A Risk Assessment of Reusing Wastewater on Agricultural Soils – A Case Study on Heavy Metal Contamination of Peach Trees in Ouardanine, Tunisia

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Abstract
Due to present demographic trends and future growth, fresh water will be an even scarce factor for future populations than it is today. By the year 2025, 60 % of the global population is estimated to suffer from insufficient fresh water resources. (Qadir 2007) In the arid and semi arid regions of the Middle East and North Africa (the MENA region), countries are facing increasingly more water shortage problems because of climatic conditions. The problem will intensify along with rise in living standards, accelerated urbanization and population growth. Even though the efficiency techniques in the use of conventional water resources have been improved, water scarce countries will have to rely more on the use of non-conventional resources to satisfy the water demand. (Qadir 2007)

When conventional water resources, such as groundwater and rivers, fail to fulfill the demands from the sectors of agriculture, tourism and industry, non-conventional resources are a feasible opportunity (El Ayni 2008) Fresh water resources have to be released for potable and primary needs and non-conventional water resources can make up for others. The reuse of wastewater can, as an alternative source of water, be a way of displacing the need for other water resources. (Bahri & Lazarova 2005)

Tunisia lies in North Africa with boarders to Algeria in the west and Libya in the south-east. It has a long coastal boarder to the Mediterranean Sea in the north and north-east. As many other countries in this area, Tunisia is facing serious shortage of water resources, due to increasing water consumption and pollution of already existing water resources (CITET 2004). Irrigation techniques with treated wastewater are well established in Tunisia (Angelakis 1999). Forecasts show an increase of water demand due to industrial, urban and touristic development, mostly for agricultural purposes. There are 98 wastewater treatment plants in Tunisia, 225 Mm$^3$ of wastewater is produced and 65 Mm$^3$ is reused. The agricultural sector uses 82 % of the available water resources and is hence the most important consumer. (El Ayni 2008) Because of an increase in fresh water demand, it has become an imperative to develop additional water resources. Wastewater reuse has become an essential part of the Tunisian national water resource strategy. (Bahri & Lazarova 2005)

Most of water reuse projects developed in the world is for irrigation purposes (Bahri & Lazarova 2005). Irrigation is vital in increasing crop yields and receiving a consistent production within agriculture. It is essential to keep the agriculture economically viable in arid and semi-arid areas. (Pescod 1992) Irrigation with reused wastewater gives an additional source of nutrition and enhances agricultural production. The major quality factors associated with reuse of wastewater are pathogen content, salinity, sodicity, ion toxicity, heavy metal content and nutrients. (Bahri & Lazarova 2005)

This study will be executed as a risk assessment and is aiming to assess the risk of hazardous heavy metal accumulation in humans consuming peaches from a field irrigated with reused wastewater in Ouardanine. Ouardanine lies outside the city of Monastir in Tunisia. Adverse effects to humans associated with heavy
metals are numerous. This study has focused on four heavy metals: cadmium, copper, lead and zinc, which are all known to cause various diseases according to epidemiological studies. In this thesis only non-carcinogenic effects are considered. The study is semi-qualitative and is, in addition to the risk assessment, analyzing the stakes and prospects for reusing wastewater for irrigation purposes in Tunisia from a health perspective, mainly for the human exposure of four heavy metals. The research questions are as follows:

- At which conditions is the wastewater irrigation conducted?
- Which factors influence the plant’s heavy metal uptake?
- Do the heavy metal concentrations found in the irrigation water, irrigated soils and peaches exceed published and recommended limits?
- Is accumulation of heavy metals in plants and human a risk?
- What are the obstacles when reusing wastewater in Tunisia and how to overcome them?

The procedure in this report is founded on several different methods. The authors conducted a field study with field sampling and laboratory analysis, interviews and discussions with responsible and involved, personal observations during the field study in Tunisia and a literature study.

The wastewater treatment plant of Ouardanine was set in April 1993. The plant collects wastewater from 17 000 citizens and has a capacity of treating 1500 m³ of wastewater a day. The collected wastewater is mainly rural and domestic, it originates from residences and commercial, institutional and similar facilities. The wastewater of Ouardanine is treated to secondary level, according to the 1975 Water Law. Thus, the wastewater has gone throughout preliminary, primary and secondary level before being used as irrigation water in agriculture. (Ben Salem 2009)

This study considers heavy metal contamination of peaches cultivated in Ouardanine. Peach trees (Prunus persica) are among the most essential fruit trees in Tunisia. The peach industry has been growing the last decade due to more plantations, along with more efficient management of orchard technology, introducing new rootstocks, cultivars, irrigation and sufficient fertilisation. Peaches are cultivated mainly in the northern and central part of the country. The cultivars are numerous and they are grown from the beginning of May to the end of September. (Ben Mimoun 2003)

In the area of Monastir, several crops are irrigated with reused wastewater. The irrigation scheme was set in 1995 as a part of the national water reuse program and covers 50 ha of irrigated land and orchards. The yields are 35 ton peaches per ha and 75 ton fodder crops per ha. Due to 1988 decree No. 89-1047, the treated effluent from the wastewater treatment plant is not allowed to be used on vegetables, whether eaten raw or cooked. The irrigation scheme in the Monastir area is a large pilot project planned by the Ministry of Agricultural and Water Resources. Since the start of the irrigation scheme, operating costs have been covered by the governmental budget (75 %) as well as by the farmers (25 %). The scheme is considered successful, since it has achieved its environmental objectives, created an economic activity throughout the entire year and jobs in Ouardanine and created a new resource of water. (Bahri 2009)

Since 2009, sludge from the wastewater plant is used as fertilizer on the field studied in this thesis and no further fertilizer is used. The estimated amount is 6000kg sludge/ha/year. The field is ploughed 5 to 6 times a year, which affect a zone with a depth of approximately 15cm. (Ben Salem 2009)

The responsibilities associated with reusing wastewater are shared amongst several institutions and ministries in Tunisia and six different ministries are distinguished as follows:
• **Ministry of Agriculture and Water Resources** is responsible for assessing, monitoring, developing, distributing, evaluating water resources and constructing, operating and maintaining water plants

• **The Ministry of Public Health** is monitoring and regulating water quality

• **The Ministry of Technology and Communication** controls the National Institute and Meteorology

• **The Ministry of Scientific Research** controls the Research Centre on Water Technologies and the Arid Regions Institute

• **The Ministry of Tourism** is a financing ministry

• **The Ministry of Environment and Sustainable Development** is controlling institutions (ANPE, ONAS, CITET)

Furthermore, associations for consumers and farmers as well as mixed group are included as stakeholders within wastewater reusing. (CITET & INECO 2008)

Wastewater reuse for agricultural purposes is regulated by legislation in Tunisia, 1975 Water Law and 1988 Decree No. 89-1047. The 1975 Water Law prohibits untreated wastewater in agriculture; secondary level (see 3.4 for further information) of treatment is required. The reused wastewater is allowed on all types of crops, except vegetables, whether eaten raw or cooked. 1988 Decree No. 89-1047 states that wastewater can be reused only after adequate treatment, effluent should not be used to irrigate vegetables which might be contaminated with wastewater and which might be eaten raw, the use of treated wastewater must be authorized by the Ministry of Agriculture and Water Resources, in agreement with Ministry of Environment and Sustainable Development and Ministry of Public Health, buffer areas must be created for sprinkler irrigation and direct grazing is prohibited. (El Ayni 2008)

The regulations demand continuous monitoring of the water quality that is used for irrigation. In this study the irrigation water did not contain any considerable amounts of heavy metal and was well below the recommended limit, according to laboratory analysis. Tunisian standards regarding heavy metals (Cd, Cu, Pb and Zn) in reclaimed wastewater used for irrigating agricultural soils were developed inspired by FAO (Food and Agriculture Organization) guidelines, WHO (World Health Organization) guideline for restricted irrigation and various Tunisian standards within irrigation and water supply. (Bahri 2002)

There are no Tunisian standards for heavy metal content in agricultural soils; instead Swedish standards are used for comparison. Regulations regarding heavy metals in Sweden are based on directives from the EU-commission, implemented in Sweden by the Swedish agricultural department Jordbruksverket (2007). The data is concerning agricultural soils which are fertilized with sludge from wastewater treatment plants, which also are the current conditions for the studied field in Ouardanine. For the soil samples collected in Ouardanine, Cu and Pb samples were all far below the recommended levels. One of the samples exceeded recommended Zn limit, while all the others were by a comfortable margin below. The conclusions concerning Cd are harder, as the recommended limit is below the IPC detection limit. Two of the samples were detected and above the recommended limit, but since the other ten samples did not give any result it is hard to give a complete picture.

No recommended limits were found for Cu and Zn, concerning intake of fruit. Cadmium levels were all below the recommended levels. The detection levels for Pb (0,25 mg/kg) were below the recommended levels in fruit (0,1 mg/kg). Although three of the samples were detected, thereby showing values two or three times more than recommended levels.

As mentioned, this thesis is a risk assessment. Risk assessment is a part of the overall risk management process. Risk is a combination between the probability and the consequence of an event. (ISO/IEC 2002) According to Kaplan and Garrick (1981) a risk can be analyzed by answering a triplet of questions;
• What can happen?
• How likely is it that that will happen?
• If it does happen, what are the consequences?

The solutions to Kaplan's triplet of questions can be answered through a risk assessment. Several definitions of risk assessment occur throughout risk literature. ISO/IEC defines it as an overall approach to risk analysis and risk evaluation. (ISO/IEC 2002) Risk assessment is the characterization of potential adverse health effects for human exposure to environmental hazards. It can be divided into four major steps; hazard identification, dose-response assessment, exposure assessment and risk characterization. (NRC/NAS 1983) In the EPA U.S. manual for ecological risk assessment hazard identification is called problem formulation (Öberg 2009); the latter term is used throughout this study.

In order to calculate the internal dose of contaminants which the endpoint is exposed to, a mass flow (intake and absorption) needs to be estimated. Oral intake is expressed as the contaminant concentration in the considered media times the flow. (Öberg 2009) The ingested dose can be expressed in different ways, but the most common one is average daily dose (ADD). ADD depends upon the concentration of the contaminant in the ingested peach, the ingestion rate, the exposure duration, the exposure frequency, the body weight of the receptor among others. (Lee et al. 2006)

Dose-response relation is an estimation of the relation between the taken dose of the contaminant and the response that is seen in a population (share of suffering), i.e. the likelihood for harm. (Rowe & Abdel-Magid 1995) One way of quantifying this relation is to use reference doses. The reference dose (Rfd) is an estimate of the highest dose that can be taken in every day without causing an adverse non-carcinogenic effect. However, for some substances Rfd values are available in databases. For others, for example lead, Rfd is not a good estimate for toxicological effects. (EPA U.S. 2009) A substitute for Rfd can be AIC (Acceptable Chronic Intakes), which is based on ADI (Acceptable Daily Intake). (Asante-Duah 1993)

The last step integrates the dose-response relations with the ADDs from the exposure assessment to qualitative or quantitative expressions for health or environmental risks. The risk characterization provides a link between risk assessment and risk management. (Rowe & Abdel-Magid 1995) In this study, only risks of non-carcinogenic effects are considered and they are expressed as the ratio between the dose resulting from exposure to the peaches from Ouardanine and the dose that is believed to be without risk of effects, even in sensitive individuals. The ratio is called hazard quotient (HQ). As mentioned before, the summary of each element’s HQ value becomes the hazard index (HI). If HI exceeds one, there is a risk for non-carcinogenic effects, and the probability tends to increase as the value of HI increases. The risks of adverse effects are separately considered for adults and children, since exposure pathways are believed to change with age. Hence, it will be discrepancy in health risks among age groups. (Zheng et al. 2007)

The cadmium concentration in the peaches was below detection limit and a worst case scenario was applied, i.e. the concentration was set to the detection limit 0,03 mg/kg WM. If cadmium is included in the HI calculations the HI for mean, minimum and maximum concentrations are 0,0526, 0,0478 and 0,0560 respectively. If it is excluded the indexes are lower, 0,0494, 0,0446 and 0,0527 respectively. If the hazard index is set to one, the safe intake rate of fruit can be calculated. If one considers the mean, minimum and maximum concentration in the peaches the intake rates are 0,144, 0,158 and 0,135 kg/day respectively. Approximately one has to eat about 150g/day. The average consumption rate has to be increased about 20 times to reach toxic levels. A peach weighs about 150g (Melgoza Villagomez et al. 2009). That means there is a risk if one consumes on peach each day for 70 years.

In order for heavy metal to move from the applied irrigation water via the peaches to the endpoint, several factors have to be considered. Numerous factors influence the plants ability to take up heavy metals. Traditionally, evaluation of contamination in soil and sediment has been founded on the total amount of contamination. However, materials strongly bound to soil or sediment is not available for interaction with
biological systems. By using the total amount of contamination in soil when evaluating the risk, it becomes highly overestimated. A better choice is therefore to use the amount of bioavailable heavy metals.

Bioavailability is defined as the amount of chemical compounds in soil or sediment, which in reality is available for interaction with biological systems. (Törneman et al. 2009) Soil properties such as particle size, organic matter and pH strongly influence the bioavailability, and can therefore be used do estimate if bioavailability is low or high. A high pH and organic matter content contributes to low heavy metal mobility. Fine soil texture and high clay content also contributes to low mobility. All the examined conditions on the field, showed that the plants’ capacity to take up heavy metal were low. The physical conditions seem to be suitable for reusing treated wastewater.

Another part within risk management is risk communication. During the field study in Tunisia the authors came across several issues interesting from a risk communication point of view. Wastewater reuse for irrigation purposes in Tunisia is currently not of public and common knowledge. The actual reuse rate in Tunisia is only 8-20 % of the treated effluent, due to several obstacles and constraints. The current planning of reuse schemes and projects is considered inadequate in terms of the low participation of users and stakeholders in the decision-making process and an overall governmental top-down approach. (IWMI/World Bank 2002)

Despite of the lower price on reused wastewater, farmers choose to use conventional irrigation water on their fields. This is mainly due to emotions associated with the reuse, also known as a yuck-factor. They perceive the reused wastewater as an unclean and non-hygienic resource. In order to win greater acceptance and change the risk perception of farmers, the wastewater should go through additional treatment, i.e. tertiary treatment. By adding treatment to the wastewater and also provide more information, wastewater reuse can gain more acceptance in the future. (Bahri 2002) In Tunisia, the government allows the farmers to buy irrigation equipment for 70% of the original price, if they use the treated wastewater as irrigation water. They also allow the farmers to buy the treated wastewater to a reduced price. The governmental subventions make the farmers find the economical benefits high enough. (IWMI/World Bank 2002)

A range of factors can influence how the public perceive risks. In the context of wastewater reuse, the perceived risk is known to be considered less risky with trust in institutions and descriptions, demonstrations and examples of reuse schemes. (Bahri & Lazarova 2005)

To engage stakeholders and use participatory planning within the reuse schemes, will improve the quality of planning and endorse democratic principles of justice and openness. (Bahri & Lazarova 2005) Information about risks is exchanged or shared among decision-makers and other stakeholders through risk communication (ISO/IEC 2002). It is up to decision makers to accept or not accept the risks and it is therefore important to present the uncertainties related to the study.

According to the risk assessment made in this study, the risk of adverse health effects from consuming peaches from the fields in Ouardanine is accepted with the current conditions and circumstances. According to this study, there should be no restriction of the amount of water applied to the field, regarding heavy metals. Lead is the limiting contaminant, and to avoid hazards the consumption rate needs to be below on peach per day for 70 years. However, it is important to continuously assess possible heavy metal accumulation due to irrigation with reused wastewater and fertilization with sludge. In case of management of wastewater reuse in Tunisia, the authors believe there is a need for extended public participation in order to increase the current reuse rate. Studies like this should be passed on to the users, in order to win acceptance and therefore gain better chance of increasing the wastewater reuse rate.

Due to time limitations, the authors could not model the water-soil-plant movement of the heavy metal and hence, could not estimate any correlations between the heavy metal concentrations in the applied irrigation water and the full-grown fruit. For further research, this would be a potential and interesting objective. At
present, sludge is also applied to the fields in Ouardanine. A study of the soil-plant movement would confirm if the accumulation in soil and plant originate from the irrigation water, sludge or if it has natural origin, such as bed-rock weathering.

Another objective for further research in this field would be to evaluate public participation and shared responsibilities within ministries associated with wastewater reuse. Functioning decision-making processes where the public get heard would be an imperative if the wastewater reuse rate should increase.
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1 Introduction

This project was executed as a master thesis for The Master of Science in Risk Management and Safety Engineering Program at the Division of Water Resources Engineering and in collaboration with the Department of Fire Safety Engineering and Systems Safety, Lund University, Sweden. The field study and the laboratory analysis were conducted at Centre International des Technologies de l’Environnement de Tunis (CITET), Tunis.

Due to present demographic trends and future growth, fresh water will be an even more scarce factor for future populations than it is today. By the year 2025, 60% of the global population is estimated to suffer from insufficient fresh water resources. (Qadir 2007) In the arid and semi-arid regions of the Middle East and North Africa (the MENA region), countries are facing increasingly more water shortage problems because of climatic conditions. The problem will intensify along with rise in living standards, accelerated urbanization and population growth. Even though the efficiency techniques in the use of conventional water resources have been improved, water scarce countries will have to rely more on the use of non-conventional resources to satisfy the water demand. (Qadir 2007)

When conventional water resources, such as groundwater and rivers, fail to fulfill the demands from the sectors of agriculture, tourism and industry, non-conventional resources are a feasible opportunity (El Ayni 2008) Fresh water resources have to be released for potable and primary needs and non-conventional water resources can make up for others. The reuse of wastewater can, as an alternative source of water, be a way of displacing the need for other water resources. (Bahri & Lazarova 2005) Non-conventional water partly consists of marginal-quality water, such as wastewater, agricultural drainage water and groundwater. Many developing countries use untreated or partly treated wastewater from domestic, industrial and commercial sectors for irrigation purposes. The main issues associated with reusing wastewater are public health and environmental problems. (Qadir 2007) Farmers see reused wastewater as a reliable source for irrigation purposes and an additional source of nutrients and fertilisation (Rutkowski 2007).

Tunisia is facing serious shortage of water resources, due to increasing water consumption and pollution of already existing water resources (CITET 2004). Irrigation techniques with treated wastewater are well established in Tunisia (Angelakis 1999). Forecasts show an increase of water demand due to industrial, urban and touristic development, mostly for agricultural purposes. There are 98 wastewater treatment plants in Tunisia, 225 Mm³ of wastewater is produced and 65 Mm³ is reused. The agricultural sector uses 82% of the available water resources and is hence the most important consumer. (El Ayni 2008) Because of an increase in fresh water demand, it has become an imperative to develop additional water resources. Wastewater reuse has become an essential part of the Tunisian national water resource strategy.

1.1 Task Description

1.1.1 Purpose

This study will be executed as a risk assessment and is aiming to assess the risk of hazardous heavy metal accumulation in humans consuming peaches (Prunus persica) from a field irrigated with reused
wastewater outside Monastir, Tunisia. The study is semi-qualitative and is, in addition to the risk assessment, analyzing the stakes and prospects for reusing wastewater for irrigation purposes in Tunisia from a health perspective, mainly for the human exposure of four heavy metals.

1.1.2 Research Questions

Under which conditions is the wastewater irrigation conducted? Do the heavy metal concentrations found in the irrigation water, irrigated soils and peaches exceed published and recommended limits? Is accumulation of heavy metals in plants and human a risk? Which factors influence the plant’s heavy metal uptake? What are the obstacles when reusing wastewater in Tunisia and how to overcome them?

1.1.3 Methodology

Methodology can be defined as a systematical or scientifical procedure of different disciplines procedure to achieve knowledge or solve problems. Methodology as its own discipline, concerns the collecting of methods that are characteristic for different sciences. (NE 2009) The choice of methodology depends on aim and character of the study and influences the result. Robson (2002) presents four methodologies, depending on the aim of the study:

- **Descriptive**, the studies mainly want to describe how something works or is performed. The study often has a broad perspective.
- **Exploratory**, the studies focus is to fundamentally understand how something works or is performed, for example through a case study.
- **Experimental**, the studies search for connections and explanations for how something works or is performed.
- **Problem solving**, the studies aim to find a solution to the identified problem.

To perform a study, different tools, like data collection and analysis, are used. Questionnaires, interviews, observations and literature studies are examples of tools. The studies can be quantitative, with a focus on mathematical models and calculations, or qualitative, with a focus on essence and quality. Semi-qualitative studies try to combine the two previous. (Regnell & Runeson 2006) A study can be accurate in different respects. Validity, reliability and representativeness can be used to measure this.

*Validity* is the connection between the object you want to measure and what is really measured. For example, to know the weight of a population measuring their feet is not a good method. A way to increase the validity is to study the object with different methods. (Regnell & Runeson 2006)

*Reliability* is the data and analysis certainty regarding random variations. To achieve a high reliability, precision is demanded when collecting data and during analysis. By showing the work steps and conditions, the reader can make an evaluation of how the procedure was conducted. The selection of test objects, for example that test persons in a population is randomly chosen, is important. It is important that if the test is redone the result would be the same, independent of who is performing the test. (Regnell & Runeson 2006)

*Representativeness* means that the study’s conclusions are general and largely depends on the selection. A mapping of a field can in reality only be valid for that specific field. Case studies and
problem solving are in principle not general. But if studies are similar, the probability increases that the observed objects behave the same. (Regnell & Runeson 2006)

Our Method
The procedure in this report is founded on several different methods, which are summarized in the bulleted list below.

- Field study (field sampling and laboratory analysis)
- Interviews and discussions (with responsible and involved)
- Personal observations (during field study in Tunisia)
- Literature study

First, a case study of the conditions in a peach field in Ouardanine, Tunisia, was performed. The case study is the foundation for the conclusions drawn in this report. The procedures and results of this case study are summarized in Appendix I and Appendix II: Laboratory Report. Originally, the aim was to measure heavy metal levels in the soil and water and then to calculate the levels in fruit and human. However, on site, it was possible to measure heavy metal levels in the fruit, which deleted one step in the calculation chain. Questionnaires, discussions, interviews and observations were used to complete the authors understanding of wastewater reuse in Tunisia.

A literature study has been conducted to deepen the authors’ knowledge. The intention was to follow the steps shown in Figure 9 to assess the risks of heavy metal accumulation. The background of wastewater reuse, wastewater treatment and interested parties were identified with a combination of the facts achieved in the case study and literature studies. Furthermore, knowledge about plants heavy metal uptake, diseases related to human heavy metal ingestion and formulas used to calculate uptake was studied. The literature study’s aim was to identify facts that could help to evaluate the risk connected to heavy metals in peaches.

To draw conclusions of heavy metal movements between the different compartments, similar studies were used. As there was no possibility to perform direct measurement on humans; water, soil and fruit conditions were measured, to draw conclusions on human heavy metal accumulation. The amount of heavy metals gathered in exposed human was calculated according to methods given in 4.3. Thereafter, a dose-response relationship was produced to establish the risks related to the irrigation.

In addition to the original method, the authors decided to add a chapter regarding risk communication and risk perception. Interesting information came up during the field study concerning Tunisians way of handling wastewater reuse as a potential risk for the citizens. Risk perception has also been an essential part in the risk education and hence it felt relevant to include this in the study.

1.1.4 Restrictions and Limitations
The study is aiming to include heavy metal risks associated with reusing wastewater for irrigation. However, due to time and knowledge limits this study is restricted. The risk assessment will be limited to four heavy metals; cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn). Copper, lead and zinc were selected on the basis of Akiça Bahri’s dissertation (Bahri 1995). The dissertation chose the three trace elements to be of most importance and interest in wastewater irrigated soils in Tunisia. Furthermore, cadmium was suggested by Professor Göran Bengtsson (2009) and is a discussed environmental issue in
Sweden and throughout many European countries. The assessment will not consider the occurrence of synergistic effects between those metals. The spatial limit is a field outside Monastir in eastern Tunisia. The temporal limit is set to be from the time of sampling and forward. The analysis is a prospective study and is aiming to describe future accumulation of heavy metals in the peaches. However, the conditions are assumed to be static.

This year, the studied field in Monastir, is fertilized with sludge from the local municipal wastewater treatment plant. The authors will not analyze this sludge and its potential risk of contaminating the field with heavy metals. In the area irrigated with reused wastewater in Monastir various plants are irrigated, in addition to peaches. This study however, is only considering peaches.

There are several routes of heavy metal exposure, however, only ingestion of peaches is included. The authors are aware that inhalation of dust in some cases can be a relevant exposure route, but time limits have not allowed further research in that area. Additionally, this study will only consider non-carcinogenic effects of the contaminants, Cd, Cu, Pb and Zn.

Due to limitations in time, the fact that the farmers and people close to the irrigated field could be more exposed to heavy metals is not considered in this thesis. The endpoint of the study considers adults, if nothing else is mentioned.
2 Background

In this chapter the background of Tunisia, the peach industry, how reuse of wastewater is managed, the examined field in Ouardanine and the involved stakeholders are presented.

2.1 Tunisian Republic

In North Africa, jagged in between Algeria in the west and Libya in the south-east lies Tunisia, see Figure 1. Tunisia has a long coastal boarder to the Mediterranean Sea in the north and north-east. The northern parts have a Mediterranean climate and the majority of the population lives here. Southwards the climate gets more arid, and the southern parts have a desert climate. In the oasis of the south, Berber tribes, the original population still lives according to their traditional customs. The country has a rich history, with a culture influenced by all the civilizations that have conquered the country, Phoenician, Roman, Arabic, Ottoman and French. The Arabic culture is especially strong, and out of the country’s ca 10 million inhabitants, 98% are Arabs and Islam is the main religion. In year 1881, Tunisia became a French colony, but regained its independence in 1956 under the leadership of President Habib Bourguiba. In 1987, the Presidency was taken over by Zine El Abidine Ben Ali. (UI 2009)

Figure 1. Map of Tunisia. (UT 2009)
Tunisia is a country with a mixture of modern values and tradition. Arabic is the official language, but French is the language used in administration and education. Since the independence, social reforms have been of priority. 74% of the population is literate, and average length of life has increased from 50 to over 70 years since 1970. BNP per inhabitant was in 2008, 4030 US dollar (To compare with 55 620 US dollar for Sweden and 47 025 US dollar for USA). (UI 2009)

Agriculture is an important sector and the main export commodities are textile products and provisions (mainly olive oil). The service sector has increased, and tourism has also become an essential part of the lands income (UI 2009)

2.2 The Peach Industry in Tunisia

The total area cultivated with fruit and nut trees is about 2 million hectares, of which peach trees are grown on 26 000 hectares. (Ben Mimoun 2003)

Peach trees (*Prunus persica*) are among the most essential fruit trees in Tunisia. The peach industry has been growing the last decade due to more plantations, along with more efficient management of orchard technology, introducing new rootstocks, cultivars, irrigation and sufficient fertilisation. Peaches are cultivated mainly in the northern and central part of the country. The cultivars are numerous and they are grown from the beginning of May to the end of September. (Ben Mimoun 2003)

80% of the total amount of produced peaches is irrigated, unlike those that are rain fed. The most essential growing areas of peaches in Tunisia are distinguished by a subtropical climate. (Ben Mimoun 2003). Peaches grown in Ouardanine, Tunisia, are shown in Figure 2.

2.3 Reuse of Wastewater

Water scarcity is becoming an increasingly pressing problem in arid and semi-arid areas. Along with population growth, water demand for food production is exposed to severe strain and is becoming an apparent issue. Whenever conventional water resources are insufficient or lack for agricultural purposes, water of marginal quality is considered. Many countries have incorporated reuse of wastewater and the use of other unconventional water resources as an important part within their national water plan. The use of marginal quality water for irrigation is associated with more intricate management and consistent monitoring than that of conventional water because of its health hazards. Besides from water scarcity, wastewater reuse can also be motivated by finding more economically viable ways to meet increasingly more stringent discharge limitations. (Pescod 1992)

Most of water reuse projects developed in the world is for irrigation purposes. (Bahri & Lazarova 2005) Irrigation is vital in increasing crop yields and receiving a consistent production within agriculture. It is essential to keep the agriculture economically viable in arid and semi-arid areas. (Pescod 1992) Irrigation with reused wastewater gives an additional source of nutrition and enhances agricultural production.
(Bahri & Lazarova 2005) The major quality factors associated with reuse of wastewater are pathogen content, salinity, sodicity, ion toxicity, trace element content and nutrients. (Bahri & Lazarova 2005)

2.3.1 Reuse of Wastewater in Tunisia

Wastewater reuse for agricultural land has always existed and is nowadays a common practice in the Mediterranean region. However, it is mostly an unintentional act. (Bahri & Brissaud 1996) Tunisia is among the leaders in reusing wastewater for agricultural purposes in the Mediterranean region. It is the National Sewage and Sanitation Agency (ONAS), under the Ministry of Agriculture, which has the responsibility of collecting, treating and disposing wastewater in Tunisia. Wastewater reuse has been made an integral and imperative element in the national water management strategy, see Table 1 below. Accessible waters (A) refer to water resources that can be mobilized and available water (B) to water resources that are mobilized. The reuse of wastewater is essential for the national tourism development; recreational areas, such as golf courses, are irrigated with reused wastewater. (Bahri & Lazarova 2005)

<table>
<thead>
<tr>
<th>Table 1. Accessible (A) and available (B) water resources (Mm³/year) in Tunisia for different time horizons, modified from Bahri (2002).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large dams</td>
</tr>
<tr>
<td>Hillside-dams and lakes</td>
</tr>
<tr>
<td>Tube wells and springs</td>
</tr>
<tr>
<td>Open wells</td>
</tr>
<tr>
<td>Reclaimed water</td>
</tr>
<tr>
<td>Desalinated water</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Wastewater from Tunis has been used as irrigation water for the Soukra area, close to Tunis, since the beginning of the sixties. Tunisia was among the first countries in the Mediterranean area setting up wastewater treatment facilities, which mostly are situated along the coastline where tourist resorts need to be protected and seawater intrusion prevented. (Bahri & Brissaud 1996) The reuse is considered to be an additional treatment phase, whereas coastal zones, sensitive receiving bodies and water resources are protected. (Bahri 2002) Generally, the wastewater is treated to secondary level (see 2.4 for further description of the treatment process). (Bahri & Brissaud 1996)

<table>
<thead>
<tr>
<th>Table 2. Parameters for influent and effluent wastewater (mg/L) and sewage sludge (mg/kg) in Tunisia, adapted from Bahri (2002).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>Cd</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Pb</td>
</tr>
<tr>
<td>Zn</td>
</tr>
</tbody>
</table>

Chemical constituents and parasitic and bacterial content of influent and effluent water from wastewater treatment plants reused in agriculture have been monitored in Tunisia. The chemical composition of effluents varied with treatment process, plant location, proportion of industrial water,
leakage of brackish/sea water into the sewerage network and the quality of the water supply, see Table 2. (Bahri 2002)

2.3.2 Strategies

Because of water shortage in Tunisia, water saving policies have been implemented, especially in the agricultural sector. As a consequence, 80% of the agricultural area in the country has been equipped with water saving systems. (AFD 2005) In 1995, the government of Tunisia launched a national water savings program, which subsidizes the purchase of water saving equipment and in 2005, 72% of the public irrigation perimeters were equipped with these devices. (Hassan 2005)

Approaches to expanding reuse of wastewater in Tunisia have been developed and adopted since the sixties. (Bahri 2002) The strategy contains four parts; (1) extending wastewater treatment to all urban areas, (2) establishing pilot- and demonstration-scale irrigation operations on agricultural and green areas, (3) establishing large scale irrigation schemes and (4) implementing a policy calling for an increase in the percentage of treated effluent that is to be reused. (El Ayni 2008)

Within the four parts for expanding reuse three phases can be distinguished. In the first phase citrus orchards in the region of La Soukra have been irrigated by wastewater from Tunis since the early 1960s to prevent salt water intrusion due to excessive groundwater pumping. The irrigation scheme was mainly during spring and summer and usually in combination with groundwater irrigation. (Bahri 2002)

The second phase considers planned reuse of wastewater, whereas the reuse wastewater policy was initiated in the early 1980s. The key applications of reused wastewater are agricultural and landscape irrigation. Pilot schemes and experimental projects within groundwater recharge, wetland development and irrigation of forests and highways have been initiated. Old wastewater treatment plants were planned separately from reuse projects, which nowadays are conjoint plans. Institutional and legal framework has been set up and regulations as 1975 Water Law and 1988 Decree No. 89-1047 is controlling water reuse (see 2.3.3). (Bahri 2002)

The third phase regards active development of the reuse of wastewater. When the quality of the effluent fails to measure up to the standards of irrigation water, several other options are available. Alternatives to agricultural options, i.e. municipal, industrial and environmental, are currently developed. The endorsement for reusing wastewater should consider an actual water demand, definitions of water quality for the different usage options, an appropriate regulation, identified and out spelled responsibilities among the concerned parties and an effective control of all uses. (Bahri 2002)

The current strategies of National Water Resources Management are surface water mobilization, soil and water conservation works, water harvesting and use of non-conventional water resources, i.e. wastewater reuse and aquifer recharge. (CITET & INECO 2008)

However, water reuse operations within agriculture are not yet fully exploited to its full economic potential and the implementation of reuse projects is still a big challenge. Economic aspects as benefits and financial performance of reuse projects are still hard to predict and quantify. Reuse approaches need to be demand driven, however it is difficult to implement in planned systems. To identify the needs and the willingness to pay for reused wastewater a market assessment should be conducted. Water Users Associations (WUAs) need to be integrated in the management and planning of reuse projects to guarantee success. (IWMI/World Bank 2002)
2.3.3 Regulations and Recommendations

Wastewater reuse for agricultural purposes is regulated by legislation in Tunisia, 1975 Water Law and 1988 Decree No. 89-1047. The 1975 Water Law prohibits untreated wastewater in agriculture; secondary level (see 3.4 for further information) of treatment is required. The reused wastewater is allowed on all types of crops, except vegetables, whether eaten raw or cooked. 1988 Decree No. 89-1047 states that wastewater can be reused only after adequate treatment, effluent should not be used to irrigate vegetables which might be contaminated with wastewater and which might be eaten raw, the use of treated wastewater must be authorized by the Ministry of Agriculture and Water Resources, in agreement with Ministry of Environment and Sustainable Development and Ministry of Public Health, buffer areas must be created for sprinkler irrigation and direct grazing is prohibited. (El Ayni 2008)

Tunisian standards regarding heavy metals (Cd, Cu, Pb and Zn) in reclaimed wastewater are listed in table 3 below. The regulations were developed inspired by FAO (Food and Agriculture Organization) guidelines, WHO (World Health Organization) guideline for restricted irrigation and various Tunisian standards within irrigation and water supply. (Bahri 2002) In Table 3 recommended limits for Cd, Cu, Pb and Zn are listed for long-term and short-term use for reclaimed wastewater for irrigation application.

<table>
<thead>
<tr>
<th>Element</th>
<th>Tunisian standard* (mg/L)</th>
<th>Long-term use** (mg/L)</th>
<th>Short-term use** (mg/L)</th>
<th>Remarks**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0,01</td>
<td>0,01</td>
<td>0,05</td>
<td>Toxic to beans, beets and turnips at very low concentrations (0,1 mg/L) in nutrient solution.</td>
</tr>
<tr>
<td>Cu</td>
<td>0,5</td>
<td>0,2</td>
<td>5,0</td>
<td>Toxic to numerous plants at concentration 0,1 mg/L to 1,0 mg/L in nutrient solution.</td>
</tr>
<tr>
<td>Pb</td>
<td>1</td>
<td>5,0</td>
<td>10,0</td>
<td>Can reduce and inhibit plant cell growth at high concentrations.</td>
</tr>
<tr>
<td>Zn</td>
<td>5</td>
<td>2,0</td>
<td>10,0</td>
<td>Toxic to numerous plants at varying concentrations; reduced toxicity at increased pH and in fine-textured or organic soils.</td>
</tr>
</tbody>
</table>

* Reclaimed wastewater reused in agriculture (NT 106.03 1983)
**Adapted from Rowe & Abdel-Magid 1995

There are no Tunisian standards for heavy metal content in agricultural soils; instead Swedish standards are used for comparison. Regulations regarding heavy metals in Sweden are based on directives from the EU-commission, implemented in Sweden by the Swedish agricultural department Jordbruksverket (2007), see Table 4. The data is concerning agricultural soils which are fertilized with sludge from wastewater treatment plants, which also are the current conditions for the studied field in Ouardanine.

Regulations for heavy metal content in peaches do not exist in Tunisia. However, the authors believe it is relevant to compare the measured concentrations in the peaches of Ouardanine to European standards. Cadmium and lead limits are given by the EU Commission (2006) and presented in Table 4. The limits refer to the eatable part of marketed fruits which are washed. Yet, zinc is not mentioned by the EU Commission. Recommended nutrient intakes for cadmium, lead and zinc presented by FAO/WHO (2001) are given in Table 4. Nutrient intake recommendations are depending on whether it is low, moderate or
high bioavailability of the nutrient in questions, i.e. not the entire amount of the ingested nutrient is taken up by the human body. The limits given in the table below considers moderate bioavailability in male adults.

Tolerable upper intake levels of copper and zinc are given by the European Food Safety Authority (EFSA), and are also presented in the table below. DM refers to dry matter and WM to wet matter. Tolerable upper intake levels are the maximum level of a chronic daily intake of an element, referring to all potential sources. The levels given are judged to be unlikely to pose risks of adverse health effects to humans; hence they are not recommended levels. (EFSA 2006)

Table 4. Cd, Cu, Pb and Zn limits and recommendations in soil and peaches.

<table>
<thead>
<tr>
<th>Element</th>
<th>Recommended limits</th>
<th>Nutrient intake recommendations</th>
<th>Tolerable upper intake level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soils (mg/kg DM)</td>
<td>Peaches (mg/kg WM)</td>
<td>(mg/kg/day)</td>
</tr>
<tr>
<td>Cd</td>
<td>0,4</td>
<td>0,050</td>
<td>0,00036</td>
</tr>
<tr>
<td>Cu</td>
<td>40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pb</td>
<td>40</td>
<td>0,1</td>
<td>0,0036</td>
</tr>
<tr>
<td>Zn</td>
<td>100</td>
<td>-</td>
<td>7,0</td>
</tr>
</tbody>
</table>

1Jordbruksverket (2007)  
3FAO/WHO (2001)  
4EFSA (2006)

2.3.4 Opportunities and Challenges

Planned water reuse projects can be very valuable for planners and local authorities, since it have several benefits. Yet, it is important to stress that not all water reuse projects deliver immediately measurable benefits. (Bahri & Lazarova 2005) Advantages and challenges are summed up and presented in Table 5.

Table 5. Advantages and challenges within reuse of wastewater in the agricultural sector in Tunisia. (Modified from Bahri & Lazarova 2005)

<table>
<thead>
<tr>
<th>Advantages and benefits</th>
<th>Challenges and constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternative source of water</strong></td>
<td><strong>Health and regulatory concerns</strong></td>
</tr>
<tr>
<td>Displace the need for other water sources</td>
<td>Health problems related to pathogens or chemicals in improperly treated wastewater</td>
</tr>
<tr>
<td>Reliable, secure and drought-free source</td>
<td>Lack of regulations and incentives for reuse</td>
</tr>
<tr>
<td>Fast and easier implementation than new freshwater supply (occasionally)</td>
<td>Water rights: Who owns and recovers the water reuse revenue?</td>
</tr>
<tr>
<td>Independence from the current freshwater purveyor (e.g. for political reasons)</td>
<td>Inadvertent exposure or unreliable operation</td>
</tr>
<tr>
<td><strong>Water conservation</strong></td>
<td></td>
</tr>
<tr>
<td>Closing water cycle</td>
<td></td>
</tr>
<tr>
<td>Saving of high-quality freshwater for potable water supply</td>
<td></td>
</tr>
<tr>
<td>More efficient water use after the retrofit of distribution systems and repair of breaks and leaks</td>
<td></td>
</tr>
</tbody>
</table>
Health and regulatory concerns

- Improved public health (farmers, downstream users)
- Enhanced policy awareness, compatibility with water/wastewater treatment policies and regulations

Economic value

- Avoided costs for new freshwater resource development, transfer and pumping
- Lower water treatment costs for downstream users
- Avoided costs for advanced wastewater treatment and discharge
- Reduced or eliminated application of commercial fertilizers
- Additional revenue from sale of recycled water and agricultural products
- Secondary economic benefits for customers and industries in case of continuous supply during drought
- Improvement of tourism activity in dry regions
- Increase in land and property values

Environmental value

- Reduced pollutant discharge into receiving bodies
- Improved recreational value of waterways
- Avoided impact of developing new freshwater resources (dams, reservoirs, etc.)
- Alternative water supply for environmental enhancement
- Alternative restrictions in wastewater discharge permits (volumes, nutrients)
- Effective use of nutrients contained in wastewater for irrigation leading to higher crop production and low fertilizer application
- Additional treatment of wastewater through irrigation before dilution with groundwater
- Provide a link between rural and urban areas with joint benefits

Sustainable development

- Source of additional water that contributes to the sustainable development of dry region (irrigation, industries, tourism)
- Increased food production
- Improved aquatic life and fish production

Social and legal concerns

- Water reuse acceptability
- Change of the socio-economic and cropping patterns of framers
- Marketability of crops might be reduced

Economic concerns

- Cost of recycled water infrastructure (additional treatment, dual distribution) and O&M, including cross-connection control
- Difficult revenue and cost recovery (uncertain water use patterns)
- Seasonal variations in demand and need for large storage capacity
- Inadequate water pricing: e.g., low price of water for farmers
- Change in market (in particular agriculture) can affect water reuse programs
- Liability for potential loss of potable water revenue
- Need for well-adapted economic approach

Environmental and agronomic concerns

- Recycled water quality, especially salts and boron, can have negative effect on crops and soil
- Surface and groundwater may be polluted by several chemical and biological components if irrigation is not properly managed (leaching)

Technical concerns

- Reliability of operation
- Appropriate choice and design of treatment technologies
2.4 Ouardanine

This study applies to the wastewater collected by the wastewater treatment plant of Ouardanine, a small region situated just outside Monastir, a city on the central shore of Tunisia, see Figure 3.

The wastewater treatment plant of Ouardanine was set in April 1993. The plant collects wastewater from 17,000 citizens and has a capacity of treating 1500 m³ of wastewater a day. The collected wastewater is mainly rural and domestic, it originates from residences and commercial, institutional and similar facilities. The wastewater of Ouardanine is treated to secondary treatment, according to the 1975 Water Law. Thus, the wastewater has gone throughout preliminary, primary and secondary level before being used as irrigation water in agriculture, see Figure 4. (Ben Salem 2009)

- **Preliminary treatment** consists of screen bars
- **Primary treatment** is the sedimentation phase
- **Secondary treatment** is activated sludge process
Figure 4. Overview of the treatment process of the Ouardanine wastewater treatment plant.

In the preliminary treatment, coarse solids and large floating matter are removed to facilitate subsequent stages in the treatment process. This treatment consists of bar screens, which separates trash, such as rags, diapers, etc. The trash is collected and depending on the composition it is dried and composted. (Ben Salem 2009)

The primary step consists of a sedimentation phase (see Figure 5) and it is in this phase most of the heavy metals are removed. The wastewater is sent to the primary sedimentation tank, which allows sludge to settle by gravity. The tank is equipped with a scraper, which collects the settled sludge from the bottom of the tank. The collected primary sludge is dried and composted to be used as a soil conditioner. No chemicals are added in the primary step. (Ben Salem 2009)

The secondary step, consists of an aeration tank with activated sludge, in which the organic content of the sewage is degraded by microorganisms. Atmospheric air is bubbled through the sewage to supply an aerobic environment for the activated sludge. The remaining wastewater is subsequently pumped to a final clarifier which allows the sludge to settle. The secondary sludge is divided in three parts. One part is dried and composted to be used as a soil conditioner, one acts as feed for the activated sludge in the aeration tank and the last one is used un-dried as an agricultural fertilizer. The remaining treated wastewater effluent is pumped to a storage reservoir and distributed as irrigation water by gravity, when demanded, to the field. (Ben Salem 2009)
2.4.1 Heavy Metals in Municipal Wastewater Treatment Plants

All wastewaters reaching treatment plants contain trace metals to some extent and wastewater of industrial origin is an obvious source. However, municipal wastewater can also be a potential source of high trace metal concentrations. The concentration of trace metals in wastewater depends on their sources and level of treatment. (Rowe & Abdel-Magid 1995)

The activated sludge process is a well-established municipal wastewater treatment technology and the most common used throughout Europe. It is a biological process that requires large amounts of energy, while generating considerable amounts of organic sludge. (Álvarez et al 2002)

In the activated sludge wastewater treatment, sludge is separated throughout the process, defined as preliminary, primary and secondary sludge. (Álvarez et al 2002) Sludge is an end-product of the wastewater treatment and contains high amounts of those contaminants and pollutants removed from the influent wastewater. (EPA U.S. 1996) The sludge holds more than 90% water and is highly biodegradable. Due to the physico-chemical processes in the activated sludge treatment heavy metals originating from the wastewater tend to accumulate in the sludge. Hence, heavy metal concentrations are higher in the sludge than in the soil that it is applied on. The contaminants can maintain in the cultivated soil layer and due to repeated agricultural sludge application, increase the soil concentrations.
of contaminants. The increase depends upon sludge application rate and heavy metal concentration. (Álvarez et al 2002)

Heavy metals in wastewater are reduced to some extent in the primary step of the wastewater treatment plant. (EPA U.S. 1996) Heavy metals accumulate in the activated sludge mainly through two chemical-physical phenomena, bioflocculation of the particulate phase and adsorption of the soluble phase. Extracellular polymers, which are produced by the bacterial biomass, can accumulate high quantities of metallic ions. (Avezú 1995)

Cadmium, chromium, copper, lead, mercury, nickel and zinc are the main elements limiting sludge application on agricultural soils. Due to potential accumulation in human tissue and biological magnification in the food-chain they are of both human health and environmental concern. (Álvarez et al 2002)

### 2.5 The Irrigated Peach Field

In the area of Monastir, several crops are irrigated with reused wastewater. The irrigation scheme was set in 1995 as a part of the national water reuse program and covers 50 ha of irrigated land and orchards. The yields are 35 ton peaches per ha and 75 ton fodder crops per ha. Due to 1988 decree No. 89-1047 (see 2.3.3), the treated effluent from the wastewater treatment plant is not allowed to be used on vegetables, whether eaten raw or cooked. The irrigation scheme in the Monastir area is a large pilot project planned by the Ministry of Agricultural and Water Resources. Since the start of the irrigation scheme, operating costs have been covered by the governmental budget (75 %) as well as by the farmers (25 %). The scheme is considered successful, since it has achieved its environmental objectives, created an economic activity throughout the entire year and jobs in Ouardanine and created a new resource of water. (Bahri 2009)

![Figure 6. Schematic figure showing drip irrigation. (Brouwer et al. 1988)](image)

The field studied in this thesis is irrigated with 3000m³ waste water/ha/year by drip irrigation (see Figure 6). Drip irrigation is the most frequent irrigation systems for irrigating orchards. 60 % (30 ha) of the reused wastewater in Ouardanine is irrigated by drip irrigation. The irrigation technique drips water onto the soil at very low rates (2-20 L/hour) from small pipes with outlets called emitters or drippers. Drip irrigation only wet the soil closest to the plant and the root zone, in contrast to surface and
sprinkler irrigation, which wet the entire soil profile. Drip irrigation is an efficient method for irrigating orchards, since it saves water due to reducing deep percolation, surface runoff and evaporation. Yet the savings both depend on management of the equipment and the equipment itself. (Brouwer et al. 1988)

Figure 7. The wastewater treatment plant of Ouardanine and the irrigated field. (Google maps 2009)

Drip irrigation includes a high installation cost. (Brouwer et al. 1988) However, the government of Tunisia subsidizes the installation cost for the irrigation system as an incitement for better water use and efficiency. The irrigation peak in Ouardanine is in May. The irrigation stops ten to fourteen days before harvest, mainly due to safety regulations. (Ben Salem 2009)

Since 2009, sludge from the wastewater plant is used as fertilizer and no further fertilizer is used. The estimated amount is 6000kg sludge/ha/year. The field is ploughed 5 to 6 times a year, which affect a zone with a depth of approximately 15cm. (Ben Salem 2009) An overview of the Ouardanine area and collected peaches from the field is shown in Figure 7 and 8.
2.6 Stakeholders

Stakeholders are defined as any individual, group or organization that can affect, be affected by or perceive themselves to be affected by a risk. (ISO/IEC 2002) The responsibilities associated with reusing wastewater are shared amongst various institutions and ministries in Tunisia; Ministry of Agriculture and Water Resources, Ministry of Public Health, Ministry of Environment and Sustainable Development, Ministry of Technology and Communication, Ministry of Scientific Research, along with 1400 consumers associations, 570 farmers associations and 70 mixed groups. (CITET & INECO 2008)

Six different ministries are distinguished in sharing the responsibilities within water reuse in Tunisia.

- **Ministry of Agriculture and Water Resources** is responsible for assessing, monitoring, developing, distributing, evaluating water resources and constructing, operating and maintaining water plants
- **The Ministry of Public Health** is monitoring and regulating water quality
- **The Ministry of Technology and Communication** controls the National Institute and Meteorology
- **The Ministry of Scientific Research** controls the Research Centre on Water Technologies and the Arid Regions Institute
• **The Ministry of Tourism** is a financing ministry
• **The Ministry of Environment and Sustainable Development** is controlling institutions (ANPE, ONAS, CITET)

Ministry of Agriculture and Water Resources disposes all tasks related to water resource management and development and controls 11 institutes, which are responsible for assessing, monitoring, developing, distributing and evaluating water resources as well as constructing, operating and maintaining the water facilities. The current use of reused wastewater consists of agricultural irrigation, landscape irrigation and groundwater recharge, although the last mentioned is still in pilot scale. The Ministry of Agriculture and Water Resources is in charge of collection, treatment and disposal of wastewater (ONAS) and control (NEPA, CITET). They also implement water reuse projects, which include operating the water distributing system, collecting fees and enforcing the regulations related to reusing wastewater in agriculture. The ministry is also in control of research

The Ministry of Public Health undertakes monitoring quality of potable water and treated wastewater, which is used for irrigation, in order to prevent and reduce water-related diseases and epidemics. The ministry regulates hygienic quality of the reused wastewater, which is used for irrigation of marketed crops. It also monitors water pollution and enforces pollution control.

The Ministry of Technology and Communication controls the National Institute and Meteorology, which in turn controls the monitoring of meteorological, oceanographic and seismic data. The Ministry of Scientific Research manages the Research Centre on Water Technologies and the Arid Regions Institute. The Ministry of Tourism finances selected wastewater reuse operations.

Ministry of Environment and Sustainable Development controls 3 institutions (ANPE (Agence Nationale de Protection de l’Environnement, National Environmental Protection Agency), ONAS (Office National de l’Assainissement, National Office of Sanitation) and CITET (Centre International des Technologies de l’Environnement de Tunis, Tunis International Center for Environmental Technologies)), which jointly manage questions related to water pollution and quality. (El Ayni 2008)

CITET is the Tunis International Center for Environmental Technologies situated in Tunis, the capital of Tunisia. The center aims to assure the needs of Tunisia and other countries in the Arab-African and Mediterranean region in terms of transferring, adapting and promoting ecologically friendly technology. CITET seeks to offer help to strengthen skills and build capacity in protecting the environment, managing natural resources and mastering environmentally friendly technologies. (CITET 2009)

Furthermore, associations for consumers and farmers are included as stakeholders within wastewater reusing. (CITET & INECO 2008)
3 Risk Theory

In this chapter the theory behind risk assessments and risk management processes will be presented. The risk assessment process in this study will focus on human health and ecological/environmental risks and not safety risks.

3.1 Risk

Risk is a combination between the probability and the consequence of an event. (ISO/IEC 2002) According to Kaplan and Garrick (1981) a risk can be analyzed by answering a triplet of questions;

- What can happen?
- How likely is it that that will happen?
- If it does happen, what are the consequences?

3.2 Risk Management

The overall reason for conducting a risk assessment is to decide on the need and character of risk management. It allows decision makers to prioritize and allocate resources based on a systematic and holistic point of view. (Kolluro 1996) The general disposition of a risk management process is presented in Figure 9. The process is inspired by ISO/IEC and EPA U.S.

![Risk management process](image)

**Figure 9.** The general process of risk management within human and ecological/environmental health (adopted from ISO/IEC 2002 & EPA U.S. 1992).

Risk management is a decision-making process which has an integrated approach of political, economical, social and engineering information together with risk-related information. The process makes it feasible to develop, analyze and compare regulatory options and to choose the suitable option as a response to a hazard. (NRC/NAS 1983)
3.2.1 Risk Assessment

The solutions to Kaplan’s triplet of questions can be answered through a risk assessment. Several definitions of risk assessment occur throughout risk literature. ISO/IEC defines it as an overall approach to risk analysis and risk evaluation. (ISO/IEC 2002) Risk assessment is the characterization of potential adverse health effects for human exposure to environmental hazards. It can be divided into four major steps; hazard identification, dose-response assessment, exposure assessment and risk characterization. (NRC/NAS 1983) In the EPA U.S. manual for ecological risk assessment hazard identification is called problem formulation (Öberg 2009); the latter term is used throughout this study.

Within human health and ecological/environmental risk assessment the approaches and major steps are similar to each other. Both approaches starts by formulate the problem, then assess the exposure, assess dose-response and then risk characterization. (Kolluro 1996) See Figure 9. Further information on the different steps within risk assessment will be given in chapter 4.

3.2.2 Risk Communication and Risk Perception

Risk communication is an integral part in the overall risk management process, see Figure 10. Participants are experts in the assessment and characterization part of the study, decisions-makers and other stakeholders as well as the public. (Öberg 2009)

All communication arises from culture. The trustworthiness of the messenger and the message is an imperative, as well as empathy and admitting the problem. Risk perception is an essential part of risk communication. (Öberg 2009) Risk perception and risk communication play a significant role in society, both in the business world and at political decisions. When new technical solutions are constructed, the risk perception of the public does not always suit the risk perception of the experts, which can lead to restrictions for technical expansions and sometimes prohibitions. Hence, it is important to politicians and other decision-makers how the individual perceive risk in different contexts. Still, they have shown to be limited in that prescience. (Sjöberg 2002)
Table 6. The public perception of various risks. Modified from Bahri & Lazarova (2005) and Akselson (2007).

<table>
<thead>
<tr>
<th>Considered less risky</th>
<th>Considered more risky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary risks</td>
<td>Memorable risks or risks associated with signal events</td>
</tr>
<tr>
<td>Natural risks</td>
<td>Risks with dreaded outcomes</td>
</tr>
<tr>
<td>Familiar risks</td>
<td>Risks perceived as unfair</td>
</tr>
<tr>
<td>Risks that are well understood</td>
<td>Morally corrupt risks</td>
</tr>
<tr>
<td>Risk controlled by self</td>
<td>A risk controlled or caused by a institution that is not trusted</td>
</tr>
<tr>
<td></td>
<td>New risks</td>
</tr>
<tr>
<td></td>
<td>Technical risks</td>
</tr>
</tbody>
</table>

A range of factors can influence how the public perceive risks, see Table 6. In the context of wastewater reuse, the perceived risk is known to be considered less risky with trust in institutions and descriptions, demonstrations and examples of reuse schemes. (Bahri & Lazarova 2005)

To engage stakeholders and use participatory planning within the reuse schemes, will improve the quality of planning and endorse democratic principles of justice and openness. (Bahri & Lazarova 2005) Information about risks is exchanged or shared among decision-makers and other stakeholders through risk communication (ISO/IEC 2002). It is up to decision makers to accept or not to accept the risks and it is therefore important to present the uncertainties related to the study. Quantitative measurements often appear as the truth.
4 Risk Assessment Theory

This study will focus on risk assessment (see Figure 11), and hence a more extensive description of the different steps within the assessment part will be given in this chapter.

- Problem formulation
- Risk analysis
  - Exposure assessment
  - Dose-response assessment
- Risk characterization

Figure 11. The general concept of risk assessment. (Adopted from ISO/IEC 2002 & EPA U.S. 1992)

4.1 Problem Formulation

In the problem formulation the hazards of the contaminants are identified. It is the process of evaluating whether the exposure of the contaminant could cause adverse effects on the endpoint. This step is a planning step where goals, width and focus of the analysis are set. The outcome of the problem formulation is a qualitative model describing how a contaminant can affect its environment, endpoints, which data that is required and which methods that will be used to analyze the data. (EPA U.S. 1992)

It is mainly a qualitative analysis, where evidence is gathered considering the potential for a contaminant to cause adverse effects in humans. The most valid evidence is well-performed epidemiological studies showing a positive relationship between the contaminant and a disease in human, however, those studies are rarely found. Instead data derived from animal experiments can be used. (Rowe & Abdel-Magid 1995)

4.2 Exposure assessment

In the exposure assessment different spread ways, through which the contaminant can reach the endpoint are evaluated. It determines or estimates the magnitude, frequency and the route of exposure to the studied contaminant. The first step is to characterize the exposure setting, whereas the physical setting and the exposed population are characterized. Physical setting considers climate, meteorology, geology, vegetation, soil type, groundwater hydrology, location and description of surface water. The exposed population is characterized with regard to proximity to the site, land use, potential future land use and societal community interests. (Rowe & Abdel-Magid 1995)

In the second step the exposure pathways are identified. An exposure pathway generally consists of a source, transport medium, point of potential human contact and an exposure route at point of contact. The last and third step is to quantify the exposure. (Rowe & Abdel-Magid 1995)

4.2.1 The Average Daily Dose (ADD)

In order to calculate the internal dose of contaminants, a mass flow (intake and absorption) needs to be estimated. Oral intake is expressed as the contaminant concentration in the considered media times the
flow. (Öberg 2009) The ingested dose can be expressed in different ways, but the most common one is average daily dose (ADD) (Lee et al. 2006). ADD can be calculated according to equation 1 below.

\[
ADD = \frac{C \cdot IR \cdot ED \cdot EF}{BW \cdot AT \cdot 365}
\]

4.3 Dose-response assessment

Dose-response relation is an estimation of the relation between the taken dose of the contaminant and the response that is seen in a population (share of suffering), i.e. the likelihood for harm. (Rowe & Abdel-Magid 1995)

There is a relationship between the quantities of chemical to which an organism is exposed and the nature and degree of consequent harmful (toxic) effects. Dose-response relationships provide the basis for assessment of hazards and risks presented by environmental chemicals. Everything is poisonous if the dose is high enough. There are several ways to measure poisonousness, where the most common end point is death. Biochemical, physiological, reproductive and behavioral effects can all be measurements of toxicity. An approach that is gaining in popularity is to establish the highest concentration or dose that will not cause an effect. NOED, no observed effect dose and NOEC, no observed effect concentration, is two ways to express the highest dose/concentration that cause no effect. A pollutant is toxic when its concentration exceeds a threshold value in a particular environmental compartment. A compartment can be a single cell, an organism or earth itself. (Walker et al. 2006)

4.3.1 Reference Dose (Rfd)

The reference dose (Rfd) is the United States Environmental Protection Agency’s estimate of the highest dose that can be taken in every day without causing an adverse non-carcinogenic effect. Rfd is defined as,

\[
Rfd = \frac{NOAEL}{UF \cdot MF}
\]

NOAEL (no observed adverse effect level) is the highest concentration of a substance at which there are no significant increases in the frequency and severity of adverse effects, comparing the exposed population with its appropriate control. UF is a standard uncertainty factor, used to extrapolate animal tested results to human and human intraspecies differences. A factor 10 is often used to characterize differences between human and animals, and a factor 10 for the intraspecies differences. MF is a modifying factor, an additional uncertainty factor between 0 and 10. It depends on professional assessments on the quality of the studied database and the number of species tested.

However, for some substances Rfd values are available in databases. For others, for example lead, Rfd is not a good estimate for toxicological effects. (EPA U.S. 2009) A substitute for Rfd can be AIC (Acceptable Chronic Intakes), which is based on ADI (Acceptable Daily Intake), se equation 3. (Asante-Duah 1993)
AIC = \frac{ADI}{BW} \quad (3)

However, one should be careful of comparing Rfd and AIC since it could be given by different professionals.

4.4 Risk characterisation

The last step integrates the dose-response relations with the exposure assessment to qualitative or quantitative expressions for health or environmental risks. The risk characterization provides a link between risk assessment and risk management. (Rowe & Abdel-Magid 1995)

4.4.1 Hazard Quotient

The quantification of non-carcinogenic effects is measured by the hazard quotient (HQ). HQ is estimated by comparing the ADD with the Rfd or AIC. The summary of each element’s HQ becomes the hazard index (HI). A HI above 1,0 implies toxicity. (Lee et al. 2006) The HQ and HI are calculated according to

\[ HQ = \frac{ADD}{Rfd} \quad (4) \]

\[ HI = \sum HQ_s = \left\{ \frac{ADD_1}{Rfd_1} + \frac{ADD_2}{Rfd_2} + ... + \frac{ADD_i}{Rfd_i} \right\} \quad (5) \]

However, if the HI is calculated as stated above, it will increase for every substance HQ one adds. No information on how to solve this problem was found in literature.
5 Results from the Risk Assessment

In this chapter the risk assessment of reusing wastewater as irrigation water in the studied peach field in Ouardanine in Tunisia is presented. The chapter includes problem formulation, exposure assessment, dose-response assessment and risk characterization. The methodology used in this study is a modified version of risk assessment according ISO/IEC (2002) and EPA U.S. (1992).

5.1 Problem Formulation

The first step in risk analysis is to formulate the actual problem. Problem formulation defines limits and scopes for all subsequent steps in the risk analysis. This part of the risk analysis is an iterative process, where hypotheses, theories and models are tested against the reality and if necessary, reformulated. (Öberg 2009) Purpose, theories and limits are presented in chapter 1.1.

5.1.1 Epidemiological Studies

To assess the health effects associated with cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), epidemiological studies were read. Below, toxicokinetics and health effects of the studied heavy metals are presented.

Cadmium

Cadmium exists naturally in the geosystem and is spread throughout the environment. It is produced as a by-product when producing others metals. The main route of exposure is orally through food, along with smoking and inhalation of cadmium oxide (CdO) fumes. It has no essential biological meaning (Alloway 1995) and in high amounts it may cause both acute and long-term effects. However, long-term effects of cadmium have raised more attention because of cadmiums long biological half-life. (Sarkar 2002) Its half-life in soil varies between 15 and 1100 years, thus cadmium contamination is a long-term problem and needs to be prevented or minimized when possible. (Alloway 1995)

Most epidemiological studies conducted on cadmium are obtained from occupationally exposed workers or on Japanese populations in highly contaminated areas. For non-smokers, food is the major source of cadmium exposure. (Roney & Colman 2004)

Cadmium exposure during a long time of food, water and/or air ingestion initially results in high cadmium concentrations in the liver. The critical effect of cadmium exposure is renal tubular disease. Absorbed cadmium is bound to the protein metallothionein in the liver. Small amounts of cadmium-metallothionein complexes leak from the liver and redistribute and accumulate in the kidneys, hence cause tubular\(^1\) damage. The complex is secreted by the primary urine. In the proximal tubule, a part of the kidney, the complex is reabsorbed and since the elimination of the complex from the tubular cells is fairly slow, an accumulation occurs in the kidneys. As the cadmium concentration elevates and becomes high in the tubular cells, an irreversible damage is a fact. The first sign of renal tubular disease is proteins in the urine. (Akademiska sjukhuset 2009)

\(^{1}\) The tubules - the part of the kidney that allows certain substances to be reabsorbed back into the system and not excreted as urine.
Cadmium is also accumulated in other tissues. The ingestion can also lead to lung damage, bone effects, liver dysfunction, carcinogenesis and reproductive toxicity. (Sarkar 2002) The biological half-life of cadmium is relatively long, about 30 years. (Akademiska sjukhuset 2009)

**Copper**

Copper is naturally present in the environment as a free metal and in the (I) and (II) oxidation states. It occurs within mineral salts as well as in organic compounds. The biological availability and toxicity are related to the (II) oxidation state; hence this study will focus on that form. Copper is essential to humans and is naturally occurring in the human diet. (Roney & Colman 2004)

Copper is absorbed in the stomach and the small intestines. The copper is then bound to metallothionein and slowly released to the blood. Copper is subsequently loosely bound to albumin and amino acids and transported to the liver, where it is released into the plasma. The excess absorbed copper is stored in the liver or excreted through the bile. The main pathway for excretion of absorbed copper is through the bile and feces. Reabsorption of biliary copper is insignificant. (Roney & Colman 2004)

Studies on toxicity of ingested copper to humans are insufficient. Case reports on large amounts of ingested copper (II), state acute gastrointestinal distress, acute hemolytic anemia, hepatic cirrhosis, hepatic necrosis and renal tubular necrosis or damage. However, toxicity doses were not available. (Roney & Colman 2004)

**Lead**

Lead contaminated soils are primarily due to vehicle exhaust and old lead pigmented paint. The majority of the lead is bound in the soil as low solubility carbonates, sulfides and in combination with iron, aluminum and manganese oxides. Hence, lead is very unavailable to plants and for leaching to groundwater. A potential harm to humans can be if children put contaminated soils in their mouths. (Brady & Weil 2008)

The health effects associated to lead exposure are uninfluenced by exposure routes, i.e. there is no difference in health effects whether it is oral exposure or inhalation. The contaminant has proven to affect practically every organ and system in the human body; hence the most sensitive parts are neurological, hematological and cardiovascular systems. (Roney & Colman 2004 pp93)

The critical organ systems, when exposed to organic and inorganic lead, are erythrocytes of the bone marrow and the central and periphery nerve systems. The inorganic lead has lower solubility than the organic lead and poorer penetration through the blood-brain barrier. The course of action involves fundamental biochemical processes, such as the ability of lead to inhibit or imitate action of calcium and to interact with proteins. (Roney & Colman 2004)

Long-term exposures to lead affect the central nerve system; it can lead to worsen memory function and apprehension and extended time of reaction. Furthermore, the hemoglobin synthesis is affected, and in the long run the exposure can lead to anemia. (Roney & Colman 2004)

---

2 The *erythrocytes* are also referred to as the red blood cells.
Zinc
Zinc is one of the most common elements in the crust of earth and is an essential constituent for humans. It is present in air, water, soil, and all foods. Exposure above the recommended dietary requirement causes anemia, gastrointestinal irritation, pancreatic and adrenal defects, and damaged immune function, among others. (Roney & Colman 2004)

Initially, zinc is concentrated in the liver and then distributed throughout the body. High amounts can be found in the prostate, retina, sperm, gastrointestinal tract, kidney, brain, skin, lung, heart, and pancreas. Zinc is excreted mainly by the faeces but also in the urine and sweat. Furthermore, zinc does not appear to accumulate in the body with age. (Roney & Colman 2004)

5.2 Exposure Assessment
NAS (1994) established that exposure assessment involves specifying the population that might be exposed to the agent of concern, identifying the routes through which exposures can occur, and estimating the magnitude, duration, and timing of the doses that people might receive as a result of their exposure.

The different pathways are illustrated in Figure 12. Arrows with dashed lines identifies indirect intake of the contaminant, while the others identifies direct intake. Only the blue pathway is considered in this thesis, although some of the other pathways are possibilities in the case of reusing wastewater in Tunisia.

![Figure 12. Pathways of exposure to contaminants in soil modified from Öberg (2009).](image-url)
5.2.1 Characterization of Physical Settings
The climate along Tunisia’s coastal boarders is defined as Mediterranean. The Mediterranean climate is characterized by its hot, dry summers and mild winter (Strahler & Strahler 2003). Precipitation is clearly limited in time and the summers are hot and arid. See Appendix IV.

Geologically, the bedrock of the Monastir region consists of stratifications from the middle to the end of the quaternary and tertiary geological time. Rocks in the area are especially known for its fragility and are made from charcoal, sandy clay, clayey sand and sandy rocks, which can contain remains of shells. The stratification can reach a depth of 1500m and are the main rock of Ouardanine. The rock is constantly exposed to erosion. (Atlas for Nabeul Governorate 2002)

Mediterranean vegetation is usually evergreen, retaining their leaves through the entire yearly cycle (Strahler & Strahler 2003). Close to the Mediterranean Sea, most of the land is cultivated and this also applies to the area around the field (NE 2009). The surroundings are rural and the vegetation in the field is represented by peach trees. There is no ground vegetation, since the ground is ploughed several times per year. Around the field, other agricultural trees are grown, like almond, figs and olive trees.

The authors defined the soil type as sandy clay silt, sandy silt clay or sandy clay (see Appendix I). Fractions of shells were also identified around the field. There is a high amount of organic compounds in the soil that is assumed to mainly come from the sludge fertilization. pH in the field indicates slightly basic conditions.

The treated wastewater is the peach field’s only irrigation source. After treatment the water is gathered in a basin and used according to demand.

5.2.2 Characterizing of the Exposed Population
As mentioned before, human is the end point of the analysis and the population that eats the fruit is the exposed population. This includes Tunisians and people in other countries to which peaches are exported. In Tunisia, peaches from fields irrigated with treated wastewater, are not separated from conventional irrigated peaches, considering distribution, labelling, selling and marketing. For exporting, it depends on the laws of the importing country if any distinguished process for separating conventional and wastewater irrigated peaches is required. (El Ayni 2009)

It is not public knowledge that treated wastewater is used for irrigation. The government does not inform the people about this, as they fear the knowledge could make people scared of eating the products. The publics’ ignorance and lack of knowledge could thereby make them unreasonably worried in proportion to the actual hazard (El Ayni 2009). Due to their proximity to the field, the farmers and their family could be more exposed. They are closer to the soil, water and fruit exposure path. The surroundings are rural and agricultural and the closest biggest town is Monastir, with a population of 71 500 people (Hole, Grosberg & Robinson 2007).

5.2.3 Identification of Exposure Pathways
Heavy metals occur naturally in soils (Alloway 1990). Due to several input and output sources of heavy metal, the total heavy metal content of agricultural soils varies. Inputs can be underlying geological material, atmospheric deposition, fertilizers, agrichemicals, organic wastes and other inorganic pollutants, while outputs are losses in metals removed in crop material, leaching and volatilization.
To assess the anthropogenic input of heavy metals to the agricultural soil and to notice abnormalities it is important to know the environmental background levels. Common values and ranges for heavy metal concentrations in agricultural soils are given in table 11.

This covers the total content of heavy metals in agricultural soils; however, the bioavailable concentrations depend for example upon soil type, organic material and pH, see 4.2.1. The residence times for heavy metal in agricultural soils vary between the elements and due to soil conditions (Alloway 1995); however, a rough estimation is given in Table 7.

**Table 7.** Heavy metal concentrations in agricultural soils (mg/kg) and their corresponding residence times (years). (Modified from Alloway 1995)

<table>
<thead>
<tr>
<th>Element</th>
<th>Range</th>
<th>Common value</th>
<th>Residence time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0.01-2.4</td>
<td>0.2-1</td>
<td>75-380</td>
</tr>
<tr>
<td>Cu</td>
<td>2-250</td>
<td>20-30</td>
<td>310-1500</td>
</tr>
<tr>
<td>Pb</td>
<td>2-300</td>
<td>10-30 rural;</td>
<td>740-5900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30-100 urban</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>10-300</td>
<td>50</td>
<td>1000-3000</td>
</tr>
</tbody>
</table>

The Ouardanine region is made of sedimentary rocks. In general, clay and shales tend to have relatively high concentrations of many elements due to their ability to absorb metal ions (Alloway 1990). As no industries are known in the area, the amount of heavy metal in soil/fruit should be derived from one of the following sources (inspired by Alloway 1990)

- Atmospheric pollution from motor vehicles (Pb)
- The combustion of fossil fuels.
- Agricultural fertilisers and pesticides
- Organic manures
- Heavy metals from erosion of the crust

Alloway (1990) points out that sewage sludge usually contains relatively high concentrations of several metals, although this mainly refers to industrial catchments. Metals have extremely long biological half-lives. This leads to, that once metals get into soil or sediment; they have long residence times before they are eluted to other compartments (Walker et al. 2006). Hence, there is a possibility for accumulation of heavy metals in soils that are irrigated/fertilized with water/sludge containing heavy metals. It also means that once a field is contaminated with heavy metals, it is not easy to reassume the previous state.

The examined exposure route is the one given in Figure 12. The soil is irrigated with treated wastewater. Thereafter, water and elements are taken up by the plant. How much of the heavy metals that is taken up by the fruit tree, largely depends on how much of the elements that exist in a bioavailable state, see chapter 5.2.4.

### 5.2.4 Factors Influencing Plant Uptake

Several factors influence the plants ability to take up heavy metals. Traditionally, evaluation of contamination in soil and sediment has been founded on the total amount of contamination. However, materials strongly bound to soil or sediment is not available for interaction with biological systems. By
using the total amount of contamination in soil when evaluating the risk, it becomes highly overestimated. A better choice is therefore to use the amount of bioavailable heavy metals.

Bioavailability is defined as the amount of chemical compounds in soil or sediment, which in reality is available for interaction with biological systems. (Törneman et al. 2009) The fraction of soil element that in fact can be absorbed by an organism and cause harm depends on the chemical form of the metal and the soils physical, biological and chemical properties (Scheckel et al. 2009). However, bioavailability is both expensive and time consuming to measure, as it demands in vivo animal feeding studies, and in vitro chemical methods. Soil properties such as particle size, organic matter and pH strongly influence the bioavailability, and can therefore be used to estimate if bioavailability is low or high.

Soil particle size influences the soils properties. Sand particles are generally visible to the eye (Brady & Weil 2008). The particles are relatively large, and so are the pores between them. The large pores cannot hold water against gravity, which leads to rapid drainage of sandy soils. Porosity varies between 15-45% (Larsson 2008). The large particles in sand possess little capacity to hold water and nutrients, which lead to that most sandy soil, are aerated and loose, infertile and exposed to drought (Brady & Weil 2008).

Fine soils include silt and clay. Fine soil is hardly drainable in practice and there is almost no permeability (Svensson 2001). Clay granules have a large surface area, giving them a large capacity to absorb water and other substances (Brady & Weil 2008). The adsorptive forces increase for the smaller soil fractions and clay have a large effect on the soil property (Svensson 2001). The fine clay particles are so small that they behave as colloids; if they are suspended in water they do not willingly settle out (Brady & Weil 2008). The pores between the particles are very small, so movement of both water and air in the soil is very slow. In clayey soils, the pores between particles are tiny in size, but huge in number, allowing the soil to hold a great deal of water, however much of it may be unavailable to plants. Clay’s properties make the possibility for heavy metals to move very low. (Brady & Weil, 2008)

Organic material in the soil creates a more open, and therefore a more compressible structure (Larsson 2008). Organic content is calculated as the weight relationship between organic mass and total firm mass. A soil is called organic, if the organic content is 20% or more. The mechanic property of soil is strongly influenced by the organic content. A high content of organic material gives the heavy metals a higher prospect to form chemical bonds in the soil. (Larsson 2008)

Most elements seem to be less mobile and less available if soil pH is neutral or above, see Figure 13. When it comes to heavy metals, pH has a noticeable effect on the solubility in soils and water. A low pH, increase some metals solubility in soil and water, and thereby making them more bioavailable (Walker et al. 2006).
Figure 13. The figure shows the adsorption of heavy metal cations on goethite, a clay-sized oxide mineral that forms coatings on many soil particles. At a high pH, more of the heavy metal is adsorbed to the surface. (Basta 2005)

A recommended treatment for heavy metal contaminated soil is to make the soil more calcareous to minimize metal availability and decrease metal bioavailability over time (Scheckel et al. 2009). Soils treated with sludge should be maintained at a pH 6.5 or higher to avoid plant uptake. (Brady & Weil 2008) Table 8 shows how mobile heavy metals are depending on soil redox and pH.

<table>
<thead>
<tr>
<th>Relative mobility</th>
<th>Oxidizing</th>
<th>Acid</th>
<th>Neutral-alkaline</th>
<th>Reducing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td></td>
<td>Zn, Cu, Co, Ni, Hg, Ag, Au</td>
<td>Zn, Cu, Co, Ni, Hg, Ag, Au</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Zn</td>
<td>Zn, Cu, Co, Ni, Hg, Ag, Au</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Medium</td>
<td>Cu, Co, Ni, Hg, Ag, Au, Cd</td>
<td>Cd</td>
<td>Cd</td>
<td>-</td>
</tr>
<tr>
<td>Low</td>
<td>Pb</td>
<td>Pb</td>
<td>Pb</td>
<td>-</td>
</tr>
<tr>
<td>Very low to immobile</td>
<td>Fe, Mn, Al, Sn, Pt, Cr, Zr</td>
<td>Al, Sn, Pt, Cr</td>
<td>Al, Sn, Cr, Zn, Cu, Co, Ni, Hg, Ag, Au</td>
<td>Zn, Co, Cu, Ni, Hg, Ag, Au, Cd, Pb</td>
</tr>
</tbody>
</table>
To sum up, in general the higher the clay and/or organic matter content, the more firmly bound are the heavy metals and the longer is their residence time in soil (Walker et al. 2006). A low pH increases the mobility of heavy metals in soil while a neutral or basic condition bounds them relatively firmly.

**Lead, Copper, Zinc and Cadmium and uptake by plants**

Plants have many natural properties that prevent heavy metal accumulation to be dangerous for themselves or their predators. Generally, plants translocate much larger amounts of metals to their leaves, than to their seeds and fruits. Leafy vegetables, like lettuce and spinach, and forage corps eaten by livestock constitute the principal risk for food chain contamination (Brady & Weil 2008). When it comes to lead, uptake of plants can occur, but often in very small amounts (Scheckel et al. 2009). This can be explained by the soil-plant barrier concept, introduced by Chaney (1980). Most elements, like lead, are so insoluble or so strongly absorbed in the soils or plant system that they do not reach plant shoots in levels, which are risky to highly exposed individuals. Chaney and Ryan (1994) observed that lead-rich soil and dust, carried into homes, constituted a larger risk to young children than lead uptake by garden food crops. Another group of metals do not comprise food-chain risk because they are phytotoxic to plants before the concentrations in the plants constitute a risk to consumers. Examples of metals that fall into this category are zinc and copper. Cadmium constitutes an exception, as it is not affected by the soil-plant barrier nor is toxic to plants before it become unsafe to predators. Cadmium can be accumulated in plants, to a level harmful to animals that consume the crops continuous. (Reeves & Chaney 2008) However, the level of phytotoxicity depends upon which type of plant that is considered. Long-lived animals, like humans, are especially exposed to the risk, and cases of human diseases connected to high levels of cadmium have been reported. Animals bioaccumulate cadmium in relative high amounts, compared to other heavy metals, as it assimilates rapidly and excretes slowly. (Walker et al. 2006)

**Examples of how much heavy metals that can be bioavailable**

A Turkish study of peach trees irrigated with water from a heavily polluted creak can work as an example of how much heavy metal that can be available for plants (Basar & Aydinalp 2005). pH in the investigated sites were between 7,7-8,1 and soil particle size showed a distribution of ca 48% sand and 52% silt and clay. Electrical conductivity was 583-926 \(\mu S/cm\) and organic matter 24-26 g/kg. According to Wang et al. (2003), the extractable concentrations of metals are considered to represent their bioavailability. In Table 9 the total and the extractable amount of heavy metal is shown.

**Table 9.** The total and extractable heavy metal content in soil for three cultivar sites (A, B, C) in Turkey. The correlation between total and extractable amounts of metal is also shown (Basar & Aydinalp 2005)

<table>
<thead>
<tr>
<th></th>
<th>Zn Total</th>
<th>Zn Extractable</th>
<th>Cu Total</th>
<th>Cu Extractable</th>
<th>Pb Total</th>
<th>Pb Extractable</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>875</td>
<td>2,2</td>
<td>82</td>
<td>9,2</td>
<td>12</td>
<td>1,3</td>
</tr>
<tr>
<td>B</td>
<td>825</td>
<td>1,5</td>
<td>74</td>
<td>7,7</td>
<td>12</td>
<td>1,2</td>
</tr>
<tr>
<td>C</td>
<td>779</td>
<td>1,9</td>
<td>67</td>
<td>10,2</td>
<td>11</td>
<td>1,2</td>
</tr>
<tr>
<td>Correlation</td>
<td>0,69</td>
<td>0,8</td>
<td></td>
<td></td>
<td>0,64</td>
<td></td>
</tr>
</tbody>
</table>

Street, Lindsay and Sabey (1977) examined the extractable amount of cadmium in four soils; the result is shown in Table 10.
Table 10. Chemical and physical characteristics of experimental soils (Street, Lindsay & Sabey 1977)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>pH</th>
<th>Organic matter (g/kg)</th>
<th>Total Cd (mg/kg)</th>
<th>Extractable Cd (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam</td>
<td>5,71</td>
<td>37</td>
<td>0,817</td>
<td>0,11</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>7,82</td>
<td>7</td>
<td>0,528</td>
<td>0,07</td>
</tr>
<tr>
<td>Sand</td>
<td>7,43</td>
<td>6</td>
<td>0,639</td>
<td>0,05</td>
</tr>
<tr>
<td>Clay loam</td>
<td>8,25</td>
<td>14</td>
<td>0,89</td>
<td>0,09</td>
</tr>
</tbody>
</table>

5.2.5 Quantifying Exposure

There were no significant amounts of heavy metals in the treated wastewater, see Appendix II. However, the test was only a single random sample and does not give a complete and representative picture of the reality. Corresponding recommended levels are given in Table 3. The heavy metal levels found in the soil in the Ouardanine peach field are presented in Table 11 together with recommended levels. In some cases not all samples were detected, due to the detection ranges of the laboratory equipment, see Appendix II. This applies to the heavy metal detection in fruit as well. DM refers to dry matter and WM to wet matter.

Table 11. Heavy metal levels (mg/kg DM) in the soil samples, see Appendix II, and recommended limits given by Jordbruksverket (2007).

<table>
<thead>
<tr>
<th>Element</th>
<th>Samples</th>
<th>Detected</th>
<th>Mean (mg/kg DM)</th>
<th>Min (mg/kg DM)</th>
<th>Max (mg/kg DM)</th>
<th>Recommended limits (mg/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd*</td>
<td>12</td>
<td>2</td>
<td>0,699</td>
<td>0,699</td>
<td>0,700</td>
<td>0,4</td>
</tr>
<tr>
<td>Cu</td>
<td>12</td>
<td>12</td>
<td>20,1</td>
<td>18,2</td>
<td>26,3</td>
<td>40</td>
</tr>
<tr>
<td>Pb</td>
<td>12</td>
<td>12</td>
<td>14,3</td>
<td>11,7</td>
<td>16,1</td>
<td>40</td>
</tr>
<tr>
<td>Zn</td>
<td>12</td>
<td>12</td>
<td>69,1</td>
<td>53,0</td>
<td>132</td>
<td>100</td>
</tr>
</tbody>
</table>

*For some samples the element is below detection limit for the ICP, i.e. <0, 6 mg/kg

The heavy metal levels in fruit are presented in Table 12 along with recommended levels.

Table 12. Heavy metal levels (mg/kg WM) in the fruit samples received, see Appendix II, and recommended limits given by EG 1881/2006 (2006).

<table>
<thead>
<tr>
<th>Element</th>
<th>Samples</th>
<th>Detected</th>
<th>Mean (mg/kg WM)</th>
<th>Min (mg/kg WM)</th>
<th>Max (mg/kg WM)</th>
<th>Recommended limits (mg/kg WM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd**</td>
<td>9</td>
<td>0</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>0,050</td>
</tr>
<tr>
<td>Cu</td>
<td>9</td>
<td>9</td>
<td>1,09</td>
<td>0,762</td>
<td>1,42</td>
<td>-</td>
</tr>
<tr>
<td>Pb*</td>
<td>9</td>
<td>3</td>
<td>0,291</td>
<td>0,267</td>
<td>0,306</td>
<td>0,1</td>
</tr>
<tr>
<td>Zn</td>
<td>9</td>
<td>9</td>
<td>1,14</td>
<td>1,00</td>
<td>1,28</td>
<td>-</td>
</tr>
</tbody>
</table>

*For some samples the element is below detection limit for the ICP, i.e. <0, 25 mg/kg
**For all samples the element is below detection limit for the ICP, i.e. <0, 03 mg/kg
Quantifying Plant Uptake
The soil properties in Ouardanine contributes to a low bioavailability of the heavy metals, see Table 13.

<table>
<thead>
<tr>
<th>Property</th>
<th>Condition</th>
<th>Bioavailability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>Clayey silt / sandy silt / sandy clay</td>
<td>Low</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>High amount</td>
<td>Low</td>
</tr>
<tr>
<td>pH</td>
<td>pH &gt; 8</td>
<td>Low</td>
</tr>
</tbody>
</table>

The peach trees ability to absorb heavy metal is low. The Turkish study presented in 4.2.1 showed similar soil properties as the Tunisian study. In the Turkish study 2 % of total Zn, 12 % of total Cu and 11 % of Pb was extractable. If the same percentage is extractable in the peach field, only a small amount of the heavy metals is available to the peach trees, see Table 14. The extractable cadmium content in the study presented in 5.2.4 was between 7-13 %. If, theoretically, the same percentage is extractable in Tunisia, the levels would be far below detectable. Since metals mainly accumulate in leaves, this lessens the chance of considerable amounts reaching the fruits even more.

<table>
<thead>
<tr>
<th>Element</th>
<th>Total</th>
<th>Extractable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>69,1</td>
<td>1,67</td>
</tr>
<tr>
<td>Cu</td>
<td>20,1</td>
<td>2,47</td>
</tr>
<tr>
<td>Pb</td>
<td>14,3</td>
<td>1,51</td>
</tr>
</tbody>
</table>

The Average Daily Dose (ADD)
The average daily dose and hazard quotient was calculated according to equation 1 and 4. The results are presented in Table 15 below together with the concentrations (C) of heavy metals in the peaches. The intake rate (IR) was set to 0,00755 kg/day, which is a mean from 2000-2006 for consumption of cherries, peaches, plums and similar fresh stone fruits (Jordbruksverket 2009). The exposure duration (ED) was estimated to 70 years, since the exposure is assumed to last a whole life time. The exposure frequency (EF) was set to 365 days, given the assumption that it is a continuous exposure throughout the entire year. The average daily dose refers to an adult person with a body weight (BW) of 70 kg. The averaging time (AT) refers to the number of years of exposure and when non-carcinogenic effects are considered, AT is equal to ED (EPA U.S. 1997), i.e. AT is set to 70.
Table 15. Concentrations and the corresponding ADD values estimated according to equations 1 in chapter 4.2.1 for the studied heavy metals.

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration (mg/kg WM)</th>
<th>ADD (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd*</td>
<td>Max 1,09</td>
<td>3,18·10⁻³</td>
</tr>
<tr>
<td></td>
<td>Mean 0,762</td>
<td>8,22·10⁻⁵</td>
</tr>
<tr>
<td></td>
<td>Min 0,762</td>
<td>8,22·10⁻⁵</td>
</tr>
<tr>
<td>Cu</td>
<td>Max 1,42</td>
<td>1,53·10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>Mean 0,291</td>
<td>3,14·10⁻³</td>
</tr>
<tr>
<td>Pb*</td>
<td>Min 0,267</td>
<td>2,88·10⁻⁵</td>
</tr>
<tr>
<td></td>
<td>Max 0,306</td>
<td>3,30·10⁻⁵</td>
</tr>
<tr>
<td>Zn</td>
<td>Min 1,00</td>
<td>1,08·10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>Max 1,28</td>
<td>1,38·10⁻⁴</td>
</tr>
</tbody>
</table>

*Some of the sample concentrations were below detection limits for the ICP, see Appendix II.

5.3 Dose-response Assessment

Rfd and AIC values are presented in Table 16. The Rfd values are derived from the IRIS database provided by EPA U.S. (2009). The AIC value for lead is derived from Asante-Duah (1993).

Table 16. Rfd and AIC values for the studied elements.

<table>
<thead>
<tr>
<th>Element</th>
<th>Rfd (mg/kg/day)</th>
<th>AIC (mg/kg/day)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0,001</td>
<td>-</td>
<td>EPA U.S. (2009)</td>
</tr>
<tr>
<td>Cu</td>
<td>0,037</td>
<td>-</td>
<td>EPA U.S. (2009)</td>
</tr>
<tr>
<td>Pb</td>
<td>-</td>
<td>0,00686</td>
<td>Asante-Duah (1993)</td>
</tr>
<tr>
<td>Zn</td>
<td>0,3</td>
<td>-</td>
<td>EPA U.S. (2009)</td>
</tr>
</tbody>
</table>

5.4 Risk Characterisation

In this study, only risks of non-carcinogenic effects are considered and they are expressed as the ratio between the dose resulting from exposure to the peaches from Ouardanine and the dose that is believed to be without risk of effects, even in sensitive individuals. The ratio is called hazard quotient (HQ). As mentioned before, the summary of each element’s HQ value becomes the hazard index (HI). If HI exceeds one, there is a risk for non-carcinogenic effects, and the probability tends to increase as the value of HI increases. The risks of adverse effects are separately considered for adults and children, since exposure pathways are believed to change with age. Hence, it will be discrepancy in health risks among age groups. (Zheng et al. 2007)

The hazard quotient (HQ) for eating peaches from the field is presented in Table 17.

Table 17. Hazard quotient for the people eating peaches.

<table>
<thead>
<tr>
<th>Element</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>Max 3,23·10⁻³</td>
</tr>
<tr>
<td></td>
<td>Mean 3,18·10⁻³</td>
</tr>
</tbody>
</table>
The hazard index (HI) is estimated according to equation 5, chapter 4.4.1. Since the cadmium concentration was below detection limit a worst case scenario was applied, i.e. the concentration was set to the detection limit 0,03 mg/kg WM. If cadmium is included in the HI calculations the HI for mean, minimum and maximum concentrations are 0,0526, 0,0478 and 0,0560 respectively. If it is excluded the indexes are lower, 0,0494, 0,0446 and 0,0527 respectively. If the hazard index is set to one, the safe intake rate of fruit can be calculated. If one considers the mean, minimum and maximum concentration in the peaches the intake rates are 0,144, 0,158 and 0,135 kg/day respectively. Approximately one has to eat about 150g/day. The average consumption rate has to be increased about 20 times to reach toxic levels. A peach weighs about 150g (Melgoza Villagomez et al. 2009). That means there is a risk if one consumes one peach each day for 70 years.


6 Communication and Perception

The current status and discovered obstacles and constraints within risk communication associated with wastewater reuse in Tunisia will be presented in this chapter. The information was collected through interviews, questionnaires and written information provided by CITET during the stay in Tunisia. Most of the obstacles and solutions emerged, apply to the overall wastewater reuse management, not only to irrigation applications.

Wastewater reuse for irrigation purposes in Tunisia is currently not of public and common knowledge. The actual reuse rate in Tunisia is only 8-20 % of the treated effluent, due to several obstacles and constraints. The current planning of reuse schemes and projects is considered inadequate according to IWMI and the World Bank in terms of the low participation of users and stakeholders in the decision-making process and an overall governmental top-down approach. There is also a lack of education and information to farmers, as well as extension of the services provided. Except for golf courses, irrigating with conventional water instead of reused wastewater is preferred, in spite of the more attractive price for reused wastewater. (IWMI/World Bank 2002)

There are multiple institutions involved within wastewater reuse management in Tunisia. This can result in overlapping responsibilities and disagreeing objectives. A bottom-up approach needs to be implemented, i.e. Water Users Associations (WUAs) need to be involved in the planning and management of wastewater reuse schemes to ensure success of the projects. An example is the lack co-ordination between ONAS (Office National de l’Assainissement) and CRDA (Commissariats Régionaux au Développement Agricole). ONAS produces treated wastewater in order to its rights and quality standards, but not necessarily to match the quality and quantity demanded by the farmers, which are the main users. On the other hand, the CRDAs who are representing the farmers’ interests want to obtain treated wastewater during the cropping season at certain times and volumes and of a quality suitable for the crops. (IWMI/World Bank 2002)

Furthermore, skills development and more extension services for the farmers are required to overcome obstacles towards wastewater reuse. There is a need for public outreach and educational programs in order to create higher acceptance to water reuse projects. It is an essential part of the planning of reused wastewater services. To facilitate for farmers in reusing wastewater, codes of good agricultural practices with wastewater reuse should be implemented. (IWMI/World Bank 2002)

Despite the lower price on reused wastewater, farmers choose to use conventional irrigation water on their fields. This is mainly due to emotions associated with the reuse, also known as a yuck-factor. They perceive the reused wastewater as an unclean and non-hygienic resource. In order to win greater acceptance and change the risk perception of farmers, the wastewater should go through additional treatment, i.e. tertiary treatment. By adding treatment to the wastewater and also provide more information, wastewater reuse can gain more acceptance in the future. (Bahri 2002) In Tunisia, the government allows the farmers to buy irrigation equipment for 70% of the original price, if they use the treated wastewater as irrigation water. They also allow the farmers to buy the treated wastewater to a reduced price. The farmers prefer not to use reused wastewater, as they think it can be unhealthy and repulsive. However, the governmental subventions make the farmers find the economical benefits high enough. (IWMI/World Bank 2002)
There is a need to reinforce the responsibilities and the participation of all users and the different local stakeholders within wastewater reuse. This is feasible through the agriculture development groups (GDAs). The reinforcement can implicate them in the decision making process and the management and maintenance of water infrastructures. There is also a need to strengthen education and capacity building of all users. (CITET & INECO 2008)

In the planning stage of reuse schemes, market assessments of reclaimed water will help to satisfy the identified needs under best possible economical conditions and to estimate the price that farmers or other users would be willing to pay. However, the current price of conventional water resources remains too low compared to tertiary treated wastewater. (IWMI/World Bank 2002)
7 Uncertainty and Variability

Assumptions were made in the risk assessment, which all are associated with uncertainties. The assessment was an iterative process and as information was limited in the initial phase, decisions have been changed during the field study. Focus on wrong potential hazards for human health associated with wastewater reuse at the studied field might be present. However, because of the iterative process the authors have been updating the objectives whenever gathered information has pointed in a different direction than the one heading at.

Only one exposure route, ingestion of peaches, was investigated, which might present an uncertainty. As mentioned in the report, inhalation of lead in field dust has been shown to exceed ingestion in some cases. However, the authors think that overlooking an important pathway of exposure is a slight possibility. Although inhalation and ingestion of dust are most unlikely for the general public, it could pose a risk for the farmers and their families that work and live close to the field.

The overall approach to confront variability in this study was to use average values. This is not an ultimate solution. However, numerous parameters were not known, for example, patterns of consumption and variability in body weight in the studied population and average values are considered the best estimate according to the authors. The consumption rate used is not only for peaches, but for all fresh stone fruits and the data is derived from Swedish consumption pattern, and do not say anything of Tunisian consumptions. Regarding the concentrations of heavy metal in peaches, maximum and minimum levels were used. This is a conservative approach and can lead to unrealistically high exposure estimates, but since this only applies to the concentrations, the authors consider it to be a feasible option.

The data collected during the field study may be of questionable quality, see Appendix II, for further discussion regarding uncertainties associated with the data collecting. Also, no test was performed to distinguish the clay and silt proportion in the soil. Since clay has considerable effect on the soil properties, it would have been preferable to have this knowledge.

In the calculation of hazard index, the amounts of heavy metal are summarized. This is the common way to handle this type of elements. Thereby one assumes that the effect of heavy metals is additive. The presence of combination effects has been neglected in this study, which pose an uncertainty in the results. It is also known that the presence of one metal can enhance or increase the uptake of another metal. This factor has not been considered in this report.
8 Discussion

Wastewater reuse is of great economical importance in the arid and semi-arid areas of the Middle East and North Africa. It poses a feasible resource, when conventional water resources are lacking. However, it comes with risks to the environment and to the health of those benefiting from it when it is not managed properly. Reuse of wastewater is a cheap alternative compared to many others technologies, like desalination. It is therefore an attractive option, especially as water resource scarcity is a current issue in numerous developing countries. As more water becomes accessible, an increase in living standard can occur in communities where water is the limiting resource for development.

Because of the risks, many farmers are reluctant to wastewater reuse, perhaps especially when irrigating their own crops with it. The solution is communicative. Information and facts need to be presented to all stakeholders, so that they can participate in the decision-making process and by that increase the chances of a successful implementation. Without the acceptance of the public, the chances of an increasing reuse rate are small. The presence of several stakeholders can also affect the efficiency as the division of responsibility can be unclear. The authors do find it hard to do any deeper analysis of risk perception, as their knowledge in Tunisian culture is limited.

To overcome the negative attitudes and perceptions towards water reuse within irrigation, the government support and sponsor the farmers. In this case study, drip irrigation is used which is preferable in both water saving and health perspective (less direct contact with the user). The high installation cost is subsidized by the government, which is a good way to pursue the wastewater reuse policy. The government also reduces the water price. Since wastewater is seen as dirty and unpleasant, the economical benefits must be high enough to cover the negative perception of it. Although it is important that the users do not feel bribed or forced into a decision.

The regulations demand continuous monitoring of the water quality. In this study no significant amounts of heavy metals were found and the contribution from wastewater to the contamination of the fruits can be seen as negligible. The levels were very low compared to the soil. The influent water entering the wastewater plant in Ouardanine was known to be mainly rural and non-industrial, which explains the low levels in the irrigation water. Thus, the heavy metal contribution of the irrigation water to the overall pollution is minimal. Considering the surrounding areas, the main metal source should be natural weathering of bedrock or application of sludge, as no industrial source was identified. Literature implies that it is important to evaluate heavy metal accumulation in soil due to sludge application, even if it does not have an industrial origin. During the study, we were informed that the soil was fertilized with sludge from the treatment plant. Although, this was the first year sludge was used, it would have been very interesting to measure heavy metal levels in the sludge. Heavy metals are known to accumulate mainly in the sludge when wastewater is treated and the authors believe that the heavy metals in the sludge will have a larger contribution to the field than heavy metals in the effluent water.

Although the current conditions in Ouardanine concerning soil properties are well suited for wastewater irrigation, it is important to consider and evaluate them continuously, since changes can result in higher (or lower) bioavailability of heavy metals and other pollutants in the soil. At present, Tunisia does not have standards for soil properties and concentrations of contaminants in the soil. Following an increase in wastewater reuse and wastewater for irrigating agricultural soils, this is an imperative.
To evaluate the risk, hazard indexes were used. None of the HI values exceeded one and by that the heavy metal levels in peaches do not cause any risk to the consumer. However, in some samples, the lead value exceeded recommended values in fruit. The difference between HI values and recommended limits is that HI considers consumption of peaches exclusively; while recommendations include that the consumer has a heavy metal intake from other sources. HQ and HI are not definite, but merely an estimation of how large the risk is. Therefore it is better not to let oneself be blinded by numbers, but to see them as part of the whole picture. HQ was very low for lead, but several samples showed values above the recommended. The conclusions that can be drawn are that the risk for human, concerning intake of heavy metals in peaches, is very low. But, lead levels in the fruit are in some cases too high, if one considers lead intake from other sources. Lead contributed over 85% of the hazard indexes. Lead limits the consumption to one peach a day for 70 years.

In risk assessment the risk is often stated as acceptable/tolerable or not. It can be seen as a cost-benefit analysis. The cost (the risk of health problems, unpleasant work conditions etc.) has to be weighed against the benefits (reliable water sources, increased harvest etc.). If the benefits are found to outweigh the cost, the risk can be seen as acceptable/tolerable. The risk in this assessment refers to the possible adverse health effects related to increased heavy metal levels in peaches irrigated with wastewater. The risk of heavy metal assembling from using wastewater for irrigation should in this case be acceptable, since no significant amounts were found. The risk of dangerous levels of heavy metals in peaches is according to the hazard index low. Therefore the risk of consuming peaches from the field in Ouardanine is acceptable. Hence, there is no need for risk treatment and risk reduction.

As information is the key to a successful wastewater reuse, the origin of the threat is important to know. Since no significant amounts of heavy metals were found in the treated wastewater, the high levels of e.g. lead in fruit could not come from the irrigation water. Hence the threat in this case is not the new technology, i.e. wastewater reuse, but most likely weathering or sludge application. As weathering is a natural process, it is not seen as a threat, especially a threat larger than irrigation with treated wastewater. The risk in this case is not the irrigation water, but other sources. It is important to scientifically evaluate the risk; otherwise feelings will have an unrealistic impact on the risk evaluation.

There are plans to develop tertiary treatment, mostly due to concerns about the microbiological content of the irrigation water. Further treatment is also a way of increasing the acceptance of reuse. However, when this is going to be is not known to the authors. How it would affect the accumulation of heavy metal in the agricultural soil it is applied on is not known to the authors either.

The lack of education and information to the farmers is limiting the wastewater reuse. The results from analyses, like this one, should be passed on to those affected by it. This is needed to win greater acceptance among farmers and other users. This way a “learning cycle” can be developed, where scientific knowledge is communicated to the users whose feedback can be used in the overall management of the water reuse. In general, openness leads to greater acceptance and hence transparency is an imperative for new successful wastewater reuse schemes.

In addition to the factors described in this report, there are several others that influence the peach trees ability to take up heavy metal. Since time and resources was limited, it was only possible to measure some of these factors to make an estimation of how much heavy metal that is bioavailable. The processes of heavy metal translocation and accumulation in soil, plants and human is very complicated and the authors do in no way claim to have a complete risk picture in this matter. According to the
authors, the four most important heavy metals were examined, but since several heavy metals were excluded from the study, a deeper understanding of risks cannot be made. The calculations are very approximate, and other studies may come to a completely different risk level. Although, we do believe, this thesis may give a rough estimation of the risk of heavy metal accumulation from irrigation with wastewater in Ouardanine.

8.1 Fulfillment of the Task

At which conditions is the wastewater irrigation conducted?
The conditions for reusing wastewater are primarily given in Chapter 2. The reuse of treated wastewater is an attractive water source, as water becomes an even more scarce resource because of population growth and changing conditions. Most reused wastewater is used for irrigation, and is an essential resource for Tunisia’s development, especially within developing the tourist industry. Tunisia has developed a strategy program to extend wastewater treatment to all urban areas, first on a pilot scale then on a large scale. The Tunisian law demands wastewater to be treated to a secondary level before used for irrigation purposes. The reused wastewater is allowed on all types of crops, except vegetables, whether eaten raw or cooked. The treatment plant in Ouardanine treats the wastewater to a secondary level. A part of the sludge is dried and used as fertilizer on the field. The treated wastewater is pumped to a reservoir and distributed on demand, by drip irrigation. There are several stakeholders involved, among them six ministries, workers and farmers. In Chapter 5.2.1, the physical conditions in Ouardanine are presented. The area consists of sandy clay silt, sandy silt clay or sandy clay. The soil is basic and contains large amounts of organic material. Thereby the physical conditions are favorable for avoiding heavy metal accumulation in plants.

Do the heavy metal concentrations found in the irrigation water, irrigated soils and peaches exceed published and recommended limits?
In Chapter 5.2.5 the amounts of heavy metals in the irrigation water, soil and fruit is presented, as well as the recommended limits. The irrigation water did not contain any considerable amounts of heavy metal and was well below the recommended limit. For soil, Cu and Pb samples were all far below the recommended levels. One of the samples exceeded recommended Zn limit, while all the others were by a comfortable margin below. The conclusions concerning Cd are harder to draw, as the recommended limit is below the IPC detection limit. Two of the samples were detected and above the recommended limit, but since the other ten samples did not show concentrations above detection limit it is hard to give a complete picture. No recommended limits were found for Cu and Zn, concerning intake of fruit. Cadmium levels were all below the recommended levels. The detection levels for Pb (0.25 mg/kg) were below the recommended levels in fruit (0,1 mg/kg). Although three of the samples were detected, thereby showing values two or three times more than recommended levels.

Is accumulation of heavy metals in plants and human a risk?
In chapter 5.4 the hazard index (HI) and the hazard quotient (HQ) is given. If HI>1, there is a health risk. The calculated HI was very low and a health risk should thereby not be especially likely. Even if HI was very low, the authors would like to point out that Pb values in the fruit were above recommended values in some samples.

Which factors influence the plant’s heavy metal uptake?
In chapter 5.2.5 factors that influence the plants ability to translocate heavy metals is given. A high pH and organic matter content contribute to low heavy metal mobility. Fine soil texture and high clay content also contribute to low mobility. All the examined conditions on the field, showed that the
plants’ capacity to take up heavy metal were low. The physical conditions seem to be suitable for reusing treated wastewater.

*What are the obstacles when reusing wastewater in Tunisia and how to overcome them?*

In chapter 6, constraints and obstacles associated with risk communication is given. At present, wastewater reuse in Tunisia is not of public and common knowledge to the citizens; hence the authors do not know the public’s opinions associated with reuse. However, the public unawareness is considered to be a constraint to further expansion of wastewater reuse in the country. The planning of various reuse schemes is believed to be inadequate, due to low participation of the stakeholders, including the public. Public participation could enlighten unknown risks and create a better foundation for understanding and acceptance among the citizens. Without their acceptance it could be difficult to expand and accelerate the current reuse rate, since they are the final consumers.

Farmers, however, are aware of the reuse of wastewater within agriculture. Still, they are reluctant to the idea. To keep them using non-conventional water resource to irrigate their crops, the government maintain a low price on the water and also subsidize the needed equipment. Along with extended education in reusing wastewater and its risks, the financial support may not have to be at the current level. The farmers may perceive irrational risks regarding health and safety, which would be solved with extended information and education. The government is considered to use an overall top-down approach in decision-making processes regarding reuse of wastewater.

In chapter 2.3.4 constraints and challenges associated with the overall management of reusing wastewater are given.
9 Conclusions

According to the risk assessment made in this study, the risk of adverse health effects from consuming peaches from the fields in Ouardanine is acceptable with the current conditions and circumstances. According to this study, there should be no restriction of the amount of water applied to the field, regarding heavy metals. Lead is the limiting contaminant, and to avoid hazards the consumption rate needs to be below one peach per day for 70 years. However, it is important to continuously assess possible heavy metal accumulation due to irrigation with reused wastewater and fertilization with sludge. In case of management of wastewater reuse in Tunisia, the authors believe there is a need for extended public participation in order to increase the current reuse rate. Studies like the present one should be passed on to the users, in order to win acceptance and therefore gain a better chance of increasing the wastewater reuse rate.

9.1 Future Steps to Take

Due to time limitations, the authors could not model the water-soil-plant movement of the heavy metal and hence, could not estimate any correlations between the heavy metal concentrations in the applied irrigation water and the full-grown fruit. For further research, this would be a potential and interesting objective. At present, sludge is also applied to the fields in Ouardanine. A study of the soil-plant movement would confirm if the accumulation in soil and plant originate from the irrigation water, sludge or if it has natural origin, such as bed-rock weathering.

Another objective for further research in this field would be to evaluate public participation and shared responsibilities within ministries associated with wastewater reuse. Functioning decision-making processes where the public get heard would be an imperative if the wastewater reuse rate should increase.

In those cases where fodder crops are irrigated with wastewater, it is even more important to investigate and keep a check on heavy metal movements within the food chain. If the heavy metal concentrations are high in the original medium, it can reach toxic levels in the final product, consumed by humans. Since also fodder crops are irrigated with reused wastewater in Ouardanine, this could be a risk to human health.

To make the risk picture of the fields of Ouardanine more complete, one should assess the health risks associated with the microbiological content of the irrigation water.
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A Risk Assessment of Reusing Wastewater on Agricultural Soils – A Case Study on a Peach Field in Ouardanine, Tunisia


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A Risk Assessment of Reusing Wastewater on Agricultural Soils
– A Case Study on a Peach Field in Ouardanine, Tunisia


Appendix I: Characterizing Soil Particle Size

Materials and Methods
The soil sampling was performed according to the procedure described in Qualité des Sols (AFNOR 1999). Three soil samples were taken from the peach field in Ouardanine, according to the sampling procedure described in Appendix II: Laboratory Report, Methods and Material: Soil, sampling. Plant parts and fauna were removed from the samples.

To eliminate large lumps, the samples were gently crushed in a mortar. Six strains, 1, 2, 3, 4, 5 and 6, with different mesh diameter (2000 µm, 1000 µm, 500 µm, 250 µm, 150 µm and 63 µm respectively) were put upon each other with the largest strain on the top. 100 g of sample 1 was passed through the sieves. To increase the speed of the process, water was flushed through the strains. Thereafter the strains were put in an oven for 4h, 105°C. After cooling, the weight of the sample fraction in each sieve was noticed. To receive the humidity of the sample, a small amount of the sample (about 2 g), was put in a container and heated in the oven for 4h. The difference in weight before and after the procedure was used to calculate the humidity.

The test was repeated for sample 2 and 3, with the difference that 50 g of the sample was used instead of 100g. No test to separate the silt/clay amount was performed.

Equations
The humidity of the sample was calculated according to equation 1;

\[
\frac{m_{\text{sample.before}} - m_{\text{sample.after}}}{m_{\text{sample.before}}} = \text{humidity}
\]  

(1)

\(m_{\text{sample.before}}\) (g) is the sample weight before heating and \(m_{\text{sample.after}}\) (g) is the sample weight after heating. The percentage by weight \(m_{wp1-5}\) for the fractions received in strain 1, 2, 3, 4 and 5 were calculated according to the principle in equation 2 and 3. \(m_{\text{tot}}\) is the total weight of the samples, and \(m_1-m_5\) are the weights of the samples after heating.

\[
\frac{m_1}{m_{\text{tot}} \cdot (1 - \text{humidity})} \cdot 100 = m_{wp1}
\]  

(2)

\[
\frac{m_2}{m_{\text{tot}} \cdot (1 - \text{humidity})} \cdot 100 = m_{wp2} \quad \text{etc.}
\]  

(3)

The percentage by weight of the fraction <63 µm was calculated according to equation 4,

\[
100 - (m_{wp1} + m_{wp2} + m_{wp3} + m_{wp4} + m_{wp5}) = m_{wp6}
\]  

(4)
## Results

Table 1 shows the results from the particle size study. The humidity test for sample 1, showed a negative result, which is impossible. Sample 1 was therefore excluded from the test.

**Table 1.** Weight and percentage by weight for sample 1, 2 and 3.

<table>
<thead>
<tr>
<th>Subsample</th>
<th>Particle size (µm)</th>
<th>Weight (g)</th>
<th>Percentage by weight (%)</th>
<th>Weight (g)</th>
<th>Percentage by weight (%)</th>
<th>Weight (g)</th>
<th>Percentage by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>&gt;2000</td>
<td>1,23</td>
<td>-</td>
<td>0,402</td>
<td>0,8</td>
<td>1,70</td>
<td>3,4</td>
</tr>
<tr>
<td>m2</td>
<td>1000-2000</td>
<td>0,731</td>
<td>-</td>
<td>0,208</td>
<td>0,4</td>
<td>0,119</td>
<td>0,2</td>
</tr>
<tr>
<td>m3</td>
<td>500-1000</td>
<td>2,76</td>
<td>-</td>
<td>1,19</td>
<td>2,4</td>
<td>1,07</td>
<td>2,2</td>
</tr>
<tr>
<td>m4</td>
<td>250-500</td>
<td>8,81</td>
<td>-</td>
<td>3,74</td>
<td>7,6</td>
<td>3,99</td>
<td>8,0</td>
</tr>
<tr>
<td>m5</td>
<td>150-250</td>
<td>12,1</td>
<td>-</td>
<td>5,49</td>
<td>11,2</td>
<td>6,76</td>
<td>13,6</td>
</tr>
<tr>
<td>m6</td>
<td>63-150</td>
<td>28,4</td>
<td>-</td>
<td>18,2</td>
<td>37,0</td>
<td>13,0</td>
<td>26,1</td>
</tr>
<tr>
<td>m7</td>
<td>&lt;63</td>
<td>-80</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Humidity</td>
<td>(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In table 2 the particles are divided according to particle size. The main substance in the soil is sand, but also clay and silt represent a large amount.

**Table 2.** The particles are divided into subdivisions according to particle size. The values are from sample 1 and 2. The division used is the Swedish classification system from 1981 (Karlsson & Hansbo 1989).

<table>
<thead>
<tr>
<th>Subsample</th>
<th>Particle size (µm)</th>
<th>Mean Percentage by weight (%)</th>
<th>Particle size</th>
<th>Percentage by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>&gt;2000</td>
<td>2,12</td>
<td>Gravel</td>
<td>2,12</td>
</tr>
<tr>
<td>m2</td>
<td>1000-2000</td>
<td>0,331</td>
<td>Sand</td>
<td>54,4</td>
</tr>
<tr>
<td>m3</td>
<td>500-1000</td>
<td>2,29</td>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>m4</td>
<td>250-500</td>
<td>7,81</td>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>m5</td>
<td>150-250</td>
<td>12,4</td>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>m6</td>
<td>63-150</td>
<td>31,5</td>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>m7</td>
<td>&lt;63</td>
<td>43,5</td>
<td>Silt/Clay</td>
<td>43,5</td>
</tr>
</tbody>
</table>

To classify the soil type, a triangle diagram and a nomogram was used, see Figure 1. According to Figure 1, the possible classifications of the soil are sandy silt, sandy clay silt, sandy silt clay or sandy clay. As no sedimentation analysis was performed, it is impossible to definite the soil exactly.
Figure 1. Classification according to SGU (Karlsson & Hansbro 1989). Start on the right side (gravel) at 2%. Draw a line that is parallel to the side that is one step counterclockwise. On the left side (sand) start at 54% and draw a horizontal line. Finally, start 44% on the side for fine sands, and draw a line that is parallel to the right side. The section where the lines meet defines the possible soil classifications. The nomogram below is used when the clay content is known. The red line defines the theoretical maximal clay content.
Discussion
It is possible that the results were affected by contamination. The sieves were cleaned between each test, but it is likely that some grains got stuck in the net. However, the authors do believe that this will not have an important effect on the result.

It would have been preferable if a sedimentation test to separate silt and clay had been performed. Since clay content largely influence the soils properties, the results would have been interesting for the report. Unfortunately there was no time to do this test.

Although it is impossible to exactly define the soil’s name, the authors do believe there is a larger probability that the soil is sandy silt clay or sandy clay. Ocular observations of the field established that the soil was very hard and needed to be ploughed several times per season. The ploughed soil formed hard lumps that were hard to crush and during the laboratory test the fraction smaller than 63 µm was sticky. All this leads the authors to draw the conclusion that the fraction of clay in the soil is of considerable amount. There is also a possibility that the soil is sandy clay silt, but the authors find it hard to believe that the soil could be sandy silt.

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Karlsson, Rudolf & Hansbo, Sven in cooperation with the Laboratory Committee of the Swedish Geotechnical Society (1989), *Soil Classification and Identification, part 2*, Byggforskningsrådet & Swedish Geotechnical Society, Stockholm
Appendix II: Laboratory Report

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Helena Claesson
Lund University
2009-26-06

Laboratory Report
Analyzing heavy metals in reused waste water, soil and peaches in Ouardanine, Monastir
Introduction

Due to present demographic trends and future growth, fresh water will be an even scarcer factor for future populations than it is today. By the year 2025, 60% of the global population is estimated to suffer from insufficient fresh water resources. In the arid and semi arid areas of the Middle East and North Africa, countries are facing increasingly more water shortage problems because of climatic conditions. The problem will intensify along with rise in living standards, accelerated urbanization and population growth. Even though the efficiency techniques in the use of conventional water resources have been improved, water scarce countries will have to rely more on the use of non-conventional resources to satisfy their water demand. (Qadir et al, 2007)

When conventional water resources fail to fulfill the demands from the sectors of agriculture, tourism and industry, non-conventional resources are a feasible opportunity. Fresh water resources have to be used for potable and primary needs and non-conventional water resources can make up for others. Non-conventional water partly consists of marginal-quality water, such as waste water, agricultural drainage water and groundwater. Many developing countries use untreated or partly treated waste water from domestic, industrial and commercial sectors for irrigation purposes (Qadir et al, 2007). Reused waste water can be seen as a reliable source for irrigation purposes and an additional source of nutrients and fertilization (Rutkowski, 2007). The main issues associated with reusing waste water is public health and environmental problems (Qadir et al, 2007).

Tunisia is facing serious shortage of water resources, due to increasing water consumption and pollution of already existing water resources. Irrigation techniques with treated waste water are well established in Tunisia (Angelakis et al, 1999). Forecasts show an increase due to industrial, urban and touristic development, mostly for agricultural purposes. There are 98 treatment plants in Tunisia, in 2007 225Mm³ of waste water was produced and 65Mm³ was reused. The agricultural sector uses 82% of the available water resources and is hence the most important consumer. Because of an increase in fresh water demand, it has become an imperative to develop additional water resources. Waste water reuse has become an essential part of the Tunisian national water resources strategy. (El Ayni, 2008)

This report intends to analyze the heavy metal levels in a peach field, irrigated with treated waste water. The laboratory work was conducted at CITET, Tunis. The results will thereafter be used to build a model, describing the translocation of the heavy metals, from water, via soil to the fruit. The model will be used to quantify the risk for combined effects of heavy metal accumulation in the fruit, which will be a part of the risk analysis that will be our master thesis in Risk Analysis and Risk Management, at the department of Technical Water Resources, Lund University, Sweden. This report presents the results and describes the proceedings with which the tests at the peach field were performed.
Literature Study

Regulations
Tunisian standards regarding heavy metals in reclaimed waste water used for irrigating agricultural soils are listed in table 1 below.

Table 1. Tunisian standards for reclaimed wastewater reused in agriculture (NT 106.03 1983).

<table>
<thead>
<tr>
<th>Element</th>
<th>Limit (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0,01</td>
</tr>
<tr>
<td>Co</td>
<td>0,1</td>
</tr>
<tr>
<td>Cu</td>
<td>0,5</td>
</tr>
<tr>
<td>Fe</td>
<td>5</td>
</tr>
<tr>
<td>Pb</td>
<td>1</td>
</tr>
<tr>
<td>Mn</td>
<td>0,5</td>
</tr>
<tr>
<td>Ni</td>
<td>0,2</td>
</tr>
<tr>
<td>Zn</td>
<td>5</td>
</tr>
<tr>
<td>Cr</td>
<td>0,1</td>
</tr>
</tbody>
</table>

Regulations regarding heavy metals in Sweden are based on directives from the EU-commission, implemented in Sweden by the Swedish agricultural department Jordbruksverket, see table 2. The data is concerning agricultural soils which are fertilized with sludge from treatment plants.

Table 2. Heavy metal limits in soil. (Jordbruksverket 2007)

<table>
<thead>
<tr>
<th>Element</th>
<th>Limit (mg/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0,4</td>
</tr>
<tr>
<td>Cu</td>
<td>40</td>
</tr>
<tr>
<td>Pb</td>
<td>40</td>
</tr>
<tr>
<td>Hg</td>
<td>0,3</td>
</tr>
<tr>
<td>Ni</td>
<td>30</td>
</tr>
<tr>
<td>Zn</td>
<td>100</td>
</tr>
<tr>
<td>Cr</td>
<td>60</td>
</tr>
</tbody>
</table>

Heavy Metals in Soil
Heavy metal contamination through irrigation with reused waste water can be a serious problem, since it is able to transfer through the food chain, particularly if the contaminants are present in a bioavailable form. However, heavy metals are usually present in agricultural soils at low levels. Due to their cumulative and toxic behavior on crops and human health an assessment of their affect is an imperative.

The translocation of heavy metals from soil to plant is carried out through the same mechanisms as nutrient transportation. The uptake is feasible with bound as well as with dissolved elements, although the dissolved form is easier to absorb. The pH of the soil is an important factor since it affects the nutrient supply and the vitality of the plant. (Larcher, 1980) A low pH allows nutrients to be more mobile since it makes them more soluble. The same discussion follows if the pH is high. If the heavy metals are more soluble, higher concentrations will be present in plants and groundwater. However, the heavy metals mobility also differs between their specific abilities. (Alloway, 1995)
Induced Coupled Plasma-Atomic Emission Spectroscopy

Atoms emit electromagnetic radiation (hv) as they relax from their excited state to their ground state. The basic aim of analytical atomic spectroscopy is to identify elements and quantify their concentration in various media. The procedure consists of three different steps; atom formation, excitation and emission. Once the electron has been excited with input energy it emits light, which is specific for that particular element. ICP-AES, Induced Coupled Plasma – Atomic Emission Spectroscopy, utilizes plasma as both atomization and excitation source. Plasma is an electrically neutral, highly ionized gas that consists of ions, electrons and atoms. The plasmas are characterized by their temperature at which they operate as well as electron and ion densities. (Manning, 1997)

In the initial step of ICP-AES, the sample is usually introduced as a liquid stream, whereas it is converted into an aerosol through nebulization. Subsequently, the sample is carried to the center of the ICP-AES, which contains the plasma, by the argon flow. The plasma is first desolvating the aerosol, by removing the solvent and usually leaving salt particles. Next, the salt particles are decomposed by vaporization and dissociated by atomization. (Boss et al, 1997)

The last two functions of the plasma are excitation and ionization, of which the exact mechanisms are not yet fully understood. Excitation and ionization enables the atom or ion to emit its characteristic radiation. The excitation is probably taking place as a result of collision of sample atoms and energetic electrons. Some elements give their strongest emission lines by their excited ions, which mean that an ionization process has to take place. The light, which is emitted by the excited atoms or ions in the plasma, is measured for providing the wanted information about the sample. Then qualitative and quantitative information can be obtained, such as which components are present and at which concentrations. By introducing standard solutions to the ICP-AES, the concentrations of the various elements in the media can be measured. (Boss et al, 1997)

The Peach Field

In the area of Monastir, Tunisia, crops are irrigated with reused waste water. In this laboratory report a peach field is analyzed regarding heavy metals in the irrigation water, the soil and the peaches. The water is mainly domestic and treated to secondary level at the waste water treatment plant of Ouardanine in the Monastir area.

The field is irrigated with 3000m$^3$ waste water/ha/year and the irrigation peak is in May. Since 2009, sludge from the waste water plant is used as fertilizer. The estimated amount is 6000kg sludge/ha/year. The soil is ploughed 5 to 6 times a year, which affect a zone with a depth of approximately 15cm. The irrigation stops ten days before harvest, mainly due to safety regulations. (Ben Salem, 2009)

Treatment process of Ouardanine

The waste water of Ouardanine is treated to secondary level, which means it has gone through preliminary, primary and secondary level before being used as irrigation water in agriculture. In the preliminary treatment, coarse solids and large materials are removed to facilitate subsequent stages in the treatment process. The primary step consists of a sedimentation phase and it is in this phase most of the heavy metals are removed. The secondary step, consist of a sedimentation phase with activated
sludge, in which organic material is digested by bacteria. The treated effluent is pumped to a storage reservoir and distributed by gravity, when demanded, to the irrigated field. (Ben Salem, 2009)

Materials and Methods

Water
Sampling
A sample of reclaimed waste water was taken from the effluent at the waste water treatment plant in Step Ouardanine, Sousse. A sample composed of sub samples, which were taken every 15min during 24h. The sample was kept 2 days in room temperature, before the test was performed.

Heavy metal determination
100mL of the water sample was mixed with 1mL HNO₃ (65%) in a glass beaker. The mixture was boiled on a tray (175°C), for about 3 hours until it was concentrated. The liquid was then cooled and poured in to a volumetric flask. The sample was diluted by distilled water to 100mL, poured into a plastic bottle and sealed. A blank sample consisting of distillate water was prepared according to the same procedures. The samples were analyzed by use of inductively coupled plasma atomic emission spectroscopy (IPC-AES). The model is Perkin Elmer Optima 3300 RL.

Soil
Sampling
The soil sampling was performed according to the procedure described in Qualité des Sol (AFNOR, 1999). 12 soil samples were taken in a peach field in Step Ouardanine, Sousse, close to the treatment plant. The samples were collected by taking lumps of soil directly from the ground and putting them in plastic bags. For pH, conductivity, salinity and organic matter tests further soil sampling was made, following the same sampling procedure. The second sampling consisted of five soil samples.

Heavy metals determination
In the laboratory, a quantity of each sample was put on a watch-glass and dried in a furnace for 24h, 40°C. Plant parts, fauna and gravel were removed from the samples. The samples were mortared and passed through a 1,5mm sieve. 0,5g of each sample was placed in a crucible and heated in a muffle oven 400°C for 4h. 5mL HF (40%) and 1,5mL HClO₄ (60%) was added to the samples, and the solutions were boiled on a tray (160°C) until the liquid had evaporated. After cooling down, 1ml HCl (37%) and some distillate water were added to the samples and heated on the tray until the crystals were dissolved. The samples were poured into test tubes and diluted with distillate water to 50mL. A blank sample was prepared according to the same procedures. The samples were run in the IPC, Perkin Elmer Optima 3300 RL.

pH, conductivity and salinity
The five soil samples from the second sampling were mixed. Plant parts, fauna and gravel were removed from the samples and large soil lumps crushed. 12g of the mixture was put in a glass beaker with the five times the equivalent volume of distillate water. The sample was mixed for about 30 minutes using a magnet stirrer and thereafter left for sedimentation for 2 hours. The supernatant was poured into a glass beaker and used to measure pH, conductivity and salinity. The measuring was made with inoLab, level 2.
Organic matter
The five soil samples from the second sampling were mixed and about 5g of the sample was put on a
watch glass and heated at 105°C for 2 hours, in a furnace. After that it was heated at 525°C for 4 hours
in a muffle oven, before it was weighed. The difference between the weight before and after heating
procedures gave the result of organic matter in the sample.

Fruits
Sampling
9 peaches were picked on the field; with no correlation to the spots were the soil samples were taken.

Heavy metal determination
The fruits were washed in water and cut into pieces consisting of both peel and pulp. A sample of 10g
was taken from each fruit and put in a glass beaker. 30mL of HNO₃ (65%) were added to the samples,
and the mixtures were put on a tray (150°C -175°C) until the peach pieces had been dissolved by the
acid. Distillate water was added to the mixtures during the heating process to keep it from drying up.
The mixture was filtrated through a 25mm filter in to a test tube and diluted with distillate water to
50mL. The mixture was run in the ICP, a Perkin Elmer Optima 3300 RL.

Result and Calculations

Equations
To convert the soil and fruit data received from the ICP equation 1 below was used.

\[
[X] = \left(\frac{B}{F}\right)_{\frac{1}{V_m}} (1)
\]

Where \(X\) (mg/kg) is the actual concentration of the heavy metal, \(C\) (mg/L) is the concentration of the
sample, \(B\) (mg/L) is the concentration of the blank sample, \(F\) the dilution factor, \(V\) (L) the volume of the
sample and \(m\) (kg) the mass of the original sample. To convert the water data received from the ICP
equation 2 below was used.

\[
[X] = \left(\frac{B}{F}\right)_{\frac{1}{V_s}} (2)
\]

Where \(X\) (mg/L) is the actual concentration of the heavy metal, \(C\) (mg/L) is the concentration of the
sample, \(B\) (mg/L) is the concentration of the blank sample, \(F\) the dilution factor, \(V_m\) (L) the volume of the
sample and \(V_s\) (L) the volume of the original sample.

Results
Since the blank sample showed contamination, it was replaced with a blank sample made the same day
by the laboratory.

In table 3, table 4 and table 5 below, the results from the ICP for heavy metals in water, soils and fruits
are presented. Since some samples were below detection limit for some elements only the detected
ones were used to calculate the mean value.
Table 3. Heavy metal levels (mg/L) in the water sample received by using Induced Coupled Plasma (ICP).

<table>
<thead>
<tr>
<th>Element</th>
<th>Samples</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>1</td>
<td>0,0880</td>
</tr>
<tr>
<td>Cd</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Co</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Cu</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fe</td>
<td>1</td>
<td>0,132</td>
</tr>
<tr>
<td>Pb</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Mn</td>
<td>1</td>
<td>0,0180</td>
</tr>
<tr>
<td>Ni</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Zn</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Cr</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Heavy metal levels (mg/kg DM) in the soil samples received by using Induced Coupled Plasma (ICP).

<table>
<thead>
<tr>
<th>Element</th>
<th>Samples</th>
<th>Detected</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd*</td>
<td>12</td>
<td>2</td>
<td>0,699</td>
<td>0,699</td>
<td>0,700</td>
</tr>
<tr>
<td>Co</td>
<td>12</td>
<td>12</td>
<td>14,8</td>
<td>14,0</td>
<td>15,9</td>
</tr>
<tr>
<td>Cu</td>
<td>12</td>
<td>12</td>
<td>20,1</td>
<td>18,2</td>
<td>26,3</td>
</tr>
<tr>
<td>Fe</td>
<td>12</td>
<td>12</td>
<td>18000</td>
<td>17000</td>
<td>20000</td>
</tr>
<tr>
<td>Pb</td>
<td>12</td>
<td>12</td>
<td>14,3</td>
<td>11,7</td>
<td>16,1</td>
</tr>
<tr>
<td>Mn</td>
<td>12</td>
<td>12</td>
<td>220</td>
<td>208</td>
<td>235</td>
</tr>
<tr>
<td>Ni</td>
<td>12</td>
<td>12</td>
<td>22,9</td>
<td>21,8</td>
<td>24,0</td>
</tr>
<tr>
<td>Zn</td>
<td>12</td>
<td>12</td>
<td>69,1</td>
<td>53,0</td>
<td>132</td>
</tr>
<tr>
<td>Cr</td>
<td>12</td>
<td>12</td>
<td>59,9</td>
<td>49,4</td>
<td>76,2</td>
</tr>
</tbody>
</table>

*For some samples the element is below detection limit for the ICP, i.e. <0, 6 mg/kg

Table 5. Heavy metal levels (mg/kg WM) in the fruit samples received by using Induced Coupled Plasma (ICP).

<table>
<thead>
<tr>
<th>Element</th>
<th>Samples</th>
<th>Detected</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd**</td>
<td>9</td>
<td>0</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
<td>&lt;0,03</td>
</tr>
<tr>
<td>Co*</td>
<td>9</td>
<td>1</td>
<td>0,257</td>
<td>0,257</td>
<td>0,257</td>
</tr>
<tr>
<td>Cu</td>
<td>9</td>
<td>9</td>
<td>1,09</td>
<td>0,762</td>
<td>1,42</td>
</tr>
<tr>
<td>Fe</td>
<td>9</td>
<td>9</td>
<td>5,92</td>
<td>2,62</td>
<td>16,8</td>
</tr>
<tr>
<td>Pb*</td>
<td>9</td>
<td>3</td>
<td>0,291</td>
<td>0,267</td>
<td>0,306</td>
</tr>
<tr>
<td>Mn</td>
<td>9</td>
<td>9</td>
<td>0,976</td>
<td>0,797</td>
<td>1,12</td>
</tr>
<tr>
<td>Ni</td>
<td>9</td>
<td>9</td>
<td>0,313</td>
<td>0,269</td>
<td>0,389</td>
</tr>
<tr>
<td>Zn</td>
<td>9</td>
<td>9</td>
<td>1,14</td>
<td>1,00</td>
<td>1,28</td>
</tr>
<tr>
<td>Cr*</td>
<td>9</td>
<td>1</td>
<td>0,337</td>
<td>0,337</td>
<td>0,337</td>
</tr>
</tbody>
</table>

*For some samples the element is below detection limit for the ICP, i.e. <0, 25 mg/kg
**For all samples the element is below detection limit for the ICP, i.e. <0, 03 mg/kg

Below, in table 6, organic matter, pH, electric conductivity and salinity for the second soil sampling is presented. The parameters were only measured once; hence there are no mean values.

Table 6. Organic matter, pH, electric conductivity and salinity for the soil sample.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>31,5 g/kg</td>
</tr>
<tr>
<td>pH (at 13,3°C)</td>
<td>8,404</td>
</tr>
<tr>
<td>Electric conductivity</td>
<td>197 μS/cm</td>
</tr>
<tr>
<td>Salinity</td>
<td>0 g/kg</td>
</tr>
</tbody>
</table>
Discussion

The analysis shows no trace of contamination in the irrigation water, only low levels of Al, Mn and Fe. This was suspected considering the water origins from a rural area. However, the water sample was not representative, since the waste water treatment plant had not been operational for 10 days. But this should not have affected the results. After collecting the sample, it was kept in room temperature for 2 days before test was performed. Neither this should have affected the composition of heavy metals.

For Cr, half of the soil samples are exceeding recommended limits set by EU-commission; however, the mean value is the same as the limit value. Two samples exceeded those limits set for Cd, whereas the other ten samples there were no detection for this element. It would be preferable to further analyze the Cd concentration in soil, since the recommended limit is below detection limit. Co and Mn lack comparable recommended limits and Fe is not a toxic element in this situation. The samples were not taken in a random way, instead it was concentrated around one point. Random sampling would have supported a more statistically stronger representative of the field. The soil samples were supposed to be composed by a mixture of the upper 20 cm. The samples were taken by collecting loose soil from the ground. This is thought to be a smaller inaccuracy, since the soil is ploughed, thereby mixing the soil.

The fruit samples mostly showed undetected or very low levels of contamination. There could be further analysis to detect those minimum levels; however, the risk model that will follow this report will not need this information. The fruit samples were not taken randomly, which contributes to a less representative sampling. The fruits were not picked in the same spots as the soil samples were taken, therefore a correlation between a specific fruit and a soil sample cannot be made. It would have been preferable to take the fruit in the same spot as the soil sample, to have the possibility to correlate the samples. The laboratory work was performed during a very hot day, and because of the evaporation process, the balance did not steady. This has affected the reading of the samples true weight.

This year the farmer started to use sludge from the secondary step at Ouardanine, which will be more likely to be a source of contamination than the irrigation water already used. Further study can be made on the sludge, to evaluate its affect on heavy metal concentration.

Heavy metals possibility to move in the soil depends on pH. Since pH indicates an alkaline environment, one can assume that heavy metal movements in the soil are limited. However, further study can be made to find correlations between heavy metal concentration and physicochemical properties. Also, in further analysis, combined effects of heavy metals should be considerate.
References

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Appendix III: Questionnaires

Questionnaire to the farmer
1. What is your name?

2. How big is the field?
   About 1.5 hectares.

3. What kind of irrigation is used?
   Drip irrigation. The farmer turns the irrigation on for about one hour/day, it depends on
   the temperature/weather conditions. The irrigation is stopped two weeks before harvest.

4. How long has the field been irrigated with treated wastewater?
   About 10 years.

5. How much fruit does the field produce?
   The farmer does not want to share this information, it is a business secret.

6. Is artificial or natural fertilizer used?
   The field is fertilized with sludge from the treatment plant that is applied at the end of
   the season. No pesticides are used.

7. What are the proportions between conventional and reused wastewater in the irrigation water?
   The wastewater from the treatment plant is the sole irrigation source.

Questionnaire about wastewater irrigation

The treatment process
1. How does the control of the reused wastewater work?

2. How often is the water measured in the treatment plant?

3. Is the water controlled/measured during the process?
   (a) Influent?
   (b) Effluent?
   (c) During the process?

4. Which parameters are checked?

5. What preliminary step is used at the treatment plant?
   (a) Bars?
   (b) Sandfond?

6. What primary step is used?
   (a) Sedimentation?
   (b) Skimming?

7. What secondary step is used?
8. What are the regulations if the values exceed allowed levels?

9. Does the farmer have to stop irrigation if levels exceed allowed values? If so, does the farmer have a back up irrigation?

10. Have the water ever needed to be stopped?

Knowledge and Regulations

11. What risks are of concern for the reuse of wastewater in Tunisia?

12. What does Tunisia do to avoid
   (a) health risks?
   (b) heavy metal assembling?

13. Which regulations for water quality are followed? WHO? Tunisian?

14. Irrigation with wastewater is stopped 2 weeks before harvest, why? Regulations?

15. What kind of education do the employees in the wastewater plant have?

16. What kind of information does the farmer have?

17. Is there any education/information given to the farmers?

18. Does the farmer apply for using the reused water?

19. How do you communicate with the users of the irrigation water?

20. If regulations are not followed, what kind of reprimand is there for the...
   (a) Farmer?
   (b) Treatment Plant?
   (c) Responsible on a higher level?
   (d) Is the products allowed to be used?
   (e) Impose of a fine?

21. Are tests performed on the fruit?

22. When and how often are tests taken?
   (a) On the soil?
   (b) On the crop?
   (c) Are tests performed on fruits in the field, super markets etc.?

23. Are tests preformed according to a regular basis or when there is something to suspect?

Opinions

24. The water issue is of great concern for Tunisia, and people are aware that this is a big problem?
   What is the opinion of reused waste water?
   (a) Governmental?
A Risk Assessment of Reusing Wastewater on Agricultural Soils
– A Case Study on a Peach Field in Ouardanine, Tunisia

(b) Users?
(c) Consumers?

25. Do the consumers know that waste water is used as irrigation? Is the subject widely discussed in for example media?

26. Public participation. Who are the stakeholders?

27. Is there a governmental plan of how the waste water is going to be used? Is there a main focus on a special area of products?
Appendix IV: Weather Conditions in Tunisia

Figure 1 Average temperature in Sousse (Foreca, 2009)

Figure 2 Average rainfall in Sousse (Foreca, 2009)