# LIFE CYCLE ASSESSMENT OF MARBLE INDUSTRY FOR CLEANER PRODUCTION TECHNOLOGY AS A POLLUTION PREVENTION MEASURE

**Ph.D Thesis**

**By**

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**DEPARTMENT OF ENVIRONMENTAL SCIENCES**

**UNIVERSITY OF PESHAWAR**

**SESSION 2010-11**

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In the Name of

# Allah,

The Most Merciful and Compassionate the Most Gracious and Beneficent Whose help and guidance we always solicit at every step, at every moment.

**This Humble Effort**

**is**

# DEDICATED

**to**

**MY FAMILY, FRIENDS,**

**COLLEAGUES AND TEACHERS**

# PREFACE

This Ph.D dissertation comprises of five chapters. These include Chapter-I: Introduction, Chapter-II: Literature review, Chapter-III: Methodology, Chapter-IV: Results and Discussions, and Chapter-V: Conclusions and Recommendations.

The chapter-I describes general introduction of the study area, marble processing industry, environmental problems associated with marble processing industry, opportunity of cleaner production, existing regulatory framework, problem statement, study objectives and methodology adopted for the execution of this study.

Chapter-II reportes the previous related literature describes harmful effects of marble wastes, LCA, cleaner production and applications of marble wastes in the construction industry and its utilization in the preparation of secondary useful materials and processes.

Chapter-III describes the detailed methodology adopted in the study. These include GIS survey, LCA, process design modification and preparation of useful products from marble waste like cement, dish washing powder, glass fibers reinforce mortar and lime.

Chapter-IV describes results and discussions of the study and includes GIS maps and spatial data base of MPUs in Khyber Pakhtunkhwa, inventory analysis, impacts assessment and result interpretations of LCA. Besides, product evaluation and its comparison with international standards were discussed in detail.

Chapter-V concluded the outcomes of the study and recommended the cleanup demonstration for marble industry based on LCA study; whereas references of text are given at the end.

# ACKNOWLEDGEMENTS

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*Wisal Shah*

**December, 2015**

# ABSTRACT

This study was conducted in 13 districts of Khyber Pukhtunkhwa province where marble processing have been takes place. The main goal of this study was to seek possibilities for the introduction of Cleaner Production (CP) techniques in the marble industry and to handle the wastes in environment friendly manner. For this purpose Life Cycle Assessment (LCA) technique was used. A comprehensive audit of marble processing units (MPUs) was carried out. This includes analysis of the raw materials inputs and outputs in terms of final products and byproducts. Besides, on-site treatment facility of the wastewater and its recycling in the process was studied along with the slurry recovery. This was done with the idea to reuse the water inside the units with the recovery of marble slurry powder. Analysis of waste marble slurry was done to identify its composition for ensuring its utilization in the subsequent secondary products. The analyses include chemical composition, moisture content, specific gravity, fineness and water absorption. It was estimated that a MPU needed 25-50 tonnes/day of raw marble stone. Water for cooling was required @ 15.6 to 31.8m$^3$/day, with the electricity requirement of 385.4 to 919.2 kWh/day. Production outputs were ranged from 18 to 40 tonnes/day and 14.72-30.74 m$^3$/day in terms of marble tiles and wastewater discharge respectively. Marble slurry waste was tested for the preparation of valuable products such as cement, dish washing powder, high strength Glass Fiber Reinforce Mortar (GFRM) and lime. After recycling of marble slurry waste in the preparation of recycled products, the necessary experimental testing of these products was also performed to check the quality according to American Society for Testing and Materials (ASTM) or international standards. Compressive and flexural strength of concrete and GFRM specimens after 28 days curing showed strength closest to control specimens and qualify the standard requirements for construction purposes. Dish washing powder prepared from 50% calcium carbonate marble slurry, 20% soda carbonate, 20% sulphonic acid and 10% soap stone shows excellent consumer's response in comparison of dish washing powder available in the market. Percent mean composition of lime prepared from marble slurry shows more purity index than the commercial grade. Life Cycle Impact Assessment results revealed that the wastewater of MPUs has got significant impacts on the physico-chemical characteristics of surface waters and soil. The waste produced from the marble processing can be converted into valuable products. It is

therefore recommended that LCA along with Cleaner Production (CP) be made as an integral parts of Environmental Impact Assessment (EIA) process in Pakistan.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| EAC | Environmental Assessment Checklist |
| EIA | Environmental Impact Assessment |
| EPA | Environmental Protection Agency |
| MPU | Marble Processing Unit |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| CP | Cleaner Production |
| GIS | Geographical Information System |
| μm | Micrometer |
| % | Percent |
| °C | Degree Centigrade |
| Std.Dev | Standard Deviation |
| ASTM | American Society for Testing and Materials |
| Cr | Chromium |
| Cu | Copper |
| CaO | Calcium Oxide |
| $Ca(OH)_2$ | Calcium Hydroxide |
| GF | Glass fiber |
| kW | Kilo Watt |
| GFRM | Glass fiber Reinforce mortar |
| KPK | Khyber Pakhtunkhwa |
| LOI | Loss on Ignition |
| Mn | Manganese |
| Mpa | Mega Pascals |
| MSD | Marble Slurry Dust |
| DWP | Dish Washing Powder |
| N | Normal |
| Ni | Nickel |
| Pb | Lead |
| PC | Portland Cement |
| PP | Plaster of Paris |

| | |
|---|---|
| ppm | Parts per million |
| PSI | Pounds per square inch |
| WAPDA | Water and Power Development Authority |
| W/C | Water to Cement ratio |
| W/P | Water to Powder ratio |
| WC | White Cement |
| Zn | Zinc |
| PS | Pakistan Standards |
| BS | British Standards |

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**List of Published, Submitted and Designed Research Papers**

1. Wisal Shah, Mohammad Nafees and Muhammad Iqbal. Evaluation of Marble Slurry Waste for Preparation of Commercial Grade Cement, Published in Journal of Engineering and Applied Sciences, Volume 34 (01) January-June 2015, ISSN 1023-862X, pp 27-36.
2. Mohammad Nafees and Wisal Shah. Physico-Chemical Investigation of Wastewater Effluents from Marble Processing Units in District Buner (Pakistan). Submitted to the Journal of Chemical Society of Pakistan.
3. Mohammad Nafees and Wisal Shah. Evaluation of Environmental Assessment Checklist developed for Marble Industry as a Pollution Prevention Measure. Submitted to the Journal of Basic and Applied Sciences.
4. Wisal Shah and Muhammad Nafees. Consumer's Response towards Eco-Friendly Products: Evaluation of Dish Washing Detergent Powder's Prepared from Marble Slurry. Submitted to the Journal of Science and Technology, University of Peshawar.
5. Wisal Shah and Mohammad Nafees. Characterization of Wastewater Effluents from Marble Processing Industries located in the Industrial Estates of Khyber Pakhtunkhwa (Pakistan)
6. Mohammad Nafees and Wisal Shah. Effects of Marble Processing Industry on Surface Water Quality: A Case study on *River Barandu* in District Buner, Pakistan. Submitted to the PLOS-ONE Journal.
7. Wisal shah, Sohail Noor, Muhammad Nafees. Study on Utilization of Marble Cutting Waste Powder in Glass Fiber Reinforced Mortar. Submitted to the Journal of Industrial Ecology.
8. Wisal Shah and Mohammad Nafees. Characterization of Marble Cutting Sludge and its utilization in Secondary Useful Products. Submitted to the Journal of Himalayan Earth Sciences.
9. Wisal Shah and Mohammad Nafees. Comparative study of Italian and Pakistani *Carara* marble quality. (design)
10. Wisal Shah, Muhammad Nafees. Impacts Assessment of Marble Slurry Waste on Surface Water Quality; A Case Study of *Subhaan Khwar*, Shabqadar, Pakistan. Submitted.

11. Wisal Shah and Muhammad Nafees. Evaluating marble slurry as an alternative of oyster shell powder in poultry feed. Submitted to the journal of Quality and Technology.
12. Muhammad Nafees and Wisal Shah. Study of Marble Slurry for Lime Production. (design)

# CHAPTER-I
# INTRODUCTION

# CHAPTER-I

# INTRODUCTION

## 1.1 Background

Dimensional stone sector largely consists of marble comprising the metamorphosed crystalline limestone having 3-4 Mohs hardness amenable to sawing and polishing and used as decorative material in construction (Ferreira et al., 2003). The users prefer physical appearance of marble such as colors in different shades and designs (Almeida et al., 2007). Marble is usually mined from surface and subsurface deposits through blasting, drilling and quarrying which creates rock waste of varying shapes and sizes (Alzboon and Mahasneh, 2009). Marble industry in Pakistan, in general, and Khyber Pakhtunkhwa, in particular, is growing day by day. Marble reserves of Khyber Pakhtunkhwa contributing 97% to the total of Pakistan marble deposits (Manan and Iqbal, 2007). Due to these enormous deposits of marble, the Khyber Pakhtunkhwa province faces an immense ecological implication. Marble processing units are generating large amount of slurry which are consist of water and fine marble particles. The processing of 1 tonne marble stone generated 1 tonne slurry containing 700kg of water (70%) and 300kg (30%) of marble sawing dust (Dhanapandian et al., 2009). This slurry is disposed off into surface water bodies like rivers, streams or lagoons, without any treatment, which causes serious environmental problems (Ammary, 2007; Karasahin and Terzi, 2007). Suspended load of Marble processing wastewater badly affect the aquatic fauna and can also block the main channels and drains, ultimately leading to drainage problems (Al-Joulani 2012).

Literature review reveals that various researchers explored the suitability of marble slurry powder as raw materials in the preparation of secondary useful products. Marble waste recycling is considered a best option to reduce the impact of marble industries on the environment, if the slurry is recovered properly (Pelisser et al., 2011; Correia et al., 2011). The main aim of this study was to identify the possibilities of marble waste recycling into valuable products.

## 1.2 Marble processing in General

First of all marble block extracted from the quarry site either by conventional blasting using explosives or by using diamond wire square block cutting technology. After that it is hauled by ten wheeler truck to the processing units. The cut block usually 50-60 tonnes in weight is stored in a yard from quarry site by means of bridge cranes. The processing of marble stone is divided in cutting and polishing stages in the processing units (Photos 1-10, Appendix-II).

Then the block is sent to dressing where mono-blade cutting machine shaped it into regular rectangular shapes. Then it is moved to gang saws units (having multiple blades) or vertical cutter (single blade) for further cutting into small and more governable sheets. A 60-blades gang saw produces total 61 slabs in which the two end pieces are wasted and remaining 59 slabs having thickness of one inch is produced. If multi-blades gang saw is not available, single vertical blades is used for sheet production. After this, the bridge cutter cut the sheets into slabs and then into tiles of 1 square feet of one inch thickness. After that they are moved to the conveyer polishing line for the polishing, where they are laid horizontally on a large conveyer type line called a polishing line. The polishing stage is made mostly with 12 to 22 headed automatic polishing machines.

### 1.3 Environmental Problems due to Marble wastes

Worldwide marble quarrying and processing generate around 25-40% of the marble stone wasted which are dumped widespread in the environment (Celik and Sabah, 2008).

Some of common environmental problems associated with marble industry are as follows:

- It causes water pollution and always poses negative impacts on surface water resources when it is dumped in water bodies (El Haggar, 2007; Vijayalakshmi et al., 2003).

- Marble slurry waste reduces porosity and permeability of the topsoil, which prohibits water infiltration. Marble slurry waste increased soil alkalinity and reduced soil fertility (Fazal Akbar, 2007).

- The marble waste dumped in the form of slurry severely threatens the ecology of areas clustering the marble processing plants (Vijayalakshmi et al., 2003).

- Marble industry indirectly contributing air pollution when dumped openly. The dry slurry has a high pH due to which it has a negative impact on the lungs and may also cause eye sores (El Haggar, 2007; Vijayalakshmi et al., 2003).

- Open disposal of marble slurry spoiling the aesthetic value of the region (Vijayalakshmi et al., 2003).

### 1.4 Cleaner Production

According to United Nation Industrial Development Organization (UNIDO), Cleaner Production (CP) is on-site recovery/reuse of the waste materials in the same process or Production of Useful By-Products like transformation of previously discarded wastes into materials that can be reused or recycled for another application outside the company and modification of product characteristics in order to minimize the environmental impacts of the product during or after its use (disposal) or to minimize the environmental impacts of its production.

The United Nations Environment Program developed in 1991 the following CP definition that is still commonly used:
"*CP is the continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment*"

To reduce pollution at source, the United Nations Environment Program introduced the concept of Cleaner Production in the dairy and petroleum sector in Pakistan in 1994 as an alternative to end of pipe (EoP) treatment (Ozbay and Demirer, 2007). Cleaner Production (CP) is an important tool that supports sustainable development by facilitating recycling and reuse of resources and handle residual wastes in a more acceptable manner. Cleaner production is a preventive strategy to minimize the negative impact of production and products on the environment by complying with environmental regulations. They also generate less harmful pollutants (Frondel et al., 2007).

In Khyber Pakhtunkhwa Marble processing industry generate a large amount of waste in the form of flag stones and slurry. There is no such institutional mechanism in place to recover and reuse these wastes. In 2001 the Mineral Testing Laboratory of Pakistan made an attempt to introduce a demonstrated model for marble waste management but it was not implemented due to unavailability of waste generation data. Mineral Testing Laboratory make products like dish washing powder, white cement and brick but these products were tested upto laboratory scale and not evaluated in real world. The demand for raw materials increases day by day in the construction sector results in huge shortage of building materials (Almeida et al., 2007). This is the only reason that civil engineers and environmentalists choose stone wastes as an alternative of construction materials (Turgut and Algin, 2007). Few years back there was no interest in utilization of waste but due to huge environmental degradation the concept of utilization of waste, green technology and low waste have been introduced and especially construction industry has shown considerable interest in this aspect (Connan et al., 2005). This marble waste use as an alternative raw material for secondary useful products because it is mainly composed of $CaCO_3$, which can utilize in the preparation of secondary useful products (Marras et al., 2010).

### 1.5 Life Cycle Assessment

Life Cycle Assessment (LCA) is another emerging tool in the field of sustainable waste management (Rebitzer et al., 2004). LCA ensure the CP by measuring the environmental performance in terms of total inputs and outputs of a specific process throughout its life cycle (Blengini and Garbarino, 2010). There are five approaches to define a typical LCA study boundaries. These include (i) cradle to grave (from resource extraction to final disposal), (ii) cradle to gate (commodities), (iii) gate to gate (specialized unit processes studies), (iv) gate to grave (market studies) and (v) well to wheel for automotive fuels (Schenck, 2010).

In Pakistan, no such idea was introduced to handle marble wastes. This study was an attempt to evaluate the products made from marble slurry waste, with the quality of products made from virgin raw resources. Beside this, a combined mechanism of LCA and CP was designed for marble waste management for the first time in Khyber Pakhtunkhwa, Pakistan and to provide a framework for future initiatives.

### 1.6 Regulatory Framework

Mineral and stone related mining, quarry and processing were started in 1960s in Pakistan. Since that time marble related activities is growing fast. In 2007 its contributing to Gross Domestic Product (GDP) was 0.67% (Khan, S 2012). Besides economic benefits, it is posing a potential threat to the environment. Marble processing units (MPU's) produce large amount of waste in the form of slurry. As per estimate, on the average one particular MPU produce 500 Kg/day waste marble slurry (MTL, 2001). This waste marble slurry negatively affect the surface water quality after discharge it into the nearby surface water body (Gokaltun, 2011). Suspended load of calcium carbonate badly affect the aquatic fauna and can also block the main channels and drains, ultimately leading to drainage problems (Al-Joulani, 2012). To overcome such potential environmental threats, Pakistan started its journey in 1983 in the form of environmental protection ordinance, which paved the way to setup environmental protection agencies (EPAs) and formulate Pakistan Environmental Protection Act (PEPA) in 1997. Under section 12 of the act, Environmental Impact Assessment (EIA) was considered as mandatory for all developmental activities and manufacturing processes. By 2000 EPA prepared EIA/IEE regulation and monitoring rules. According to these regulations, detail EIA is only mandatory for large scale project like sugar mill, dam, and Paper mill etc. If the project is of small scale and the cost is in Pak-Rs 10 to 50 million, IEE is suggested. As the cost of individual Marble Processing Unit (MPU) is always less than Rs. 10 million, therefore, Pakistan Environmental Protection Agency developed Environmental Assessment Checklist (EAC) in 2004 with the objective to make environmental assessment study simple. This study was also an attempt to evaluate the effectiveness of the Environment Assessment Checklist (EAC) developed for marble processing industry for pollution reduction and to save water. This is especially important for decision makers in preparing policy, rules and regulations.

### 1.7 Aims and Objectives

1- To conduct a reconnaissance survey of marble processing units in the study area and ascertain their status, number and their distribution;

*2-* To prepare GIS data base for mapping out the locations of existing marble processing unit's in the study area;

3- To measure the required inputs such as raw materials, water, energy usage and quantify the overall environmental releases per unit production;

4- To assess the environmental impacts associated with inputs and outputs of marble processing industry;

5- To search out new techniques and process modification for water recycling and recovery of marble slurry;

6- To develop a plan for marble wastes collection and its utilization in various industrial units like cement, Calcium hydroxide, paper mill, bricks and dish-washing powder.

### 1.8 Research Problem

Most of the LCA studies conducted so far have focused on energy estimation, Green house gases emission and economic analysis. Little importance has been given to the recycling or waste handling aspects of marble production processes. This study was an attempt to use the concept of LCA in an innovative way and to use it as a problem solving tool in the implementation of Cleaner production. Cleaner Production mechanism will help marble industry to avoid/reduce environmental pollution by recycling of waste water in the process and to recover marble slurry before flushing into the stream. This technique will also be helpful in saving mineral resources and protect the environment. Beside this, no work was done for the proper recovery and collection of marble processing waste. The goal of this study is how to combine LCA and CP concepts to obtain a model for marble waste management.

### 1.9 Methods

#### 1.9.1 Preliminary activities

Study and evaluate previous literature, reports and existing regulatory measures to know about the sustainability and significance of proposed LCA study.

#### 1.9.2 Study Area

According to preliminary survey the marble quarrying and processing takes place in 13 districts of Khyber Pakhtunkhwa (Fig 1.1). This survey helps us to find out the allocation and total number of marble quarries and Marble Processing Units in the study area. The districts where marble processing takes place are Buner, Peshwar, Mardan, Charsadda, Nowshera, Malakand, Dir(L), Chitral, Swat, Abbottabad, Haripur, Mansehra and Swabi.

### 1.9.3 GIS Survey

To prepare GIS data base for mapping out the locations and distribution of existing MPUs in the study area was one of the objectives of this study. For that purpose Global Positioning System (GPS) was used for the collection of coordinates from each district where marble processing takes place. Arc-GIS software was used for the preparation of location wise GIS maps of MPUs distribution. It is useful for easy tracking of these MPUs for monitoring and future survey. Besides, this also helps in identification and quantification of marble processing units clustered in the industrial estates, marble city or scattered outside.

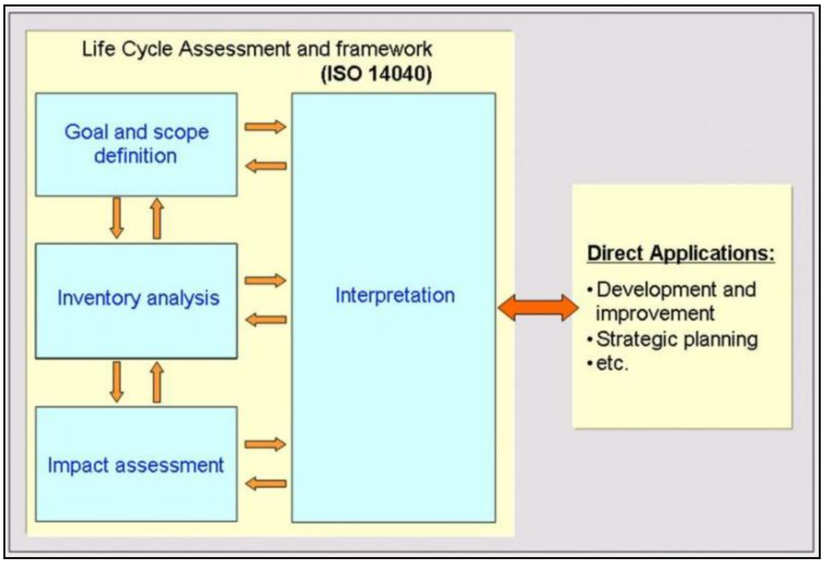
**Figure 1.1: Showing map of the Study Area**


**Source: Khyber Pakhtunkhwa Mineral Development Department**

### 1.9.4 LCA Framework

The current LCA study was conducted according to the standardized methodological framework set by the International Standard Organization ISO (Fig. 1.2). The main goal behind the proposed study is to develop a procedure of Life Cycle Assessment for marble industry in order to develop a mechanism of cleaner production.

**Figure 1.2: Methodological Frame work for LCA**




Source: ISO 14040-2006

Inventory analysis includes determining inputs and outputs of Marble Processing Units (MPU's) with the main emphasis on water usage, raw materials consumption, energy and wastes produce in each production phase/step of the product life cycle. Listing unit operation and constructing process flow diagram was made to identify the system boundary and estimate the quantities of input and output of materials flow in terms of resource consumption, production and wastages.

Life Cycle Impacts Assessment (LCIA) is an important step in LCA study. It includes characterization; evaluation and allocation of potential impacts posed by the marble industry on the environment. In the current study, the issues of waste water containing marble slurry and marble waste produce during processing phase was considered. It includes the impacts of marble processing waste on surface water quality its usage and soil quality. LCA data interpretation was done statistical data presentation tools like word processing, Excel spreadsheet, sigma plot 10.0 software etc.

### 1.9.5 Slurry Recovery

Measurement and evaluation of current level of onsite treatment facility of wastewater and its recycling in the process was studied along with slurry recovery. This was done with the idea to keep the water fit for recycling inside the units with recovery of marble slurry powder. A draft recovery plan was prepared for marble processing waste based on the total quantity of waste produced in the study area and its usability in other valuable products. This will provide a framework for future initiatives.

### 1.9.6 Preparation of valuable products

After completing the necessary testing, marble slurry waste was utilized as raw material in the preparation of valuable products such as cement, dish washing detergent powder, Glass Fiber Reinforce Mortar (GFRM) and calcium hydroxide. After recycling of marble slurry waste in the preparation of recycled products, the necessary required experimental testing of these products was also performed to check the quality according to ASTM or international standards.

## 1.10 Report Structure

This dissertation consists of five chapters that discuss various aspects of GIS, LCA, CP and products preparation using marble slurry dust (MSD) related with relevance to this study. Chapter one explains the introduction, objectives, study area and methods of the research. Chapter two covers the literature review that discusses the previous studies done by different authors about the relevant work. Chapter three relates to details of methodology employed in the study. Chapter Four explained results and discussion of the study and its findings. Chapter five shows conclusions and recommendations of the study.

# CHAPTER-II

# LITERATURE REVIEW

# CHAPTER-II

# LITERATURE REVIEW

A brief literature review of the related studies previously conducted in different parts of the world has been discussed here to understand the significance of conducting the present research. These were divided into subsections; Harmful impacts of marble wastes, Life Cycle Assessment, Cleaner Production and applications of marble wastes in useful products.

## 2.1 Harmful Effects of Marble Wastes

Jehangir et al. (2015) investigated the health risk associated with Marble effluents. They worked on renal (kidney) stone formation in the dwellers of district *Buner* in Khyber Pakhtunkhwa province of Pakistan. Kidney stone was observed in 1000 patients using Marble wastewater contaminated drinking water. Moreover, the finding of this study shows that marble processing industry poses a potential human health risk due to chronic exposure of marble effluents. This induced chronic condition of renal stone formation requires proper attention and mitigations in order to protect the human health.

El-Gammal et al. (2011) worked on health risk associated with marble dust at marble processing units in Damietta City Egypt. They work to records pathological changes occurring in rats' lungs after exposing to inhale dried marble dust. As a results, It was concluded that the long exposure of marble dust cause lung disorders in rats therefore the workers work in the marble industry are on potential health risk which requires mitigation measures to manage health and safety of human beings.

Amit and Singh (2013) reports the problem associated with inappropriate disposal of Marble slurry waste with the objective of its utilization as soil conditioner. They stated that marble waste disposal is an emerging problem because it needs huge space and it will become a hazard if it is dries up. Nearly 15-20 lacs Tonnes of marble slurry waste is produced in the study area. By utilization of alkaline waste as soil amendment it would be the best option to get rid of this waste.

Sharma and Saxena (2012) emphasized the need to address damage to environment and human beings on urgent basis due to rapid expansion of marble cutting and processing industries in Rajasthan, India. The Rajasthan marble industry generates huge quantity of slurry along with 43,000 liters of water per hour per gang-saw. Almost 20% out of mined marble resources is dumped on empty land and road sides. This creates a lot of environment and public health problems. The study investigated adverse effects of marble waste like cracking, spalling and delamination on crops and lands and declares the issue as severe.

Fakher and Mohammad (2008) investigated environmental impacts of rapidly growing marble industry in Jordan and to assess the adequacy of Jordanian environmental legislations in controlling environmental impacts of marble industry of the area. The study focused on Environmental assessment of eight marble processing and manufacturing units. Waste material and by products of the industries were compared with the standards determined by environmental regulations and legislations in force. These findings concluded that marble waste generation is creating problems for human beings after being discharged into the domestic sewage system. Besides, violations of the land use classification and municipality limits were also recognized.

### 2.2 Life Cycle Assessment

Cabeza et al. (2014) summarized to review the previous literature on life cycle assessment (LCA), life cycle energy analysis (LCEA) and life cycle cost analysis (LCCA) studies. The review showed that most of the researchers conducted LCA and LCEA on modern sophisticated buildings and few studies were done on traditional buildings such as found in our cities. Finally, this review concluded that worldwide the LCA studies are not equally distributed because, most of the literature available on such studies which were done on urban environment and not much literature available on the studies conducted in rural areas.

Nicoletti et al. (2002) compared Life Cycle Assessment of marble and ceramic tiles in order to identify the one with the best environmental profile. For that purpose critical points were considered for both products includes consumption of raw materials, energy and hazardous air emissions. The final results showed that marble tile have best environmental profile than the ceramic tile.

Huntzinger and Eatmon (2009), conducted LCA study to evaluate the best environmental profile of four cement manufacturing processes: (1) Portland Cement, (2) Natural Pozzolans, (3) Production of cement with recycling of 100% of cement kiln dust (CKD) (4) Portland cement manufactured when waste CKD is used to sequester $CO_2$ emissions. Analytical tool like Sima-Pro 6.0 were used for analysis which shows that manufacturing of Portland cement using waste CKD as sequester $CO_2$ emissions provide the great environmental savings. The recycling of CKD in blended cement was found with little environmental savings over the traditional process.

Bribian et al. (2011) presented LCA study for commonly used building materials with comparison of eco-friendly building materials. The aim of this study was to analyze the possibilities for selecting suitable building materials in eco-design of new and existing buildings. The study concluded that the impact of construction industry can be reduced significantly by using eco-friendly building materials and promoting eco-innovation by substituting the use of natural resources. These types of studies would ensure the competition between manufacturers to launch more eco-friendly products.

Bovea et al. (2010) have done Life Cycle Assessment to calculate the environmental performance of 1$m^2$ ceramic tiles. This was done by executing a detailed inventory analysis of all the stages from mining the red clay to the manufacturing of ceramic tiles. Besides, matrials and processes were identified having greatest environmental impacts. On the basis of which series of improvements in the manufacturing process were proposed to reduce the environmental impacts and increase performance efficiency of the process.

Dos Santos et al. (2009) presented the results of a research project which executed in 13 marble and granite processing units. The objectives of this study was to establish regulatory and sustainable design guidelines for marble and granite products, which provide a frame work for future initiatives for a non-renewable material. During the investigation, a significant lack of literature was identified on these materials which could support the regulatory measures and sustainable design process, particularly regarding the issue of recycling. The main finding of this study has choosing cascade approach for recycling particularly for all possible wastages in the entire life cycle of the product in this sector.

Maleche (2012) reported the applications of life cycle assessment (LCA) to estimate the greenhouse gas emissions of new renewable liquid fuels. The given biomass feed stocks of the two regions were analyzed for comparison include algae and cane bagasses. The results of these feedstocks along diesel and gasoline were calculated and compared in different scenarios conducted in different condition. The inputs and outputs data were incorporated into LCA model and concluded the LCA results. The results interpretation shows that the greenhouse gas (GHG) emissions savings of 58-98% were estimated for given biomass with respect to gasoline and diesel fossils fuels.

Li et al. (2014) carried out Life Cycle Inventory analysis (LCI) to make potential improvements in cement industry. The detailed life cycle inventory (LCI) of cement manufacturing plant included complete input and outputs. The functional units are 1Tonne of Portland Ordinary cement. The input data contain not only the traditional items such as raw materials includes limestone, clay, gypsums, energy (coal and electricity), and admixtures (furnace slag and fly ash), but also fresh water which is not paid attention in other literature. The output data contain not only greenhouse gases but also the hazardous air pollutant as well as noise and heavy metal emissions which are usually neglected by other researchers. The data were measured on-site and evaluated for in order to incorporate it into the applications of reducing pollutants and waste heat recovery technologies in cement industry.

Valderrama et al. (2012) conducted comparative assessment of old and new production line of a cement plant by using LCA methodology. The study revealed that the standard methodology used for conducting LCA has based on the both design of new and old production line for easy quantification of inputs, outputs and the environmental impacts. For that purpose, to reduce the uncertainty a cradle-to-gate life-cycle assessment approach of both scenarios was conducted. Analysis using software Sima-Pro 7.2 showed that new production line provided a significant reduction of the environmental and health impacts as compared to the former lines.

Gursel et al., (2014), reviews the strengths and weaknesses of concrete LCIs to date, and offers a research initiative roadmap for improvement in the quality of future LCA studies in that sector. This research road map offers Life Cycle Assessment based decision support system for manufacturers. A comprehensive literature survey was conducted in this regard and their main results were composed and compared. It was revealed that in undertaking any LCA study the compilation of credible data of life-cycle inventory (LCI) is an important and critical step. On the basis of which subsequent LCA and LCIA (life cycle impact assessment) can be based.

De-Benedetto and Klemes (2009) reported the SEPI (Sustainable Environmental Performance Indicator) as a measure for sustainability. For that purpose Life Cycle Assessment is a holistic tool for analyzing economic and environmental impacts of a product. LCA is act as a novel approach in the decision making process in environmental and finanacial consideration of a production process. Based on this a graphical hierarchy was design which represent environmental performance strategy of the product.

Traverso et al. (2010), studied the environmental performance of typical Sicilian marble tiles and slabs by using LCA methodology. In first phase data were collected for life cycle inventory analysis based on which impact assessment was done. For that purpose $1m^3$ marble tile and slab were considered as a functional unit. The impact assessment includes the potential of acidifications, global warming, eutrophication and photochemical smog. The results were compared and evaluated. The environmental hot spots identified in this study are: the amount of stone waste in the form of fragments and sludge produced during extraction, cutting and polishing. Due the lack of cooling water recycling facility huge amount of water wasted in the saw mill and quarry site. Besides, high electricity consumption was recorded. Overall, results show that the manufacturing of marble tiles has higher environmental performance indicators values.

Schau (2012), developed LCA methodology fish products. Previous literature shows that most of LCA studies have been developed for commodity products but this work contributes to extending the applications of LCA to food products. For that purpose system engineering principles and processes were follows to systematize the analysis of the life cycle of the fish product. Relevant environmental performance indicators for fish products have been selected to explored impact of fish products. Great attention has been given to the fishing vessels because their energy consumption accounts for the largest environmental impacts of the fish products.

Ioannidou et al. (2014), reported Life Cycle Assessment (LCA) to identify best waal treatment system facility having less environmental impacts. For that purpose data were collected from two stone processing facilities in the study area and evaluated. Besides, the use of other wall treatment systems like thin cladding and rock walling used were also evaluated. The results show that the stone product largely used in the structure instead of thin cladding or rock wall system. It was due to the availability of raw materials locally. Therefore it was concluded that the use of stone products in wall system has less environmental hotspot as compare to other process.

Norgate and Haque (2010) worked on the impacts of green house gases (GHG) emission generated as a results of mining and mineral processing activities. They focused on the Life Cycle Assessment study of iron, bauxite and copper ore mining and their processing. They concluded that as results of drilling, blasting, hammering, loading, hauling, unloading, crushing and grinding of these ores contributed high amount of GHG emission. The main reason was that, these operations run on power diesel and electricity and by applying cleaner production technologies in mineral sector the emission of GHG would be anticipated in future.

Ortiz et al. (2009) Worked out on the recent development in the construction sector based on LCA studies. For that purpose detailed literature survey was done and focused on the methodologies adopted for LCA in building sector over the last 7 years, from 2000 to 2007. It was concluded that the application of LCA is fundamental to sustainability and improvement in building and construction sector.

Hauschild et al. (2005) reviewed the status of Life Cycle Assessment (LCA) in the product chain. For that purpose previous literature was surveyed to find out the role of LCA in product policy. Besides, the role of industry was discussed in meeting the issues and challenges and sustainable problem solving options such eco-efficiency, green labeling and green products. Finally, it was identified that there is a need for stronger regulation/legislation and for environmental education, awareness and attitude building among future engineers and citizens.

Elduque et al. (2014) Conducted Life Cycle Assessment of electronic board in order to assess their environmental performance. For that purpose electronic board with 4 hobs and 7.2 kW of nominal power was defined as the functional unit. The electronic boards used in this study are of two types one is Printed Circuit Board and one touch control electronic board. Each one has been thoroughly analyzed and created the LCA model using SimaPro 7.3.3 software. Touch Control unit has significant impact on Ozone Layer Depletion as compared to printed circuit assembly unit. The overall analysis and results interpretation shows that there are so many areas for improvement in terms of reducing environmental impacts and end-of-life treatment.

### 2.3 Cleaner Production

Huang et al. (2013) reported to introduce the concept of cleaner production in a medium- size ceramic tile plant. For that purpose a complete audit was done in the selected plant on the basis of which pollution points were identified. It was found that 31 different measures, including technology improvement, facility replacement, process control, plant management, raw material and waste reutilization and worker training have been suggested/proposed in a feasible way and implemented. Through the introduction of cleaner production, the ceramic plant achieved the expected outcomes in energy conservation and pollution reduction. It was estimated that the energy and water consumption for a unit product were reduced by 4.33% & 22.33% respectively. in the account of air pollution the emission of $SO_2$ was also cut down by 8% for each unit product.

Eliche-Quesada et al. (2012) reported the application of waste materials in the production of lightweight bricks. The waste material includes spent earthy materials, sawdust, marble and compost. First of all chemical composition, mineralogical properties and thermal behavior were determined for wastes and clay. After that, ceramic bricks were prepared and fired at 950-1050ºC on trial basis containing 0–10 wt% sawdust, 0–20 wt% marble and 0–30 wt% compost and spent earth. Different test were performed like compressive strength, water absorption capacity, linear shrinkage, bulk density and scanning electron microscopy (SEM). The results show that the suitable sintering temperature is 1050ºC because below this increased in open porosity was observed. The best percentages of wastes were 5 wt% of sawdust, 10 wt% of compost and 15 wt% of the spent earth and waste marble which suitable mechanical properties.

Shu et al. (2010) worked out to introduce a novel approach of preparing press powder in the ceramic tile manufacturing industry and tested. In this process the ceramic materials suspension was sprayed directly into the granulator and dry ceramic powder jetted to enwrap and form granules, after that the press powder were formed and lab analysis were carried out. Test results show that the prepared press powder have normal and uniform grain size, shape, flow-ability and bulk density as those prepared by traditional methods. Moreover, as compared with traditional process pollutant emission of 98% dust, 65% sulfur oxides and 71% nitrogen oxides and resource consumption of 24% energy and 69% water can be reduced.

Gupta et al. (2014) attempts to introduce water jet abrasive cutting method of marble stone instead of conventional methods. In this method jet of water containg abrasive slurry is introduce to cut the material. During the design of this method three process parameters were considered; pressure of water containing slurry, nozzle hydraulics and flow rate. To evaluate the obtained data Analysis of variance (ANOVA) was used to determine the significance of the process. The results show that the transverse speed of nozzle was considered the most significant process factor.

Fernandez-Caliani and Barba-Brioso (2010) estimated the amount of waste sludge produced in a year during processing of marble stone in the study area and explored its potential to reutilize this waste for secondary applications. The waste produced as a result of marble processing can be used as soil amendment and remediation of heavy metals contaminated sites. For that purpose trial experiments were conducted on soil samples collected from mine abandoned site by applying different amendment doses of marble wastes on it. Results shows that the optimum amendment applications was very effective in reducing concentrations of (Fe, Al, Mn, sulfate) and potentially hazardous trace elements mainly Cu, Pb, Zn and Cd.

Careddu et al. (2014) investigated the properties and feasibility of marble powder waste into industrial applications. The waste marble slurry predominantly consists of calcium carbonate and mistakenly viewed as waste instead of by-product that has to be disposed of in landfill. For that purpose there is a need to introduce recovery and utilization of calcareous marble waste into secondary useful applications. If this is recovered properly with economic feasibility it can be used in many industrial applications such as in paper industry, rubber industry, paints, and pharmaceuticals industry as fillers. For that purpose the properties of this waste sludge powder evaluated and compared its results with Calcium carbonate used in paper, rubber and tires production. Finally it was concluded that this waste can be used as an alternative resource of Calcareous materials.

Careddu and Siotto (2011) worked on the environmental impacts of marble quarrying and processing. Mitigatory measures are proposed using three dimensional topographic simulation model to prevent their impact on the environment. The main aim of these models was to establish guidelines for introducing sustainable processes technologies to yield green products. Results show that models for land management and planning for industrial area is very important for both LCA and process improvement in order to meet the environmental performance standards.

Gameiro et al. (2014) evaluated the durability of concrete containing varied percentages of waste fine aggregates generated from quarrying operations. For that purpose concrete specimens were made containing 0%, 20%, 50% and 100% of the total volume of fine aggregates and tested for bulk density, water absorption capacity, chloride penetration and drying shrinkage of hardened concrete, were determined. It was concluded that the durability properties of concrete containing fine aggregates of granite, basalt and river sand tend to improve, remain constant and decrease, respectively, with the incorporation of fine aggregates from marble quarrying waste. However, these changes do not compromise the use of these secondary aggregates in structural concrete.

Hanieh et al. (2014) focused on the environmental, economic, and social impact of stone and marble processing industry. The objective of the study was to presents the lifecycle of the process, identification of pollution hotspot and proposes mitigation measures for efficient use of raw materials including natural stone, water consumption and energy use during processing. Recovery, Reuse and Recycle, 3Rs principles are used to maximize the yield and minimize the wastes in order to improve process efficiency. This will provide a frame work for future initiative in this sector.

Andre et al. (2014) assess the opportunity of replacing primary aggregates with marble aggregates. To evaluate this, three mixture of concrete specimens using both type of aggregates were used. For that purpose no additives or admixtures were used which change the properties of resulting concretes. The conventional primary aggregates includes basalt, granite and limestone were replaced in the three families by coarse marble aggregates at ratios of 20%, 50% and 100% of the aggregates total volume. These concrete mixes were tested for compressive strength, water absorption capacity and chloride penetration in hardened state. The results show that there were not any significant differences found in concrete specimens prepared using coarse marble aggregates with conventional primary aggregates.

Segadaes et al. (2005) worked on the rejects of marble and granite stone processing waste and its utilization in ceramics floor tiles as an alternative of primary raw materials. For that purpose fractions of these wastes were used in addition with red clay based admixture up to 30% by weight and tested for thermal analysis, water absorption and mechanical strength including compressive strength. Results shows that by using marble and granite waste the properties of sintered ceramics tiles can be improved.

Mashaly et al. (2012) Worked on the characterization of marble slurry waste and its compatibility for recycling it in various valuable products. Characterization includes analysis of water contents, size analysis, whiteness index, Calcium and Magnesium oxides. Comparative values of both calcareous slurry and virgin calcium carbonate shows that it can be use in cement manufacturing, paper industry, water paints, PVC, fertilizer, desulphurization, bitumen mixture, steel manufacturing, ceramic industry and in Solvay process.

Kumar and Reddy (2012) Worked on the life cycle assessment case study of Barytes mineral pulverizing industry in Kadapa district, Andhra Pradesh north of India. They used Life Cycle approach to investigate the negative impacts of Barytes rocks mining on the environment. They suggested Life Cycle Assessment as a regulatory and management tool in the mitigation of adverse impacts and as a safety measures especially in mining sector.

Gazi et al. (2012) Worked on the Energy efficiency and environmental life cycle assessment of a typical marble quarry and processing plant. They studied the performance of (SMEs) Small and Medium Enterprises involves in marble processing. They used inventory analysis, impacts assessment and interpretation methods to assess the current scenario of theses SMEs. They addressed that SMEs need technological modification to enhance the production efficiency and material reduction to minimize wastes.

Bilgin et al. (2012) reported the Usability of waste marble slurry powder as additive in the brick industry. To check its compatibility and usability various physical, chemical and mechanical tests was applied on the bricks made of marble slurry waste sintered at different temperatures. Test for evaluation includes strength test, water absorption and chemo-mechanical properties were determined. It was found that the amount of marble dust additive had positive effect on the physical, chemical and mechanical strength of the produced industrial brick. Therefore the utilization/recycling of marble slurry waste in brick mortar have positive impacts on the economy and environment.

Zornoza et al. (2013) worked on the mineralization of carbon associated with microbial activity and metal dynamics in tailing ponds treated with pig slurry and marble waste. They used these amendments for soil remediation contaminated with heavy metals with decreases up to 98%, 75% and 97% for Cd, Pb and Zn, respectively. They also concluded that the combined applications of Pig Slurry + Marble Waste reduced the degradability of the organic compounds and increase microbiological enzymatic activities in soil which reduce heavy metals availability.

Mehmet et al. (2012) Worked on Fresh and hardened characteristics of self compacting concretes made with combined use of marble powder, limestone filler, and fly ash. They check the usability of lime filler, fly ash and waste marble slurry powder in self compacting concrete. They were observing the results of concrete mixture series with different ratios of marble powder, lime filler and fly ash by doing Strength test of Self compacting concrete. They concluded that the mechanical properties of Self Compacting Concrete were enhancing by using marble slurry waste powder and lime filler.

Karasahin and Terzi (2007) worked on Evaluation of waste marble slurry dust in the utilization of asphalt concrete mixture. Considerable amount of marble stone slurry is produced during shaping, cutting and polishing of marble stone. They obtained waste marble slurry from nearby marble processing units and used it as a filler material in the asphaltic concrete mixtures. They used different bitumen slurry mixture ratios for the determination of tensile strength. The tensile strength test includes Marshall Stability and dynamic plastic deformation tests were carried out on the prepared samples. The tests results showed that marble slurry wastes after drying could be used in asphalt mixtures as filler materials. The cost of transportation of marble slurry waste is lower than the ordinary filler materials.

Eui-Huang et al. (2008) worked on the effect of polymer cement modifiers on mechanical and physical properties of polymer-modified mortar using recycled artificial marble waste fine aggregate. marble waste fine aggregates were investigated for its usability for recycling into modified concrete mortar. They used these marble fine aggregates waste with cement either without and with other modifiers like Styrene–butadiene rubber (SBR) latex and polyacrylic ester (PAE) into mortar mixture in order to reduce water cement ratio. Compressive strength results shows that in the presence of these polymer cement modifiers compared to that of no polymer cement modifiers. so it was concluded that the marble fine aggregates produce as results of cutting, sawing and polishing of marble stone could be use as cement modifier.

Gencel et al. (2012) worked on the utilization of marble waste into concrete paving block. it was used as alternative natural aggregate in the concrete mixture. After mechanical strength tests results show that the marble waste can be used instead of natural aggregate in concrete block production mixture.

Hebhoub et al., (2011) worked on to demonstrate the practicability of utilizing marble waste aggregates in concrete. For these purpose three different practical concrete formulations was carried out for testing: sand substitution mixture, gravel substitution mixture and a mixture of both aggregates (sand and gravel). The concrete formulations were produced with a constant water/cement ratio. Test results shows that by using 75 % of marble waste aggregate are excellent for concrete resistance properties and beneficial for construction activities.

Akbulut and Guerer (2007). Using marble waste aggregates in asphalt mixture for paving. They investigate that 95% of natural aggregates used in asphalt mixture. This high demand of natural aggregates can leads to the depletion of natural resources and environmental degradation. Therefore by using waste marble aggregate as recycling aggregates can help to meet the demands of natural aggregates and Environment. For this purpose waste marble aggregates were used in the different asphalt mixture specimens and tested for its durability. Test results shows that the waste marble aggregates can be used instead of natural aggregates.

Ahmed et al. (2013) worked on the effect of silica on the properties of marble sludge filled hybrid natural rubber composites. They tested different composition of natural rubber compounds mixed with marble slurry waste and silica as a filler materials. After examining the Mechanical properties of natural rubber composites including elongation, tensile strength, tear strength, modulus, swelling, hardness, crosslink density, shearing modulus and volume fraction before and after ageing. They revealed that Marble Slurry waste generated by marble processing units can be used as filler materials in natural rubber composites compound for cost savings.

Barrera et al. (2013) Worked on the effectiveness of fine marble particles on the durability of polymer concrete. They evaluate the Polymer concrete made up with different marble particles and impacts of gamma radiation on it. The tests performed like compressive strength and elasticity modulus of polymer concrete and compare it with Portland cement concrete. Test results revealed that compressive strength of concrete depend on the marble particles size and applied gamma radiation. Finally, It was concluded that polymer concrete need further improvements to use it for load bearing purposes.

Alyamac and Ince (2009) work on design for self compacting concrete with waste marble powder based on three laws (i) Arbam's law (ii) Lyse's law (iii) Molinari's law. They make a mix design approach model called monogram to find the relationships of properties of fresh SCC and hardened SCC containing waste marble powder. For this purpose different SSC mixes were tested with different water/cement ratio and water powder ratio. Test results of slump flow, Sieve segregation resistance analysis T-500 time by using slump cone, L-box and V-funnel were applied for fresh Self compacting concrete and hardened tests were performed such as compressive and flexural strength at 7, 28 and 90 days which shows suitable results for hardened concrete and suggested labeling for Self Compacting Concrete.

Quesada et al. (2012) reported the utilization of various waste materials like marble waste, compost waste, saw dust, and spent earth from oil filtration in the manufacturing of light weight bricks. First of mineralogical properties of these waste and clay used in the preparation of light weight bricks were determined. After that light weight bricks were prepared from these wastes and tested for compressive strength, linear shrinkage, water absorption capacity, bulk density and suction absorption. Tests results revealed that the light weight bricks made from wastes like sawdust 5%/wt, compost waste 10%/wt, spent earthen materials and marble 15%/wt shows good mechanical properties and can be use as raw materials in light weight brick manufacturing.

Ali Ergun (2011) investigated the mechanical properties of concrete specimens made up of diatomite and marble slurry waste powder originated from marble processing units as partially replacement of cement. The laboratory works includes the characterization of virgin raw materials and waste materials to check it feasibility in concrete. Different concrete specimens were prepared by using different ratios of diatomite and waste marble powder. To evaluate the feasibility of utilizing diatomite and waste marble powder in concrete mixture compressive and flexural test were conducted. Test results shows that the concrete specimens made of 10% diatomite, 5% waste marble powder separately and 5% waste marble powder+10% diatomite together as replacement of cement by weight having best compressive strength and flexural strength. It was concluded that the replacement of cement with diatomite and waste marble powder separately and together admixture could be utilized to improve the mechanical properties of the conventional concrete mixtures.

Ghazy and Gad (2014) worked on the usability of waste marble powder for lead removal from water. They use adsorption technique to separate lead ions from aqueous solution of water. Analytical results show that 100% lead removal from different natural water samples was attained by using waste marble powder in batch experiments. They concluded that waste marble powder could be use in the adsorption mechanism of lead removal from the natural water.

Celik and Sabah (2008) studied the environmental impacts of marble waste in afyon-turkey. They worked on the characterization of marble waste in terms of their mineralogical properties. For this purposes X-ray Diffraction (XRD) and X-ray florescence XRF were used. test results revealed that lime or calcium was the main constituent of marble waste with very less elemental portion. They suggest that

Research on possible uses of marble waste in various sectors as raw material and additives should contribute to both the economy of the marble industry and the environment.

Topcu et al. (2009) worked on the “Effect of waste marble dust content as filler on properties of self-compacting concrete”. They used marble slurry waste in self compacting concrete as alternate aggregate and test it for compressive and flexural strength after 28 days curing. Test results shows that the properties of Self Compacting Concrete has been affected if marble dust content were used above 200 kg/m$^3$. However if it was used up to 200 kg/m3 they were not affected the properties of Self Compacting Concrete. Therefore they concluded that Waste marble slurry dust could be used in self compacting concrete mixture.

### 2.4.0 Marble waste in construction industry

### 2.4.1 Concrete production

Bacarji et al. (2013) investigated the marble and granite stone processing waste and its utilization in concrete. For that purpose marble and granite stone processing waste were collected and analyzed. Laboratory analysis shows that the marble and granite stone processing waste not contained any hazardous and reactive materials and thus it will use as natural fillers. Concrete specimens were prepared containing granite and marble stone processing waste and were tested for Compressive strength, elastic modulus and water absorption tests. The mechanical test results show that marble and granite waste will be use as an alternative of natural aggregates and cement in concrete production.

Uygunoglu et al. (2014) investigated the use of marble waste and recycled aggregate in the production of Self Compact Concrete. For that purpose series of control specimens of concrete containing marble waste and recycled aggregates were prepared and tested for slump test, J-Ring test, air content, compressive and tensile strength along modulus of elasticity were determined. Results show that not any significant difference were observed in the mechanical properties of self compacting concrete using marble waste and recycled aggregates. It was concluded that the marble waste and recycled aggregates can be used in self compacting concrete.

Alzboon and Mahasneh (2009) investigated the use of marble slurry waste in concrete production in Jordan. To achieve this aim the marble slurry sludge was used as a source of water in preparation of concrete. Chemical, physical and mineralogical analyses of the waste sludge were performed and compared with typical sand used in the preparation of concrete. Results showed that 96% of marble slurry sludge contains water, so it can be reused as a source of water. Marble slurry with 25 percent of water content has given good results in terms of compression tests. Settling process was used for removal of suspended solids up to 99 percent.

Shirule et al. (2007) studied that around 40% marble slurry is produced during processing of marble in Maharashtra, India. The marble industry presents about 68 million Tonnees of processed products. They investigated that the compressive strength of cubes prepared from 10% waste marble powder by weight of cement increase, while any addition more than that will decrease the compressive strength. This means with the addition of marble powder the strength of concrete increase gradually up to a certain limit but then decreases. In this study they analyzed the physical, chemical and mechanical properties of the marble slurry waste. The main aim of the study was to check the feasibility of using the marble slurry waste in concrete production when used as a partial replacement of cement.

Fakher (2009) studied the possibility of using marble slurry waste in the preparation of useful materials, especially house building materials in Zarqa, Jordan. 178 specimens of different compositions were prepared among them five compositions have given promising results. The experiments performed by author showed that the complete substitution of marble waste with sand and gravel were not suitable but partial replace shows good results. Blocks with a size 15 cm at age of 28 days have good properties in terms of water absorption and compressive strength.

Binici et al. (2007), analyzed mechanical properties of concrete samples prepared from marble and limestone dusts. Seven mix proportions were prepared in three different series using 400 kg of cement as binder with concentration of 5, 10 and 15 % marble powder. Limestone dust was used in place of fine sand aggregate. Preparation of concrete samples was followed by the measurement of compressive strength, Sodium sulphate resistance, abrasion resistance and water penetration. The results showed that the mix proportions can be used for durable concrete preparation.

Rai et al. (2011) investigated the effect of using marble slurry dust and granules in concrete production by reducing quantities of cement has been studied. The results obtained from partial replacement were satisfactory. The increased marble powder or marble granules ratio in concrete preparation has result in increased workability and compressive strengths.

Hameed and Sekar (2009) studied the use of quarry rock dust and marble waste powder as hundred percent substitute for natural sand in concrete production. After the production of concrete from marble waste powder and quarry rock dust the durability studies of the concrete were carried out in order to check the feasibility. The results showed almost 14% increase in the split tensile and compressive strengths of concrete. The sulphate resistance was also notably increased. As marble powder is used as filler in concrete production, so it helps to reduce the total voids content in concrete. Natural sand is not graded properly and has excessive organic impurities while quarry rock dust does not contain organic impurities, so this contributes to improve the strength of concrete.

Almeida et al. (2007) also studied incorporation of marble waste of Lisboa, Portugal in other industrial applications. The results found that replacing 5% sand in a concrete by marble slurry resulted in a higher compressive strength, splitting tensile and higher modulus of elasticity while the incorporation of 20% marble slurry resulted in reduced strength.

Demirel (2010) investigated the effect of using marble slurry waste powder as a fine material and studied their mechanical properties after use. To achieve this goal a series of concrete mixtures containing marble slurry were prepared. Fine sand passing 0.25 mm sieve was replaced with marble powder at a proportion of 0, 25, 50 and 100% by weight. After replacing the marble dust the mechanical properties were analyzed along with compressive strength at 3, 7, 28 and 90 days. A subsequent comparison was drawn between the new product and traditional concrete.

Misra et al. (2010) studied the suitability of using marble slurry waste from marble processing plants in the construction of roads in New Delhi, India. For this reason 20-30% of soil was replaced with marble powder. After replacing the technology was validated by performing full scale trials in the field.

Patel et al. (2013) evaluated recovery and use of marble powder in making a low cost concrete. A marble powder of 0, 5, 10, 15 and 20% was used along with cement, sand and coarse aggregate. The mechanical properties showed 5-10% higher strength than the references concrete, which shows that increasing the marble dust, compressive strength also increases. Strength obtained after 28 days of curing with the addition of 0% marble powder was 38 N/mm2 while using 15% marble powder was 40.5 N/mm2.

Huwang et al. (2008) investigated the fine marble particles as additives in polymer modified mortar. It was applied in different ratios in modified mortar and compared their values. Results shows that the mechanical properties like compressive and tensile flexural strength increases by using marble fines but decreases in the presence of polymer cement modifiers compared to that of no polymer cement modifiers, but the compressive strength of 20% of polymer–cement ratio was higher than that of 10%. After the hot water resistance test, both compressive strength and flexural strength were decreased.

### 2.4.2 Production of bricks

Hamza et al. (2011) investigated the utilization of marble and granite waste of different sizes in the manufacturing of concrete bricks. In this study the authors reported the replacement of conventional coarse and fine aggregates with marble waste scrapes and slurry powder up to 40%. The prepared specimens were tested for physical and mechanical properties according to American Standards for Testing and Materials (ASTM) and the Egyptian Code. The results showed that the prepared brick has got the ability to qualify for use in the construction sector.

Marras et al. (2010) studied the use of marble dust in the traditional bricks to improve the quality of the bricks. The work focuses on the Sardinia (Italy) area. In the study area the clay part of the brick was partially replaced with marble slurry dust. The result obtained from the study was very encouraging and feasible.

Hamza et al. (2011) utilized different sizes of marble and granite slurry powder in the preparation of concrete bricks. In this study the researchers replaced up to 40% of the conventional coarse and fine aggregates with marble scrapes and powder. The bricks were tested according to ASTM and the Egyptian code. Mechanical testing was carried out to check the quality of brick. Results showed that the incorporation of 10% marble waste showed good results in accordance with the testing procedures of ASTM.

### 2.4.3 Production of tiles

Gupta et al. (2009) used marble powder in the preparation of floor tiles. Mixtures with different proportions were prepared for the study. The flexural strength of the product was determined. The results of the flooring tiles containing marble powder showed that the tiles are according to the requirement of IS: 1237.

Alzboon and Mahasneh (2009) investigated the utilization of marble waste in preparation of tiles. Complete characterization of marble slurry obtained from Samara Factory in Jordan was carried out and then utilized in the tiles preparation. This study showed a good transverse strength and water absorption. All the results comply with Jordanian Standards.

Acchar et al. (2006) conducted a study on the behavior of the clay minerals after addition of waste marble and granite sludge. For that purpose clay mixture along marble and granite sludge were fired at the temperature ranging from 950 to 1150 ◦C. mineralogical and chemical analysis was done by using X-Rays Diffraction and X-Rays Florescence spectrometry, thermal analysis, density, water absorption capacity, compressive and flexural strength were determined. Results show that the marble and granite sludge can be added to the clay material and they have no detrimental effect on the properties of the sintered clay products. The marble and granite sludge acts as a flux agent, reducing the sintering temperature of the clay material.

Saboa et al. (2010) studied the residues of ornamental stone industry generating from sawing and polishing operation of marble stone and its uses in ceramic industry. For that purpose ceramic brick were prepared and molded in marble powder and sintered at temperature ranges from 750 to 950 ºC and theirs mechanical properties were tested and evaluated. Results shows that the marble powder have not any effects on the mechanical properties of ceramics bricks and they decreases the sintering temperature which is good for energy efficacy because the kiln used in ceramic industry are Hoffman kiln type, where temperatures above 900 ºC, is difficult to be obtained.

### 2.4.4 Glass Fibers reinforced concrete

Gornale et al. (2012) has studied glass fiber reinforced concrete recently introduced in the construction industry. The paper reviews the existing information about glass fiber in concrete production and concludes that it is light in weight, cannot rust like steel and when used in concrete it reduces the cost. Glass fiber reinforced concrete GFRC is the use of glass fiber as reinforcer instead of steel.

Chandramouli (2010) investigated the use of alkali resistant glass fiber in the preparation of concrete. Glass fiber has a role in increasing energy absorption, toughness, resistance and durability. In this study glass fiber has been used for the preparation of concrete and after preparation investigated the effect on compressive, split tensile and flexural strength on different mix proportions of the concrete. Ordinary concrete without using glass fiber was compared with a concrete using glass fiber. The increase was found to be 15 to 20% after 28 days curing.

Kelestemur et al. (2014) investigated the effects of marble dust and glass fiber on mechanical and physical properties of cement mortars exposed to high temperature as experimentally and statistically. For this purpose, the mixes containing marble dust (0%, 20%, 40% and 50% by volume) and glass fiber (0 kg/m$^3$, 0.25 kg/m$^3$, 0.50 kg/m$^3$, 0.75 kg/m$^3$) were prepared. The compressive strength and porosity value of the cement mortars were determined after being exposed to high temperatures (400, 600 and 800 $^oC$). Percentage of marble dust, amount of glass fiber and degree of temperature were changed to explore their effects on the compressive strength and porosity values of specimens. Finally, Statistical results were determined by using analysis of variance (ANOVA) method.

Kelestemur et al., (2014), identified the recycling option of marble powder and glass fibers in cement mortars experimentally. For that purpose series of cement mortars were prepared containing marble dust and glass fibers. The mechanical properties include compressive and flexural tensile strengths of the concrete specimens were determined. Statistically effects of the factors were also determined by using analysis of variance (ANOVA) method.

## 2.5 Other applications

Al-Hamaiedh (2010) utilized different types of industrial wastes in the production of ceramic tiles. These ceramic tiles were tested for changes in physical and mechanical properties prepared from materials containing marble slurry industries in Al-Karak, Jordan. The results revealed that the waste particularly from marble industries can be used in preparation of ceramic tiles.

Mashaly et al. (2012) investigated the physical and chemical characteristics of marble waste slurry samples of Shaq El Thoaban industrial zone, Egypt in order to find its compatibility for various recycling applications. After analysis marble slurry waste was checked for its compatibility with cement, paper, water paints, plastics, fertilizer and ceramics industries. The results showed that the waste can be used in different industrial applications.

Tozsin et al. (2014) Worked on the utilization of marble quarrying and cutting waste as soil conditioner and amendment. They determined the effects of marble quarrying and cutting waste on Hazelnut crops yield for a year in marble waste amended and not amended soil.  They concluded that by using marble waste for the neutralization of acidic soil is an alternative of agricultural lime. By doing so, the burden of marble quarrying and cutting waste on the environment can be reduced by utilizing it in useful agricultural raw materials.

Antonio and Jorge (2014) worked on an attempt of converting marble quarrying waste into a valuable by-product. The by-product can be use as an alternative of primary aggregate in concrete admixture. In experimentation the conventional aggregates were replaced with waste marble aggregates at ratios of 20%, 50% and 100% by volume. After that the mixture were tested for compressive strength, water absorption by capillarity and immersion, Density, carbonation and chloride penetration. The results indicate that there are no significant differences between a concrete produced using Marble aggregates with one made with primary aggregates in terms of durability, which making marble waste as a perfect alternative of concrete aggregate.

Al-Hamaiedh, (2010) Ceramic industry is capable of incorporating and reusing different types of industrial waste materials. Recently, the reuse of ornamental stone cutting sludge slime in this industry is becoming a common practice. This work investigates the changes in the physical and mechanical properties of the produced ceramic tiles from raw materials containing marble sludge slime produced in the ornamental stone processing industry in Jordan. The results show that partial replacement of kaolin, feldspar and $CaCO_3$ by the sludge slime caused a deformation out of the plane (binding) of the produced tiles. However, the replacement of all the pentonite by sludge slime did not affect the mechanical strength of the produced tiles and significantly decreased the shrinkage values of the tiles from 1.66% to 0.5 %. The results presented in this paper show that all of the produced sludge slime can be consumed successfully in ceramic production, which would decrease the expensive management of the residues with landfill and preserve an equivalent amount of natural mineral resources (pentonite); thus increasing the environmental sustainability.

Haddad et al. (2015) worked on the removal of Phosphorus from synthetic solutions by using marble powder. For that purpose different doses of calcium carbonate marble powder were applied to the solution containing phosphorus. Phosphorus was removed either by adsorption and calcium phosphate complex formation. Analysis shows that 10g/L dose was enough to ensure more than 97% phosphorus precipitated out. Scan electron microscopy (SEM), energy dispersive spectroscopy and XRD shows that the precipitate formed is most probably hydroxyapatite. The results shows that marble powder have high phosphorus removal efficiencies.

# CHAPTER-III

# METHODOLOGY

# PART-I

# CHAPTER-III

# METHODOLOGY

## PART-I

The Part-I of this chapter discussed the detailed methodology adopted for conducting MPUs surveys, preparation of GIS database, Life Cycle inventory included inputs and outputs, impacts assessment and data analysis. Inputs include raw materials, water usages, energy whereas outputs are products and by-products. For impacts assessment analysis of effluents were done and results of its effects on surface water and soil was presented.

### 3.1.1 Preparation of GIS Database

To prepare GIS data base for mapping out the locations of existing marble processing units in the study area. Field visits were conducted to all selected districts namely Buner, Peshwar, Mardan, Charsadda, Nowshera, Malakand, Dir(L), Chitral, Swat, Abbottabad, Haripur, Mansehra and Swabi. GPS coordinates of all MPUs clusters along with their numbers in each district were taken by using Garmin E-trex 10 Handheld-H GPS navigator made by Garmin technology Taiwan. These GPS coordinates were located on the base map by using Arc-GIS software. Area wise total numbers of MPUs were confirmed from SDO-WAPDA of the concerned area.

### 3.1.2 Life Cycle Assessment

As per ISO 14040, Life Cycle Assessment studies consisting of four major steps (i) Identification of goal and scope of the study, (ii) life cycle inventory analysis, including quantification of major input and output (iii) impact assessment and (iv) Interpretation of results.

#### 3.1.2.1 Goal and Scope

The scope and system boundary of this study´s covers processing stage only and the functional unit comprises 1 Tonne of polished tile. Other subsystems like the blocks transportation from quarries to processing plants were not considered in this inventory. For that purpose Gate-to-Gate approach was selected in which the study focused on specialized unit processes. It was estimated that how much raw materials consumes and wastage produced during production of 1 Tonne of marble tiles.

### 3.1.2.2 Inventory Analysis

Inventory analysis includes determining, quantifying and compilation of inputs and outputs of Marble Processing Units (MPU's) with the main emphasis on raw materials consumption, water usage, energy and wastes produce in the product life cycle (Photos 11-14, Appendix-II). Detailed inventory analysis was carried out through extensive inventory field surveys. In the first phase of survey a total of 80 technical field data collection visit were conducted. Four different operational scenarios (C1, C2, C3 and C4) of marble processing were identified covered 1405 MPUs in different cluster of the study area. In order to understand the uncertainties in certain input and output data, statistically acceptable representative sample size of 20 MPUs 5 from each uniform operational scenario were selected. For that purpose disproportionate stratified random sampling technique was used to avoiding biased in LCI data collection. In the second phase of survey, visits to only selected representative units were conducted for LCI primary data collection after every 4 months for year duration. In order to avoid any impact on the business interests of the marble processing plants and to fulfill the required research ethics, these marble industries have been given sample codes as mentioned in Table 3.1.1.

**Table 3.1.1: Category and description of MPUs along with codes**

| MPU's Category | Codes | Description |
|---|---|---|
| Category 1 | C1 | MPUs having dressing, cutting and polishing processing |
| Category 2 | C2 | MPUs having dressing and cutting processing |
| Category 3 | C3 | MPUs having cutting and polishing processing |
| Category 4 | C4 | MPUs having cutting processing only |

Each category having its own energy, water and raw materials requirement and levels of emissions. These were asses through MPUs assessment checklist (Appendix-III) and observations. Marble processing units equipped with bridge cranes, gang saws, vertical cutters, large circular saws sizing machines, polishing machines and others auxiliary equipments used for edging and smoothing (Table 3.1.2). The process input includes raw material (marble stone), cooling water and energy.

**Table 3.1.2: Machinery Requirement of Different MPUs for their Operations**

| MPUs category | Bridge Crane | Mono Blade | Gang Saw | Verticals' cutter | Bridge Cutter | Polisher |
|---|---|---|---|---|---|---|
| **C1** | X | X | X | X | X | X |
| **C2** | X | X | X | X | X | |
| **C3** | | | | | X | X |
| **C4** | | | | | X | |

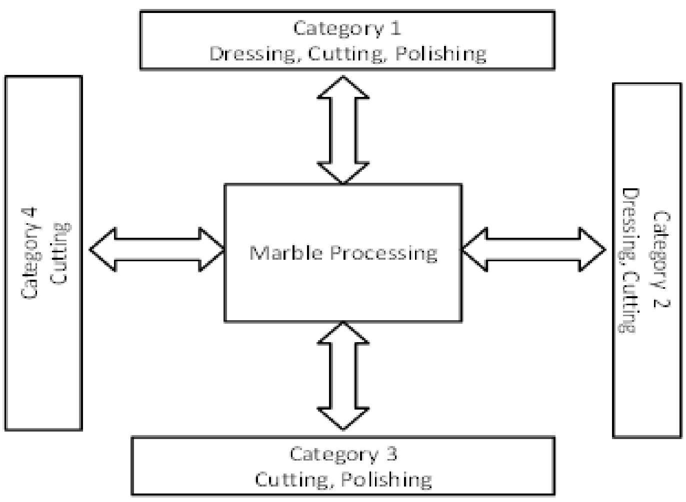
Listing unit operation and constructing process flow diagram was made to identify the system boundary and estimate the quantities of input and output of materials flow in terms of resource consumption, production and wastages. This was done by observing 5 representative MPUs from each category (Table 3.1.3).

**Table 3.1.3: Major activities, inputs, outputs and impacts of marble processing**

| Phase | Activities | Inputs | Outputs | Impacts |
|---|---|---|---|---|
| Processing | Dressing<br>Cutting<br>Polishing | Marble stone,<br>Cooling water,<br>Energy | Product<br>By product<br>Wastewater | Water and soil's pollution |

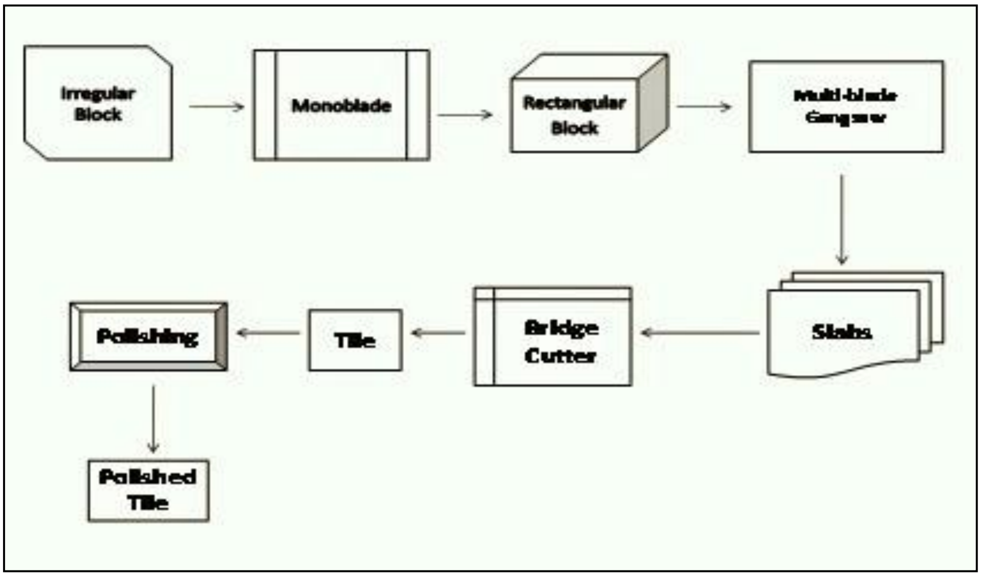
Operational Scenarios of above mentioned MPUs categories are expressed in Fig: 3.1.1. The system boundaries of this LCA study confined to the processing unit (Gate-to-Gate) only. In which no transportation/loading/unloading is involved. The study was based only on specialized unit process.

**Figure 3.1.1: Different operational scenarios of MPUs**



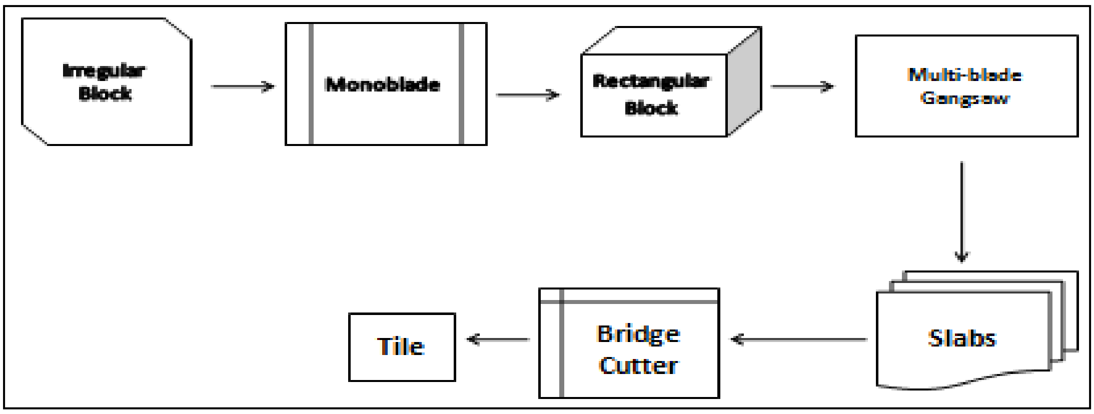
The operational scenario of category 1 marble processing units was highlighted in figure 3.1.2.

**Figure 3.1.2: Operational scenario of a typical Category-1 Marble Processing Unit**



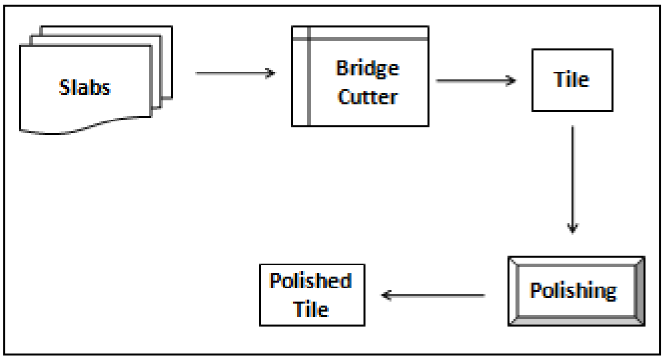

In the second scenario the irregular marble blocks coming from quarries site are passes through the same stages like in category 1 exept polishing stage. For polishing these tiles are may send to other MPUs having polishing facility. The outline of operational scenario for category 2 MPUs is highlighted into the fig 3.1.3.

**Figure 3.1.3: Operational scenario of a typical Category-2 Marble Processing Unit**



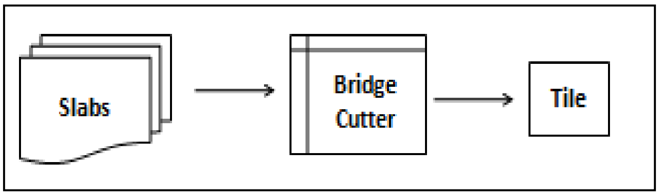

The operational scenario of 3rd category consists of tiles cutting from the incoming slabs of different marble stones and its polishing. In the third category these slabs are come from gang saws units of other MPUs. The outline of the operational scenario is highlighted in fig 3.1.4.

**Figure 3.1.4: Operational scenario of a typical Category-3 Marble Processing Unit**




The operational scenario of 4th category MPUs consists only of cutting tiles from slabs without polishing step. The process flow diagram of this category is shown in Fig 3.1.5.

**Figure 3.1.5: Operational scenario of a typical Category-4 Marble Processing Unit**




For the assessment of inputs and outputs common to all of the above processing scenarios, the proposed methodology (choice of operating scenarios) can be easily extended and applied to any MPU's of similar nature.

**Raw Material:** Rough marble stone from quarry site reached to processing unit are normally transported via ten wheeler trucks. Their weights are normally measured at quarry site when it was hauled. Quantity of raw material was also asked from MPUs managers by filling MPU's assessment checklist (Appendix-III). District wise raw marble stone consumption for each category MPUs on daily basis was estimated by multiplication of average consumption by each category with total numbers of MPUs belongs to same category in the study area. Stone consumption on the basis of per unit tonne of finished product was estimated by dividing daily inputs in term of raw stone by daily output in term of finished product.

**Cooling Water Usage:** To estimate the cooling water used in the process flow/discharge of installed pumps were measured. This was done by using a 20 liter bucket, in which the water was collected and time of the flow was recorded with a stopwatch.

Steps for estimation cooling water used in the process:

i. Opened the flow valve and pumps turns on;
ii. Used a bucket of 20 liters capacity to collect and measure all water discharge until the bucket fill;
iii. Recorded the bucket fill time by stopwatch;
iv. Divided the number of a liters collected in the bucket by number of seconds in which the bucket fills;
v. Multiplied the answer of step (iv) by 60 to convert the flow rate into liters per minute (LPM);
vi. Divided the results of step (v) by 1000 to convert it into cubic meter.

District wise consumption of cooling water for each category MPUs on daily basis was estimated by multiplication of average consumption by each category with total numbers of MPUs belongs to same category in the study area. Daily cooling water inputs was divided by daily production output to obtain cooling water usage on per unit tonne of finished product.

**Energy Consumption:** Grid electricity was used for marble processing inside the units. For energy estimation monthly electricity bills were noted for consumable electricity units from each category. To avoid any bias in data 20 monthly electricity bills, 5 from each category were recorded. District wise consumption of electricity for each category MPUs on daily basis was estimated by multiplication of average consumption by each category with total numbers of MPUs belongs to same category in the study area. Daily and per unit tonne of finished product energy consumption was calculated from monthly consumed electricity units.

**Production:** Overall the product estimation was done by weighting the final polished tile and multiplies this individual tile weight with the total number of tiles produced from total raw stone. District wise production for each category MPUs on daily basis was estimated by multiplication of average production by each category with total numbers of MPUs belongs to same category in the study area.

**By-Product:** The weight difference of final product and raw marble stone before processing gave the overall wastages. The overall marble waste constituted the waste stone pieces and marble slurry dust/powder. To quantify the stone and powder waste, per litter wastewater was analyzed for the marble slurry powder quantification and water concentration by standard gravimetric methods (APHA 2005) used for TSS measurement. The amount of resultant slurry powder in per liter wastewater was multiplied by the total wastewater discharge/day from each MPU to quantify the slurry powder waste. For cutted stones waste quantification the amount of slurry powder waste was subtracted from the overall wastage. To avoid any bias in recording data 20 representatives MPUs 05 from each category were chosen. District and category wise production of wastes on daily basis was estimated by multiplication of average wastage by each category with total numbers of MPUs belongs to same category in the respective districts of study area. By dividing the daily wastage per daily production gives wastage on per unit tonne of final finished product.

**Wastewater Discharge:** The amount of wastewater containing marble sludge generated per day was estimated by measuring the flow of wastewater. For that purpose MPUs having proper slurry collection drains was selected from each category. First a smooth place of the drain with uniform length, width and depth was chosen and these were measured with a measuring tape. Two spots A and B were marked on the bank of main effluent drain. A plastic ball was placed at point A in wastewater drain and on reaching to point B time interval was noted using a stopwatch. After taking three different readings the mean flow rate was calculated using formula.

$$\text{Flow rate (volume per second)} = \frac{\text{Width} \times \text{Depth} \times \text{Length}}{\text{Time}}$$

Where, W = Width, D= Depth, L= Length

T= Time interval

District and category wise production of wastes on daily basis was estimated by multiplication of average wastage by each category with total numbers of MPUs belongs to same category in the respective districts of study area. Wastewater discharge on per unit tonne of the finished product was calculated by dividing the daily discharge on daily production.

#### 3.1.2.3 Impacts Assessment

It includes analyzing the impacts of marble processing wastes on the environment (soil, water). For that purpose physico-chemical characterization of marble processing effluent, surface water and soil was done. For impact assessment Buner valley was selected where both marble quarrying and processing takes place. Buner area is scenic mountainous region having great potential of tourism, where agricultural activities also take place beside marble quarrying and processing. River Barandu a tributary of River Indus flows between the Buner valley (Photos 15-18 in Appendix-II).

**Surface and Wastewater Sampling:** For the analysis of wastewater effluents 20 random grab samples, 5 from each category (C1, C2, C3 and C4) were collected. Upstream and Downstream level of River Barandu was selected for their environmental studies by taking surface water samples during low flow (winter) during the January to March and high flow (summer) during the months of June to August seasons. A total of 12 surface water samples (2 samples/month) were collected from upstream and downstream conditions. Special polyethylene bottles were used for taking grab samples after washed with distilled water and respective stream water. Samples were taken from the midpoint of stream. All bottles were tied soon after sample collection and were labeled. Field and trip blanks were used for sampling quality control and assurance. For the analysis of Heavy metals each effluent and surface water sample were filtered and a few drops of 5% nitric acid were added to prevent further microbial growth invoice of standard methods. All water samples were placed in ice box and transported to the Department of Environmental Sciences, Pakistan Council for Scientific and Industrial Research (PCSIR), Centralized Resource Laboratories (CRL), University of Peshawar, Pakistan, and stored at 4 °C for further laboratory analysis.  Marble stone slurry was also collected from sedimentation tanks and packed in plastic bags.

**Surface and Wastewater Analysis:** Samples analysis including pH, E.C, Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Chemical Oxygen Demand (COD) were performed using procedure outlined in the standard methods APHA-2005. Selected heavy metals analysis includes Chromium (Cr), Copper (Cu), Manganese (Mn) and Nickel (Ni). Atomic Absorption Spectro-photometer (AAS) Perkin Elmer USA was used for the heavy metals analysis according to the standard procedure.

**pH Measurement:** The pH value was determined in the laboratory in quickest possible time. For that purpose the WTW-Ino-Lab pH meter Model 3856 was calibrated with required buffer accordingly. Three types of buffer solutions (pH 4, 6 and 8), prepared from standards tablets (BDH, BH151TD, England) were used. Then pH values of samples were measured.

**Total Suspended Solids (TSS):** Pre dried filter paper was taken and weighed it by using electronic balance. Wastewater sample of 20 mL was filtered through it. The non-filterable materials were retained on the filter paper. This filter was placed in oven at 104°C overnight for dryness. After drying it was cooled in desiccators and again weighed the filter paper. The difference between initial and final weights of filter paper gives suspended solids. The results were obtained in mg/L using following equation 3.1.1.

TSS (mg/L) = A-B (1000/mL of sample)………………………Eq. 3.1.1

A= Filter paper weight with residues

B= Filter paper weight without residues

(APHA 2005)

**Total Dissolved Solids (TDS):** TDS were measured according to Arnold et al. (1996), 100 mL of filtrate sample was dried in a crucible. In order to evaporate, the crucibles were kept in the oven in a range of 103 to 105°C temperature. When the sample was completely evaporated, the crucible cooled in desiccators and weighed. The change in weight corresponded to the weight of dissolved solids (Equation 3.1.2). For cross checking conductivity meters were used.

**Calculation**

Total Dissolve Solid (mg/L) = A-B (1000/ml of sample)…………………Eq. 3.1.2

A= weight of dissolved solids + dish

B= weight of empty dishes

**Chemical Oxygen Demand (COD):** Chemical Oxygen Demand (COD) was measured by using open reflux method according to APHA-2005. In this method water sample was digested with standards 0.25N potassium dichromate solution in the presence of sulfuric acid and using silver sulphate and mercuric sulphate as catalyst. After that the digested sample was titrated with standard 0.25N Ferrous Ammonium Sulfate (FAS) solution in the presence of Ferroin indicator. The amount of COD level quantified by using equation 3.1.3.

**Calculation**

$$\text{COD(mg/L)} = \frac{(B\text{-}T)N \times 1000 \times 8}{\text{Sample volume (ml)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eq.3.1.3}$$

Where:

**T** = Volume of titrant (FAS) used against sample (ml).

**B** = Volume of titrant (FAS) used against blank (ml).

**N** = Normality of titrant (FAS) 0.25.

Equivalent weight of oxygen is 8.

**Heavy Metals:** Atomic Absorption Spectro photometer (Perkin Elmer GF-ASS-700, USA) was used for heavy metals analysis invoice of standard method (APHA 2005). For that purpose analytical grade chemicals with 99.98% purity (Merck-Germany) were used for samples preparation and analysis. Double deionized distilled water was used throughout the analysis. Standard solutions of the selected heavy metals were prepared by diluting 1000mg/L certified standard solutions (Fluka Kamica, Buchs, Switzerland) of corresponding metal ions. The concentrations of selected heavy metals

(Cr, Cu, Mn, Ni) in surface and wastewater effluents were analyzed. In view of data quality assurance, each sample was analyzed in a triplicate and after every 10 samples two standards, one blank and another 2.5 µg/L of respective metal were analyzed on ASS. The reproducibility was found to be at 95% confidence level. The integration and delay time of ASS was 5 seconds, while the instrumental detection limits of Cr, Cu, Mn and Ni were 0.0030, 0.0015, 0.0015 and 0.006mg/L respectively. All of these heavy metals analysis were performed at the CRL, University of Peshawar, Pakistan.

**Soil sampling and Analysis:** Three soil samples were collected from each selected point (irrigated with marble wastewater and fresh water) for laboratory analysis. Soil samples were taken at the depth of 0-12.5 cm according to standard methods packed and labeled in plastic bags. After that the bulk density, porosity, pH, electrical eonductivity, calcium and magnesium were determined invoice of standard procedures (Photos 19-20, Appendix-II).

#### 3.1.2.4 LCA Results Interpretation

In this step data of inventory and impacts assessment were analyzed. All of the inputs and outputs of mass and energy as well as generated waste, within study boundaries were quantified.

# METHODOLOGY

# PART-II

# METHODOLOGY

## PART-II

The Part-II discussed the materials and methods adopted for physical and chemical characterization of marble slurry and its recycling in the preparation of valuable products are discussed. These include Portland cement, Dish Washing Powder, Glass Fiber Reinforced Mortar, and lime. After preparatory phase these products were evaluated with commercial products and with ASTM standards. Besides, experiment for design slurry recovery is also demonstrated based on settling operation.

### 3.2.1 Characterization of Marble Slurry

#### 3.2.1.1 Slurry sampling

Marble slurry was collected from 20 MPUs, 5 representative samples from each category randomly and was packed and labeled accordingly to keep a record. The slurry was dried in oven until its water content dropped to zero. Drying of marble slurry turns it into a consolidated mass. As the study requires utilizing the marble powder in its original form (fineness), therefore, it was manually ground to bring it into its original form. Before analytical work, conning and quartering was carried out in order to reduce the sample of marble slurry to a convenient size for testing. The followed principle is that the quarter should be representative of the whole. By this method, representative samples of marble dust were extracted. The importance of this characterization was to investigate its exact nature after which we can use it in secondary useful products. Therefore, in order to characterize the marble physical and chemical characterization were carried out (Photos 21-24, Appendix-II).

#### 3.2.1.2 Physical Characterization

Physical characterization of marble slurry dust included determination of moisture contents, Loss on ignition, Fineness, Specific Gravity, Density and Water Absorption.

**Moisture:** Marble slurry powder collected from settling tanks containing about 25-30% moisture. For moisture determination ten grams of these collected samples of marble slurry were put in an oven to dry at a temperature of 110 ± 5°C. At fixed intervals (1 hour, 4 hours, 12hours, 24 hours, 48 hours, and 72 hours) the weight loss/moisture was registered with the aim to reach the constant weight.

**Loss on ignition (LoI):** After calculating the moisture content, loss on ignition (LoI) was calculated by taking approximately 3g of marble slurry waste from each sample. These samples were taken in porcelain crucibles and heated to 950°C in a muffled furnace maintaining the temperature from half to one and hour and then weighing again to calculate the percent loss on ignition (ASTM C25, 2011).

**Fineness:** Separation of fine and coarse aggregates of marble slurry was performed by sieving. To perform this test marble sample was kept in oven at 110ºC to maintain constant weight (100g) prior to sieving. Sufficient water was added to the sieve. The sample was continuously agitated so as to separate fines (75µm) from the remaining mass. The process repeated several times until the water was clear. Sieve of Fritsch Analysette Company, Oberstein, Germany, was used for this purpose. After that the separated component under 75µm was dried at 110ºC and weighed (ASTM C117, 2004).

**Specific Gravity, Density and Water Absorption:** Density, specific gravity, and water absorption of marble grains of diameter more than 4.75 mm were analyzed by (ASTM C127, 2007), while diameter less than 4.75 mm (75 µm) was determined by (ASTM C128, 2007).

#### 3.2.1.3 Chemical Characterization

Chemical analysis of all waste material was done by using P-analytical, X-ray fluorescence Spectrometry Bruker, model No. 7KP1060-IAA14-1BB, Germany. Analysis using this method is fast, precise and non-destructive, and it also requires minimum sample. The dried powdered samples were ground into a completely homogeneous powder and pressed in the form of pellets for the absorption of primary X-Rays. The samples were analyzed using X-Rays or Gamma Rays by excitation of the sample, these rays dislodge inner orbital electrons causing ionization, the electrons in higher orbital falls into lower orbital releasing fluorescence.

### 3.2.2 Process Design for Slurry Recovery

The most significant components of under observation in MPUs wastewater are usually suspended solids. To design a wastewater treatment system for MPUs wastewater mostly contains Marble saw dust were based on simple settling operations without the addition of chemicals.

**Physical treatment:** In physical treatment the samples were treated with detention time and no chemicals were added. Complete sedimentation was observed for 24 hours time in order to quantify the whole sample size sludge. Then, the same samples were analyzed again for equal interval of time to note the optimum settling time for sedimentation. It was observed that about 90% of suspended load settled in a 1 hour time.

Percent sludge settling per unit time was calculated by using equation 3.2.1.

**Calculation**

$$\text{Percent Settle able solids} = \frac{\text{Settled Sludge, ml}}{\text{Sample Size, ml}} \times 100 \text{------------------------Eq. 3.2.1}$$

The focused parameters were pH, TSS, TDS, BOD, COD, Cr, Cu, Mn and Ni which were analyzed before and after sedimentation. For that purpose samples of wastewater were grabbed from end of pipe instead of settling plant.

The time taken by suspended solids to settle down in the bottom of glass cylinder column constitutes settling time and the rate by which these particles settle down constitutes settling velocity. The settling process was visually monitored and focused on sedimentation. Settling velocity of marble dust particles was determined by using graduated glass cylinder of 1000mL and 2.5 diameters filled with sample. Here primary settling operation proceeded without the addition of chemical coagulants, time was noted in stopwatch the suspended matter is slightly heaving than water and settles slowly usually in the range of 3-5m/hr. Normally 12 cylinders were used for each sample to observed settling operation after 5 minutes interval.

**Design Modification:** Existing wastewater treatment facility in the form of sedimentation tanks for water recycling was studied. And discussed its pros and cons with MPUs owners in order to identify the problems areas in its operational scenarios. After that listing unit operations and process flow diagrams of marble processing were made. These observations were discussed with industrial design engineers and hydraulic experts. And as a result modified water reuse mechanism design was finalized with an option of slurry recovery.

### 3.2.3 Preparation of Valuable Products

#### 3.2.3.1 Cement

The raw materials mainly used in the manufacturing of Ordinary Portland cement consist of lime stone, Oxides of silica, alumina and iron. The resultant of firing is the clinker after interacting with one another in kiln at 1450 ºC. The clinker is mixed with gypsum and ground further into powder to produce the Portland cement. Chemical characterization shows that the main bulk of marble slurry consists of $CaCO_3$. This was used as an alternate of virgin calcareous materials in cement manufacturing process.

**Materials:** Marble stone slurry was obtained from nearby marble processing units and dried in sunlight. Common raw $CaCO_3$ used in the manufacturing of commercial grade cement was taken from cement industry. Both the raw materials analyzed for physico-chemical characterization. Physical characterization includes average particle size; porosity and density were done according to ASTM C373-8 & ASTM C136-01 designation. Chemical analysis of dried marble slurry generating from marble processing units and raw calcium carbonate was done by using X-ray Fluorescence spectrometer (PANalytical Axios Max WD-XRF) according to ASTM C25-11 designation.

**Preparation:** Test specimens were prepared in the laboratory by using marble slurry waste as a source of raw calcium carbonate, used in cement manufacturing process. In the laboratory 78 % of lime obtained from the calcinations of marble slurry was mixed with 12 % silica sand, 5 % iron oxide, and 5 % aluminum-silicates clay minerals according to standard formulation. This means that for 1.0 kg of clinker, we have to burn approximately 1.54 kg of raw materials. All of these were mixed together and saturated with water to form slurry. This slurry was heated in a batch rotary kiln, inside high alumina brick with 2 feet internal diameter, 5 feet length having capacity of 50 kg at 1400 ºC with a rotational speed of 10rpm and then cooled by using centrifugal exhaust blower fan. After that solid prismatic stone like clinker materials were formed. These solid aggregates were crushed into fine powder by using vibratory ball mill of Fritsch pulverisette Company, Oberstein, Germany. After this 05% gypsum by weight was added for setting of cement (See Photos 25-30 in Appendix-II).

**Evaluation:** The cement used for evaluation purpose in the experiment was commercial grade Portland cement available in market say as CEM I and cement prepared in laboratory from marble slurry powder called as CEM II. For evaluation of both types of cement physical, chemical and mechanical properties of their concrete mixture were determined (See Photos 31-34 in Appendix-II).

**Physical Properties:** Initial and final settling times for both specimens were determined invoice with ASTM-C 266 by using Gilmore needles methods along with volume expansion by Le-Chattlier method. The density was also determined by using pycnometer according to ASTM C373-88 designation. To determine the fineness of hydraulic cement two methods are generally used i.e. (i) sieve methods for particles size determination and (ii) Blaine air permeability method. In current study sieving method was used (Standard EN 196-6).

**Chemical Properties:** The testing procedures based on British Standards (BS12: 1992) have been followed for chemical analysis of Portland cement. Amount of total SiO2, Al2O3, Fe2O3, lime content, MgO, SO3, IR, free lime and LOI were determined. Chemical analysis of commercial cement (CEM I) and cement prepared in the laboratory (CEM II) were carried out for $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO, MgO, $K_2O_3$ and $Na_2O$ by using PANalytical Axios Max WD PW 2582/00 (Philips) XRF spectrometer XRF, Whereas free lime was determined by using X-Rays Diffraction (Bruker-Germany D8 Discover XRD) . The loss on ignition (LOI) was determined by heating both cements samples at 950-1000ºC in a furnace and subtracted the loss in weight.

**Mechanical Properties:** To determine the effectiveness of prepared cement in the laboratory using marble slurry, it was evaluated with a commercial brand available in market. For that purpose concrete specimens were prepared from both cements and were analyzed for compressive strength and water absorption capacity. Making concrete mixture of cement prepared in laboratory and commercial cement available in the market with sand, gravel and cement (S:G:C) ratio of 10:10:80, 20:20:60, 30:30:40, 40: 40:20 respectively. For this purpose crushed stones and dry clean natural river sand were used in concrete mixture. Cylindrical Concrete block Specimens of 6x3 inch (150x30 mm) were casted and de-molded after 48 hours and were tested at 7 to 28 days of curing age. For this purpose overall 16 cylindrical blocks were prepared, 4 cylindrical block of the each specimen/ratio were prepare and each cylinder block was tested for water absorption capacity and compressive strength at the interval of 7, 14, 21, and 28 days.

**Water absorption capacity:** The test of Water Absorption capacity (Wa) was carried out according to ASTM C373-88 (2006) designation by immersing the tested specimen in water for 48 hours after 7, 14, 21, and 28 days curing time. After curing the specimens were dried in oven at 110 ºC to evaporate occluded water. The value of (Wa) was calculated by the following formula (Equation 3.2.2).

$$Wa = \frac{W2-W1}{Wa} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2.2)$$

Wa = water absorption capacity

W1= weight before immersion

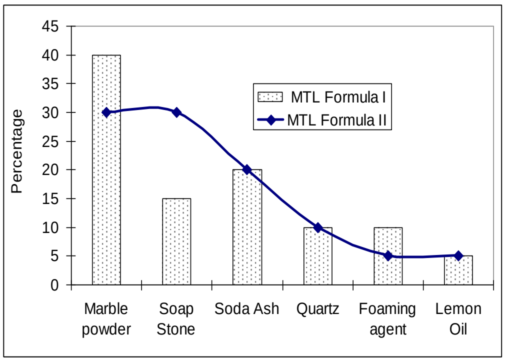
W2= weight after immersion

**Compressive strength:** This is the most important test to check the quality of hardened concrete. The concrete should be tested for its compressive test prior to use it in construction works. To avoid subsequent cracking and shrinkage compressive Strength tests were not performed on the paste of neat cement. Compressive Strength of concrete specimens made of different cement – sand-gravel mortar in specific proportion. Removing irregularities and capping of cylindrical specimens were done by using grinding technique and sulfur lock mortar. For compressive strength of testing specimen IPC Global Servo Hydraulic Universal Compressive Testing Machine (UTM 100) was used. The common breakage pattern observe in the testing specimen were conical fracture pattern. All of the above procedure was invoice of ASTM 31-12 and ASTM C39.

### 3.2.3.2 Dish Washing Powder

Two formulation of dish washing powder prepared in 2001 by Mineral Testing Laboratory (MTL) revealed that 30-40% marble powder and 60-70% virgin materials like soap stone, soda ash, quartz, foaming agent and lemon oil were used (Fig 3.2.1). In these two formulations the uses of virgin materials were comparatively high. Therefore, it was assumed that they might not be cost effective options.

**Fig. 3.2.1: Formulation of Dish washing powder prepared by MTL**




To decrease the contents ratio of virgin raw materials and increase the quantity of Marble slurry waste, four different compositions were prepared. Various chemicals additives including sodium carbonate (soda ash), sodium hydroxide (caustic soda), citric acid, soap stone, and sulfunic acid were used as ingredients in the preparation of dish washing powders along with 50-60% dehydrated Marble slurry. Based on chemical composition four different formulations Type 1 (T1), Type 2 (T2), Type 3 (T3) and Type 4 (T4) of dish washing powders were prepared in laboratory (Table 3.2.1). To evaluate the quality of dish washing detergent powder and consumer confidence level, the new and MTL formulations along with commercial brand were distributed among 05 households one by one for comparison. Before distribution labels packing were removed from the commercial brand (See Photos 41-46 in Appendix-II).

**Table 3.2.1: Formulation of dish washing powder prepared in Laboratory**

| S No | Raw Material | Percentage Composition | | | |
|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 |
| 1 | Marble powder | 60 | 50 | 60 | 50 |
| 2 | Soap Stone | 10 | 10 | 10 | 10 |
| 3 | Soda Ash | 15 | 20 | 00 | 00 |
| 4 | Caustic soda | 00 | 00 | 15 | 20 |
| 5 | Sulfunic Acid | 00 | 20 | 00 | 20 |
| 6 | Citric Acid | 15 | 00 | 15 | 00 |

**Evaluation:** A commercial brand common among the respondents was selected for comparison. The MTL formulation was also prepared for comparison.

The consumers' responses were recorded and evaluated on a pre-set point based criteria like;

a. Safe to use in terms of skin sensitivity, allergy and softness. In the survey, questions were asked from the consumers that after which wash (1$^{st}$, 2$^{nd}$, 3rd, 4$^{th}$ and 5$^{th}$) the skin problem was observed, on the basis of which points were awarded.
b. Easy to rinse.
c. Highly effective cleaning and foaming, and
d. Consumer friendly in term of economy as compared to dish washing powder available in market.

Respondents' responses were recorded after five days usage of each dish washing powder on the above point based criteria for comparison (Table 3.2.2). The criterion of unit price of all new formulations was determined on the basis of raw material cost, used in preparation. Percentage weight-age values was assigned on how important the each criterion, is100% weight-age was divided into four sub-weight-age breakup values according to set point based criteria (Table 3.2.2).

**Table 3.2.2: Point based criteria for the evaluation of dish washing powders**

| Criteria | Sub-Criteria | Scores | Response | % Weight age |
|---|---|---|---|---|
| **Skin Complaint** | 5th Wash | 10 | Excellent | 30 |
| | 4th Wash | 8 | Very Good | |
| | 3rd Wash | 6 | Good | |
| | 2nd Wash | 4 | Satisfactory | |
| | 1st Wash | 2 | Poor | |
| | | | | |
| **Rinse Easily** | 1st Wash | 10 | Excellent | 20 |
| | 2nd Wash | 8 | Very Good | |
| | 3rd wash | 6 | Good | |
| | 4th wash | 4 | Satisfactory | |
| | 5th wash | 2 | Poor | |
| | | | | |
| **Clean Efficiently** | 1st Wash | 10 | Excellent | 20 |
| | 2nd Wash | 8 | Very Good | |
| | 3rd wash | 6 | Good | |
| | 4th wash | 4 | Satisfactory | |
| | 5th wash | 2 | Poor | |
| | | | | |
| **Unit Price** | less by 70% or below | 10 | Excellent | 30 |
| | Less by 60% | 8 | Very Good | |
| | Less by 40% | 6 | Good | |
| | Less by 20% | 4 | Satisfactory | |
| | Equal to CDWP | 2 | Poor | |
| Total weightage | | | | 100 |

Maximum score for point based criteria survey was assumed 10 for excellent response, while minimum score was 2 awarded for poor response. For product evaluation Points awarded to each criterion was calculated by following equation (see equation 3.2.3).

$$\text{Score awarded for each point} = \frac{\text{Mean Survey Score}}{\text{Weight age}} \times \% \, 100 \quad \text{……….Eq. 3.2.3}$$

#### 3.2.3.3 Glass Fiber Reinforced Mortar

First of all the marble slurry was collected directly from the marble industries, packed and labeled accordingly to keep a record. The amount of marble waste generated per day was estimated and already discussed in LCA section of this study. Marble slurry dust samples collected from these plants were characterized physically and chemically.

**Binders used:** For experimental phase ordinary Portland cement obtained from local market were used. Some portion of this binder was taken for testing and dried in oven at 150 $^{o}$C in the laboratory to calculate the occluded water and then analyzed for chemical characteristics by using XRF spectrometer.

**Sand used:** Sand was obtained from the local market where it is sold for construction purposes having specific gravity of 2.61 g/cm3. Sand was chemically characterized by using XRF spectrometer.

**Glass fibers used:** The glass fibers used in these experiments were named as Cem-FIL Anti - Crack HD having 72 GPa modulus of elasticity, 14 microns filament diameter, 2.68 specific gravity, 12mm length, 857.1 aspect ratio and having 212 million fibers per kg.

**Water used:** In this study tap water supplied to the PCSIR Labs Peshawar for domestic consumption was used for curing the mix proportions. For all subsequent physical and chemical analyses distilled water was used.

**Preparatory Phase:** After completing the necessary testing, marble slurry collected from different marble processing plants were mixed together and utilized as raw materials in the preparation of value added products using Portland cement as binders (See Photos 35-40 in Appendix-II).

In order to observe the effectiveness and replacement level of Marble slurry dust in masonry mortar total 12 blends in two series were make. The two series consist of binary and ternary formulations. Binary formulations contain ordinary Portland cement (PC) as binder and fine aggregates (Sand and MSD as fine aggregate substitute). Ternary formulations contain PC, Fine aggregate (Sand and MSD) and Glass Fibers (GF).

Of these 12 formulations 2 were control specimens each from ternary and binary series with and without Glass fiber (PC+S+GF and PC+S) in which the fine aggregates was not replace with MSD and 10 were trial specimens five with glass fiber and five without glass fiber for comparison to provide a distinguishable observation. A constant replacement level of 30% by total weight of binder content was considered for control and trial specimens, while the various replacement levels of MSD (10%, 20%, 30%, 40% and 50%) were employed for all trial specimens. All of these blended mixtures were casted at water to binder ratio (w/b) of 0.35. Details of the mortar mixture proportioning along with samples ID's are given in (Table 3.2.3).

**Table 3.2.3: proportions of two control mortar specimens**

| S.No | Specimens IDs | Portland Cement | Sand | Glass Fibers | Water cement Ratio |
|---|---|---|---|---|---|
| 1 | PC(S)GF | 30 | 69.70 | 0.3 | 00.50 |
| 2 | PC(S) | 30 | 70.00 | 00.00 | 00.50 |

Five ternary specimens were prepared by mixing Portland cement, fine aggregate and glass fibers. MSD used as substitute of fine aggregates. The proportion of PC and GF remain in constant quantity. The substitution level of MSD was tested in the range of 10-50% with 0.5 % water to cement ratio (Table 3.2.4).

**Table 3.2.4: Mix proportions percentage prepared from Portland cement, marble slurry dust, sand and glass fibers**

| S.No | Specimens IDs | Portland Cement | Sand | MSD | Glass Fibers | Water cement Ratio |
|---|---|---|---|---|---|---|
| 1 | PC(MSD50)GF | 30 | 19.70 | 50 | 0.3 | 00.50 |
| 2 | PC(MSD40)GF | 30 | 29.70 | 40 | 0.3 | 00.50 |
| 3 | PC(MSD30)GF | 30 | 39.70 | 30 | 0.3 | 00.50 |
| 4 | PC(MSD20)GF | 30 | 49.70 | 20 | 0.3 | 00.50 |
| 5 | PC(MSD10)GF | 30 | 59.70 | 10 | 0.3 | 00.50 |

**Five** binary specimens of mortar were prepared from PC as binder, whereas MSD and sand as fine aggregate without glass fibers. MSD used as substitute of sand in the replacement range of 10-50% with 0.50% water cement ratio (Table 3.2.5).

**Table 3.2.5: Mix proportions percentage prepared from Portland cement, Sand and Marble slurry dust without glass fiber**

| S.No | Specimens IDs | Portland Cement | Sand | MSD | Water cement Ratio |
|---|---|---|---|---|---|
| 1 | PC(MSD50) | 30 | 20 | 50 | 00.50 |
| 2 | PC(MSD50) | 30 | 30 | 40 | 00.50 |
| 3 | PC(MSD50) | 30 | 40 | 30 | 00.50 |
| 4 | PC(MSD50) | 30 | 50 | 20 | 00.50 |
| 5 | PC(MSD50) | 30 | 60 | 10 | 00.50 |

According to the standard specification of ASTM C270 for masonry mortar, the ratio of raw materials (cement:sand) is 1:3 respectively. Different compositions were prepared by mixing different ratios of raw materials by blending of Portland cement, sand, MSD and glass fibers. In each experiment mixing was done by first blending the powder homogenously to respective binder. After that sand was added to the mixer. These materials were mixed dry manually for about 5 minute. After dry mix, water was added. The wet mix was mechanically agitated for more than 5 minutes. After homogeneity was achieved, glass fiber was added, the mix material was fabricated in a copper mold of 2x2 inch and 9x3 inch dimensions for 24 hours.

**Curing of specimens:** Curing is an important step after molding; all specimens were placed in a tub full of water to achieve enough strength. Curing the specimens ensures that moisture is retained and not lost rapidly until testing period (ASTM C192, 2012). Each of the specimen was marked using permanent ink marker, date and time of production and identification number. The prepared specimens were tested for compressive strength, Flexural strength, water absorption and density.

**Compressive Strength:** For compressive strength determination, 2x2 inch test specimen were prepared and tested according to (ASTM C109, 2012). To determine the compressive strength test of the products, twelve samples were prepared from each mixed composition. In order to avoid error each specimen was prepared in triplicate and the compressive strength was determined after 3, 7, 14 and 28 days of curing respectively. The results were determined by taking an average value. Universal Testing Machine Model No. UH-1000KN 1, Shimadzu, Japan, was used for the determination. Before starting the test stored samples were removed, wiped out any traces of moisture and tested for compressive strength. After 3, 7, 14 and 28 days curing time, different cubes from each set were tested for their compressive strength (ASTM C109, 2012). The results are presented in pound per square inch.

**Flexural Strength:** For flexural or tensile splitting strength determination (9″length, 3″width and 1″thickness) test specimens were prepared and tested according to ASTM C293. All the specimens were analyzed by Universal testing machine Model No. UH-1000KN1, Shimadzu, Japan. The specimens were placed on the supporting rollers of the bending device and the loading roller was applied using the test machine after the start of loading, recording the maximum load in Newton supported by the test specimens (ASTM C293, 2002).

**Water absorption:** For determination of water absorption all product specimens with varied compositions were placed in oven at a temperature of 105°C till attaining substantially constant weight. This was followed by cooling the specimens to room temperature and determining their final weight. Thereafter, specimens were kept in water for 24 hours, then removed and wiped with a cloth to remove any traces of water and weighed again. The difference in weight showed the result of water absorption percent by mass. Water absorption was determined in percentage by equation 3.2.4.

$$(W1- W3) / (W2- W1) \times 100 \quad \text{……………………………….Eq.3.2.4}$$

**Density:** Density of the oven dried product specimens was determined by measuring the height, width, and length of the cubes followed by weighing them on a balance. The mass in grams and volume in cubic centimeters determines the density (ASTM C 642, 2006).

#### 3.2.3.4 Lime

Calcium hydroxide can be prepared by calcinations of lime stone. In this process the lime stone was crushed into optimum size of boulder and burned in a lime kiln at about 1000 C, where it decomposes (calcines) into calcium oxide and carbon dioxide:

$$\mathbf{CaCO_3 \longrightarrow CaO + CO_2 \qquad 165{:}54\ kJ/mole}$$

The dry CaO is slaked (hydrated) with water at temperatures of 30–50 C, producing a $Ca(OH)_2$ slurry .

$$\mathbf{CaO + H_2O \longrightarrow Ca(OH)_2 \qquad -65{:}47\ kJ/mole}$$

**Material:** Marble slurry collected from five marble industries located in Hayatabad Industrial Estate Peshawar for the characterization of physical and chemical properties. Marble slurry was collected directly from the marble industries in clean polyethylene plastic bags, packed and labeled accordingly.

**Lime preparation:** On trial basis quick and hydrated lime was prepared from marble slurry dust in the laboratory and compared its quality with commercially available quick and hydrated lime. For that purpose marble slurry was heated in a muffle furnace (Nabertherm Model L9/06KM) at 1100 $^{o}$C. Then it was cooled by laying it on asbestos sheet. Hydrated lime was obtained by adding water to burnt quick lime.

**Commercial lime sampling and analysis:** Commercially available quick and hydrated lime samples collected from five different areas. For the elemental chemical analysis XRF-Bruker Germany was used according to ASTM C25-11(See Photos 47-48 in Appendix-II).

# CHAPTER-IV

# RESULTS AND DISCUSSIONS

# (PART-I)

# CHAPTER-IV

# RESULTS AND DISCUSSION

## PART-I

The part-I of this chapter presents the district wise distribution data of MPUs by making GIS database and LCA data include estimation of process inputs and outputs in terms of raw materials, final product and marble wastes generation as well as its impacts on environment.

### 4.1.1 GIS Database

Marble waste management, which became a very important issue during the last couple of decades, is only recently a matter of concern. However, responsibilities for marble waste management are not clearly defined in the legislation. Due to which marble wastes are dumped at convenience by the MPUs owners. These Open dumps processing wastes of marble are the cause of several environmental problems. That’s why the area required for suitable dumping or storage sites for marble wastes. Geographical Information System is an emerging technology in the field of sustainable waste management. GIS database was also used to gather information regarding optimum dumping delivery distances, which minimize the fuel consumption cost of collection and transportation but also provides a digital database for long term monitoring, management and planning. Due to the unavailability of spatial data regarding the distribution and allocation of MPUs in the province. Geographic Information System GIS is used for making database with the intension to apply it in the whole country for the MPUs as soon as spatial data become available.

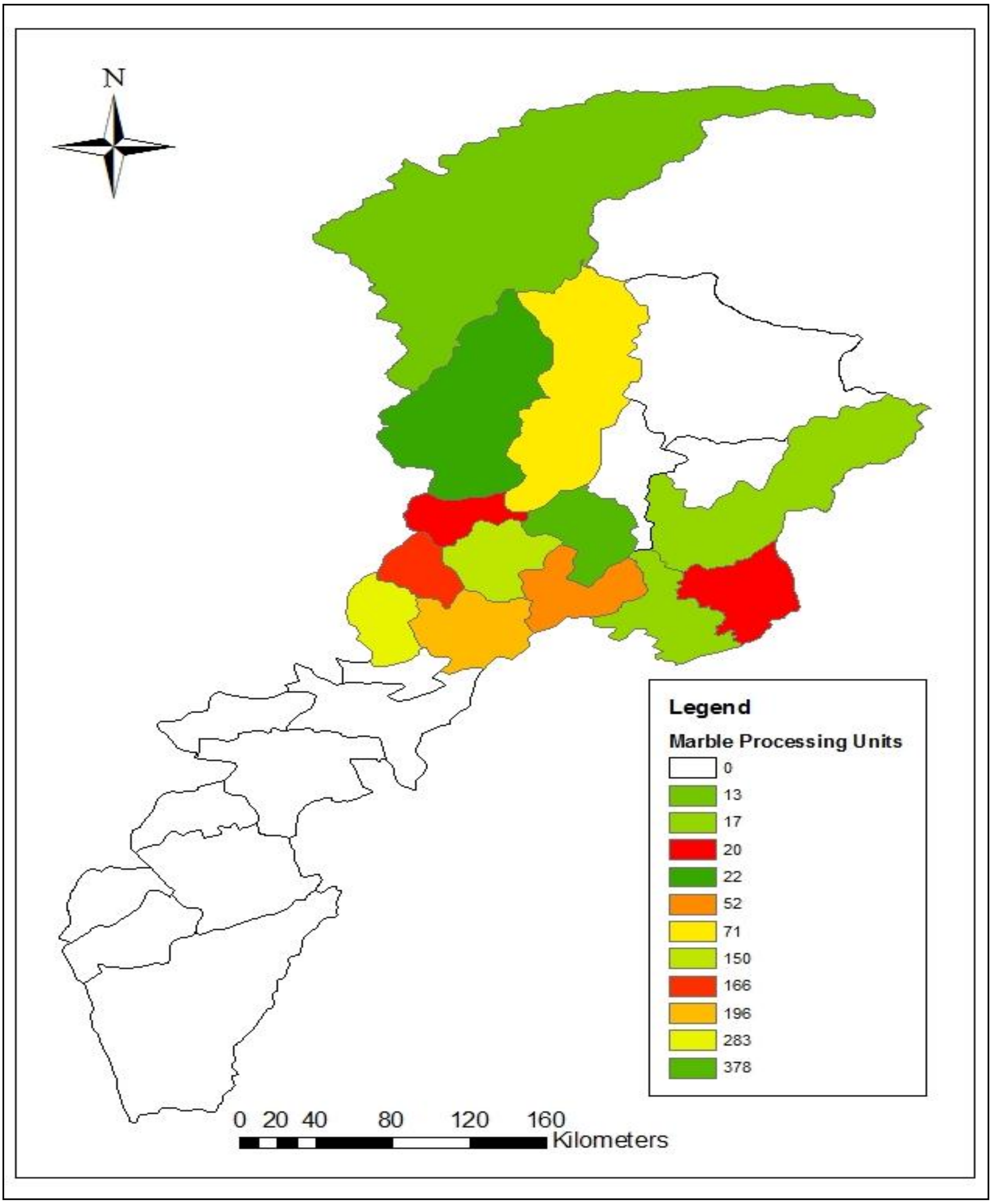
Khyber Pakhtunkhwa a province of Pakistan having 25 districts. Out of these, marble processing takes place in 13 districts. In total there are 1405 marble processing units are scattered in these districts. Results show that a huge amount of MPUs present in the central Khyber Pakhtunkhwa includes Peshawar, Charsadda, Mardan, Nowshera, and Buner, which constitutes 83% of the total units (Table 4.1.1).

**Table 4.1.1: District wise Distribution of Different MPUs Categories**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 63 | 76 | 110 | 129 | 378 |
| 2 | Peshawar | 55 | 68 | 95 | 65 | 283 |
| 3 | Charsadda | 35 | 20 | 65 | 46 | 166 |
| 4 | Mardan | 25 | 38 | 47 | 40 | 150 |
| 5 | Nowshera | 34 | 45 | 75 | 42 | 196 |
| 6 | Swat | 19 | 10 | 30 | 12 | 71 |
| 7 | Malakand | 3 | 4 | 8 | 5 | 20 |
| 8 | Dir (L) | 5 | 2 | 10 | 5 | 22 |
| 9 | Chitral | 6 | 3 | 3 | 1 | 13 |
| 10 | Haripur | 5 | 3 | 5 | 4 | 17 |
| 11 | Abbottabad | 4 | 6 | 8 | 2 | 20 |
| 12 | Mansehra | 3 | 2 | 10 | 2 | 17 |
| 13 | Swabi | 10 | 6 | 20 | 16 | 52 |
| **Total** | | **267** | **283** | **486** | **369** | **1405** |

As mentioned in the previous chapter, MPUs were divided into four main categories. Category "C3" was the highest in number mainly clustered in Buner district. These various categories of marble processing units are distributed in the upper northern half of Khyber Pukhtunkhwa province (Fig: 4.1.1). A total of 378 MPUs were scattered over in district Buner which contributed 26.9% of the total MPUs in Khyber Pakhtunkhwa. Similarly, *283* MPUs in Peshawar (20%), 166 in Charsadda (11.8%), 150 in Mardan (10.6%), 196 in Nowshera (13.9%), 71 in Swat (05%), 20 in Malakand (1.4%), 22 in Dir (L) (1.5%), 13 in Chitral (1.0%), 17 in Haripur (1.2%), 20 in Abbottabad (1.4%), 17 in Mansehra (1.2%), and 52 in Swabi contributed 3.7% of the total MPUs.

**Figure 4.1.1: Map showing District wise Distribution and Quantification of MPUs in Khyber Pakhtunkhwa**



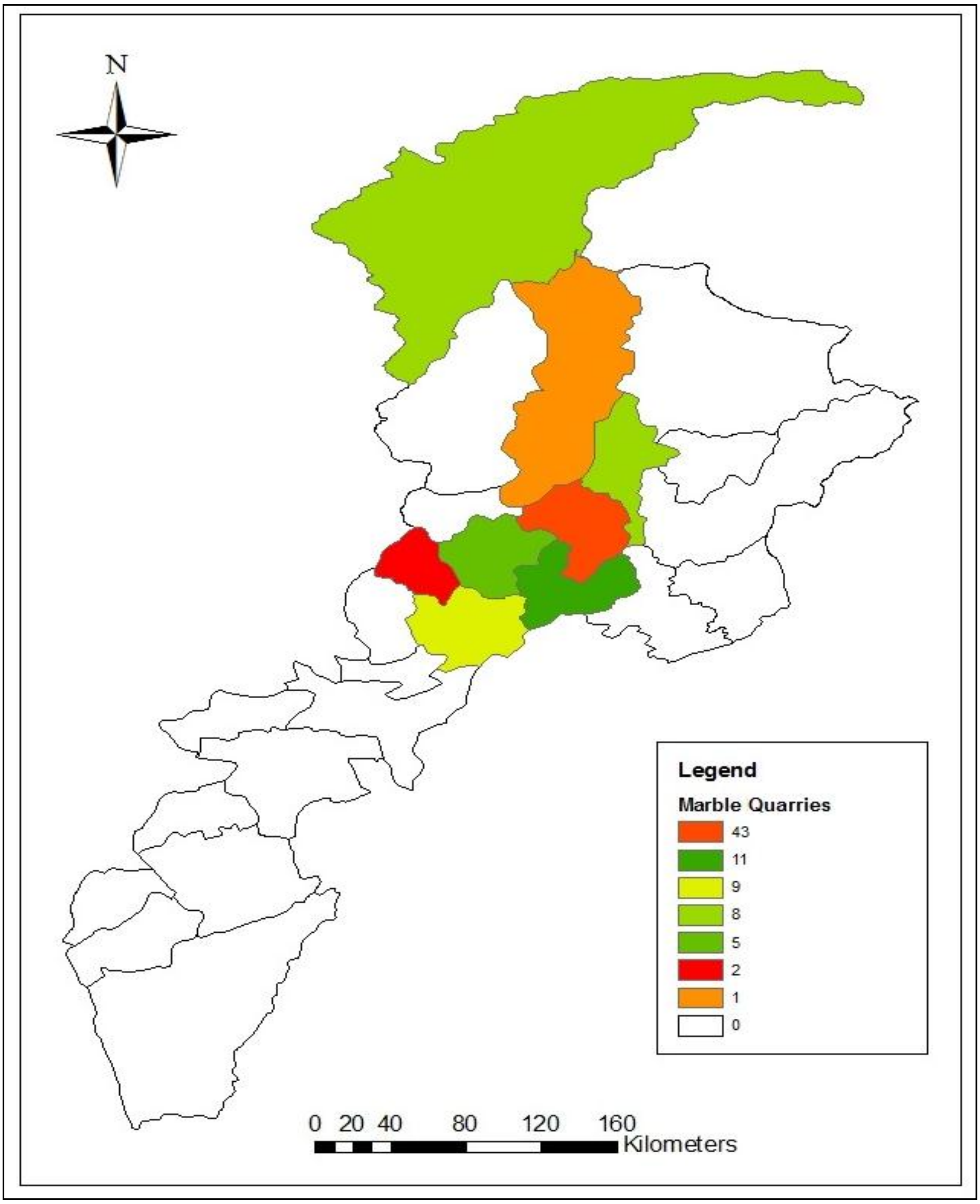

There are total 79 Marble quarries exists in the whole Khyber Pakhtunkhwa province. Quarries allocation map shows that large number of quarries found in the Buner district. District wise quarries data shows that there are 43 Marble Quarries are distributed in district Buner, 11 in Swabi, 09 in Nowshera, 08 each in Chitral and Shangla, 05 in Mardan, 02 in Charsadda and 01 in Swat (Table 4.1.2).

**Table 4.1.2: District wise Distribution of Marble Quarries**

| S. No | Districts Name | Quarries Locations | No. of Quarries at each Location | Total Quarries in each district |
|---|---|---|---|---|
| 1 | Swabi | Maneri Bala | 3 | 11 |
| | | Ghundai Tarakho | 8 | |
| 2 | Nowshera | Darwazgai | 2 | 9 |
| | | Pitao Bala | 5 | |
| | | Nizampur | 2 | |
| 3 | Charsadda | Tangi Reef | 2 | 2 |
| 4 | Buner | Khaista Baba | 5 | 43 |
| | | Matwani Buner | 10 | |
| | | Bazargai-I | 5 | |
| | | Bazargai-II | 8 | |
| | | Bampokha | 10 | |
| | | Salarzai | 3 | |
| | | Zaga Kalay | 2 | |
| 5 | Mardan | Rustam | 2 | 5 |
| | | Katlang | 3 | |
| 6 | Swat | Shahderai | 1 | 1 |
| 7 | Chitral | Barbaluk | 1 | 6 |
| | | Gahriat | 2 | |
| | | Istoor | 1 | |
| | | Shoghor | 2 | |
| 8 | Shangla | Bailay Baba | 5 | 8 |
| | | Matta Awan | 3 | |
| | **Total** | | | **79** |

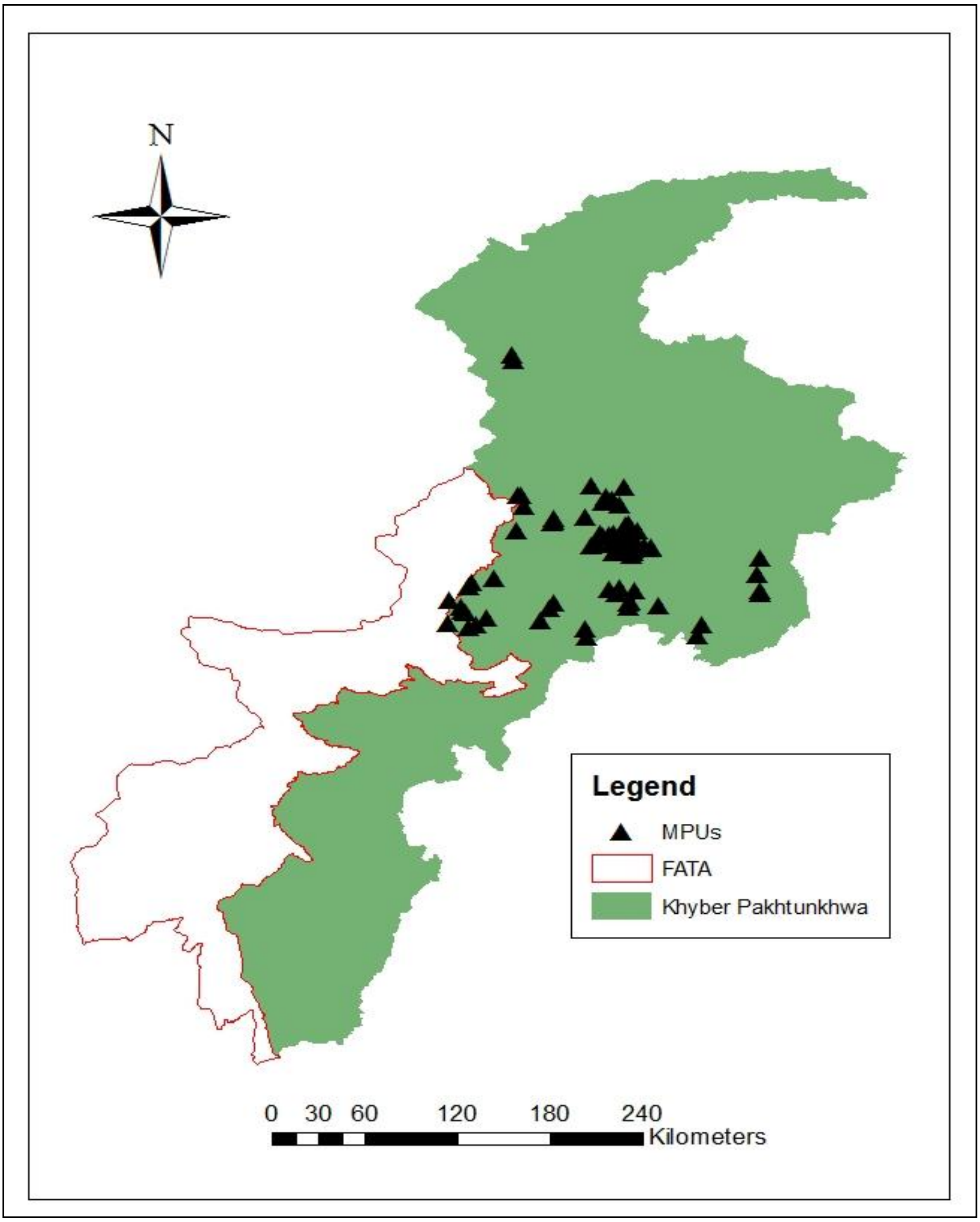
District wise distribution of Marble quarries shows that district Buner contributed 54.4%, Charsadda 02.5%, Mardan 06.3%, Nowshera 11.3%, Swat 01.2%, Chitral 7.5%, Shangla 10.1% and Swabi 13.9% of the total marble stone quarries in Khyber Pakhtunkhwa (Fig. 4.1.2).

**Figure 4.1.2: Map showing District wise Distribution and Quantification of Marble Quarries in Khyber Pakhtunkhwa**




GPS coordinates points showing locations of MPUs were allocated on base maps. Location wise GIS map of shows that mostly MPUs are found in the central KPK (Fig: 4.1.3).

**Figure 4.1.3: Map showing Distribution of MPUs and their locations in Khyber Pakhtunkhwa**




It will be useful for easy tracking of these marble processing units for monitoring and future survey. It will also be helpful in quantification of marble processing units, marble waste and its management.

### 4.1.2 Scope and System Boundary

The scope of current LCA study was limited to processing of marble stone only. All the equipments and machines as well as consumables used in the process such as diamond wire, saws and lubricants were not included in this study. It was also assumed that there are no chemicals used in the process. The mass functional unit has been chosen was 1 Tonne of polished marble tiles. The main goal behind the present LCA study was to contribute to the improvement of the productive processes of the dimensional stone´s industry in Pakistan from the environmental point of view. Develop a mechanism of cleaner production through innovative solutions and strategic planning in marble industry.

### 4.1.3 Inventory Analysis

The data regarding inputs and outputs in inventory analysis represent the small to large size MPUs in the 13 districts of Khyber Pakhtunkhwa. Sufficient input and output data was acquired. Because none of these all four categories MPUs were agreed to provide the primary data. The scope of current LCA study was limited to the environmental impacts only, and didn't include evaluation of any economic and social impacts.

**Raw Material:** During survey it was observed that the daily raw material consumption in the form of marble stone ranges from 40-60 tonnes/day with an average of 50±7.90 tonnes/day for category 1 MPUs. For the category 2 MPUs this ranges from 30-40 tonnes/day with an average of 35±3.53 tonnes/day. For category 3 the consumption were found in the range of 20-30 tonnes/day with an average of 25±3.53 tonnes/day. In category 4 this range was found within 20-30 with an average of 25±3.53 tonnes/day (Table 4.1.3).

**Table 4.1.3: Daily raw material consumption of different MPUs categories (Tonnes/Day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 50 | 60 | 55 | 40 | 45 | 40 | 60 | 50±7.90 |
| C2 | 35 | 35 | 30 | 35 | 40 | 30 | 40 | 35±3.53 |
| C3 | 25 | 30 | 20 | 25 | 25 | 20 | 30 | 25±3.53 |
| C4 | 25 | 20 | 30 | 25 | 25 | 20 | 30 | 25±3.53 |

Among the all four categories an average of raw stone consumption on daily basis were recorded from 25-50 tonnes. In these, high demand of raw stone requires for C1 MPUs due to its multipurpose operational scenario and heavy machines like gang saws units. On the other hand C3 and C4 types process less stone due its limited processing sequence. At C1 type MPU a rough marble block is cutted into shaped block and then further cut into Sheets, Slabs and polished Tiles under the one roof in a sequential order. The other three categories of MPUs jointly perform similar activities executed by C1 category alone. The operational scenarios of all four categories are discussed in chapter III. Category and district wise consumption/processing of raw marble stone reported in table 4.1.4.

**Table 4.1.4: Districts and category wise Marble Stone consumption (Tonnes/Day)**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 3150 | 2660 | 2750 | 3225 | 11785 |
| 2 | Peshawar | 2750 | 2380 | 2375 | 1625 | 9130 |
| 3 | Charsadda | 1750 | 700 | 1625 | 1150 | 5225 |
| 4 | Mardan | 1250 | 1330 | 1175 | 1000 | 4755 |
| 5 | Nowshera | 1700 | 1575 | 1875 | 1050 | 6200 |
| 6 | Swat | 950 | 350 | 750 | 300 | 2350 |
| 7 | Malakand | 150 | 140 | 200 | 125 | 615 |
| 8 | Dir (L) | 250 | 70 | 250 | 125 | 695 |
| 9 | Chitral | 300 | 105 | 75 | 25 | 505 |
| 10 | Haripur | 250 | 105 | 125 | 100 | 580 |
| 11 | Abbottabad | 200 | 210 | 200 | 50 | 660 |
| 12 | Mansehra | 150 | 70 | 250 | 50 | 520 |
| 13 | Swabi | 500 | 210 | 500 | 400 | 1610 |
| | **Total** | **13350** | **9905** | **12150** | **9225** | **44630** |

Category wise MPUs results revealed that instead of less in number the C1 type MPUs consuming huge amount of marble stone as compared to other categories. It was estimated that among all four categories C1 consumes 29.91%, C2 22.1%, C3 27.2% and C4 20.6% of the total raw marble stone processing on daily basis. District wise results showed that Buner contributed 26.4%, Peshawar 20.4%, Charsadda 11.7%, Mardan 10.6%, Nowshera 13.8%, Swat 05.2%, Malakand 1.3%, Dir (L) 1.5%, Chitral

1.1%, Haripur 1.2%, Abbottabad 01.4%, Mansehra 01.1% and Swabi 03.6% of the total daily marble stone processing in Khyber Pakhtunkhwa.

In contrast to daily consumption of marble stone by each category, the result for unit tonne of finished product was calculated and presented in Table 4.1.5. Results showed dramatic variations as compared to daily input and output. An average stone consumption on per unit tonne of finished product was estimated from 1.25 to 1.40 tonnes. In these, high demand is requires for C3 MPUs because slabs of different dimensions comes here from different MPUs for finishing. In that situation gang-saw unit operation is not possible like in C1 and C2 type unit. In C1 type MPUs a rough marble block is cutted into shaped block and then further cut into Sheets, Slabs and polished tiles under the single roof in a sequential order. Loss is minimizing by using gang-saw unit operation. In big units like C1 and C2 their daily input and output is more as compared to C3 and C4 types units.

**Table 4.1.5: Marble stone consumption for unit tonne of finished product**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Avg | Std.Dev |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| C1 | 1.25 | 1.2 | 1.22 | 1.33 | 1.28 | 1.2 | 1.33 | 1.256 | 0.05 |
| C2 | 1.25 | 1.25 | 1.2 | 1.34 | 1.33 | 1.2 | 1.34 | 1.274 | 0.06 |
| C3 | 1.38 | 1.5 | 1.66 | 1.25 | 1.25 | 1.25 | 1.66 | 1.408 | 0.17 |
| C4 | 1.25 | 1.33 | 1.2 | 1.25 | 1.25 | 1.2 | 1.33 | 1.256 | 0.04 |

**Water Consumption:** Marble processing requires massive use of water for cutting of stones. Daily water consumption, used for cooling purpose was recorded for each category. Category-1 MPUs was found higher with the range of 30 to 35$m^3$ with an average of 31.8 $m^3$. Similarly, for category 2 this range was observed from 18 to 20 $m^3$ with an average of 18.4 $m^3$. For category 3 this range was in 16 to 18.5 $m^3$ with an average of 17.3$m^3$. In category 4 the daily cooling water requirement ranges from 15 to 16 $m^3$ with an average of 15.6 $m^3$ (Table 4.1.6).

**Table 4.1.6: Cooling water usage in marble processing ($m^3$/day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 35 | 32 | 32 | 30 | 30 | 30 | 35 | 31.8±2.05 |
| C2 | 20 | 18 | 18 | 18 | 18 | 18 | 20 | 18.4±0.90 |
| C3 | 18.5 | 18 | 16 | 16 | 18 | 16 | 18.5 | 17.3±1.20 |
| C4 | 16 | 16 | 15 | 16 | 15 | 15 | 16 | 15.6±0.54 |

Nowadays, almost each and every MPU use wet cutting technology. Cooling water is used for wet cutting/sawing of marble stone in order to reduce the heat produced due to friction of saws blades and marble stone and catch marble dust. Cooling water obtained from ground water through water pumps and transported to each water jets above the saws and diamond wire. Cooling water results showed that on daily basis the C1 type MPUs consumed huge amount of water as compared to other MPUs. It was due to large amount of stone processing. District and category wise water usage is presented in table 4.1.7.

**Table 4.1.7: Category and District wise cooling water usage ($m^3$/day)**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 2003.4 | 1398.4 | 1903 | 2012.4 | 7317.2 |
| 2 | Peshawar | 1749 | 1251.2 | 1643.5 | 1014 | 5657.7 |
| 3 | Charsadda | 1113 | 368 | 1124.5 | 717.6 | 3323.1 |
| 4 | Mardan | 795 | 699.2 | 813.1 | 624 | 2931.3 |
| 5 | Nowshera | 1081.2 | 828 | 1297.5 | 655.2 | 3861.9 |
| 6 | Swat | 604.2 | 184 | 519 | 187.2 | 1494.4 |
| 7 | Malakand | 95.4 | 73.6 | 138.4 | 78 | 385.4 |
| 8 | Dir (L) | 159 | 36.8 | 173 | 78 | 446.8 |
| 9 | Chitral | 190.8 | 55.2 | 51.9 | 15.6 | 313.5 |
| 10 | Haripur | 159 | 55.2 | 86.5 | 62.4 | 363.1 |
| 11 | Abbottabad | 127.2 | 110.4 | 138.4 | 31.2 | 407.2 |
| 12 | Mansehra | 95.4 | 36.8 | 173 | 31.2 | 336.4 |
| 13 | Swabi | 318 | 110.4 | 346 | 249.6 | 1024 |
| **Total** | | 8172.6 | 5096.8 | 8061.8 | 5506.8 | 27862 |

Category wise MPUs results show that among the all four categories C1 consumes 29.3%, C2 18.2%, C3 28.9% and C4 19.7% of the total cooling water usages on daily basis. District wise results show that Buner contributed 26.2%, Peshawar 20.3%, Charsadda 11.9%, Mardan 10.5%, Nowshera 13.8%, Swat 05.3%, Malakand 01.3%, Dir (L) 01.6%, Chitral 01.1%, Haripur 01.3%, Abbottabad 01.4%, Mansehra 01.2% and Swabi 03.6% of the total coolling water usages for marble processing in Khyber Pakhtunkhwa.

Per unit tonne production basis cooling water usage was calculated (Table 4.1.8). In these C3 and C4 required highest demand for cooling water usages due to low production output and more water consumption scenario. On the other hand C1 and C2 consumed less water with respect to high yield and less cooling water consumption scenarios. Because multi-blades gang-saws utilized less cooling water for cutting as compared to single blades machines.

**Table 4.1.8: Cooling water usage ($m^3$/tonne) of the final product**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.87 | 0.64 | 0.71 | 1.00 | 0.85 | 0.64 | 0.87 | 0.755±0.16 |
| C2 | 0.80 | 0.64 | 0.72 | 0.69 | 0.60 | 0.60 | 0.80 | 0.69±0.07 |
| C3 | 1.02 | 0.90 | 1.33 | 0.80 | 0.90 | 0.80 | 1.33 | 0.99±0.20 |
| C4 | 0.80 | 1.06 | 0.60 | 0.80 | 0.75 | 0.60 | 1.06 | 0.802±0.16 |

**Energy Consumption:** Grid electricity is used for marble processing inside the units. For energy estimation monthly electricity bills were noted for consumable electricity units from each category. It was observed that monthly power consumption for category 1 MPUs were found in the range of 26295 to 29166 kWh with an average of 27578.2 kWh. Similarly, category 2 consumption range was 14385 to 16600 kWh, with an average of 15151kWh. For category 3 this range were found from 14375 to 16830 kWh, with an average of 15290.4 kWh and category 4 ranged 10775 to 12340 kWh with an average of 11562kWh (Table 4.1.9).

**Table 4.1.9: Power consumption in ($kWh^{-1}$) for different categories of MPUs**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 29166 | 26295 | 26980 | 27800 | 27650 | 26295 | 29166 | 27578.2±1070 |
| C2 | 16600 | 14500 | 15510 | 14760 | 14385 | 14385 | 16600 | 15151±920 |
| C3 | 16830 | 15552 | 14475 | 15220 | 14375 | 14375 | 16830 | 15290.4±993 |
| C4 | 12340 | 10775 | 11220 | 11495 | 11980 | 10775 | 12340 | 11562±616 |

Marble processing requires massive use electricity for machinery. The energy consumption was recorded from 11562-27578.2 kWh/Month. Therefore a separate transformer of at least 200 KVA is installed. Based on our preliminary MPUs survey and previous literature, it becomes clear that cutting and polishing is the by-far the most energy demanding processes. No evidence of fossils fuel burning machines were detected, the only source of energy at MPUs is the electricity provided from grid. Category and distrct wise energy consumption for marble processing were presented in table 4.1.10.

**Table 4.1.10: District Wise energy consumption ($kW.h^{-1}$) of MPUs Categories**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 1737427 | 1151476 | 1681944 | 2007498 | 6578345 |
| 2 | Peshawar | 1516801 | 1030268 | 1452588 | 1011530 | 5011187 |
| 3 | Charsadda | 965237 | 303020 | 993876 | 715852 | 2977985 |
| 4 | Mardan | 689455 | 575738 | 718648.8 | 622480 | 2606322 |
| 5 | Nowshera | 937658.8 | 681795 | 1146780 | 653604 | 3419838 |
| 6 | Swat | 523985.8 | 151510 | 458712 | 186744 | 1320952 |
| 7 | Malakand | 82734.6 | 60604 | 122323.2 | 77810 | 343471.8 |
| 8 | Dir (L) | 137891 | 30302 | 152904 | 77810 | 398907 |
| 9 | Chitral | 165469.2 | 45453 | 45871.2 | 15562 | 272355.4 |
| 10 | Haripur | 137891 | 45453 | 76452 | 62248 | 322044 |
| 11 | Abbottabad | 110312.8 | 90906 | 122323.2 | 31124 | 354666 |
| 12 | Mansehra | 82734.6 | 30302 | 152904 | 31124 | 297064.6 |
| 13 | Swabi | 275782 | 90906 | 305808 | 248992 | 921488 |
| Total | | 7363380 | 4287733 | 7431134 | 5742378 | 24824625 |

Category wise MPUs results show C1 consumes 29.6%, C2 17.2%, C3 29.9% and C4 23.13% of the total cooling water usages on daily basis. District wise results show that Buner contributed 26.4%, Peshawar 20.1%, Charsadda 11.9%, Mardan 10.4%, Nowshera 13.7%, Swat 05.3%, Malakand 01.3%, Dir (L) 01.6%, Chitral 01.0%, Haripur 01.2%, Abbottabad 01.4%, Mansehra 01.1% and Swabi 03.7% of the total coolling water usages for marble processing in Khyber Pakhtunkhwa. Energy input was also calculated on per unit production basis. In which C3 showed high energy demand as compared to other units. Results showed in table 4.1.11.

**Table 4.1.11: Energy input (kW/h) on per unit tonne production**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 24.3 | 17.53 | 19.98 | 30.88 | 26.33 | 17.53 | 30.88 | 23.80±5.26 |
| C2 | 22.13 | 17.26 | 20.68 | 18.92 | 15.98 | 15.98 | 22.13 | 18.99±2.48 |
| C3 | 31.16 | 25.92 | 40.2 | 25.36 | 23.95 | 23.95 | 40.2 | 29.31±6.66 |
| C4 | 20.56 | 23.94 | 14.96 | 19.15 | 19.96 | 14.96 | 23.94 | 19.71±3.22 |

**Product:** The results showed the amount of production and wastage during processing. It was observed that the per day production rate of C1 MPUs were found in the range of 30 to 50 tonnes with an average of 40 tonnes. Similarly, the production range of C2 was found from 25 to 30 tonnes having average of 26.8 tonnes. For C3 this ranges from 12 to 20 tonnes having average of 18 tonnes. In C4 the range were found from 15 to 25 tonnes having average of 20 tonnes (Table 4.1.12).

**Table: 4.1.12. Daily production rate of different MPUs categories (Tonnes/Day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 40 | 50 | 45 | 30 | 35 | 30 | 50 | 40±7.90 |
| C2 | 25 | 28 | 25 | 26 | 30 | 25 | 30 | 26.8±2.16 |
| C3 | 18 | 20 | 12 | 20 | 20 | 12 | 20 | 18±3.46 |
| C4 | 20 | 15 | 25 | 20 | 20 | 15 | 25 | 20±3.53 |

Based on the rate of raw marble stone consumption the C1 type MPUs give an average of 40 tonnes product out of 50 tonnes raw stone on daily basis. Daily production rate of C2 26.8, C3 18.0 and C4 yield 20.0 tonnes/day out of 30, 20 and 25 tonnes/day respectively. Daily production rate of all four categories from each district was recorded in table 4.1.13.

**Table 4.1.13: District wise Production rate of MPUs categories**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 2580 | 1766.6 | 1323.92 | 1936.62 | 7607.14 |
| 2 | Peshawar | 1300 | 1525.7 | 1184.56 | 1690.7 | 5700.96 |
| 3 | Charsadda | 920 | 1043.9 | 348.4 | 1075.9 | 3388.2 |
| 4 | Mardan | 800 | 754.82 | 661.96 | 768.5 | 2985.28 |
| 5 | Nowshera | 840 | 1204.5 | 783.9 | 1045.16 | 3873.56 |
| 6 | Swat | 240 | 481.8 | 174.2 | 584.06 | 1480.06 |
| 7 | Malakand | 100 | 128.48 | 69.68 | 92.22 | 390.38 |
| 8 | Dir (L) | 100 | 160.6 | 34.84 | 153.7 | 449.14 |
| 9 | Chitral | 20 | 48.18 | 52.26 | 184.44 | 304.88 |
| 10 | Haripur | 80 | 80.3 | 52.26 | 153.7 | 366.26 |
| 11 | Abbottabad | 40 | 128.48 | 104.52 | 122.96 | 395.96 |
| 12 | Mansehra | 40 | 160.6 | 34.84 | 92.22 | 327.66 |
| 13 | Swabi | 320 | 321.2 | 104.52 | 307.4 | 1053.12 |
| **Total** | | **7380** | **7805.16** | **4929.86** | **8207.58** | **28322.6** |

Category wise MPUs production rate represents C1 yield 26.0%, C2 27.5%, C3 17.4% and C4 28.9% of the total final production on daily basis. District wise results show that Buner contributed 26.8%, Peshawar 20.1%, Charsadda 11.9%, Mardan 10.5%, Nowshera 13.6%, Swat 05.2%, Malakand 01.3%, Dir (L) 01.5%, Chitral 01.0%, Haripur 01.2%, Abbottabad 01.4%, Mansehra 01.1% and Swabi 03.7% of the total production yield in Khyber Pakhtunkhwa.

**By-product:** The amount value of marble sludge powder and irregular flag stone constitute the whole wastage. Based on the rate of raw marble stone consumption the C1 type MPUs give an average of 10 tonnes wastages out of 50 tonnes raw stone on daily basis. Daily overall wastages rate of C2 08.2, C3 07.0 and C4 generates 05.0 tonnes/day out of 30, 20 and 25 tonnes/day of raw marble stone respectively (Table 4.1.14).

**Table 4.1.14: Overall Stone and powder Wastages of Different MPUs Categories (Tonnes/day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10±0.00 |
| C2 | 10 | 7 | 5 | 9 | 10 | 05 | 10 | 8.2±2.16 |
| C3 | 07 | 10 | 08 | 05 | 05 | 05 | 10 | 7±2.12 |
| C4 | 05 | 05 | 05 | 05 | 05 | 05 | 05 | 5±0.00 |

The result showed that the marble processing plants in the study area consist of small and medium size industries, where the waste generated per day was in the range of 05-10 tonnes. The average waste generated by each C1 processing plant was found to be 10.0 tonnes per day. Similarly, C2 generates 8.2, C3 7.0 and C4 5.0 tonnes per day respectively. So it has been estimated that on average each processing unit located in the study area produces about 150-300 tonnes of marble waste per month or 1800-3600 tonnes per year.

**Stone Waste:** Stone Waste in the form of fragments produced in the range of 8.5-9.5 tonne/day, having average value of 9.2 tonne/dayfor category 1 MPUs. For category 2 MPUs this ranges from 2.5-9.6 tonne/day, having average of 7.8Tonne/day. This ranges from 4.8 – 9.6 tonne/day having average value of 6.7 tonnes/day for category 3 MPUs. Similarly, for category 4 MPUs this ranges from 4.6-4.8 tonnes/day, having average value of 4.72 tonnes/day (Table 4.1.15).

**Table 4.1.15: Amount of Stone waste generated by different MPUs categories (Tonnes/day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 9.5 | 8.5 | 9.5 | 9 | 9.5 | 8.5 | 9.5 | 9.2±0.44 |
| C2 | 9.5 | 6.8 | 4.6 | 8.5 | 9.6 | 2.5 | 9.6 | 7.8±2.11 |
| C3 | 6.7 | 9.6 | 7.6 | 4.8 | 4.8 | 4.8 | 9.6 | 6.7±2.02 |
| C4 | 4.6 | 4.8 | 4.6 | 4.8 | 4.8 | 4.6 | 4.8 | 4.72±0.10 |

Among the all four categories of MPUs the stone waste generation range were found 4.72-9.2 tonnes/day. District wise daily stone waste generation rate of all four categories was presented in table 4.1.16.

**Table 4.1.16: Districts and category wise Stone Waste Generation (Tonnes/Day)**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 579.6 | 592.8 | 737.0 | 608.8 | 2518.2 |
| 2 | Peshawar | 506.0 | 530.4 | 636.5 | 306.8 | 1979.7 |
| 3 | Charsadda | 322.0 | 156.0 | 435.5 | 217.1 | 1130.6 |
| 4 | Mardan | 230 | 296.4 | 314.9 | 188.8 | 1030.1 |
| 5 | Nowshera | 312.8 | 351.0 | 502.5 | 198.2 | 1364.5 |
| 6 | Swat | 174.8 | 78.0 | 201.0 | 56.6 | 510.4 |
| 7 | Malakand | 27.6 | 31.2 | 53.6 | 23.6 | 136 |
| 8 | Dir (L) | 46.0 | 15.6 | 67.0 | 23.6 | 152.2 |
| 9 | Chitral | 55.2 | 23.4 | 20.1 | 4.7 | 103.4 |
| 10 | Haripur | 46.0 | 23.4 | 33.5 | 18.8 | 121.7 |
| 11 | Abbottabad | 36.8 | 46.8 | 53.6 | 9.4 | 146.6 |
| 12 | Mansehra | 27.6 | 15.6 | 67.0 | 9.4 | 119.6 |
| 13 | Swabi | 92.0 | 46.8 | 134.0 | 75.2 | 348.3 |
| **Category wise waste Generation** | | **2456.4** | **2207.4** | **3256.2** | **1741.6** | **9661.6** |

Category wise MPUs stone wastage rate represents C1 yield 25.4%, C2 22.8%, C3 33.7% and C4 18.0% of the total stone waste generated on daily basis. District wise marble stone waste generation rate shows that the total waste from all categories were found in the range of 119.64 -2518.28 tonnes/day. In which, Buner contributed 26.06%, Peshawar 20.4%, Charsadda 11.7%, Mardan 10.6%, Nowshera 14.1%, Swat 05.2%, Malakand 01.4%, Dir (L) 01.5%, Chitral 01.0%, Haripur 01.2%, Abbottabad 01.5%, Mansehra 01.2% and Swabi 03.6% of the total fragmented/cutted stone wastage in Khyber Pakhtunkhwa.

**Powder waste:** Analytical results showed that powder Waste in the form of slurry produced in the range of 0.5-1.5 tonnes/day, having average value of 0.8 tonne/day for category 1. For category 2 MPUs this ranges from 0.2-0.5 tonne/day, having average of 0.4 tonne/day. This ranges from 0.2-0.4 tonne/day having average value of 0.3 tonne/day. Similarly, for category 4 MPUs this ranges from 0.2-0.4 tonne/day, having average value of 0.28 tonne/day (Table 4.1.17).

**Table 4.1.17: Marble powder waste generation from different MPUs categories (Tonnes/Day)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.5 | 1.5 | 0.5 | 1.0 | 0.5 | 0.5 | 1.5 | 0.8±0.44 |
| C2 | 0.5 | 0.2 | 0.4 | 0.5 | 0.4 | 0.2 | 0.5 | 0.4±0.12 |
| C3 | 0.3 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0.4 | 0.3±0.10 |
| C4 | 0.4 | 0.2 | 0.4 | 0.2 | 0.2 | 0.2 | 0.4 | 0.28±0.10 |

Slurry consists of Powder waste and cooling water arise from sawing the marble stone. Among all four categories of MPUs the powder waste generation range were found 0.28-0.80 tonnes/day. District wise powder waste generation was recorded in Table 4.1.18 for all categories of MPUs.

**Table 4.1.18: Category and District wise Marble Powder Waste generation (Tonnes/Day)**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 50.4 | 30.4 | 33 | 36.12 | 149.92 |
| 2 | Peshawar | 44 | 27.2 | 28.5 | 18.2 | 117.9 |
| 3 | Charsadda | 28 | 8 | 19.5 | 12.88 | 68.38 |
| 4 | Mardan | 20 | 15.2 | 14.1 | 11.2 | 60.5 |
| 5 | Nowshera | 27.2 | 18 | 22.5 | 11.76 | 79.46 |
| 6 | Swat | 15.2 | 4 | 9 | 3.36 | 31.56 |
| 7 | Malakand | 2.4 | 1.6 | 2.4 | 1.4 | 7.8 |
| 8 | Dir (L) | 4 | 0.8 | 3 | 1.4 | 9.2 |
| 9 | Chitral | 4.8 | 1.2 | 0.9 | 0.28 | 7.18 |
| 10 | Haripur | 4 | 1.2 | 1.5 | 1.12 | 7.82 |
| 11 | Abbottabad | 3.2 | 2.4 | 2.4 | 0.56 | 8.56 |
| 12 | Mansehra | 2.4 | 0.8 | 3 | 0.56 | 6.76 |
| 13 | Swabi | 8 | 2.4 | 6 | 4.48 | 20.88 |
| **Category wise Waste** | | 213.6 | 113.2 | 145.8 | 103.32 | 575.92 |

Category wise MPUs results showed that C1 generates 37.0%, C2 19.6%, C3 25.3% and C4 18.0% of the total powder waste on daily basis. District wise marble powder waste generation rate showed that the total waste from all categories were found in the range of 6.76 -149.92 tonnes/day. In which, Buner contributed 26.03%, Peshawar 20.4%, Charsadda 11.8%, Mardan 10.5%, Nowshera 13.7%, Swat 05.4%, Malakand 01.3%, Dir (L) 01.5%, Chitral 01.2%, Haripur 01.3%, Abbottabad 01.4%, Mansehra 01.1% and Swabi 3.6% of the total powder waste generated in Khyber Pakhtunkhwa. Overall stone and powder waste generated on daily basis by these MPUs from each district were estimated and expressed in Table 4.1.19.

**Table 4.1.19: Overall District wise Marble Waste Produced (Tonnes/Day)**

| S.NO | Districts | Powder Waste | Stone Waste | Total |
|---|---|---|---|---|
| 1 | Buner | 149.92 | 2518.28 | 2668.2 |
| 2 | Peshawar | 117.9 | 1979.7 | 2097.6 |
| 3 | Charsadda | 68.38 | 1130.62 | 1199 |
| 4 | Mardan | 60.5 | 1030.1 | 1090.6 |
| 5 | Nowshera | 79.46 | 1364.54 | 1444 |
| 6 | Swat | 31.56 | 510.44 | 542 |
| 7 | Malakand | 7.8 | 136 | 143.8 |
| 8 | Dir (L) | 9.2 | 152.2 | 161.4 |
| 9 | Chitral | 7.18 | 103.42 | 110.6 |
| 10 | Haripur | 7.82 | 121.78 | 129.6 |
| 11 | Abbottabad | 8.56 | 146.64 | 155.2 |
| 12 | Mansehra | 6.76 | 119.64 | 126.4 |
| 13 | Swabi | 20.88 | 348.32 | 369.2 |

On the basis of per unit tonne production, marble wastage was also calculated for each category (Table 4.1.20).

**Table 4.1.20: Overall wastage (Tonnes/tonne.product)**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.25 | 0.2 | 0.22 | 0.33 | 0.28 | 0.2 | 0.33 | 0.2575±0.06 |
| 2 | 0.4 | 0.25 | 0.2 | 0.34 | 0.33 | 0.2 | 0.4 | 0.304±0.07 |
| 3 | 0.38 | 0.5 | 0.66 | 0.25 | 0.25 | 0.25 | 0.66 | 0.408±0.17 |
| 4 | 0.25 | 0.33 | 0.2 | 0.25 | 0.25 | 0.2 | 0.33 | 0.256±0.04 |

**Wastewater Discharge:** Daily flow rate of wastewater discharge recorded for category 1 MPUs were found in the range of 28.8 to 32.4 $m^3$ having average of 30.74 $m^3$. Similarly, for category 2 this range was observed from 16.9 to 18.1 $m^3$ having of 17.42 $m^3$. For category 3 this range were found in 14.6 to 17.2 $m^3$ having average of 16.06 $m^3$. In category 4 this ranges from 13.5 to 15.8 $m^3$ having average of 14.72 $m^3$ (Table 4.1.21).

**Table 4.1.21: Wastewater Discharge from different categories of MPUs**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 32.4 | 30.5 | 31.8 | 30.2 | 28.8 | 28.8 | 32.4 | 30.74±1.41 |
| C2 | 18.1 | 17.5 | 17.1 | 16.9 | 17.5 | 16.9 | 18.1 | 17.42±0.46 |
| C3 | 17.2 | 16.8 | 14.6 | 15.2 | 16.5 | 14.6 | 17.2 | 16.06±1.10 |
| C4 | 14.4 | 15.8 | 13.5 | 15.1 | 14.8 | 13.5 | 15.8 | 14.72±0.85 |

Due to processing of high amount of marble stone the consumption of cooling water also recorded high in C1 category. Due to which the wastewater generates with high discharge. Overall, among the all four categories of MPUs the wastewater generations ranged were found 14.72-30.74$m^3$/day. District wise wastewater discharge was recorded in table 4.1.22 for all categories of MPUs.

Category wise wastewater discharge in the province show that C1 generates 31.1%, C2 18.6%, C3 29.59% and C4 20.59% of the total wastewater discharge on daily basis. District wise marble processing wastewater generation rate shows that the total wastewater from all categories were found in the range of 317.1- 6926.02 $m^3$/day. In which, Buner contributed 26.2%, Peshawar 20.3%, Charsadda 11.9%, Mardan 10.5%, Nowshera 13.8%, Swat 05.3%, Malakand 01.3%, Dir (L) 01.6%, Chitral 01.1%, Haripur 01.3%, Abbottabad 01.4%, Mansehra 01.2% and Swabi 3.6% of the total marble processing wastewater generated in Khyber Pakhtunkhwa.

**Table 4.1.22: District wise Wastewater Discharges of all MPUs categories**

| S.NO | District | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|
| 1 | Buner | 1936.62 | 1323.92 | 1766.6 | 1898.88 | 6926.02 |
| 2 | Peshawar | 1690.7 | 1184.56 | 1525.7 | 956.8 | 5357.76 |
| 3 | Charsadda | 1075.9 | 348.4 | 1043.9 | 677.12 | 3145.32 |
| 4 | Mardan | 768.5 | 661.96 | 754.82 | 588.8 | 2774.08 |
| 5 | Nowshera | 1045.16 | 783.9 | 1204.5 | 618.24 | 3651.8 |
| 6 | Swat | 584.06 | 174.2 | 481.8 | 176.64 | 1416.7 |
| 7 | Malakand | 92.22 | 69.68 | 128.48 | 73.6 | 363.98 |
| 8 | Dir (L) | 153.7 | 34.84 | 160.6 | 73.6 | 422.74 |
| 9 | Chitral | 184.44 | 52.26 | 48.18 | 14.72 | 299.6 |
| 10 | Haripur | 153.7 | 52.26 | 80.3 | 58.88 | 345.14 |
| 11 | Abbottabad | 122.96 | 104.52 | 128.48 | 29.44 | 385.4 |
| 12 | Mansehra | 92.22 | 34.84 | 160.6 | 29.44 | 317.1 |
| 13 | Swabi | 307.4 | 104.52 | 321.2 | 235.52 | 968.64 |
| **Total** | | **8207.58** | **4929.86** | **7805.16** | **5431.68** | **26374.28** |

Wastewater discharge data on the basis of per unit tonne of finished product was also calculated (Table 4.1.23).

**Table 4.1.23: Wastewater flow rate ($m^3$/tonne) for per unit tonne of production**

| Category | 1 | 2 | 3 | 4 | 5 | Min | Max | Mean±St.D |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.81 | 0.61 | 0.70 | 1.00 | 0.82 | 0.61 | 0.82 | 0.73±0.09 |
| C2 | 0.72 | 0.62 | 0.68 | 0.65 | 0.58 | 0.58 | 0.72 | 0.65±0.05 |
| C3 | 0.95 | 0.84 | 1.21 | 0.76 | 0.82 | 0.76 | 1.21 | 0.91±0.17 |
| C4 | 0.72 | 1.05 | 0.54 | 0.75 | 0.74 | 0.54 | 1.05 | 0.76±0.18 |

### 4.1.4 Impacts Assessment

**Impacts on surface water:** Laboratory results showed that the liquid effluent of MPUs have high values of TSS. Liquid effluent of C1 MPUs showed TSS values in the range of 20050-29700 mg/L with an average of 26330 mg/L. In C2 this range was found from 17800-19800 mg/L with an average of 18970 mg/L. Results of C3 were found in the range of 17500-18800 mg/L with an average of 18040 mg/L. C4 results of TSS were found in the range of 17650-19200 mg/L with an average of 18660 mg/L (Table 4.1.24).

**Table 4.1.24: TSS results (mg/L) of MPUs Effluents Samples**

| **Category** | 1 | 2 | 3 | 4 | 5 | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 27500 | 25500 | 28900 | 20050 | 29700 | 20050 | 29700 | 26330±3855.45 |
| C2 | 19800 | 18750 | 19000 | 17800 | 19500 | 17800 | 19800 | 18970±772.65 |
| C3 | 18800 | 17600 | 17500 | 18000 | 18300 | 17500 | 18800 | 18040±531.97 |
| C4 | 18900 | 19150 | 19200 | 18400 | 17650 | 17650 | 19200 | 18660±647.49 |

Marble effluents contained high concentration of TSS resulting from marble cutting dust (Khan et al. 2012). Results of TSS of all four categories MPUs effluent samples were found above the permissible limit of Pakistan-National Environmental Quality Standards (NEQS) for wastewater. High concentration of TSS makes water unsafe for drinking and aquatic life (Vinod and Chopra, 2012). It affects light penetration in water bodies which alters photosynthetic activities and decreases oxygen level. Besides, high TSS level increases microbial growth which can also decreases dissolved oxygen level in water bodies (Paul 2011).

Results of TDS in C1 MPUs were found in the range of 980-1250 mg/L with an average of 1122 mg/L. In C2 effluents samples it was found in the range of 960-1150 mg/L with an average of 1078 mg/L. In C3 it was ranges from 950-1140 mg/L with an average of 1025 mg/L. In C4 it was in the range of 950-1210 mg/L with an average of 1090 mg/L (Table 4.1.25).

**Table 4.1.25: TDS (mg/L) results of MPUs Effluents Samples**

| **Category** | 1 | 2 | 3 | 4 | 5 | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 1250 | 1190 | 980 | 1140 | 1050 | 980 | 1250 | 1122±108.02 |
| C2 | 1100 | 1110 | 1070 | 1150 | 960 | 960 | 1150 | 1078±71.90 |
| C3 | 1140 | 985 | 980 | 1070 | 950 | 950 | 1140 | 1025±78.26 |
| C4 | 1020 | 1150 | 950 | 1120 | 1210 | 950 | 1210 | 1090±104.16 |

TDS change the density of water, especially toward the bottom to form a chemocline by reducing light penetration in the water, so affect adversely photosynthesis (Town, 2013). High value for TDS may exert adverse economic and physiological effects, primarily osmotic and may impart taste and odor. Marble waste mostly consists of calcium carbonate is not contributing to dissolved substances. Due to which total dissolved solids were within permissible limits of Pak-NEQS.

Concentrations of Chromium (Cr) in C1 MPUs were found in the range of 0.01-0.06 ppm with an average of 0.026 ppm. In C2 effluents samples it was found in the range of 0.00-0.01 ppm with an average of 0.004 ppm. In C3 it ranges from 0.00-0.03 ppm with an average of 0.012 ppm. In C4 it was observed in the range of 0-0.01 ppm with an average of 0.004 ppm. (Table 4.1.26).

**Table 4.1.26: Cr concentration (ppm) in MPUs Effluents Samples**

| **Category** | 1 | 2 | 3 | 4 | 5 | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.03 | 0.01 | 0.01 | 0.02 | 0.06 | 0.01 | 0.06 | 0.026±0.02 |
| C2 | 0.01 | 0.0 | 0.0 | 0.01 | 0.0 | 0.0 | 0.01 | 0.004±0.00 |
| C3 | 0.02 | 0.01 | 0.0 | 0.0 | 0.03 | 0.0 | 0.03 | 0.012±0.01 |
| C4 | 0.01 | 0.0 | 0.0 | 0.01 | 0.0 | 0.0 | 0.01 | 0.004±0.00 |

Concentrations of Cupper (Cu) in C1 MPUs were found in the range of 0.01-0.05 ppm with an average of 0.024 ppm.. In C2 effluents samples it was found in the range of 0.01-0.03 ppm with an average of 0.02 ppm. In C3 it range from 0.00-0.03 ppm with an average of 0.012 ppm. In C4 it was observed in the range of 0-0.02 ppm with an average of 0.008 ppm (Table 4.1.27).

**Table 4.1.27: Cu concentration (ppm) in MPUs Effluents Samples**

| **MPU Category** | **1** | **2** | **3** | **4** | **5** | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.01 | 0.01 | 0.05 | 0.03 | 0.02 | 0.01 | 0.05 | 0.024±0.01 |
| C2 | 0.01 | 0.03 | 0.01 | 0.02 | 0.03 | 0.01 | 0.03 | 0.02±0.01 |
| C3 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.02 | 0.008±0.01 |
| C4 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 | 0.006±0.01 |

Concentrations of Nikel (Ni) in C1 MPUs were found in the range of 0.01-0.03 ppm with an average of 0.022 ppm. In C2 effluents samples it was found in the range of

0.01-0.03 ppm with an average of 0.02 ppm. In C3 it ranges from 0.01-0.04 ppm with an average of 0.022 ppm. In C4 it was observed in the range of 0.01-0.04 ppm with an average of 0.028 ppm. (Table 4.1.28).

**Table 4.1.28: Ni concentration (ppm) in MPUs Effluents samples**

| **Category** | 1 | 2 | 3 | 4 | 5 | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.01 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.03 | 0.022±0.01 |
| C2 | 0.02 | 0.03 | 0.01 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02±0.00 |
| C3 | 0.01 | 0.01 | 0.03 | 0.04 | 0.02 | 0.01 | 0.04 | 0.022±0.01 |
| C4 | 0.01 | 0.03 | 0.02 | 0.04 | 0.04 | 0.01 | 0.04 | 0.028±0.01 |

Concentrations of Manganese (Mn) in C1 MPUs were found in the range of 0.02-0.56 ppm with an average of 0.236±0.28. In C2 effluents samples it was found in the range of 0.03-0.06 ppm with an average of 0.042 ppm. In C3 it ranges from 0.00-0.02 ppm with an average of 0.008 ppm. In C4 it was observed in the range of 0-0.01 ppm with an average of 0.004 ppm (Table 4.1.29).

**Table 4.1.29: Mn concentration (ppm) in MPUs Effluents Samples**

| **Category** | 1 | 2 | 3 | 4 | 5 | **Min** | **Max** | **Mean±St.D** |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.54 | 0.04 | 0.56 | 0.02 | 0.02 | 0.02 | 0.56 | 0.236±0.28 |
| C2 | 0.06 | 0.05 | 0.03 | 0.03 | 0.04 | 0.03 | 0.06 | 0.042±0.01 |
| C3 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.02 | 0.008±0.01 |
| C4 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.004±0.00 |

Heavy metals such as Cr, Cu, Ni and Mn were expected. The concentration of these various metals was also found within the permissible limit of NEQS.

Upstream and downstream investigation of parameters for summer and winter seasons revealed that pollution load in River Barandu have been increasing. The upstream data showed that surface water quality was better when compared with downstream. The downstream surface water quality of River Barandu deteriorated significantly due to disposal of untreated effluent from marble processing units as compared to Pakistan Surface water quality guidelines (Table 4.1.30). TSS concentrations in upstream and downstream conditions were found beyond the surface water quality guidelines for recreational and healthy aquatic life in both seasons of the year.

**Table 4.1.30: Physico-chemical Characteristics of River Barandu at up and downstream conditions with seasonal variations**

| Parameters | Summer | | Winter | | Pak-Surface Water Guidelines |
|---|---|---|---|---|---|
| | Upstream | Downstream | Upstream | Downstream | |
| pH | 7.51±0.28 | 8.17±0.44 | 7.71±0.20 | 7.99±0.41 | 6.5--8.5 |
| TSS | 11.66±2.88 | 193.33±15.27 | 17.33±1.15 | 198.00±12.48 | 5 |
| TDS | 243.33±10.40 | 659.00±26.22 | 99.00±13.52 | 626.66±112.39 | 1000 |
| COD | 93.33±28.22 | 112.43±32.44 | 96.45±13.53 | 128.33±34.23 | 150 |
| Cu | 0.02±0.02 | 0.19±0.10 | 0.38±0.53 | 0.45±0.18 | 1.5 |
| Cr | 0.09±0.03 | 0.10±0.09 | 0.06±0.05 | 0.02±0.02 | 0.05 |
| Ni | 0.04±0.04 | 0.05±0.03 | 0.10±0.10 | 0.03±0.02 | 0.05 |
| Mn | 0.28±0.20 | 1.00±0.42 | 0.21±0.07 | 0.67±0.46 | 0.3 |

All units are in mg/L except pH (pH scale)

Marble processing units have negative environmental impacts on surface water quality during both season of the year. That’s why, the water use trends have also been changed to a big extent. In the study area, the use of surface water for industrial purposes (up take and discharge of effluent) started in 1994. At that time limited numbers of marble processing industries existed and the impacts were minimum. With the passage of time there was an increase in MPUs and the impacts become visible after few years. After 2003 local residents avoided the surface water use for washing and drinking purposes. This is mainly attributed to the loss of aesthetic value as well as poor deteriorating surface water quality in the form of whitish coloration due to presence of marble particles. As figure 2 indicates, bathing and recreation was stopped after 2007. Water uses for irrigation however remained consistent (Fig: 4.1.4).

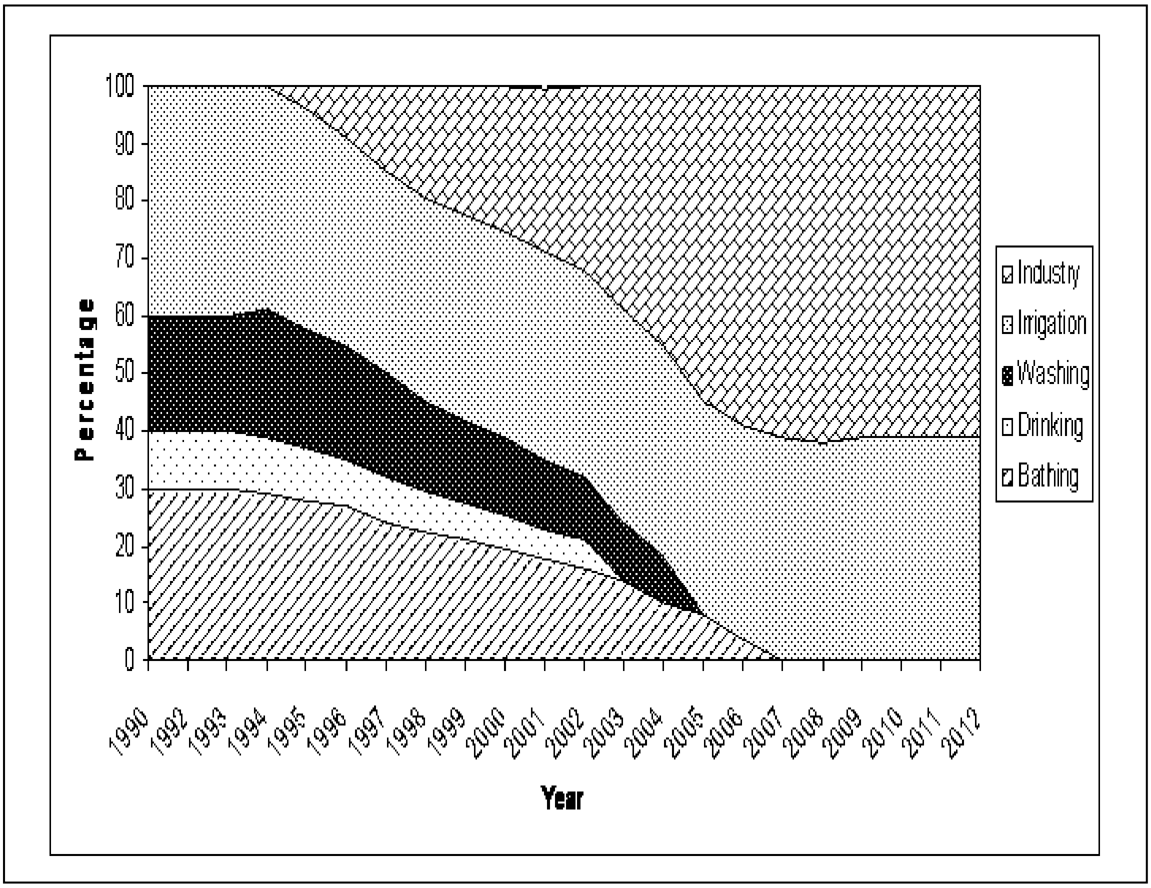



**Figure 4.1.4: Deterioration of Surface water usage due to Marble processing wastewater**

The regulatory measures set by Pakistan Environmental Protection Agency and the National Environmental Quality Standards (NEQS) not permit the effluent discharge of any municipal and industrial wastewater effluent into any receiving water bodies after having TSS concentration more than 150 mg/L to be discharged in any receiving body without any treatment. That is why the proponent of MPUs should operate sedimentation tank to keep the TSS below the permissible limit. Once the sedimentation tank is filled, the deposited slurry flows to the river during the rain. As nothing has been mentioned for treatment and disposal of waste slurry in EAC, therefore, it is not obligatory on the proponent to treat the slurry or dispose it safely.

There are some technical questions raised in the existing regulation EAC like asking about the ecological sensitivity of project site, asking about the surety that IEE/EIA is not required, how to describe biological, physical and social environment and how to assess potential impacts and mitigation measures. These questions are not answered by owner of MPU's in an appropriate and unbiased manner. Beside these, obligation of regular monitoring by EPA and self monitoring is addressed in EAC guidelines but not implemented properly due to inappropriate legitimate periodic check. Because once the sedimentation tanks are filled with slurry it is not cleaned up by the owner. If the EPA officials visit the site, the owner shows them these tanks as a proof of compliances and mitigation measures for minimizing pollution load and water consumption. The use of ground water is not addressed in the checklist. Besides, treatment or disposal for the marble slurry is also missing**.**

**Impacts on Soil quality:** The samples collected were analyzed for bulk density and porosity according to invoice of the stated methodology. The water movement in soil is dependent on soil porosity. Bulk density and soil porosity have inverse relation to each other. As the bulk density increases the number of pores in soil decreases, hence the percolation of water will be limited. The result shows that the average porosity of the non-effected soil is greater as compared to the effected soil.

The concentration of calcium in effluents affected soil was found in the range of 412-445mg/kg. And the concentration in Non-affected soil was 102mg/kg and 119mg/kg. The values show much difference in the Ca concentrations. The value of Mg amount in effluents affected soil is 173mg/kg and 198mg/kg. And values in non-affected soil are 7mg/kg and 10mg/kg. The value shows much difference due to Marble effluents concentrations. Table 4.1.31 shows the physical and chemical characteristics of effected and non effected soil irrigated with wastewater and fresh water respectively.

**Table No. 4.1.31 Physical and chemical properties of Soil affected by Marble wastewater**

| S. No | Property | Sample No | Affected | Non-Affected |
|---|---|---|---|---|
| 1 | Bulk Density (g/cm$^3$) | 1 | 1.19 | 1.06 |
| | | 2 | 1.21 | 1.09 |
| | | 3 | 1.29 | 1.06 |
| | | **Average** | **1.23** | **1.07** |
| 2 | Porosity | 1 | 0.51 | 0.63 |
| | | 2 | 0.53 | 0.61 |
| | | 3 | 0.51 | 0.6 |
| | | **Average** | **0.51** | **0.61** |
| 3 | pH | 1 | 8.02 | 5.9 |
| | | 2 | 7.34 | 7 |
| | | 3 | 7.9 | 5.8 |
| | | **Average** | **7.75** | **6.23** |
| 4 | E. Cond. (µS/cm) | 1 | 422 | 315 |
| | | 2 | 388 | 339 |
| | | 3 | 365 | 289 |
| | | **Average** | **391.66** | **314.33** |
| 5 | Ca (mg/kg) | 1 | 445 | 119 |
| | | 2 | 385 | 112 |
| | | 3 | 412 | 102 |
| | | **Average** | **414** | **111** |
| 6 | Mg (mg/kg) | 1 | 173 | 8 |
| | | 2 | 185 | 10 |
| | | 3 | 198 | 7 |
| | | **Average** | **185.33** | **8.33** |

Data analysis revealed that the average bulk density of soil decreased with the decrease in porosity. The bulk density of affected soil was found higher than the non affected soil. Soil with high bulk density has lower infiltration rate. The pH of affected soil was found slight alkaline. Similarly, the values of EC, Ca and Mg in affected soil samples were found above the non-affected soil samples. Fazal Akbar et al. (2007) studied the impacts of marble effluents and seed germination. Marble effluents increases the pH of soil, retard plant growth and seed germination.

**Impacts on Air Quality:** Inside MPUs the marble cutting and polishing processes is based on wet medium. Therefore, no dust emission was detected inside the unit, but after disposed off the marble sludge openly the particles of marble sludge becomes air borne after drying. However, our study was upto the specialized unit processes so inside the unit the dust is entrapped in cooling water. Besides, no evidence of fossils fuels burning machines were detected which pose a threat to air quality.

### 4.1.5 LCA Results Interpretation

In this study four different operating scenarios were selected. The C1 related to block dressing, cutting and polishing, C2 executed block dressing and cutting without polishing, C3 relate cutting and polishing and C4 having cutting processes only. Results of inventory analysis showed that these all categories have its own requirements in terms of raw material usages and outputs in terms of products and by-products. The processing of marble stone not related to processing lineup but also environmental impacts of this were also considered. For that purpose three aspects of marble processing were selected includes; i) raw materials consumption in terms of marble stone, water usage and energy consumption; ii) Production and environmental pollution; iii) Material waste management.

The inventory survey data were collected within Marble processing units. The boundaries of this LCI included processing activities (gate to gate), specialized unit operation study. All inputs and outputs of raw materials, cooling water and energy as well as product and by-products were quantified (Table 4.1.32).

**Table 4.1.32: Mean values of overall Inputs and outputs data of different MPUs categories on daily basis**

| Major Inputs and Outputs | CATEGORY 1 | | CATEGORY 2 | | CATEGORY 3 | | CATEGORY 4 | |
|---|---|---|---|---|---|---|---|---|
| | Input | Output | Input | Output | Input | Output | Input | Output |
| Electricity (kWh) | 919.27 | | 505.03 | | 509.68 | | 385.4 | |
| Water ($m^3$) | 35 | 32.4 | 20 | 18.1 | 18.5 | 17.2 | 16 | 14.4 |
| Production (Tonne) | 50 | 40 | 35 | 26.8 | 25 | 18 | 20 | 15 |
| Stone waste (Tonne) | | 9.2 | | 7.8 | | 6.7 | | 4.72 |
| Slurry Powder (Tonne) | | 0.8 | | 0.4 | | 0.3 | | 0.274 |

The data were designed according to the LCA standard methodology. The Inventory data collection was the most time consuming step and the most difficult of all the activities of an LCA. An average consumption of raw material varies significantly along the four categories of MPUs ranging from 20 to 50 Tonnes/day (working day). Similarly, production outputs were calculated ranges from 15-40 Tonnes/ day. Massive amount of water were used for cooling cutting and polishing machines. Average cooling water consumption varied from 16 to 35$m^3$/day. The difference of raw material consumption and product gives the amount of wastages, where solid waste in the form of stone pieces ranges from 4.72 to 9.2 Tonnes/day and liquid slurry powder ranging from 0.27 to 0.8 Tonnes/day. However, the difference between raw material consumption and production is not necessary assigned as waste products but rather could be byproducts. The utilized energy at the marble factories was only generated directly from electric source. No fossils fuel burning devices were detected at the sites, which in turn, minimize the environmental impact from energy consumption sources. Therefore, energy consumption was not a considerably focused within this study. However, energy consumption was also variable between inspected manufactures by which the energy consumption varied from 385.4-919.27 kWh/day. On daily basis the C1 and C2 types units showed high values for materials gave and take in terms of inputs and outputs. But it was noted that if these calculation based on per unit production of finished product C3 and C4 showed high demand for material inputs for given yield. These uncertainties in data regarding input and output is resolves by LCA softwares like Sima-Pro, Gabbi or Senkey etc. This is another area of interest for future research in this sector.

# RESULTS AND DISCUSSION

# PART-II

# CHAPTER-IV

# RESULTS AND DISCUSSION

## PART-II

The part-II this chapter presents physical and chemical characterization of marble slurry waste and its utilization in valuable products like Cement, Dish Washing Powder, Glass Fibers Reinforce Mortar and lime. This was followed by evaluation of these products with commercial products according to ASTM specifications. The test results obtained are presented, discussed, analyzed and compared with respective ASTM standards.

### 4.2.1 Characterization of Marble Slurry Waste

#### 4.2.1.1 Physical Characterization

**Moisture:** Moisture content of the waste slurry was determined according to ASTM C25. Average percentage of moisture was calculated as 19.42% (Table 4.2.1). Data showed a huge variation in the moisture content that ranges from 1.62 to 32.61 %. This is due to the slurry condition at the time of sampling. According to study conducted by Mashaly et al. 2012 reported that the average water content of the marble sludge samples is 17.26%. In marble processing plants the waste produced from cutting contained water that was initially stored in the storage tanks, where water content was separated out till dryness and then the dried waste is thrown out with the help of trolley tractors.

**Table 4.2.1: Percent moisture of marble slurry waste**

| Category | Sample ID | Moisture (%) |
|---|---|---|
| C1 | C1.1 | 22.29 |
| | C1.2 | 32.61 |
| | C1.3 | 21.66 |
| | C1.4 | 15.43 |
| | C1.5 | 16.65 |
| C2 | C2.1 | 3.56 |
| | C2.2 | 18.23 |
| | C2.3 | 1.62 |
| | C2.4 | 25.61 |
| | C2.5 | 30.63 |
| C3 | C3.1 | 22.21 |
| | C3.2 | 28.36 |
| | C3.3 | 15.53 |
| | C3.4 | 8.63 |
| | C3.5 | 25.73 |
| C4 | C4.1 | 22.88 |
| | C4.2 | 16.75 |
| | C4.3 | 15.55 |
| | C4.4 | 22.63 |
| | C4.5 | 21.98 |
| **Average** | | **19.42** |

**Fineness:** In order to check the suitability of marble dust as filler, fineness of marble slurry powder was determined by sieving according to ASTM C117. The results are presented in Table 4.2.2. Results showed that the percentage fine particles passing through 75 µm sieve was nearly 85%, while almost 15 % particles were retained. According to a study conducted by Hamza et al. 2011 reported that 90% of the Marble sludge powder samples are of diameter less than 50 µm. It is imperative that the marble dust is used in its original fineness without further grinding to reduce the cost.

**Table 4.2.2: Sieve analysis of pass and retained percentage of dried marble slurry waste particles**

| Category | Sample ID | Percentage Pass (75µm) | Percentage Retained (75µm) |
|---|---|---|---|
| C1 | C1.1 | 86.37 | 13.63 |
| | C1.2 | 83.95 | 16.05 |
| | C1.3 | 86.46 | 15.54 |
| | C1.4 | 83.97 | 16.03 |
| | C1.5 | 83.43 | 16.57 |
| C2 | C2.1 | 81.99 | 18.01 |
| | C2.2 | 81.59 | 18.41 |
| | C2.3 | 86.59 | 13.41 |
| | C2.4 | 86.17 | 13.83 |
| | C2.5 | 85.11 | 14.89 |
| C3 | C3.1 | 86.33 | 13.67 |
| | C3.2 | 85.16 | 14.84 |
| | C3.3 | 83.29 | 16.71 |
| | C3.4 | 84.56 | 15.44 |
| | C3.5 | 84.46 | 15.54 |
| C4 | C4.1 | 85.27 | 14.73 |
| | C4.2 | 83.32 | 16.68 |
| | C4.3 | 86.44 | 13.56 |
| | C4.4 | 83.64 | 16.36 |
| | C4.5 | 84.74 | 15.26 |
| **Average** | | **84.64** | **15.46** |

Data showed that the marble dust have higher proportion of fine particles, which impart good cohesiveness in mortar and concrete. Concrete is a composite material made up of filler and binder. The role of a binder is to hold the filler together. Cement along with water is used as a binder while sand (coarse aggregate) and marble dust (fine aggregate) are used as fillers.

**Bulk density, specific gravity and water absorption:** The bulk density, specific gravity and water absorption of the marble powder used in experimental phase are shown in Table 4.2.3. The measured average specific gravity is 2.70, which is little higher as compared to reference literature for calcite. The higher value is due to the presence of iron, grit and lime as abrasive powder which is used in sawing operations in large units. The specific gravity of slurry powder depends on the cutting and processing operations. The average water absorption is 0.43 ranging from 0.40 to 0.46. It shows that marble waste has very low water absorption capacity due to which it quickly attains dryness. The average bulk density is 1.4 $g/cm^3$. The result showed a little high value, which is due to the particles with large surface area that in turn require high water content for saturation.

**Table 4.2.3: Specific gravity, Bulk density and Water absorption test of marble slurry**

| Category | Sample ID | Bulk Density (g/cm3) | Specific gravity | Water Absorption |
|---|---|---|---|---|
| C1 | C1.1 | 1.4 | 2.73 | 0.43 |
| | C1.2 | 1.4 | 2.69 | 0.44 |
| | C1.3 | 1.4 | 2.72 | 0.43 |
| | C1.4 | 1.4 | 2.75 | 0.42 |
| | C1.5 | 1.4 | 2.69 | 0.44 |
| C2 | C2.1 | 1.4 | 2.78 | 0.46 |
| | C2.2 | 1.4 | 2.76 | 0.44 |
| | C2.3 | 1.4 | 2.68 | 0.43 |
| | C2.4 | 1.3 | 2.67 | 0.44 |
| | C2.5 | 1.4 | 2.73 | 0.43 |
| C3 | C3.1 | 1.3 | 2.69 | 0.43 |
| | C3.2 | 1.4 | 2.68 | 0.4 |
| | C3.3 | 1.4 | 2.71 | 0.41 |
| | C3.4 | 1.4 | 2.77 | 0.43 |
| | C3.5 | 1.4 | 2.73 | 0.43 |
| C4 | C4.1 | 1.4 | 2.71 | 0.42 |
| | C4.2 | 1.3 | 2.64 | 0.42 |
| | C4.3 | 1.3 | 2.66 | 0.44 |
| | C4.4 | 1.4 | 2.68 | 0.4 |
| | C4.5 | 1.4 | 2.71 | 0.45 |
| Average | | 1.4 | 2.7 | 0.43 |

According to Hamza et al. 2011, reported specific gravity of marble slurry powder is as low as 2.55 and as high as 3.0 and water absorption is from one to two percent.

### 4.2.1.2 Chemical Characterization

Chemical analyses of twenty marble slurry waste samples were carried out using XRF. Table 4.2.4 shows the major constituents in weight percent whereas Table 4.28 gives minor constituents in ppm.

**Table 4.2.4: Chemical characteristics (major constituents) of marble slurry waste collected from different marble industries**

| Category | Sample ID | Major Constituents Percentage | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $P_2O_5$ | $TiO_2$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | LOI |
| C1 | C1.1 | 0.76 | 0.16 | 0.15 | 0.12 | 0.00 | 53.56 | 2.51 | 0.33 | 0.22 | 0.00 | 42.15 |
| | C1.2 | 0.78 | 0.26 | 0.18 | 0.11 | 0.03 | 53.56 | 3.32 | 0.26 | 0.31 | 0.16 | 41.03 |
| | C1.3 | 0.39 | 1.14 | 0.13 | 0.08 | 0.04 | 53.94 | 2.32 | 0.04 | 0.09 | 0.00 | 41.79 |
| | C1.4 | 0.84 | 0.70 | 0.23 | 0.00 | 0.09 | 53.37 | 3.41 | 0.11 | 0.1 | 0.15 | 41.02 |
| | C1.5 | 1.44 | 0.59 | 0.34 | 0.07 | 0.00 | 52.77 | 3.56 | 0.14 | 0.23 | 0.00 | 40.72 |
| C2 | C2.1 | 10.49 | 4.38 | 2.62 | 0.02 | 0.03 | 36.09 | 12.53 | 0.36 | 0.59 | 0.00 | 32.88 |
| | C2.2 | 0.13 | 1.03 | 0.14 | 0.04 | 0.01 | 53.12 | 3.27 | 0.15 | 0.29 | 0.00 | 41.74 |
| | C2.3 | 0.69 | 1.31 | 0.25 | 0.00 | 0.02 | 53.36 | 2.43 | 0.29 | 0.11 | 0.00 | 41.49 |
| | C2.4 | 0.98 | 0.68 | 0.26 | 0.00 | 0.00 | 53.28 | 2.78 | 0.13 | 0.22 | 0.00 | 41.63 |
| | C2.5 | 1.23 | 0.98 | 3.55 | 0.13 | 0.02 | 51.65 | 2.54 | 0.05 | 0.18 | 0.00 | 39.64 |
| C3 | C3.1 | 1.19 | 1.20 | 0.18 | 0.09 | 0.04 | 52.84 | 2.88 | 0.24 | 0.14 | 0.00 | 41.18 |
| | C3.2 | 0.73 | 1.68 | 0.25 | 0.06 | 0.03 | 52.29 | 2.83 | 0.23 | 0.12 | 0.13 | 41.62 |
| | C3.3 | 1.66 | 1.53 | 0.32 | 0.00 | 0.00 | 52.78 | 2.63 | 0.16 | 0.04 | 0.00 | 40.79 |
| | C3.4 | 0.78 | 1.31 | 0.16 | 0.11 | 0.00 | 52.61 | 2.19 | 0.36 | 0.29 | 0.00 | 42.17 |
| | C3.5 | 1.22 | 1.23 | 0.32 | 0.00 | 0.05 | 53.23 | 2.22 | 0.11 | 0.02 | 0.00 | 41.61 |
| C4 | C4.1 | 0.64 | 0.54 | 1.21 | 0.12 | 0.06 | 52.89 | 2.53 | 0.22 | 0.2 | 0.00 | 41.53 |
| | C4.2 | 1.88 | 1.70 | 0.69 | 0.09 | 0.07 | 51.44 | 3.63 | 0.23 | 0.11 | 0.00 | 40.13 |
| | C4.3 | 1.13 | 1.12 | 1.15 | 0.00 | 0.02 | 51.85 | 2.65 | 0.12 | 0.18 | 0.12 | 41.53 |
| | C4.4 | 1.99 | 1.24 | 0.37 | 0.07 | 0.03 | 52.57 | 2.68 | 8.00 | 0.16 | 0.00 | 40.73 |
| | C4.5 | 1.61 | 0.48 | 2.69 | 0.08 | 0.00 | 51.47 | 2.79 | 0.22 | 0.31 | 0.0 | 40.28 |
| **Average** | | **1.53** | **1.16** | **0.76** | **0.08** | **0.04** | **51.93** | **3.28** | **0.11** | **0.19** | **0.14** | **40.78** |

The results showed that the most abundant constituent of marble dust was $CaCO_3$. Average calcium oxide (CaO) concentration was found to be 51.93%, while average loss on ignition (LOI) is around 40.78%. CaO value ranged 36.09-53.94% while loss on ignition was 32.88-42.17%. Besides calcium oxide and loss on ignition as major constituents small amounts of other elements like MgO (>3%), $SiO_2$ (>1%), $Al_2O_3$ (>1) and $Fe_2O_3$ (>0.5%) are also present. Silica as SiO2 is present in the range of (0.13-10.49%), $Al_2O_3$ (0.16-4.38%), $Fe_2O_3$ (0.13-3.55%), MgO (2.19-12.53%), $Na_2O$

(0.04-0.36%), $K_2O$ (0.04-0.59%), $P_2O_5$ (0.02-0.13%), $TiO_2$ (0.01-0.09%) and $SO_3$ (0.12-0.16%). Higher value of silica, aluminum and iron in some of the samples, especially in sample mentioned above could be due to the grit in the cutting procedure as abrasive material or cutting of granite besides marble by a particular industry. As presented in Table 4.28 negligible amount of trace elements like lead, chromium, manganese, copper, nickel and zinc are also present in some marble slurry samples.

**Table 4.2.5: Chemical characteristics (minor constituents %) of Marble slurry waste collected from different marble industries**

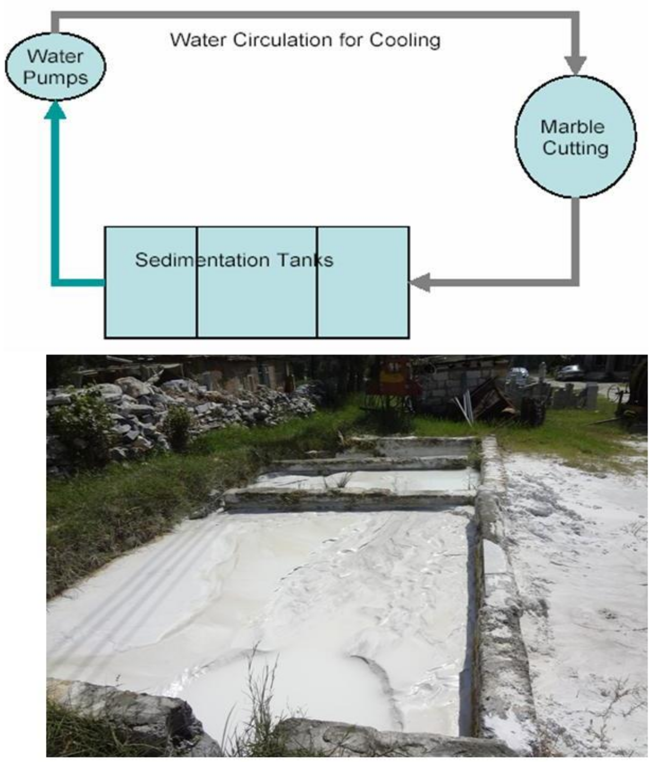
| Category | Sample ID | Minor Constituents Percentage | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Pb** | **Cr** | **Mn** | **Ni** | **Cu** | **Zn** |
| C1 | C1.1 | 0.00 | 0.06 | 0.00 | 0.03 | 0.00 | 0.00 |
| | C1.2 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 |
| | C1.3 | 0.10 | 0.00 | 0.05 | 0.00 | 0.00 | 0.03 |
| | C1.4 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 |
| | C1.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2 | C2.1 | 0.31 | 0.02 | 0.54 | 0.00 | 0.02 | 0.01 |
| | C2.2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | C2.3 | 0.02 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| | C2.4 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| | C2.5 | 0.32 | 0.03 | 0.56 | 0.03 | 0.03 | 0.13 |
| C3 | C3.1 | 0.01 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| | C3.2 | 0.00 | 0.05 | 0.00 | 0.02 | 0.00 | 0.00 |
| | C3.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | C3.4 | 0.00 | 0.04 | 0.00 | 0.00 | 0.03 | 0.11 |
| | C3.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C4 | C4.1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | C4.2 | 0.33 | 0.02 | 0.38 | 0.00 | 0.01 | 0.00 |
| | C4.3 | 0.29 | 0.04 | 0.47 | 0.00 | 0.05 | 0.00 |
| | C4.4 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 |
| | C4.5 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| **Average** | | 0.069 | 0.013 | 0.103 | 0.009 | 0.007 | 0.014 |

Lead as Pb is present in the range of (0.01-0.33ppm), Chromium as Cr (0.02-0.06ppm), Manganese as Mn (0.01-0.56ppm), Nickel as Ni (0.01-0.03ppm), Copper as Cu (0.01-0.05ppm) and Zinc as Zn (0.01-0.13ppm).

### 4.2.2 Slurry Recovery Design

Marble cutting and processing generate large amount of slurry waste containing water and marble dust. The water is used mainly for the cooling of cutting blades and to catch the dust formed during cutting. (Torres et al., 2004, Hernandez and Rincon 2001). To overcome on this, construction of sedimentation tank is obligatory under Pakistan environmental regulation-2004.

**Figure 4.2.1: Existing Schematic water reuse system**




This part of the study was carried out to know about the performance of existing treatment facility for marble wastewater.

The existing one way water reuse system is consisting of three sub-tanks (Figure 4.2.1). This slurry is stored in the sedimentation tanks, where the sediments settles and water reuse. These not only remove marble particles but also ensure the reuse of wastewater in MPU and decrease the pressure on already scarce fresh water resources. The life of this water reuse system is finished when these sedimentation tanks filled with marble sludge. Because once the sedimentation tanks are filled from marble sludge it is not cleanup by the owners. It is due lack of awareness regarding this beneficial byproduct and unavailability of easiest and economical cleaning methodology. If the Environmental Protection Agency (EPA) officials get visit of the site the owners shows them these tanks as a proof of compliances and mitigation measures for minimizing pollution load and water consumption.

The study confirmed that the performance of treatment facility in reducing pollution was not satisfactory. The physico-chemical nature of the effluent discharged showed that some parameters showed high concentration than their respective allowable limits. Physical parameters specifically the average TSS values were found beyond the limits of Pak NEQS. Therefore laboratory scale treatment was applied on effluents of MPUs with main focus on TSS parameter which was violating the Pak NEQS.

Wastewater analysis results showed that all of the parameters were in the allowable limits of National Environmental Quality Standards (NEQS) except TSS values (Table 4.2.6).

**Table 4.2.6: Results of Wastewater before sedimentation**

| S. No | Parameters | Min | Max | Average | NEQS |
|---|---|---|---|---|---|
| 1 | pH | 6.9 | 7.2 | 7.05 | 6-10 |
| 2 | TSS | 19110 | 29000.00 | 24055 | 150 |
| 3 | TDS | 298.00 | 450.00 | 374 | 3500 |
| 4 | BOD | 45.00 | 67.00 | 56 | 80 |
| 5 | COD | 110.00 | 140.00 | 125 | 150 |
| 6 | Copper | 1.08 | 1.20 | 1.14 | 1.00 |
| 7 | Chromium | 0.02 | 0.11 | 0.065 | 1.00 |
| 8 | Manganese | 0.11 | 0.25 | 0.18 | 1.5 |
| 9 | Nickel | 0.09 | 0.12 | 0.105 | 1.0 |

Note: All results are in mg/L except pH

The analytical work revealed that the effluents are carrying heavy load of pollution in the form of Suspended Solids and violates the limit of Pak NEQS. The average TSS value was found to be in the range of 1910-3900 mg/L with an average of 2905 mg/L. The high TSS content clearly indicates the poor performance of the installed treatment facility in removing suspended load from MPUs effluents.

Generally, the suspended solids are small in size and have large surface area in relation to their weight. In water the suspended materials offer adsorption sites for chemical and biological agents and in addition to that water which has high suspended load will have increase turbidity and low clarity (**Peavey, 1985**).

The overall results for heavy metals were within permissible limit set in Pak NEQS but the role of existing treatment facility in further removing the heavy metal ions from the effluents are unsatisfactory. Almost all of the heavy metals are toxic but some are extremely dangerous even if their concentration is low like arsenic, chromium, lead and mercury. These metals are very toxic poses a threat to the marine life and canbio accumulate in food chain **(Manahan, 1994).** After characterization of MPUs effluents, parameters found above the permissible limit were subject to laboratory treatment.

**Physical treatment:** After Physical treatment, the TSS value of the effluent samples showed decrease in suspended solids. The average level of TSS decreased from 24055 to 77.5 mg/L (99.6%). Similarly, average BOD and COD were also decreased by 94% in simple retention time. The quality comparison of parameters of fresh ground water and recycled wastewater after sedimentation is given in Table 4.2.7. The results of both fresh and wastewater after sedimentation shows not any significant difference and was fit for reuse and cooling purposes.

**Table 4.2.7: Results of fresh and reuse water after sedimentation**

| S. No | Parameters | Fresh cooling Water | | | Re-use cooling water | | | NEQS |
|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Avg | Min | Max | Avg | |
| 1 | pH | 6.9 | 7.2 | 7.05 | 7.5 | 7.9 | 7.70 | 6-10 |
| 2 | TSS | 0.00 | 0.00 | 0.00 | 65.00 | 90.00 | 77.50 | 150 |
| 3 | TDS | 98.00 | 150.00 | 124.00 | 115.00 | 175.00 | 145.00 | 3500 |
| 4 | BOD | 00.00 | 01.00 | 0.50 | 01.00 | 05.00 | 3.00 | 80 |
| 5 | COD | 0.00 | 0.00 | 0.00 | 2.50 | 11.50 | 7.00 | 150 |
| 6 | Copper | 0.82 | 0.91 | 0.865 | 1.00 | 1.20 | 1.10 | 1.00 |
| 7 | Chromium | 0.01 | 0.03 | 0.02 | 0.01 | 0.11 | 0.06 | 1.00 |
| 8 | Manganese | 0.08 | 0.09 | 0.085 | 0.12 | 0.25 | 0.18 | 1.5 |
| 9 | Nickel | 0.03 | 0.08 | 0.055 | 0.09 | 0.12 | 0.10 | 1.0 |

Note: All results are in mg/L except pH

Normally sedimentation is carried out to get rid of those suspended particles which have high specific gravity than water and so can be settled. In running water, the particles remain suspended but when the water speed decreases, the particle in suspension tends to settle down (Gaur, 2008).

**Design Modification:** It was recommended that collects the marble sludge from these tanks of the individuals units and store it in a common storage depot. After which it is sent to those industrial units where it can utilize in secondary useful product. This will not be accomplished without upgrading and modification of existing sedimentation tanks. In the upgraded design of water reuse system, the sedimentation tanks will be equipped with high pressure marble sludge suction pump, an assembly of collecting ducts, supplemented with a network of segregation valves and a filter press (Figure 4.2.2). In this design the facility of segregation of different particle size was also included. The Marble sludge will be sucked by a powerful sludge suction pump through assembly of collecting ducts after sedimentation. Then it will be passed to filter press for dewatering and long term storage in the form of cakes. After the removal of these ultrafine marble dust particles the clarified water from the sedimentation tanks and filter press reuse again in the process.

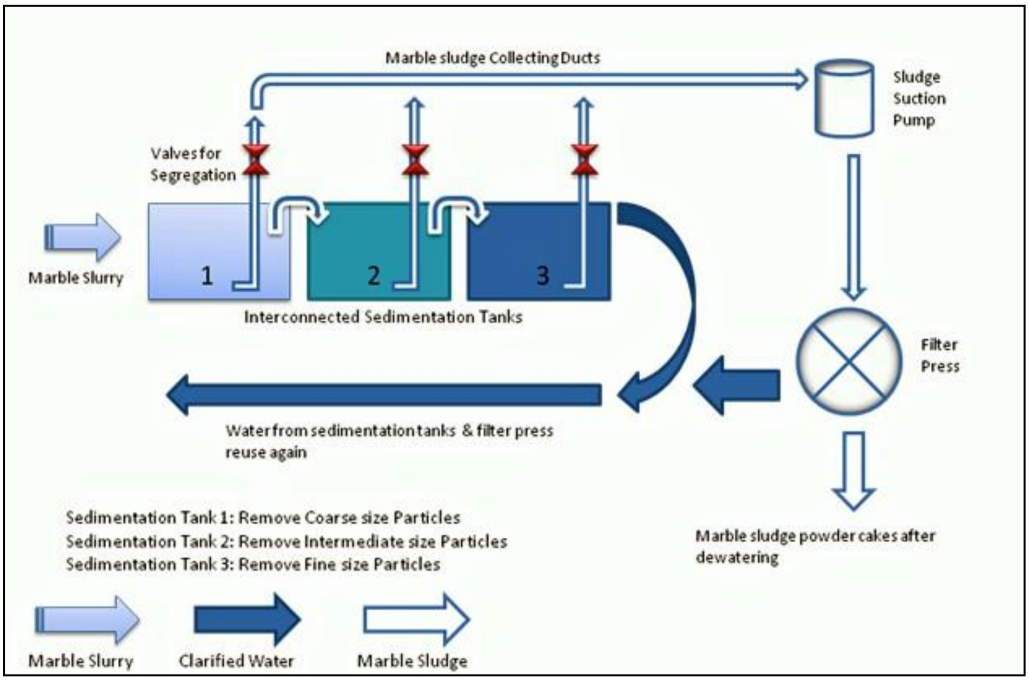



**Figure 4.2.2: Schematic Diagram of Modified Wastewater Reuse System for MPUs**

Chemical analysis of Marble slurry powder showed $CaCO_3$ (>90%) as the major constituent main bulk of $CaCO_3$, and small amounts of $SiO_2$ (<2%), MgO and $Fe_2O_3$ (<3%) as indicated in the Table 4.2.4. which show its high compatibility to use in the manufacturing of other secondary useful products.

### 4.2.3 Test Results of Value added Product prepared from marble slurry

#### 4.2.3.1 Cement

**Physical Properties:** Physical properties of both types of specimens CEM-I and CEM-II reported in Table 4.2.8. Physical properties include setting time, volume expansion, density and sieve analysis. The cement paste setting time are categorized into initial and final setting time. Initial setting time is the approximate time at which the fresh cement paste begin to stiffen, while final setting time indicates the approximate time at which the cement paste has hardened and can support load. Generally average initial settling time for a cement used for construction purpose are between 60-240 minutes, while for final settling the range is 180-360 minutes and the volume expansion of commercial cement should not be more the 0.8% of the volume of tested specimen.

**Table 4.2.8: Physical Characteristics of commercial grade Portland cement (CEM I) and Cement prepared from marble slurry waste (CEM II)**

| S. No | Properties | CEM- I | CEM –II | Pakistan Standards (PS-232-1983-R) |
|---|---|---|---|---|
| 1 | Initial setting (min) | 90-120 | 110-140 | Not below 45 |
| 2 | Final setting (min) | 300-360 | 320-380 | Not above 600 |
| 3 | Volume expansion (mm) | 0.800-1.00 | 0.60-1.00 | 10 |
| 4 | Density (g/cm3) | 2.900-3.200 | 3.00-3.200 | -- |
| 5 | **Sieve analysis (passing %)** | | | |
| | Particle size 100µm | 100 | 100 | 72 µm<br>'or' 225$m^2$/kg 'or'<br>2250 $cm^2$/g |
| | Particle size 75µm | 94 | 85 | |
| | Particle size 50µm | 88 | 80 | |
| | Particle size 25µm | 65 | 58 | |
| | Particle size 15µm | 60 | 55 | |
| | Particle size < 5µm | 20 | 25 | |

The results of both types of cement pastes were satisfactory and the results of CEM -II initial and final settling time were show less difference as compare to CEM- I results. The soundness or volume expansion is an important test of cement physical quality assessment. The volume expansion of the cement dominate over the attractive crystallization forces as a results of which no hardening takes place or the hardening effect of cement decreases (Holland eta al., 2001; Estrela et al., 2000). The results of volume expansion for both types of cements were 1mm which is less than the standards maximum allowable value of 0.8%. Density and average particle size results for both types of cement were marginally different. Particles size distribution shows 100% passing of both specimens from 100µm sieve (Fig: 4.2.3).

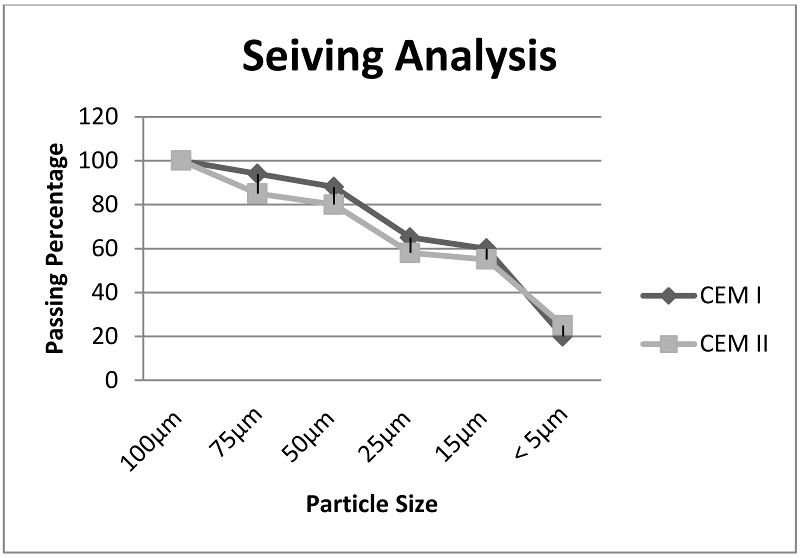



**Figure 4.2.3: Average particle size of CEM I and CEM II**

**Chemical Properties:** The results of chemical parameters were showed less significant difference from each other except slight change in silica contents, iron oxide and loss on ignition (Table 4.2.9). According to ASTM and ACI cement standards Magnesium oxide should be present in Commercial cement up to 6%, loss on ignition 3% and alkalis ($Na_2O$, $K_2O$) 0.6%.

**Table 4.2.9: Chemical characteristics of ordinary commercial Portland cement (CEM I) and cement (CEMII) prepared from marble slurry (WEIGHT %)**

| Parameters | CEM-I | | | CEM-II | | | |
|---|---|---|---|---|---|---|---|
| | Min | Max | Average | Min | Max | Average | Standards |
| $SiO_2$ | 23.2 | 23.9 | 23.6±0.2 | 20.0 | 20.3 | 20.2±0.1 | 23.5-25.5* |
| $Al_2O_3$ | 5.6 | 7.0 | 6.3±0.5 | 5.4 | 7.2 | 6.3±0.6 | 8.0-9.0* |
| $Fe_2O_3$ | 0.3 | 3.5 | 1.9±1.1 | 2.1 | 5.5 | 3.8±1.1 | 3.0-4.0* |
| CaO | 58.1 | 68.2 | 63.2±3.4 | 56.5 | 69.8 | 63.2±4.5 | -- |
| MgO | 1.5 | 2.1 | 1.8±0.2 | 1.7 | 1.8 | 1.8±0.0 | 4.0-6.0** |
| $K_2O$ | 0.5 | 1.1 | 0.8±0.2 | 0.9 | 1.0 | 1.0±0.0 | 0.75* |
| $Na_2O$ | 0.2 | 0.2 | 0.2±0.0 | 0.1 | 0.5 | 0.3±0.1 | 0.75* |
| $SO_3$ | 0.5 | 1.5 | 1.0±0.3 | 0.6 | 1.6 | 1.1±0.3 | 3.25** |
| Free Lime | 0.8 | 1.0 | 0.91±0.5 | 1.0 | 1.2 | 1.1±0.3 | 1.5* |
| LoI | 4.5 | 5.5 | 5.0±0.3 | 5.4 | 6.0 | 5.7±0.2 | 3-4** |

**Pakistan Standards PS:232 – 1983 (R)
* British Standards BS:12-1996

**Mechanical Properties**

**Water absorption capacity:** Water absorption capacity test was done for the determination for pore structure of concrete specimens to check the durability of both types of cements. With the help of water absorption capacity test of the concrete gives the reachable volume of total pores capacity of the hardened concrete. Water absorption capacity also investigate the apparent porosity increase in porosity means decrease in the quality of concrete materials or more porosity weaker concrete (Mukherjee et al., 2011*)*. Water absorption capacity of concrete depends upon the types of aggregates used in the concrete mixture. If coarse aggregates will be used the water absorption capacity increases due to formation of high pores spaces as compare to fine aggregates concrete mixture (Table 4.2.10). The water absorption capacity of 30 minutes emersion concrete should be <3% for low, 3-4% for average and >4% for high absorption concrete (Basheer 2001).

**Table 4.2.10: Curing age and Composition wise water absorption capacity of Concrete cylindrical block made of CEM I & CEM II concrete cement mixtures**

| Specimen | Sand (%) | Gravel (%) | Cement (%) | Curing period (days) | Water Absorption Capacity (%) | |
|---|---|---|---|---|---|---|
| | | | | | CEM I | CEM II |
| 1 | 10 | 10 | 80 | 7 | 05 | 06 |
| | | | | 14 | 4.5 | 05 |
| | | | | 21 | 04 | 4.5 |
| | | | | 28 | 03 | 04 |
| | | | | | | |
| 2 | 20 | 20 | 60 | 7 | 5.5 | 06 |
| | | | | 14 | 05 | 05 |
| | | | | 21 | 05 | 5.5 |
| | | | | 28 | 4.5 | 5.5 |
| | | | | | | |
| 3 | 30 | 30 | 40 | 7 | 6.0 | 7.0 |
| | | | | 14 | 5.5 | 6.5 |
| | | | | 21 | 4.0 | 4.0 |
| | | | | 28 | 3.8 | 4.0 |
| | | | | | | |
| 4 | 40 | 40 | 20 | 7 | 7.0 | 7.0 |
| | | | | 14 | 6.8 | 7.0 |
| | | | | 21 | 6.5 | 6.5 |
| | | | | 28 | 6.0 | 6.5 |

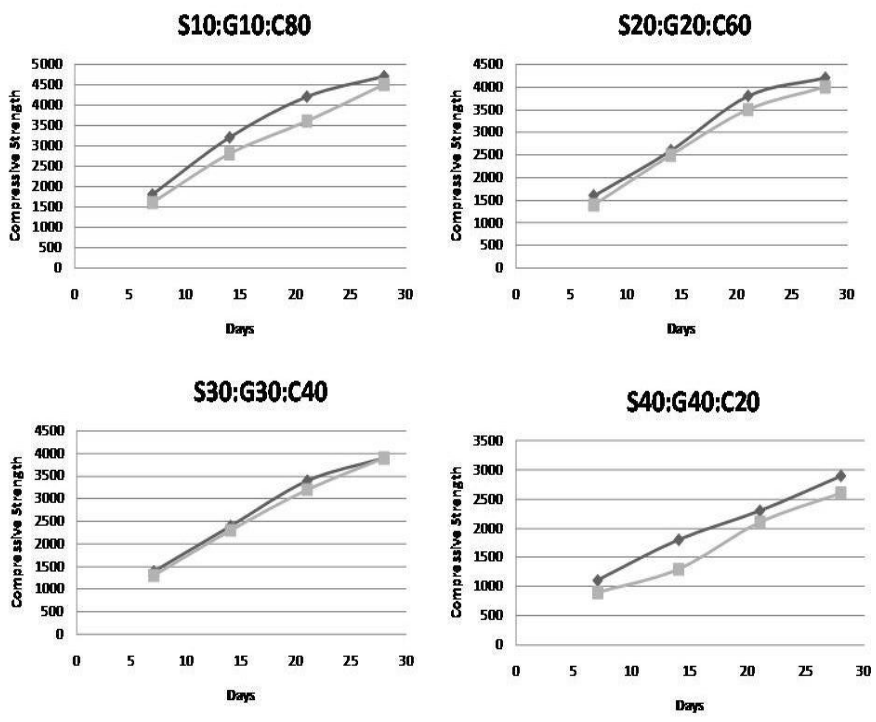
**Compressive Strength:** The cylindrical specimens were made and tested for 7, 14, 21 and 28 days of curing age strength. Compressive strength requirement for concrete are 2500 psi for residential purposes and 4000 psi to higher in commercial structures *(NRMCA 2003)*. Compressive test results of specimens 1,2 and 3 showed excellent strength as compare to Pakistan PS:232 – 1983 (R) standards for concrete quality which is 2800 psi (Table 4.2.11 & Fig: 4.2.4).

**Table 4.2.11: Curing age and Composition wise Compressive strength of Concrete cylindrical block made of CEM I & CEM II concrete cement mixtures**

| Specimens | Sand (%) | Gravel (%) | Cement (%) | Curing period (days) | Compressive strength (psi) | |
|---|---|---|---|---|---|---|
| | | | | | CEM I | CEM II |
| 1 | 10 | 10 | 80 | 7 | 1800 | 1600 |
| | | | | 14 | 3200 | 2800 |
| | | | | 21 | 4200 | 3600 |
| | | | | 28 | 4700 | 4500 |
| | | | | | | |
| 2 | 20 | 20 | 60 | 7 | 1600 | 1400 |
| | | | | 14 | 2600 | 2500 |
| | | | | 21 | 3800 | 3500 |
| | | | | 28 | 4200 | 4000 |
| | | | | | | |
| 3 | 30 | 30 | 40 | 7 | 1400 | 1300 |
| | | | | 14 | 2400 | 2300 |
| | | | | 21 | 3400 | 3200 |
| | | | | 28 | 3900 | 3900 |
| | | | | | | |
| 4 | 40 | 40 | 20 | 7 | 1100 | 900 |
| | | | | 14 | 1800 | 1300 |
| | | | | 21 | 2300 | 2100 |
| | | | | 28 | 2900 | 2600 |
| Note: According to Pakistan PS:232 – 1983 (R) section 6.3 standards for concrete cubes quality, at 28$^{th}$ day the compressive test should not less than 2800 PSI | | | | | | |

Compressive strength was also graphically presented to shows the trend of compressive strength for different concrete specimens made by both types of cements (Fig: 4.8). All the four types of tested specimens showed good compressive strength results in different curing ages. At the SGC ratio 30:30:40, same compressive strength was recorded on the 28th day. It is suggested that the specimen number 1 and 2 would be used for high commercial structures construction while specimen 3 and 4 are suitable for residential purposes.

**Figure 4.2.4:** Curing age and Composition wise Compressive strength of both types of cement concrete




CEM I ◆ CEM II ■
S=Sand, G=Gravel, C=Cement

#### 4.2.3.2 Dish washing powder

Sieve test of dried marble slurry and dish washing powder (formulations and sample collected from the market) revealed that particles size of all powder were less than 2.00 mm. A slight difference of 4-2% and 5-10% in particle size was observed when passed through 0.3 and 0.075 mm sieve respectively. This showed that the marble slurry needs no extra treatment in terms of grinding and can be used directly for preparation of dishwashing powder (Table 4.2.12).

**Table 4.2.12: Sieve Analysis for the Determination of Particle Size of dish washing powder made from marble slurry and dish washing powder available in market**

| S. No | Sieve size (mm) | Average Passing %age | | |
|---|---|---|---|---|
| | | Dried Marble Slurry | Dish washing powder made from Marble slurry | Dish washing Powder available in the market |
| 1 | 2.00 | 100.00 | 100.00 | 100.00 |
| 2 | 0.60 | 99.00 | 99.00 | 99.00 |
| 3 | 0.30 | 96.00 | 96.00 | 98.00 |
| 4 | 0.075 | 95.00 | 90.00 | 94.00 |

Chemical analysis shows that marble slurry consist of 97% calcium carbonate (CaO=45, LoI=45%). Rest of which is consists of silica contents, 2.87% and fractions of iron oxide, 0.02%, aluminum oxide 0.01%, and magnesium oxide , 0.05% (Table 5). Loss on ignition (LoI) at 950 ºC shows that about 45% Marble Slurry contents was converted into $CO_2$. All of the investigated heavy metals found bellow the detection limit of instrument 0.001 ppm (Table 4.2.13).

Presence of heavy metals or any hazardous agent is objectionable and the secondary use is generally not recommended. As all the laboratory test conducted for such metals was within the permissible limit and the marble slurry dust qualifies for the preparation of dish washing powder.

**Table 4.2.13: Percentage chemical composition of Dried Marble Slurry used in the preparation of Dish Washing Powder**

| S.NO | Chemical Analysis | Results (%) |
|---|---|---|
| 1 | $SiO_2$ | 02.87 |
| 2 | $Al_2O_3$ | 00.01 |
| 3 | $Fe_2 O_3$ | 00.02 |
| 4 | Mg O | 00.05 |
| 5 | Ca O | 52.00 |
| 6 | LoI | 45.00 |
| 7 | Cd | BDL |
| 8 | Mn | BDL |
| 9 | Cr | BDL |
| 10 | Ni | BDL |

BDL=Bellow Detection Limit

Mean values of household survey scores was considered after recording responses from five households against each set criteria to shows the results. Results of household evaluation to check the applicability of marble slurry in dish washing powder. Among all formulation Type II dish washing powder having good response as compare to commercial dish washing powder (Table 4.2.14).

**Table 4.2.14: Household survey Percent Weight-age results for Dish washing powder Product Evaluation**

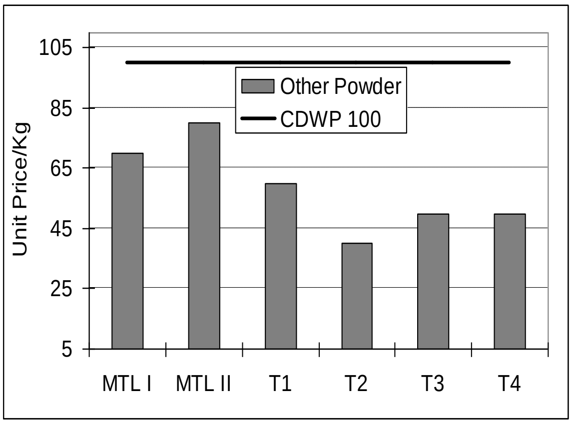
| Formulation | Skin Friendly | Clean Efficiently | Rinse Easily | Unit Price | Total Points |
|---|---|---|---|---|---|
| MTL I | 21.60 | 15.20 | 16.00 | 12.00 | 64.80 |
| MTL II | 22.80 | 14.40 | 16.00 | 18.00 | 71.20 |
| T1 | 15.60 | 12.80 | 15.20 | 24.00 | 67.60 |
| T2 | 26.40 | 19.20 | 19.20 | 24.00 | 88.88 |
| T3 | 16.80 | 16.00 | 13.60 | 24.00 | 70.40 |
| T4 | 19.20 | 15.20 | 15.20 | 24.00 | 73.60 |
| CDWP | 27.60 | 16.80 | 17.60 | 6.00 | 68.00 |

Consumers' response for skin friendly criterion was recorded after using it for the 5th time each dish washing powder. Results showed that CDWP, MTL I, MTL II and TII have 27.6, 21.6, 22.8 and 26.4 percent weight-age respectively out of whole 30 percent weight-age. Skin problems were observed in T1, T3 and T4 dish washing powders. These include slippery skin, skin breakage, skin itching, and rashes. These problems are caused due to the additives.

The assessment in the account of easy to rinse criteria revealed that the CDWP and T2 dish washing powders shows highest percent weight-age 17.6 and 19.2 respectively out of the total 20 percent weight-age, as compared to others competent dish washing powders in the consumers response survey. In the survey, question was asked from the consumers that in which wash the washing powder rinse completely from dish.

The criterion for cleaning efficiency showed good response for CDWP and T2 among all formulation. The percent weight-age obtained by CDWP and T2 were 16.8 and 19.2 respectively out of total 20 percent weight-age, which was higher than the others. Respondents were asked about their satisfaction from the cleaning ability of tested dish washing powder.

**Figure 4.2.5: Comparison of Unit price per Kg of Dish Washing Powders**




Unit price criterion in term of consumer's economics was evaluated without respondents' participation. It was assessed by calculating the cost of ingredients used in the preparation of a known quantity unit (Kg) of dish washing powders. Results showed that Type II dish washing powder has 60% less cost than CDWP available in the market. It was due the high amount of marble slurry utilization than the raw materials. By reducing the amount of raw materials the cost of product was also reduced (Fig: 4.2.5).

The consumer response towards T2 composition was due to the formation of sodium salt of linear alkyl-benzene sulfunic acid (Na-LAS). Sodium salt of alkyl-benzene sulfunic acid (Na-LAS) is formed by the neutralization of linear alkyl-benzene sulfunic acid (H-LAS) with sodium carbonate (Equation2). Because sodium salt of alkyl-benzene sulfunic acid (Na-LAS) is the most common surfactant used in the detergernt manufacturing. According to soap and detergent association the exposure percentage of LAS composition in dishwashing detergent should be in the range of 5-30% (Organization of Existing Chemcials Database, 2005). It has earned its popularity due to its eco-friendly nature and easy biodegradability once released to waste water and high washing, Na-LAS can be found in many cleaning products like dish washing powders and washing pellets. According to Unilever's group of companies , the fine particles of calcium carbonate, preferably calcite, used as crystallization seed to enhance the efficiency of sodium carbonate as a builder matrix in dish washing detergent powder (Gregorius et al., 1987).

The chemical reaction is called dry neutralization and its stoichiometric equation can be written as follows:

$$\mathbf{2H\text{-}LAS\ (l) + Na_2CO_3\ (s) \rightarrow 2Na\text{-}LAS\ (s) + CO_2\ (g) + H_2O\ (l)}$$

It was concluded that dish washing powder prepared from 50% marble stone slurry, 20% soda ash, 20% sulfunic acid and 10% soap stone was good and user friendly. By doing so, impact of marble industry on environment can be minimized and is strongly recommended.

#### 4.2.3.3 Glass Fiber Reinforce Mortar

In this study glass fiber has been used for the preparation of masonry mortar and after preparation investigated the effect on compressive, split tensile and flexural strength on different mix proportions. Ordinary mortar without using glass fiber was compared as a control. Portland cement and sand used in mix proportions were tested for their chemical composition and the results are presented in Table 4.2.15 and 4.2.16.

**Table 4.2.15: Percent composition of Portland cement contents used in Mortar Cubes**

| **Parameters** | **Percentage** |
|---|---|
| Silica ($SiO_2$) | 19.99 |
| Iron ($Fe_2O_3$) | 05.38 |
| Aluminum ($Al_2O_3$) | 08.40 |
| Calcium ($CaO$) | 57.81 |
| Magnesium ($MgO$) | 02.52 |
| Sodium ($Na_2O$) | 01.95 |
| Potassium ($K_2O$) | 01.85 |
| Sulphate ($SO_3$) | 00.48 |
| Loss on Ignition | 01.53 |
| Total | 99.91 |

The chemical composition of ordinary Portland cement was compared with ASTM C150, which was found to be within limits.

Marble slurry powder used as major constituent and other raw materials like glass fibers, binders, sand were used as minor constituents. Chemical analysis of marble slurry powder were carried out using XRF which results are discussed in detailed in chapter 3.

**Table 4.2.16: Percent Chemical composition of sand used in the preparation of Mortar Cubes**

| **Parameters** | **Percentage** |
|---|---|
| Silica ($SiO_2$) | 67.62 |
| Iron Oxide($Fe_2O_3$) | 05.58 |
| Aluminum Oxide ($Al_2O_3$) | 15.43 |
| Calcium Oxide (CaO) | 03.25 |
| Magnesium Oxide (MgO) | 02.83 |
| Sodium Oxide ($Na_2O$) | 01.03 |
| Potassium Oxide ($K_2O$) | 00.92 |
| Sulphate ($SO_3$) | 00.08 |
| Loss on Ignition | 03.25 |
| Total | 99.99 |

**Compressive strength:** The results of compressive strength obtained were presented in Tables 8.5-8.6. Considering the binary mixtures without GF it was observed that there was a systematic reduction in compressive strength of mortar as MSD was used (10, 20,30,40,50 %). On the contrary, the mixtures with GF showed a distinguishable increase in the compressive strength values at 28 day. The highest compressive strength of 4337.96 psi was obtained for the control composition without marble dust with glass fibers as a reinforcement agent. The specimen having 10% MSD showed highest compressive strength of 4255.26 psi which was closest to compressive strength value of control specimen (Table 4.2.17).

**Table 4.2.17: Effect of curing time on the compressive strength of specimens prepared from marble slurry dust, Portland cement sand and glass fibers**

| sample ID | Sample No. | Compressive Strength (psi) | | | |
|---|---|---|---|---|---|
| | | **3 days** | **7 days** | **14 days** | **28 days** |
| PC(S)GF | 1 | 1099.75 | 2850.15 | 3019.48 | 4334.04 |
| | 2 | 1087.64 | 2841.02 | 3023.54 | 4348.2 |
| | 3 | 1085.37 | 2856.99 | 3033.88 | 4331.63 |
| | **Avg** | **1090.92** | **2849.39** | **3025.63** | **4337.96** |
| PC(MSD50)GF | 1 | 563.67 | 1015.21 | 1365.56 | 2215.26 |
| | 2 | 569.91 | 1021.72 | 1356.85 | 2201.77 |
| | 3 | 575.04 | 1026.39 | 1359.12 | 2200.09 |
| | **Avg** | **569.54** | **1021.11** | **1360.51** | **2205.71** |
| PC(MSD40)GF | 1 | 618.23 | 1258.04 | 1488.46 | 2581.23 |
| | 2 | 623.76 | 1253.84 | 1480.32 | 2572.15 |
| | 3 | 634.94 | 1245.11 | 1475.07 | 2570.27 |
| | **Avg** | **625.64** | **1252.33** | **1481.28** | **2574.55** |
| PC(MSD30)GF | 1 | 818.69 | 1705.89 | 2020.44 | 3333.43 |
| | 2 | 843.29 | 1715.92 | 2015.73 | 3318.56 |
| | 3 | 831.1 | 1719.01 | 2013.22 | 3325.91 |
| | **Avg** | **831.02** | **1713.6** | **2016.46** | **3325.97** |
| PC(MSD20)GF | 1 | 905.81 | 2030.34 | 2430.64 | 3930.71 |
| | 2 | 914.28 | 2035.39 | 2433.37 | 3915.82 |
| | 3 | 918.88 | 2038.29 | 2428.29 | 3932.76 |
| | **Avg** | **912.99** | **2034.33** | **2430.77** | **3926.43** |
| PC(MSD10)GF | 1 | 1030.19 | 2431.16 | 2789.26 | 4265.32 |
| | 2 | 1022.2 | 2425.27 | 2769.18 | 4245.28 |
| | 3 | 1033.62 | 2423.87 | 2773.62 | 4255.19 |
| | **Avg** | **1028.67** | **2426.76** | **2777.35** | **4255.26** |

Mortar specimens with MSD without GF had lower compressive strengths than the control mortar specimens containing only sand. The same tendency was observed in mortar specimens with GF, however, the ranges of the compressive strength values were higher than that of specimens without GF (Table 4.2.18).

**Table 4.2.18: Effect of curing time on the compressive strength of specimens prepared from marble slurry dust, Portland cement and Sand without glass fibers**

| sample ID | Sample No. | Compressive Strength (psi) | | | |
|---|---|---|---|---|---|
| | | **3 days** | **7 days** | **14 days** | **28 days** |
| PC(S) | 1 | 1021.67 | 2418.46 | 2767.93 | 3798.65 |
| | 2 | 1022.56 | 2424.09 | 2772.3 | 3815.56 |
| | 3 | 1033.94 | 2439.43 | 2778.9 | 3791.55 |
| | **Avg** | **1026.06** | **2427.33** | **2773.04** | **3801.92** |
| PC(MSD50)S | 1 | 510.36 | 963.83 | 1259.2 | 1780.67 |
| | 2 | 518.46 | 984.92 | 1267.81 | 1775.45 |
| | 3 | 520.89 | 971.8 | 1265.62 | 1778.76 |
| | **Avg** | **516.57** | **973.51** | **1264.21** | **1778.29** |
| PC(MSD40)S | 1 | 584.12 | 1149.12 | 1368.38 | 2130.34 |
| | 2 | 570.24 | 1157.23 | 1372.37 | 2134.23 |
| | 3 | 573.26 | 1153.45 | 1378.11 | 2138.12 |
| | **Avg** | **575.87** | **1153.27** | **1372.95** | **2134.23** |
| PC(MSD30)S | 1 | 759.87 | 1630.33 | 1950.49 | 2690.55 |
| | 2 | 764.98 | 1635.75 | 1944.29 | 2686.84 |
| | 3 | 762.58 | 1622.88 | 1953.16 | 2682.47 |
| | **Avg** | **762.47** | **1629.65** | **1949.31** | **2686.62** |
| PC(MSD20)S | 1 | 855.49 | 1987.19 | 2263.28 | 3240.84 |
| | 2 | 857.53 | 1981.92 | 2268.43 | 3235.65 |
| | 3 | 859.21 | 1983.61 | 2260.37 | 3243.11 |
| | **Avg** | **857.41** | **1984.25** | **2264.03** | **3239.87** |
| PC(MSD10)S | 1 | 990.27 | 2236.09 | 2418.43 | 3625.14 |
| | 2 | 1035.76 | 2241.87 | 2424.76 | 3628.82 |
| | 3 | 1004.87 | 2245.35 | 2429.58 | 3635.39 |
| | **Avg** | **1010.3** | **2241.1** | **2424.26** | **3629.78** |

**Flexural strength:** Flexural strength of the specimens of given dimensions (9″length, 3″width and 1″thickness) were determined according to ASTM C78. All of the specimens with and without GF qualify the minimum standards for all types of mortars (N,S,M,O) as per ASTM C1329. But it was noted that significant impact on flexural strength using glass fiber as reinforce was observed. The results presented and discussed enable us to conclude that the flexural strength of test mortar specimen was higher than ASTM requirement with the replacement of 10, 20 and 30% marble slurry dust along with glass fiber. Therefore, the study strongly recommends the use of marble dust in the manufacturing of general purpose masonry mortar. The results of this experimentation are illustrated in Tables (4.2.19 & 4.2.20). The results also indicated that high water cement/water powder ratio results in lower flexural strength.

**Table 4.2.19: Effect of curing time on the flexural strength of specimens prepared from marble slurry dust, Portland cement, sand and glass fibers**

| sample ID | Sample No. | Flexural Strength (psi) | | | |
|---|---|---|---|---|---|
| | | **3 days** | **7 days** | **14 days** | **28 days** |
| PC(S)GF | 1 | 335.08 | 822.08 | 891.62 | 1163.09 |
| | 2 | 338.76 | 832.81 | 895.18 | 1172.65 |
| | 3 | 229.34 | 829.34 | 905.63 | 1169.9 |
| | **Avg** | **301.06** | **828.07** | **897.47** | **1168.55** |
| PC(MSD50)GF | 1 | 101.32 | 346.01 | 367.23 | 595.85 |
| | 2 | 108.36 | 349.37 | 372.28 | 605.82 |
| | 3 | 105.55 | 353.48 | 363.51 | 607.46 |
| | **Avg** | **105.07** | **349.62** | **367.67** | **603.04** |
| PC(MSD40)GF | 1 | 158.63 | 392.12 | 493.82 | 763.95 |
| | 2 | 166.36 | 389.47 | 503.34 | 770.25 |
| | 3 | 162.85 | 398.75 | 508.56 | 772.18 |
| | **Avg** | **162.61** | **393.44** | **501.9** | **768.79** |
| PC(MSD30)GF | 1 | 202.12 | 551.21 | 623.24 | 882.61 |
| | 2 | 200.72 | 558.05 | 634.64 | 878.17 |
| | 3 | 201.38 | 549.15 | 632.48 | 875.47 |
| | **Avg** | **201.4** | **552.8** | **630.12** | **878.75** |
| PC(MSD20)GF | 1 | 245.19 | 635.37 | 729.11 | 963.53 |
| | 2 | 252.49 | 637.32 | 735.93 | 975.38 |
| | 3 | 243.53 | 645.71 | 738.79 | 960.17 |
| | **Avg** | **247.07** | **639.46** | **734.61** | **966.36** |
| PC(MSD10)GF | 1 | 293.68 | 790.55 | 885.12 | 1108.67 |
| | 2 | 301.38 | 801.21 | 878.48 | 1118.76 |
| | 3 | 298.45 | 794.38 | 889.62 | 1095.34 |
| | **Avg** | **297.83** | **795.38** | **884.4** | **1107.59** |

**Table 4.2.20: Effect of curing time on the flexural strength of specimens prepared from marble slurry dust, Portland cement and sand without glass fibers**

| sample ID | Sample No. | Flexural Strength (psi) | | | |
|---|---|---|---|---|---|
| | | **3 days** | **7 days** | **14 days** | **28 days** |
| PC(S) | 1 | 161.38 | 328.67 | 371.22 | 478.98 |
| | 2 | 158.74 | 319.76 | 367.17 | 470.36 |
| | 3 | 155.03 | 325.13 | 369.34 | 473.12 |
| | **Avg** | **158.38** | **324.52** | **369.23** | **474.15** |
| PC(MSD50)S | 1 | 67.23 | 163.86 | 189.18 | 267.18 |
| | 2 | 68.87 | 168.25 | 192.52 | 277.89 |
| | 3 | 75.91 | 172.03 | 185.47 | 272.71 |
| | **Avg** | **70.67** | **168.04** | **189.05** | **272.59** |
| PC(MSD40)S | 1 | 89.53 | 192.46 | 233.98 | 347.88 |
| | 2 | 94.03 | 193.13 | 230.39 | 357.54 |
| | 3 | 84.16 | 196.57 | 229.5 | 342.34 |
| | **Avg** | **89.24** | **194.05** | **231.29** | **349.25** |
| PC(MSD30)S | 1 | 98.32 | 218.11 | 255.24 | 382.12 |
| | 2 | 101.36 | 227.43 | 251.87 | 389.72 |
| | 3 | 107.78 | 211.59 | 247.82 | 395.41 |
| | **Avg** | **102.48** | **219.04** | **251.64** | **389.08** |
| PC(MSD20)S | 1 | 114.13 | 275.67 | 315.15 | 415.98 |
| | 2 | 118.83 | 284.17 | 309.19 | 418.65 |
| | 3 | 121.79 | 266.21 | 322.38 | 421.38 |
| | **Avg** | **118.25** | **275.35** | **315.57** | **418.67** |
| PC(MSD10)S | 1 | 147.41 | 313.76 | 365.44 | 453.12 |
| | 2 | 156.21 | 309.65 | 375.49 | 461.39 |
| | 3 | 160.24 | 318.38 | 371.72 | 465.55 |
| | **Avg** | **154.62** | **313.93** | **370.88** | **460.02** |

Mixing a material properly and correctly is vital for durable and long lasting. In order to prepare proper mix proportion water cement ratio also plays a critical role. The compressive and flexural strengths of mix proportions increase when less water is used to make mixture. This is due to hydration reaction that requires specific amount of water. More water is consumed in the hydration reaction to increase workability of mortar/concrete; this extra water retained in the microstructure pore spaces renders the mortar/concrete weak due to decrease in calcium silicate hydrate bonds. The results showed that water cement ratio of the mix proportions increases with the increase in marble waste dust. This is due to large specific surface area of the marble dust.

**Density and water absorption capacity:** Density and water absorption of specimens were determined by ASTM C 642 and the results are presented in Tables 4.2.21 and 4.2.22. The results showed that in most of the samples having 10 to 20% marble dust with Portland cement and glass fiber fulfills the requirement of ASTM C 55 which require greater than 2g/cm$^3$ for normal weight mortar specimen. Specimens prepared using more than 20% MSD failed to qualify for ASTM C 55. The result presented in the study revealed that density of the cubes is inversely proportional to the marble contents in concrete. Increase in marble waste dust results in decreased density. Actually, the marble powder used in the mix proportions has the lowest density as compared to other aggregates present in the mix. Preparation of mix proportions containing 10 to 20% marble powder does not affect the overall density of the specimen, but when the amount increases to 30, 40, 50% it affects the density as well as water cement ratio.

**Table 4.2.21: Average density and water absorption of cubes prepared from marble slurry dust, Portland cement, sand and glass fibers**

| Sample ID | Sample No | Density (gm/cm$^3$) | Water Absorption % |
|---|---|---|---|
| PC(S)GF | 1 | 2.24 | 6.23 |
| | 2 | 2.3 | 6.34 |
| | 3 | 2.18 | 6.28 |
| | **Avg** | 2.24 | 6.28 |
| MSD(PC)GF 50 | 1 | 1.77 | 12.32 |
| | 2 | 1.81 | 12.3 |
| | 3 | 1.79 | 12.34 |
| | **Avg** | 1.79 | 12.32 |
| MSD(PC)GF 40 | 1 | 1.96 | 11.93 |
| | 2 | 1.97 | 11.98 |
| | 3 | 1.95 | 11.9 |
| | **Avg** | 1.96 | 11.93 |
| MSD(PC)GF 30 | 1 | 2.03 | 11.63 |
| | 2 | 2.05 | 11.65 |
| | 3 | 2.08 | 11.58 |
| | **Avg** | 2.05 | 11.62 |
| MSD(PC)GF 20 | 1 | 2.18 | 9.93 |
| | 2 | 2.21 | 9.95 |
| | 3 | 2.19 | 9.99 |
| | **Avg** | 2.19 | 9.95 |
| MSD(PC)GF 10 | 1 | 2.29 | 6.11 |
| | 2 | 2.24 | 6.06 |
| | 3 | 2.27 | 6.1 |
| | **Avg** | 2.26 | 6.09 |

Water absorption was determined by ASTM C 642. After determination the products were compared with ASTM C 55 specifications, which showed a maximum limit of 7.5% for grade N, 10.1%, for grade S. In the samples analyzed, specimens with 10% marble dust having Portland cement and white cement as binder fulfills the water absorption requirement of grade N while 20% marble dust fulfills the requirement of grade S. This study showed that the bricks and tiles specimens shown above are acceptable for structural use.

**Table 4.2.22: Average density and water absorption of cubes prepared from marble slurry dust, Portland cement and sand without glass fiber**

| Sample ID | Sample No | Density (gm/cm3) | Water Absorption % |
|---|---|---|---|
| PC(S) | 1 | 2.23 | 6.36 |
| | 2 | 2.19 | 6.32 |
| | 3 | 2.22 | 6.32 |
| | **Avg** | 2.21 | 6.33 |
| PC(MSD50)S | 1 | 1.79 | 11.95 |
| | 2 | 1.8 | 11.88 |
| | 3 | 1.82 | 11.85 |
| | **Avg** | 1.8 | 11.89 |
| PC(MSD40)S | 1 | 1.99 | 11.74 |
| | 2 | 1.98 | 11.71 |
| | 3 | 1.99 | 11.65 |
| | **Avg** | 1.98 | 11.7 |
| PC(MSD30)S | 1 | 1.97 | 10.88 |
| | 2 | 1.96 | 10.76 |
| | 3 | 1.98 | 10.82 |
| | **Avg** | 1.97 | 10.82 |
| PC(MSD20)S | 1 | 2.11 | 9.87 |
| | 2 | 2.08 | 9.84 |
| | 3 | 2.12 | 9.91 |
| | **Avg** | 2.1 | 9.87 |
| PC(MSD10)S | 1 | 2.19 | 6.67 |
| | 2 | 2.15 | 6.34 |
| | 3 | 2.16 | 6.23 |
| | **Avg** | 2.16 | 6.41 |

Nowadays, due to stringent environmental legislation the use of recycled materials in mortar and concrete admixture is encouraged. The issues regarding the cost, recycling the industrial wastes, rehabilitation in durability and mechanical performance of concrete will therefore put a pressure on the utilization of such materials (Gesoglu et al., 2012). Utilization of stone cutting sludge in the formulation of low cost decorative tiles and concrete bricks was also explored (Alzaboon and Tahat, 2009; Alzaboon et al., 2010). Most suitable replacement ratio of waste marble powder as binder in cement in conventional concrete mix was determined as 5-10% (Ulubeyli, 2015).

In that perspective various researchers carries out different studies to evaluate the feasibility of substituting aggregates stone waste (Al-Hamaiedh, H. 2010; Almeida et al., 2007; Cornaldesi et al., 2010; Guneyisi et al., 2008; Gupta and Misra, 2009 ) and also of replacing cement with marble powder (Topcu et al., 2008; Alyamac and Ince, 2009). Fines of limestone are used frequently in the ingredients of self compacting concrete (Binici et al.,2007). Gornale et al. (2012) reported glass fiber reinforced concrete recently introduced in the construction industry. The objective of the study was to review the existing information about glass fiber in concrete production and concludes that it is light in weight, cannot rust like steel and when used in concrete it reduces the cost. Alzaboon and Khalid in (2009) reported the sludge recovery mechanism with wastewater recycling in concrete. Results of research revealed that the use of stone cutting slurry sludge as water source in concrete production has insignificant effect on compression strength (Alzaboon and Khalid, 2009).

As per ASTM C270 Standards specifications for masonry mortar are described below.

**Type-M:** This type of masonry mortar should have minimum strength of 2500 psi and used in structures where high compressive and flexural strength are required such as bridges and retaining walls.

**Type-S:** This type of mortar having minimum strength of 1800 psi and less strong than type-M mortar also known as medium-strength mortar (minimum 1800 psi). It is used in ordinary construction projects such as road lateral, shallows retaining walls, paving etc.

**Type-N:** This type of mortar is the most common type of masonry mortar with minimum strength of 750 psi and used for general purpose interior reinforcement to prevent cracking of the masonry units.

**Type-O:** This type of mortar is low grade strength mortar having minimum strength of 350 psi. This type of mortar is used for plasticizing and repair purposes with limited exterior use.

### 4.2.3.4 Lime

Chemical analysis of Marble slurry powder shows that it contain silica ($SiO_2$) in the range of 1.43-2.0%, with an average of 1.6%, magnesium oxide (MgO) found in the range of 0.4-0.62%, Calcium Oxide (CaO) present in the range of 54.5-57.2%, with an average of 55.7% and Loss on ignition (LoI) was estimated in the range of 40.5-42.5% with an average of 41.7% (Table 4.2.23).

**Table 4.2.23: Marble slurry composition used in lime preparation**

| Components (%) | MPUs | | | | | Min | Max | Avg | Std.Dev |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | | |
| **$SiO_2$** | 2 | 1.45 | 1.75 | 1.8 | 1.43 | 1.43 | 2 | 1.686 | 0.243372 |
| **MgO** | 0.5 | 0.54 | 0.52 | 0.62 | 0.4 | 0.4 | 0.62 | 0.516 | 0.079246 |
| **CaO** | 54.5 | 55.6 | 57.2 | 55.2 | 56 | 54.5 | 57.2 | 55.7 | 1.004988 |
| **LOI** | 42.5 | 42 | 40.5 | 41.5 | 42 | 40.5 | 42.5 | 41.7 | 0.758288 |
| **Total** | 99.5 | 99.59 | 99.97 | 99.12 | 99.83 | 99.12 | 99.97 | 99.602 | 0.327979 |

**Analysis of Commercial Quick lime:** Analytical results of commercial quick lime showed that it contained silica ($SiO_2$) in the range of 3.2-4.8%, with an average of 4.2%., magnesium oxide (MgO) found in the range of 6.5-8.5%, with an average of 7.76%., Calcium Oxide (CaO) present in the range of 79.5-85%, with an average of 82.5% (Table 4.2.24).

**Table 4.2.24: Analytical results of commercial Quick lime**

| Components (%) | CaO Comercial | | | | | Min | Max | Avg | Std. Dev |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | | |
| **$SiO_2$** | 4.2 | 4.4 | 3.2 | 4.8 | 4.6 | 3.2 | 4.8 | 4.24 | 0.622896 |
| **MgO** | 7.8 | 8.5 | 7.6 | 8.4 | 6.5 | 6.5 | 8.5 | 7.76 | 0.801873 |
| **CaO** | 82 | 79.5 | 83 | 83 | 85 | 79.5 | 85 | 82.5 | 2.00 |
| **Total** | 94 | 92.4 | 93.8 | 96.2 | 96.1 | 92.4 | 96.2 | 94.5 | 1.627882 |

**Analysis Quick Lime prepared from Marble Slurry:** Results of quick lime prepared in the laboratory on trial basis showed that it contained silica ($SiO_2$) in the range of 2.6-3.5%, have average of 2.9%, magnesium oxide (MgO) found in the range of 0.68-1.08%, have average of 0.89%, Calcium Oxide (CaO) present in the range of 94.7-96.2%, have an average of 95.58% (Table 4.2.25).

**Table 4.2.25: Analytical results of Quick lime prepared from marble slurry**

| Components (%) | CaO Trial | | | | | Min | Max | Avg | Std.Dev |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | | |
| **SiO2** | 3.5 | 2.65 | 2.8 | 2.95 | 2.6 | 2.6 | 3.5 | 2.9 | 0.362284 |
| **MgO** | 0.87 | 0.94 | 0.92 | 1.08 | 0.68 | 0.68 | 1.08 | 0.898 | 0.144637 |
| **CaO** | 94.7 | 96 | 96.2 | 95 | 96 | 94.7 | 96.2 | 95.58 | 0.679706 |
| **Total** | 99.07 | 99.59 | 99.92 | 99.03 | 99.28 | 99.03 | 99.92 | 99.378 | 0.375593 |

**Table 4.2.26: Comparative Analysis of commercial and trial quick lime**

| S.No | Components (%) | Commercial grade | Trial grade |
|---|---|---|---|
| 1 | CaO | 82.5 | 95.58 |
| 2 | $SiO_2$ | 4.24 | 2.9 |
| 3 | MgO | 7.76 | 0.89 |
| 4 | Total | 99.37 | 94.5 |

Pure quicklime, CaO, has 100% available CaO (Boynton & Robert 1966, Holmes and Wingate 1997). Pure hydrated lime, $Ca(OH)_2$ contained 75.56% available CaO (Boynton and Robert 1966, Holmes and Wingate 1997). In general Percent mean composition of both commercial and trial quick lime sample shows that the trial grade having more purity index than the commercial grade quick lime. About >95% CaO contents and less silica and magnesia content make it suitable from commercial grade (Table 4.2.26).

**Analysis of Commercial Hydrated Lime:** Laboratory results showed that calcium hydroxide available in the market having SiO2 in the range of 1.8-2.6% with an average of 2.12%. while MgO was found in the range of 2-3.4% with an average of 2.78%, CaO have in the range of 69-71% with an average of 69.8% (Table 4.2.27).

**Table 4.2.27: Analytical results of commercial Hydrated Lime**

| Components (%) | $Ca(OH)_2$ Comercial | | | | | Min | Max | Avg | Std.Dev |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | | |
| $SiO_2$ | 2.2 | 2 | 2 | 1.8 | 2.6 | 1.8 | 2.6 | 2.12 | 0.303315 |
| MgO | 3.4 | 3.2 | 2.8 | 2 | 2.5 | 2 | 3.4 | 2.78 | 0.55857 |
| CaO | 69 | 69 | 70 | 71 | 70 | 69 | 71 | 69.8 | 0.83666 |
| Total | 74.6 | 74.2 | 74.8 | 74.8 | 75.1 | 74.2 | 75.1 | 74.7 | 0.331662 |

**Analysis of Hydrated Lime prepared from Marble Slurry:** Result showed that calcium hydroxide prepared in the laboratory on trial basis having $SiO_2$ contents in the range of 1-2.2%, with an average of 1.73%. while MgO was found in the range of 0.68-1.08% with an average of 0.88%, CaO have in the range of 73-74% with an average of 73.56% (Table 4.2.28).

**Table 4.2.28: Analytical results of Trial Hydrated Lime**

| Components (%) | $Ca(OH)_2$ Trial | | | | | Min | Max | Avg | Std.Dev |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | | |
| SiO2 | 1 | 1.65 | 2 | 2.2 | 1.8 | 1 | 2.2 | 1.73 | 0.457712 |
| MgO | 0.82 | 0.94 | 0.92 | 1.08 | 0.68 | 0.68 | 1.08 | 0.888 | 0.148728 |
| CaO | 73.8 | 74 | 74 | 73 | 73 | 73 | 74 | 73.56 | 0.517687 |
| Total | 75.62 | 76.59 | 76.92 | 76.28 | 75.48 | 75.48 | 76.92 | 76.178 | 0.61832 |

High calcium hydrated lime - high calcium quicklime produces a hydrated lime containing generally 72 to 74 percent calcium oxide and 23 to 24 percent chemically combined water (NLA 2007). Percent mean composition of both commercial and trial hydrated lime sample shows that the trial grade having more purity index than the commercial grade hydrated lime. Mean percentage composition shows that about >70% CaO contents and less silica and magnesia content make it suitable from commercial grade (Table 4.2.29).

**Table 4.2.29: Comparative analysis of commercial and trial hydrated lime**

| Components (%) | Commercial Grade | Trial Grade |
|---|---|---|
| CaO | 69.8 | 73.56 |
| $SiO_2$ | 2.12 | 1.73 |
| MgO | 2.78 | 0.88 |
| Total | 74.70 | 76.17 |

This process is the simplest recycling option for converting calcium carbonate waste marble slurry into products like quick and hydrated lime. Therefore, it is usually conducted in a satellite facility adjacent to marble processing plant. Recycling has been encouraged throughout the world. Marble waste recycling is, undoubtedly, the best alternative to reduce the impact of marble industries on the environment, if the slurry is recovered properly (Correia et al., 2011; Pelisser et al., 2011). As known, marble slurry, chemically composed of calcium carbonate has many applications in most of the industries. Recent researches showed that it can be used in the manufacturing of cement, soda, lime, cosmetics and pharmaceuticals, filler in the paper, paint, and polypropylene, agricultural soil amendment, blast furnace flux, neutralizer for industrial effluents and for the sorption of heavy metal, desulphurization of flue gases, resin conglomerates for flooring and coatings in the building industry, thanks to their chemical and physical characteristics (Davini, 2000; Dhanapandian and Gnanavel, 2010; Aruntas et al., 2010; Pereira, 2008; Binici et al., 2008; Alzboon et al., 2010; Topcu et al., 2009; Al-Hamaiedh, 2010; Manan and Iqbal, 2007; Peter, 2002). Recently attempts have been made to utilize marble wastes in construction industry like bricks, tiles, pavements, embankments, concrete, asphalt aggregates, cement, road construction and as other building materials (Dak, 2000).

# CHAPTER-V

# CONCLUSIONS

# AND

# RECOMMENDATIONS

# CHAPTER-V

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

From LCA perspective, there were no studies conducted in Pakistan that considered Marble and other dimensional stones processing in a systematic manner taking into account the environmental aspects. Within this context, the initiative of LCA presents itself as an important vector in the dissemination of sustainable thinking, and will hopefully contribute to the technological, energy and environmental improvements in this sector. Spatial data base was developed for MPUs and quarries site by using GIS for the first time in Khyber Pakhtunkhwa. This would provide feedback for decision makers.

Major findings of the study are:

- C1 types MPUs equipped with dressing, cutting and finishing (polishing) facility. Once a raw material in the form of marble stone enters in this type of unit it is processed into final product under the single roof. On the other hand C2, C3 and C4 types MPUs have limited processing facilities, where the raw material process in one unit can be sent to another for finishing. Because, the equipments or machine for one operation is present in one MPU and for second operation it is present in another unit. Due to which more than one unit is involve in completing the process.
- The wastes generates as a result of marble processing in C1 category is easily measurable and segregated properly. But wastes generated in other MPUs categories are difficult to quantify and unmanageable.
- At C1 type MPUs the processing completed in a single production line up at a single place while on the other hand it is completed in several steps and many places. The energy and water requirement is easily manageable at one place but difficult for scattered unit and production line up.
- The C1 type MPUs operates 12 months throughout a year, 08 hours per day and provided employment to 20-25 people. But other type of MPUs categories

rarely operational throughout the year because of its interring dependency on each others.

- Mostly MPUs in the study area are installed outsides the industrial estates due to which regulatory issues arise such as implementation of monitoring rules.
- It was also found that more wastes are generated when marble processing lineup completed in a single unit like in C1 as compared to split processing lineup.

- Besides, marble processing units have negative environmental impacts on surface water quality. Due to which, the water use trends have also been changed to a big extent.

- The designed EAC guidelines seem ineffective in addressing environmental problems and cannot be considered as alternative of detail EIA study. It was also found that the existing sedimentation tanks was effective in water re-use only but not for marble sludge disposal and recycling.

This study contributed to the three main areas; i-Knowledge, ii- Methodology, and iii-Legislative framework. The innovative part of this study was to ensure CP by the help of LCA. Without the diffusion of these both concepts the implementation of CP will not ensure properly. Because LCA would be used as a diagnostic tool for measuring environmental performances in terms of inputs and outputs of any industrial process and provide a clear picture to the decision makers.

Besides, no work was done for the recovery mechanism of marble wastes in Pakistan. The existing mechanism in MPUs is found not effective in term of slurry recovery. In this study an engineered based wastewater treatment design is proposed. The upgraded design ensures 100% CP in terms of water reuse and slurry recovery option in MPUs. It is recommended to include LCA as an integral part of EIA for any developmental activity to make EIA process more precise, effective and sound.

Last but not the least without polluting the environment the most appropriate method for inactivating the marble wastes is recycling. Therefore, CP ensure Recycling which provides saving opportunities' in economy, Energy, Natural resources and decreasing the wastes in more sustainable way. The preparation of secondary useful products and its evaluation with standards will provide a framework for future initiatives.

Analysis of Marble stones Slurry collected from different MPUs categories in Khyber Pakhtunkhwa showed that it did not contain any hazardous materials or heavy metals and it can be used in the preparation of secondary useful products. Marble Stone Slurry wastes predominantly consist of by 99% calcium carbonate and very small particle size with more than 80% particles passing 75 micron sieves. Therefore, by using this Marble Stone Slurry, as raw materials in different sectors, will help to protect the environment and would be cost effective.

Its strengths are here summarized:

- The high calcium carbonate content;
- The absence of heavy metals and pollutants;
- The particle size with high percentages of ultrafine;

The properties of secondary useful products prepared from marble slurry dust were investigated and were compared with control specimen properties. Exploring the following industrial fields:

- Cement Manufacturing;
- Dish Washing Powder;
- Masonry Mortar;
- Lime.

Calcium carbonate waste marble slurry dust is similar in characteristics of the raw calcium carbonate use in cement manufacturing process. The utilization of marble slurry waste as an alternative resource of calcium carbonate in industrial manufacturing process of cement has been studied. By recovery, reusing and recycling of this waste material in the manufacturing of cement have a great contribution to the environment and economy by minimizing pollution load coming from marble processing industry and by utilizing waste into valuable product. The cement prepare from Marble slurry dust having almost similar standards when it was compare to commercial cement during evaluation because the mean compressive strength test result shows less difference with each other. Compressive strength testing of specimen in the study was used for the acceptance of cement, quality control, evaluation or for the estimating the concrete strength in a structure for the purpose of scheduling construction operation. Beside from this a policy should be made under which cement industry compelling to utilize the waste of marble industry into its production process.

By using the marble slurry waste in dish washing powders is one of the good options. The percent composition of raw materials can be reduced which ultimately reduce the unit cost of product, and increases cleaning and rinsing ability. Similarly, by reducing the amount of acidic and alkaline materials in households dish washing powders the skin sensitivity problems was not observed. It was concluded that dish washing powder prepared from 50% marble stone slurry, 20% soda ash, 20% sulfunic acid and 10% soap stone was good and user friendly. By doing so, impact of marble industry on environment can be minimized and is strongly recommended.

The results GFRM showed that marble waste dust has got a large surface area due to high fineness, which in turn increases water cement/water plaster ratio. So increase in marble slurry dust will increase the water cement/water plaster ratio of the prepared products decreasing the compressive and flexural strength. Density of the cubes also depends upon the marble contents in mortar. Increase in marble waste dust results in decrease in density. Specimens with high density have high compressive and flexural strength. Addition of glass fiber has a great effect on the compressive strength as well as flexural strength. There is a remarkable increase in flexural strength by using glass fiber. The findings of this study show that by using 10, 20 and 30% of marble dust qualify for the ASTM requirement, while above 30% it does not qualify for the requirement of ASTM.

On the basis of the results obtained, it is concluded that by using marble slurry waste as a raw material for calcinations we can reduce the ugly sites of waste heaps here and there and also prevent negative impacts of it on the environment. This effort will help in preservation of natural resources, reutilize industrial residues, reformulate the construction and building products and further improve their properties. Beside, the study present a reliable data to be available for pilot plant studies and as well as for industrial production.

### 5.2 Recommendations

The existing water reuses system supporting end of pipe treatment in terms of sedimentation and disposal of marble sludge powder. The sediments produce (marble slurry powder) was disposed off along the bank of stream after sedimentation in settling tanks. This is not only contributing to water pollution but also deteriorates soil quality. It is therefore recommended to up-grade the existing water reuse system with marble sludge recovery and recycling for implementation of CP. Filter press should be used in MPUs for separation of water and marble powder from slurry. If the slurry is properly collected, it can be used as a raw material in another industry.

- Environmental Management System should be materialized and Environmental friendly Eco Industrial Cluster (EIC) should be developed.
- Government should issue NOC to C1 type MPUs only to ensure processing at one place and discourage the split processing in more than one unit place.
- This industrial cluster should be based on public-private partnership, while government should regulate and inspect the private sector by enforcing the regulations for collecting the waste.
- A huge amount of marble waste is generated during mining stage, which poses a threat to the environment. This waste can be reduced by avoiding the traditional and old methods cutting and blasting.
- Marble slurry waste from the study areas can be used in the production of concrete bricks and tiles and there are so many marble processing plants available in the study area, which may use this byproduct at feasible cost. In future, the government should work out some sort of policies with marble processing plants for establishing such industries near the processing plants.
- To materialize this plan a waste receiving station need to be established and located in area around marble processing plants and industries where all plants and industries would be required to transport their wastes. These waste depots can become the hub of a raw material supply for other industrial sectors.
- Detailed physical, chemical, mineralogical, thermal, engineering and morphological properties of the marble wastes need to be analyzed to get

precise data for its utilization in a variety of industries such as filler, binder and as an alternate material in construction industry.

- The studies of these marble wastes should be further enhanced by preparation of hollow bricks, lightweight tiles and blocks and preparation of other lightweight construction material having reduced density.
- The marble processing plants covered in this research study belong to Khyber Pakhtunkhwa. The future research studies may be extended to other parts of the country.
- It is advised for future studies to do a cost comparison by using some organic binders (polystyrene, epoxies and resins) instead of inorganic binders (cement and plaster of paris), and the studies may be further enhanced by addition of super plasticizers to increase workability.
- All the research data should be made available to the universities, research centers and to the industries for effective utilization and commercialization.
- The universities, industries and research centers should be encouraged to investigate, produce and commercialize new processes and products using marble wastes as raw materials for establishing secondary industries.
- Awareness should be created among mine owners and marble processors in order to manage marble waste effectively and efficiently.
- Consultancies should be provided to interested parties to establish marble waste based products industries.
- There is a need of effective liaison of government and administration for effective waste management.
- Marble waste dumping/storage sites should be allocated near to the marble processing plants for effective waste recycling.

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## APPENDIX-1: District wise GPS data of MPUs Clusters & Quarries

| S .No | Districts | MPU's Locations | ID's | Latitude | Longitude | MPU's No | Total MPUs |
|---|---|---|---|---|---|---|---|
| 1 | Peshawar | Hayatabad Industrial Estate | PSW 1 | 33.99111º | 71.41112º | 35 | 283 |
| | | Ring Road East | PSW 2 | 33.98379º | 71.57312º | 8 | |
| | | Ring Road West | PSW 3 | 33.96384º | 71.52988º | 6 | |
| | | Sardar Ghari, GT Road | PSW 4 | 34.02168º | 71.63348º | 5 | |
| | | Putwar, Warsak Road | PSW 5 | 34.06965º | 71.49707º | 67 | |
| | | Pir Bala, Warsak Road | PSW 6 | 34.09309º | 71.48413º | 15 | |
| | | Darmangi, Warsak Road | PSW 7 | 34.05684º | 71.51365º | 32 | |
| | | Sufaid Sang, Warsak Road | PSW 8 | 34.14146º | 71.41684º | 115 | |
| 2 | Charsadda | Subhan Khwar, Shabqadar | CHD 1 | 34.22661º | 71.53232º | 75 | 166 |
| | | Samanaat, Shabqadar | CHD 2 | 34.22424º | 71.52791º | 40 | |
| | | Khawaja Wos, Shabqadar | CHD 3 | 34.24893º | 71.54886º | 45 | |
| | | Kanewar, Tangi | CHD 4 | 34.28348º | 71.68243º | 6 | |
| 3 | Nowshehra | Khairabad | NSR 1 | 33.9028º | 72.22373º | 80 | 196 |
| | | Jehangira | NSR 2 | 33.95615º | 72.2142º | 44 | |
| | | Amangarh | NSR 3 | 34.00828º | 71.94926º | 5 | |
| | | Risalpur | NSR 4 | 34.09106º | 71.9993º | 67 | |
| 4 | Swabi | Zaida | SWB 1 | 34.11773º | 72.46454º | 4 | 52 |
| | | Firdous abad | SWB 2 | 34.18105º | 72.40016º | 5 | |
| | | Shahmansoor | SWB 3 | 34.09338º | 72.46449º | 10 | |
| | | Mansabdar | SWB 4 | 34.21108º | 72.35233º | 4 | |
| | | Gadoon | SWB 5 | 34.10638º | 72.64315º | 15 | |
| | | Tarakho | SWB 6 | 34.21895º | 72.41775º | 4 | |
| | | Maneri | SWB 7 | 34.13412º | 72.47744º | 10 | |
| 5 | Mardan | Mardan Industrial Estate | MDN 1 | 34.12575º | 72.02603º | 150 | 150 |
| 6 | Buner | Sowarai | BNR 1 | 34.46274º | 72.49016º | 25 | 378 |
| | | Elai | BNR 2 | 34.50069º | 72.42632º | 20 | |
| | | Daggar Gokand | BNR 3 | 34.52766º | 72.47897º | 7 | |
| | | Tango Pull | BNR 4 | 34.48046º | 72.56278º | 15 | |
| | | Dewana Baba | BNR 5 | 34.47383º | 72.59873º | 23 | |
| | | Dewana Baba Road | BNR 6 | 34.47703º | 72.55183º | 20 | |
| | | Katkala Salarzai | BNR 7 | 34.55581º | 72.34957º | 12 | |
| | | Bazargai Kalay | BNR 8 | 34.55282º | 72.32111º | 10 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Char Kalay | BNR 9 | 34.56667º | 72.379º | 8 | |
| | | Nanser | BNR 10 | 34.49114º | 72.25074º | 10 | |
| | | Zaga Kalay | BNR 11 | 34.512º | 72.45229º | 7 | |
| | | Kulyari | BNR 12 | 34.48283º | 72.59522º | 6 | |
| | | Elum Gokand | BNR 13 | 34.57213º | 72.29757º | 6 | |
| | | Totalai | BNR 14 | 34.19709º | 72.50047º | 5 | |
| | | Salarzai | BNR 15 | 34.49435º | 72.26156º | 12 | |
| | | Hisar Kalay | BNR 16 | 34.54167º | 72.49005º | 5 | |
| | | Bampokha | BNR 17 | 34.50139º | 72.28957º | 8 | |
| | | Anghapur | BNR 18 | 34.50717º | 72.38588º | 12 | |
| | | Kandao | BNR 19 | 34.42928º | 72.48366º | 15 | |
| | | Cheena Kalay | BNR 20 | 34.44382º | 72.48983º | 8 | |
| | | Banda Kalay | BNR 21 | 34.44591º | 72.37967º | 7 | |
| | | Batai, Qadir Nagar | BNR 22 | 34.62595º | 72.46827º | 8 | |
| | | Sultanwas | BNR 23 | 34.57094º | 72.4504º | 12 | |
| | | Karapa | BNR 24 | 34.47038º | 72.42706º | 6 | |
| | | Ambella | BNR 25 | 34.55905º | 72.44908º | 5 | |
| | | Jalal Khan Kalay | BNR 26 | 34.55541º | 72.45166º | 10 | |
| | | Ghazi Khan Kalay | BNR 27 | 34.55267º | 72.44781º | 8 | |
| | | Pir Abai | BNR 28 | 34.53191º | 72.43782º | 15 | |
| | | Mula Yusup Kalay | BNR 29 | 34.45459º | 72.43583º | 7 | |
| | | Babu Khan Kalay | BNR 30 | 34.54089º | 72.44435º | 6 | |
| | | Pir Baba, Malakpur | BNR 31 | 34.61587º | 72.44611º | 25 | |
| | | Gokand, Daggar Rd | BNR 32 | 34.58634º | 72.51977º | 5 | |
| | | Torwarsak | BNR 33 | 34.51011º | 72.36704º | 30 | |
| 7 | Swat | Ali Grama | SWT 1 | 34.80697º | 72.33115º | 8 | 71 |
| | | Qambar | SWT 2 | 34.76789º | 72.33101º | 10 | |
| | | Barikot | SWT 3 | 34.67508º | 72.21451º | 12 | |
| | | Takht Band | SWT 4 | 34.76857º | 72.31321º | 20 | |
| | | Shah Derai | SWT 5 | 34.87475º | 72.24509º | 5 | |
| | | Charbagh | SWT 6 | 34.86475º | 72.43985º | 5 | |
| | | Kokarai | SWT 7 | 34.74771º | 72.41641º | 5 | |
| | | Fiza Ghat | SWT 8 | 34.78903º | 72.36768º | 6 | |
| 8 | Malakand | Pull Saokay | MKD 1 | 34.64228º | 72.03081º | 5 | 20 |
| | | Totakaan | MKD 2 | 34.58452º | 71.81072º | 7 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Amandara | MKD 3 | 34.63789º | 72.01619º | 8 | |
| 9 | Haripur | GT Road | HRP 1 | 33.98479º | 72.89401º | 5 | 17 |
| | | Hattar Industrial Estate | HRP 2 | 33.90847º | 72.86434º | 12 | |
| 10 | Abbottabad | GT Road | ABT 1 | 34.18531º | 73.23211º | 4 | 20 |
| | | Mandian | ABT 2 | 34.20039º | 73.23523º | 16 | |
| 11 | Dir Lower | Talaash | DIR 1 | 34.74314º | 71.85615º | 7 | 22 |
| | | Chakdara | DIR 2 | 34.65979º | 72.02816º | 5 | |
| | | Timergara | DIR 3 | 34.81502º | 71.83433º | 5 | |
| | | Balambat | DIR 4 | 34.81278º | 71.81522º | 5 | |
| 12 | Mansehra | Mansehra | MNR 1 | 34.30286º | 73.21743º | 12 | 17 |
| | | Dhodial | MNR 2 | 34.41406º | 73.23452º | 5 | |
| 13 | Chitral | Ayun | CHT 1 | 35.71655º | 71.78032º | 3 | 13 |
| | | Gahriyat | CHT 2 | 35.67512º | 71.79064º | 10 | |

**Quarries GPS Location Data**

| S. No | Districts | Locations | Latitude | Longitude | No. of Quarries | Total Quarries |
|---|---|---|---|---|---|---|
| 1 | Swabi | Maneri Bala | 34.15729º | 72.46632º | 3 | 11 |
| | | Ghundai Tarakho | 34.21821º | 72.41725º | 8 | |
| 2 | Nowshera | Darwazgai | 33.83776º | 72.20522º | 2 | 9 |
| | | Pitao Bala | 33.9172º | 72.13875º | 5 | |
| | | Nizampur | 33.80199º | 72.07753º | 2 | |
| 3 | Charssada | Tangi Reef | 34.31069º | 71.67456º | 2 | 2 |
| 4 | Buner | Khaista Baba | 34.45983º | 72.63526º | 5 | 43 |
| | | Matwani Buner | 34.48068º | 72.62102º | 10 | |
| | | Bazargai-I | 34.52829º | 72.31834º | 5 | |
| | | Bazargai-II | 34.53989º | 72.33185º | 8 | |
| | | Bampokha | 34.50218º | 72.30355º | 10 | |
| | | Salarzai | 34.49737º | 72.26011º | 3 | |
| | | Zaga Kalay | 34.52204º | 72.45692º | 2 | |
| 5 | Mardan | Rustam | 34.38441º | 72.16942º | 2 | 5 |
| | | Katlang | 34.38203º | 72.12088º | 3 | |
| 5 | Swat | Shahderai | 34.88456º | 72.26508º | 1 | 1 |
| 6 | Chitral | Barbaluk | 35.72609º | 71.80126º | 1 | 6 |
| | | Gahriat | 35.66578º | 71.79544º | 2 | |
| | | Istoor | 35.9582º | 72.04864º | 1 | |
| | | Shoghor | 36.00985º | 71.75448º | 2 | |
| 7 | Shangla | Bailay Baba | 34.88976º | 72.68499º | 5 | 8 |
| | | Matta Awan | 34.88396º | 72.70018º | 3 | |

## APPENDIX- 2: Field and Lab work Photos Attachments

### a. Pictorial Representation of Marble processing

Photo 1: Stone wastes at Marble Quarry Site

Photo 2: Transportation of Marble Blocks

Photo 3: Marble blocks Storage yard

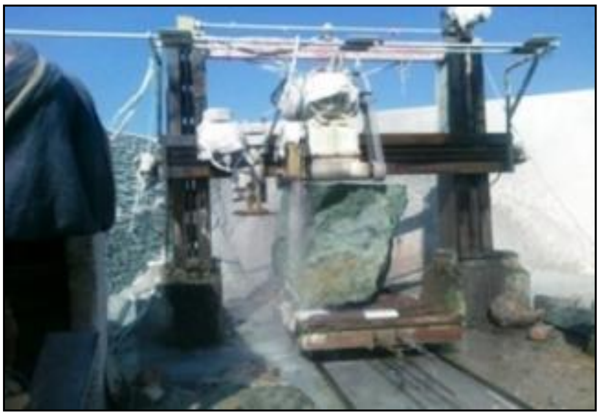

Photo 4: Dressing of marble block

Photo 5: Vertical blade cutting of marble block

Photo 6: Gangsaws Cutting of Marble blocks

Photo 7: Marble Slabs after gang saws cutting

Photo 8: cutting of Slabs into desire size tiles

Photo 9: Polishing Stage

Photo 10: Final Product

**b. Pictorial overview of Field Work**

**Photo 11: Settling tanks filled from Slurry wastes**

**Photo 12: Stone waste at MPU**

**Photo 13: Cooling water usages**

**Photo 14: Wastewater containing marble dust**

Photos of Surface water Pollution

Photo 15: River Barandu (upstream) in winter

Photo 16: River Barandu (downstream) in winter

Photo 17: River Barandu (upstream) in summer Photo 18: River Barandu (downstream) in summer

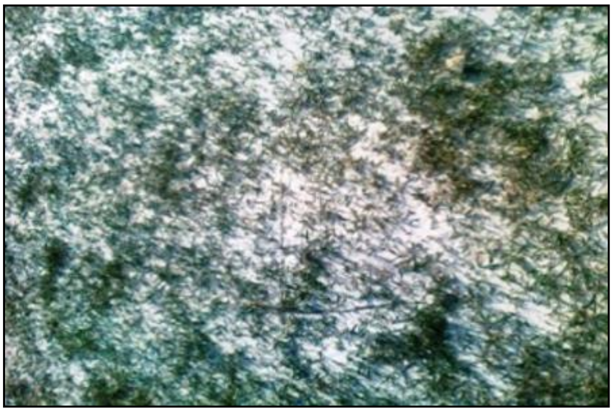

Photo 19: Irrigation of MPUs wastewaterPhoto 20: Soil pollution

### c. Pictorial overview of Laboratory works

Photo 21: Wet Marble Slurry Sample


Photo 22: XRF used for chemical analysis

Photo 23: analysis of marble and cement dust


Photo 24: Oven used for Moisture contents

d. Preparation of Value Added Product

**Cement preparation**

Photo 25: Formulation or raw material

Photo 26: Making paste of raw material

Photo 27: Heating of raw materials


Photo 28: Clinker after heating in furnace

Photo 29: Clinker formed after cooling

Photo 30: Mixing of clinker with Gypsum

Photo 31: Gravel used in concrete specimen

Photo 32: Sand used in concrete specimen

Photo 33: Concrete specimen Preparation

Photo 34: Specimen for compressive strength

**Glass Fibers Reinforced Mortar (GFRM)**



Photo 35: Glass fiber used as reinforce

Photo 36: Mixing of raw materials

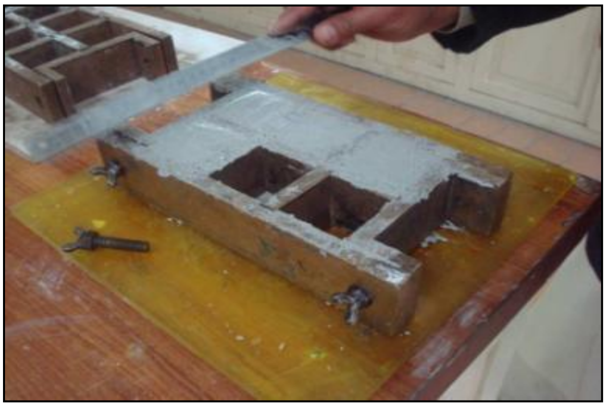

Photo 37: Molding of specimens


Photo 38: Prepared specimens

Photo 39: Determination of Compressive Strength

Photo 40: Determination of flexural strength

Dish Washing Powder

Photo 41: citric acid used as raw material

Photo 42: Sulfunic acid

Photo 43: Soda Ash

Photo 44: Dry Marble Slurry Powder

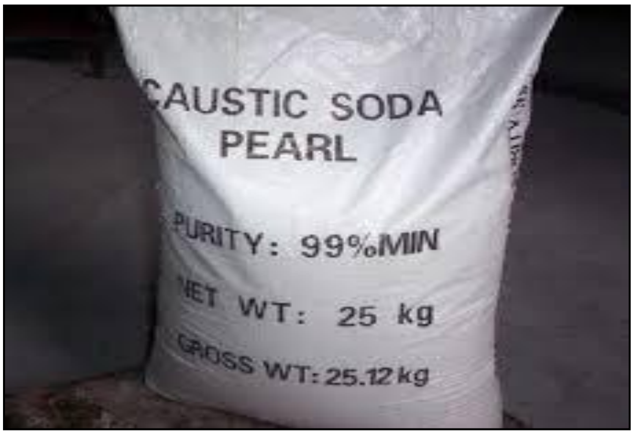


Photo 45: Caustic Soda

Photo 46: Mixing step after weighing

Lime Preparation

Photo 47: Commercial lime

Photo 48: Trial lime prepared from Marble Slurry

## APPENDIX-3 MPU's Assessment Checklist

### MPUs Assessment Checklist

1. Industry name

   ____________________________________________________________

2. Area location

   ____________________________________________________________

3. Contact No.

   ____________________________________________________________

4. Govt. Registered

   ____________________________________________________________

5. Settling tanks present

   ____________________________________________________________

6. Source of cooling water

   ____________________________________________________________

7. Water demand

   ____________________________________________________________

8. Energy source

   ____________________________________________________________

9. Energy demand

   ____________________________________________________________

10. No. of Employees

    ____________________________________________________________

11. Main operations (Specific Size Categories)

____________________, ____________________, ____________________

____________________, ____________________, ____________________

12. Machinery present

____________________, ____________________, ____________________

____________________, ____________________, ____________________

13. Amount of raw materials received______________________________________________
14. Product obtained____________________________________________
15. Slurry and waste disposal site____________________________________
16. Any Key measures ____________________________________________

Remarks__________________________________________________________
__________________________________________________________
__________________________________________________________

**APPENDIX-4 Dish Washing Powder Evaluation Checklist**

1. Age ______________________________________________
2. Income Level ______________________________________________
3. No. of individual in household____________________________________
4. Dirt removal

1st wash, 2nd wash, 3rd wash, 4th wash, 5th wash

5. Skin corrosion

1st wash, 2nd wash, 3rd wash, 4th wash, 5th wash

6. Rinse easily

1st wash, 2nd wash, 3rd wash, 4th wash, 5th wash

7. Are you satisfied from the performance overall

High satisfied, Satisfied, Neutral, de-satisfied, highly de-satisfied

**Remarks:**___________________________________________________________

___________________________________________________________

___________________________________________________________