FACULTY OF TECHNOLOGY

Environmentally Friendly Alternatives to Reduce Dust Emission and Salt Use in the Sand and Stone Production Industry

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ABSTRACT

This study investigated environmentally friendly alternatives to reduce dust emissions and salt use in the sand and stone production industry to mitigate groundwater contamination. A qualitative research methodology was employed, utilizing online questionnaires and focused group interviews to gather insights from industry experts, focusing on the current status of dust control in the aggregate industry, groundwater monitoring practices, and opinions on new environmental approaches. The survey findings revealed that salt mixed with water was the most commonly used method for dust control, followed by salt application and water spraying. Challenges identified included obtaining environmental permits, concerns over groundwater contamination, water shortage, and limited knowledge about alternative options. Regional variations were observed in the permitting processes; however, restrictions on the use of salt in the processes were common. Experts expressed concerns about nitrates, petroleum products, and heavy metals. Compliance with regulatory agencies and prompt actions in the event of groundwater contamination were emphasized. Water was widely acknowledged as an environmentally friendly component in dust control. The sand and stone production industry showed receptiveness to exploring environmentally friendly alternatives for dust control. Future research recommendations include evaluating the effects of salt usage, exploring environmentally beneficial alternatives, and improving high-pressure water-spreading systems in quarries.

Keywords: Groundwater pollution; Water quality; Saltwater alternatives; Aggregate industry; Dust; Dust emission

FOREWORD

I would like to express my sincere gratitude to Professor Björn Klöve for entrusting me with such a compelling dissertation topic. His guidance, valuable instructions, encouraging words, and support kept me on track throughout this endeavor. I would also like to thank him for his meticulous review of my work and for providing essential feedback to improve the thesis report.

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Oulu 19.07.2023 Tonmoy Roy Tonu

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1. INTRODUCTION

1.1 BACKGROUND

The sand and stone production industry significantly contributes to local dust emissions. Salt addition is currently used to prevent dust emissions; however, this can lead to groundwater contamination (US EPA, 2023). Since dust emissions from sand and stone production operations can negatively impact vegetation, ecosystems, and human health (Niosh, 2019), making them a primary environmental concern. Dust particles can also travel long distances, leading to regional air pollution (EPA, 2023c). In order to reduce dust emissions, saltwater has been widely used for decades in aggregate production. In Finland, the utilization of salt water in aggregate production is often confined by environmental authorities because of its adverse environmental effects, especially on groundwater, as it can drain into the soil and contaminate the water supply (Oscarsson, 2007). As a result, aggregate producers are looking for new ways to manage dust emissions in order to obtain environmental permits.

The study focused on finding saltwater substitutes, evaluating their efficiency in lowering dust emissions, and exploring the potential environmental and financial effects of using these substitutes. The findings of this research provide valuable information to aggregate industries' stakeholders and policymakers to inform decision-making regarding saltwater use and enhance their ability to fulfill the requirements to get the environmental permit without negatively impacting the environment.

A qualitative research methodology was used in this research to get insights from industry experts and stakeholders. Questionnaires and interviews were chosen as the methodology as they are the most effective way to collect data since less information is published about the alternatives to salt water. This methodology was expected to provide valuable insights into the current practices used to reduce dust emissions, the potential for environmentally friendly alternatives to salt water, and the challenges faced by the industry. In addition, questionnaires provide a structured format for collecting data from many people, while interviews allow for more in-depth conversations with key stakeholders.

This research study was ordered by INFRA ry, to examine the current dust control methods in sand and stone production and explore the possibility of using environmentally friendly alternatives to saltwater. The potential environmental impacts of these alternatives, as well as their feasibility in Finland, were considered. Overall, this study discussed the potential for utilizing environmentally friendly alternatives to saltwater in the sand and stone production industry to lower dust emissions and reduce groundwater pollution, as well as the potential advantages of using these alternatives and potential difficulties in putting them into practice. It has also offered recommendations for further study and implementation of these alternatives.

1.2 OBJECTIVES

The main aim of this research was to explore the feasibility of environmentally friendly alternatives to saltwater in reducing dust emissions in the sand and stone production industry to minimize groundwater pollution and obtain environmental permits.

Specific objectives include:

- Identify the current methods used in the sand and stone production industry to reduce dust emissions in Finland and some other countries.
- Analyze the environmental impacts of saltwater on groundwater pollution.
- Investigate the potential of environmentally friendly alternatives to saltwater in reducing dust emissions.
- Assess the cost-effectiveness of environmentally friendly alternatives to saltwater.
- Evaluate the effectiveness of the proposed alternatives in reducing dust emissions.
- Recommend the most suitable alternative for reducing dust emissions for the sand and stone production industry.

1.3 AGGREGATE PRODUCTS

1.3.1 AGGREGATES

The European Aggregates Association states that "aggregates are granular construction materials comprised of various substances, including sand, gravel, crushed rock, marine aggregates, recycled aggregates, and manufactured aggregates." These materials serve as essential components in producing various construction products and infrastructure. Natural sources, such as quarries, sand and gravel pits, and, in some nations, marine dredging, are used to extract primary aggregates. Secondary aggregates, on the other hand, are comprised of recycled and reclaimed materials from previous construction projects. In addition, manufactured aggregates are derived from industrial byproducts, including electric furnace slag, blast furnace slag, and china clay residues. (UEPG, 2023)

Aggregates are essential for the construction sector since they are components of concrete, asphalt, and other building materials. Roads, bridges, buildings and other infrastructure could not be constructed firmly without aggregates. Moreover, adding aggregates to construction materials gives them strength, durability, and other crucial qualities. The following are different types of aggregates (Figure 1) and their importance in construction (See Figure 2).

Sand

Sand is a fine-grained substance comprising mineral grains and small rock fragments frequently used to produce concrete, mortar, and plaster as a foundation for paving (BuildersMART, 2019). The granular material known as sand consists of small fragments of limestone and minerals and is a naturally occurring component. It is frequently used as a foundation material for concrete and asphalt. In addition, it is used for drainage projects, including roadside edge drains, retaining wall drains, foundation drains, as well as French drains, and sanitary drain fields. (Hanganu, 2021)

Gravel

Gravel is a loose accumulation of rock pieces and consists of rounded or angular rock fragments, usually larger than sand. Gravel is widely used in creating concrete, building roads, installing drainage systems, landscaping tasks, and as a base material for driveways, walks, roads, and drainage applications. (Buildings, 2020)

Crushed rock

In order to produce construction materials like crushed rock, suitable rock deposits must first be mined, and the retrieved rock is then crushed to the required size (Wikipedia, 2022). Crushed rock is utilized in construction projects as aggregate. Limestone, dolomite, granite, and traprock are common rock types used to make crushed rock. (Coalition, 2023)

Marine aggregates

Marine aggregates are sourced from the seabed through dredging operations, which serve various purposes, including beach nourishment, coastal protection, and construction projects in coastal areas. (Tarmac, 2023)

Manufactured aggregates

Industrial operations are the source of manufactured aggregates. For example, these aggregates are manufactured using stone-crushing equipment to pulverize solid rocks. Manufacturing aggregates differ from gravel as well as sand in terms of particle size, texture, and shape. Manufactured aggregates frequently have an angular shape, rough surface texture, and poor size distribution due to the crushing process. They also frequently have a cubical or elongated shape. The proper crushing methods and apparatus can improve aggregate form and size distribution. (Yuan et al., 2021) These aggregates find applications in concrete production, road construction, and other building materials (Aggregates, 2022).

Recycled aggregates

Recycled aggregates are materials obtained from the processing and reprocessing of previously used construction materials. Recycled aggregate produced from construction detritus could reduce the demand for natural materials and the associated mining concerns. When demolished building residue is recycled for use in new construction, the lifespan of building components is extended. The construction industry could reduce waste and contributes to sustainable practices by recycling and reusing materials. (Yuan et al., 2021)

Figure 1. Different types of aggregates.

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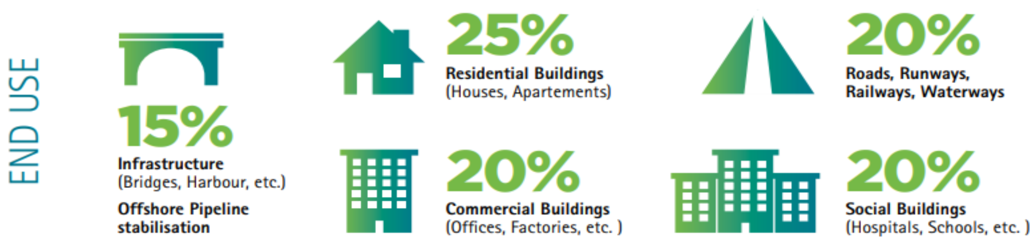

Figure 2. Aggregates in construction.

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1.3.2 DUST EMISSIONS AND ITS IMPACTS

According to Oyedele et al. (2019), during the production of aggregate, dust is generated and emitted in the quarry during the operations by the wind, the use of crushing and screening equipment, construction activities, and vehicle traffic on access and haul roads. In addition, weather variables like wind, temperature, and rainfall significantly impact dust levels. Moreover, dust is typically produced in more significant quantities in hot, dry environments. In the same study, Oyedele et al. (2019) also noted that dust comprises particulate components of air pollutants that are solid particles with a diameter ranging between 1 and 100 µm. The authors claim that these materials frequently include metals or mineral compounds in the same size range (<100 µm) and soil or rock material (silica and silicates). To illustrate, metal-oxides, trace metals, non-metals including arsenic, coal, phosphorous, asbestos, and metals including lead, manganese, chromium, iron, nickel, and vanadium fall into these materials. Additionally, the particles have additional substances, including fly ash (solids from burning coal) and smoke (liquid, gas and solid).

Silica, also known as quartz, is found in various rocks, gravel, clays, and sands, as well as shale. Fine particles containing crystalline silica can pose health risks to individuals working in the quarry industry. Workers in such industries with significant exposure to this dust can develop a chronic lung disease called silicosis, which could be severely disabling. In addition to the risks associated with silicosis, evidence suggests that long and heavy exposure to dust-containing silica increases the risk of developing lung cancer. However, this increased risk appears to be more prevalent among workers who have already developed silicosis. (HSE, 2023)

Narayanan (2009) claims that particles in the atmosphere are intricate combinations of organic and inorganic materials that can be either liquids, solids, or a combination of both. The study notes that:

- Road transportation accounts for 25% of the principal sources of airborne particles
- Non-combustion industrial operations (such as drilling, blasting, and mining) (40%)
- Public electricity generation (such as coal combustion in thermal power facilities) (15%), and
- Other sources (20%)

In addition, the particles typically resist domineers and pose substantial health risks to people when inhaled (Table 1).

Table 1: Additional environmental Contaminants (dust/particles) associated with quarrying and their effects (Narayanan, 2009).

S/No.	Contaminants	Source	Health Risk
1	Arsenic	Mining	Lung and Skin Cancer
2	Asbestos	Mining	Asbestosis Lung Cancer
3	Cadmium	Mining (Zinc-ore)	Kidney Damage
4	Chromium	Mining	CNS Deterioration
5	Coal/Fly Ash	Mining/Power generation	Black Lung Cancer
6	Iron	Mining	Nausea and Vomiting
7	Lead	Mining	CNS Deterioration
8	Nickel	Mining	Bronchial Cancer
9	Phosphorous	Mining	Gastro-Irritation
10	Vanadium	Mining (Coal-ores)	Cough, Conjunctivitis
11	Manganese	Mining	CNS Deterioration
12	Silica	Quarrying/Aggregates Production	Silicosis
13	Zinc	Mining/Metallurgy	Toxic

Oyedele et al. (2019) reported several environmental effects of quarry dust. For example, dust affects vegetation through physical as well as chemical processes. According to their study, in the physical process, the presence of dust on a leaf's surface can reduce the amount of light accessible for photosynthesis, or obstruct stomata. In addition, occlusion may increase the resistance to gas exchange or prevent full stomata closure, which results in water stress. Moreover, one common reaction to dust exposure is increased transpiration. During the chemical process, quarry dust from operations involving hard acidic rocks or some sandstone may be relatively inert or strongly alkaline (limestone). In addition, on the surfaces of leaves, alkaline quarry dust may have adverse chemical effects. Moreover, pest and pathogen infestation is likely to increase. (Oyedele et al., 2019). Additionally, the soil may have indirect effects, particularly if alkaline quarry dust is dumped on acidic soils, which can raise the pH and the amount of calcium available, changing the composition of the invertebrate community and the vegetation. If the quarry dust is alkaline or can provide limiting minerals (such as calcium or magnesium), there may be local beneficial effects for unmanaged ecosystems made acidic by atmospheric deposition of sulphuric and nitric acids. (Oyedele et al., 2019)

2. LITERATURE REVIEW

2.1 AFFECTS ON GROUNDWATER

2.1.1 GROUNDWATER

Groundwater refers to the water beneath the surface of soil, sediment, and rock (Figure 3). The storage and slow movement of groundwater occur within geologic formations known as aquifers, which are typically composed of fractured rock or sandstone and sand as well as gravel. These materials possess interconnected and spacious voids, making them permeable and enabling water movement. The groundwater flow rate depends on the extent of the voids within the rock or soil and their degree of connectivity. (Foundation, 2022)

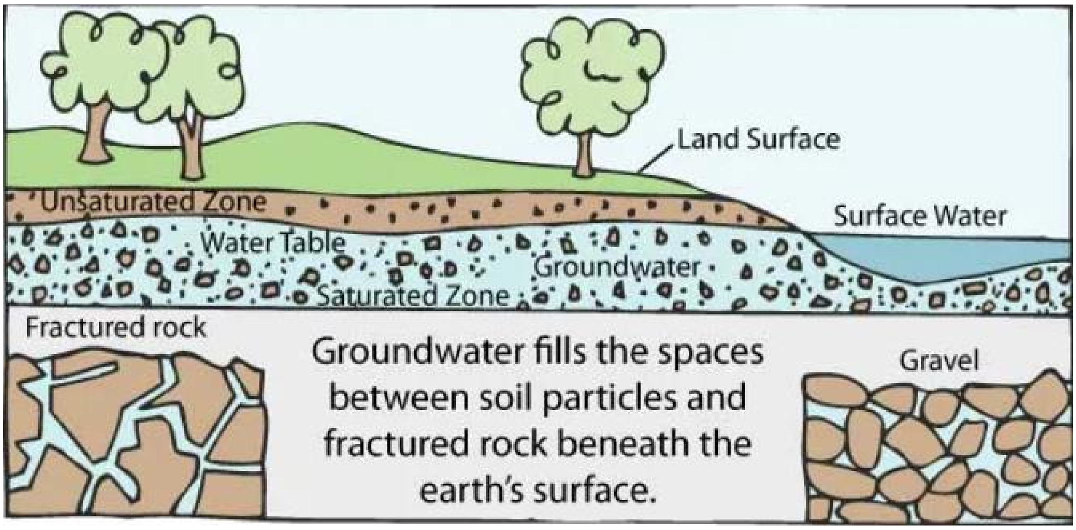

Figure 3. Schematic representation of groundwater.

Groundwater is widely distributed and can be found in various locations. The depth of the water table, which represents the upper boundary of the saturated zone, can vary from shallow to deep and fluctuate in response to multiple factors. Heavy precipitation or snowmelt can raise the water table, whereas extensive groundwater extraction can lower it. (Foundation, 2022)

The replenishment, or recharge, of groundwater occurs through the infiltration of rainwater and melting snow into cracks as well as crevices under the surface of the land. However, in certain regions of the world, severe water shortages are experienced as groundwater is exploited faster than its natural replenishment. Additionally, human activities contribute to the groundwater pollution in various regions. Pollutants can readily contaminate groundwater where the soil above the aquifer is accessible. Consequently, if groundwater becomes polluted, it loses its suitability for drinking purposes and can no longer be considered safe. (Foundation, 2022)

Importance of groundwater

Water availability of adequate quality is important to numerous ecosystems and economic sectors in Europe. As a safe and sustainable resource, groundwater plays a crucial role in meeting the demands for drinking water, agriculture, industry, and tourism. Specifically, the fulfillment of water requirements for drinking and agriculture heavily relies on groundwater, which constitutes 65% of the drinking water supply and 25% of the water used for agricultural irrigation. However, protecting groundwater from pollution and excessive exploitation is essential due to its finite nature. This safeguarding is crucial to ensure the long-term sustainability of groundwater for both human activities and natural ecosystems. (European Environment Agency, 2022)

Groundwater is an integral component of the natural water cycle, and once it becomes degraded or depleted, the recovery process may take years or even decades (European Environment Agency, 2022). Therefore, it is imperative to prioritize the preservation and sustainable management of groundwater resources to maintain their availability and quality for present and future generations.

2.1.2 SALT USE IN AGGREGATE PRODUCTION

The challenges associated with dust generation during aggregate production, a crucial component in construction projects, necessitate effective dust-control methods. Dust poses risks to human health and can hinder performance and operational security, making it essential to address this issue.

One effective method of dust suppression in the aggregate industry is using salt. Salt, particularly calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$), is commonly employed as a dust suppressant due to its hygroscopic properties. Hygroscopic substances attract moisture from the air; in the case of salt, this moisture helps prevent dust particles from becoming airborne. When salt is applied to the road's surface, it actively absorbs moisture from the air and creates a thin layer of brine, essentially water saturated with sodium chloride. This brine helps weigh down the dust particles, preventing them from becoming airborne. (Chloride, 2023)

Calcium chloride is best applied for optimal effectiveness just before the roads reach a dry and dusty state, as it can retain the moisture already present on the road surface (Figure 4). The recommended method for applying calcium chloride involves utilizing a tank truck equipped with a rear-mounted distribution bar (Figure 5). This ensures the liquid solution's even spreading over the road surface (see Figure 6). Specifically, an 18% calcium chloride solution is commonly used for this purpose. (Southwest Middlesex, 2023)

Figure 4. Watering the road surface until it is lightly saturated.

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Figure 5. Applying calcium chloride uniformly across the entire width of the road.

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Figure 6. Road surface treated with calcium chloride.

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Additionally, salt aids in stabilizing the aggregate surface, reducing dust generated by vehicle traffic or other activities on the surface. For instance, calcium chloride absorbs moisture from the air, producing a solution in road gravel that maintains the road's surfaces consistently moist despite a dry and hot environment. Moisture aids in adhering particulates together, resulting in a dense and compact road texture. In addition, calcium chloride penetrates a few inches into the road's base, enhancing the overall stability of the road surface. It also reduces the freezing point of the condensation on the road surface, thereby minimizing wintertime frost heave degradation. (Chloride, 2023)

Various other dust-control strategies, such as lignin, asphalt emulsions, natural clays, and plant oils, exist, chloride solutions, including salt-based options, are the most widely utilized. Water is a transient dust suppressant on gravel pits, quarries, and construction sites. Water can bind gravel particles together and prevent dust; however, it requires repeated application to maintain proper moisture levels. This results in apparatus costs as well as high labor, especially in arid regions. (Chloride, 2023) Contrarily, salt can regulate dust by holding moisture in the road surface for longer periods, reducing the need to water roads frequently. The crust formed by salt on the road surface temporarily reduces particulate levels. (Dust-A-Side, 2019) Thus, unlike alternative dust-control methods such as water, salt-based solutions offer long-lasting effectiveness, making them a preferred choice in many scenarios.

2.1.3 EFFECTS OF SALT USE ON GROUNDWATER

One major drawback of using chlorides as a dust suppressant is their solubility in water (Oscarsson, 2007). In the absence of water, the salt remains stored below ground, and salinity does not pose a problem. However, due to the salt solubility in water, and the movement of water as groundwater beneath the ground surface, interactions between groundwater and the ground surface can lead to the development of salinity. As groundwater flows through the ground, salts become dissolved and can accumulate in the soil near or at the ground surface when the groundwater level is within 2 meters from the surface. This salt concentration occurs when the water evaporates, leaving behind the non-evaporable salt. (CMA, 2023)

Aquifers located beneath industrial areas can serve as valuable sources of potable water. However, the release of contaminants from both point sources and diffuse sources in industrial areas can significantly impact groundwater quality, affecting its suitability for human consumption. Common chemicals threatening groundwater quality in industrial areas include nutrients, metals, hydrocarbons, and chlorinated solvents. (European Environment Agency, 2022)

Impacts on vegetation and soil

Plants' growth and vitality rely on water absorption through their roots, making them susceptible to saltwater contamination. Salt inhibits plant roots' ability to absorb water by interfering with their osmotic process. Similar to the effects of drought, this restriction can cause a decline in the health and vitality of vegetation, ultimately resulting in plant mortality. Additionally, salt can alter soil clay particles' structure, causing compaction and erosion. These changes disrupt the soil's moisture retention and drainage properties, further impacting plant growth and soil health. (CMA, 2023)

Biodiversity loss and aesthetic degradation

Salt in groundwater has a profound impact on both vegetation and the soil that supports it, posing obstacles to the survival of plant and animal species. As salt concentrations increase in an area, it becomes increasingly challenging for salt-sensitive species to thrive. Consequently, the biodiversity of the affected area diminishes as species die off or migrate, leaving only a few salt-tolerant species dominating the ecosystem. This loss of biodiversity not only affects the ecological balance but also diminishes the aesthetic beauty of the area, impacting its visual appeal. (CMA, 2023)

Degradation of man-made structures

Structures in contact with the ground, such as buildings and infrastructure, are also susceptible to the detrimental effects of saltwater contamination. Salt, an electrolyte, accelerates the corrosion process of metals, particularly iron. Exposure to salty water increases the rate of metal corrosion compared to exposure to pure water alone. In addition, salty water possesses mild acidity, which can degrade concrete. The corrosion of steel reinforcement within concrete weakens the overall strength of structures, while the deterioration of concrete itself further compromises its stability. Moreover, salt's hygroscopic properties contribute to the absorption and retention of water, leading to freeze-thaw damage in materials like concrete, wood, and brick. This damage is particularly prominent around the foundations of buildings, resulting in cracks and fractures. (CMA, 2023)

Health risks

Groundwater contamination from microorganisms or synthetic chemicals poses significant health risks. Drinking water contaminated with bacteria and viruses can lead to illnesses like hepatitis, cholera, or giardiasis. Methemoglobinemia can be caused by high nitrate levels in drinking water, particularly affecting infants. Additionally, lead contamination in drinking water is associated with learning disorders in children, nerve, liver, and kidney problems, as well as pregnancy-related dangers. While regulations exist for some contaminants, many other chemicals remain unregulated, with their health effects inadequately understood. It is essential to prevent pollutants from entering groundwater in order to reduce the health hazards linked to poor drinking water quality. (Epa, 2023)

Overall, the environmental and health impacts of saltwater contamination of groundwater are extensive; risks posed to vegetation, soil, and human health. Understanding these effects and implementing appropriate mitigation measures are essential for preserving ecosystems, maintaining biodiversity, and safeguarding the well-being of communities dependent on groundwater resources.

2.1.4 REGULATIONS TO PROTECT GROUNDWATER

According to the Ministry of the Environment, groundwater protection aims to maintain a decent qualitative and quantitative groundwater status, which holds significant importance in Finland due to its susceptibility to human activities. In order to avert the deterioration of groundwater quality, preventative measures must be implemented. (Ministry of the Environment, 2023)

Groundwater protection and the associated legislation are the responsibility of the Ministry of the Environment. The Ministry collaborates with various stakeholders to ensure effective measures are in place to safeguard groundwater resources. (Ministry of the Environment, 2023)

In addition, section 17 of the Environmental Protection Act (527/2014) prohibits groundwater pollution, a vital provision in Finland's groundwater protection framework. Additionally, section 16 of the same Act addresses the prohibition against soil contamination, emphasizing the need to protect groundwater quality from pollution originating through the soil.

Section 4a of the Government Decree on Substances Dangerous and Harmful to the Aquatic Environment (1022/2006), which restricts the emission of pollutants into groundwater, provides further details of the prohibition. Moreover, chapter 14 of the Environmental Protection Act establishes regulations for treating contaminated soil and polluted groundwater.

Meanwhile, the Act on the Organisation of River Basin Management and the Marine Strategy (1299/2004) requires groundwater to maintain a good status in quantity and quality. It strictly forbids the degradation of groundwater classified as "good" and emphasizes identifying and reducing substances that weaken its status. The Economic Development, Transport, and Environment Centres determine groundwater areas and classify them according to their suitability for water abstraction and their requirement for protection. Groundwater protection plans propose additional measures in addition to those outlined in the Act's action plans for attaining a good groundwater status. (Ministry of the Environment, 2023)

Additionally, the Government Decree on Water Resources Management (1040/2006) establishes environmental quality standards that serve as benchmarks for evaluating the health of groundwater. These standards ensure that levels of harmful substances in aquatic ecosystems are not exceeded, protecting both human health and the environment.

Furthermore, the Water Act (587/2011) administered by the Ministry of Justice contains provisions regarding permits needed to conduct water resources management projects, obligations associated with these authorizations, and regulations regarding water abstraction, protected areas surrounding abstraction locations, coordination of abstraction requires, and the preservation of aquatic ecosystems. Notably, a permit from the Regional State Administrative Agency referred to in the Water Act, is mandatory for the abstraction of water planned for municipal water supplies. (Ministry of the Environment, 2023)

2.2 ENVIRONMENTAL DUST CONTROL

2.2.1 DUST SUPPRESSANTS

Dust suppressants control fugitive dust from unpaved roads, construction sites, and mining operations. This literature review examines different dust suppressants, focusing on their basic information and potential environmental implications. Major dust suppressants include organic compound-based, biopolymer with chemical agents, and inorganic compound-based dust suppressants (Figure 7) (Parvej et al., 2021).

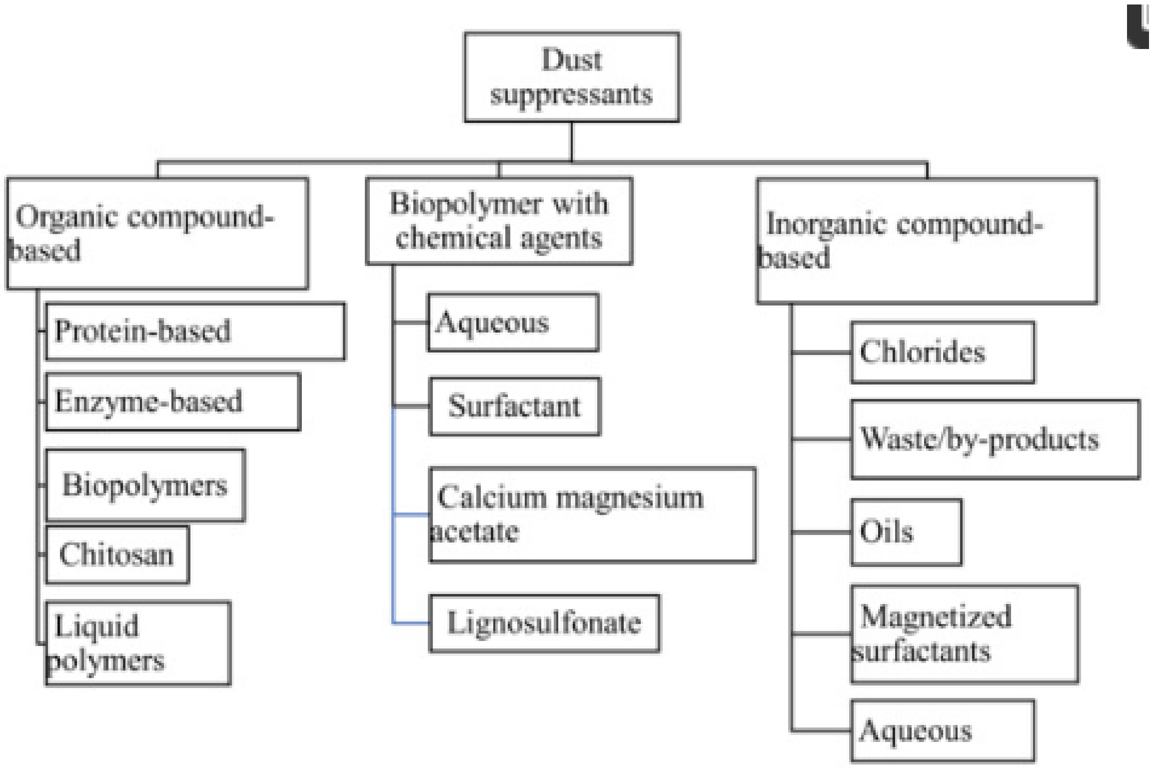

Figure 7. Flowchart depicting various categories of dust suppressants.

Organic compound-based

Organic compound-based dust suppressants are derived from natural sources such as plants, bacteria, and fungi. They can be combined with synthetic polymers to improve performance and are biodegradable. Typical examples include lignosulfonate, guar gum, and chitosan, as well as corn starch and xanthan gum. In addition to being biodegradable, these suppressants feature copious availability, increased water solubility, and low toxicity, as well as low flammability. (Parvej et al., 2021)

- **Protein-based**

Protein-based dust suppressants have water retention properties that facilitate the agglomeration of dust particles and the formation of a compact matrix, thereby reducing their propensity to become airborne (Jin et al., 2019). Examples include protein-based dust suppressants produced from molasses (Andrew et al., 2004) and dunder (Usher, 2008). They can be effective in high-dust environments such as quarries and mines (Jin et al., 2019). Protein-based suppressants are considered eco-friendly and biodegradable (Jin et al., 2019), although their higher cost limits their widespread use (Andrew et al., 2004).

- **Enzyme-based**

Enzyme-based dust suppressants are newer suppressants that utilize enzymes to lower fugitive dust (Zhan et al., 2016). Bacterial enzyme-based organic dust suppressants and enzyme-induced carbonate precipitation techniques are examples of this approach. These suppressants agglomerate dust particles and form calcite layers that provide erosion resistance. (Parvej et al., 2021) Enzyme-based dust suppressants are environmentally friendly but require frequent application, increasing maintenance costs (Zhan et al., 2016).

- **Biopolymers**

Biopolymers extracted from plants, such as corn starch and guar gum, stabilize dust particles through agglomeration (Parvej et al., 2021). Corn starch controls dust emission by restraining water evaporation, while guar gum interacts with dust particles, forming a coating that facilitates agglomeration (Zhang et al., 2018). Dust suppressants composed of cornstarch and guar gum are biodegradable and non-hazardous to the environment (Bao et al., 2019; Niaounakis, 2015).

- **Chitosan**

Chitosan, derived from chitin, is an inexpensive and degradable biopolymer used as a dust suppressant (Niaounakis and Halvadakis, 2006). It forms a shield around dust particles, preventing wind erosion (Liu et al., 2018). N-(2-hydroxyl) propyl-3-trimethyl ammonium chitosan chloride, a modified form of chitosan, has shown promising results in suppressing dust particles (Parvej et al., 2021). Dust suppressants based on chitosan are environmentally benign (SEGAL, 2016); however, may require further modification to improve solubility (Liu et al., 2018).

- **Liquid polymers**

Liquid polymer-based dust suppressants utilize polymers mixed with water to maintain moisture in dust sources, reducing the emission of fine particles. Examples include liquid amphiphilic poly triblock copolymers and polyethylene glycol solutions. Liquid polymers offer biocompatibility and eco-friendliness; however, the decomposition of certain polymers may pose a risk of secondary pollution. (Lee et al., 2019)

Bio-polymers with chemical agents

Hybrid dust suppressants combine bio-polymers with chemical agents to achieve effective dust suppression. These suppressants are designed to withstand dynamic conditions, such as heavy traffic that is moving and toppling. Lower glass transition temperature (Tg) polymers have been found to exhibit increased dust suppressant performance. However, the use of inorganic compounds in these suppressants can pose a threat to the environment. (Parvej et al., 2021)

- **Aqueous**

Polymer-based aqueous dust suppressants agglomerate dust particles using water-based polymers such as polyacrylate and synthetic rubber, as well as natural rubber, silicone polymers, and polyurethane. Different concentrations of dust suppressants, including sodium carboxymethyl cellulose (CMC A) and polyacrylamide (PAM B), as well as polyethylene oxide (PEO A), have been tested for their optimal performance in controlling dust. While these suppressants show promising results, the inorganic compounds can harm certain plant species and the environment. (Parvej et al., 2021)

- **Surfactant**

Surfactant-based dust suppressants employ additives, as well as phospholipids and surfactants, to create biodegradable aqueous-based solutions for dust control (Devi et al., 2013). These suppressants often utilize inorganic salts as synergists to enhance their dust suppression effect. However, the synergist ions used, such as sodium chloride (NaCl) and calcium chloride (CaCl2), as well as hydrated magnesium chloride (MgCl2•6H2O) and sodium sulfate (NaSO4), may have negative impacts on the environment. (Sanders and Addo, 1993)

- **Calcium magnesium acetate**

Calcium magnesium acetate (CMA), predominantly employed as a de-icer, has additionally been suggested as a dust suppressant. CMA forms a hygroscopic coating on road surfaces, keeping them moist and preventing dust entrainment. (Parvej et al., 2021) The efficacy of CMA as a dust suppressant varies depending on factors such as relative humidity, solar radiation, pavement types, and road dustiness (Norman and Johansson, 2006). Frequent application is often required for optimal results (Parvej et al., 2021).

- **Lignosulfonate**

The dust suppressant lignosulfonate (L.S.) is a naturally occurring substance produced by the sulfite digestion of plant material. L.S. can retard water evaporation and agglomerate soil or dust particles, effectively suppressing dust emissions. (Parvej et al., 2021) Field tests have shown significant reductions in dust emissions after applying L.S. as a stand-alone dust suppressant or in combination with other materials (Sanders et al., 1997). However, heavy rain can reduce the binding capability of L.S., and its water solubility limits its long-term effectiveness (Sanders and Addo, 1993). Modified L.S. dust suppressants have been synthesized to overcome these limitations (Fan et al., 2018).

Inorganic compound-based

Inorganic compound-based dust suppressants, which constitute a significant portion of dust control materials, include a variety of substances, including chloride salts as well as silicates, and surfactants (Parvej et al., 2021).

- **Chlorides**

The dust suppression capabilities of chloride-based salts, including sodium chloride (NaCl), magnesium chloride (MgCl2), and calcium chloride (CaCl), have been extensively investigated. These salts have hygroscopic properties that enable them to absorb atmospheric moisture and bind particulates together, thereby reducing dust emissions. (Parvej et al., 2021) While chloride-based dust suppressants are effective and less toxic, their adverse impact on aquatic ecosystems and the need for frequent applications should be considered (Elsholz, 2012).

- **Byproducts and waste products**

Dust suppression alternatives derived from petroleum refineries and beverage production facilities have been investigated. Expired beverages, including juices and soft drinks, have been used as dust suppressants on construction sites (Cotter, 2008). Petroleum refinery waste, Wastes from petroleum refinement, including sulphidic waste and phenolic waste, have also shown promise in agglomerating dust particles; however, further studies are required to assess these dust suppression methods' environmental and health impacts (Dixon-Hardy et al., 2008).

- **Inorganic oil chemical combination**

Triglycerides derived from natural oils and inorganic compounds have been used as dust suppressants (Hey et al., 2008). Glycerol-based non-organic suppressants, derived from biodiesel fuel co-products, have also demonstrated dust control capabilities (Medeiros et al., 2012). These suppressants form a thin layer on soil particles, blocking the wind and reducing dust emissions. Polymer emulsion and nonhazardous crude oil-containing materials have also been used for dust suppression, providing high efficiency and longevity; however, these suppressants' cost and potential environmental impurities should be considered (Parvej et al., 2021).

- **Magnetized surfactants**

Magnetized surfactants, possessing hydrophilic properties and magnetic capabilities, have been investigated for their dust suppression potential. Among the various surfactants studied, magnetized Triton solution has superior performance in reducing surface tension and capturing coal dust particles. This type of surfactant offers advantages such as availability, water solubility, and cost-effectiveness. (Ding et al., 2011)

- **Aqueous**

Aqueous-based dust suppressants, including foam-sol as well as aqueous dispersion approaches, have been explored for their ability to reduce airborne dust. Foam-sol, created through a cross-linking reaction, exhibits high viscosity and cohesion, enabling it to bind soil particles and reduce their generation in the air. (Xi et al., 2014) Aqueous dispersion streams formed through surfactant compositions have also effectively agglomerated dust particles (Brien, 2016). However, further investigation is required to assess these dust suppressants' environmental and health impacts (Xi et al., 2014).

2.2.2 IMPORTANCE OF ENVIRONMENTAL DUST CONTROL

The appropriate amount of salt required for effective dust control depends on several factors, including the type of aggregate, climate conditions, and surface activity levels. In order to prevent environmental damage and other adverse effects, avoiding the over-application of salt is crucial. (Oscarsson, 2007)

Using chlorides, such as salt-based solutions, can lead to corrosion on equipment that operates on treated roads faster than usual. Furthermore, chlorides can harm vegetation and pose risks to personnel if there is skin or eye contact. Due to their solubility in water, chlorides can also leach from a road's surface during rainfall, resulting in a progressive decline in functionality. (Niosh, 2019)

On a global scale, the use of salt significantly increases its concentration in freshwater bodies. The excess salt in the environment is toxic and can be lethal to aquatic life, pollute drinking water, and cause infrastructure damage. (US EPA, 2023)

Excessive salt can trigger a condition known as the syndrome of freshwater salinization (FSS). This phenomenon arises from direct as well as indirect salt effects on the environment, leading to increased concentrations and mobility of other contaminants in water pipelines, soil, and both surface and groundwater. Salts can accelerate the mobilization of metals from pipes and soils, exemplifying one of the impacts of salt use. Additionally, salts can elevate the concentration of radioactive elements, such as radium, in groundwater, surface water, and soils. High salinity levels can also facilitate the release of excess nutrients in the soil, such as nitrate-nitrogen, exacerbating nutrient pollution. High nutrient contamination in lakes and rivers can result in harmful algal blooms and reduced dissolved oxygen levels. The excess salt content negatively affects freshwater biodiversity and species and necessitates increased expenses for water treatment processes. (US EPA, 2023)

Considering the potential passive consequences associated with salt usage, it becomes imperative for the aggregate industry to prioritize environmentally-friendly dust control methods. By implementing passive measures, such as alternative dust suppression strategies, the industry can minimize the negative impacts on the environment and ensure sustainable operations.

3. METHODS

This research methodology utilizes an online questionnaire survey and interviews with industry representatives. The online questionnaire survey gathers data from a wider pool of industry experts, while interviews allow for more personalized and in-depth conversations. By employing this combination of methods, diverse perspectives, and insights can be obtained.

3.1 ONLINE SURVEY

An online survey was made to a diverse range of industry experts. The questionnaire design consisted of 30 questions divided into three parts which were carefully prepared by reviewing various literature sources related to the subject matter, ensuring comprehensive coverage of the relevant topics.

- Part I consisted of nine questions focused on the current status of dust control in the aggregate industry.
- Part II consisted of nine questions about groundwater monitoring in the industry.
- Part III comprised twelve questions to gather opinions on new environmental approaches.

The online survey tool Webropol (http://webropol.oulu.fi/) was selected for this study. A unique weblink was generated and sent to the respondents, ensuring that the weblink was not publicly available unless shared by the researcher. This approach maintained confidentiality and controlled access to the survey, providing a secure and controlled environment for participants to provide their responses.

The survey was conducted on April 19, 2023 and participants were given two weeks to respond. Industry experts from around 24 companies were invited to participate in the survey, and five industries actively participated. The primary roles of the participants in the industry varied, with the highest representation from management and environmental managers, both accounting for 44.4% of the participants (see figure 8). Production roles accounted for 33.3%, while quality control and other roles represented 11.1% each.

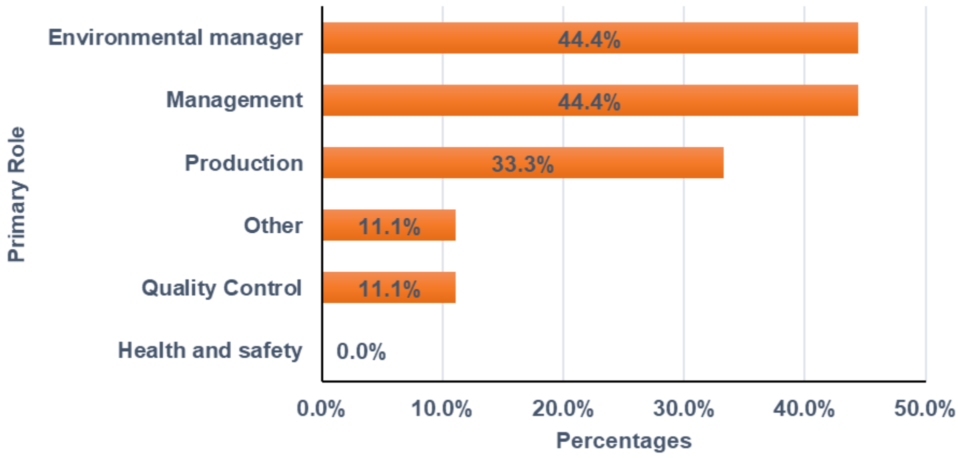

Figure 8. Primary role in the industry.

The survey questions are presented in ANNEX 1.

3.2 FOCUSED GROUP INTERVIEWS

The focused group interview was chosen for this study as it allows for collecting responses from a group of people rather than individuals, enabling the clarification of results obtained in the online survey and obtaining a broader view of the research topic (George, 2021).

Two weeks were allotted for participants to schedule and participate in the interviews (from May 29 to June 9). Five industries were invited to participate in the interview; however, three actively participated. The interview was conducted online using Microsoft Teams as the mode of communication, ensuring convenience and flexibility for participants to engage in the discussion.

The invitation process for the focused group interview involved emailing the selected industries, providing them with details of the interview and the purpose of their participation. Additionally, participants were given a Doodle link where they could select their available time slots, allowing for flexibility in scheduling the interview sessions based on their convenience.

The data collected from the focused group interviews were analyzed in conjunction with the data obtained from the online survey, aiming to gain collective results and a comprehensive understanding of the research topic. The explanation of the interview questions based on the survey findings is presented in the results and discussions section, providing insights into the perspectives shared during the interviews. The specific interview questions listed in ANNEX 2 provide a comprehensive overview of the interview procedure and the topics discussed.

4. RESULTS

4.1 CURRENT STATUS OF DUST CONTROL IN AGGREGATE INDUSTRY

The online survey findings on the current status of dust control in the aggregate industry show that all participants acknowledged water as a vital component in dust control methods, with 100% of the respondents mentioning its use (Figure 9). One common approach to dust control, mentioned by 44.4% of the experts, involved using salt mixed with water. Another method used by 33.3% of the experts involved first applying salt followed by water spraying. Contrarily, 11.1% of the respondents reported not having any specific measures in place for dust control, highlighting the need for interventions in the industry. This finding aligns with the interview data, which supported the industry's reliance on salt for dust control. The interviews revealed that regulations concerning salt usage were diligently followed, with restrictions outlined in environmental permits to safeguard groundwater quality.

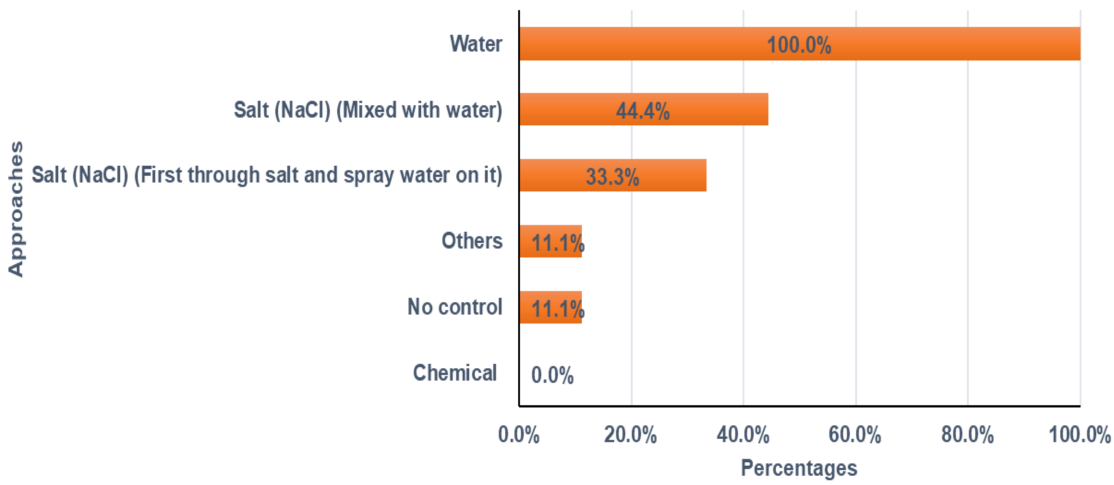

Figure 9. Company's current approaches to dust control.

The survey identified several challenges faced by the sand and stone production industries. The primary challenge included water shortage, reported by 55.6% of respondents. Following closely behind were obtaining environmental permits and needing more knowledge about alternative options, both at 44.4%. These challenges were of similar concern to the participants. In contrast, groundwater contamination concerns were reported at a lower percentage of 11.1%. While still a concern, it was identified as a relatively lesser challenge than the other factors (see Figure 10).

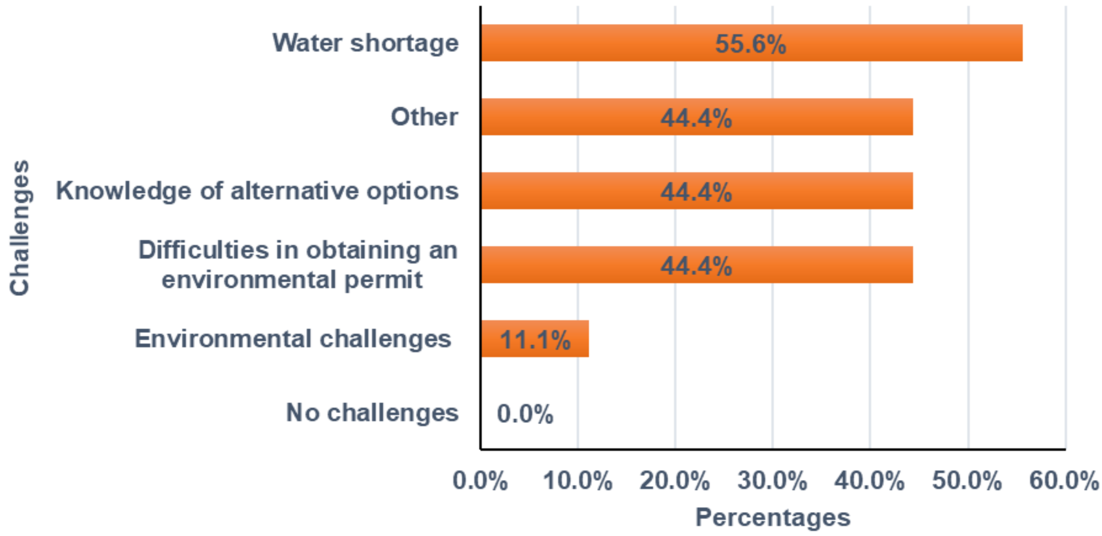

Figure 10. Challenges faced by industries with current dust control approaches.

Restrictions on salt usage were common in permitting processes, reported by 77.8% of the experts (see Figure 11). Regional differences in permitting requirements were acknowledged by 66.7% of the respondents, with specific variations highlighted in Finland, as shown in Figure 12.

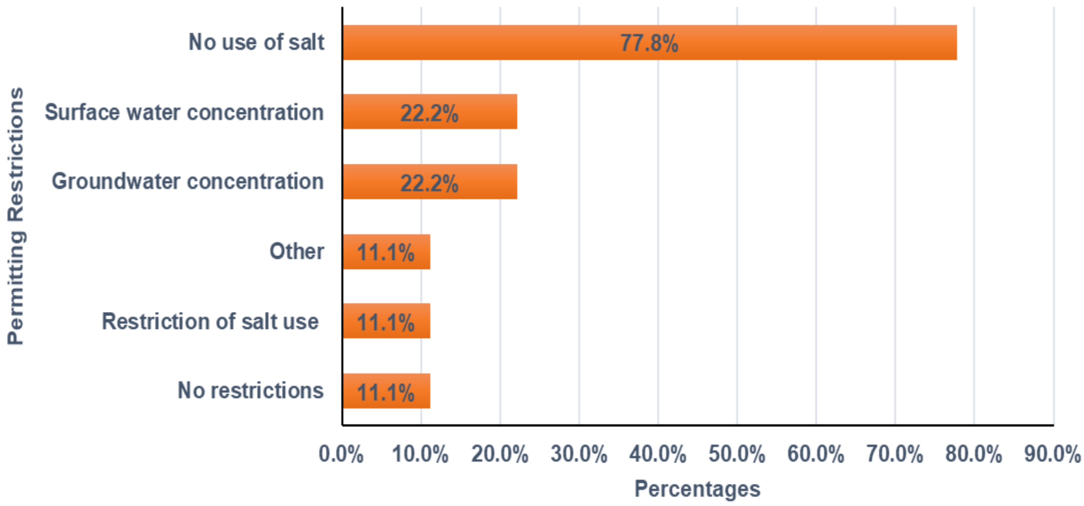

Figure 11. Permitting restrictions for a new and renewed permit.

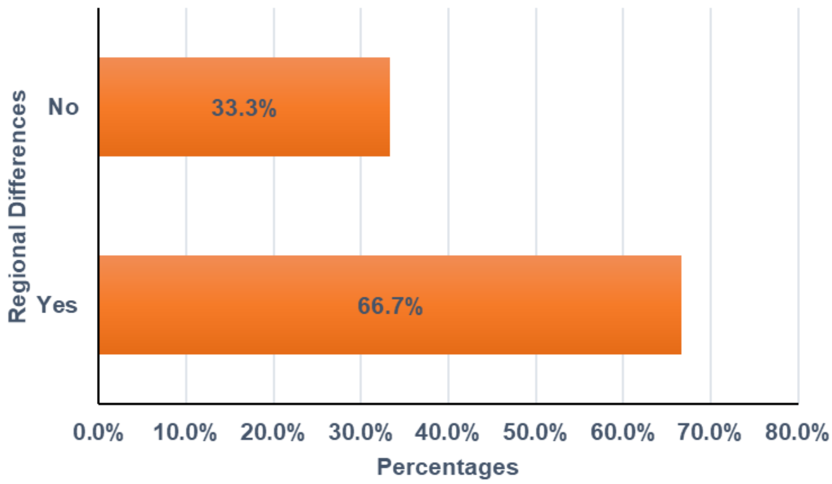

Figure 12. Regional differences in environmental dust permitting requirements.

Testing of alternative methods was limited, with 55.6% of the experts not conducting any tests (See Figure 13). Alternative methods tested included potassium-based solutions, hoovers, water jets, chemical solutions, foams, and snow; however, they were ineffective and costly.

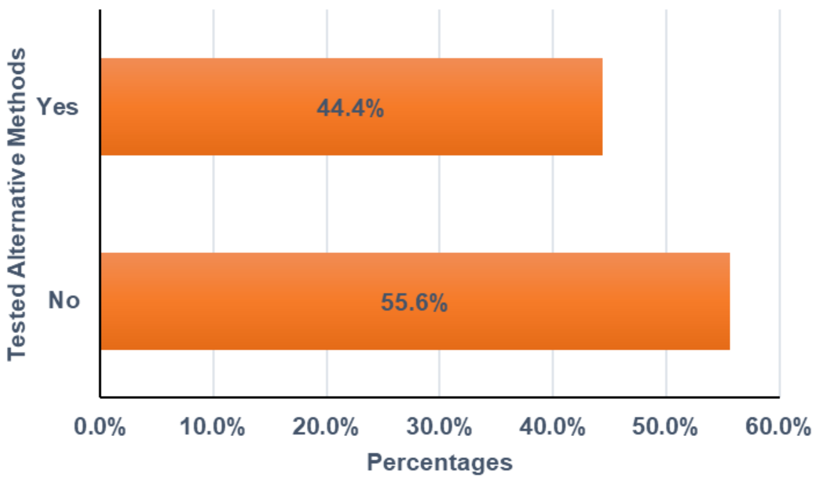

Figure 13. Alternative methods tested for dust control.

Overall, the online survey and interview findings shed light on the current state of dust control in the aggregate industry. Salt mixed with water emerged as the most common approach, supported by both sources of information. Water was acknowledged as a vital component in dust control methods, emphasizing its significance. The interview findings further highlighted the adherence to regulations regarding salt usage, particularly in areas with essential or sensitive groundwater.

4.2 STATUS OF GROUNDWATER MONITORING

The results from both the online survey and the interviews provide extensive insights into the practices of monitoring groundwater in the industry. The most commonly used method for monitoring groundwater levels, as reported in the survey, is manual measurements using rods or tapes, accounting for 77.8% of responses. Remote sensing techniques were mentioned by 22.2% of participants, while piezometers were cited by 11.1%, adopted from Figure 14. The findings from the interviews highlight that qualified monitoring companies are often responsible for carrying out these activities, demonstrating the industry's reliance on external expertise.

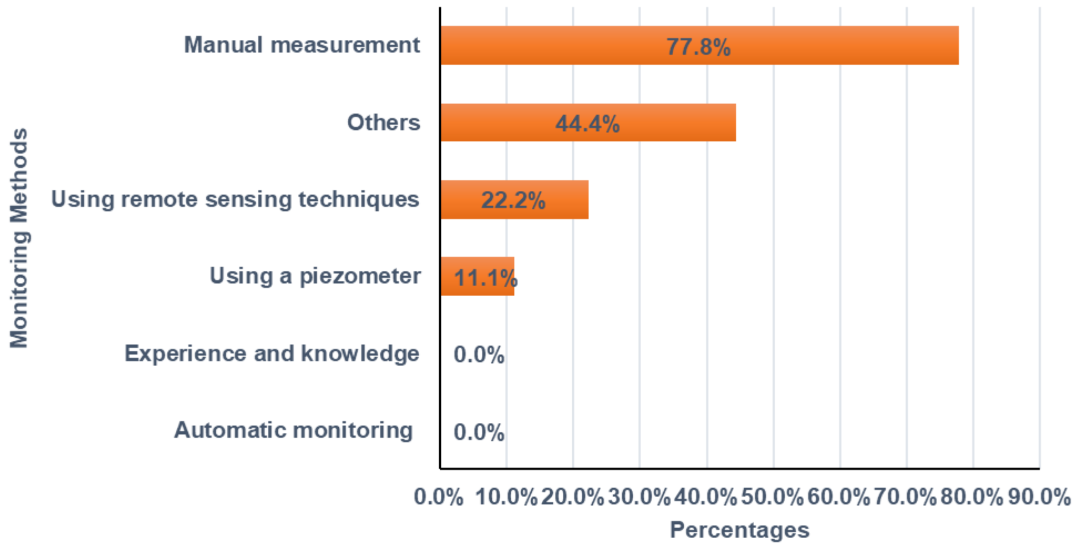

Figure 14. Commonly used methods for monitoring groundwater levels.

Seasonal monitoring was commonly practiced, allowing for tracking groundwater level changes over time, as shown in Figure 15. Regarding groundwater quality monitoring, laboratory analysis of collected samples emerged as the predominant method in the online survey (88.9%) (see Figure 16). This is further supported by the interview findings, which highlight the meticulousness of monitoring methods and companies' involvement in sampling, analysis, and reporting. Additionally, the interview responses emphasize the strict adherence to regulatory settings and monitoring requirements established by regional authorities. Compliance with permits and regulatory requirements is prioritized throughout operations, further underscoring the industry's commitment to groundwater protection.

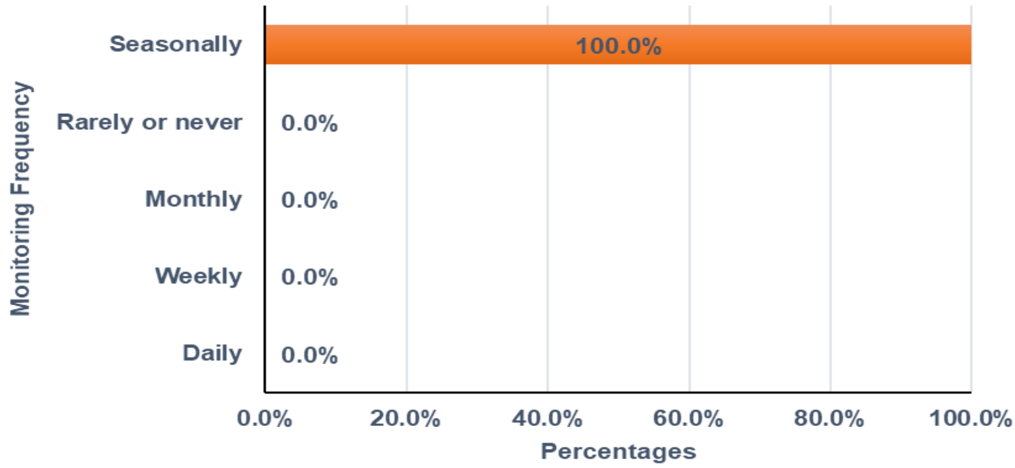

Figure 15. Groundwater monitoring frequency in the sand and stone production industries.

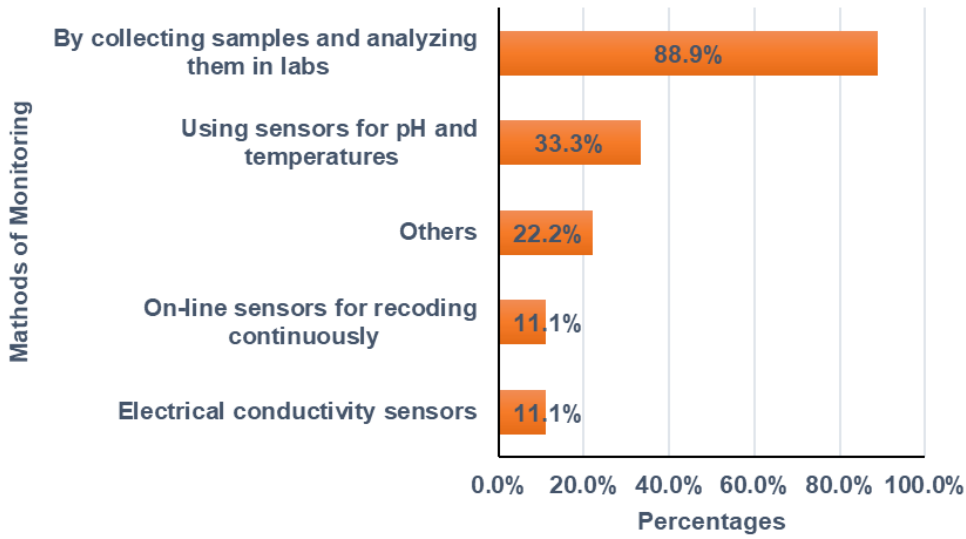

Figure 16. Commonly used methods for monitoring groundwater quality.

Both the online survey and the interviews shed light on the industry's concerns regarding contaminants and the implementation of appropriate actions. The survey identified petroleum products (77.8%), nitrates (66.7%), and heavy metals (22.2%) as significant concerns (see Figure 17), while the interview findings emphasize the immediate corrective actions taken if any alarming signs are observed. Integrating protective measures, such as maintaining sand layers as barriers, establishing vegetation, and employing double-walled oil canisters and peat sacks, indicates a proactive approach to prevent groundwater contamination.

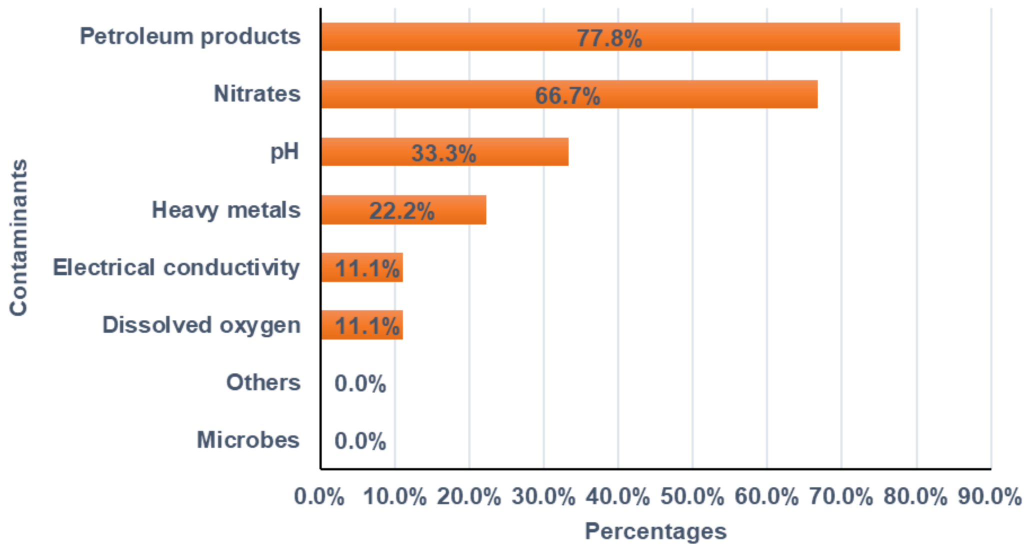

Figure 17. Groundwater contaminants.

Overall, the combined results highlight a comprehensive understanding of the significance of groundwater monitoring within the industry. The industry is strongly committed to environmental compliance and safeguarding water resources during sand and stone production activities. The integration of qualified monitoring companies and strict adherence to regulatory settings ensure that groundwater monitoring is conducted meticulously and in accordance with established guidelines. Efforts are made to prioritize environmentally friendly practices and minimize potential impacts on groundwater.

4.3 OPINIONS ON NEW ENVIRONMENTAL APPROACHES

The survey findings provide valuable insights into industry experts' opinions on new environmental approaches in the sand and stone production industry. Most experts (88.9%) are familiar with environmentally friendly alternatives for reducing dust emissions (Table 2). However, 11.1% a few admitted to being unfamiliar with these alternatives, indicating a need to bridge the knowledge gap within the industry. Despite this knowledge gap, the survey revealed a general openness among the experts, with most of the percentage expressing receptiveness towards exploring these alternatives.

Table 2: Level of familiarity of environmentally friendly alternatives to saltwater for reducing dust emissions.

Level of Familiarity	% of Respondents
Not familiar	11.1%
Slightly familiar	33.4%
Familiar	33.3%
Somewhat familiar	22.2%
Very familiar	0.0%

While no experts considered environmentally friendly methods very effective, a significant portion (44.5%) perceived them as average, and 22.2% considered them above average (Table 3). The survey also highlighted that 44.5% of the experts reported that their industry had already started utilizing environmentally friendly alternatives, with water being the predominant choice for dust control, as shone in Figure 18. However, the wider adoption of these alternatives faced challenges such as cost, availability, technical complexities, and permitting requirements.

Table 3: Level of effectiveness of environmentally friendly alternatives to saltwater for reducing dust emissions.

Level of Effectiveness	% of respondents
Not effective	11.1%
Below average	22.2%
Average	44.5%
Above average	22.2%
Very effective	0.0%

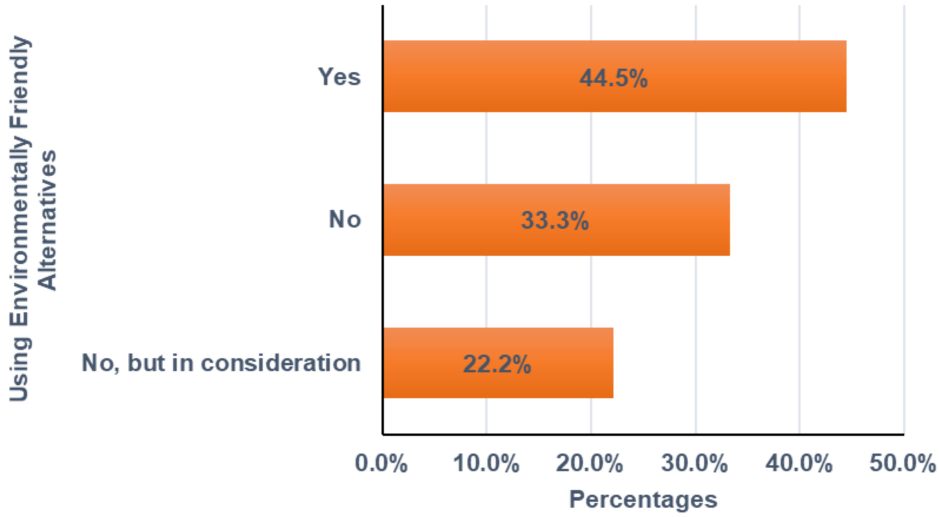

Figure 18. Adoption of environmentally friendly alternatives to saltwater for dust emission reduction.

The interview findings provided additional insights into the industry's exploration of environmentally friendly methods. Various approaches were discussed, including watering, vegetation, compost, mulching, windbreaks, gravel, biopolymers, pine oil mixed with water, and foam. While watering was acknowledged as an alternative to salt in restricted areas, it was deemed labor-intensive and inefficient. Vegetation showed promise in preventing dust emissions and promoting environmental sustainability. However, methods like compost, mulching, gravel, pine oil mixed with water, and foam were either ineffective, costly, or both. The interview findings emphasized the challenges associated with implementing environmentally friendly methods in stone production, highlighting the need for cost-effective and practical solutions.

Overall, the online survey results indicate a general receptiveness among industry experts towards environmentally friendly alternatives for dust emissions reduction, despite a knowledge gap that needs to be addressed. Water emerges as the primary choice for dust control, but challenges such as cost, availability, and technical complexities hinder wider adoption. The interview findings complement the survey results by discussing various environmentally friendly methods explored in the industry. While some methods, such as vegetation, show promise, others are ineffective or costly. Integrating survey and interview findings underscores the importance of finding cost-effective and practical solutions to promote sustainable dust control practices in the sand and stone production industry.

5. DISCUSSIONS

5.1 DUST CONTROL IN AGGREGATES

The findings from the online survey and interviews provide valuable insights into the current dust control methods in the sand and stone production industry, focusing on using saltwater and exploring environmentally friendly alternatives. Based on the results of an online questionnaire survey and interviews with industry professionals, the discussion below explains dust management strategies in the aggregate business.

Salt-based dust control methods

The online survey revealed that the most commonly reported approach to dust control in the sand and stone production industry is the use of salt mixed with water. This method, accounting for 44.4% of the responses, involves creating a saltwater solution applied to the production area to suppress dust emissions (see Figure 9). Additionally, approximately 33% of the respondents mentioned a sequential method involving using salt first and then spraying water onto it. These findings demonstrate the prevalence of salt-based dust control methods in the industry.

Water as a dust control measure

The online survey revealed that water is commonly used for dust control in the sand and stone production industry, as stated by 100% of the respondents, adopted from Figure 9. Water implementation varies from sprinkling water onto the production area to incorporating it as a primary component in dust suppression systems. Water use aligns with the industry's preference for more environmentally friendly approaches, as none of the experts mentioned using chemical-based methods. This emphasizes water's vital role in mitigating dust emissions in the industry. On the other hand, a small percentage of the experts (11.1%) mentioned other methods employed by their companies, such as watering blasted stones before the crushing process when necessary. This targeted use of water highlights the industry's focus on minimizing dust generation at specific stages of the production process, demonstrating a proactive approach to dust control.

Quantity of salt used and application frequency

The amount of salt used for dust control was unknown by approximately 40% of the experts. However, among those who were aware, around 60% provided an estimated amount of salt used per produced ton specifically for crushed rock, which was reported to be 0.03 kg. The application of salt for dust control in crushed rock production is typically carried out 1-2 times during the summer season, with a specific amount of salt applied depending on the size of the quarry area. (ANNEX 1)

The interview findings indicated that saltwater use for dust control in the sand and stone production industry is subject to restrictions imposed by authorities. In areas where groundwater is classified as essential or sensitive, salt usage is explicitly prohibited by permits. However, despite these restrictions, some companies still use salt water for dust control, adhering to regulations whenever permitted in operations. The decision to use salt water depends on its effectiveness in reducing dust and ensuring permit compliance. Authorities emphasize the need for salt or other dust-preventing chemicals not to pose any problems to groundwater quality, suggesting that concentration limits are in place for groundwater protection. (ANNEX 2)

Perception of saltwater as a dust suppression method

Approximately 28% of experts surveyed believed saltwater is a potential solution for reducing dust emissions, perceiving it as a potentially effective solution. A larger proportion (57.1%) expressed a neutral opinion, indicating a need for further evaluation or more information on the feasibility and potential impacts of using saltwater as a dust suppression method (see Figure 19). No respondents expressed a negative opinion, suggesting that using saltwater in the industry is generally viewed favourably or at least not as detrimental. Additionally, 28.6% of the experts considered saltwater the only available dust control method, indicating a reliance on this particular approach due to a lack of viable alternatives.

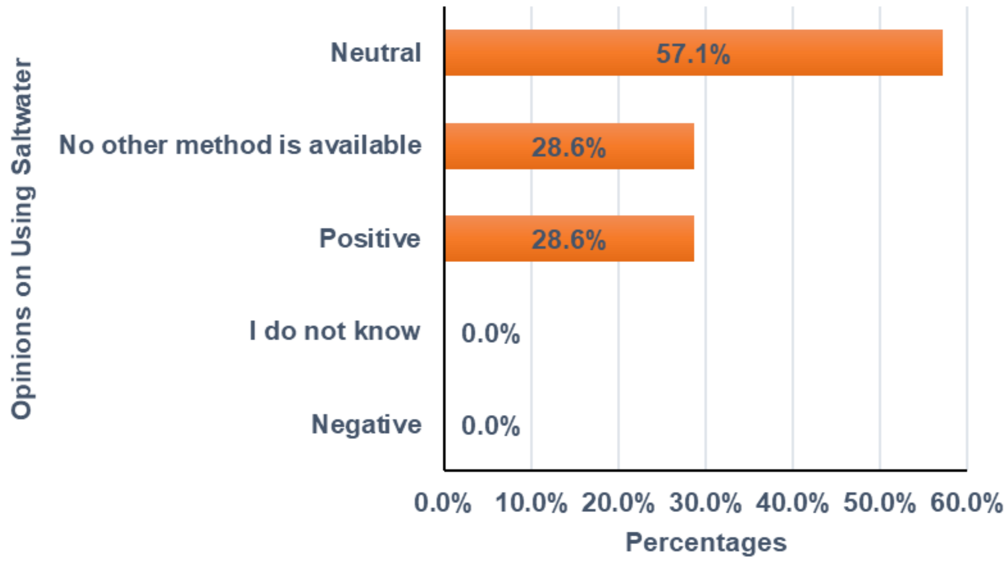

Figure 19. Opinion on using saltwater to reduce dust emissions.

Satisfaction with current dust control methods

Approximately 66% of the experts expressed a neutral level of satisfaction with their company's current dust control methods (Table 4), indicating an ambivalent stance regarding the effectiveness and performance of the implemented measures. This demonstrates that the effectiveness of current dust management techniques could use some improvement. Conversely, around 33% of the experts indicated satisfaction with their company's current dust control methods, expressing contentment with the effectiveness and outcomes of the measures employed.

Table 4: Level of satisfaction with current dust control method.

Level of Satisfaction	% of Respondents
Very dissatisfied	0.0%
Dissatisfied	0.0%
Neutral	66.7%
Satisfied	33.3%
Very satisfied	0.0%

Challenges faced by the industry

The survey responses highlighted several challenges the sand and stone production industry faced. The highest percentage of experts, approximately 55%, identified water shortage as a significant challenge, indicating limited availability and accessibility of water resources for effective dust suppression measures (see Figure 10). Obtaining environmental permits for new projects and renewals was mentioned by 44.4% of the experts, indicating the complexity and time-consuming nature of the permitting process. 11,1% of respondents raised concerns about groundwater contamination, emphasizing the industry's focus on maintaining water quality and preventing contamination. Additionally, 44.4% of the respondents expressed a challenge related to the knowledge of alternative options for dust control, suggesting a lack of awareness or information regarding environmentally friendly alternatives to traditional methods. Other challenges mentioned varied, including restrictions on salt usage due to permit limitations and difficulties in implementing dust control measures during winter or freezing conditions.

Permitting restrictions

The questionnaire explored the permitting restrictions encountered by companies in the sand and stone production industry. As Figure 11 indicates, a significant majority (77.8% of the experts) mentioned a specific restriction regarding the use of salt. This aligns with the industry's efforts to mitigate potential environmental negative impacts, particularly groundwater contamination. Additionally, restrictions related to groundwater and surface water concentration were reported by 22.2% of the respondents, indicating considerations regarding the impact on water resources. Some experts (11.1%) reported restrictions on the amount of salt used per ton produced, reflecting limitations imposed on the quantity of salt used in relation to the production quantity.

Regional differences

As Figure 12 mentioned, approximately 66% of the experts acknowledged regional differences in environmental dust permitting requirements. These differences depend on the municipal authorities responsible for setting specific regulations and guidelines. Companies operating in different regions need to navigate and comply with the requirements established by regional authorities. The severity of dust control measures may be influenced by the potential impact on public health and environmental quality, as indicated by one expert who mentioned higher dust control requirements in areas with denser populations.

Testing of alternative methods

Regarding the testing of alternative methods for dust control, the majority of experts (55.6%) responded negatively, indicating that no tests had been conducted (Figure 13). On the other hand, 44.4% reported having tested alternative methods. A potassium-based solution, hoovers, water jets, chemical solutions, different foams, and even snow were considered alternatives; however, they were later determined to be insufficiently effective or prohibitively expensive. For instance, it was found that snow impeded the crushing process, perhaps because it altered the material's moisture content and consistency.

Overall, the findings suggest that salt-based methods, primarily involving saltwater, are prevalent in the sand and stone production industry for dust control. However, restrictions imposed by permits and concerns about groundwater contamination necessitate the exploration of environmentally friendly alternatives. Water is commonly used as a dust control measure, aligning with the industry's preference for more sustainable approaches. The industry faces challenges related to permits, groundwater contamination, water shortage, and a lack of knowledge about alternative options. Regional differences in permitting requirements further highlight the need for compliance with specific regulations. Despite the neutral satisfaction levels expressed by experts, there is a recognition of the need to improve current dust control methods. Testing alternative methods has been limited, with most experts yet to explore viable alternatives.

5.2 GROUNDWATER MONITORING ANALYSIS

Groundwater monitoring plays a critical role in the aggregate industry to ensure groundwater quality and quantity protection. The following discussion presents a comprehensive analysis of the status of groundwater monitoring and analysis within the industry based on survey findings and interviews with industry experts.

Groundwater monitoring knowledge

The survey findings indicate that industry experts possess a high level of knowledge and understanding of groundwater monitoring (Table 5). Most respondents rated their level of information on groundwater monitoring as high or very high, suggesting substantial awareness within the industry regarding the importance of this practice. This is a positive sign, reflecting a commitment to responsible environmental management within the sand and stone production industry.

Table 5: Level of information on groundwater monitoring.

Level of Information	% of Respondents
Very low	0%
Low	0%
Average	0%
High	55.6%
Very high	44.4%

Methods used for groundwater monitoring

As Figure 14 indicates, the survey results reveal that the industry relies on manual measurement techniques to monitor groundwater levels. Approximately 77% of the experts mentioned the use of manual methods, such as inserting rods or tapes into the ground, to determine groundwater levels. This traditional approach allows physical measurements at specific monitoring points. However, it's important to note that a sizable portion (44.4%) of respondents mentioned other methods, such as the use of consultants and adherence to particular monitoring requirements outlined in permits, suggesting that monitoring practices vary depending on specific circumstances and regulatory obligations.

In addition to manual measurements, remote sensing techniques were mentioned by 22.2% of the experts. Remote sensing can provide valuable insights into groundwater levels over larger areas without the need for physical measurements at each location. Furthermore, 11.1% of the experts mentioned the use of piezometers, specialized instruments that measure groundwater pressure and provide insights into groundwater levels. According to Chaulya and Prasad (2016), a piezometer transforms water pressure into a frequency signal using a diaphragm and a tensioned steel wire—the wire's tension changes in response to the diaphragm's pressure changes. A magnetic coil can cause a wire to vibrate at its natural frequency. The wire's vibration in the magnetic coil's proximity generates a frequency signal transmitted to the readout device, and the readout device processes the signal and displays a reading. These diverse methods highlight the industry's efforts to employ various approaches to groundwater monitoring.

Frequency of groundwater monitoring

Based on the online survey findings, all industry experts reported conducting seasonal monitoring of groundwater levels (see Figure 15). Taylor and Alley (2001) reported that water levels follow a natural cyclic pattern of seasonal fluctuation. Seasonal monitoring involves assessing groundwater levels at regular intervals corresponding to specific seasons, which allows the industry to track changes and fluctuations in groundwater levels over time. By identifying potential trends and detecting issues related to groundwater levels early, the industry can implement timely interventions and proactive water resource management strategies.

Based on interview findings, groundwater levels change due to seasonal variations influenced by snow melt and rainfall, particularly during the summer. It is crucial to remember that Finnish law expressly prohibits any alterations to groundwater levels. The industry prioritizes preserving groundwater quality and quantity, and adherence to these rules is necessary to guarantee business continuity. (ANNEX 2)

Groundwater quality monitoring methods

The survey findings indicate that laboratory analysis is the predominant method employed by industry to monitor groundwater quality. Around 89% of experts mentioned the collection of water samples for subsequent laboratory testing, adopted from Figure 16. This approach allows for a comprehensive assessment of various parameters, including chemical composition and contaminants, providing valuable insights into groundwater quality and demonstrating the industry's commitment to protecting groundwater resources.

In addition, 44.4% of the experts mentioned using sensors for real-time monitoring of specific parameters such as pH, temperature, and electrical conductivity. These sensors provide continuous data, enabling instant monitoring and assessment of groundwater quality. Additionally, 22.2% of respondents mentioned other methods, such as relying on consultants and adhering to specific monitoring requirements outlined in permits. This highlights the industry's adaptability in employing different approaches based on specific circumstances and regulatory obligations.

It's important to note that according to interview findings, the industry does not conduct monitoring activities directly. Instead, consultants are employed to perform monitoring on behalf of the industry. The consultants deliver comprehensive reports that are meticulously examined by industry experts and promptly shared with the appropriate authorities. By maintaining this approach, industry experts stay informed about the monitoring process and its outcomes. (ANNEX 2)

Contaminants

The survey explored the contaminants of greatest concern in groundwater monitoring within the sand and stone production industry (see Figure 17). The most commonly mentioned concern was nitrate, expressed by 66.7% of the experts. Nitrates can contaminate a private well through groundwater flow, surface water seepage, and runoff. Once ingested, nitrates are transformed into nitrites. These chemicals decrease the blood's capacity to carry oxygen. Moreover, drinking water with excessive nitrate levels can severely unwell infants under six months old and even cause death. (EPA, 2023a) 77.8% of the experts identified petroleum products as another major concern. These products comprise hydrocarbons and chemicals related to fuels and lubricants made of petroleum. When contaminated, petroleum products can significantly impair the environment and human health. (ScienceDirect, 2021) Heavy metals were a concern for 22.2% of the experts. These metals can occur naturally or result from industrial activities, posing toxicity risks, including acute and chronic toxicity, liver, kidney, intestinal damage, anemia, and cancer in elevated concentrations. (EPA, 2023a)

Other contaminants mentioned, albeit with relatively lower levels of concern, included pH, dissolved oxygen, and electrical conductivity. pH affects aquatic ecosystems. High amounts of metals for which there are drinking water limits and related health consequences, such as staining, etching, or scaling, can result when the pH values that are not neutral are higher than 8.5 or lower than 6.5. (pH, 2023) Dissolved oxygen is vital for aquatic organisms. Drinking water with high quantities of dissolved oxygen tastes better; however, this can damage water pipes by causing corrosion. On the contrary, low dissolved oxygen concentrations below 5.0 mg/L stress aquatic life and result in hypoxic conditions. (AtlasScientific, 2022)

Electrical conductivity provides insights into salinity and overall water quality. Electricity can flow across the water, and electrical conductivity gauges this ability. More electricity can be conducted if there are more salts per unit volume in the water. A measure of electrical conductivity cannot identify the contaminant; however, it can help determine if a problem may harm invertebrates or fish. Moreover, dramatically increased electrical conductivity indicates the presence of pollution in the river. (CHESSWATCH, 2023) The industry's awareness of these contaminants and their potential impact on groundwater highlights its commitment to safeguarding water resources.

Regulatory agencies and compliance

The survey findings indicate that industry experts primarily follow the guidelines and regulations set by regional ELY centers, as mentioned by 77.8% of the experts (see Figure 19). Local county regulations, mentioned by 44.4% of the experts, play a crucial role in setting guidelines and standards for groundwater protection within the sand and stone production industry. Compliance with these regulations is essential to ensure responsible operations and protect groundwater resources.

According to interview findings, regulatory settings established by regional ELY centers and local authorities ensure adequate supervision of operations. The monitoring requirements specified in environmental permits are diligently followed, and the results are submitted to the authorities for review. Monitoring activities encompass various aspects, including groundwater monitoring, dust emissions monitoring, and water usage monitoring, and can vary between regions and communities. (ANNEX 2)

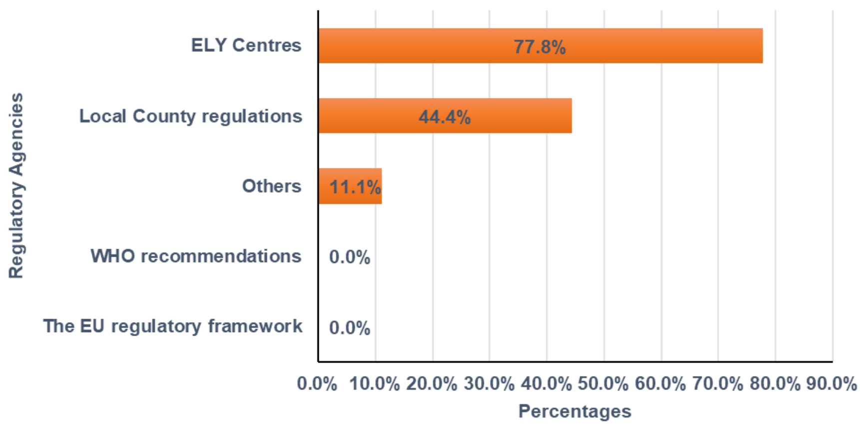

Figure 19. Agencies for monitoring groundwater quality and quantity.

Actions in response to groundwater contamination

The survey findings reveal that the most common action taken in response to detected groundwater contamination is notifying regulatory agencies, as mentioned by 77.8% of the experts (see Figure 20). This reflects the industry's commitment to compliance and the recognition of the importance of involving the appropriate authorities when contamination is identified. Other actions reported by the experts included:

- Implementing source control measures to prevent further contamination,
- Remediation or removal of contaminated soil or groundwater, and
- Upgrading water treatment systems.

These responses highlight the industry's proactive approach to addressing and mitigating the impact of groundwater contamination.

Furthermore, based on the online survey, the actions taken depend on factors such as:

- The nature and extent of the contamination,
- Regulatory requirements, and
- Site-specific conditions.

In addition, experts emphasized the need for additional sampling and testing to ensure the efficacy of remediation efforts and confirm the purity of treated groundwater. This demonstrates the industry's commitment to thoroughly investigating and verifying remediation outcomes.

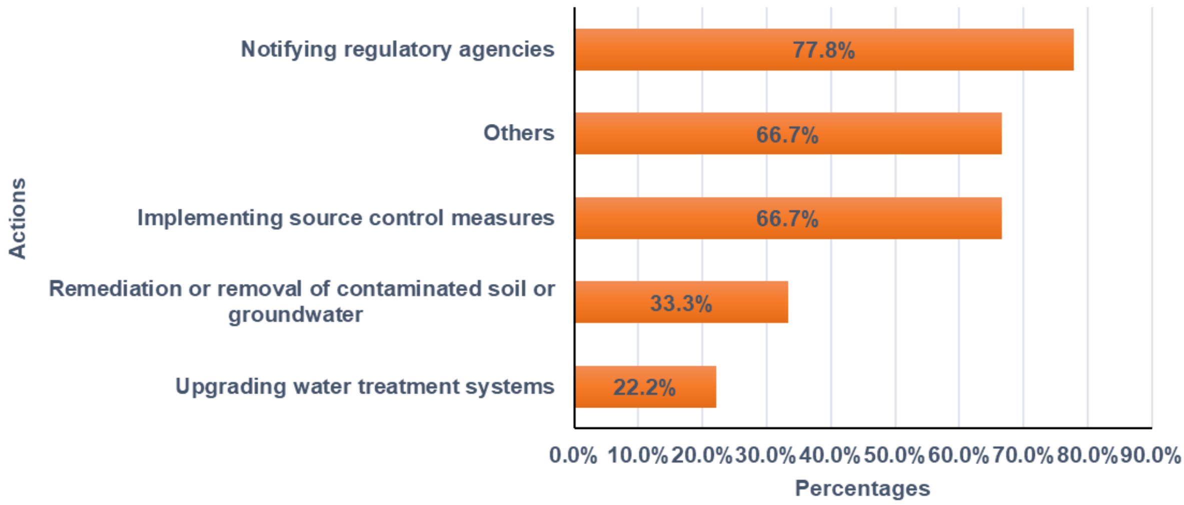

Figure 20. Actions after detecting groundwater contamination.

According to the interview findings, several procedures and initiatives have been implemented for groundwater protection, and to ensure responsible activities, Finland has strict regulations in place. For instance, in the case of gravel production, a minimum of around two-six meters of sand layer must remain between the groundwater level and operational areas, which serves as a barrier to protect the groundwater.

Moreover, aftercare is considered essential. The region is reinforced by the establishment of trees and other vegetation types, which contribute to the preservation of groundwater. Additionally, local efforts are focused on preventing hazards such as oil leaks. Thorough checks of daily operations are conducted to ensure their proper functioning and mitigate potential risks.

In addition, certain precautions are taken to safeguard groundwater from contamination by oils and lubricants from equipment used in the quarry. Double-walled oil canisters are employed, featuring an additional protective layer that prevents leaks and ensures safety. The tanks used for storing oil must also meet the requirements of having double walls to mitigate any potential risks to groundwater. The double-walled oil canisters are set on plastic covers that serve as spill-absorbent surfaces for any possible oil spills. Moreover, lead that may be present in the environment is absorbed by peat sacks.

Furthermore, continuous monitoring of groundwater quality and level occurs, even where salt is utilized, and no harmful consequences have been observed thus far. Maintaining a vigilant approach allows for immediate response to any alarming signs, and appropriate corrective actions are taken to prevent their recurrence. As a result, significant impacts on groundwater quality have been successfully avoided. (ANNEX 2)

Salt use strategy

Based on interview findings, the primary method of dust control employed by industry experts aim to minimize the risks of groundwater contamination. Salt usage is restricted in certain areas as per permit requirements, especially in regions with classified or valuable groundwater. According to one interviewee, salt has been used in specific areas for many years without any noticeable impacts on groundwater. However, authorities have imposed restrictions on salt use to minimize potential risks despite lacking evidence indicating detrimental effects.

The interview findings recommend optimizing the timing of salt usage for maximum efficiency. Salt application is ensured during periods when production is temporarily halted, such as during summer breaks. This approach reduces the chances of aggregate spillage and subsequent dust generation during active production and transportation. The strategic timing of salt application, followed by the placement of new aggregate, effectively reduces dust emissions. The limited frequency of salt spreading ensures efficient dust control throughout the year. Additionally, it is crucial to note that salt usage is prohibited within the quarry area where crushing activities occur, and reliance solely on clean water for dust suppression is practiced. This approach helps mitigate potential impacts on groundwater quality. (ANNEX 2)

Overall, the surveyed and interviewed sand and stone production industry demonstrates a high level of knowledge and understanding of groundwater monitoring. Manual measurements and laboratory analysis are the predominant methods employed to monitor groundwater levels and quality. The industry closely follows regulatory guidelines, conducts seasonal monitoring, and proactively responds to detected groundwater contamination. Dust control measures are implemented to minimize risks to groundwater, and comprehensive groundwater protection measures are in place to ensure responsible activities and safeguard water resources.

5.3 ENVIRONMENTAL APPROACHES

The findings from the survey and interviews provide valuable insights into the familiarity, belief, perception, adoption, benefits, challenges, potential risks, and recommendations associated with environmentally friendly alternatives to reduce dust emissions and salt use in the sand and stone production industry. This discussion will present a detailed analysis of these aspects, highlighting key points and implications.

Familiarity

It is indicated by the survey results that basic to advanced knowledge of environmentally friendly methods for dust control is possessed by most industry experts (88.9%), adopted from Table 2. This demonstrates a certain level of exposure and understanding within the industry. However, the fact that none of the experts reported being very familiar with alternatives suggests that industry professionals may have limited exposure or extensive knowledge. The need to bridge the knowledge gap and increase familiarity with these alternatives is highlighted, which can be achieved through further research and information dissemination.

Belief in using

A positive outlook concerning the utilization of environmentally friendly alternatives is unveiled by the survey responses among industry experts. Most experts (77.8%) expressed openness to the possibility of using alternatives, demonstrating a willingness to consider and explore them for dust control (see Figure 21). Furthermore, 22.2% of the experts firmly believed in the feasibility and effectiveness of environmentally friendly alternatives in reducing dust emissions. This indicates a general receptiveness and recognition of the potential benefits of adopting more sustainable dust control methods in the industry. Importantly, none of the experts outright dismissed the idea or expressed a belief that environmentally friendly alternatives are not applicable in their industry.

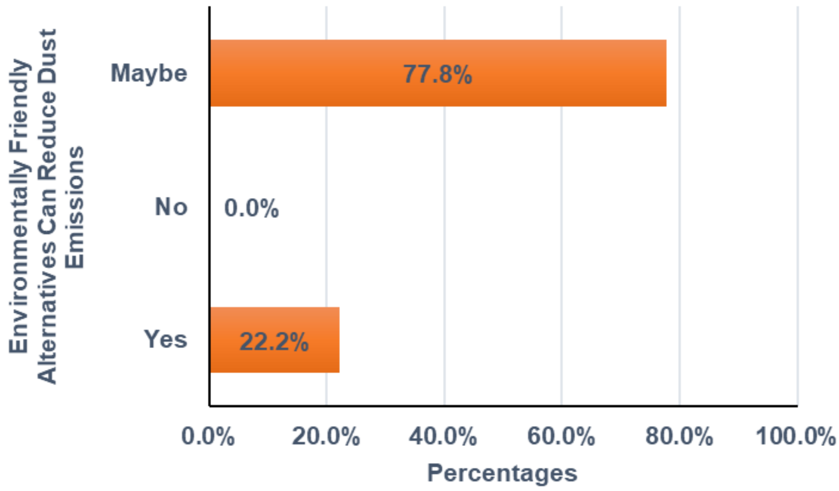

Figure 21. Environmentally friendly alternatives to saltwater can be used to reduce dust emissions.

Perception of the effectiveness

The survey findings suggest that the perception of the effectiveness of environmentally friendly methods in reducing dust emissions varies among industry experts (Table 3). While no experts specifically stated that these methods are very effective, most responses (44.5%) indicated an average perception of effectiveness. This suggests that some experts believe these methods have a moderate impact on reducing dust emissions. Additionally, 22.2% of the experts expressed an above-average perception of effectiveness, indicating a positive view of the efficacy of environmentally friendly methods in dust control. However, it is important to note that 33.3% of experts perceived effectiveness as below average or deemed these methods ineffective, highlighting the need for further evaluation and research to identify the most effective alternatives for dust emission reduction.

Adoption

The survey responses indicate a mixed status among industry experts regarding adopting environmentally friendly alternatives (see Figure 18). Although 44.5% of experts stated their company has already begun implementing these alternatives, a notable portion (33.3%) acknowledged their industry still needs to put them into practice. Some experts not currently using these alternatives expressed their consideration and willingness to explore them in the future. The reasons for not adopting environmentally friendly alternatives mentioned by experts include concerns about their effectiveness and high costs based on past testing.

The interviews shed light on specific alternatives considered or tested in the industry. Compost and mulching were deemed costly and ineffective due to the potential contamination of products by organic materials, making them unsuitable for product requirements. Windbreaks were primarily mentioned for noise control rather than dust control. While barriers are implemented during topsoil removal, their efficiency in dust control needs to be well-established. Gravel, mentioned as an environmentally friendly method, may have limitations in effectively controlling dust in specific operations, both in terms of long-term effectiveness and the scale of implementation. The quantity of gravel needed and the associated costs could be prohibitive. However, vegetation has shown promise as a potential solution for future implementation. Introducing vegetation in already quarried areas is under consideration as it can effectively prevent dust emissions and promote environmental sustainability. In addition, biopolymers are acknowledged as a potential solution; however, their high cost is a limiting factor. If the price of biopolymers decreases and regulatory authorities grant approval, exploring their utilization would be interesting as an environmentally friendly dust control method. These findings emphasize the significance of developing efficient substitutes in lowering dust emissions and are practical for the aggregate sector. (ANNEX 2)

Benefits

It is indicated by the survey findings that industry experts recognize several benefits of using environmentally friendly alternatives to saltwater for dust suppression (see Figure 22). A significant percentage of experts (85.7%) recognized the ability to reduce groundwater pollution as a substantial benefit, demonstrating their high understanding of the negative environmental effects of using saltwater and the significance of safeguarding groundwater resources. Furthermore, the same percentage of experts (85.7%) emphasized that compliance with environmental regulations becomes easier when using environmentally friendly alternatives. The alignment between sustainable dust suppression practices and regulatory compliance is highlighted by this recognition, reducing the risk of non-compliance and potential penalties. The potential for lower costs is mentioned as a benefit by a smaller percentage of experts (14.3%), indicating an awareness of potential cost savings associated with sustainable dust suppression methods.

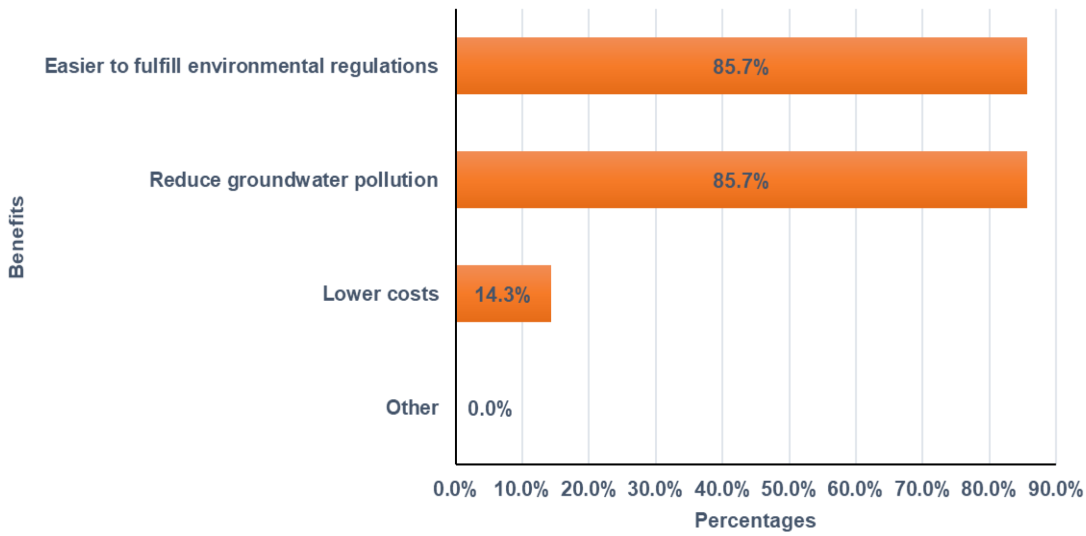

Figure 22. Benefits of using environmentally friendly alternatives.

Challenges

Industry experts identified several challenges associated with using environmentally friendly alternatives for dust suppression (see Figure 23). The most commonly mentioned challenge was cost, with 77.8% of experts identifying it as a significant factor. This suggests that the expenses associated with implementing and maintaining environmentally friendly alternatives may present a barrier for some companies. The availability of these alternatives was mentioned by 44.4% of experts, indicating that sourcing or accessing them may pose difficulties, potentially limiting their adoption. Technical or other complexities were mentioned by 22.2% of experts, suggesting that some environmentally friendly methods might require specialized knowledge, equipment, or additional infrastructure, making their implementation more challenging. Concerns about effectiveness were raised by 66.7% of experts, highlighting the need for robust evaluation and testing of alternative methods. Permitting requirements were mentioned by 22.2% of experts, indicating that navigating regulatory processes and obtaining necessary permits for using environmentally friendly alternatives can be challenging. Other challenges mentioned included winter conditions. These challenges underscore the need for careful consideration and evaluation of the practical aspects associated with the implementation of environmentally friendly alternatives.

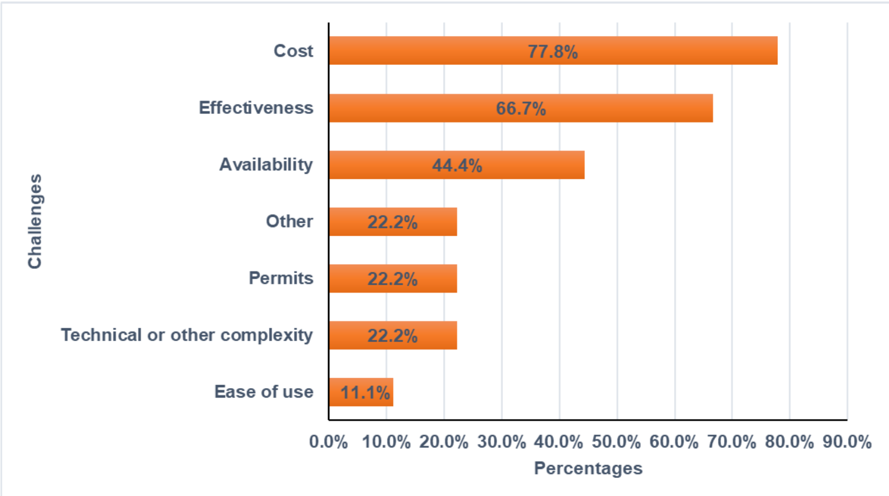

Figure 23. Challenges of using environmentally friendly alternatives.

Potential Risks

The survey responses indicate a range of concerns raised by industry experts regarding the potential risks associated with using environmentally friendly alternatives for dust emissions reduction (see Figure 24). Some experts mentioned the product quality risk, suggesting that alternative methods may impact the quality of the final sand and stone products. Other concerns included economic risks due to potentially higher costs, the risk of increased dust emissions if alternatives are not as effective, and potential emissions of different chemicals. These findings emphasize the importance of thoroughly evaluating the potential risks and conducting robust testing of alternative methods to ensure their suitability and safety in the sand and stone production industry.

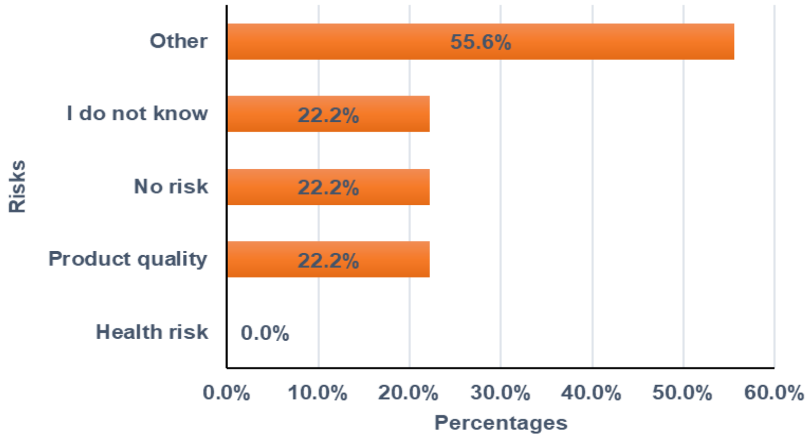

Figure 24. Potential risks that could arise from using an environmentally friendly alternative.

Likelihood of recommending

The survey responses indicate a range of opinions among industry experts regarding the likelihood of recommending environmentally friendly alternatives to other sand and stone production companies (Table 6). 55.6% of the experts indicated to have a neutral stance on their views. However, 22.2% of the experts expressed a lower likelihood of recommending these alternatives, indicating some concerns. The remaining 22.2% of the experts were likely to recommend the alternatives, indicating a higher level of confidence in their efficacy.

Table 6: Level of recommendation an environmentally friendly alternative to other sand and stone production companies.

Level of Recommending	% of Respondents
Very unlikely	0.0%
Somewhat unlikely	22.2%
Neutral	55.6%
Somewhat likely	11.1%
Very likely	11.1%

According to the interview findings, efforts to explore alternatives to salt have included experimenting with biochemicals in pilot projects. However, these alternatives have proven expensive and less long-lasting than salt. While they offer improved efficacy over water, their durability does not match that of salt. Nevertheless, using environmentally friendly products is prioritized, and advanced machinery is employed to minimize potential impact. In addition, in rock quarries, efforts are made to ensure that explosives are used to minimize any potential impact on groundwater, particularly by aiming for optimal detonation to prevent the release of nitrogen into the groundwater. (ANNEX 2)

Water as an environmentally friendly alternative

Based on the experts' opinions from the survey, water emerges as the recommended cost-effective and environmentally friendly alternative to saltwater for dust reduction in the sand and stone production industry. This aligns with the findings that water is currently being used as a primary method for dust control. However, according to the interview findings, this approach presents challenges and drawbacks. Frequent application is required due to the quick drying of roads, necessitating an average of five daily rounds with water trucks, which makes this method very labor-intensive and inefficient since it consumes significant time and effort. In addition, this practice results in significant fuel consumption, contributing to increased expenses and harmful climate impacts. Monitoring of water trucks is closely conducted to prevent any leakage risks, although it remains an issue to consider. Furthermore, using water below zero degrees Celsius in winter is impractical.

Regarding sourcing clean water and applying methods, the interviews revealed different approaches. According to one industry, rainwater is the primary source of clean water used for dust control. In cases where rainwater is insufficient, groundwater extracted from wells is utilized. If a well is unavailable in the vicinity, alternate methods, such as the water supply network, provide the necessary water for dust control. Generally, the water used for dust suppression consists of rainwater or groundwater obtained from wells.

Regarding water application, diverse methods are employed depending on the location. Within the quarry's roads, water is typically poured onto the road surface using a wheel loader bucket and water trucks. This practice aids in dust emission control and maintains dampness on the roads. A pump extracts stored rainwater within the crushing plant or other quarry areas requiring water. The water is dispensed through nozzles or other mechanisms, suppressing dust and generating a spray effect in specific areas.

According to another industry, several methods are used to obtain pure water as an eco-friendly saltwater replacement. When natural sources are unavailable, water is collected from lakes and put into tanks using a pump. Water from lakes may contain biological particles that make it inappropriate due to insufficient cleanliness; therefore, using a pump when obtaining water from lakes ensures the water is clear and free of pollutants. The water is then applied by spraying or other appropriate methods to effectively control dust emissions and minimize environmental impact. (ANNEX 2)

5.4 RECOMMENDATIONS

Based on the findings, several important recommendations for future research can be made to address the problems with salt use and dust emission in the sand and stone-producing sector.

- The widespread availability, cost-effectiveness, and efficient dust control properties of salt make it a popular choice for dust suppression in aggregate industries. However, conducting a comprehensive study to investigate the actual impact of salt use on dust management is crucial due to its potential link to alter groundwater quality. A thorough understanding of the effects on groundwater quality can be achieved by thoroughly assessing the risks and impacts of controlled salt usage in various industries across different regions. These findings will provide valuable insights to the long-term consequences of salt application for dust control, ensuring that any unnoticed impacts on groundwater contamination are identified and addressed for sustainable environmental management.
- The lack of accessible and effective alternatives to salt makes the search for environmentally friendly substitutes essential. Considerable research is required to find chemicals or substances that are both effective at preventing dust and more environmentally friendly.
- Research on high-pressure water-spreading systems should be prioritized to improve dust control while consuming the least water possible. In order to minimize dust emissions, these systems apply pressurized water to dust-producing regions. These systems' design and operation can be enhanced to manage dust with less water, reducing their negative environmental impact and boosting the sector's cost-effectiveness.

These recommendations put value as industry experts assert that the water quality and quantity data become publicly available after it is reported to the appropriate authorities, which follows standard practice in Finland. Consequently, approaching the relevant authority grants access to the most recent data, and individuals seeking the requested information for future research and development endeavors will receive it.

6. CONCLUSION

This study investigated the current practices of dust control and groundwater monitoring in the sand and stone production industry, focusing on identifying environmentally friendly alternatives to reduce dust emissions and minimize groundwater contamination.

The study's findings indicate that the most common method for dust control involved using salt mixed with water or applying salt followed by water spraying; however, there was a preference for environmentally friendly approaches. Freshwater was recognized as the most used environmentally friendly approach for dust control in aggregate industries. The study also highlighted various challenges, including obtaining environmental permits, concerns over groundwater contamination, water scarcity due to uncontrolled and excessive use of surface/groundwater and limited knowledge of alternative options.

Regarding groundwater monitoring practices, industry experts demonstrated high awareness and expertise. Manual measurements using rods or tapes were the most prevalent method, followed by remote sensing techniques and piezometers. Laboratory analysis of collected samples was the primary approach for groundwater quality monitoring. However, the consultants responsible for monitoring activities, sample collection, and laboratory analyses are likely to possess more information as they know the technologies currently available or under development. In order to learn more about groundwater monitoring, it is advisable to engage consulting companies specialized in this field, as aggregate industries are not directly involved in monitoring; consultants are employed to perform the monitoring on their behalf.

The study explored industry experts' opinions on new environmental approaches for reducing dust emissions. While some familiarity with alternatives to saltwater was observed, challenges such as cost, availability, technical complexities, and permitting requirements hindered their widespread adoption. Nevertheless, there was a receptiveness to exploring these alternatives, driven by the potential benefits of facilitating compliance with environmental regulations.

Based on the findings, additional research on water quantity, quality and availability is recommended for future studies since water is highly used for dust control. This study was conducted considering limited aggregate industries, so further research could be expanded by considering more stone and aggregate industries. The additional impact of using salt in controlling dust can be further studied by considering its linkages with soil and groundwater flow.

7. REFERENCES

Aggregates, S. D., 2022. *Types of Aggregates*. Available at: http://samedayaggregates.com/types-of-aggregates/ (Accessed: 9 July 2023).

Andrew, W., Joseph, P., & Mark, F., 2004. Control of Dust. *US Patent*, *6* (2004), 14.

AtlasScientific, 2022. *How Does Dissolved Oxygen Affect Water Quality?* Available at: https://atlas-scientific.com/blog/how-does-dissolved-oxygen-affect-water-quality/ (Accessed: 9 July 2023).

Bao, Q. *et al.,* 2019. Preparation and characterization of a binary-graft-based, water-absorbing dust suppressant for coal transportation. *Journal of Applied Polymer Science*, 136(7), p. 47065. doi: 10.1002/APP.47065.

Bhandari, P., 2020. *What Is Qualitative Research? | Methods & Examples*. Available at: https://www.scribbr.com/methodology/qualitative-research/ (Accessed: 9 July 2023).

Brien, O., 2016. Methods of and systems for controlling dust. Available at: https://patents.google.com/patent/US10927280B2/en (Accessed: 12 July 2023).

BuildersMART, 2019. *Importance of Sand in Construction*. Available at: https://www.buildersmart.in/blogs/everything-about-sand (Accessed: 9 July 2023).

Buildings, D., 2020. *Gravel in construction*. Available at: https://www.designingbuildings.co.uk/wiki/Gravel_in_construction (Accessed: 9 July 2023).

CHESSWATCH, 2023. Water quality indicator: Electrical conductivity.

Chloride, O. C., 2023. *Choosing the Right Dust Suppressant - Dust Control Road Base Stabilization and Full-Depth Reclamation*. Available at: https://www.oxycalciumchloride.com/building-better-roads/controlling-dust/how-to-control-dust/choosing-the-right-dust-suppressant (Accessed: 9 July 2023).

CMA, 2023. *Salinity Explained*. Available at: https://salinitywatch.gbcma.vic.gov.au/salinity-explained.html (Accessed: 9 July 2023).

Coalition, M. E., 2023. *Crushed Stone*. Available at: https://mineralseducationcoalition.org/minerals-database/crushed-stone/ (Accessed: 9 July 2023).

Cotter, J., 2008. Start Flank on Delvery Vehicle with Expred Beverages. *US Patent US*, *873*, A1.

Devi, R. M., Madhavan, N., Bhattacharyya, A., & Arumugum, N., 2013. Dust Suppressant Compositions, Methods for Making and Methods for Using. *World Intellectual Property Organization WO*, *108057*.

Ding, C. *et al.*, 2011. Experimental Research on Optimization and Coal Dust Suppression Performance of Magnetized Surfactant Solution. *Procedia Engineering*, 26, pp. 1314–1321. doi: 10.1016/J.PROENG.2011.11.2306.

Dixon-Hardy, D. W. *et al.*, 2008. The Use of Oil Refinery Wastes as a Dust Suppression Surfactant for Use in Mining. *https://home.liebertpub.com/ees*, 25(8), pp. 1189–1195. doi: 10.1089/EES.2007.0177.

Dust-A-Side, 2019. *Is hyper-saline water alone an effective dust suppressant?* Available at: https://news.dustaside.com.au/is-hyper-saline-water-effective-dust-suppressant (Accessed: 9 July 2023).

Elsholz, C., 2012. Dust Suppressant Use and Alternatives at Carnegie State Vehicular Recreation Area. *Off-Highway Motor Vehicle Recreation Division Department of Parks and Recreation State of California: Sacramento, CA, USA*.

Environment, M., 2023. *Protection of groundwater*. Available at: https://ym.fi/en/protection-of-groundwater (Accessed: 9 July 2023).

EPA, U., 2023a. *Potential Well Water Contaminants and Their Impacts | US EPA*. Available at: https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts (Accessed: 9 July 2023).

EPA, U., 2023b. *Salt*. Available at: https://www.epa.gov/risk/salt (Accessed: 9 July 2023).

EPA, U., 2023c. *What is Particle Pollution?* Available at: https://www.epa.gov/pmcourse/what-particle-pollution (Accessed: 13 July 2023).

European Environment Agency, 2022. Europe's groundwater: a key resource under pressure. Available at: https://www.eea.europa.eu/publications/europes-groundwater#:~:text=Many ecosystems and economic sectors,%2C agriculture%2C industry and tourism. (Accessed: 9 July 2023).

Fan, T., Zhou, G. and Wang, J., 2018. Preparation and characterization of a wetting-agglomeration-based hybrid coal dust suppressant. *Process Safety and Environmental Protection*, 113, pp. 282–291. doi: 10.1016/J.PSEP.2017.10.023.

Foundation, T. G., 2022. *What is Groundwater?* Available at: https://groundwater.org/what-is-groundwater/ (Accessed: 9 July 2023).

George, T., 2021. *What is a Focus Group | Step-by-Step Guide & Examples*. Available at: https://www.scribbr.com/methodology/focus-group/ (Accessed: 9 July 2023).

Hanganu, D., 2021. NOTES ABOUT CRUSHING SAND FROM BITUMINOUS SCHIST. doi: 10.2478/bipca-2021-0009.

HSE, 2023. *Quarries - Silica*. Available at: https://www.hse.gov.uk/quarries/silica.htm (Accessed: 13 July 2023).

Jin, H. *et al.*, 2019. Development of Environmental Friendly Dust Suppressant Based on the Modification of Soybean Protein Isolate. *Processes 2019, Vol. 7, Page 165*, 7(3), p. 165. doi: 10.3390/PR7030165.

Lee, T. *et al.*, 2019. Liquid amphiphilic polymer for effective airborne dust suppression. *RSC Advances*, 9(68), pp. 40146–40151. doi: 10.1039/C9RA06787F.

Liu, Y. *et al.,* 2018. Solidifying dust suppressant based on modified chitosan and experimental study on its dust suppression performance. *Adsorption Science and Technology*, 36(1–2),pp.640–654. doi:10.1177/0263617417713624/ASSET/IMAGES/LARGE/10.1177_0263617417713624-FIG8.JPEG.

Medeiros, M. A., Leite, C. M. M. and Lago, R. M., 2012. Use of glycerol by-product of biodiesel to produce an efficient dust suppressant. *Chemical Engineering Journal*, 180, pp. 364–369. doi: 10.1016/J.CEJ.2011.11.056.

Michael Niaounakis, C. P. H., 2006. *Olive Processing Waste Management: Literature Review and Patent Survey - Google Books*. Available at: https://books.google.fi/books?hl=en&lr=&id=hpuaBjSoMs0C&oi=fnd&pg=PP1&ots=AIa9CvUvm_&sig=D3ZWIA5d4KHg-D7lDQjx1e4E2cA&redir_esc=y#v=onepage&q&f=false (Accessed: 13 July 2023).

New England, E., 2023. Ground Water Contamination: Magnificent Ground Water Connection. Available at: https://www.epa.gov/sites/default/files/2015-08/documents/mgwc-gwc1.pdf (Accessed: 9 July 2023).

Niaounakis, M., 2015. *Biopolymers: Applications and Trends - Google Books*. Available at: https://books.google.fi/books?hl=en&lr=&id=6_ucBAAAQBAJ&oi=fnd&pg=PP1&ots=5X3LZ3Fc1D&sig=9Ma2uzgwRpZCu82iFVrrYdGS4Nk&redir_esc=y#v=onepage&q&f=false (Accessed: 12 July 2023).

Niosh, 2019. NIOSH Mining Program Report of Investigations Dust Control Handbook for Industrial Minerals Mining and Processing Second Edition. doi: 10.26616/NIOSHPUB2019124.

Norman, M. and Johansson, C., 2006. Studies of some measures to reduce road dust emissions from paved roads in Scandinavia. *Atmospheric Environment*, 40(32), pp. 6154–6164. doi: 10.1016/J.ATMOSENV.2006.05.022.

Oscarsson, K., 2007. Dust suppressants for Nordic gravel roads. Available at: http://www.diva-portal.org/smash/get/diva2:11937/FULLTEXT01.pdf (Accessed: 9 July 2023).

Oyedele E. O.*, O. O. C. and I. H. O., 2019. *Assessment and control of noise and dust pollution in mines and quarries: A review*. Available at: https://www.researchgate.net/publication/361507408_Assessment_and_control_of_noise_and_dust_pollution_in_mines_and_quarries_A_review (Accessed: 9 July 2023).

Parvej, S. *et al.*, 2021. Fugitive Dust Suppression in Unpaved Roads: State of the Art Research Review. *Sustainability 2021, Vol. 13, Page 2399*, 13(4), p. 2399. doi: 10.3390/SU13042399.

PH, 2023. *Groundwater-Quality Analyte Descriptions*. Available at: https://kgs.uky.edu/kgsweb/datasearching/water/analyteDescr.asp (Accessed: 9 July 2023).

Sanders, T. G. *et al.*, 1997. Relative Effectiveness of Road Dust Suppressants. *Journal of Transportation Engineering*, 123(5), pp. 393–397. doi: 10.1061/(ASCE)0733-947X(1997)123:5(393).

Sanders, T. G. and Addo, J. Q., 1993. EFFECTIVENESS AND ENVIRONMENTAL IMPACT OF ROAD DUST SUPPRESSANTS.

ScienceDirect, 2021. *Petroleum Contamination - an overview*. Available at: https://www.sciencedirect.com/topics/chemistry/petroleum-contamination (Accessed: 9 July 2023).

SEGAL, M. T. R. A., 2016. Chitosan coagulant as a binder and dust control agent.

Southwest Middlesex, 2023. MORE ABOUT CALCIUM CHLORIDE USED FOR DUST CONTROL ON GRAVEL SURFACES. Available at: https://www.southwestmiddlesex.ca/sites/default/files/2021-06/Document MORE ABOUT

CALCIUM CHLORIDE USED FOR DUST CONTROL ON GRAVEL SURFACES.pdf (Accessed: 9 July 2023).

Stocks, S. H. A. N., 2008. Dust Suppression and Reduction of Surface Oxidation for Mineral Agglomerates.

Tarmac, 2023. *Marine Aggregates*. Available at: https://tarmac.com/marine/marine-aggregates/ (Accessed: 9 July 2023).

UEPG, 2023. *Products - Aggregates Europe*. Available at: https://www.aggregates-europe.eu/aggregates/products/ (Accessed: 8 July 2023).

Usher, J., 2008. Dust Suppressant. *International Patent Classification (s) C09K. Australian Patent Office (54)(51)(21)(31)(43)(43)(71)(72)(74)*, *4*.

Wikipedia, 2022. *Crushed stone*. Available at: https://en.wikipedia.org/wiki/Crushed_stone (Accessed: 9 July 2023).

Xi, Z. *et al.*, 2014. Experimental study on advantages of foam–sol in coal dust control. *Process Safety and Environmental Protection*, 92(6), pp. 637–644. doi: 10.1016/J.PSEP.2013.11.004.

Yuan, Q. *et al.,* 2021. Portland cement concrete. *Civil Engineering Materials*, pp. 59–204. doi: 10.1016/B978-0-12-822865-4.00003-9.

Zhan, Q., Qian, C. and Yi, H., 2016. Microbial-induced mineralization and cementation of fugitive dust and engineering application. *Construction and Building Materials*, 121, pp. 437–444. doi: 10.1016/J.CONBUILDMAT.2016.06.016.

Zhang, H. *et al.*, 2018. Preparation and experimental dust suppression performance characterization of a novel guar gum-modification-based environmentally-friendly degradable dust suppressant. *Powder Technology*, 339, pp. 314–325. doi: 10.1016/J.POWTEC.2018.08.011.

ANNEX

ANNEX 1: Online Survey Questions

UNIVERSITY OF OULU

Environmentally Friendly Alternatives to Reduce Dust Emission and Salt Use in the Sand and Stone Production Industry

Mandatory questions are marked with a star (*)

Dear participants,

The survey will include questions **about the current methods used to control dust emissions and potential environmentally friendly alternatives** that have been found in literature, such as:

Watering: One of the most practical methods of dust suppression is watering. The increased moisture prevents the soil from disintegrating.

Biopolymers: Lignin-based biopolymers, generated from wood, bind particles together, reducing the possibility that they may go airborne.

Petroleum: Petroleum-based binders give particles a thin layer of protection, increasing particle mass and lowering the probability that they will go airborne.

Gravel: Adding gravel to roads can help to reduce dust emissions. The gravel helps to bind the soil particles together, reducing the amount of dust that is released into the air.

Vegetation and Mulching: Planting vegetation such as grasses, shrubs, and trees and applying mulch to the soil can help to reduce dust emissions by trapping particles in the air and providing a barrier to wind.

Windbreaks: Installing windbreaks such as fences or walls can help to reduce dust emissions by blocking the wind and preventing particles from becoming airborne.

Water Sprinklers: Installing water sprinklers in areas prone to dust emissions can help to reduce dust by creating a fine mist that binds to the dust particles and prevents them from becoming airborne.

Compost: Applying compost to the soil can help to reduce dust emissions by increasing the soil's ability to retain moisture and preventing particles from becoming airborne.

This section is **divided into three parts**; the first part is **about the current status of dust control** in the aggregate industry, the second part is **about how groundwater monitoring is done** in the industry, and the final part is **about your opinions on new environmental approaches**. The **survey will take 10-15 minutes**, and all the collected information will be confidential and used for academic purposes following the "General Data Protection Regulation (**GDPR**)".

General information *

Company name

Your Name

Email

Country

Your primary role in the industry

- [ ] Production
- [ ] Management
- [ ] Quality Control
- [ ] Health and safety
- [ ] Environmental manager
- [ ] Other

Part I: Current status of dust control in the aggregate industry
(Note: Please feel free to select multiple options)

What is your company's current approach to dust control?

- [ ] No control
- [ ] Salt (NaCl) (Mixed with water)
- [ ] Salt (NaCl) (First through salt and then put water on it)
- [ ] Water
- [ ] Chemical, Please Specify ______________
- [ ] Others, Please Specify ______________

If your industry uses salt for dust control, please specify the amount used.

- [ ] I do not know
- [ ] Yes, I know. Please tell us the estimated amount per produced ton for:
- [ ] i) sand and stone and ______________
- [ ] ii) crushed rock ______________

What is your opinion on using saltwater to reduce dust emissions in the sand and stone production industry?

- ☐ Positive
- ☐ Neutral
- ☐ Negative
- ☐ No other method is available
- ☐ I do not know

How satisfied are you with your current dust control methods?

	1	2	3	4	5	
Very dissatisfied	○	○	○	○	○	Very satisfied

What challenges are you currently experiencing?

- ☐ No challenges
- ☐ Difficulties in obtaining an environmental permit (for new and renewed)
- ☐ Environmental challenges (e.g., groundwater contamination)
- ☐ Water shortage in dust control
- ☐ Knowledge of alternative options for dust control
- ☐ Other. Please, specify your answer here:

Permitting restrictions for newly issued and renewed permit

- ☐ No restrictions
- ☐ No use of salt
- ☐ Groundwater concentration
- ☐ Surface water concentration
- ☐ Restriction of salt use per ton produced
- ☐ Other. Please, specify your answer here:

Do you have regional differences in environmental dust permitting requirements?

- ○ No
- ○ Yes. Please, specify your answer here:

Have you tested alternative methods?

- ○ No
- ○ Yes. Please inform us about the methods and user experience: ____________

Which department do you operate in?

- ☐ Production
- ☐ Management
- ☐ Quality Control
- ☐ Health and safety
- ☐ Environmental manager
- ☐ Other

PART II How groundwater monitoring is done in the industry
(Note: Please feel free to select multiple options)

Could you please rate your information on groundwater monitoring in your industry *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

How do you monitor the groundwater level?

- ☐ Manual measurement by inserting a rod or tape
- ☐ Automatic (recording) monitoring in wells
- ☐ Using remote sensing techniques
- ☐ Using a piezometer
- ☐ Experience and knowledge
- ☐ Others. Please, specify your answer here: ____________

How frequently do you monitor and assess groundwater levels?

- ○ Daily

- ◯ Weekly
- ◯ Monthly
- ◯ Seasonally
- ◯ Rarely or never

How do you monitor groundwater quality?

- ☐ By collecting samples and analyzing them in labs
- ☐ Using sensors for pH and temperatures
- ☐ Electrical conductivity sensors
- ☐ On-line sensors for recoding continuously
- ☐ Others. Please, specify your answer here:

How frequently do you monitor and assess groundwater quality?

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Seasonally
- ◯ Rarely or never

Which contaminants are you most concerned about when monitoring groundwater in the sand and stone production industry?

- ☐ Microbes
- ☐ Heavy metals
- ☐ Nitrates
- ☐ Dissolved oxygen
- ☐ Petroleum products
- ☐ pH
- ☐ Electrical conductivity
- ☐ Others. Please, specify you answer here:

Which regulatory agency or agencies do you follow when monitoring groundwater quality and quantity?

- [ ] Environmental Protection Agency (EPA, ELY centres)
- [ ] The EU regulatory framework
- [ ] Local County regulations
- [ ] WHO recommendations
- [ ] Others. Please, specify you answer here:

What actions do you take if your facility detects contaminated groundwater?

- [ ] Implementing source control measures
- [ ] Upgrading water treatment systems
- [ ] Remediation or removal of contaminated soil or groundwater
- [ ] Notifying regulatory agencies
- [ ] Others. Please, specify you answer here:

How do you determine whether groundwater contains contaminants?

- [ ] By visual inspection
- [ ] By analyzing samples in a laboratory
- [ ] Online monitoring
- [ ] By observing changes in water levels
- [ ] Others. Please, specify you answer here:

PART III Your opinions on new environmental approaches
(Note: Please feel free to select multiple options)

Are you familiar with environmentally friendly alternatives to saltwater for reducing dust emissions?

	1	2	3	4	5	
Not familiar	○	○	○	○	○	Very familiar

Can saltwater be replaced with more environmentally friendly alternatives in your industry to reduce dust emissions?

○ Yes

○ No

○ Maybe

How effective do you think environmentally friendly methods are in reducing dust emissions?

	1	2	3	4	5	
Not effective	○	○	○	○	○	Very effective

Has your industry started using environmentally friendly alternatives to saltwater to reduce dust emissions?

○ Yes. Please specify the methods: ____________

○ No. Please move to the question after the next question

○ No, but we are considering it. Please inform us of your consideration: ____________

What do you think are the main benefits of using environmentally friendly alternatives to saltwater in dust suppression?

☐ Reduce groundwater pollution

☐ Lower costs

☐ Easier to fulfil environmental regulations

☐ Other. Please, specify your answer here: ____________

What are the main challenges of using environmentally friendly alternatives to saltwater in dust suppression?

☐ Cost

☐ Availability

☐ Technical or other complexity

☐ Ease of use

☐ Effectiveness

☐ Permits

☐ Other. Please, specify your answer here: ____________

Do you believe utilizing an environmentally friendly saltwater alternative would benefit your business?

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Do you believe utilizing an environmentally friendly saltwater substitute would be beneficial for the environment?

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Do you believe utilizing an environmentally friendly saltwater substitute would help you obtain environmental permits?

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

What are the potential risks of reducing dust emissions using an environmentally friendly alternative?

- ☐ Product quality
- ☐ Health risk
- ☐ No risk
- ☐ Other ____________________
- ☐ I do not know

How likely will you recommend an environmentally friendly alternative to other sand and stone production industries to reduce dust emissions?

	1	2	3	4	5	
Very unlikely	○	○	○	○	○	Very likely

Which of the following methods can be recommended considering the cost-effectiveness and environmentally friendly alternative to saltwater for dust reduction?

- ☐ Water
- ☐ Vegetable oil

- [ ] Compost
- [ ] Other. Please, specify your answer here: ______________________

Do you know of some company or expert in environmentally friendly alternatives that could be contacted?

- ○ No
- ○ Yes. Please provide their names and company name: ______________________

ANNEX 2: Interview Questions

Questions in Groundwater Monitoring

- In the survey, we notice that monitoring requirements are set in the environmental permit, by regional ELY centers and also local authorities. Can you comment on the roles these regulatory settings have in monitoring?
- What measures or strategies have been implemented to minimize the impact of sand and stone production on groundwater quality?
- From the survey, it is found that industries use manual monitoring. Are there any emerging technologies or innovations that you are considering or exploring for improved groundwater monitoring in the future?
- Have you noticed any trend of changes in the groundwater level?
- What methods are you currently implementing to minimize groundwater pollution other than salt, and what are the outcomes?
- What recommendations would you make to other sand and stone production industry stakeholders to reduce dust emissions and minimize groundwater pollution?

Questions about Using Saltwater

- Saltwater effectively reduces dust, but from the answers, it is found that using saltwater has been banned by some authorities; however, some companies still use it. Considering this restriction, why do you think some companies still use salt? Is there any concentration limit in the water sprayed?

Questions on Environmentally Friendly Approaches

- From the list, which environmentally friendly method have you used and found costly and ineffective? Do you have any plan to use any other environmentally friendly method like, **Watering, Biopolymers, Gravel, Vegetation and Mulching, Windbreak, Compost** Or only water?
- From the survey, water was found to be the most renowned environmentally friendly alternative to saltwater. What is the source of that clean water? How is this water applied?
- What do you think is important to focus on in research and development in the future, considering permitting, groundwater monitoring, and dust control?

Remarks (Open-ended question)

- Are there any additional insights, concerns or suggestions related to the environmental impact on groundwater that you would like to share?
- Can you share data on water quality and quantity with researchers?