be released into air Removal of biological activities Might need pre-treatment
Excavation and soil washing	The soil can be returned to site after washing Effective	Mercury could be released into air Removal of biological activities
Excavation and thermal desorption	The soil can be returned to site after washing Well-tested Effective	Mercury could be released into air Removal of biological activities Might require pre-treatment

8.2.5 CHEMICAL IMMOBILISATION

The immobilisation method does not remove the contaminant from site, but immobilises the heavy metal in order to make it less hazardous and to prevent it from spreading and contaminating its surroundings. The chemical remediation method uses a chemical reagent that is added to the soil in order to make the contaminant immobile (Svenska Geotekniska Föreningen 2018). Since most reagents and equipment needed for this method are already on the market in large-scale and are not very expensive, the costs will be relatively low (Derakhshan Nejad, Jung and Kim 2018). Data of soil properties and the chemistry needs to be collected before making a detailed analysis of the choices of the immobilisation method, since mercury has a complex chemistry (He et al. 2015). In this report some of the chemical immobilisation methods will be presented and discussed.

There are studies showing that adding sulphide-containing reagents can react with Hg^{2+} to form mercury sulphide, which is a stable and insoluble compound (ibid.). The efficiency of this immobilisation method was 99 %, which means that only about 1 % of the mercury leached to the surroundings. A change in pH could affect the efficiency of the method, but it was still considered very effective (approximately 98 % when pH was approaching 10). Another study stated that adding sulphur to mercury contaminated soil might not be preferable since it can be flammable at relatively low temperatures (190 ^{o}C) (Worthington et al. 2017). Sulphur also increases the hydraulic resistance during filtration and is not very compatible with other remedial actions. It can also, in the long run, enhance the growth of sulphate-reducing bacteria leading to increasing concentrations of methylmercury. The same study showed that the properties of a sulphur rubber (containing sulphur and unsaturated cooking oils that have been polymerised) could be used for remedial purposes. The sulphur rubber was found effective to capture different forms of mercury in different media. A low production cost for the raw materials might be motivational to keep developing this method, since sulphur is a by-product from the petroleum industry.

The costs for chemical immobilisation was difficult to estimate and it depends on the choice of immobilisation method. A compilation of studies showed a cost range of 230 000-2 800 000 $ for a selection of previous studies of immobilisation studies in full-scale (Otto and Bajpai 2007). Important to have in mind was that the capital costs or the maintenance costs for the studies presented were not always known. Therefore, the total cost for the whole remedial action of immobilisation was not known.

The environmental consequences for the immobilisation alternative could be that if the conditions in the soil changes, there could be a release of mercury into the environment. Therefore, it is important to have continuous supervision of the area. The choice of immobilisation chemical should be well examined in order to not affect the environment negatively. Also, the biological activity could be affected by the choice of immobilisation method if it becomes toxic to organisms. Usually, the immobilisation method is based on converting mercury to a sort of insoluble mercury salt, leading to toxicity not being a problem since it is not bioavailable. Also, it is important to choose an immobilisation method that only immobilises the target contaminant and not affecting other metals or nutrients that might be important to the ecosystem. The advantages and disadvantages of immobilisation are presented in Table 26.

Table 26: Compilation of advantages and disadvantages of the immobilisation remediation method

Immobilisation	
Advantages	**Disadvantages**
Effective for mercury	Efficiency dependant on concentration in soil
Relatively low costs	Efficiency can be affected by changed soil properties, such as pH or water content
Several technologies under development	Requires continuous supervision
Can be applied on different soils	Contaminant is not removed from site

For mercury, the vitrification technology could be effective (Derakhshan Nejad, Jung and Kim 2018). Vitrification is based on adding reagents or materials to the contaminates soil in order to encapsulate the contaminant. The immobilised contaminant then becomes unable to migrate to its surroundings, such as water, soil, air and plants (ibid.). The immobilisation method with the vitrification technology can last for decades, and even hundreds of years. However, the efficiency of vitrification is partly limited by the concentration of mercury in the soil, which should preferably be below 50 mg/kg (He et al. 2015). Therefore, it might not be a suitable method for the factory site, which had records of high levels of mercury in several places.

When using the immobilisation method, the contaminant remains in the soil, which leads to a need of continuous supervision. It might limit the exploitation possibilities since the contaminant should not be mobilised when e.g. infrastructural development uses excavation on the soil, leading to the contaminant suddenly being released. The release of contaminant can also be caused by changes in the soil properties, e.g. pH, water content etc. (Svenska Geotekniska Föreningen 2018). There might follow land use restrictions when using this kind of remediation method since the contamination remains in the soil, even though it is immobilised. Overall, the immobilisation remediation method is primarily based on preventing the spread of contaminant to other areas. The cost is difficult to estimate since it varies with the choice of chemical and the extent of the contaminated site. Even though the technology might be effective, the amount of mercury in soil remains. Therefore, this technology requires constant supervision since the mercury could be mobilised if the conditions in the soil changes.

8.2.6 SUGGESTED REMEDIAL ACTIONS IN COMPARISON WITH THE ACTIONS CONDUCTED BY HUL

The remedial actions that HUL was obligated to commence, in accordance with the court decision, to reach the site specific guideline value of 20 mg/kg were excavation and soil washing. The excavated soil will be cleaned and when the desired concentration is reached the soil will be returned to the site (HUL 2017). The remedial actions suggested for the factory site in 2007 were excavation of contaminated soil and soil washing in order to return the cleaned soil back, i.e. the same actions as decided in 2016 (ERM 2007). In this project, all site specific guideline values were about ten times lower than the court decided value. The lower values in this project led to an evaluation of more restrict and effective remedial actions since the soil needs to be cleaned to a lower level than 20 mg/kg. In the ERM report, used for the court decision, the evaluation of remedial alternatives for the factory site might not have been extensive enough, in order to consider enough suitable options. There could have been more investigations related to remedial alternatives in the ERM report, but it was difficult to examine if there had been enough evaluated remediation methods before deciding upon a final remediation method.

8.3 EVALUATION OF REMEDIAL ALTERNATIVES FOR VELLAGAVI

The village of Vellagavi mostly contains of small houses, pedestrian roads and animals. There are no cars in the village since it can only be reached by foot. The village is located about 2 km from the factory site. Since no previous data was available for Vellagavi, an evaluation of remedial alternatives was difficult to conduct. It could be argued that data needs to be collected in Vellagavi in order to make an analysis. Therefore, if the soil in Vellagavi was to be found contaminated there should be measures taken. Depending on the outcome of the testing (soil, sediment, water, houses, air etc.) different remedial actions can be taken. What to take into consideration is that the area is difficult to access and therefore it can be difficult to make more extensive actions, since there are no proper roads leading to the village. It would be considered more efficient to take actions on the factory site instead of in Vellagavi.

8.3.1 BASELINE ALTERNATIVE

For Vellagavi, the baseline alternative might lead to elevated mercury levels in soil and eventually biomass. Since the inhabitants have much contact with soil, there might be a risk choosing the baseline alternative since the inhabitants might be exposed to too high concentrations of mercury during a long time. But there are no tests conducted in the area, leading to limited knowledge of the concentration of mercury in Vellagavi. If it would be shown that the soils in Vellagavi are mercury contaminated, then in situ remediation would be the most reasonable option since it needs to be made without any big machines in order to not destroy the environment.

8.3.2 DISCUSSION OF REMEDIATION IN VELLAGAVI

For Vellagavi, chemical immobilisation could be considered as a remedial alternative, if the site was to be found contaminated. Since there was limited access to the village, the remedial action should be possible to implement without an abundance of equipment. This is an important aspect to take into consideration, as long as a road to Vellagavi does not exist.

A complementary option could be to increase the knowledge of mercury to the inhabitants of Vellagavi, e.g. symptoms of mercury intake such as nausea or headache. With the knowledge of mercury and its impact, then the villagers can be more observant if they would be affected by high concentrations of mercury. In case of increasing agriculture of more self-serving crops a heavy metal pollution in croplands can result in enhanced dietary exposure through soil–plant–food chain transfers (Derakhshan Nejad, Jung and Kim 2018). Therefore, soil testing should be made on the farming lands to estimate the magnitudes of exposure. It is most logical to reason for conducting remedial actions on the factory site instead of in Vellagavi.

8.4 SUMMARY AND DISCUSSION OF REMEDIATION ANALYSIS

The results from the remediation analysis showed that for the factory site it is important to take actions in order to prevent present and future mercury exposure. Depending on the choice of method, the outcome will vary. There are several possible remedial options for the factory site, but more data and investigations needs to be collected before deciding upon what alternative to choose. For Vellagavi, it is more efficient to take remedial actions at the source of contamination instead of taking remedial actions in Vellagavi. It is important to examine the situation of contamination in the village before concluding anything about the choice of action. The remedial analysis that was made in this project is not possible to conduct on the factory site, since it was already decided in court about the guideline value and what measures to be taken. This study could more likely be seen as a suggestion of what to do in future, similar situations, and what can be taken into account if the suggested remedial actions from court does not succeed.

The choice of following the Swedish risk assessment procedure and applying it to the Kodaikanal area had some difficulties. The court decided upon a site specific guideline value that was based on international standards, and was not presented as transparently as it was suggested in the Swedish standards. This made the comparison and evaluation of remedial actions in this report in relation to HUL challenging. The remedial actions suggested in this extended focus was based on what was calculated in the risk assessment in this report. Since the site specific guideline value was set to a lower value in this report than what was decided in court, the suggested remedial actions in the evaluation was not necessarily the same. The arguments put through in the Indian court decision was that the suggested site specific guideline value from the NGO:s would not have been possible, since the execution of remediation would have led to too much of an environmental impact on the factory site. This can be on one hand, found questionable since higher concentrations of mercury in soil could pose a threat to the environment and human health. On the other hand, it could be considered reasonable since the contaminated site is huge and applying excavation, for instance, the physical impact of excavating all the soil on the factory site would be extremely damaging to the biological life in the soil. The choice of remedial action should also consider the sensitive forest area (the Pambar Shola Forest), adjacent to the factory site, and what impact it might have on the forest. It is important to remediate the soil, but in the same time be aware of the consequences of different remedial actions.

The estimation of costs for remedial actions was difficult to perform since most of the costs in previous studies were based on American standards, leading to a high probability of other costs in India. Some of the costs presented were based previous studies, which had evaluated the cost in different ways. The total cost of the remedial action was not always available, making it difficult to perform a valid comparison. In this study the actual cost was not the important part; it was the relation between the different remedial actions, i.e. the order of magnitude.

Overall, the procedure suggested by SEPA promotes transparency in the evaluation process and makes the procedure easy to conduct and to follow. Extensive information was needed, in order to use the procedure in this project. For example, the toxicity of mercury depends on pH and HUL did not take any measurements of pH. Therefore, such basic information was not available, hence making the evaluation incomplete. For future projects, similar to this one, there would be preferable to have access to more results connected to soil characterisation and site related parameters.

The limited amount of alternative could have affected the outcome of the evaluation of remedial alternatives. In the case of HUL and the court decision, it was maybe important to choose a well-tested method that would guarantee an expected outcome. Therefore, innovative remedial solutions might not even have been discussed. The lack of transparency in the assessment from HUL made it difficult evaluate if a reasonable numbers of alternatives were discussed.

8.5 FUTURE REMEDIATION STUDIES

Remedial Alternatives

It would be interesting to evaluate different kind of phytoremedial options for this kind of contamination situation. The factory site could have been used as a pilot project for using phytoremediation on a large-scale. Such project could have been used as a foundation of the development of environmentally sustainable remediation methods. This will not be the case since the remedial action is already decided, but maybe this evaluation could be used as an inspiration for future contamination situations.

The Pambar Shola Forest

The Pambar Shola Forest lies between Vellagavi and the factory site (see Figure 2). The forest is a protected area and have high biodiversity, mostly because of the unique set of indigenous species (Encyclopaedia Britannica n.d.). The Pambar Shola forest is owned by the Tamil Nadu Pollution Control Board (TNPCB) and permission is required to enter the forest. There have been measurements that showed elevated levels of mercury in the part of the forest below the factory. Since the forest is situated adjacent to the factory site and in the same catchment area, the elevated levels of mercury could be traced back to the factory site. The contaminant has probably travelled down to the forest, but in what extent is unknown. Therefore, it is important to study if there are any remedial options for such protected area for not exceeding the acceptable levels of mercury in soil, water, sediments, and air. An important part is carefully planning remedial actions in the forest since it is a protected area and, in some places, non-accessible wild forest. This area could be a subject for future investigations in order to get better understanding of mercury contaminated places and prevent future risks related to a contaminated indigenous forest. The work could be initiated by the municipality and/or TNPCB.

9 SUMMARY AND CONCLUSION

The conclusions for the research are presented in this section, which is divided in to three parts - the joint focus of risk assessment, the first extended focus of implementations of risk assessments in India and Sweden and the second extended focus of remediation methods.

9.1 RISK ASSESSMENT

- How can the Swedish risk assessment tool, Computer Program for Calculation of Guideline Values, be used in an environmental risk assessment of the mercury contaminated sites in the Kodaikanal area?

- How does the concentration of mercury in soil pose a risk to the biodiversity and human health in the Kodaikanal area?

The CPCGV, showed great promise for use in an Indian setting. The tool had an advantage of the flexibility to variate a large quantity of parameters. There was a need for further investigations on how a climate, different from Sweden, could affect the parameters within model's calculations.

In this project it was found that a suitable site specific guideline value for the factory site in Kodaikanal ranged between 0.1-2.4 mg/kg. The guideline values for environmental aspects ranged between 0.1-5 mg/kg while the site specific guideline value for health effects was 2.4 mg/kg. The soil concentrations at some locations within the factory site were notably higher than the site specific guideline values obtained in this project. Therefore, it was found that the contamination within the area could pose a risk for both human health and the environment. An Indian court order had set the guideline value to 20 mg/kg. In a forward dose calculation it was found that a soil concentration of 20 mg/kg would lead to exceedance of the TDI for mercury. The exposure pathway with the greatest impact was found to be inhalation of vapour stemming from polluted soil and inhalation of vapour stemming from skin whitening creams.

This study also evaluated that a suitable site specific guideline value for the village Vellagavi. The result showed that a value between 0.1-0.55 mg/kg probably is suitable, when considering only human health. The study showed the importance of conducting measurements in Vellagavi to make sure that a second hand pollution not have arisen from the mercury released from the factory.

9.2 RISK ASSESSMENT IMPLEMENTATIONS

The research question for the first extended focus was:

- What are the differences and similarities for implementing environmental risk assessment in India compared to Sweden?

The conclusion from the evaluation was that implementation of risk assessments in India showed several differences compared to Sweden. The practice of risk assessments in India was not common and there was a lack of implementation of the proposed guidelines. The proposed guideline documents for India showed great similarities with the Swedish approach. However, the generic guideline value for mercury was much higher in the proposed Indian approach. Despite the big difference between the generic guideline value for mercury, a general trend of having higher generic guidelines for either of the countries could not be identified.

The initiation of a risk assessment was different in the two countries. In India it was common that risk assessments were initiated due to the public bringing possible malpractice to attention, while Sweden heavily relies on the supervisory authority to request a risk assessment. The process for determining a site specific guideline value used for the factory site in Kodaikanal followed an approach similar to the Swedish guidelines. The main differences between the approach used by the Indian report were:

- The Indian report assumed that remedial actions that had not yet been conducted would take place, and based on that assumption the report excluded the exposure pathway from inhalation of vapour.

- The Indian report used a forward dose calculation to reach the site specific guideline value. In Sweden, a backwards dose calculation is commonly used.

To improve the Swedish CPCGV, a process for making forward calculations could be included. To improve the Indian process for risk assessment the supervisory authority in the country could be provided with more resources so that a more standardised way of initiating risk assessments could be achieved.

9.3 REMEDIATION METHODS

The research question for the second extended focus was:

- What remediation methods can be applied on the factory site and in Vellagavi to reduce risks imposed by mercury on environment and human health?

There were several possible remedial alternatives that could be used on the factory site in order to reduce the risks imposed by the mercury contamination. A potentially promising alternative that was evaluated in this report was phytoremediation, since it is the most sensitive method to the environment. The phytoremediation method is still under development and the efficiency depends on the choice of plant(s), leading to the method's efficiency being variable. Other methods could also be suitable for the site. In the initial analysis of remedial actions it could be concluded that there are several options that are appropriate for the factory site. Excavating the soil might the most expensive one, with greatest environmental impact for the factory site. For Vellagavi, there are not many options available. In this study, it could be pointed out that it is predominantly most effective to take remedial actions on the source of contamination, i.e. the factory site.

REFERENCES

Alghanmi, S. I., Tahani A. El-Zayat, A. F. A. S. nad, Alhogbi, B. G. and Salam, M. A. (2015). Acid leaching of heavy metals from contaminated soil collected from Jeddah, Saudi Arabia_ kinetic and thermodynamics studies — Elsevier Enhanced Reader. *International Research and Training Center on Erosion and Sedimentation and China Water and Power Press*. Library Catalog: reader.elsevier.com. DOI: 10.1016/j.iswcr.2015.08.002. Available: https://reader.elsevier.com/reader/sd/pii/s2095633915300745?token=9c9d2dee316c6c3ad8603a6e29e1d7afbb5a27a631ec298f8704707f8989f339%20eea97a61d90223fe8b0d2502bb4c6396 [22/04/2020].

Ashok, K. and Morrison, R. D. (2007). 'PHYSICAL PROPERTIES OF LIQUIDS AND GASES'. *Ludwig's Applied Process Design for Chemical and Petrochemical Plants (Fourth Edition), Volume 1*. Gulf Professional Publishing, p. 1024. Available: https://www-sciencedirect-com.ezproxy.its.uu.se/topics/earth-and-planetary-sciences/henry-law.

Athavale, R. N. and Murti, C. S. (1980). Measurement of recharge rates in soils through detection of tritium produced in Chinese thermonuclear tests. en. *Proceedings of the Indian Academy of Sciences - Earth and Planetary Sciences*, vol. 89 (2), pp. 145–151. DOI: 10.1007/BF02913746. Available: https://doi.org/10.1007/BF02913746 [15/05/2020].

Axelström, K., Back, P. and Carling, M. (2001). Platsspecifika riktvärden för f d impregneringsanläggningar. Förstudie. sv, p. 82.

Back, P. and Nilsen, J. (2012). *Sweco Environment AB GeoMiljögruppen Karlstad*. sv. Tech. rep. 133.1160 400. Karlstad: Sweco Environment AB GeoMiljögruppen Karlstad, p. 88.

Bagyaraj, M., Ramkumar, T., Venkatramanan, S. and Gurugnanam, B. (Mar. 2013). Application of remote sensing and GIS analysis for identifying groundwater potential zone in parts of Kodaikanal Taluk, South India. *Frontiers of Earth Science*, vol. 7 (1), pp. 65–75. DOI: 10.1007/s11707-012-0347-6. Available: http://link.springer.com/10.1007/s11707-012-0347-6 [23/01/2020].

Beardsley-Schoonmaker, P. (Oct. 2011). *A Comparison of Understory Floral Diversity and Soil Quality and the Implications of Human Disturbance in Shola Forests and Abandoned Plantations in the Palni Hills of Tamil Nadu, India*. Minnesota: St. Olafs College, p. 21. [29/02/2020].

Bernhoft, R. A. (2012). Mercury Toxicity and Treatment: A Review of the Literature. *Journal of Environmental and Public Health*, vol. 2012. DOI: 10.1155/2012/460508. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3253456/ [05/11/2019].

Burger Chakraborty, L., Qureshi, A., Vadenbo, C. and Hellweg, S. (2013). Anthropogenic Mercury Flows in India and Impacts of Emission Controls. en. *Environmental Science & Technology*, p. 130726132711009. DOI: 10.1021/es401006k. Available: https://pubs.acs.org/doi/abs/10.1021/es401006k [20/04/2020].

Canada Environment and Climate Change (2009). *Mercury: chemical properties*. aem. Available: https://www.canada.ca/en/environment-climate-change/services/pollutants/mercury-environment/about/chemical-properties.html [23/01/2020].

Canadian Council of Ministers of the Environment (1999a). *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health - Mercury (Inorganic)*. en. Tech. rep. Winnipeg: Canadian Council of Ministers of the Environment, p. 8.

Canadian Council of Ministers of the Environment (1999b). *Guidance manual for developing site-specific soil quality remediation objectives for contaminated sites in Canada*. Tech. rep. 1299. Winnipeg: Canadian Council of Ministers of the Environment.

Cascade Environmental (n.d.). *Cascade Environmental — The Thermal Remediation Experts*. Thermal Remediation. Library Catalog: www.cascade-env.com. Available: https://www.cascade-env.com/thermal-remediation/ [03/05/2020].

Cochran, R. C. and Ross, J. H. (2017). A method for quantitative risk appraisal for pesticide risk assessments. *Journal of Toxicology and Environmental Health, Part A*, vol. 80 (1). Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/15287394.2016.1224747, pp. 1–17. DOI: 10.1080/15287394.2016.1224747. Available: https://doi.org/10.1080/15287394.2016.1224747 [18/05/2020].

Community Environmental Monitoring (2015). *Report of Lichen, Moss and Sediment Sampling around the premises of Hindustan Unilever's Mercury Thermometer Factory in Kodaikanal*, p. 7. Available: http://kodaimercury.org/backdoor/wp-content/uploads/2015/06/Kodai-Moss-Lichen-Report-.pdf [05/05/2020].

Copan, L., Fowles, J., Barreau, T. and McGee, N. (2015). Mercury Toxicity and Contamination of Households from the Use of Skin Creams Adulterated with Mercurous Chloride (Calomel). *International Journal of Environmental Research and Public Health*, vol. 12 (9), pp. 10943–10954. DOI: 10.3390/ijerph120910943. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4586653/ [06/05/2020].

Copan, L., Ujihara, A., Jones, C., Das, R., Kreutzer, R., Roisman, R., Haas, R., Perez, G., Moezzi, B., Miller, M., Solomon, G., Ryals, R., Vitale, L., Davis, M., Rogow, M., Leprell, R., Flammia, D., Bradshaw, R., Maclaurin, K. and Bender, T. J. (2012). Mercury exposure among household users and nonusers of skin-lightening creams produced in Mexico - California and Virginia, 2010. *Morbidity and Mortality Weekly Report*, vol. 61, pp. 33–36.

COWI (2015). *Inventory and mapping of Contaminated Sites in India*. Tech. rep. A019251. MINISTRY OF ENVIRONMENT, FOREST & CLIMATE CHANGE.

Department of Agriculture & Cooperation and Farmers Welfare (2018). *About Sugarcane*. Available: https://farmer.gov.in/cropstaticssugarcane.aspx [28/01/2020].

Derakhshan Nejad, Z., Jung, M. C. and Kim, K.-H. (2018). Remediation of soils contaminated with heavy metals with an emphasis on immobilization technology. *Environmental Geochemistry and Health*, vol. 40 (3), pp. 927–953. DOI: 10.1007/s10653-017-9964-z. Available: http://link.springer.com/10.1007/s10653-017-9964-z [17/04/2020].

Dow AgroSciences (n.d.). *Dithane® M45*. Available: https://www.dowagro.com/en-in/india/products/fungicides/dithane-m45.htm.html [19/04/2020].

ELI (2014). *Enforcing Hazardous Waste Rules in India: Strategies and Techniques for Achieving Increased Compliance*. Tech. rep. Washington, D.C: Environmental Law Institute.

Encyclopaedia Britannica (n.d.). *Kodaikanal — India*. Encyclopedia Britannica. Library Catalog: www.britannica.com. Available: https://www.britannica.com/place/Kodaikanal [29/04/2020].

ERM (Environmental Resources Management) (2007). *Detailed Project Report: Soil Remediation at HUL Factory Site, Kodaikanal, Tamil Nadu, India*. Available: http://kodaimercury.org/backdoor/wp-content/uploads/2015/10/Report-SSTL-ERM-2007.pdf [02/02/2020].

European Commission (n.d.). *Skin lightening cream*. en. Library Catalog: ec.europa.eu. Available: https://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/alerts/?event=viewProduct&reference=A12/00084/19&lng=en [20/04/2020].

Falandysz, J. (2017). Mercury accumulation of three Lactarius mushroom species. *Food Chemistry*, vol. 214, pp. 96–101. DOI: 10.1016/j.foodchem.2016.07.062. Available: https://linkinghub.elsevier.com/retrieve/pii/S0308814616310846 [01/05/2020].

Fanger, G., Elert, M., Höglund, L. O. and Jones, C. (2006). *Laktester för riskbedömning av förorenade områden underlagsrapport 3: sammanställning av underlagsdata och användning av modeller för tolkning av laktester*. OCLC: 938660133. Stockholm: Naturvårdsverket. Available: http://www.naturvardsverket.se/Documents/publikationer/620-5558-5.pdf [29/06/2020].

Federal Remediation Technologies Roundtable (n.d.). *4.28 Excavation, Retrieval, and Off-Site Disposal*. Remediation Technologies Screening Matrix and Reference Guide. Available: https://frtr.gov/matrix2/section4/4-29.html [10/05/2020].

G.S.R No. 395 (E) (n.d.). *Hazardous and Other Wastes (Management and Transboundary Movement) Rules*. New Delhi: MINISTRY OF ENVIRONMENT, FOREST and CLIMATE CHANGE.

GeoEngineer (2013). *Thermal Desorption*. GeoEngineer. Library Catalog: www.geoengineer.org. Available: https://www.geoengineer.org/education/web-class-projects/cee-549-geoenvironmental-engineering-winter-2013/assignments/thermal-desorption#advantages [17/05/2020].

Glenn, E. N. (2008). YEARNING FOR LIGHTNESS: Transnational Circuits in the Marketing and Consumption of Skin Lighteners. *Gender and Society*, vol. 22 (3). Publisher: Sage Publications, Inc., pp. 281–302. Available: https://www.jstor.org/stable/27821646 [06/05/2020].

Government of Tamil Nadu (2020). *About the District — Dindigul District — India*. en-US. Available: https://dindigul.nic.in/about-district/ [23/01/2020].

Greenpeace (2010). *Dangerous Mercury Thermometer Factory and Waste Dump in India Has Links to Major U.S. Company*. Greenpeace USA. Library Catalog: www.greenpeace.org Section: Toxics. Available: https://www.greenpeace.org/usa/news/children-and-workers-exposed-t/ [29/04/2020].

Greipsson, S. (2011). *Phytoremediation*. The Nature Education. Available: https://www.nature.com/scitable/knowledge/library/phytoremediation-17359669/.

He, F., Gao, J., Pierce, E., Strong, P. J., Wang, H. and Liang, L. (2015). In situ remediation technologies for mercury-contaminated soil. *Environmental Science and Pollution Research*, vol. 22 (11), pp. 8124–8147. DOI: 10.1007/s11356-015-4316-y. Available: https://doi.org/10.1007/s11356-015-4316-y [07/06/2020].

Heaton, A. C. P., Rugh, C. L., Wang, N.-j. and Meagher, R. B. (1998). Phytoremediation of Mercury- and Methylmercury-Polluted Soils Using Genetically Engineered Plants. *Journal of Soil Contamination*, vol. 7 (4), pp. 497–509. DOI: 10.1080/10588339891334384. Available: https://www.tandfonline.com/doi/full/10.1080/10588339891334384 [17/04/2020].

Hindustan Lever Limited (2006). *Former HLL Mercury Thermometer Factory, Kodaikanal, Tamil Nadu, India: Site Specific Target Levels*. Kodaikanal, p. 57. Available: http://kodaimercury.org/backdoor/wp-content/uploads/2015/10/FORMER-HLL-MERCURY.pdf?fbclid=IwAR057HPL9p_22VzamxIEibAvKuA9qPrk6dzv45XyQTEI37qe09XiQGOkp6E [06/05/2020].

HUL (Hindustan Unilever Limited) (2017). *Environmental Monitoring Parameters - Contaminated Soil Washing Trials*. Available: http://kodaimercury.org/backdoor/wp-content/uploads/2018/08/Environmental-Monitoring-Parameters-%5C%E2%5C%80%5C%93-Contaminated-Soil-Washing-Trials-%5C%E2%5C%80%5C%93-HUL.pdf [26/05/2020].

HUL (Hindustan Unilever Limited) (2018). *Information Note: Soil remediation at our former thermometer factory in Kodaikanal, India*. Available: https://www.unilever.com/Images/soil-remediation-kodaikanal-india-march18_tcm244-479921_en.pdf.

Hunter, L. (2016). Mercury Pollution in Kodaikanal Caused by a Thermometer Factory Spill in 2001. *Researchgate* (A6-A11). Available: https://www.researchgate.net/publication/313120886_Mercury_Pollution_in_Kodaikanal_Caused_by_a_Thermometer_Factory_Spill_in_2001 [28/01/2020].

Iarossi, G. (2006). *Power of Survey Design: A User's Guide for Managing Surveys, Interpreting Results, and Influencing Respondents*. Herndon, UNITED STATES: World Bank Publications. Available: http://ebookcentral.proquest.com/lib/uu/detail.action?docID=459526 [28/01/2020].

Indian Institute of Tropical Meteorology (2020a). *KODAIKANAL*. Available: http://city.imd.gov.in/citywx/localwx.php [15/05/2020].

Indian Institute of Tropical Meteorology (2020b). *HYDERABAD*. Available: http://city.imd.gov.in/citywx/localwx.php [15/05/2020].

Inglezakis, V. J. and Menegaki, A. N. (2016). *Environmental Quality Standard - an overview — ScienceDirect Topics*. Vol. 2016. 978-0-444-62733-9. Elsevier. Available: https://www-sciencedirect-com.ezproxy.its.uu.se/topics/earth-and-planetary-sciences/environmental-quality-standard [22/05/2020].

ISO (n.d.). *ISO/TC 190/SC 7 - Impact assessment*. en. Library Catalog: www.iso.org. Available: https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/committee/05/44/54408.html [01/05/2020].

Jose, A. and Ray, J. G. (2018). Toxic content of certain commercially available fairness creams in Indian market. *Cogent Medicine*, vol. 5 (1). Ed. by U. Schumacher. Publisher: Cogent OA _eprint: https://www.tandfonline.com/doi/pdf/10.1080/2331205X.2018.1433104, p. 1433104. DOI: 10.1080/2331205X.2018.1433104. Available: https://www.tandfonline.com/doi/abs/10.1080/2331205X.2018.1433104 [06/05/2020].

Karthik, R., Paneerselvam, A., Ganguly, D., Hariharan, G., Srinivasalu, S., Purvaja, R. and Ramesh, R. (2017). Temporal variability of atmospheric Total Gaseous Mercury and its correlation with meteorological parameters at a high-altitude station of the South India. en. *Atmospheric Pollution Research*, vol. 8 (1), pp. 164–173. DOI: 10.1016/j.apr.2016.08.010. Available: http://www.sciencedirect.com/science/article/pii/S1309104216302380 [23/01/2020].

Kaushik, K. and Tavinder, S. (2020). *International Comparative Legal Guides*. en. Text. Archive Location: United Kingdom Library Catalog: iclg.com Publisher: Global Legal Group. Available: https://iclg.com/practice-areas/environment-and-climate-change-laws-and-regulations/india [18/05/2020].

Kemakta Konsult AB (2016). *Datablad för kvicksilver*. Tech. rep. Institutet för Miljömedicin. Available: https://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/fororenade-omraden/kvicksilver-.pdf.

KilPlayPesticides (n.d.). *Agricultural pesticides—Insecticides Products—Fungicides Products— Herbicicdes Products—Plant Growth Regulators*. English. Available: http://kilplaypesticides.com/products/insecticides/mercury/ [19/04/2020].

Kiyono, M., Oka, Y., Sone, Y., Nakamura, R., Sato, M. H., Sakabe, K. and Pan-Hou, H. (2013). Bacterial heavy metal transporter MerC increases mercury accumulation in Arabidopsis thaliana. *Biochemical Engineering Journal*, vol. 71, pp. 19–24. DOI: 10.1016/j.bej.2012.11.007. Available: https://linkinghub.elsevier.com/retrieve/pii/S1369703X12003129 [18/04/2020].

Krishna, P., Jyothirmayi, V. and Madhusudhana Rao, K. (2014). Human health risk assessment of heavy metal accumulation through fish consumption, from Machilipatnam Coast, Andhra Pradesh, India. *International Research Journal of Public and Environmental Health*, pp. 121–125.

Available: https://www.researchgate.net/profile/Madhusudhana_Kotte2/publication/276290217_Human_health_risk_assessment_of_heavy_metal_accumulation_through_fish_consumption_from_Machilipatnam_Coast_Andhra_Pradesh_India/links/5556006c08ae6943a8733490.pdf [21/01/2020].

Lominchar, M. A., Sierra, M. J. and Millán, R. (2015). Accumulation of mercury in Typha domingensis under field conditions. *Chemosphere*, vol. 119, pp. 994–999. DOI: 10.1016/j.chemosphere.2014.08.085. Available: http://www.sciencedirect.com/science/article/pii/S0045653514010777 [05/06/2020].

Målnsätra Gård (n.d.). *Vanliga frågor - Molnsätra Gård AB*. Molnsätra Gård - För din trädgård. Available: https://molnsatra.se/vanliga_fragor [13/05/2020].

Marrugo-Negrete, J., Durango-Hernández, J., Pinedo-Hernández, J., Olivero-Verbel, J. and Díez, S. (2015). Phytoremediation of mercury-contaminated soils by Jatropha curcas. *Chemosphere*, vol. 127, pp. 58–63. DOI: 10.1016/j.chemosphere.2014.12.073. Available: https://linkinghub.elsevier.com/retrieve/pii/S004565351401515X [18/04/2020].

MetService (n.d.). *Past Weather for Gisborne Airport as Ruatoria has no past weather data*. [15/05/2020].

Minister of National Health and Welfare (1995). *Investigating human exposure to contaminants in the environment: a handbook for exposure calculations.* en. OCLC: 237104184. Ottawa: Health Canada. Available: http://publications.gc.ca/Collection/H49-96-1-1995E-1.pdf [29/05/2020].

Ministry of Environment and Forests (2015a). *Guidance document for assessment and remediation of contaminated sites in India: Volume I - Methodologies and Guidance*.

Ministry of Environment and Forests (2015b). *Guidance document for assessment and remediation of contaminated sites in India: Volume II - Standards and checklists*.

Ministry of Environment, Forest and Climate Change (2015). *Inventory and Mapping of Probably Contaminated Sites in India*. Tech. rep. A019251.

Moreno, T., Higueras, P., Jones, T., McDonald, I. and Gibbons, W. (2005). Size fractionation in mercury-bearing airborne particles (HgPM10) at Almadén, Spain: Implications for inhalation hazards around old mines. en. *Atmospheric Environment*, vol. 39 (34), pp. 6409–6419. DOI: 10.1016/j.atmosenv.2005.07.024. Available: http://www.sciencedirect.com/science/article/pii/S1352231005006321 [28/01/2020].

Napoli, M., Cecchi, S., Grassi, C., Baldi, A., Zanchi, C. A. and Orlandini, S. (2019). Phytoextraction of copper from a contaminated soil using arable and vegetable crops. *Chemosphere*, vol. 219, pp. 122–129. DOI: 10.1016/j.chemosphere.2018.12.017. Available: http://www.sciencedirect.com/science/article/pii/S0045653518323397 [05/06/2020].

Naturvårdsverket (n.d.). *Förorenade områden, riktvärden för förorenad mark*. Naturvårdsverket. Available: https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Fororenade-omraden/Riktvarden-for-fororenad-mark/ [22/01/2020].

Navarro, A., Cardellach, E., Cañadas, I. and Rodríguez, J. (2013). Solar thermal vitrification of mining contaminated soils. *International Journal of Mineral Processing*, vol. 119, pp. 65–74. DOI: 10.1016/j.minpro.2012.12.002. Available: https://linkinghub.elsevier.com/retrieve/pii/S030175161200138X [03/05/2020].

Niu, Z., Zhang, X., Wang, Z. and Ci, Z. (2011). Field controlled experiments of mercury accumulation in crops from air and soil. en. *Environmental Pollution*. Nitrogen Deposition, Critical Loads and Biodiversity, vol. 159 (10), pp. 2684–2689. DOI: 10.1016/j.envpol.2011.05.029. Available: http://www.sciencedirect.com/science/article/pii/S0269749111003162 [27/01/2020].

Otto, M. and Bajpai, S. (2007). Treatment technologies for mercury in soil, waste, and water. *Remediation Journal*, vol. 18 (1), pp. 21–28. DOI: 10.1002/rem.20150. Available: http://doi.wiley.com/10.1002/rem.20150 [07/06/2020].

Palmer, R. B., Godwin, D. A. and McKinney, P. E. (2000). Transdermal Kinetics of A Mercurous Chloride Beauty Cream: An In Vitro Human Skin Analysis. *Journal of Toxicology: Clinical Toxicology*, vol. 38 (7), pp. 701–707. DOI: 10.1081/CLT-100102383. Available: https://doi.org/10.1081/CLT-100102383 [29/01/2020].

Park, C. M. (2011). 'Mercury specation during thermal remediation and in post-treatment environments'. Accepted: 2012-01-30T18:53:35Z. thesis. Available: https://repositories.lib.utexas.edu/handle/2152/ETD-UT-2011-12-4533 [03/05/2020].

Park, C. M., Katz, L. E. and Liljestrand, H. M. (2015). Mercury speciation during in situ thermal desorption in soil. *Journal of Hazardous Materials*, vol. 300, pp. 624–632. DOI: 10.1016/j.jhazmat.2015.07.076. Available: https://linkinghub.elsevier.com/retrieve/pii/S0304389415006135 [02/05/2020].

Plume Labs (n.d.). *Air Quality Ooty — Live Air Quality and Pollution Forecasts*. en. Library Catalog: air.plumelabs.com. Available: https://air.plumelabs.com/air-quality-in-ooty-5gdH [29/04/2020].

Regeringskansliet (2006). *Regeringens proposition: Ett utvidgat miljöansvar*. Available: https://data.riksdagen.se/fil/5D57E597-8017-4F99-8C30-05FAB5533896.

Renberg, R. (n.d.). *Phytoremediation - A promising green solution for soil pollution - Luleå University of Technology*. Available: https://www.ltu.se/research/subjects/Avfallsteknik/Forskningsprojekt/Fytosanering-En-lovande-gronlosning-for-sanering-av-fororenad-mark-1.80554?l=en [15/04/2020].

Reynaers, E. and Nandeshwar, G. (2020). *Environmental law and practice in India: overview*. en-GB. THOMSON REUTERS. Available: http://uk.practicallaw.thomsonreuters.com/0-503-2029?transitionType=Default&contextData=(sc.Default)&firstPage=true&bhcp=1 [18/05/2020].

Roderick, M. L. and Farquhar, G. D. (2005). Changes in New Zealand pan evaporation since the 1970s. en. *International Journal of Climatology*, vol. 25 (15). _eprint: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/joc.1262, pp. 2031–2039. DOI: 10.1002/joc.1262. Available: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.1262 [15/05/2020].

Royal Society of Chemistry (n.d.). *Mercury - Element information, properties and uses — Periodic Table*. Available: https://www.rsc.org/periodic-table/element/80/mercury [23/01/2020].

Sahu, R., Saxena, P. and Johnson, S. (2014). *Heavy Metals in Cosmetics*. Tech. rep. PML/PR-45/2014. Centre for Science and Environment. [29/01/2020].

Al-Saleh, I. (2016). Potential health consequences of applying mercury-containing skin-lightening creams during pregnancy and lactation periods. en. *International Journal of Hygiene and Environmental Health*, vol. 219 (4), pp. 468–474. DOI: 10.1016/j.ijheh.2016.03.002. Available: http://www.sciencedirect.com/science/article/pii/S1438463916300207 [29/01/2020].

SEPA (2009a). *Att välja efterbehandlingsåtgärd en vägledning från övergripande till mätbara åtgärdsmål.* OCLC: 938854454. Stockholm: Naturvårdsverket. Available: http://www.naturvardsverket.se/Documents/publikationer/978-91-620-5978-1.pdf [29/01/2020].

SEPA (2009b). *Riktvärden för förorenad mark - Modellbeskrivning och vägledning*. Tech. rep. 5976. Available: https://www.naturvardsverket.se/Documents/publikationer/978-91-620-5976-7.pdf [29/04/2020].

SEPA (2009c). *Biotillgänglighet som företeelse och vid riskbedömningar av förorenade områden*. Tech. rep. 5895.

SEPA (2010). *Riskbedömning av förorenade områden: en vägledning från förenklad till fördjupad riskbedömning.* sv. OCLC: 938966245. Stockholm: Naturvårdsverket.

SEPA (2016). *Handledning för beräkningsprogram*. Tech. rep. 5976. Available: https://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/fororenade-omraden/berakning-riktvarden/bilaga-4-handledning-berakningsprogram.pdf.

SEPA (2020). *Vägledning om att inventera förorenade områden*. sv. text. Library Catalog: www.naturvardsverket.se. Available: https://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledningar/Fororenade-omraden/Att-inventera-fororenade-omraden/ [08/05/2020].

SFS 2020:75 (n.d.). *Miljöbalk*. Stockholm: Miljö- och energidepartementet.

SGI (2018). *Förorenade områden - SGI*. Available: https://www.swedgeo.se/sv/kunskapscentrum/om-geoteknik-och-miljogeoteknik/geoteknik-och-markmiljo/fororenade-omraden/ [18/05/2020].

Spimfab (2014). *Drivmedelsbolagens undersökningar och saneringar av förorenade bensinstationer: slutrapport av Spimfab:s arbete under 1997 till 2014.* sv. OCLC: 941387843. Stockholm: Spimfab.

Stockholms stad (2019). *Storstadsspecifika riktvärden för jord i Stockholm*. Tech. rep. E2019-01666. Exploateringskontoret Miljöförvaltningen.

Sujatha, E. R. and Sridhar, V. (2017). Mapping debris flow susceptibility using analytical network process in Kodaikkanal Hills, Tamil Nadu (India). en. *Journal of Earth System Science*, vol. 126 (8), p. 116. DOI: 10.1007/s12040-017-0899-7. Available: https://doi.org/10.1007/s12040-017-0899-7 [04/06/2020].

Svenska Geotekniska Föreningen (2018). *Stabilisering och solidifiering - fördjupning*. Åtgärdsportalen. Available: http://atgardsportalen.se/metoder/jord/in-situ/metod-2-1/stabilis-fordjupn [17/05/2020].

Svenska Geotekniska Föreningen (2019). *Metoder*. Åtgärdsportalen. Available: http://atgardsportalen.se/metoder [14/05/2020].

Svenska Geotekniska Föreningen (2020). *Fytosanering - fördjupning*. Åtgärdsportalen. Available: http://atgardsportalen.se/metoder/jord/in-situ/fytosanering/fytosanering-fordjupn [08/05/2020].

Syngenta (2016). *FOLIO GOLD*. en. Available: https://www.syngenta.co.uk/product/crop-protection/fungicide/folio-gold [19/04/2020].

TerraTherm (n.d.). *Thermal Conduction Heating — In Situ Thermal Desorption — In Pile Thermal Desorption*. TerraTherm - a Cascade Company. Available: http://www.terratherm.com/thermal/tch/index.htm [04/05/2020].

Turull, M., Komarova, T., Noller, B., Fontàs, C. and Díez, S. (2018). Evaluation of mercury in a freshwater environment impacted by an organomercury fungicide using diffusive gradient in thin films. en. *Science of The Total Environment*, vol. 621, pp. 1475–1484. DOI: 10.1016/j.scitotenv.2017.10.081. Available: http://www.sciencedirect.com/science/article/pii/S0048969717327845 [28/01/2020].

Tyag, A. (2013). *Development of National Programme for Rehabilitation of Polluted: Sites Final Report on Task - 1 Review of Current Systems and Task – 2 Overview of International Practices*. Tech. rep. Ministry of Environment and Forests, Government of India.

Unilever (n.d.). *Kodaikanal, India*. Unilever Global Company Website. Library Catalog: www.unilever.com. Available: https://www.unilever.com/sustainable-living/what-matters-to-you/kodaikanal-india.html [28/04/2020].

United States Environmental Protection Agency (2020). *Dense nonaqueous phase liquids (dnapls) treatment technologies*. Contaminated Site Clean-Up Information. Available: https://clu-in.org/contaminantfocus/default.focus/sec/dense_nonaqueous_phase_liquids_(dnapls)/cat/treatment_technologies/p/12/n/1/ [26/05/2020].

USGS (n.d.). *Mercury*. Available: https://www.usgs.gov/mission-areas/water-resources/science/mercury?qt-science_center_objects=0#qt-science_center_objects [21/01/2020].

Wan, X., Lei, M. and Chen, T. (2016). Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil. *Science of The Total Environment*, vol. 563-564, pp. 796–802. DOI: 10.1016/j.scitotenv.2015.12.080. Available: http://www.sciencedirect.com/science/article/pii/S0048969715312377 [05/06/2020].

Wang, L., Hou, D., Cao, Y., Ok, Y. S., Tack, F. M. G., Rinklebe, J. and O'Connor, D. (2020). Remediation of mercury contaminated soil, water, and air: A review of emerging materials and innovative technologies. *Environment International*, vol. 134, p. 105281. DOI: 10.1016/j.envint.2019.105281. Available: http://www.sciencedirect.com/science/article/pii/S0160412019324754 [03/05/2020].

World Air Map (n.d.). *Air Quality Ooty — Live Air Quality and Pollution Forecasts*. Plume Labs Air Report. Library Catalog: air.plumelabs.com. Available: https://air.plumelabs.com/air-quality-in-ooty-5gdH [27/04/2020].

World Bank (2018). *Life expectancy at birth, total (years) - India — Data*. Available: https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=IN [29/04/2020].

Worthington, M. J. H., Kucera, R. L., Albuquerque, I. S., Gibson, C. T., Sibley, A., Slattery, A. D., Campbell, J. A., Alboaiji, S. F. K., Muller, K. A., Young, J., Adamson, N., Gascooke, J. R., Jampaiah, D., Sabri, Y. M., Bhargava, S. K., Ippolito, S. J., Lewis, D. A., Quinton, J. S., Ellis, A. V., Johs, A., Bernardes, G. J. L. and Chalker, J. M. (2017). Laying Waste to Mercury: Inexpensive Sorbents Made from Sulfur and Recycled Cooking Oils. *Chemistry – A European Journal*, vol. 23 (64). Publisher: John Wiley & Sons, Ltd, pp. 16219–16230. DOI: 10.1002/chem.201702871. Available: https://chemistry-europe.onlinelibrary.wiley.com/doi/full/10.1002/chem.201702871 [15/05/2020].

Xu, J. (2013). *Feasibility study of soil washing to remediate mercury contaminated soil*. OCLC: 940733279. Luleå. Available: http://pure.ltu.se/portal/sv/publications/feasibility-study-of-soil-washing-to-remediate-mercury-contaminated-soil(9ba07408-a2c8-44e2-bc45-962d3c35f6c0).html [17/05/2020].

Xu, L., Chen, J., Niu, Z., Yin, L. and Chen, Y. (2013). Characterization of mercury in atmospheric particulate matter in the southeast coastal cities of China. en. *Atmospheric Pollution Research*, vol. 4 (4), pp. 454–461. DOI: 10.5094/APR.2013.052. Available: http://www.sciencedirect.com/science/article/pii/S1309104215303676 [27/03/2020].

Xun, Y., Feng, L., Li, Y. and Dong, H. (2017). Mercury accumulation plant Cyrtomium macrophyllum and its potential for phytoremediation of mercury polluted sites. *Chemosphere*, vol. 189, pp. 161–170. DOI: 10.1016/j.chemosphere.2017.09.055. Available: https://linkinghub.elsevier.com/retrieve/pii/S0045653517314704 [18/04/2020].

Appendices

APPENDIX A FARMERS' INTERVIEWS

General information from the interviews

The dry season is considered to be from January to April.

On the first interview, we asked all the questions that we had prepared, but there were some communication difficulties. Therefore, we dismissed some of the questions for the nest two farmers. Another reason for cutting some of the questions was that the farmers were busy and did not have time to answer all of the questions prepared.

Farmer 1

The farm consists of approximately 14 different levels where the crops grow. Drip irrigation is used.

Village name: Valai Kattu Odai, Pallangi.
Farm area: 1.25 acres.
Inorganic or organic: 60 % inorganic, 40 % organic.
Crops grown: Carrots, beans, potato and kohlrabi.

Table 27: The first farmer's crops, its quantity and growing period

Crop	Total Produced Amount [kg]	Time Period
Carrots	13 000 - 16 000	3 - 4 months
Beans	4 000 - 5 000	3 months
Potatoes	6 500 - 9 000	4 months
Kohlrabi	-	-

Place where the crop is sold: Madurai.
Source of irrigation water: From the nearby stream (*observation: a very small stream and there are some bigger "bags" in the stream to hold up the water*).
Pesticides, herbicides or fungicides used: Condap, Folio gold and Carset.
Type of crops that pesticides, herbicides or fungicides are used on: all crops.
Frequency of use: In rainy season every 5-10 days. For carrots every 10 days. Lower frequency during dry season.

Farmer 2

Village name: Valai Kattu Odai, Pallangi.
Farm area: 2 acres (leasing).
Inorganic or organic: Inorganic (maybe organic in the future).
Crops grown: Carrot, beans (2-3 varieties), potato, beetroot, sweet peas, radish, kohlrabi and turnip.
Place where the crop is sold: Madurai and Kodaikanal Sunday Market (personally goes to the market).
Source of irrigation water: Mostly pumping from the nearby river, (maybe has a well too).
Pesticides, herbicides or fungicides used: Applied with spray (power spray). He also uses fertilizer.

Table 28: The second farmer's use of pesticides and fungicides

Product name	Used on Crop	Frequency [every X days]
Indofil	Carrots and potatoes	20 - 25 days
Tag Temper	Carrots	20 - 25 days
Power Win	All crops	20 - 25 days (carrots) 8 days (beans)
X-TRA Power	Beans	8 days
Nuvacrop	All crops	20 - 25 days (carrots) 8 days (beans)
Tarzan Ril	All crops	20 - 25 days (carrots) 8 days (beans)

Farmer 3

Village name: Valai Kattu Odai, Pallangi.
Farm area: 7 acres (leasing).
Crops grown: carrots, beans (2-3 varieties) and kohlrabi.
Place where the crop is sold: Madurai, local markets and Kodaikanal Sunday Market (sellers come and get crops from here to sell at the market).
Source of irrigation water: Well (2 open wells) and storing rainwater.
Pesticides, herbicides or fungicides used: 2 kg pesticides are used per acre.

Table 29: The third farmer's use of pesticides and its frequency

Product name	Used on Crop	Frequency
Indofil m:45	All crops	Rainy season: every 5 days Dry season: every 8 - 10 days
Ditheme m:45	All crops	Rainy season: every 5 days Dry season: every 8 - 10 days
Monset	All crops	Rainy season: every 5 days Dry season: every 8 - 10 days

APPENDIX B SURVEY

B.1 SURVEY QUESTIONNAIRE

The questionnaire used during the survey is presented in Figure 13.

1. Female: ☐ Male: ☐

2. Adult (7 years or older): ☐ Child (under 7 years): ☐

3. How many hours per day you spend in the house (daily): ___________________

4. How many days/weeks per year you do not spend in Vellagavi: ___________________

What is the source for the driningwater?

5. Do you grow any food yourself? ☐ Yes ☐ No

   a) If yes, what kind of crop? __________________
   b) How much of the crop do you eat? _______________

6. Where do you buy your potatoes?

   ☐ Kodaikanal - Sunday market

   ☐ Other: _______________

7. Where do you buy your carrots?

   ☐ Kodaikanal - Sunday market

   ☐ Other: _______________

8. Where do you buy your other food?

   ☐ Kodaikanal - Sunday market

   ☐ Other: ________________

   9. Where do you get your water from? __________________________

10. Do you own a cow? ☐ Yes ☐ No

If yes, is the milk consumed in the household? ☐ Yes ☐ No

Do you own a goat? ☐ Yes ☐ No

If yes, is the milk consumed in the household? ☐ Yes ☐ No

   a)

11. Have you in the last 6 months used a fairness cream?

   ☐ Yes

   ☐ Wish not to answer

   ☐ No

   a) If the answer is yes, what is the name of the product?
   b) Do you use it daily?

12. Do you agree that these answers will be used anonymously in our report?

Figure 13: The questionnaire used for the Survey in Vellagavi.

B.1.1 REMOVAL OF SURVEY QUESTIONS

Some of the questions where removed after consulting the translators. The complete survey form, including the questions that were removed, can be found in Appendix B.1A. The questions and the reason for its removal are presented below:

Do you own a cow? If so, is the milk consumed in the household?
The translators reported that no one in the village owned a cow or a goat. No cows or goats were observed in the village during the field work. The question was therefore removed to reduce the numbers of questions.

Do you own a goat? If so, is the milk consumed in the household?
Reason for removal was the same as above.

Do you agree that these answers will be used anonymously in our report?
This question was a part of the survey with respect to the General Data Protection Regulation (GDPR). The question raised concern and scepticism with the villagers due to miscommunication and misunderstanding. Each survey session started with a brief explanation of why the survey was conducted. The agreement to answer the questions after explanation was considered to be enough of an approval to use the data, since it seemed clear for all parties that the results were going to be used anonymously in the report. The interpretation of the situation was that the question was not understood correctly since most of the inhabitants had never heard of GDPR before or did not understand the purpose of the question. This was confirmed by the translators.

B.2 SURVEY ANSWERS

The answers from the survey in Vellagavi can be found in Table 30 and 31.

Table 30: Interview answers from the first three families of Vellagavi

Questions	**Family 1**	**Family 2**	**Family 3**
1. Male (M) and female (F) 2. a) No. of adults (>7 years) 2. b) No. of children (<7 years)	M1, F1 2 0	M1, F1 2 0	M2, F2 3 1
3. How many hours per day do you spend in the house?	F: almost all day M: few hours a day, some seasons sleeping outside to guard the crops	F: - M: 5pm-9am	F: almost all day M: few hours a day (meals at home)
4. How many days per year do you not spend in Vellagavi?	F: 3-4 times/month M: 1-2 times/week	F: 1-2 times/month M: 1-2 times/month	F: - M: goes to KSM
5. Do you grow any food yourself? a) What kind of crop? b) How much of the crop do you eat? 6. Where do you buy your potatoes? 7. Where do you buy your other food?	Yes, but sell most of it - - Kodaikanal Sunday Market Kodaikanal Sunday Market	Yes - Nothing Kodaikanal Sunday Market Kodaikanal Sunday Market	Yes Cardemum, coffee, fruits *Nothing?* Kodaikanal Sunday Market Kodaikanal Sunday Market
8. Where do you get your water from?	The well	The well	The well
9. Have you inte the last 6 months used a fairness cream?	No	No	No

Table 31: The interview answer from the other three families of Vellagavi

Questions	**Family 4**	**Family 5**	**Family 6**
1. Male (M) and female (F) 2. a) No. of adults (>7 years) 2. b) No. of children (<7 years)	M1, F1 2 0	M2, F2 4 0	M3, F1 4 0
3. How many hours per day do you spend in the house?	F: almost all day, except from 2 hours M: few hours a day	F: - M: 5pm-9am	F: all day M: 9-5 in field
4. How many days per year do you not spend in Vellagavi?	*1 time in every two months?*	F: 4-5 times/year M: 1 time/week	1-2 times/week
5. Do you grow any food yourself? a) What kind of crop? b) How much of the crop do you eat? 6. Where do you buy your potatoes? 7. Where do you buy your other food?	Yes Cardemum, coffee Nothing Kodaikanal Sunday Market Kodaikanal Sunday Market	Yes *Greens?, Coffee, avocado, cardemum* *Nothing?* Kodaikanal Sunday Market Kodaikanal Sunday Market	Yes Fruits, coffee *Nothing?* Kodaikanal Sunday Market Kodaikanal Sunday Market
8. Where do you get your water from?	The well	The well	The well
9. Have you inte the last 6 months used a fairness cream?	No	No	No

APPENDIX C LINKEDIN MESSAGE

The message that was sent to LinkedIn users that had listed working with contaminated sites in India on their profile was:

" Hello! I'm conducting my M.Sc in Environmental Engineering at Uppsala University. One focus of the project is to compare different models for risk assessment. Therefore, I'm looking for someone with experience of risk assessments for contaminated soil in India that could answer some questions. "