Faculty of Graduate Studies

Master Program of Water and Environmental Sciences

MSc. Thesis

"Pretreatment Options for Wastewater from Stone Cutting Industry in Hebron District"

"خيارات المعالجة الأولية للنفايات السائلة الخارجة من مناشير الحجر في منطقة الخليل"

Master's Thesis Submitted By

Malek Abu Al-Failat

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Supervised By

Dr.-Eng. Rashed Al-Sa'ed

May 2013

BIRZEIT UNIVERSITY

كلية الدراسات العليا

برنامج ماجستير علوم المياه والبيئة

رسالة ماجستير

"خيارات المعالجة الأولية للنفايات السائلة الخارجة من مناشير الحجر في منطقة الخليل"

قدمت رسالة الماجستير من

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This thesis was submitted in partial fulfillment of the requirements for the Master's Degree in Water and Environmental Sciences from the Faculty of Graduate Studies, Birzeit University, Palestine

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Pretreatment Options for Wastewater from Stone Cutting Industry in Hebron District

Submitted by: Malek Abualfailat

Student No.: 1095214

This thesis was prepared under the main supervision of Dr.-Eng. Rashed Al-Sa'ed and has been approved by all members of the examination committee.

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Date of Defense: May 29th, 2013

The findings, interpretations and the conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the MSc. Committee or the views of their respective employers.

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ABSTRACT

The Hebron stream has been suffering for over three decades from a variety of domestic, agricultural and industrial pollution sources together with development pressures in the city of Hebron and illegal Israeli settlement “Kiryat Arba” in the open spaces that surround the stream.

The stream entails discharges from 172 stone cutting firms in total, 145 only covered by this study concerning the consumption and discharge of an amount 1252 m^3/day into the stream with more than 2000 mg/L of TSS and more than 10000 NTU of turbidity, and that was reflected into GIS maps describe the daily consumption and discharge, type of treatment, and how the wastewater discharged.

The study also covers the current situation of treatment units in industrial zone of Hebron and it concludes that the decentralized treatment system is the better and more affordable than the centralized system.

In this study an investigation done to check the technical feasibility of using two types of coagulants (Polymer, and Ferric) using lab jar test to investigate their effects on both TSS and turbidity under certain rotation, waiting time for each sample.

It was found that the best coagulant to be used is the Electro-Polymer with a concentration of 0.5 mg/L at 120 RPM for 1 min and waiting time 12 minutes.

It was recommended to implement a full-scale decentralized treatment project that includes all the stone cutting firms in Hebron industrial area is required before building and developing a municipal treatment plant on the stream, and benefit from the solid cake that discharge after the treatment into local industries.

الخلاصة:

تعاني منطقة وادي الخليل منذ أكثر من ثلاثة عقود من مجموعة متنوعة من مصادر التلوث المنزلية والزراعية والصناعية جنبا إلى جنب مع ضغوط التنمية في مدينة الخليل إضافةإلىمستوطنة إسرائيلية غير شرعية تسمى "كريات أربع" في المساحات المفتوحة التي تحيط بهذا الوادي.

يطرح في وادي الخليل مخلفات سائلة لـ 172 منشأة قطع حجر، تم مسح 145 مصنع منها لدراسة الاستهلاك اليومي للمياه وكمية المياه العادمة التي تخرج منها وتبين بعد عملية المسح ان 1252 متر مكعب يطرح بشكل يومي من هذه المصانع بتركيز مواد عالقة يتجاوز 2000 ملغم/لتر وعكورة تتجاوز NTU 10000، وتم ترجمة المسوحات من خلال خرائط تبين مدى الاستهلاك اليومي و كيفية المعالجة وكيفية التصريف للمياه العادمة.

غطت هذه الدراسة الوضع الحالي لوحدات المعالجة الموجودة في المنطقة الصناعية وخلصت الدراسة الى ان نظم المعالجة اللامركزية هي أفضل وانجع من الناحية الفنية والمالية من نظم المعالجة المركزية.

في هذه الدراسة تم فحص الامكانية الفنية لاستخدام مخثرات البوليمرات وكلوريد الحديد الثلاثي باستخدام تقنية "الجرة" لبحث تأثير المخثرات على كل من العكورة وتركيز المواد العالقة بناء على سرعة دوران محددة و زمن انتظار وزمن دوران.

من خلال العمل المخبري تبين أن افضل مخثر ممكن هو البوليمر او ما يسمى "بالفوكلاند" بتركيز 0.5 ملغم/لتر وزمن دوران 1 دقيقة على 120 لفة لكل دقيقة وزمن انتظار 12 دقيقة.

توصي الدراسة بعمل مشروع معالجة لا مركزي يستوعب كافة مصانع الحجر في المنطقة قبل البدء في مشروع صرف صحي منزلي، والاستفادة من مخلفات هذه الصناعة في صناعات فلسطينية أخرى.

Dedications

I Dedicate this it to my Parents, Mr. Zuhdi Abualfailat and Mrs. Ibtisam Abualfailat

I really want to dedicate this work to wonderful Wife Hiba for Her support and encouragement.

I finally dedicate this work to all who suffer from stone cutting wastewater in Hebron District,

Acknowledgments

Apart from the efforts of me, the success of this work depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this work.

I would like to show my acknowledge and appreciation to Judges Committee by their names Dr. Rashed Al-Sa'ed, Dr. Nidal Mahmoud, and Dr. Uraib Al-Sairafi for their efforts and reviews to the Study procedures.

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List of Abbreviations

PWA: Palestinian Water Authority

MCM: Million Cubic Meters

GDP: Gross Domestic Product

CH2MHILL: American Consulting Company

TSS: Total Suspended Solids

GNP : Gross National Product

USM: Union of Stone and Marble Industry in Palestine

SCI: Stone Cutting Industries

EC: Electrical Conductivity

TDS: Total Dissolved Solids

ARIJ: Applied Research Institute-Jerusalem

USAID: United States Agency for International Development

WWTP: Wastewater Treatment Plant

FoEME: Friends of the Earth Middle East

EU: European Union

NIS: New Israeli Shekels

INP II: Infrastructure Need Program II

MoNE: Ministry of National Economy

MoEA: Ministry of Environmental Affairs

EPA: Environmental Protection Agency

THMs: Tri-Halo Methanes

DBPs: Disinfection By-Products

NOM: Natural Organic Matter

BOD: Biochemical Oxygen Demand

GPS: Global Positioning System

RPM: Round Per Minuit

NFR: Non-Filterable Residue

GIS: Geographical Information System

BZU: Birzeit University

IEWS: Institute of Environmental and Water Studies.

PA: Palestinian Authority

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Chapter One
Introduction

1.1 Overview

As well as all over the world Palestine give a great attention through Palestinian Water Authority (PWA) to protection of water resources and consider it as a major concern for sustainable developments in the region. Future population growth and increasing both agricultural and industrial needs of water is anticipated that Palestine will experience serious water deficits, where the water shortage is projected to reach about 271 Million Cubic Meter(MCM) in the year 2020 (Mimi and Smith, Statistical domestic water demand model for the West Bank 2000).

In recognition of the scarcity of water and the inevitable population growth in the region, conservation and efficient use of existing water sources is becoming imperative. Saving water and protection of water supply, rather than development of new water resources and supply projects may prove to be in many cases the appropriate and optimal policy. Moreover, form an environmental perspective, it is advisable to minimize leakage, to prevent pollution, and address specific wastewater discharges (Mimi, Ziara and Nigim, Water conservation and its perception in Palestine-a case study 2003).

In the West Bank Fig. 1.1, the stone cutting industry is one of the largest industrial sectors; its contribution to Gross Domestic Product (GDP) is about 10% and it is one of the largest water consuming industries; currently at about 0.5 MCM per year.

Figure 1. 1: Palestine Map (Nasseraldein, 2009)

Nasserdine(Nasserdine, et al. 2009)reported that this discharge has caused high maintenance costs on existing sewer pipes and open channels for several kilometers downstream. During wet weather events, large volumes of fine stone solids are re-suspended and deposited on the downstream agricultural lands, causing soil contamination and reducing soil quality. Furthermore, the discharge areas of these liquid stone wastes are located in the recharge areas of the principle aquifers used for drinking water supply, the Eastern and Western Aquifers.

The annual amounts of wastes generated by this process include 700,000 tons of slurry waste in addition to 1 million tons of solid waste. The dumping of this waste in open areas has created several environmental problems, and negatively impacts agriculture, humans, and groundwater (Al-Jabari and Sawalha 2002).

Wastewater and sludge from stone cutting industries in Jordan has been characterized and reused in various processes. In Jordan, Ammary (2007) applied the cleaner production principles on stone cutting industries, where he showed that modifications in production processes have achieved a zero-liquid discharge by recycling the pretreated effluent. He also reused the chemical sludge for the production of building bricks, thus eliminating the need for water for producing bricks and reducing the costs of chemical sludge disposal. Few pretreatment systems(CH2MHILL 2002) concentrated on short-term collection of data to install small pilot-scale pretreatment systems without giving and adequate long-term strategic solution for the management of stone slurry in Hebron district. The initial results of pilot-scale trials (Nasserdine, et al. 2009)were of limited chance for a replication on a national scale.

In addition, lack of centralized wastewater treatment exacerbated by stringent effluent standards required for discharge into surface water bodies have created political conflict between the Palestinian Water Authority and Israeli water related agencies. Therefore, a sustainable management of the wastewater discharges from the stone cutting industry in Hebron district through a survey of both quantities and qualities of the industrial discharge is of priority, where a feasible pre-treatment alternative is crucial for a sustainable management of this heavy polluter industry offering practical recycling options for the treated effluent.

1.2 Major Goal and Specific Objectives

1.2.1 Main Goal

The major goal of this study is to develop an environmentally sound, technically practical and financially affordable pretreatment option for the liquid waste stream from the stone cutting industry in Hebron.

1.2.2 Specific Objectives

The specific objectives are the followings:

- Compile qualitative and quantitative data on liquid waste stream from stone cutting industry.
- Develop, erect and run lab-scale experiments using lab jar tests to identify the best chemical agent for the removal of TSS and turbidity.
- Evaluate the technical aspect of the developed lab-scale experiments
- Raising public awareness towards environmental impacts.

1.3 Expected Results

Upon successful implementation of this research study, the following results are expected to be achieved:

- Full data base on physical-chemical quality and volumes of liquid waste discharged from selected stone cutting industry in Hebron district.
- Design data on unit operations of the developed and tried lab-scale pretreatment alternative.
- Gain practical experience on design, install and operation of small-scale pre-treatment units.
- Recommendations on best practical solution to reduce pollution loads and promote advice to decision makers as to how better manage heavy polluter discharges.

- The acceptance from stone cutting firms owners would be raised, to develop and implement decentralized pretreatment units under the fact sheet in term of coagulant dose depends on TSS and turbidity content.
- For further research work pretreated solid cake can be used as a raw material in other industries (e.g. ceramics, concrete, bricks, papers, and medicine industry).

1.4 Research Approaches

To carry out the study in a systematic approach, a detailed research methodology has been developed, taking into account the costs and time frame of the study:

1. Lab work will be carried out through Jar test experiments to measure the effect of dose (mg/L), and effect of waiting time (min).
2. Through pH measurement, TSS measurement, and Turbidity measurement, results were implemented.
3. Community engagement and public acceptance raising will be made through intensive data collection gathered via development, distribution, collection of a specialized questionnaire, it include the risk resolution, impact on agriculture, impact on nearest water tank, and health risk.
4. Statistical analysis were carried out using Microsoft Office Excel 2007.

1.5 Thesis Body

- Chapter 2 will discuss briefly the stone cutting industry in Hebron; its consumption of water, the processes of industry, and characteristics of wastewater.
- Chapter 3 will discuss in details physio-chemical processes that achieved in lab jar test with details about the tool itself, also it will discuss the type of coagulants used locally and globally.
- Chapter 4 will show and describe the research methodologies and material used in the lab.
- Through chapter 5 results will be discussed and analyzed to recommend the best alterative(s) used.
- Finally chapter 6 will show the conclusions, recommendations, and future work.

Chapter Two
Stone Cutting Industry in Hebron

2.1 Industry Profile

Mosques, cathedrals, churches and monuments have stood for centuries in Palestine as evidence of the strength, durability and timelessness of Holy Land marble and stones. The Palestinian marble and stones industry has helped to protect and to preserve the country's history. Historically, the stones and marble industry has tended to consist of family run enterprises, the ownership of which was passed down through hereditary lines. Recently, this sector still comprised mainly of family owned businesses with minimal direct foreign investment.

The marble and stone industry in Palestine is considered one of the most significant and active natural resource based sectors that plays a predominant role in the Palestinian economy. Nationally, it contributes approximately 25% to Palestine's overall industrial revenue, 10% to the Gross National Product (GNP) and 5.5% to the GDP(CH2MHILL 2002).

This industry is significant and unique where the product varieties, colors and features that characterize the Palestinian stone do not only meet the local standards but also meet the regional and global standards. Researchers agreed on the fact that Palestine is one of those countries in which raw materials for construction stone is available at a commercial quantities(Nasserdine, et al. 2009), and distinguished for its type, quality and multicolor.

The Palestinian marble and stones derives its unique commercial value from three key characteristics:

1. Holy Land Origin that creates spiritual and symbolic imagery.
2. The variety of colors and textures of the products, (Table 2.1).
3. Exceptional Quality.

Table 2. 1: Classifications of Major types of Stones Used in West Bank and Gaza, Source: ECB 2002.

StoneType	Source	Classifications	Specifications	Uses
Injasah	Hebron-Bini Na'em	It is classified into four major categories: Asfar, Sid, Ardi, Sous.	The "Ardi" type is the best one. White color, veined, different colors, hard, minimal absorption water	"Chiseled" for building, polished stone, paving sidewalks, Garden walls, decorating public places.
Jarra'ah	Nablus	Band 60, and Band40	Usually gray, minimal absorption water, veined, hard, uniform color	Building, paving, decorating public places
Aseerah	Nablus-Aseerah	Band 60, and Band40	White, minimal absorption of water, hard, uniform color	Building (all sides), paving, decorations
Al Shyoukh	Hebron-Al -Shyoukh	Asfar, Sid, Ardi	Ardi White color, absorbs water, not uniform color	Building, paving, decorating public places, renovating ancient places
Tafouh	Hebron - Tafouh	Bind Asfar, Ardi	Beige color, soft stone, absorbs water, not uniform color	Paving, polished stone, decoration
Samou'	Hebron-Samou'	Asfar, Ardi	Different colors, hard stone, minimal absorption of water	Building, paving, decoration
Qabatya	Jenin-Qabatya	Bind Awal (cover) Bind Ardi	Different colors (almost beige), absorbs water, color is changeable with time, hard stone	Building, paving
Yatta	Hebron - Yatta	Bind Asfar, Ardai	White color, hard, almost uniform color, absorbs water	Building, polished, paving, decoration

2.2 Environmental Impact of Stone Cutting

Although the stone cutting industry is one of the largest industrial sectors in the West Bank, this industry is reported to be one of the most polluting industries in the area, due to its impacts on Environment and health.

According to the Union of Stone and Marble (USM) in Palestine, since 2004 there have been significant decrease of exporting Palestinian stones and the market has been depressed but has slowly been picking up over the last two years.

Over 50% of sales go to the West Bank and Gaza while Israel has been the biggest export market of Palestinian stone and marble in the past. Before the second Intifada it was shipped directly but now goes through dealers and agents. Outside of Israel and the West Bank, China continues to be the largest and fastest growing international market(IMG and European Commission 2010).

Many field visits conducted to southern of Hebron (Al-Fahs area), and it shows statistically that there is a need of management plans to collect, treat, and reuse the stone cutting wastewater.

In a study on effluents and consumption water for and from stone cutting industries (SCI) in Hebron district (CH2MHILL 2002), reported that industry discharge slurry with high TSS content reaching about 120,000 mg/L, and the consumption of water currently about 0.5 Mm^3.

Strong storm weather conditions cause erosion and transport of huge amounts of colloidal solids from point of discharge into downstream, where flooding of adjacent agricultural lands are heavily polluted with stone slurry.

This high production in a relatively small area creates a series of major environmental problems for both Palestinians and Israelis. In the absence of proper treatment of wastewater from the stone cutting factories environmental, health and economic impacts abound:

1. Major Health Concerns: Evaporation of water from the slurry leaves behind chalk dust with suspended mineral matter constituting a serious respiratory health threat to the nearby population. Furthermore the stone industry wastewater produces a layer of substrate that seals the streambed and creates an ideal environment for mosquitoes to breed. In recent summers, mosquitoes carrying the life threatening West Nile Virus have been discovered reaching Kibbutz Tze 'elim, dozens of kilometers at the western edge of the Hebron Basin. The density of the slurry causes blockages if the slurry is dumped by industry untreated into the domestic sewage

network, leading to the frequent flooding of residential neighborhoods in Hebron with raw sewage and an increased probability of spreading disease.

2. Water Contamination and Degradation of the landscape: The failure to pre-treat industrial sewage in Hebron has led to the sewage treatment plants built on the Israeli side of the Green Line to clog and fail to treat the wastewater, leading to the heavy pollution of streams flowing through Israeli communities, including the city of Beersheba with associated odors and mosquito infestation. The leaching of sewage and industrial waste into the aquifer are also likely to contaminate nearby wells, often the sole water source for local communities both Palestinian and Israeli. Chalk dust dumped on nearby road sides and sludge disposed in open areas clogs the soil pores resulting in soil and plant damage. Significant economic damage has been caused to the local agricultural sector due to damage of otherwise productive land.
3. Economic Hardships due to unilateral Actions: Hebron stream sewage treatment facilities that have been built in Israel were financed under a unilateral decision by Israel of deducting Palestinian Authority taxes collected by Israel. Together with fines imposed, it is estimated that over 100 million NIS (United State Agency for International Developments (USAID) 2012)have been denied to the Palestinian treasury on Hebron sanitation issues alone. Furthermore in June 2012 the Israeli Military prevented for several weeks the export to Israel of stones from the West Bank and threatened to close down the whole industrial area, threatening the jobs and income for thousands of Palestinian families. USAID's emergency intervention led to the lifting of these measures and the re-export of stone into Israel.
4. Effects on Soil: In 2007 Al-Joulani (2007) studied the soil pollution caused by the stone slurry discharged from the stone cutting industry in Hebron district. He reported that the stone slurry has moderate and week effects on the physical-chemical (pH, EC, salinity and TDS) of Terra Rosa and sandy soils; respectively. However, further analysis of the spatial data, he showed a polluted area in Hebron district between 0.73% and 20.6% of the total Hebron municipality boundaries area, due to uncontrolled discharge of stone slurry(Al-Joulani 2008).

The greatest threat to the environment from the SCI is the sludge produced when dust generated during cutting mixes with the water used in cooling the cutting equipment, dust absorption and lubrication during polishing the stone.

The sludge, consisting of calcium carbonate (chalk) solid and water is relatively inert, but the large volumes generated and its tendency to set into an impermeable mass creates considerable disposal problems. It was observed from visits to the area that emissions from industry are not well regulated; large amounts of stone dust are apparent all over the factories and on the buildings, vegetation and ground around the area for distances of up to several hundred meters.

Moreover, it is apparent that there has been illicit dumping of waste sludge on roadsides and empty land within and around the industrial area. The main effects of the sludge in the environment were investigated through interviews with stakeholders around the area (see table 2.1bellow. The main impacts, including the secondary effects of illicit dumping are summarized in the following table.

Table 2. 2:A comparison of different disposal methods and It's Potential on Soil

Disposal Method	Potential Impact
Sludge is dumped on site.	Dust is created which is a hazard to worker's health. It settles around the site from where, particularly when vehicles are moving, it is blown around the adjacent areas, damaging crops, gardens, amenity and the health of nearby residents. Nearby residents are forced to keep their windows closed during plant operating hours. They complain of high incidence of asthma in their children. Some properties are vacant, abandoned by owners with other options. The area of the site taken up can be considerable, restricting site activities and the potential for the growth of the enterprise.
Sludge is dumped into the public sewerage system	The sewers may periodically become blocked by accumulated sludge sediment. This increases the maintenance cost. In winter (i.e.: periods of high water flow) this leads to overflow of sewage into residential areas leading to increased incidence of diarrheal diseases and risk of deadly epidemics such as typhoid and cholera. In summer (periods of low flow and high evaporation) it leads to odor and spread of diseases by insect vectors. In addition, the presence of a large amount of stone sludge in the wastewater stream interferes with biological methods of sewage treatment. The Israeli National Sewage Administration has identified solid residues from the Hebron stonecutting industry as a threat to the operation of its Wastewater Treatment Plant (WWTP) at Shoket.
Sludge is dumped on open public land	There is visual intrusion on the landscape, of unsightly heaps of white sludge. Gradually dust spreads onto agricultural land, reducing crop yields by coating the plants and blocking drainage of soils.

2.3 Stone quarrying

The West Bank's sources of stone include 222-255 quarries(The Union of Stone and Marble Industry (USM) 2006).The vast majority of these quarries are concentrated in the Hebron and Bethlehem areas. Stone and marble factories, workshops, and quarries in Palestine are, however, distributed all over the West Bank and the Gaza Strip. Stone production in Palestine constitutes around 4% of the world total, making Palestine the 12th largest stone producer in the world (The Union of Stone and Marble Industry (USM) 2005). Palestinian stone characteristics differ but most Palestinian stone types meet international standards and safety specifications. The West Bank has a rich stock of good quality stone, both soft stone and hard stone (marble), and represents the largest natural resource stock available to the Palestinian economy (Union of Stone and Marble Industry in Palestine 2004). This sector contributes approximately 25% to the Palestinian industrial revenue, which forms 4.5% to the total Palestinian GNP, and 5.5% of the Gross Domestic Product (GDP). The total annual revenue of this industry is estimated to be 450 million $, 65% of which comes from exports to Israel and about 6% comes from direct export to international markets (The Union of Stone and Marble Industry (USM) 2005).

In 1997, the Applied Research Institute-Jerusalem (ARIJ) reported 7 Israeli quarries in the region, those quarries, occupying an area of 1,673.3 hectares (4,183 acres), are built on land that Israel consecrated after the signing of the Oslo I Agreement of 1993 (Applied Research Institute-Jerusalem (ARIJ) 1997). Most of these quarries have operated for a number of years, (of the seven quarries, there are only 4 in operation today). These quarries represent a systematic pirating of Palestinians' natural resources, as well as destruction of their land. The quarries are violations of international law, specifically the Fourth Geneva Convention. As an Occupying Power, Israel is prohibited, by international law, to expropriate and utilize the natural resources of Palestine, unless the use of these resources is for the sole benefit of the Occupied Population (Applied Research Institute-Jerusalem (ARIJ) 1997).

From an environmental point of view mining essentially is a destructive developmental activity. Due to the nature of mining, the impacts on environment are generally large. Mining operations involve deforestation, damage to or destruction of the natural vegetation, physical features and cause significant disturbance to wildlife. Leakage from the disturbed stone cutting facilities into groundwater could be a potential source of surface and groundwater contamination. And if, the used water runs into the soil, it could affect the soil stability and cause soil erosion. Other considerations include noise and dust impacts. Large amounts of particulate materials and dust are produced from quarries and stone cutting facilities as many of them located near residential areas. Particulate materials are harmful to human health, especially the respiratory system.

2.4 Hebron Stream

The Hebron Stream basin is the largest of the cross border streams, beginning in the West Bank and flowing through Israel and then the Gaza Strip before reaching the Mediterranean Sea. A significant portion of the pollution currently flowing to the stream originates from the Hebron City area, the settlement of Kiryat Arba, and surrounding Palestinian villages. As seen in Table 2.2, the source of wastewater is both domestic and industrial sewage, with domestic sewage (estimated at 6.4 MCM a year) making up 94% of the total flow of sewage. Despite this, the proper treatment of industrial sewage from the City of Hebron has emerged as a significant challenge that needs to be addressed in order to deal with the sanitation situation as a whole(Lu n.d.).

Table 2. 3: Sources and amount of pollution flowing into Hebron Stream. (Source: Field Research, Abualfailat, 2012; Israeli Knesset Center for Research and Science, 2011)

Source	Estimated Amount of Water/Year
Stone Mixture from Hebron Stonecutting Industry	0.4 million cubic meters
Wastewater from Tannery Industry	0.03 million cubic meters
Domestic Sewage from the City of Hebron	5.9 million cubic meters
Domestic Sewage from Kiryat Arba	0.5 million cubic meters

The Hebron Stream flows southwest from the City of Hebron for 43.5 km until it crosses the Green line within Israel, the stream flows westward alongside Palestinians and Israeli communities, spilling into the Beer Sheva Stream, adjacent to Israel's largest metropolitan city in the south. The Beer Sheva Stream flows westward, feeding the Besor Stream, and crossing the border into the Gaza Strip on its way to the Mediterranean Sea.

Wastewater currently flowing through Hebron Stream is especially Problematic due to the fact that it is a mix of domestic and industrial sewage containing a high level of solid waste and hazardous materials originating from the stonecutting, tannery, metal, and olive oil industries. Until the recent intervention of USAID, Industrial wastewater has been discarded directly into nature or discharged into the sewage network which is not connected to a wastewater treatment plant (WWTP), eventually flowing into a stream channel leading to the Hebron Stream. As of July 2012, USAID launched a much welcomed and extensive program of dealing with the issue as part of an emergency program.(United State Agency for International Developments (USAID) 2012).

Considering the limited natural water sources available to residents within the Hebron area, the development of a hermetic and sustainable wastewater treatment system for the city is an essential step in securing future water security. As Hebron is situated at the head of the stream, damages caused by the lack of proper wastewater treatment have acute impacts on large populations downstream. Failure to address the "root cause" of Hebron’s wastewater adds to the lack of trust between Palestine and Israel and has led to environmental and economic unilateral actions by Israel.

2.5 Existing Facilities onsite

In December 2009 the PWA presented an emergency plan to prevent the illegal dumping of slurry into the municipal sewage system. Components of the plan included:

1. Laying of sewage lines bypassing the Hebron Industrial Area, in order to prevent those factories that are currently independently connected to the existing network to continue to dump untreated industrial wastewater into the municipal sewage system.
2. Increase of the capacity of the Hagar Plant or the creation of an additional facility.

2.5.1 CH2MHILL Investment

CH2MHILL is an American consulting company working in Palestine from the Oslo 2 signing agreement, it has many infrastructure projects in the region, part of the project is stone cutting pretreatment unit project in Hebron which is served a 20 stone cutting firms from the 172 stonecutting firms currently active in Hebron. A portion of them were installed as part of a 2002 USAID pilot(CH2MHILL 2002), while others were purchased independently by the firms themselves. Today, only eight of the onsite treatment systems include "dewatering press filters units" a pretreatment technology which separates the liquid from the slurry for recycling and creates a solid byproduct called a 'waste cake', which is dumped or discharge into old quarries or landfill site.

This technology is the most effective way to separate the slurry and requires investment in ongoing maintenance and the replacement of parts as necessary. A survey was conducted in the area for 100 factories in Hebron, identified 22 firms with onsite basic sedimentation pools. By installing a dewatering system based on this infrastructure, it could be possible to increase the efficiency of water recycling and the separation of solid waste at the factory site. According to written communication between Friends of the Earth Middle East (FoEME) and the Israeli Civil Administration, USAID is planning to purchase 30 to 35 additional press filter units to be installed on site at the larger stone cutting factories at a cost of $100,000 a unit(Israeli Civil Administration 2012).

2.5.2 Hagar Project

In 2007, the stone cutting waste (solid and liquid) was raised as a high priority serious environmental problem from all concern stakeholders (Palestinian, and Israeli Water Authorities, Municipality of Hebron, Hebron Chamber of Commerce, and Union of Stone and Marble Industry), afterward the Hagar project was submitted to EU for fund, then it start operating in 2009 .

The project was jointly funded as a pilot project by the EU, Hebron Municipality, and the Italian organization Agenfor Italia. While the original plan was for the plant to include four centrifuging tanks with a daily capacity of treating 375 m^3 of slurry per day, only two centrifuging tanks were built with a potential of 180 m^3 of slurry being treated daily. Regarding to the USAID intervention only one tank was functioning at approximately 50% capacity of 90 m^3 a day. USAID has subsequently repaired the second unit and has also increased the operation time of the plant from previously 6 hours of operation a day to presently 24 hours, 6 days a week (United State Agency for International Developments (USAID) 2012).

Currently, upon meeting with plant operator, the highest load the plant can receive is only 40 CM/day because the running cost, which was planned to be covered by the stone cutting firms owners through the fees of 20 NIS/ Truck, which was cancelled.

The problems of this project is not only in term of capacity, and running cost, but also the location is not suitable at all since it is located over one of the highest hills in the industrial zone which is hard on trucks driver to climb the street to reach the inlet point of the facility.

Moreover technical problem is the dose of electro-polymer per cubic meter added, since the operators doesn't depend on a fact sheet in terms of concentration dose depending on concentration of TSS, which resulted high viscous solution ending with clogging of the pumps and pipes.

The other problem in this regards in term of running and feasibility of the project in general which summaries all the points above, since this system is centralized it is really hard to control the quality, but if the system installed in decentralized shape it will be better from financial, technical, and environmental, perspectives.

2.5.3 USAID Emergency Project

Since industrial waste is treated differently than municipal waste, the discharge of slurry into the system requires additional treatment. Currently, the Israeli Civil Administration fines the Palestinian Authority for this additional treatment, with the total amount deducted to date around $100M. As a result of the inaction by the Palestinian Authority to correct this ongoing problem, the Israeli's recently moved to more serious repercussions – threatening to close the Industrial Zone in its entirety if this issue was not resolved.

Considering the stone and marble industry represents a large portion of the overall Palestinian economy, USAID became involved with the problem to assist with an immediate solution through the Infrastructure Need Program II (INP II) program and its contractor, Black & Veatch.

Starting on July 1st, 2012 and one month before, trucks and tankers have been working 6 days a week transporting waste to the designated disposal site – the Municipality's landfill outside Yatta. First, tankers transport liquid slurry waste from factories to the Municipality's Plant for processing. Afterward, trucks transport the resulting solid waste sludge, along with any sludge processed onsite at the factories, to the landfill. Finally, any remaining liquid slurry from the factories is then transported to the Yatta landfill.

Trucking operations are regulated by a pre-determined route for each vehicle. The Hebron Industrial Zone was separated into "blocks" based on the density of factories in the area, daily production of waste, and type of waste produced. The factories were then aggregated into the most optimized grouping to maximize the collection of waste by each vehicle. The collection and transportation of waste is then monitored by Black & Veatch field inspectors – stationed at the Municipality Plant ("Hagar"), Yatta landfill, and on roving patrol of the area.

While the ongoing efforts solve the problem in the near term, they are not the final solution. USAID recognizes this issue will require multiple, and concurrent, solutions in order to truly address the slurry waste problem. In addition to the leased vehicle program, USAID is working with the Hebron Municipality on the possible purchase of vehicles and required operational structure for the Municipality to continue this trucking program after June 2013.

Currently, USAID is researching press filter units and preparing for the solicitation of technical and pricing proposals. If the few largest factories could process slurry onsite, this would remove the majority of the waste from the equation. Furthermore, the planned PWA and Hebron Municipality expansion of the Hagar Processing Plant will allow for all remaining, smaller factories to transport their slurry waste for processing at the plant; therefore effectively removing all liquid waste from the system.

Ultimately, the long-term solution desired by all parties would be the reuse of the solid sludge waste. If the liquid slurry waste could be eliminated through the two identified solutions above, then the remaining solid waste would be the only concern. Although not ideal, the material could continue being disposed of at the landfill; however, finding a better solution – such as the conversion to a marketable commodity – is preferred. Preliminary research has indicated that are may be secondary markets for this material, especially in the form of building materials. In coordination with other USAID efforts, plans are underway to research this potential, test several pilot projects, and transition these solutions from an immediate, donor-supported activity to a long-term, locally-sustainable solution.

There was little movement in this plan however until the recent USAID led intervention. USAID helped create a Steering Committee comprised of representatives from Hebron Municipality, Union of Stone and Marble, Palestinian Water Authority, Ministry of National Economy (MoNE) , Ministry of Environmental Affairs (MoEA) and USAID. The Steering Committee following a consultation process launched a temporary but extensive trucking and disposal program.

Chapter Three
Literature review

This chapter reviews the literature on Coagulation and Flocculation processes includes its applications, lab jar test, characteristics of Industrial discharges, and types of coagulants that were used.

3.1 Coagulation and Flocculation

Coagulation and flocculation constitute the backbone processes in most water and advanced wastewater treatment plants. Their objective is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration. Colloidal particles and other finely divided matter are brought together and agglomerated to form larger size particles that can subsequently be removed in a more efficient fashion.

Coagulant plays an important part in areas of water treatment and sewage reuse. But some kinds of inorganic coagulant that are used widely have disadvantages such as large dosage, low effect and harmful to human body, and synthetic organic coagulant has disadvantages of high price and toxicity, so their application was limited (Lu n.d.).

The traditional use of coagulation has been primarily for the removal of turbidity from potable water. However, more recently, coagulation has been shown to be an effective process for the removal of many other contaminants that can be adsorbed by colloids such as metals, toxic organic matter, viruses, and radio nuclides (Sawyer, McCarty and Parkin 1994), (Rao, et al. 1988). Enhanced coagulation is an effective method to prepare the water for the removal of certain contaminants in order to achieve compliance with the EPA (Environmental Protection Agency) newly proposed standards. These contaminants include arsenic(Cheng, et al. 1994), (U. S. Environemtal Protection Agency (EPA) 2000), emerging pathogens such as Cryptosporidium and Giardia(Logsdon, et al. n.d.), and humic materials (U.S. Environmental Protection Agency (EPA) 1999). Humic substances are the precursors of THMs (trihalomethanes) and other DBPs (disinfection byproducts) formed by disinfection processes.

Amirtharaja and O'Melia (Amirtharajah and O'Melia, Coagulation and Flocculation 1999) divided the coagulation process into three distinct and sequential steps:

1. Coagulant formation
2. Particle destabilization
3. Interparticle collisions

The first two steps are usually fast and take place in a rapid-mixing tank. The third step, interparticle collisions, is a slower process that is achieved by fluid flow and slow mixing. This is the process that causes the agglomeration of particles and it takes place in the flocculation tank.

Coagulation is usually achieved through the addition of inorganic coagulants such as aluminum or iron-based salts, and/or synthetic organic polymers commonly known as poly-electrolytes. Coagulant aids are available to help in the destabilization and agglomeration of difficult and slow to settle particulate material.

3.2 Applications of Coagulation

3.2.1 Water Treatment

1. Enhancing the effectiveness of subsequent treatment processes.
2. Removal of turbidity.
3. Control of taste and odor.
4. Coagulation of materials causing color.
5. Removal of bacteria and viruses.
6. Removal of Giardia and Cryptosporidium.
7. Coagulation of NOM (natural organic matter), humic materials which are the precursors of THMs and other DBPs.
8. Removal of arsenic and radio nuclides.

3.2.2 Municipal Wastewater Treatment

1. Improving efficiency of primary treatment plants.
2. Obtaining removals intermediate between primary and secondary treatments.
3. Tertiary treatment of secondary effluents for water reuse.

4. Handling of seasonal loads.
5. Meeting seasonal requirements in receiving streams.
6. Conditioning of biosolids before dewatering.

3.2.3 Industrial Waste Treatment

1. Improving removals from secondary effluents.
2. Removal of metals.
3. Treatment of toxic wastes.
4. Control of color.
5. Handling seasonal wastes.
6. Providing treatment to meet stream and disposal requirements at lower capital cost.

3.2.4 Combined Sewer Overflow

1. Removal of particulate matter and BOD (Biochemical Oxygen Demand).
2. Handling irregular occurrence of storm events.
3. Preventing treatment upset by varying water quality.
4. Meeting seasonal requirements in receiving streams.

3.3 Properties of Colloidal Systems

Colloids are very small particles that have extremely large surface area. Colloidal particles are larger than atoms and ions but are small enough that they are usually not visible to the naked eye. They range in size from 0.001 to 10 μm resulting in a very small ratio of mass to surface area. The consequence of this smallness in size and mass and largeness in surface area is that in colloidal suspensions (Sawyer, McCarty and Parkin 1994):

1. Gravitational effects are negligible, and
2. Surface phenomena predominate.

Because of their tremendous surface, colloidal particles have the tendency to adsorb various ions from the surrounding medium that impart to the colloids an electrostatic charge relative to the bulk of surrounding water (Reynolds 1982).

3.3.1 *Electro-kinetic Properties*

The electrokinetic properties of colloids can be attributed to the following three processes (Sawyer, McCarty and Parkin 1994),(Amirtharajah and O'Melia, Coagulation and Flocculation 1999):

1. Ionization of groups within the surface of particles.
2. Adsorption of ions from water surrounding the particles.
3. Ionic deficit or replacement within the structure of particles.

$$R\text{–}NH_3^+ \rightarrow R\text{–}NH_2 + H^+ \qquad (1)$$

$$R\text{–}COOH \rightarrow R\text{–}COO^- + H^+ \qquad (2)$$

The resulting charge on the surface of such particles is a function of the pH. At high pH values or low hydrogen ion concentrations, the above reactions shift to the right and the colloid is negatively charged. At a low pH, the reactions shift to the left, the carboxyl group is not ionized, and the particle is positively charged due to the ionized amino group. When the pH is at the isoelectric point, the particle is neutral, i.e., neither negatively nor positively charged. Proteinaceous material, containing various combinations of both amino and carboxyl groups, are usually negatively charged at pH values above 4 (Amirtharajah and O'Melia, Coagulation and Flocculation 1999).

3.3.2 *Hydration*

Water molecules may also be sorbed on the surface of colloids, in addition to or in place of, other molecules or ions.

3.3.3 *Brownian Movement*

Colloids exhibit a continuous random movement caused by bombardment by the water molecules in the dispersion medium.

3.3.4 *Tyndall Effect*

Because colloidal particles have an index of refraction different from water, light passing through the dispersion medium and hitting the particles will be reflected. The turbid appearance due to this interference with the passage of light is termed the Tyndall effect. However, it should be noted that this might not always be the case. Water-loving, hydrophilic, colloids may produce just a diffuse Tyndall cone or none at all. The reason for this behavior can be attributed to the bound water layer surrounding colloids. These particles will have an index of refraction not very different from that of the surrounding water. Hence, the dispersed phase and the dispersion medium behave in a similar fashion toward the passage of light.

3.3.5 *Filterability*

Colloids are small enough to pass through ordinary filters, such as paper and sand, but are large relative to ions in size, diffuse very slowly, and will not pass through membranes. As a result, colloidal particles can be readily removed by ultrafiltration but require coagulation prior to their efficient removal by ordinary filtration.

3.4 Influencing Factors

Many factors affect the coagulation process. In addition to mixing that will be explained in greater detail in separate sections, the following discussion covers the most important factors.

3.4.1 *Colloid Concentration*

Colloidal concentration has a large impact on both the required dosage and the efficiency of the coagulation process itself. The dosage of coagulants required for the destabilization of a colloidal dispersion is stoichiometrically related to the amount of colloidal particles present in solution (Stumm and O'Melia 1968).

3.4.2 *Coagulant Dosage*

The effect of aluminum and iron coagulant dosage on coagulation, as measured by the extent of removing particles causing turbidity in water, has been studied and evaluated in great detail by Stumm and O'Melia (1968) and O'Melia (1972)(Stumm and O'Melia 1968),(O'Melia 1972). They divided the relationship into four zones starting with the first low-dosage zone and increasing the dosage progressively to the highest dosage that is applied in zone four:

Zone 1: Not enough coagulant is present for the destabilization of the colloids.

Zone 2: Sufficient coagulant has been added to allow destabilization to take place.

Zone 3: Excess concentration of coagulant can bring about charge reversal and restabilization of particles.

Zone 4: Oversaturation with metal hydroxide precipitate entraps the colloidal particles and produces very effective sweep coagulation.

The range of coagulant dosage that triggers the start, end, or elimination of any of the above zones is dependent on colloidal particle concentration and pH value.

3.4.3 Zeta Potential

The zeta potential represents the net charge of colloidal particles. Consequently, the higher the value of the zeta potential, the greater is the magnitude of the repulsive power between the particles and hence the more stable is the colloidal system. The magnitude of the zeta potential is determined from electrophoretic measurement of particle mobility in an electric field.

3.4.4 Affinity of Colloids for Water

Hydrophilic (water-loving) colloids are very stable. Because of their hydration shell, chemicals cannot readily replace sorbed water molecules and, consequently, they are difficult to coagulate and remove from suspension. The stability of hydrophilic dispersions depends more on their "affinity" for water than on their electrostatic charge. It has been estimated that suspensions containing such particles require 10–20 times more coagulant than what is normally needed to destabilize hydrophobic particles (Hammer 1986).

3.4.5 pH Value

The solubility of colloidal dispersions is affected radically by pH, $Al(OH)_3$ is amphoteric in nature and is soluble at low and high pH. The greatest adsorption occurs in the pH range where there is minimum solubility. Examples of optimum pH ranges for metallic salts are shown in Table 3.1(McGhee 1991).Amirtharajah and Mills (1982) (Amirtharajah and Mills, Rapid mix design for mechanisms of alum coagulation 1982)reported that optimal coagulation with alum takes place at pH values near 5 and 7. At these points, the positively charged aluminum hydroxide neutralizes the negatively charged turbidity-producing colloidal particles, resulting in zero zeta potential. However, in the pH range from 5 to 7 the colloidal particles are re-stabilized due to charge reversal brought about by excess adsorption of the positively charged aluminum hydroxide species. pH also plays a part in affecting the amount of aluminum residual in the treated water (Van Benschoten, Jensen and Rahman 1994).

The influence of pH on the polymer's behavior and effectiveness in coagulation is particularly important because of the interaction between pH and the charge on the electrolyte. The extent of charge change with pH is a function of the type of active group on the polymer (carboxyl, amino, etc.) and the chemistry of those groups.

Table 3.1: Optimum pH Values for Metallic Coagulants

Coagulant	pH
Aluminum sulfate Ferrous sulfate Ferric chloride Ferric sulfate	4.0 to 7.0 8.5 and above 3.5 to 6.5 and above 8.5 3.5 to 7.0 and above 9.0

Source: T. J. McGhee, 1991

3.4.6 Anions in Solution

Coagulation with alum is brought about by various species of positively charged aluminum hydroxides. Aluminum hydroxide possesses its lowest charge and lowest solubility at its isoelectric point that lies in the pH range of 7 to 9 (Amirtharajah and O'Melia, Coagulation and Flocculation 1999). As a result, when the alum dosage is increased within this pH range, sweep coagulation takes place due to the formation of the aluminum hydroxide precipitate. However, at lower pH values (5–7), higher dosages of alum will tend to increase the positively charged alum species that get adsorbed on particles' interface leading to charge reversal and the restabilization of the colloidal particles. Similar concepts and conclusions are applicable to iron coagulants.

3.4.7 Cations in Solution

The presence of divalent cations, such as Ca^{2+} and Mg^{2+}, in raw water is commonly considered not only to be helpful in the coagulation of negatively charged colloidal clay particles by anionic polymers but also to be necessary. Three reasons have been suggested to be responsible for this beneficial effect (Black, Birkner and Morgan 1965):

1. Compression of the colloidal double layer.
2. Reduction of the colloidal negative charge and minimization of repulsive potential.
3. Reduction in the range of repulsive barrier between adsorbed polymers.

3.4.8 Temperature

Coagulation by metallic salts is adversely affected by low temperature (Van Benschoten, Jensen and Rahman 1994)(Morris and Knocke 1984). However, the effect has been reported to be more pronounced in using alum, hence the recommendation to switch to iron salts when operating under low water temperatures (Morris and Knocke 1984),(Leprince, Fiessinger and Bottero 1984). The increase in rate and effectiveness of coagulation at higher temperatures can be attributed to the following:

1. Increase in velocity of molecules and hence in kinetic energy.
2. Increase in rate of chemical reactions.
3. Decrease in time of floc formation.
4. Decrease in viscosity of water.
5. Alteration in the structure of the flocs resulting in larger agglomeration.

3.5 Coagulants

Coagulants, i.e., chemicals that are added to the water to achieve coagulation, should have the following three properties (Mackenzie and Cornwell 1985):

1. Trivalent metallic cations or polymers whose effectiveness as coagulants has been determined.
2. Nontoxic and without adverse physiological effects on human health.
3. Insoluble or low solubility in the pH ranges common in water-treatment practice. This is necessary in order to have an efficient coagulation process and to be able to leave the lowest possible residual of the chemical in the treated water.
4. The most commonly used coagulants in water and wastewater treatment include aluminum sulfate (alum), ferric chloride, ferric sulfate, ferrous sulfate known as (copperas), sodium aluminate, poly-aluminum chloride, and organic polymers.

3.6 Coagulation Control

Theoretical analysis of coagulation is essential for understanding the process, for knowing how it works and what it can achieve as well as for discerning how to obtain the maximum performance out of it. There are four types of colloidal systems (O'Melia 1972):

Type I: High colloidal concentration, low alkalinity: This is the least complicated system to treat. At low pH 4–6 levels metallic salts in water produce positively charged hydroxometal polymers. These in turn destabilize the negatively charged colloids by adsorption and charge neutralization. The high concentration of particulate material provides an ample opportunity for contact and building of good flocs. As a result, one has to determine only one variable—the optimum coagulant dosage.

Type II: High colloidal concentration, high alkalinity*:* Destabilization can also be accomplished, as in Type I, by adsorption and charge neutralization. However, in order to overcome the high alkalinity, there are two possible approaches. One alternative is to feed a high coagulant dosage that is sufficient to consume the excess alkalinity as well as to form the positively charged hydroxometal polymers. The second alternative is to add an acid to lower the pH before feeding the coagulant. In this case one has to determine two variables— the optimum coagulant dosage and optimum pH.

Type III: Low colloidal concentration, high alkalinity: Because of the low chance of interparticle contacts due to the low colloidal concentration, the feasible approach in this case is to achieve sweep coagulation by feeding a high coagulant dosage that results in the entrapment of the colloidal particles in the metal hydroxide precipitate. A second alternative approach is to add a coagulant aid that will increase particle concentration and hence the rate of interparticle contact. A lower coagulant dosage will then be needed to achieve coagulation by charge neutralization.

Type IV: Low colloidal concentration, low alkalinity: This is the most difficult case to handle. The low colloidal concentration and depressed rate of interparticle contacts do not allow effective coagulation by adsorption and charge neutralization. On the other hand, the low alkalinity and low pH of the suspension do not enable rapid and effective destabilization by sweep coagulation. Coagulation in this system can be achieved by the addition of a coagulation aid (increase colloidal concentration), addition of lime or soda ash (increase alkalinity), or the addition of both but at lower concentrations.

However, because the process is so complex and the number of variables is so large, in most cases it is not feasible either to predict the best type of coagulant and optimum dosage or the best operating pH. The most practical approach is to simulate the process in a laboratory setting using the jar test. Other available alternatives and/or supplementary techniques include the zetameter (electrophoretic measurement) and the streaming current detector.

3.7 Lab jar test

The jar test is the most valuable tool available for developing design criteria for new plants, for optimizing plant operations, and for the evaluation and control of the coagulation process. A jar test apparatus is a variable speed, multiple station or gang unit that varies in configuration depending on the manufacturer. The differences, such as the number of test stations (usually six), the size (commonly 1000 mL) and shape of test jars (round or square), method of mixing (paddles, magnetic bars, or plungers), stirrer controls, and integral illumination, do not have an appreciable impact on the performance of the unit.

The jar test can be run to select each of the following:

1. Type of coagulants.
2. Dosage of coagulants.
3. Coagulant aid and its dosage.
4. Optimum operating pH.
5. Sequence of chemical addition.
6. Optimum energy and mixing time for rapid mixing.
7. Optimum energy and mixing time for slow mixing.

The detailed procedure for the setting up, running, and interpreting a jar test is explained in various publications(Black, et al. 1957),(Ervin, Mangone and Singley 1980), and (Hudson and Wagner 1981). Basically, for dosage optimization, samples of water/wastewater are introduced into a series of jars, and various dosages of the coagulant are fed into the jars. The coagulants are rapidly mixed at a speed of 60–80 rpm for a period of 30–60 s then allowed to flocculate at a slow speed of 25–35 rpm for a period of 15–20 min. The suspension is finally left to settle for 20–45 min under stationary conditions. The appearance and size of the floc, the time for floc formation, and the settling characteristics are noted. The supernatant is analyzed for turbidity, color, suspended solids, and pH. With this information in hand, the optimum chemical dosage is selected on the basis of best effluent quality and minimum coagulant cost.

Chapter Four
Material and Methodology

4.1 Introduction

The evaluation of technical, social, and economical situation for stone cutting firms in Hebron district was assessed by carrying out statistical and lab analysis as well as mapping analysis. The key factors that play role towards the industrial wastewater of the district were identified. For coagulants selection three parameters were measured; pH, TSS, and Turbidity.

To identify the most sewer dumping site a questionnaire were distributed to stone cutting firms in 100 firms in Hebron city area.

To identify the risk of stone cutting firms with mixing with tanning industry a map analysis was carried out.

4.2 Data collection

A questionnaire has been developed for Stone cutting owners, workers, and other relevant parties, to stand on the current situation in the area; questionnaire was distributed on two times, one May 2011 and one July 2012.

The first questionnaire was to find the amount of wastewater discharging daily from each firm, in addition to installed facility for treatment (See Appendix 1).

The second questionnaire was to find the current situation of facility water consumption and type of supplier. In both first and second stage a 145 coordinates (Appendix 2) was collected using GPS type GRAMIN –*e*trex.

Figure 4.1: GPS Device (Gramin-*e*trex).

4.3 Lab Work

4.3.1 Jar Test Principle

A useful laboratory experiment for the evaluation of coagulation/flocculation of untreated water is the jar test. This test provides information on the effects of the concentrations of the coagulants, mixing of the raw water, and the water quality parameters such as pH and alkalinity on the coagulation process. The jar test is often used for the design of treatment facilities and in the routine operation of treatment plants.(Iowa State University n.d.)

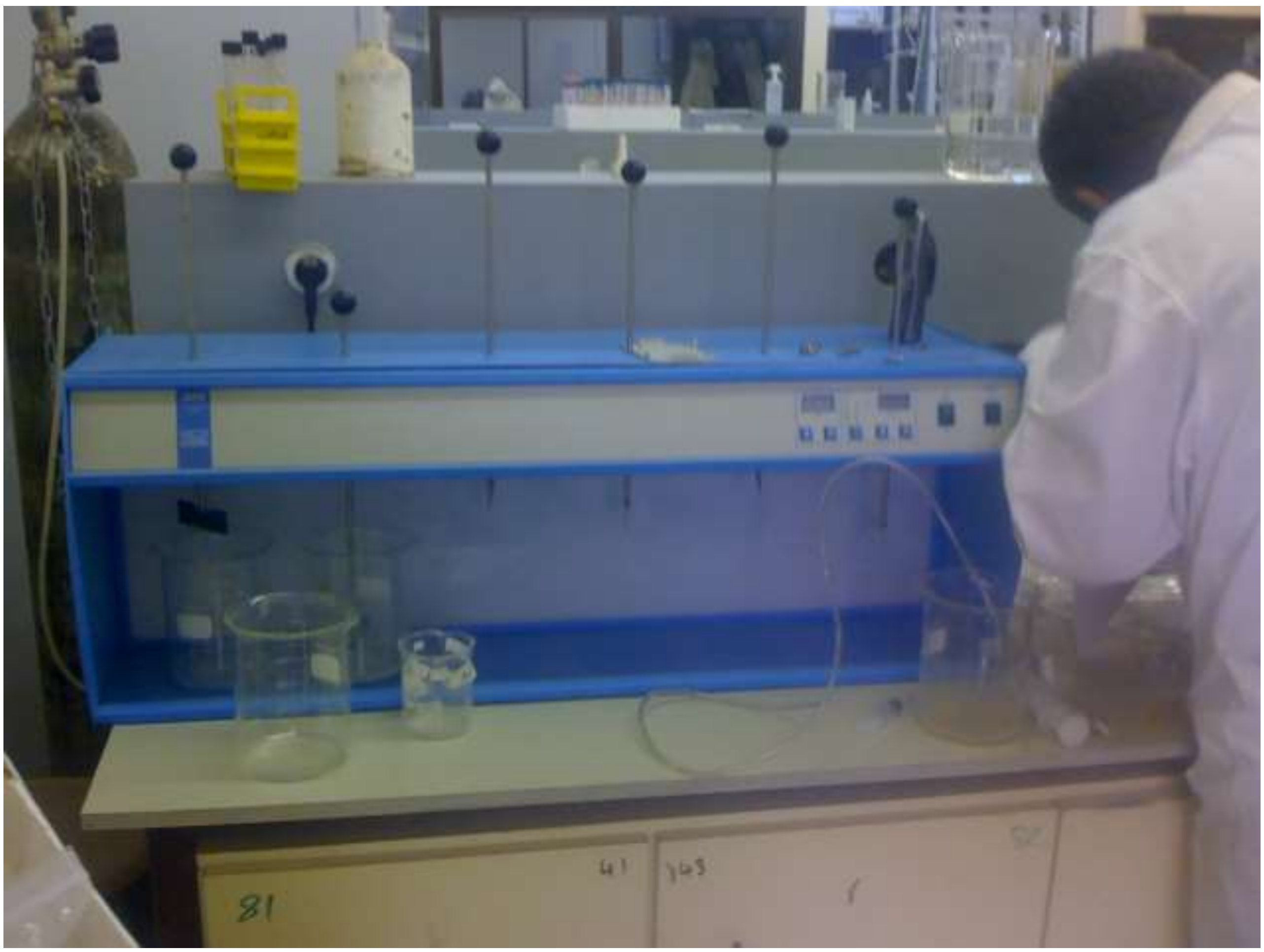


Figure 4. 2: Lab Jar Test in IEWS-Birzeit University, 2011

A lab jar test experiment was carried out to conduct the coagulation process with different coagulants, dose, waiting time, rotation time. The pH, TSS, Turbidity measurement was found to indentify the difference between two main coagulants used; conventional polymer (Electro-Polymer or know commercially as Fokland), and Ferric Chloride ($FeCl_3.6H_2O$).

4.3.2 Solutions Preparations

Two solutions were prepared to conduct the experiment of coagulation of CaCO3 as coagulants dose experiment:

1. Polymer solution preparation

a. Prepare one liter of tap water at 25° C.
b. Add 0.01 mg of polymer into 1 L beaker.
c. Put the solution on the mixer and leave it for 20 Sec to be well mixed.

The resulted solution will be 0.01 mg/L of polymer.

Different concentrations were added to the solution of slurry wastewater just before run the jar test for 1 min and 120 RPM.

2. Ferric Chloride Solution preparation

a. A pure sample of FeCL3.6H2O weighted 1 gm and add to tap water, shacked well under 25° C.
b. A various concentrations were prepared.
c. Solution pH was 2.3 which directly affect the pH of solution which is basic.

Identifying variables for both coagulants

1. Dose dependent

A different 15 dose were added to 15 samples with 1 min retention time and 120 RPM, after 15 min waiting time after the completion of reaction.

TSS, Turbidity, and pH were measured for all samples are recorded (See Results)

2. Waiting time dependent

Waiting time refers to the time after completion of whole process from the moment of adding the dose of coagulant until the completion of rotation time, at that moment waiting time measured.

Eight samples were determined using different waiting time; TSS, turbidity, and pH were measured and recorded.

4.3.3 Turbidity meter principle

Turbidity is described in the Standard Methods for the Examination of Water and Wastewater Method 2130B (EPA Method 180.1) for turbidity measurement as, “an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample” (Standard Methods 1995). This chapter includes a detailed summary of the various types of instruments used to measure turbidity and includes descriptions of the physical properties associated with the measurements of turbidity and design configurations.

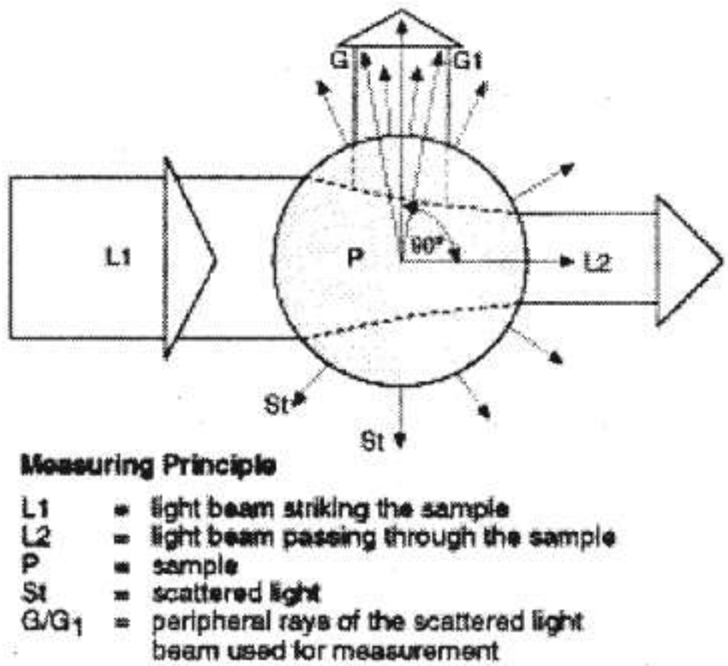


Figure 4.3: Scattered Light at 90°

As shown in Figure 4.2, modern turbidimeters use the technique of nephelometry, which measures the amount of light scattered at right angles to an incident light beam by particles present in a fluid sample. In general, all modern turbidimeters utilize the nephelometric measurement principals, but instrument manufacturers have developed several different meter designs and measurement configurations.

In this research, portable turbidimeters (Figure 4.3) were used to measure the turbidity similar to the bench top units, except that they are designed for portable use and are battery operated. Portable turbidimeters are available in a variety of designs, including the single beam and ratio designs. The accuracy of portable instruments is comparable to the bench top units, but the resolution of low turbidity reading may only be 0.01 NTU as compared to the 0.001 NTU resolutions of bench top units (EPA n.d.).

Portable turbidimeters are designed for use in the field with grab samples. These instruments are designed to be rugged and capable of withstanding the effects of moving the instrument as well as variable field conditions(EPA n.d.).

Figure 4. 4: HACH Turbidimeter used in IEWS lab.

4.3.4 TSS Measurement

Total suspended solids is a water quality measurement usually abbreviated **TSS**. It is listed as a conventional pollutant. This parameter was at one time called non-filterable residue (**NFR**), a term that refers to the identical measurement: the dry-weight of particles trapped by a filter, typically of a specified pore size. However, the term "non-filterable" suffered from an odd (for science) condition of usage: in some circles (Oceanography, for example) "filterable" meant the material retained on a filter, so non-filterable would be the water and particulates that passed through the filter(Wikipedia contributors 2013).

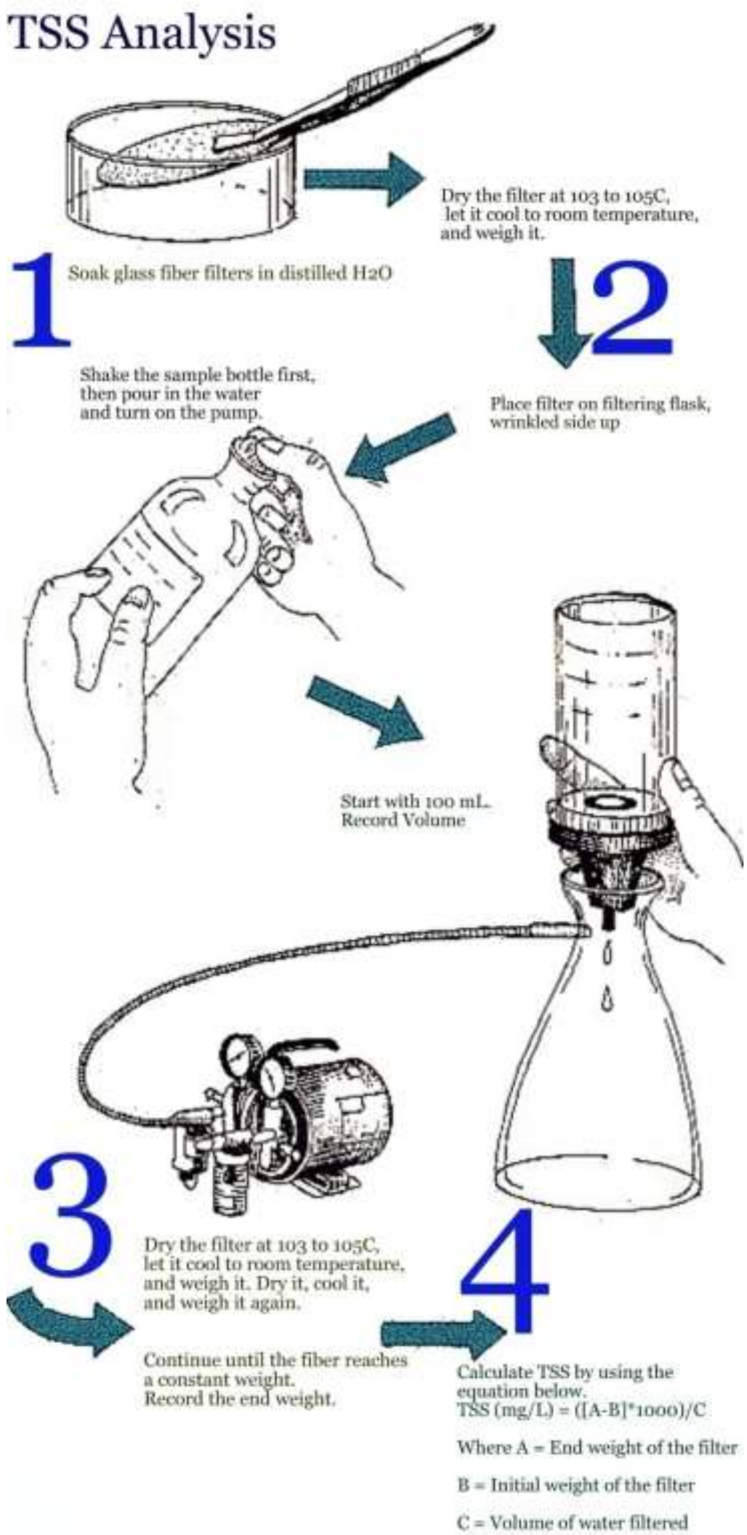


Figure 4.5: TSS Analysis, Source: Dept of Ecology, State of Washington University

4.4 Software Analysis

The Microsoft Excel 2007 package were used for results statistical analysis, manipulate and process the figures and charts, and make comparison of different coagulants, in addition the study tours survey data analysis.

4.5 GIS map

Licensed ArcGIS 9.3.1 software was used to create, and manipulate the Distributabce of stone cutting firms in term of discharges amount, locations, and carrying out certain treatment systems were installed before.

Chapter Five
Results and Discussion

5.1 Introduction

In this chapter the results will be presented and discussed to define what is the best coagulants to be used in the industry, also it will focus on the current status of water consumption and wastewater discharge as well as the current status from treatment perspective.

Table 5.1 describes the average physical characteristics of raw wastewater from stone cutting firms through different sample collection tours on both TSS which is varied from 1700-11000 mg/L and Turbidity which varied from 3100-19350 NTU, that's because of the heterogeneous nature of the wastewater which seriously affected by the type of stone and type of cutter that has a serious effect.

Table 5. 1: Physical Characteristics of Raw wastewater from Stone cutting in Hebron

Physical Characteristics	Value
Average TSS	5015 mg/L
Average Turbidity	7288 NTU
Average pH	7.6

5.2 Polymer Coagulant Effect

The PRAESTOL® 55540 product is used for flocculation mainly of mineral and hydroxide type solid particles and colloids. It is most suitable for the clarification of washing water used in the treatment of mining raw materials, such as hard coal, rock salt, sand, gravel and clay. Further range of application are in the treatment of surface and ground waters, and of various types of waste water after treatment with hydroxide formers. The mode of action of anionic PRAESTOL® products is based essentially on charge exchange between the electrical charges along the polymer chains, which are present in aqueous solution, and the surface charges of the suspended solid particles (Ashland Deutschland GmbH n.d.).

5.1.1 Polymer Description

Table 5.2: Physical, and Chemical properties of Polymer *(Ashland Publications, 2007)*

Feature	Description
Composition	high molecular weight, medium anionic charge polyelectrolyte based on acrylamide and sodium acrylate
Appearance	white to light yellow granular material
Charge type	anionic
Bulk density	approx. 750 kg/m^3
Viscosity (0.5 % in deionized water)	approx. 800 mPa
Viscosity (0.1 % in deionized water)	approx. 450 mPa
Viscosity (0.1 % in tap water)	approx. 125 mPa
Viscosity (0.5 % in tap water)	approx. 15 mPa
pH-value (0.1 % in tap water)	approx. 7
Effective in pH-range	6 – 10
CAS-Number of the main component ("active substance")	25085-02-3, 2-Propenoic acid, sodium salt, polymer with 2-propenamide

5.1.2 Polymer Effect:

A. Dose Effect on TSS Removal:

The figure bellow represent a correlation between the Polymer dose and the removal of TSS started from 56.29% at 0.001 mg/L from the solution until reaching platue (99%) at 0.1 mg/L of polymer under 25˚C and pH 7.99 with time, rotation per minute independent factors at 15 min waiting, and 120 RPM See Appendix 3.

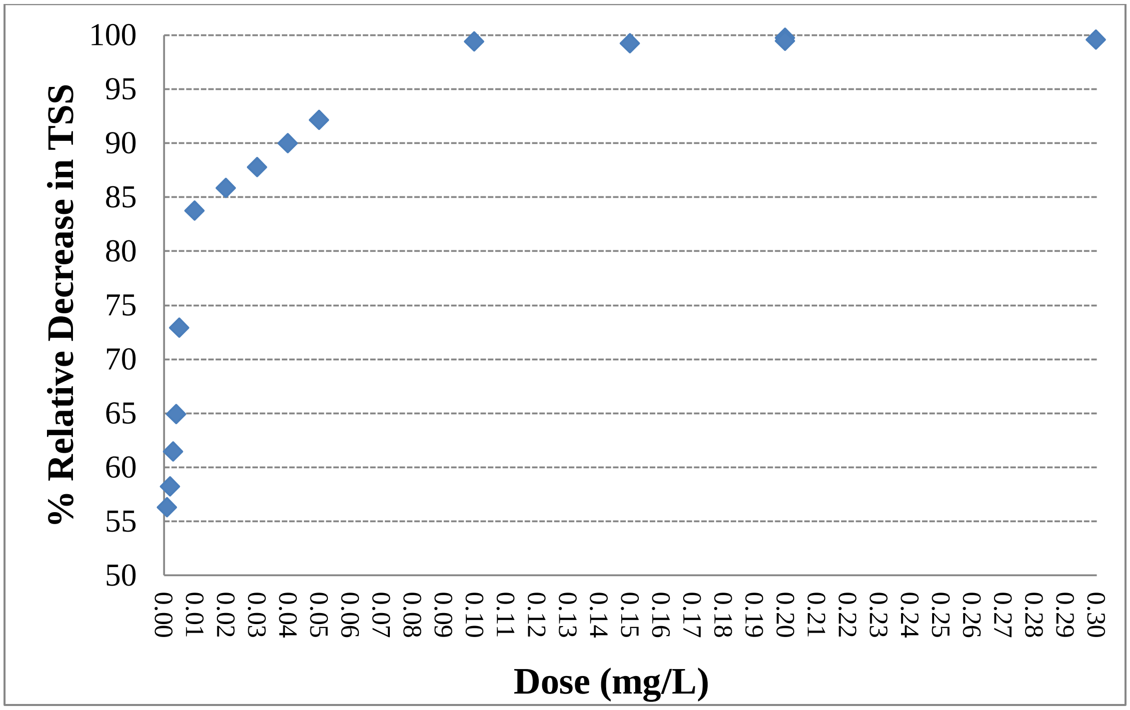


Figure 5.1: Equilibrium percentage relative decrease in TSS as a function of dose of Polymer.

B. Dose Effect on Turbidity Removal

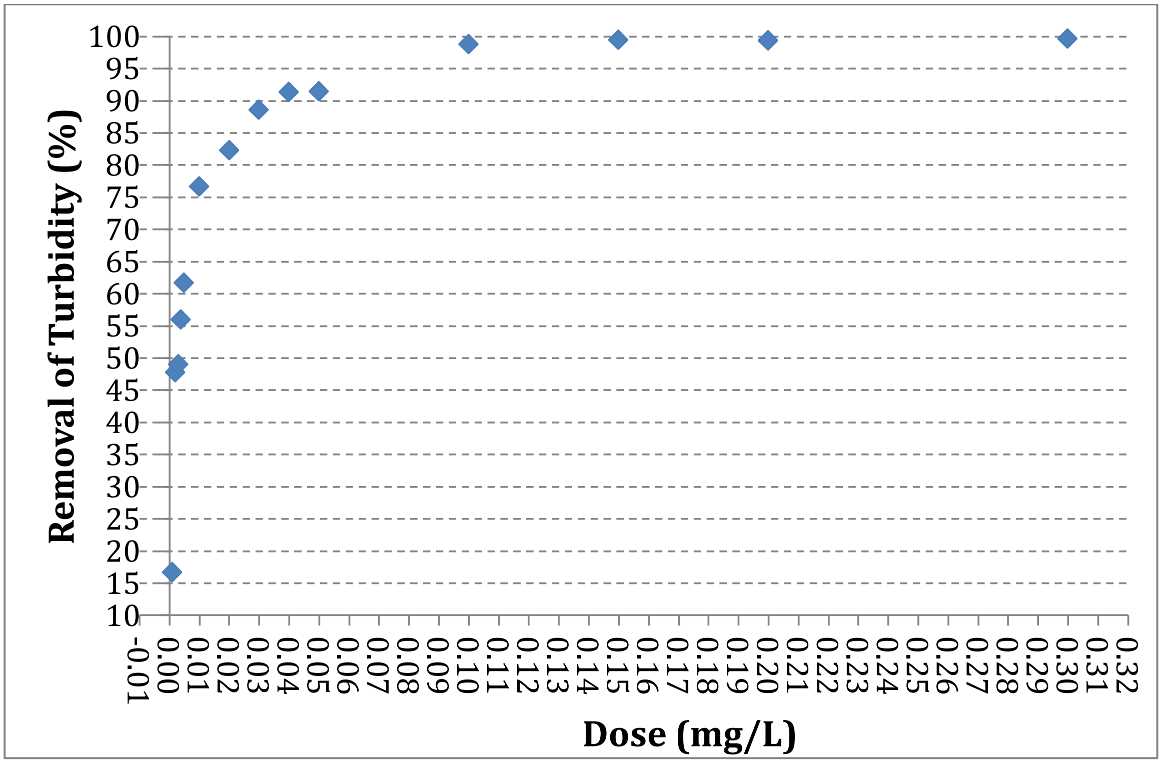


Figure 5.2: Equilibrium percentage relative decrease in Turbidity as a function of dose of Polymer.

From figure 5.2, a representation of positive proportion between the Polymer dose and the removal of Turbidity started from 16.68% at 0.001 mg/L from the solution until reaching platue (99%) at 0.1 mg/L of polymer under 25˚C and pH 7.99 with time, rotation per minute independents factors at 15 min waiting, and 120 RPM See Appendix 3.

C. Time Effect of TSS, and Turbidity Removal

A percent decrease of TSS and turbidity starting from the time zero after the completion of reaction resulting an 86%, and 92.45% for TSS and Turbidity respectively, at dose of 0.3 mg/L polymer See Figure 5.3.

An approach of full TSS removal achieved after 3 min from the completion of reaction with 0.5 mg/L concentration of the dose at 120 RPM. See appendix 4, 5, and 6.

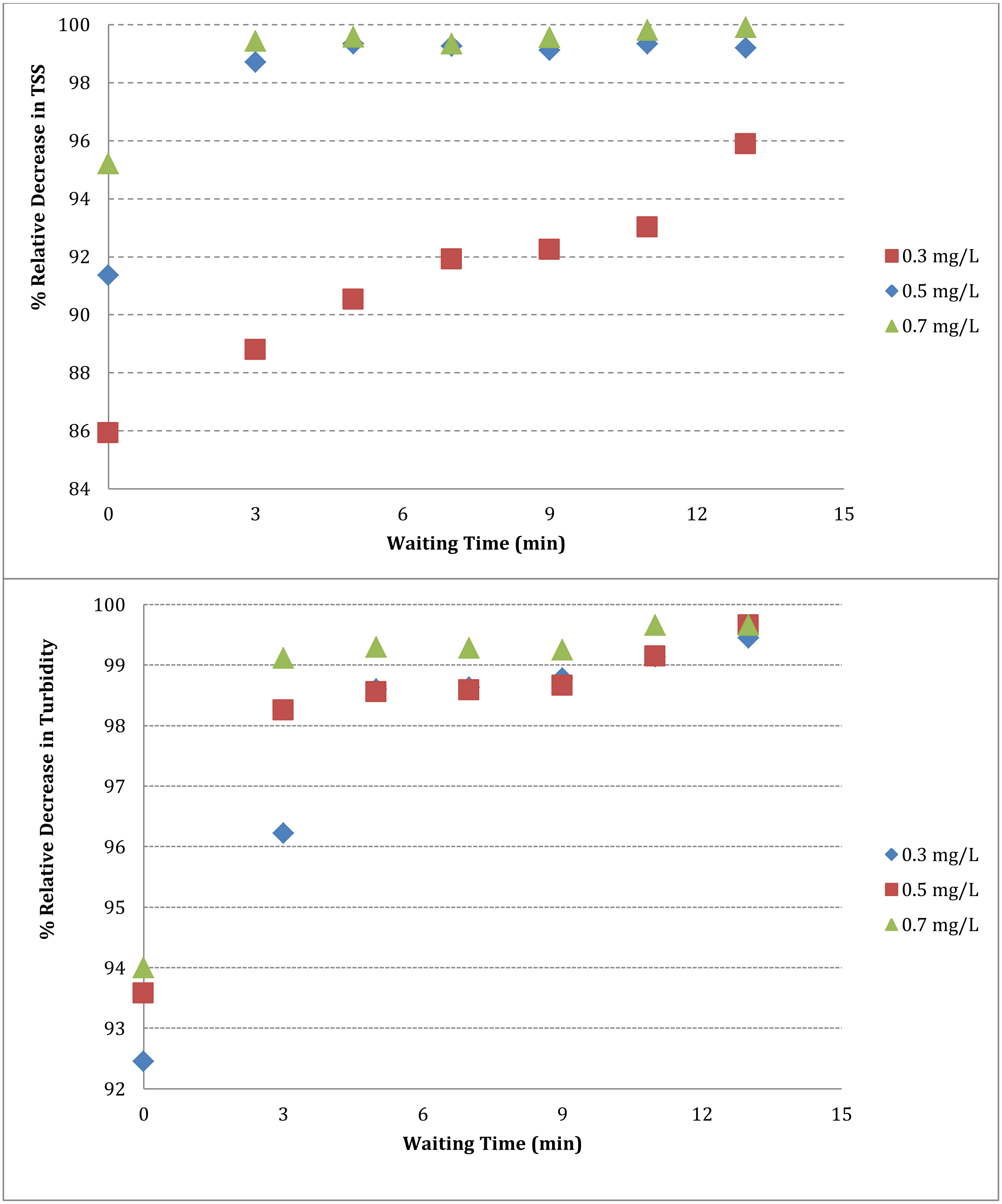


Figure 5.3: Percentage relative decrease in both of TSS and Turbidity as a function of waiting time for Coagulation experiments.

5.3 Ferric Chloride Coagulant Effect

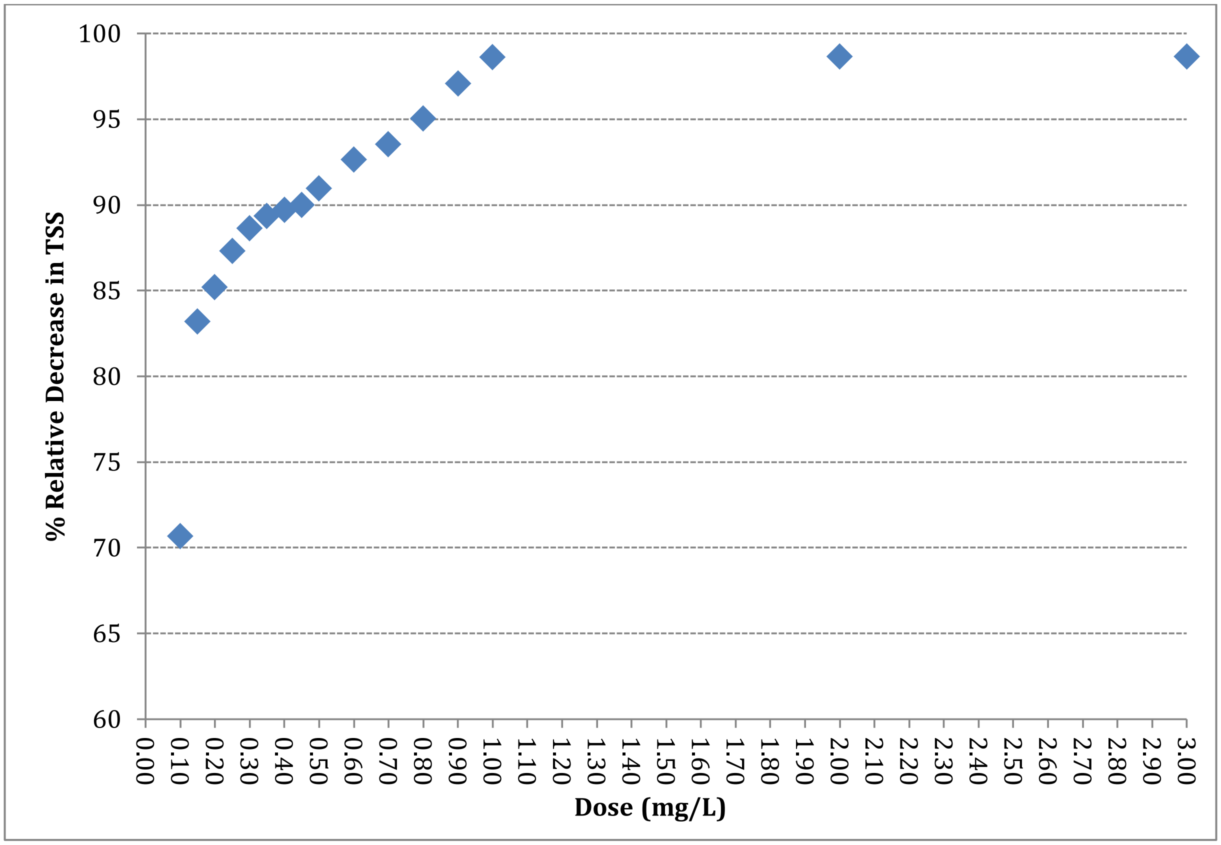


Figure 5.4: Equilibrium percentage relative decrease in TSS as a function of dose of Ferric chloride.

A positive correlation between the Ferric Chloride dose and the % Relative decrease in TSS started from 71% at 0.1 mg/L from the solution until reaching platue (99%) at 0.2 mg/L of polymer under 25˚C and pH 7.05 with time, rotation per minute independents factors at 15 min waiting, and 120 RPM See appendix 7.

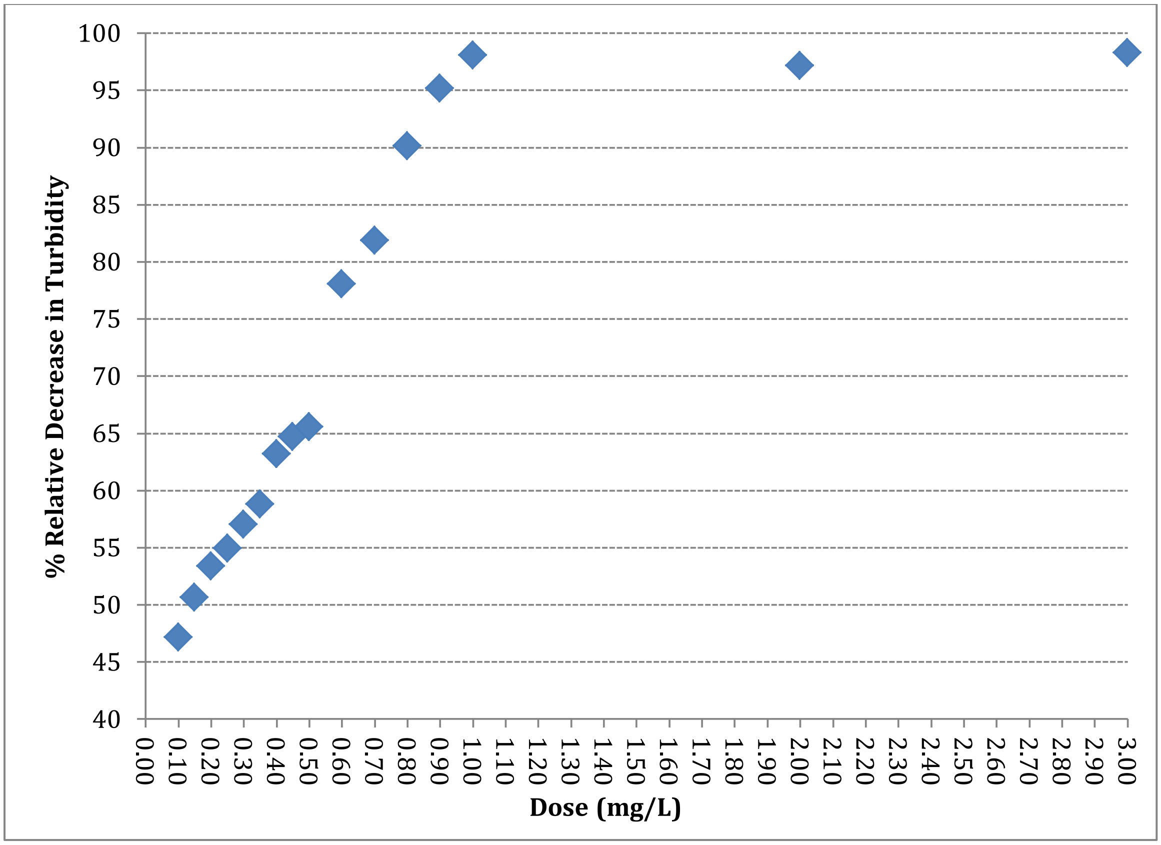


Figure 5. 5: Equilibrium percentage relative decrease in Turbidity as a function of dose of Ferric chloride.

A positive correlation between the Ferric chloride dose and the removal of Turbidity started from 47% at 0.1 mg/L from the solution until reaching platue (99%) at 0.3 mg/L of polymer under 25˚C and pH 7.99 and pH 7.99 with time, rotation per minute independents factors at 15 min waiting, and 120 RPM, See appendix 8, 9, and 10. See figures bellow.

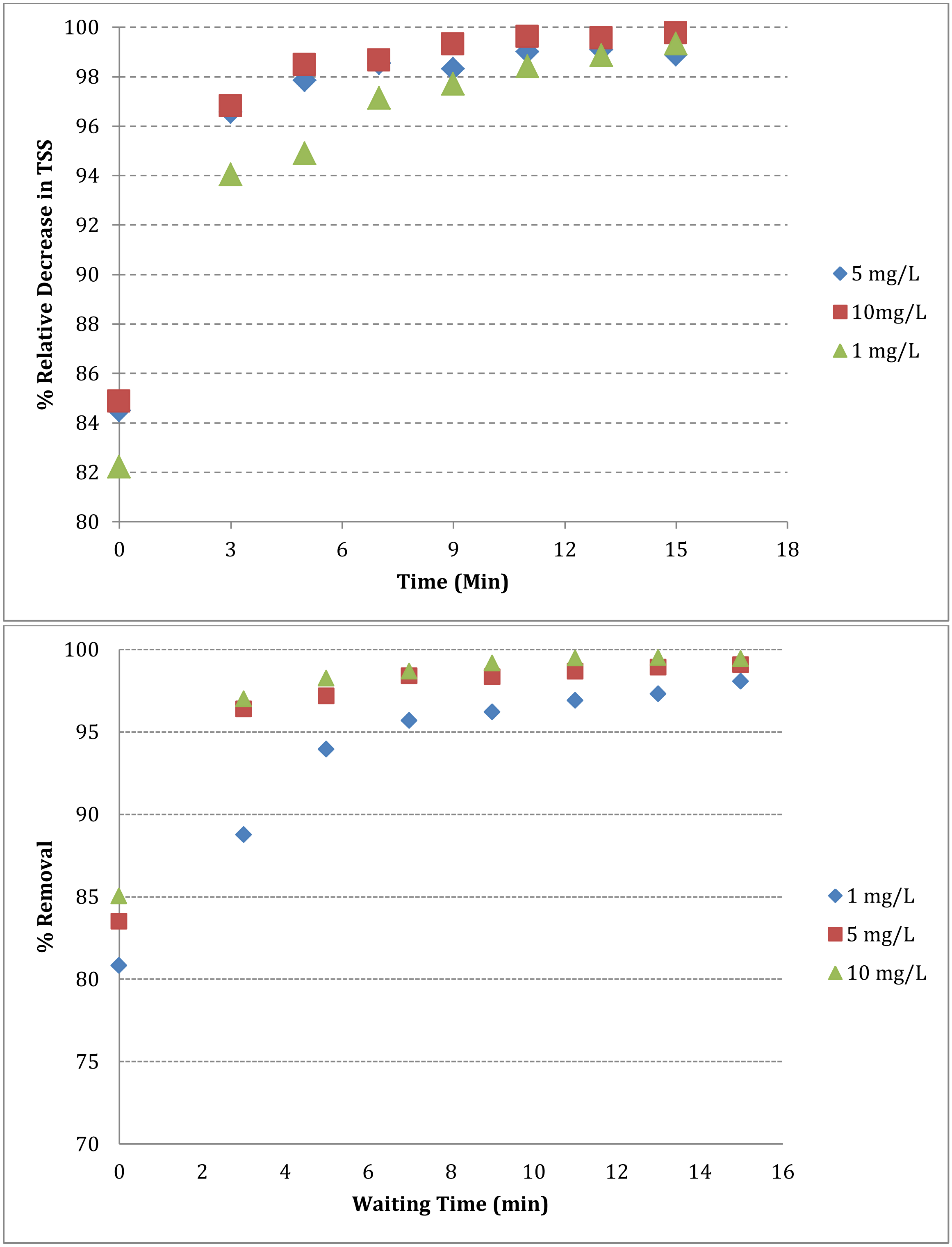


Figure 5. 6: Percentage relative decrease in both of TSS and Turbidity as a function of waiting time for Coagulation experiments.

5.4 Pollution study tours in the industrial zone

Two phases of study tours in the study area were done one in May 2011 and one in July 2012, two phases were mainly concerned on the daily discharging of wastewater from factories, effect on people toward such attitude, impact on environmental life, and economical situation.

5.4.1 Phase one

In this phase data describing the discharging amounts of wastewater, the type of treatment, and location of discharges was collected mapped, and analyzed.

1. Discharge amount and methods of discharge

Table 5.2 describes the amount of wastewater discharging per day, and months, in both wastewater and solid waste.

This study was involved into different type of treatment systems that currently running in term of press filter system which doesn't discharge liquid waste but solid one as the USAID and other private sector treatment facilities.

Data were analyzed and manipulated to be applied on 172 stone cutting firms currently running in the industrial zone, after taking the average from the targeted 145 firms.

Table 5.3: Stone cutting firms discharge of wastewater and solid waste.

Parameters	Descriptions
Average Wastewater Discharge per firm per day	7.82 m^3/Day
Average Wastewater Discharge per firm per Month	160.22 m^3/month
Total Discharge Monthly for 172 stone cutting firms	27557.80 m^3/month
Total daily discharge for 172 stone cutting firms	1252.63 m^3/Mon
Total solid waste discharge from 8 stone cutting firms with USAID facility monthly	62 ton/month
Average discharge of solid waste from 8 stone cutting firms with USAID facility per firm per month	7.75 ton/firm/month

Figure 5.7 describe the waste water and solid cake discharging methods used in 145 selected stone cutting firms, it was found that 30.3 % discharge their wastewater and solid cake into wadis and old quarries, 40% discharge into local municipal sewer system, 8 % using the existing Hagar Project plant, and 20.6 % using their private lands, which means that at least 453.56 m^3 of wastewater discharges directly into sewer system, added to them 344 m^3 that discharge into wadies which reaches the Hebron stream because of the geography of the area.

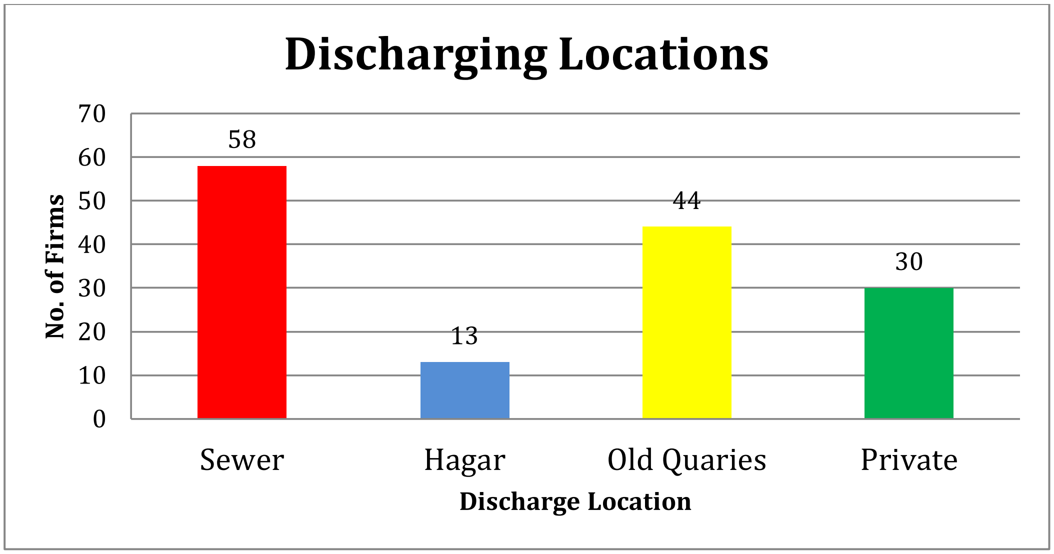


Figure 5.7: A Number of firms as a function of discharging Location stone cutting industry in Hebron

Figures bellow classifies and describes the type of treatment systems used for stone cutting firms in Hebron Industrial zone as follow:

1. Sedimentation Pools, an old fashion traditional sedimentation system depends on gravity to sedmintate the calcium carbonate without coagulants, this method was widely used before CH2MHILL project in 2002, then it became less used because of negatives regarding the area, risks of sinking into the pools, and the hardness to discharge it, See Figure 5.8 bellow.

Figure 5.8: Sedimentation Pools

2. Centrifuging Tanks commercially know (Silo), which considers as a recent method used at the beginning of 1990s in Hebron city since, it composed of both rotation tank and centrifuging tank, it become the alternative of sedimentation pools because of high load capacity varies from 25-50 m^3 and did not require large area to install, in addition low running cost including operation and maintenance since it is manufactured locally with affordable price, See Figure 5.9.

Figure 5.9: Centrifuging Tank - Hebron Industrial Zone

3. Press Filter (Dewatering System), it refer to a process done after completion of separation of water layer from the slurry layer in centrifuging tank, which composed of number of press filters depends on the capacity and dense of slurry, after processing the slurry from Silo it become dried and semi-solid (Solid Cake), See Figure 5.10.

Figure 5.10: Press Filter System, Hebron Industrial Zone

Figure 5.11 describes the treatment systems in term of No. stone cutting firms in Hebron Industrial zone was found that 53% of firms uses Silo system with and without press filters, 17 of them using filters only,which indicates the importance to use appropriate type of coagulants to give the selected industries the best quality of treated effluent to be reused again. Also it was found that 20% of stone cutting firms using sedimentation pools.

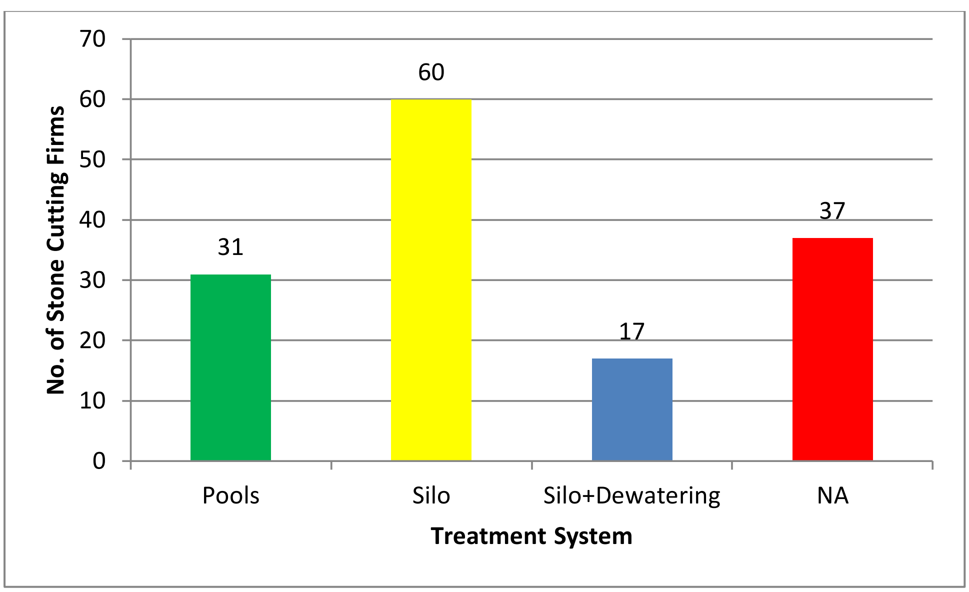


Figure 5.11: Number of stone cutting firms per treatment System

5.4.2 Phase two

Phase two of the study included two important questions in term of amount of water used on daily base and type of water source.

Figure 5.12 describes the water source for the selected firms; it was found that 46% of stone cutting firms depend on water tank trucks to supply their firms, and 40% using water supply network, but also those using tanks in the shortage water seasons.

19% of stone cutting firms depending on Runoff through water collection systems were built on their stone cutting firms roof, connected to the storage tanks underground of the firms.

It was discovered that 4% only uses spring as the water source for their industries in the zone which raise the risk here to attitude of others who to dig and abstract water from shallow aquifers.

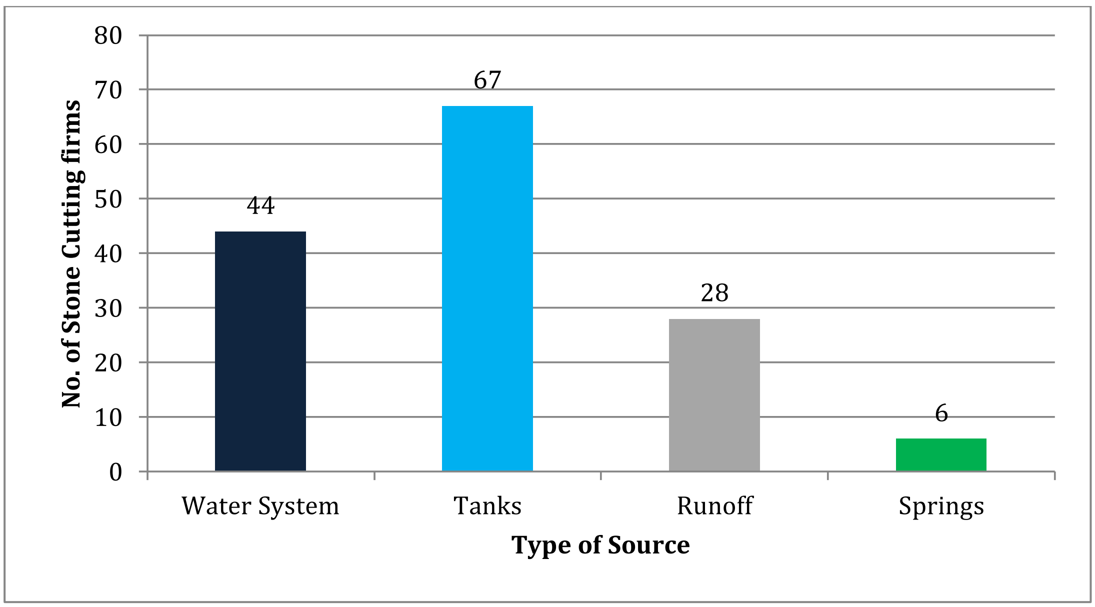


Figure 5.12: A survey of the source of water to stone cutting firms

Figure 5.13 describe water consumption of stone cutting firms per daywhich exceeds 800m^3/day of water from different supply, which mean that the discharge includes 63% of water.

The figure also it represents the water amount per firm as 30% using 100-150 m^3/day, 22% using 50-100 m^3/day, 16% using 150-200 m^3/day, and 10% using more than 200m^3/day.

Through the surveys tours the first and second it was found that part of stone cutting firms owners don't respond to answer all questions, because of trust problem, or product quantity figures and numbers which consider as a confidential data.

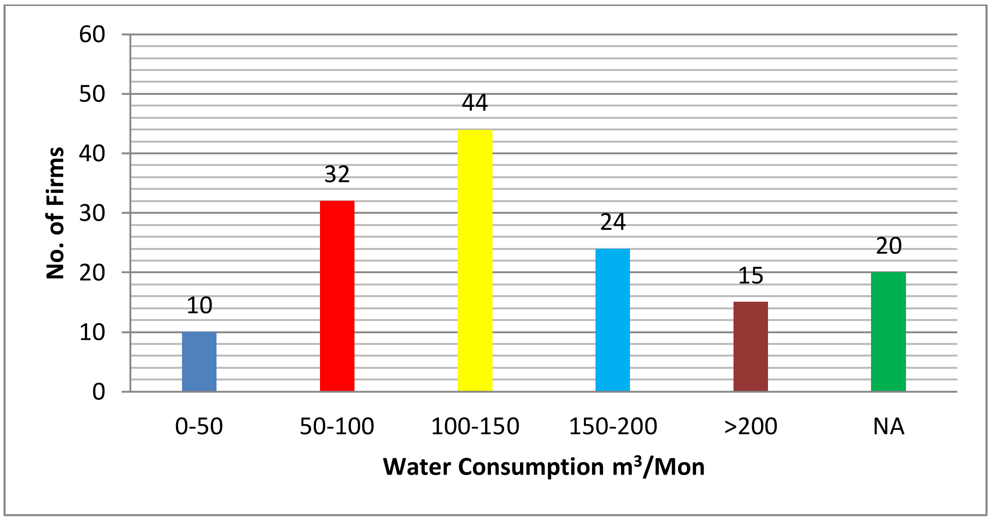
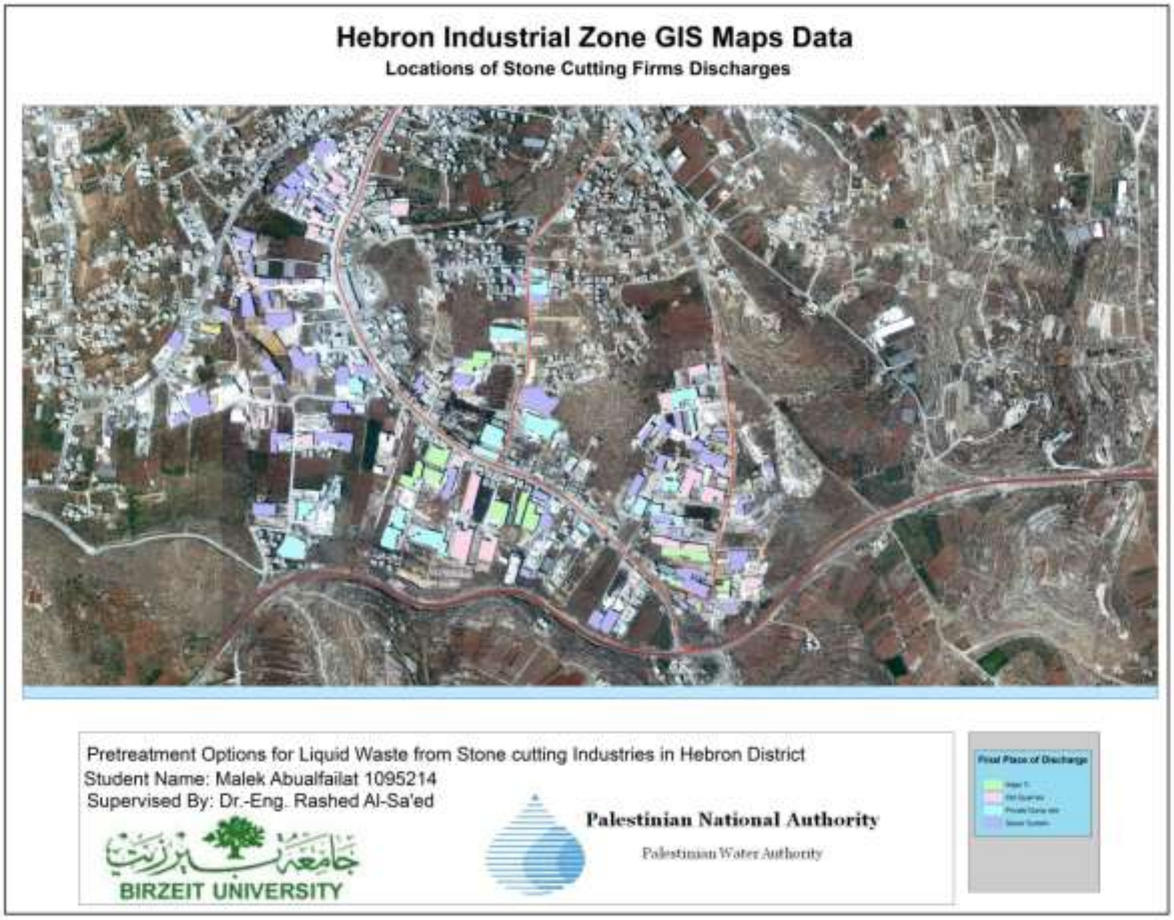


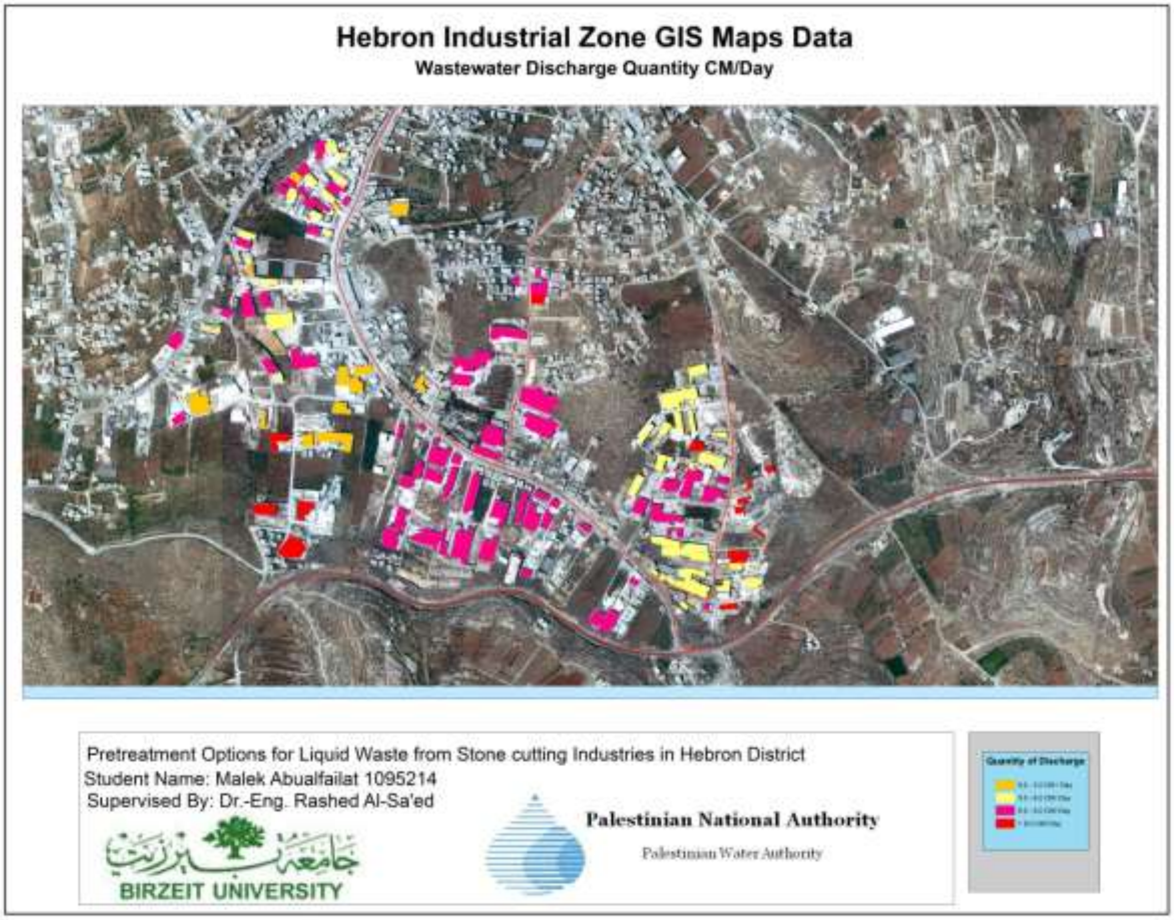
Figure 5. 13: Number of stone cutting firms per amount of consumption as Cubic meter of water per month

5.4.3 <u>GIS Maps</u>

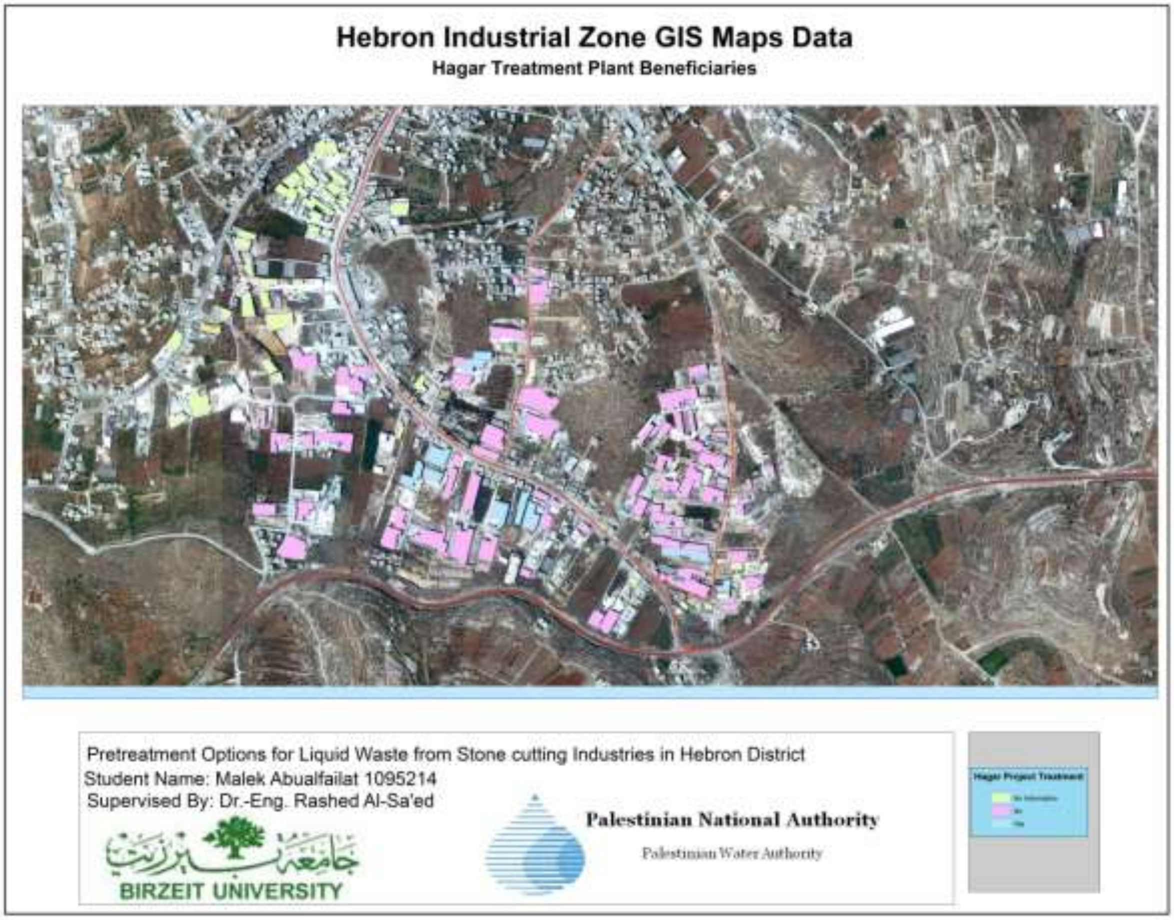
A GIS maps was carried out using ESRI Arch GIS 9.3.1 Licensed copy describing the discharges amounts, locations of discharge, and description of current implemented two projects.



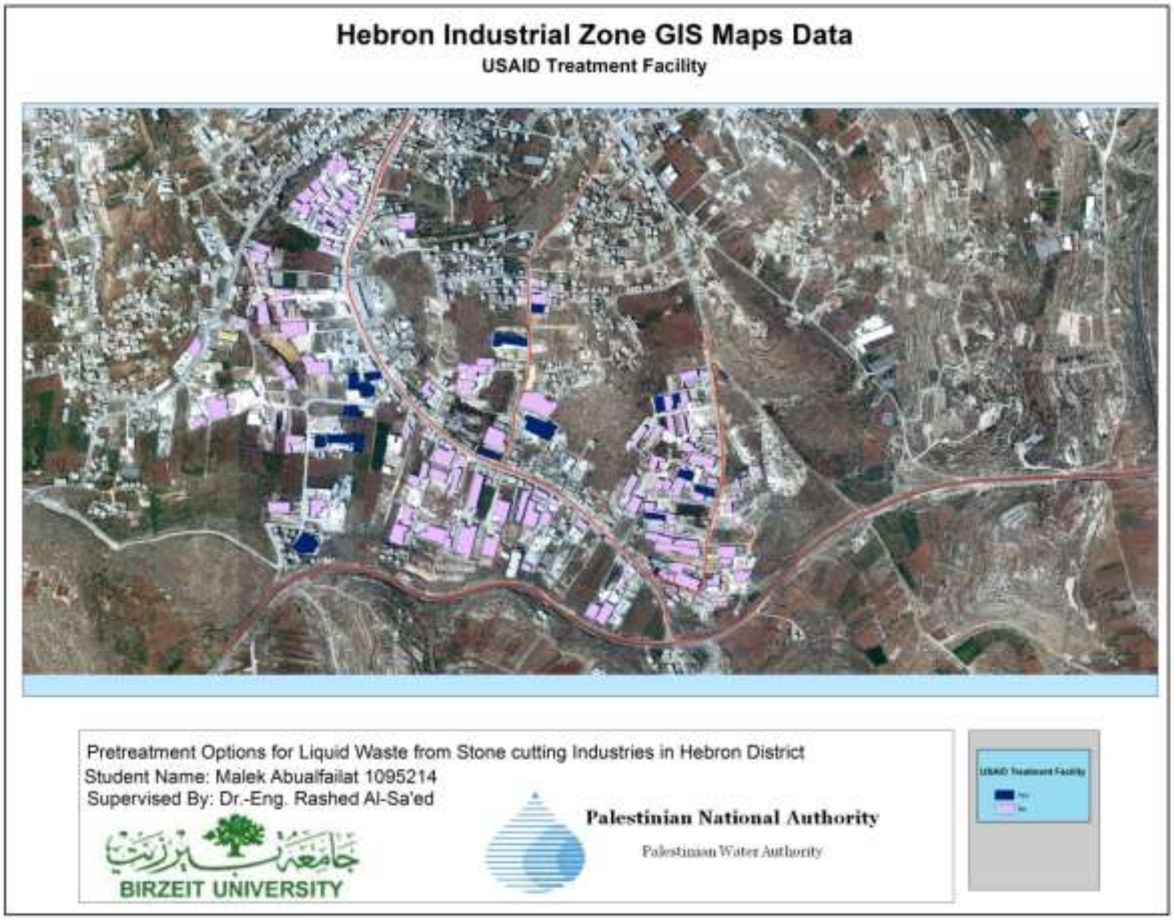
Map 5. 1: Locations of Stone Cutting Firms Discharges



Map 5. 2: Wastewater Discharges Quantity m^3/Day



Map 5. 3: Hagar Treatment Plant Beneficiaries



Map 5. 4: USAID Treatment Facilities Beneficiaries

Chapter Six
Conclusions and Recommendations

6.1 Conclusions

Through this study it was concluded that the current situation of the industrial zone in Hebron city is completely harmful to environment in general, more specific conclusions as follow:

1. Stone cutting industry needs a decentralized treatment units project for all stone cutting firms, upon clear fact sheet indicates the best dose concentration of coagulant should be used.
2. The total amount of consumption of fresh water for stone cutting industry is exceeding 1000 m^3 per day.
3. The total discharge of stone cutting liquid waste is exceeding 1250 m^3per day.
4. Another alternative is presented instead of electro-polymer with a dose concentration of ferric chloride.
5. The stone cutting industry is depends mainly on tank truck water source and that indicate of low level of service from water supplier in the city.
6. The best conditions to remove 96% of both TSS and Turbidity is 0.5 mg/L of Electoro-polymer, at 120 RPM for 1 min, and waiting 12 min, or 5 mg/L of Ferric chloride at the same conditions.
7. Electro polymer is the best alternative as coagulant from technical and financial wise.
8. There is an opportunity of decreasing the total amount of discharge since the firms' ownersare interested in silo system which decreases the water consumption around 30%.

6.2 Recommendations

1. Further investigations and projects are needed in stone cutting industrial zone in term of solid waste and water management.
2. Large projects should be invested via private sector.

3. More coagulants should be investigated in addition to ferric and electro-polymer.
4. A master plan is needed to connect stone cutting industry to further treatment options, centralized or decentralized treatment systems.
5. An awareness and enforcement campaigns needed to prevent Hebron stream from stone cutting slurry.

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Appendices

Appendix 1: Survey Questionnaires

1. Discharge Questionnaire

Palestinian National Authority
Palestinian Water Authority
سلطة المياه الفلسطينية

جامعة بيرزيت
BIRZEIT UNIVERSITY

Pretreatment options for waste water discharged from stone cutting industry in Hebron district

استبيان أصحاب مناشير الحجر مع محطات معالجة أو نظام ميلو

1 - معلومات الاستمارة		
1.1	اسم الباحث	
1.2	رقم الاستمارة	☐☐☐
1.3	تاريخ تعبئة الاستمارة	/ /

2 - معلومات عامة عن المنشأة الصناعية:

الرقم	السؤال	الإجابة	هذا العمود خاص بأعمال التحليل وليس للتعبئة
2.1	المحافظة		☐☐
2.2	سنة انشاء المنشأة		☐☐
2.3	عدد العمال		☐☐
2.4	الموقع الجغرافي X		☐☐☐☐
2.5	الموقع الجغرافي Y		☐☐
2.6	ما مقدار فاتورة المياه الحالية؟ (شيكل/شهر)		☐☐☐☐
2.7	كمية المياه المستخدمة شهرياً لغرض الصناعة؟ ($م^3$/شهر)		
2.8	كمية المياه العادمة الخارجة من المنشأة شهرياً ($م^3$/شهر)		

3 - معلومات نظام المعالجة المستخدم:

3.1	ما هو نوع نظام المعالجة المستخدم	1 - ميلو 2 - وحدة معالجة	☐
3.2	سنة انشاء نظام المعالجة؟	....	☐☐☐☐
في حال استخدام وحدة معالجة:			
3.3	هل تستخدم نظام معالجة كامل يحتوي على وحدة تجفيف ووحدة تزويد لدائن؟	1 - نعم 2 - لا	☐
3.4	ما اسم المادة المستخدمة؟	....	☐☐☐☐☐
3.5	هل تعيد استخدام المياه المعالجة؟	1 - نعم 2 - لا	☐
3.6	حجم خزان التجميع	....	☐☐
3.7	كمية اللدائن المضافة الى خزان؟	....	☐☐☐☐
3.8	القدرة الكهربائية للمحطة	....	☐☐☐☐
3.9	معدل تفريغ الخزان يومياً؟	....	☐☐☐☐

Palestinian National Authority
Palestinian Water Authority
سلطة المياه الفلسطينية

جامعة بيرزيت
BIRZEIT UNIVERSITY

Pretreatment options for waste water discharged from stone cutting industry in Hebron district

3.10	هل يوجد سيلو مع نظام المعالجة؟	1. نعم 2. لا	☐
3.11	حجم خزان السيلو	....	☐☐☐☐☐
في حال وجود سيلو فقط:			
3.12	حجم خزان السيلو	....	☐☐☐☐☐
3.13	أين يتم التخلص من النفايات الصلبة؟	....	☐☐☐☐
3.14	كم مرة يفرغ السيلو يومياً؟	....	☐☐☐☐

4	معلومات المبحوث	
4.1	اسم المبحوث	
4.2	رقم الهاتف	

2. Water Consumption Questionnaire

Palestinian National Authority
Palestinian Water Authority
سلطة المياه الفلسطينية

جامعة بيرزيت
BIRZEIT UNIVERSITY

Pretreatment options for waste water discharged from stone cutting industry in Hebron district

استبيان أصحاب مناشير الحجر كميات المياه ومصادر الجولة الثانية حزيران 2012

1 - معلومات الاستمارة		
1.1	اسم الباحث	
1.2	رقم الاستمارة	□□□
1.3	تاريخ تعبئة الاستمارة	/ /

2 - معلومات عامة عن المنشأة الصناعية:

الرقم	السؤال	الإجابة	هذا العمود خاص بأعمال التحليل وليس للتعبئة
2.1	المحافظة		□□
2.2	سنة انشاء المنشأة		□□
2.3	عدد العمال		□□
2.4	الموقع الجغرافي X		□□□□
2.5	الموقع الجغرافي Y		□□
2.6	ما مقدار فاتورة المياه الحالية؟ (شيكل/شهر)		□□□□
2.7	كمية المياه المستخدمة شهرياً لغرض الصناعة؟ (م³/شهر)		
2.8	ما هو مصدر المياه للمنشار؟		

4 معلومات المبحوث		
4.1	اسم المبحوث	
4.2	رقم الهاتف	

Appendix 2: 140 Coordinates for Stone cutting firms in Hebron

No.	X	Y
2.	209902.9844	601,007.50
3.	209957.3438	601,014.50
4.	210076.7344	601,047.50
5.	210087.7813	601,048.88
6.	210088.6563	601,051.38
7.	210090.3281	601,077.69
8.	210095.125	601,097.38
9.	210131.6094	601,102.75
10.	210134.5938	601,108.19
11.	210136.25	601,112.25
12.	210147.5625	601,114.00
13.	210172.0781	601,115.00
14.	210174.7344	601,122.94
15.	210175.3438	601,126.75
16.	210182.4375	601,136.50
17.	210203.7813	601,138.69
18.	210209.1406	601,141.69
19.	210210.375	601,156.44
20.	210220.1719	601,182.88
21.	210237.2969	601,190.19
22.	210238.6094	601,201.38
23.	210240.875	601,205.38
24.	210242.0938	601,207.00
25.	210250.4375	601,213.88
26.	210254.2344	601,214.88
27.	210261.3594	601,216.81
28.	210266.3125	601,226.69
29.	210268.1875	601,232.63
30.	210274.4688	601,233.25
31.	210285.2813	601,246.38
32.	210285.3125	601,250.69
33.	210307.1563	601,252.19
34.	210308.9531	601,261.94
35.	210310.0313	601,280.69
36.	210314.8906	601,285.06
37.	210316.1563	601,286.31
38.	210325.7188	601,287.44
39.	210329.4531	601,290.31
40.	210333.3438	601,301.50

41.	210341.6406	601,308.63
42.	210346.875	601,310.31
43.	210347.9375	601,310.44
44.	210354.25	601,313.75
45.	210359.9688	601,317.56
46.	210381.1875	601,318.69
47.	210401.3594	601,325.56
48.	210474.2969	601,332.94
49.	210499.9219	601,340.81
50.	210502.0781	601,347.50
51.	210503.1563	601,353.56
52.	210520.75	601,357.13
53.	210549.1094	601,367.94
54.	210557.2813	601,374.88
55.	210561.9063	601,375.38
56.	210576.6094	601,376.00
57.	210589.625	601,378.88
58.	210600.0313	601,381.56
59.	210605.0781	601,385.81
60.	210617.8594	601,387.88
61.	210636.125	601,401.25
62.	210654.8594	601,402.63
63.	210657.9531	601,417.00
64.	210666.1563	601,419.31
65.	210668.7969	601,427.50
66.	210695.2813	601,439.19
67.	210697.4063	601,444.75
68.	210724.9219	601,445.50
69.	210733.2344	601,453.88
70.	210739.8906	601,463.50
71.	210751.25	601,480.38
72.	210770.2969	601,491.38
73.	210791.4688	601,494.81
74.	210814.9063	601,496.88
75.	210829.9688	601,497.63
76.	210840.8594	601,506.00
77.	210854.9219	601,508.88
78.	210873.2969	601,513.25
79.	210873.8438	601,516.13
80.	210874.3906	601,522.81
81.	210875	601,529.75

82.	210879.5	601,531.56
83.	210883.2344	601,536.50
84.	210896.3125	601,542.75
85.	210911.2344	601,545.94
86.	210918.8906	601,549.94
87.	211000	601,550.00
88.	211030.9531	601,553.19
89.	211066.0781	601,582.75
90.	211133.2656	601,596.50
91.	211138.7031	601,603.63
92.	211149.8906	601,606.56
93.	211165.7656	601,608.75
94.	211188.1719	601,617.94
95.	211192.9844	601,618.19
96.	211200.8281	601,645.44
97.	211207.6719	601,648.94
98.	211209.4844	601,660.13
99.	211211.7031	601,666.94
100.	211218.5781	601,670.19
101.	211221.7656	601,684.50
102.	211222.9219	601,685.13
103.	211227.3594	601,697.19
104.	211230.9844	601,701.44
105.	211231.8281	601,709.13
106.	211237.875	601,713.19
107.	211239.6875	601,725.88
108.	211244.5	601,785.94
109.	211247.8594	601,820.75
110.	211254.8438	601,861.50
111.	211256.0625	601,876.81
112.	211257.4688	601,878.88
113.	211269.5469	601,907.38
114.	211275.4219	601,926.56
115.	211276.1094	601,949.63
116.	211288.2656	601,958.06
117.	211289.4531	601,983.81
118.	211291.9375	602,030.31
119.	211292.5	602,052.88
120.	211296.375	602,055.81
121.	211300.2344	602,055.88
122.	211300.4844	602,068.63

123.	211304.0469	602,105.56
124.	211304.9688	602,112.25
125.	211331.5625	602,121.94
126.	211332	602,129.94
127.	211344.2031	602,133.75
128.	211350.1094	602,136.44
129.	211366.5781	602,142.69
130.	211373.6094	602,159.19
131.	211374.125	602,161.63
132.	211378.0938	602,169.63
133.	211391.4219	602,173.50
134.	211410.5781	602,176.94
135.	211414.625	602,193.19
136.	211417.4844	602,201.06
137.	211428.7969	602,207.31
138.	211442.8906	602,207.50
139.	211456.8906	602,228.56
140.	211469.8281	602,267.44
141.	211499.2813	602,282.00

Appendix 3:Effect of Electro-Polymer on Both TSS and Turbidity (Dose Dependent)

Constants	**V=500 mL**		**Retention Time = 1 min**		**Speed= 120 RPM**	**No. Samples=25**		**T = 19 C** **Waiting time=15 M**	**Polymer**
Sample No.	Dose Mg/L		TSS mg/L (PPM)					Turbidity (NTU)	pH
		Mass Before	Mass After	Difference (g)	TSS Value	% Removal	NTU	% Removal	
PM	0.0000	27.4934	28.0594	0.5660	11320.00	0.00	19350.00	0.00	7.92
PA17	0.0010	27.9123	28.1597	0.2474	4948.00	56.29	16122.00	16.68	7.92
PA18	0.0020	26.8542	27.0908	0.2366	4732.00	58.20	10123.00	47.68	7.89
PA19	0.0030	28.6122	28.8305	0.2183	4366.00	61.43	9866.00	49.01	7.91
PA20	0.0040	29.3167	29.5153	0.1986	3972.00	64.91	8523.00	55.95	7.88
PA21	0.0050	26.8418	26.9952	0.1534	3068.00	72.90	7422.00	61.64	7.93
PA22	0.0100	27.2012	27.2933	0.0921	1842.00	83.73	4522.00	76.63	7.92
PA23	0.0200	26.1718	26.2519	0.0801	1602.00	85.85	3428.00	82.28	7.95
PA24	0.0300	27.1525	27.2219	0.0694	1388.00	87.74	2213.00	88.56	7.88
PA25	0.0400	27.678	27.7347	0.0567	1134.00	89.98	1688.00	91.28	7.80
PA13	0.0500	27.1606	27.2053	0.0447	894.00	92.10	1662.00	91.41	7.83
PA15	0.1500	27.6068	27.6111	0.0043	86.00	99.24	121.00	99.37	7.97
PA16	0.2000	27.4417	27.4433	0.0016	32.00	99.72	133.00	99.31	7.96
PA7	0.1000	26.4287	26.4322	0.0035	70.00	99.38	243.00	98.74	7.99
PA8	0.2000	27.7542	27.7575	0.0033	66.00	99.42	130.00	99.33	8.06
PA9	0.3000	28.1894	28.1919	0.0025	50.00	99.56	79.50	99.59	7.95
PA10	0.4000	27.1250	27.1276	0.0026	52.00	99.54	74.10	99.62	7.94
PA11	0.5000	26.6797	26.6818	0.0021	42.00	99.63	65.50	99.66	7.91
PA12	0.6000	26.2665	26.2685	0.0020	40.00	99.65	51.70	99.73	7.94
PA1	0.5000	28.8072	28.8096	0.0024	48.00	99.58	24.10	99.88	7.92
PA2	1.0000	28.1903	28.1914	0.0011	22.00	99.81	17.70	99.91	7.91
PA3	1.5000	29.2836	29.2852	0.0016	32.00	99.72	15.50	99.92	7.88
PA4	2.0000	27.6216	27.6224	0.0008	16.00	99.86	19.70	99.90	7.86
PA5	2.5000	27.4946	27.4952	0.0006	12.00	99.89	18.60	99.90	7.90
PA6	3.0000	26.8512	26.8523	0.0011	22.00	99.81	26.50	99.86	7.86

Appendix 4: Effect of Electro-Polymer on Both TSS and Turbidity (Waiting Time Dependent) at 0.3 mg/L

Constants	**Dose = 0.3 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**			**T = 19 C**	**Polymer**
Sample No.	Time (min)	TSS mg/L (ppm)					Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS value	% Removal	NTU	% Removal	
PT1	0.0000	26.4283	26.508	0.0797	1594	85.92	1460.00	92.45	7.92
PT2	3.0000	26.6796	26.743	0.0634	1268	88.80	730.00	96.23	7.91
PT3	5.0000	26.2635	26.3171	0.0536	1072	90.53	270.50	98.60	7.88
PT4	7.0000	30.6476	30.6934	0.0458	916	91.91	264.00	98.64	7.86
PT5	9.0000	27.6153	27.6592	0.0439	878	92.24	235.00	98.79	7.90
PT6	11.0000	27.1780	27.2175	0.0395	790	93.02	166.00	99.14	7.86
PT7	13.0000	27.7499	27.7732	0.0233	466	95.88	107.00	99.45	7.99

Appendix 5: Effect of Electro-Polymer on Both TSS and Turbidity (Waiting Time Dependent) at 0.5 mg/L

Constants	**Dose = 0.5 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**			**T = 19 C**	**Polymer**
Sample No.	Time (min)	TSS mg/L (ppm)					Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS value	% Removal	NTU	%Removal	
PT15	0.0000	27.7980	27.8469	0.0489	978	91.36	1242.50	93.58	7.79
PT16	3.0000	26.7297	26.737	0.0073	146	98.71	338.00	98.25	7.84
PT17	5.0000	26.4748	26.4785	0.0037	74	99.35	279.00	98.56	7.83
PT18	7.0000	27.2319	27.2361	0.0042	84	99.26	273.00	98.59	7.87
PT19	9.0000	27.1759	27.1809	0.0050	100	99.12	258.00	98.67	7.84
PT20	11.0000	26.3148	26.3185	0.0037	74	99.35	165.00	99.15	7.83
PT21	13.0000	27.6609	27.6654	0.0045	90	99.20	65.50	99.66	7.83

Appendix 6: Effect of Electro-Polymer on Both TSS and Turbidity (Waiting Time Dependent) at 0.7 mg/L

Constants	**Dose = 0.7 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**			**T = 19 C**	**Polymer**
Sample No.	Time (min)	TSS mg/L (ppm)					Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS value	% Removal	Turbidity (NTU)	%Removal	
PT8	0.0000	26.9666	26.9937	0.0271	542	95.21	1160.00	94.01	7.89
PT9	3.0000	28.9604	28.9636	0.0032	64	99.43	170.00	99.12	7.85
PT10	5.0000	27.7576	27.76	0.0024	48	99.58	136.00	99.30	7.81
PT11	7.0000	29.1276	29.1313	0.0037	74	99.35	139.00	99.28	7.77
PT12	9.0000	26.6608	26.6633	0.0025	50	99.56	144.00	99.26	7.84
PT13	11.0000	28.2463	28.2473	0.0010	20	99.82	65.70	99.66	7.82
PT14	13.0000	29.3364	29.3369	0.0005	10	99.91	65.00	99.66	7.83

Appendix 7: Effect of Ferrus-Chloride on Both TSS and Turbidity (Dose Dependent)

Constants	**Waiting time=15 M**	**V=500 mL**	**Retention Time = 1 min**		**Speed= 120 RPM**		**T = 19 ° C**		
Sample No.	Dose mg/L	**TSS mg/L (ppm)**					Turbidity (NTU)		pH
		Mass Before	Mass After	Diffrence (G)	TSS Value	% Removal	NTU	%Removal	
PM	0.00	27.4934	28.0594	0.5660	11320.00	0	19350.00	0	7.92
FeA14	0.10	30.1272	30.2933	0.1661	3322.00	71	10220.00	47	7.82
FeA15	0.15	29.1814	29.2765	0.0951	1902.00	83	9547.00	51	7.85
FeA16	0.20	27.1522	27.2359	0.0837	1674.00	85	9022.00	53	7.90
FeA17	0.25	30.2117	30.2835	0.0718	1436.00	87	8714.00	55	7.60
FeA18	0.30	28.2888	28.3532	0.0644	1288.00	89	8310.00	57	7.70
FeA19	0.35	26.1715	26.2317	0.0602	1204.00	89	7966.00	59	7.80
FeA20	0.40	29.6156	29.6738	0.0582	1164.00	90	7122.00	63	7.66
FeA21	0.45	30.1214	30.1781	0.0567	1134.00	90	6828.00	65	7.50
FeA22	0.50	27.2152	27.2663	0.0511	1022.00	91	6662.00	66	7.88
FeA23	0.60	26.6284	26.6701	0.0417	834.00	93	4240.00	78	7.93
FeA24	0.70	28.1121	28.1487	0.0366	732.00	94	3501.00	82	7.67
FeA25	0.80	29.6626	29.6907	0.0281	562.00	95	1910.00	90	7.86
FeA26	0.90	26.8732	26.8898	0.0166	332.00	97	930.00	95	7.36
FeA1	1.00	27.7973	27.8052	0.0079	158.00	99	374.00	98	7.11
FeA2	2.00	27.6575	27.6651	0.0076	152.00	99	544.00	97	7.05
FeA3	3.00	27.2278	27.2355	0.0077	154.00	99	333.00	98	7.23
FeA4	4.00	27.1717	27.1779	0.0062	124.00	99	327.00	98	7.19
FeA5	5.00	26.6636	26.6682	0.0046	92.00	99	293.00	98	7.63
FeA6	6.00	28.9606	28.966	0.0054	108.00	99	278.00	99	7.16
FeA7	7.00	26.8799	26.8832	0.0033	66.00	99	264.00	99	6.89
FeA8	8.00	29.3331	29.3369	0.0038	76.00	99	187.00	99	7.12
FeA9	9.00	26.7263	26.7286	0.0023	46.00	100	181.00	99	7.11
FeA10	10.00	26.3123	26.3172	0.0049	98.00	99	104.00	99	7.34
FeA11	11.00	28.2379	28.2391	0.0012	24.00	100	107.00	99	7.53
FeA12	12.00	26.4713	26.4721	0.0008	16.00	100	93.20	100	7.54
FeA13	13.00	29.1305	29.1319	0.0014	28.00	100	77.50	100	7.61

Appendix 8: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 5 mg/L

Constants	**Dose = 5 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**		**T = 19 °C**		
Sample No.	Time (min)			**TSS mg/L (ppm)**			Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS Value	% Removal	NTU	%Removal	
FET1	0.0000	26.3104	26.3981	0.0877	1754	84.51	3195.00	83.49	7.68
FET2	3.0000	26.4675	26.4869	0.0194	388	96.57	702.00	96.37	7.89
FET3	5.0000	29.3275	29.3397	0.0122	244	97.84	550.00	97.16	7.86
FET4	7.0000	29.1270	29.1353	0.0083	166	98.53	311.00	98.39	7.89
FET5	9.0000	26.8760	26.8855	0.0095	190	98.32	321.00	98.34	7.89
FET6	11.0000	27.5317	27.5373	0.0056	112	99.01	257.00	98.67	7.91
FET7	13.0000	27.6542	27.6594	0.0052	104	99.08	212.00	98.90	7.92
FET8	15.0000	28.2372	28.2435	0.0063	126	98.89	180.0000	99.07	7.9100

Appendix 9: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 10 mg/L

Constants	**Dose = 10 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**		**T = 19 °C**		
Sample No.	Time (min)			**TSS mg/L (ppm)**			Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS Value	% Removal	NTU	%Removal	
FET9	0.0000	27.1668	27.2525	0.0857	1714	84.86	2900.00	85.01	2900.00
FET10	3.0000	27.4899	27.508	0.0181	362	96.80	580.00	97.00	580.00
FET11	5.0000	28.8574	28.866	0.0086	172	98.48	339.00	98.25	339.00
FET12	7.0000	27.7848	27.7924	0.0076	152	98.66	259.00	98.66	259.00
FET13	9.0000	27.2245	27.2284	0.0039	78	99.31	163.00	99.16	163.00
FET14	11.0000	30.6954	30.6976	0.0022	44	99.61	105.00	99.46	105.00
FET15	13.0000	27.2060	27.2085	0.0025	50	99.56	101.00	99.48	101.00
FET16	15.0000	26.7229	26.7242	0.0013	26	99.77	109.00	99.44	109.00

Appendix 10: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 1 mg/L

Constants	**Dose = 1 mg/L**	**V=1000mL**	**Retention Time = 1 min**		**Speed= 120 RPM**		**T = 19 °C**		
Sample No.	Time (min)			**TSS mg/L (ppm)**			Turbidity (NTU)		pH
		Mass Before	Mass After	Difference (g)	TSS Value	% Removal	NTU	%Removal	
FET17	0.0000	29.1247	29.2253	0.1006	2012	82.23	3710.00	80.83	3710.00
FET18	3.0000	28.2342	28.2679	0.0337	674	94.05	2180.00	88.73	2180.00
FET19	5.0000	26.3033	26.3322	0.0289	578	94.89	1175.00	93.93	1175.00
FET20	7.0000	26.4679	26.4841	0.0162	324	97.14	837.00	95.67	837.00
FET21	9.0000	26.8763	26.8893	0.0130	260	97.70	735.00	96.20	735.00
FET22	11.0000	29.3288	29.3377	0.0089	178	98.43	598.00	96.91	598.00
FET23	13.0000	27.5334	27.5398	0.0064	128	98.87	525.00	97.29	525.00
FET24	15.0000	27.6519	27.6557	0.0038	76	99.33	374.00	98.07	374.00