



## Environmental Impacts of Marble Industrial Effluents on Water and Soil in Tehsil Shabqadar, Khyber Pakhtunkhwa

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### ABSTRACT

The marble industry plays a significant role in the economic development of Khyber Pakhtunkhwa, Pakistan, particularly in Tehsil Shabqadar. However, the environmental impacts of marble industrial effluents on water and soil quality remain a growing concern. This study investigates the effects of marble industry discharges on the surrounding environment, focusing on water and soil contamination. Water and soil samples were collected from areas affected by marble processing units and analyzed for pH, electrical conductivity, total dissolved solids, heavy metal concentrations, and other physicochemical parameters. The results revealed significant deviations in water quality, with increased alkalinity and elevated levels of heavy metals such as lead (Pb), chromium (Cr), and cadmium (Cd), exceeding permissible limits set by environmental protection agencies. Similarly, soil samples indicated higher concentrations of calcium carbonate, leading to changes in soil texture and reduced fertility. The findings highlight the detrimental impact of untreated marble effluents on natural ecosystems, posing risks to agricultural productivity and public health. This study underscores the urgent need for implementing proper effluent treatment systems and adopting sustainable practices to mitigate environmental degradation. Public awareness and government intervention are essential to enforce regulations and promote eco-friendly technologies in the marble industry. The study of marble industrial effluents in Tehsil Shabqadar, Khyber Pakhtunkhwa, reveals severe environmental consequences for water and soil quality. Untreated discharges contaminate water, increasing turbidity and reducing oxygen levels, harming aquatic life. Soil quality also deteriorates due to calcium carbonate accumulation, affecting fertility. Future solutions should include eco-friendly treatment methods, stricter regulations, and community awareness to balance industrial growth with environmental sustainability, ensuring long-term ecological health and agricultural productivity.

### INTRODUCTION

Marble is a metamorphic rock composed mainly of calcite (CaCO<sub>3</sub>) and dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>), has been extensively used in construction, art, and decoration for centuries due to its durability, aesthetic appeal, and availability [1]. The global demand for marble has led to a significant increase in marble extraction and processing, resulting in the generation of substantial amounts of waste. Approximately 70% of marble is lost during various stages of mining, cutting, polishing, and finishing, contributing to environmental pollution [2].

The marble industry has become a cornerstone of economic development in various regions, including Pakistan, where Tehsil Shabqadar in Khyber Pakhtunkhwa has witnessed a boom in marble extraction and processing activities [3]. However, this rapid industrialization has brought with it significant environmental concerns [4]. The marble processing

plants generate vast quantities of slurry, a semi-liquid waste composed of fine marble particles, water, and polishing chemicals. In the absence of proper waste management practices, this slurry is often discharged untreated into nearby water bodies or spread across agricultural lands, creating severe environmental repercussions [5].

One of the most profound impacts of marble effluents is the alteration of soil properties. The continuous deposition of marble dust increases soil alkalinity and reduces its permeability, ultimately affecting crop productivity [6]. The high calcium carbonate content in marble waste binds soil particles, leading to compaction and reduced water infiltration, thereby affecting plant growth and agricultural yields. Moreover, the leaching of heavy metals such as lead

(Pb), chromium (Cr), and cadmium (Cd) into the soil poses long-term ecological and health risks [7].

The contamination of water bodies is another major concern. The direct discharge of marble slurry into rivers and streams increases turbidity and alters the pH, which can be detrimental to aquatic life [8]. High turbidity reduces sunlight penetration, disrupting photosynthesis in aquatic plants and reducing oxygen availability for aquatic organisms. Additionally, heavy metals leaching into the water can accumulate in the food chain, posing risks to human health [9].

Despite these environmental challenges, there is a notable lack of research focusing on the localized impact of marble industrial effluents in Tehsil Shabqadar [10]. While some studies have investigated broader regions, the specific effects on the soil and water quality of this area remain underexplored. Understanding the localized impact is crucial for developing effective waste management strategies and mitigating environmental degradation. Furthermore, existing waste management practices are inadequate, often relying on rudimentary techniques that fail to address the long-term environmental consequences [8].

Addressing these gaps, this research aims to comprehensively assess the environmental impacts of marble industrial effluents on water and soil quality in Tehsil Shabqadar, Khyber Pakhtunkhwa. The study will analyze changes in physicochemical properties, assess heavy metal contamination levels, and identify implications for agricultural productivity and human health. Additionally, the research seeks to propose sustainable waste management strategies to minimize these adverse effects and promote environmental conservation.

## MATERIALS AND METHODS

### Materials and Equipment

#### Glassware and Containers

- Polyethylene bottles (for water sample collection)
- Glass bottles (for acid digestion)
- Beakers (50 mL, 100 mL, 250 mL)
- Conical flasks
- Measuring cylinders
- Pipettes and micropipettes
- Funnels

#### Instruments and Equipment

- pH meter (HANNA 210)
- Electrical conductivity (EC) meter (JENWAY 4320)
- Flame Atomic Absorption Spectrophotometer (FAAS)
- Oven (for soil drying)
- Muffle furnace (for organic matter analysis)
- Analytical balance (for weighing samples)
- Incubator (for BOD measurement)

- Spectrophotometer (for nitrate analysis)

### Chemicals and Reagents

- Buffer solutions (pH 7, 10, and 12) for pH calibration
- Potassium chloride (0.01N KCl) for EC calibration
- Ethylenediaminetetraacetic acid (EDTA) for hardness determination
- Phenol disulphonic acid for nitrate estimation
- Potassium dichromate for COD analysis
- Concentrated nitric acid (HNO<sub>3</sub>) and hydrochloric acid (HCl) for acid digestion in heavy metal analysis

## METHODOLOGY

### Water Sample

Water samples were collected from five different locations along Subhan Khwar to assess contamination from industrial wastewater effluents. Clean polyethylene bottles were used, pre-rinsed with the sample water, and filled to avoid air bubbles. Samples were immediately stored at 4°C to prevent chemical changes.

### Soil Samples

Soil samples were collected from the stream banks at a depth of 5–15 cm, ensuring uniform sampling across the selected sites. Each sample was air-dried, ground, and sieved through a 2 mm mesh to remove debris and stones. The processed samples were stored in sealed bags for further analysis.

**Table 1**

Sample Type	Number of Locations	Depth (for Soil)	Storage Conditions
Water Samples	5	—	Stored at 4°C
Soil Samples	5	5–15 cm	Air-dried, sieved, stored in sealed bags

### Sample Analysis

The collected samples underwent detailed physical, chemical, and biological analyses to assess pollution levels and identify heavy metal contamination.

### Water Analysis

12 parameters were analyzed to determine water quality, categorized into physical, chemical, and biological parameters, along with heavy metals. The physical parameters included pH, electrical conductivity (EC), turbidity, and total dissolved solids (TDS), which provide insight into the general condition and clarity of the water. Chemical parameters such as hardness, nitrate, and alkalinity were assessed to understand the water's chemical composition and potential impacts on aquatic life and human health. Biological parameters, including biological oxygen demand (BOD) and chemical oxygen demand (COD), were measured to evaluate the organic matter present and the level of pollution due to microbial

activity. Additionally, heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), and lead (Pb) were analyzed, given their toxicity and persistence in the environment, posing significant risks to both ecosystems and human health. This comprehensive analysis provides a detailed understanding of water quality, encompassing various physical, chemical, and biological aspects.

### Soil Analysis

Soil quality was assessed by analyzing pH, EC, moisture content, soil texture, and organic matter.

**Table 2**

*Parameters techniques and standard method for soil analysis*

Parameter	Technique	Standard method
pH	HANNA 210 PH meter, calibrated with buffers at PH 7, 10, and 12	Standard method for water analysis
Electrical conductivity	JENWAY4320 EC meter, calibrated with 0.01 N KCl	APHA 2510B
Total dissolved solids (TDS)	Gravimetric method	APHA2540C
Hardness	EDTA titration method	APHA2340C
Nitrate	Phenol di sulphonic acid method	APHA 4500-NO <sub>3</sub> -B
Biological oxygen demand (BOD)	5-day incubation at 20 °C followed by titration	APHA 5210B
Chemical oxygen demand	Dichromatic reflux method	APHA 5220B
Heavy metals (Cd, Cr, Cu,Pb)	Flame Atomic Absorption Spectroscopy (FAAS) after acid digestion	APHA 3111B

### Instrumentation and Techniques

- **pH:** Measured using a HANNA 210 pH meter calibrated with standard buffer solutions at pH 7, 10, and 12.
- **EC:** Determined using a JENWAY 4320 EC meter calibrated with 0.01N KCl solution.
- **TDS:** Measured by evaporating a known volume of the filtered sample and weighing the residue.
- **Hardness:** Determined using EDTA titration, where EDTA binds to calcium and magnesium ions, indicating total hardness.
- **Nitrate:** Estimated using the phenol disulphonic acid method, where nitrate reacts to produce a yellow color, measured spectrophotometrically.
- **BOD:** Evaluated by incubating water samples for five days at 20°C and measuring oxygen depletion.
- **COD:** Determined by the dichromate reflux method, measuring the amount of oxygen required to oxidize organic matter.
- **Heavy Metals (Cd, Cr, Cu, Pb):** Analyzed using Flame Atomic Absorption Spectrophotometry

(FAAS) after acid digestion with nitric and hydrochloric acids.

## RESULTS AND DISCUSSIONS

**pH:** The pH of wastewater samples ranged from 8.62 to 8.43, indicating slightly alkaline conditions, which were within the permissible NEQS limits (6.0 to 10.0). Slight alkalinity could be attributed to industrial effluents and agricultural runoff.

**Figure 1**  
*pH of Sample*

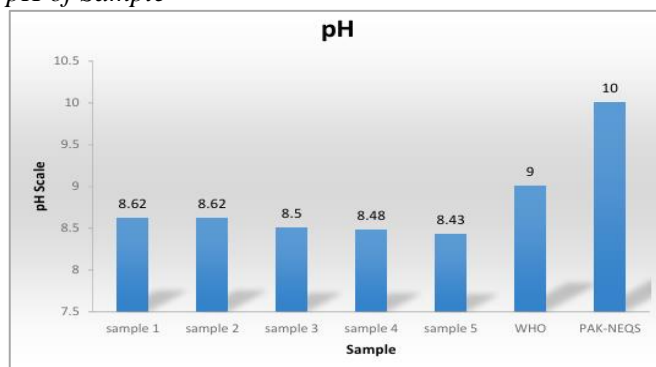


Figure 1 illustrates the pH values of wastewater samples collected from five locations along Subhan Khwar. The pH ranged from **8.62 to 8.43**, indicating slightly alkaline conditions. This falls within the permissible limits set by **Pakistan's National Environmental Quality Standards (NEQS)**, which recommend a pH range of **6.0 to 10.0** for wastewater, and the **World Health Organization (WHO)** guidelines, which suggest a range of **6.5 to 9.0**. The slight alkalinity observed could be attributed to industrial effluents and agricultural runoff, contributing to the accumulation of calcium carbonate and other alkaline substances in the water. Alkaline conditions can impact aquatic life and crop irrigation, as high pH levels may reduce nutrient availability and alter microbial activity.

### Electrical Conductivity (EC)

EC values ranged from 700  $\mu\text{S}/\text{cm}$  to 458  $\mu\text{S}/\text{cm}$ , surpassing the NEQS limit of 400  $\mu\text{S}/\text{cm}$ , indicating a high concentration of dissolved salts due to industrial discharge.

**Figure 2**  
*Electrical Conductivity*

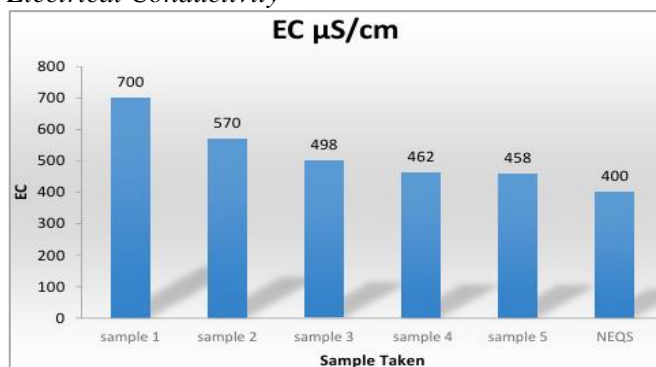


Figure 2 illustrates the electrical conductivity (EC) values of wastewater samples collected from five different locations along Subhan Khwar. The EC values ranged from **700  $\mu\text{S}/\text{cm}$**  in Sample 1 to **458  $\mu\text{S}/\text{cm}$**  in Sample 5. The highest EC was observed at the main drainage point of the marble industry, where industrial effluents are discharged directly into the stream. In contrast, the lowest EC value was recorded at the downstream location, indicating a gradual dilution effect as the wastewater mixed with cleaner water sources. According to the **National Environmental Quality Standards (NEQS)**, the permissible limit for EC in wastewater is **400  $\mu\text{S}/\text{cm}$** . All samples exceeded this limit, highlighting significant contamination due to dissolved salts and ionic compounds from marble processing activities. High EC in water indicates increased concentrations of ions such as calcium, magnesium, and bicarbonates, which can negatively impact aquatic life and reduce the suitability of the water for irrigation.

### Turbidity

The turbidity ranged between 452 NTU and 0.35 NTU, reflecting varying levels of suspended particles and indicating the impact of marble slurry on water clarity.

**Figure 3**

*Turbidity*

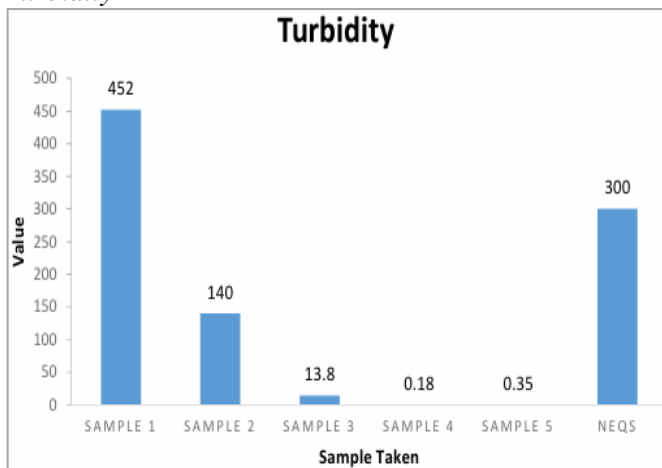


Figure 3 shows the turbidity levels of water samples collected from five different locations along Subhan Khwar. The turbidity values varied significantly across the samples, ranging from **452 NTU** in Sample 1 to as low as **0.35 NTU** in Sample 5. Notably, Samples 1, 2, and 3 exhibited higher turbidity levels, with values of **452 NTU**, **140 NTU**, and **13.8 NTU**, respectively. In contrast, Samples 4 and 5 showed much lower turbidity levels, at **0.18 NTU** and **0.35 NTU**, respectively. The **National Environmental Quality Standards (NEQS)** set a limit of **300 NTU** for industrial wastewater, meaning that Samples 1 and 2 exceeded this limit, indicating high levels of suspended solids. The elevated turbidity in these samples is attributed to direct industrial discharge from marble processing units. Suspended

materials, such as clay, silt, organic matter, and microorganisms, can scatter or absorb light, affecting water clarity and reducing light penetration. High turbidity not only impacts aquatic ecosystems but also poses challenges for water treatment processes.

### Total Dissolved Solids (TDS)

TDS values ranged from **455 mg/L** to **320 mg/L**, remaining within the acceptable range but suggesting mineral dissolution from industrial waste.

**Figure 4**

*Total Dissolved Solids*

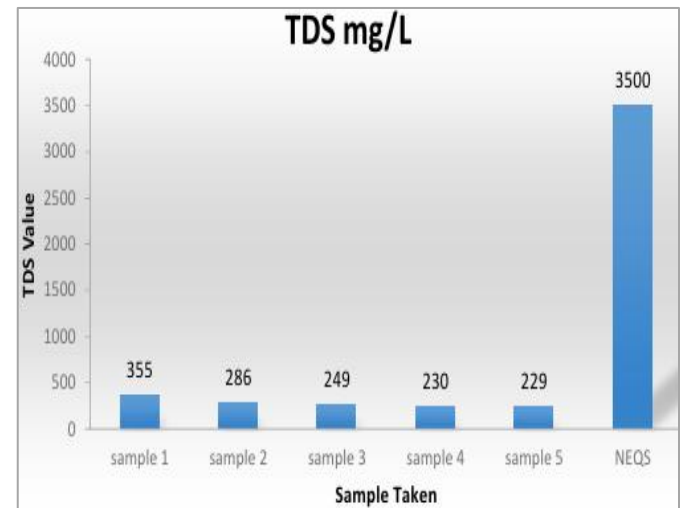


Figure 4 presents the Total Dissolved Solids (TDS) levels in wastewater samples collected from five locations along Subhan Khwar. The TDS values ranged between **455 mg/L** in Sample 1 and **229 mg/L** in Sample 5, with all values remaining well within the **National Environmental Quality Standards (NEQS)** limit of **3500 mg/L** for municipal and industrial effluents. TDS measures the combined content of inorganic salts and small amounts of organic matter dissolved in water, including calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulfates, and nitrates. Elevated TDS levels indicate increased mineral content, which could result from industrial discharge, particularly from the marble industry in this study area. High TDS can reduce water clarity, affecting aquatic plants by limiting photosynthesis due to light penetration reduction. While the measured values are within acceptable limits, continuous industrial effluent discharge can gradually increase these concentrations, impacting water quality over time.

## RESULTS AND DISCUSSION

### Alkalinity

The alkalinity values ranged from **1200 mg/L** to **900 mg/L**, exceeding the WHO permissible limit. This elevation was attributed to marble waste effluents released during the polishing of calcite and dolomite, contributing to high bicarbonate ion concentrations. The results are illustrated in **Figure 5**

**Figure 5**  
Alkalinity

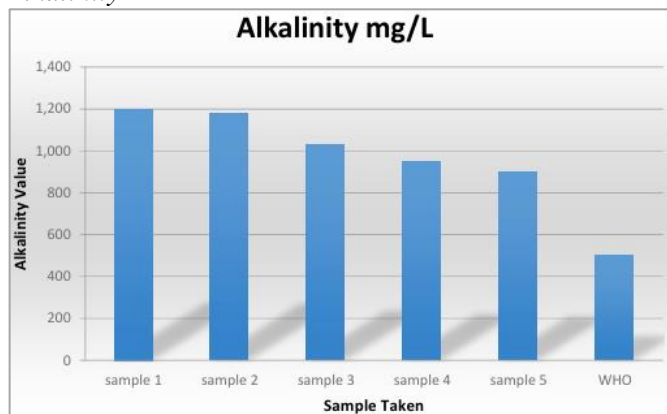


Figure 4 illustrates the alkalinity levels of wastewater samples collected from five different locations along Subhan Khwar. The alkalinity values ranged between 1200 mg/L in Sample 1 and 900 mg/L in Sample 5, all of which exceed the permissible limit set by the World Health Organization (WHO), which is 500 mg/L

Alkalinity reflects the water's ability to neutralize acids, primarily due to the presence of carbonates, bicarbonates, and hydroxide ions. High alkalinity levels observed in these samples are likely due to the discharge of marble industry effluents during the polishing process of calcite and dolomite, which releases bicarbonate ions into the water. Elevated alkalinity can lead to an unpleasant taste in drinking water and may cause scaling in pipelines and industrial equipment.

The variation in alkalinity across different samples indicates that the extent of contamination decreases downstream, as industrial effluents get diluted. However, persistent discharge from marble processing units contributes significantly to maintaining high alkalinity levels in the water

### Calcium

Calcium concentrations varied significantly, with the highest recorded value being **385 mg/L** in Sample 1. Elevated calcium levels aligned with marble industry effluents, contributing to increased hardness in the water. This is depicted in **Figure 6**

**Figure 6**  
Calcium (mg/L)

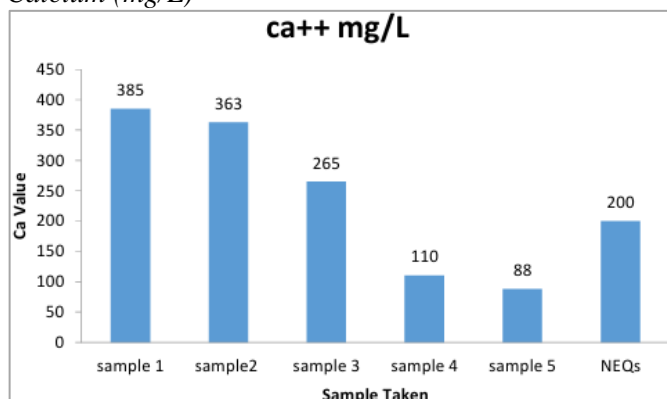


Figure 6 presents the calcium ( $\text{Ca}^{2+}$ ) concentrations in wastewater samples collected from five locations along Subhan Khwar. The calcium levels ranged from **385 mg/L** in Sample 1 to **88 mg/L** in Sample 5. The highest concentrations were observed in samples taken near marble processing units, where industrial effluents are directly discharged into the water, leading to increased calcium levels. The **World Health Organization (WHO)** recommends a maximum calcium concentration of **50 mg/L** in drinking water, meaning all samples exceeded this limit significantly. Calcium in water is usually derived from limestone ( $\text{CaCO}_3$ ), gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), and other calcium-rich minerals carried by runoff. Elevated calcium concentrations can lead to scaling in pipelines, reduced efficiency of heating systems, and the formation of hard water, which requires additional treatment for household or industrial use. In agricultural practices, excessive calcium can reduce soil permeability and affect the availability of other essential nutrients like potassium and magnesium.

### Magnesium

Magnesium levels ranged from **436.14 mg/L** to **96.86 mg/L**, following a pattern similar to calcium. The co-release of calcium and magnesium from marble effluents significantly contributed to water hardness, as shown in **Figure 7**.

**Figure 7**  
Magnesium (mg/L)

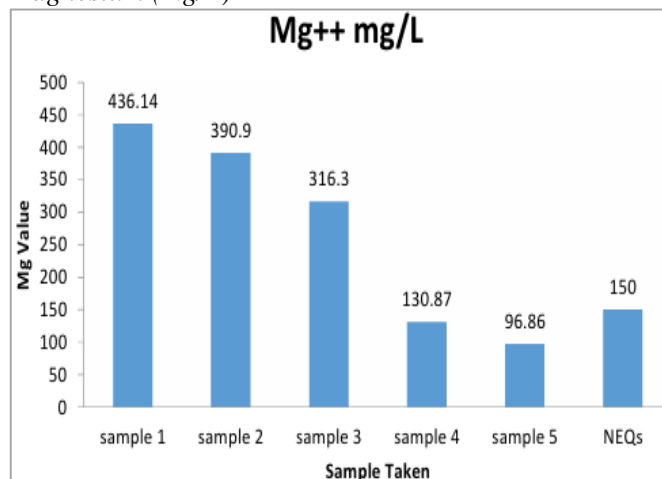


Figure 7 shows the magnesium ( $\text{Mg}^{2+}$ ) concentrations in wastewater samples collected from five locations along Subhan Khwar. The magnesium levels varied from **436.14 mg/L** in Sample 1 to **96.86 mg/L** in Sample 5. The highest concentrations were observed at sites closest to marble processing units, indicating that industrial effluents are a major source of magnesium contamination. The **World Health Organization (WHO)** recommends a limit of **150 mg/L** for magnesium in drinking water. In this study, Samples 1, 2, and 3 exceeded this limit, with values of **436.14 mg/L**, **390.9 mg/L**, and **316.3 mg/L**, respectively. Elevated magnesium levels can contribute to water hardness and

pose health risks such as diarrhea and dehydration when consumed in high concentrations. Additionally, high magnesium levels can negatively affect soil structure, leading to compaction, reduced water infiltration, and increased soil alkalinity, which impacts agricultural productivity

### Total Hardness

Total hardness values exceeded the permissible limit of **500 mg/L** in most samples, with the highest value recorded at **821.14 mg/L**. The elevated hardness resulted from increased calcium and magnesium concentrations due to industrial discharges. This data is presented in **Figure 8**

**Figure 8**

*Total Hardness*

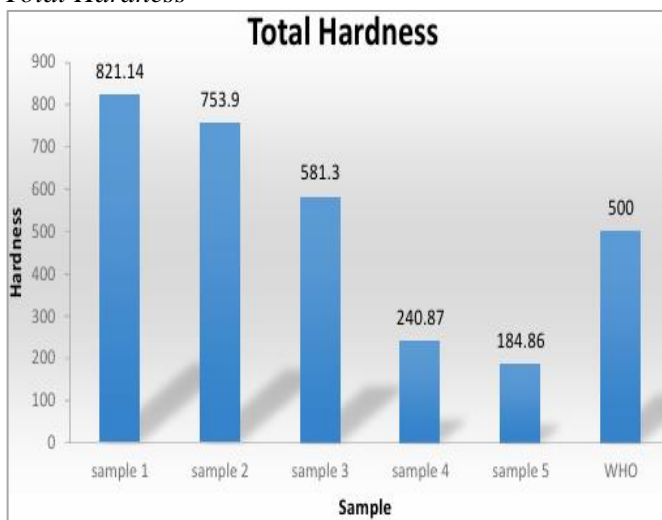


Figure 8 illustrates the total hardness of wastewater samples collected from five different locations along Subhan Khwar. The total hardness values ranged from **821.14 mg/L** in Sample 1 to **184.86 mg/L** in Sample 5, with the highest values observed at points closer to marble processing units. According to the **World Health Organization (WHO)**, the permissible limit for total hardness in water is **500 mg/L**. In this study, Samples 1, 2, and 3 exceeded this limit significantly, indicating high concentrations of calcium and magnesium ions, which are primary contributors to water hardness. Hard water is not inherently harmful to health; in fact, calcium and magnesium have protective effects against some diseases. However, high hardness levels can cause scaling in pipelines, reduce the efficiency of heating systems, and interfere with industrial processes. In agricultural practices, elevated hardness affects soil structure, reducing permeability and impacting crop productivity

### Nitrate

Nitrate concentrations ranged from **19.5 mg/L** to **2 mg/L**. While within permissible limits, the variation indicated potential contamination from industrial and agricultural runoff, as represented in **Figure 9**

**Figure 9**

*Nitrate (NO<sub>3</sub>)*

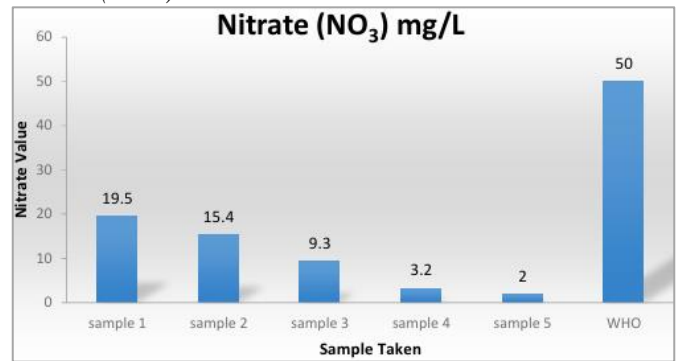


Figure 9 illustrates the nitrate (NO<sub>3</sub>) concentrations across various water samples. Nitrate in water primarily originates from agricultural runoff, dairy farm drainage, residential waste, and industrial discharges. Additional sources include sewage, leachate from abandoned landfills, and atmospheric washout. In this study, nitrate levels were found to be within the permissible limit of **50 mg/L** set by the **WHO**. Nitrate is essential for plants, animals, and humans; however, its excess can be harmful to aquatic ecosystems and human health. Elevated nitrate levels contribute to **eutrophication**, promoting unhealthy algal growth. Furthermore, concentrations above **10 ppm** can impair the ability of red blood cells to transport oxygen, leading to conditions such as **blue baby disease**. The data in Figure 4.9 confirms that nitrate levels in the analyzed samples remained below the threshold, indicating minimal contamination from agricultural or industrial activities

### CONCLUSION AND FUTURE PERSPECTIVE

The study of marble industrial effluents in Tehsil Shabqadar, Khyber Pakhtunkhwa, highlights significant environmental impacts on water and soil quality. The discharge of untreated effluents into nearby water bodies leads to the accumulation of suspended solids, heavy metals, and other pollutants, resulting in water contamination. This alters water chemistry, increases turbidity, and reduces dissolved oxygen levels, posing risks to aquatic life and making the water unsuitable for human consumption and agricultural use.

Likewise, the disposal of marble waste into the soil affects its physical and chemical properties. High concentrations of calcium carbonate and other residues alter soil pH, disrupt nutrient balance, and reduce fertility. Over time, these changes degrade soil structure, hinder plant growth, and lower agricultural productivity, impacting local farming communities.

Future efforts should focus on developing and implementing eco-friendly, cost-effective treatment technologies to reduce pollutant loads before discharge. Techniques such as phytoremediation, constructed wetlands, and advanced filtration methods offer promising solutions. Regular environmental monitoring

and stricter enforcement of regulations are essential to minimize pollution and ensure compliance with environmental standards.

Raising awareness about sustainable practices among industrial operators is crucial to promoting cleaner production techniques. Collaboration between policymakers, environmental agencies, and local communities is needed to develop effective management

plans that balance industrial growth with environmental protection.

In conclusion, mitigating the environmental impacts of marble effluents requires a multi-faceted approach combining scientific innovation, regulatory measures, and community engagement to ensure long-term environmental sustainability.

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