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

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Supervised By

Dr.-Eng. Rashed Al-Sa’ed

May 2013
كلية الدراسات العليا
برنامج ماجستير علوم المياه والبيئة
رسالة ماجستير
"خيارات المعالجة الأولية للنفايات السائلة الخارجة من مناشير الحجر في منطقة الخليل"

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أيار 2013
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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

May 2013
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.
# Table of Contents

ABSTRACT .............................................................................................................................. VIII

IX .................................................................................................................................................. al-khilaşa:hta

Dedications ................................................................................................................................. X

Acknowledgments ..................................................................................................................... XI

List of Abbreviations ................................................................................................................ XII

List of Figures ............................................................................................................................ XIV

List of Maps ............................................................................................................................... XIV

List of Tables ............................................................................................................................. XV

Chapter One ............................................................................................................................... 1

Introduction ................................................................................................................................. 1

1.1 Overview ................................................................................................................................ 1

1.2 Major Goal and Specific Objectives .......................................................................................... 3

1.2.1 Main Goal .............................................................................................................................. 3

1.2.2 Specific Objectives ................................................................................................................ 3

1.3 Expected Results ...................................................................................................................... 3

1.4 Research Approaches .............................................................................................................. 4

1.5 Thesis Body ............................................................................................................................ 4

Chapter Two ............................................................................................................................... 5

Stone Cutting Industry in Hebron .............................................................................................. 5

2.1 Industry Profile ....................................................................................................................... 5

2.2 Environmental Impact of Stone Cutting .................................................................................. 6

2.3 Stone quarrying ....................................................................................................................... 10

2.4 Hebron Stream ....................................................................................................................... 11

2.5 Existing Facilities onsite .......................................................................................................... 12

2.5.1 CH2MILL Investment ......................................................................................................... 12

2.5.2 Hagar Project ....................................................................................................................... 13

2.5.3 USAID Emergency Project ................................................................................................. 14

Chapter Three ........................................................................................................................... 17

Literature review ......................................................................................................................... 17

3.1 Coagulation and Floculation ................................................................................................. 17

3.2 Applications of Coagulation ................................................................................................. 18
Appendix 9: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 10 mg/LXIV

Appendix 10: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 1 mg/LXV
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 جنبًا إلى جنب مع ضغوط التنمية في مدينة الخليل إضافةً إلى المستوطنة الإسرائيلية غير شرعية تسمى "كريات أربع" في المساحات المفتوحة التي تحيط بهذا الوادي.

بطرح في وادي الخليل مخلفات سائدة لـ 172 مشاكل قطع حجر، تم مسح 145 مصنع منها لدراسة الاستهلاك اليومي للمياه وكمية المياه العادمة التي تخرج منها وتبين بعد عملية المسح أن 1252 متر مكعب يطرح بشكل يومي من هذه المصانع بتركيز مواد عالية يتجاوز 2000 ملغ/لتر وعوارة تتجاوز 10000 NTU، وتم ترجمة السوائح من خلال خانات تبين مدى الاستهلاك اليومي وكيفية المعالجة وكيفية التصرف للمياه العادمة.

غطت هذه الدراسة الوضع الحالي لوحدات المعالجة الموجودة في المنطقة الصناعية وخلصت الدراسة إلى أن نظام المعالجة اللامركزية هي أفضل وناجح من الناحية الفنية والمالية من نظم المعالجة المركزية.

في هذه الدراسة تم فحص الأشكالية الفنية باستخدام مختبرات البوليمات وكولوريد الحديد الثلاثي باستخدام تقنية "الجرة" لبحث تأثير المختبرات على كل من العوارة وتركيز المواد العادمة بناءً على سرعة دوران محددة و زمن انتظار و زمن دوران من خلال العمل المخبري تبين أن أفضل مختبر ممكن هو البوليمر، أو ما يسمى "بالفولوماند" بتركيز 0.5 ملغ/لتر و زمن دوران 1 دقايق على 120 لغة لكل دقيقة و زمن انتظار 12 دقيقة.

توصي الدراسة بعمل مشروع معالجة لا مرزكي 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.

I would like to show my greatest appreciation to Dr. Eng. Rashed Al-Saéd. I can't say thank you enough for his tremendous support and help. I feel motivated and encouraged every time I attend his meeting. Without his encouragement and guidance this work would not have materialized.

I would like to express my appreciation to Palestinian Water Authority and the Austrian Agency for Development for their financial support for this work, without forgetting the root of this financial support to Salah family whom support me and my wife to be in the program.

I would to send Great words of thanks and appreciation to my Wife Ms. Hiba Ajlouny for her reviewing, supporting, encouraging, motivating, and promoting this work.

I would greatly show my thanks to the lab technician Mr. Saleh Sulieman for his guidance and notices to the experiments.
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
List of Figures

Figure 1.1: Palestine Map (Nasseraldein, 2009) ........................................................................... 1
Figure 4.1: GPS Device (Gramin-etrex). ......................................................................................... 28
Figure 4.2: Lab Jar Test in IEWS-Birzeit University, 2011 ................................................................. 29
Figure 4.3: Scattered Light at 90°...................................................................................................... 31
Figure 4.4: HACH Turbidimeter used in IEWS lab. ......................................................................... 32
Figure 4.5: TSS Analysis, Source: Dept of Ecology, State of Washington University .......................... 33
Figure 5.1: Equilibrium percentage relative decrease in TSS as a function of dose of Polymer. ....... 36
Figure 5.2: Equilibrium percentage relative decrease in Turbidity as a function of dose of Polymer. 37
Figure 5.3: Percentage relative decrease in both of TSS and Turbidity as a function of waiting time for Coagulation experiments. .................................................................................. 38
Figure 5.4: Equilibrium percentage relative decrease in TSS as a function of dose of Ferric chloride. ........................................................................................................................................ 39
Figure 5.5: Equilibrium percentage relative decrease in Turbidity as a function of dose of Ferric chloride ....................................................................................................................................... 40
Figure 5.6: Percentage relative decrease in both of TSS and Turbidity as a function of waiting time for Coagulation experiments. .................................................................................. 41
Figure 5.7: A Number of firms as a function of discharging Location stone cutting industry in Hebron ....................................................................................................................................... 43
Figure 5.8: Sedimentation Pools ..................................................................................................... 43
Figure 5.9: Centrifuging Tank - Hebron Industrial Zone ................................................................. 44
Figure 5.10: Press Filter System, Hebron Industrial Zone .............................................................. 45
Figure 5.11: Number of stone cutting firms per treatment System ................................................. 45
Figure 5.12: A survey of the source of water to stone cutting firms .............................................. 46
Figure 5.13: Number of stone cutting firms per amount of consumption as Cubic meter of water per month .................................................................................................................................. 47

List of Maps

Map 5.1: Locations of Stone Cutting Firms Discharges ................................................................. 48
Map 5.2: Wastewater Discharges Quantity m³/Day ....................................................................... 49
Map 5.3: Hagar Treatment Plant Beneficiaries .............................................................................. 50
Map 5.4: USAID Treatment Facilities Beneficiaries ....................................................................... 51
List of Tables
Table 2. 1: Classifications of Major types of Stones Used in West Bank and Gaza, Source: ECB 2002.
Table 2. 2: A comparison of different disposal methods and It's Potential on Soil ........................................ 9
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) .................................................... 11
Table 3. 1: Optimum pH Values for Metallic Coagulants ........................................................................... 23
Table 5. 1: Physical Characteristics of Raw wastewater from Stone cutting in Hebron ................................ 35
Table 5. 2: Physical, and Chemical properties of Polymer (Ashland Publications, 2007) ......................... 36
Table 5. 3: Stone cutting firms discharge of wastewater and solid waste .................................................. 42
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, from 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 alternative(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.

<table>
<thead>
<tr>
<th>StoneType</th>
<th>Source</th>
<th>Classifications</th>
<th>Specifications</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injasah</td>
<td>Hebron-Bini Na‘em</td>
<td>It is classified into four major categories: Asfar, Sid, Ardi, Sous.</td>
<td>The “Ardi” type is the best one. White color, veined, different colors, hard, minimal absorption water</td>
<td>“Chiseled” for building, polished stone, paving sidewalks, Garden walls, decorating public places.</td>
</tr>
<tr>
<td>Jarra’ah</td>
<td>Nablus</td>
<td>Band 60, and Band 40</td>
<td>Usually gray, minimal absorption water, veined, hard, uniform color</td>
<td>Building, paving, decorating public places</td>
</tr>
<tr>
<td>Aseerah</td>
<td>Nablus-Aseerah</td>
<td>Band 60, and Band 40</td>
<td>White, minimal absorption of water, hard, uniform color</td>
<td>Building (all sides), paving, decorations</td>
</tr>
<tr>
<td>Al Shyoukh</td>
<td>Hebron-Al-Shyoukh</td>
<td>Asfar, Sid, Ardi</td>
<td>Ardi White color, absorbs water, not uniform color</td>
<td>Building, paving, decorating public places, renovating ancient places</td>
</tr>
<tr>
<td>Tafouh</td>
<td>Hebron - Tafouh</td>
<td>Bind Asfar, Ardi</td>
<td>Beige color, soft stone, absorbs water, not uniform color</td>
<td>Paving, polished stone, decoration</td>
</tr>
<tr>
<td>Samou‘</td>
<td>Hebron-Samou‘</td>
<td>Asfar, Ardi</td>
<td>Different colors, hard stone, minimal absorption of water</td>
<td>Building, paving, decoration</td>
</tr>
<tr>
<td>Qabatya</td>
<td>Jenin-Qabatya</td>
<td>Bind Awal (cover) Bind Ardi</td>
<td>Different colors (almost beige), absorbs water, color is changeable with time, hard stone</td>
<td>Building, paving</td>
</tr>
<tr>
<td>Yatta</td>
<td>Hebron - Yatta</td>
<td>Bind Asfar, Ardai</td>
<td>White color, hard, almost uniform color, absorbs water</td>
<td>Building, polished, paving, decoration</td>
</tr>
</tbody>
</table>

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 (CH2MHLILL 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 Mm³.

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(AI-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 2.1below. 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

<table>
<thead>
<tr>
<th>Disposal Method</th>
<th>Potential Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge is dumped on site.</td>
<td>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.</td>
</tr>
<tr>
<td>Sludge is dumped into the public sewerage system</td>
<td>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.</td>
</tr>
<tr>
<td>Sludge is dumped on open public land</td>
<td>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.</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Source</th>
<th>Estimated Amount of Water/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mixture from Hebron Stonecutting Industry</td>
<td>0.4 million cubic meters</td>
</tr>
<tr>
<td>Wastewater from Tannery Industry</td>
<td>0.03 million cubic meters</td>
</tr>
<tr>
<td>Domestic Sewage from the City of Hebron</td>
<td>5.9 million cubic meters</td>
</tr>
<tr>
<td>Domestic Sewage from Kiryat Arba</td>
<td>0.5 million cubic meters</td>
</tr>
</tbody>
</table>

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 (CH2MILLL 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 m³ of slurry per day, only two centrifuging tanks were built with a potential of 180 m³ of slurry being treated daily. Regarding to the USAID intervention only one tank was functioning at approximately 50% capacity of 90 m³ 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 there 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. Environmental 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.
7. Coagulation of NOM (natural organic matter), humic materials which are the precursors of THMs and other DBPs.

#### 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.

### 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.

\[
\begin{align*}
R-\text{NH}_3^+ & \rightarrow R-\text{NH}_2^+ + H^+ \\
R-\text{COOH} & \rightarrow R-\text{COO}^- + H^+
\end{align*}
\]

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 re-
stabilization of particles.

**Zone 4**: Oversaturation with metal hydroxide precipitate entrapsthe 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>
<thead>
<tr>
<th>Table 3.1: Optimum pH Values for Metallic Coagulants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coagulant</td>
</tr>
<tr>
<td>Aluminum sulfate</td>
</tr>
<tr>
<td>Ferrous sulfate</td>
</tr>
<tr>
<td>Ferric chloride</td>
</tr>
</tbody>
</table>

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.
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.
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 –etrex.

Figure 4.1: GPS Device (Gramin-etrex).
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.)

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 identify the difference between two main coagulants used; conventional polymer (Electro-Polymer or know commercially as Fokland), and Ferric Chloride (FeCl$_3$·6H$_2$O).
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 Four: Materials and Methodology

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.

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.).

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.
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>
<thead>
<tr>
<th>Physical Characteristics</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average TSS</td>
<td>5015 mg/L</td>
</tr>
<tr>
<td>Average Turbidity</td>
<td>7288 NTU</td>
</tr>
<tr>
<td>Average pH</td>
<td>7.6</td>
</tr>
</tbody>
</table>

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)*

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Composition</td>
<td>high molecular weight, medium anionic charge polyelectrolyte based on acrylamide and sodium acrylate</td>
</tr>
<tr>
<td>Appearance</td>
<td>white to light yellow granular material</td>
</tr>
<tr>
<td>Charge type</td>
<td>anionic</td>
</tr>
<tr>
<td>Bulk density</td>
<td>approx. 750 kg/m³</td>
</tr>
<tr>
<td>Viscosity (0.5 % in deionized water)</td>
<td>approx. 800 mPa</td>
</tr>
<tr>
<td>Viscosity (0.1 % in deionized water)</td>
<td>approx. 450 mPa</td>
</tr>
<tr>
<td>Viscosity (0.1 % in tap water)</td>
<td>approx. 125 mPa</td>
</tr>
<tr>
<td>Viscosity (0.5 % in tap water)</td>
<td>approx. 15 mPa</td>
</tr>
<tr>
<td>pH-value (0.1 % in tap water)</td>
<td>approx. 7</td>
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<tr>
<td>Effective in pH-range</td>
<td>6 – 10</td>
</tr>
<tr>
<td>CAS-Number of the main component (&quot;active substance&quot;)</td>
<td>25085-02-3, 2-Propenoic acid, sodium salt, polymer with 2-propenamide</td>
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</tbody>
</table>

### 5.1.2 Polymer Effect:

**A. Dose Effect on TSS Removal:**

The figure below 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 plateau (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.](image)
B. *Dose Effect on Turbidity Removal*

![Graph showing the relationship between dose and turbidity removal.](image)

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 plateau (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 plateau (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 plateau (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 below.
Figure 5.6: Percentage relative decrease in both of TSS and Turbidity as a function of waiting time for Coagulation experiments.
5.4 Pollutio

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>
<thead>
<tr>
<th>Parameters</th>
<th>Descriptions</th>
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<tbody>
<tr>
<td>Average Wastewater Discharge per firm per day</td>
<td>7.82 m³/Day</td>
</tr>
<tr>
<td>Average Wastewater Discharge per firm per Month</td>
<td>160.22 m³/month</td>
</tr>
<tr>
<td>Total Discharge Monthly for 172 stone cutting firms</td>
<td>27557.80 m³/month</td>
</tr>
<tr>
<td>Total daily discharge for 172 stone cutting firms</td>
<td>1252.63 m³/Mon</td>
</tr>
<tr>
<td>Total solid waste discharge from 8 stone cutting firms with USAID facility monthly</td>
<td>62 ton/month</td>
</tr>
<tr>
<td>Average discharge of solid waste from 8 stone cutting firms with USAID facility per firm per month</td>
<td>7.75 ton/firm/month</td>
</tr>
</tbody>
</table>

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 m³ of wastewater discharges directly into sewer system, added to them 344 m³ that discharge into wadies which reaches the Hebron stream because of the geography of the area.
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 sedimentate 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.
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.

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 5.11 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.
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.

![Bar Chart](image_url)

**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 day which exceeds 800m³/day of water from different supply, which mean that the discharge includes 63% of water.
The figure also 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 200 m$^3$/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](image)

5.4.3 GIS Maps

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
Chapter Five: Results and Discussions

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$^3$ per 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 Electro-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’ owners are 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.
References


Israeli Civil Administration. “Letter from Israeli Civil Administration to FoEME for Stone cutting situation.” 2012.


Tal-Spiro, O. *Israeli-Palestinian Cooperation on Water issues.* Israeli Knesset Research and Information Center, 2011.


Appendices

Appendix 1: Survey Questionnaires

1. Discharge Questionnaire

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<tr>
<td>1.3</td>
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</table>

<table>
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<tr>
<td>نسبة النيود الماء الخالية (كم/س)</td>
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<td>نسبة العاملية المجانية الماء</td>
<td>2.8</td>
</tr>
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</table>

| ما نوع نظام المعالجة المستخدم؟ | 3.1       |
| ما نوع نظام المعالجة المستخدم؟ | 3.2       |
| هل استخدام نظام معالجة كلية يجب أن يكون متصلًا مع وحدة توليد الدوائر؟ | 3.3       |
| هل تستخدم نظام معالجة كلية؟ | 3.4       |
| هل تعتبر استخدام النشاط المائي؟ | 3.5       |
| حجم حزام التجميع                             | 3.6       |
| كمية النفايات المقصدة إلى حزام؟ | 3.7       |
| الفكيرة الالكترونية لحلبة                | 3.8       |
| محل تجميع الغاز يوميا؟                       | 3.9       |
Pretreatment options for waste water discharged from stone cutting industry in Hebron district

3.10
1. Name of the mill
2. Name of the mill's owner

3.11
Volume of mill's output

3.12
In case of water spillage, what is the amount of spillage?

3.13
If spills occur, are they treated?

3.14
How many times is the spillage used?

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>اسم المجهود</td>
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<tr>
<td>رقم الهيكل</td>
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2. Water Consumption Questionnaire

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</table>

<table>
<thead>
<tr>
<th>Question</th>
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<tbody>
<tr>
<td>What is the name of the company?</td>
<td>2.1</td>
</tr>
<tr>
<td>Number of employees in the company</td>
<td>2.2</td>
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<tr>
<td>Years of operation in the industry</td>
<td>2.3</td>
</tr>
<tr>
<td>Geographic location</td>
<td>2.4</td>
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<tr>
<td>Geographic location 2</td>
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<tr>
<td>What is the frequency of waste water discharge (monthly)?</td>
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<td>What is the concentration of waste water? (parts per million)</td>
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<td>What is the type of waste water?</td>
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<td>Number of employees</td>
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Appendix 2: 140 Coordinates for Stone cutting firms in Hebron

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Appendices

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

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<th>V=500 mL</th>
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Appendices

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

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

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<th>Mass After</th>
<th>Difference (g)</th>
<th>TSS mg/L (ppm)</th>
<th>TSS value</th>
<th>% Removal</th>
<th>NTU</th>
<th>%Removal</th>
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## Appendix 6: Effect of Electro-Polymer on Both TSS and Turbidity (Waiting Time Dependent) at 0.7 mg/L

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<th>Polymer</th>
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<td>Difference (g)</td>
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Appendices

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

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<th>% Removal</th>
<th>Turbidity (NTU)</th>
<th>pH</th>
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## Appendix 8: Effect of Ferrus-Chloride on Both TSS and Turbidity (Waiting Time Dependent) at 5 mg/L

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<th>Difference (g)</th>
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<th>TSS Value</th>
<th>% Removal</th>
<th>NTU</th>
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Appendices

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

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

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