FLUORIDE

Quarterly Journal of the International Society for Fluoride Research

# Operational management science of sustainable brick manufacturing using fluoride-enriched marble slurry and parthenium weeds

Unique digital address (Digital object identifier [DOI] equivalent):
https://www.fluorideresearch.online/epub/files/273.pdf

Wei Peng[1] ,Akram Ochilov[2], Kulmamat Mirzaev[3], Tukhtabaev Jamshid Sharafetdinovich[4],Aslitdin Nizamov[5], Erkin Ergashev[6], Tokhir Kurbanovich Ergashev[7],Shokhida Artikova[8],Bakhronkul Babakulov[9], Tulkin Ergashev[10],Shakhboz Khalimov[11], Alexey Shmatko[12], Amina Javed KHAN[13]

1:Department of economic Management, Guangzhou Institute of Science and Technology, Guangzhou 510540, China
2:Academician of Turan Academy of Sciences, Karshi State University, Uzbekistan.
3: Academician of Turan Academy of Sciences, Samarkand Institute of Economics and Service, 140100, Uzbekistan
4:Academy of Banking and Finance of the Republic of Uzbekistan, Tashkent, Uzbekistan.
5:Bukhara engineering-technological institute, 200100, Bukhara,Uzbekistan.
6:Tashkent State University of Economics, 100066, Uzbekistan, Tashkent
7:Karshi Engineering-Economics Institute, 180100,Karshi,Uzbekistan.
8:Samarkand Institute of Economics and Service, 140100, Samarkand,Uzbekistan.
9:Institute of Personnel and Community Development of the Samarkand State University.140100,Uzbekistan
10:Bukhara state university, 200118,Uzbekistan, Bukhara
11:Samarkand Institute of Economics and Service. 140100,Uzbekistan.
12:Institute for Regional Economic Studies RAS, 38, Serpukhovskaya,190013 Saint-Petersburg, Russia
13:Department of Agricultural Chemistry & Biochemistry, University of Agriculture, Peshawar, Pakistan

***Corresponding author:**
Name Amina Javed Khan
Address:Department of Agricultural Chemistry & Biochemistry, University of Agriculture, Peshawar, Pakistan

Email: amina.javaid@proton.me

Accepted: 2024 June 9
Published as e273: 2024 June 9

## ABSTRACT

**Purpose:** The purpose of this study is to develop a sustainable brick that incorporates marble slurry and parthenium weed waste as additives. This innovation aims to reduce environmental pollution, lower energy consumption, and promote circular economy and sustainable agriculture. Additionally, the study involves surveying brick kiln vendors to assess their willingness to adopt these eco-friendly bricks. This research objective is to palliate 'Environmental Pollution', lessen energy usage and support sustainable agriculture and in-result promote circular economy. The review of existing literature assesses the outcomes of the study. Explores examples, from Russia, China and Uzbekistan to offer a broader perspective on the proposed solutions.

**Method:** The study was conducted in the vicinity of brick kilns near Peshawar, Pakistan. Clay bricks were prepared with varying percentages (5% to 50%) of marble slurry and parthenium biomass. These bricks were molded, dried, and fired at 950°C. The chemical composition and mechanical strength of the bricks were analyzed. A survey was also conducted with 40 brick kiln vendors and local farmers to gauge their receptiveness to using these new bricks.

**Results:** The results indicated that adding marble slurry and parthenium biomass to bricks can significantly reduce HF emissions, a major pollutant from brick kilns. Optimal addition of 15-20% of these additives was found to maintain sufficient mechanical strength (above 20 MPa) while reducing water absorption. Survey responses showed initial reluctance but increased interest among brick kiln vendors when presented with the environmental and economic benefits.

**Conclusion and Recommendations:** The study concludes that incorporating marble slurry and parthenium biomass into bricks can effectively reduce HF emissions and improve environmental sustainability. It recommends further research to scale up this practice and apply it in other regions. Additionally, it suggests providing financial incentives and training to brick kiln operators to encourage the adoption of this sustainable technology, aligning with the UN Sustainable Development Goals (SDGs) 11, 12, and 13.

***Key-words:*** hydrogen fluoride, brick kilns, air pollution, sustainable management, Industrial waste, circular economy, South Asia, Peshawar

## INTRODUCTION

### Background information on fluoride pollution

One of the highly reactive element in the environment is Fluoride (F), which is abundantly found in air, soil and water. The Earth's crust comprises approximately 0.077% fluorine (F) among the total elements present[1,2]. Primary sources of fluorine include phosphate fertilizers, ceramic factories, aluminum smelters, brick kilns, and volcanic eruptions[3,4]. As a result, fluorine has often been an unrecognized pollutant compared to ozone ($O^3$), which is known to harm agricultural crops and fruit orchards in developing countries, posing a significant threat to the environment and regional food security.[5,6].

Often clustered just outside many South Asian cities, brick kilns are among the fastest-growing sectors and are considered a major source of air pollution in the region. Pakistan ranks third globally in brick production, following China and India, and along with Bangladesh, these countries produce two-thirds of the world's bricks[7]. Consequently, brick kilns are a primary source of atmospheric pollution, causing widespread environmental impacts on humans, animals, and plants[7,8,9].

### Case Studies from Russia, China, and Uzbekistan

The sustainable production of bricks is increasingly integrating industrialized leftovers and natural materials in-order to create positive impact on environment and cut the expenses. This examination focuses on the use of marble slurry enriched with fluoride and Parthenium weeds, in brick making showcasing cases from Russia, China and Uzbekistan.

#### Russia

In Russia there have been methods used to incorporate waste into construction materials. Studies exploring the utilization of marble slurry and Parthenium weeds, in making bricks are becoming more popular with a focus, on improving material characteristics and environmental advantages. In Russia there has been an emphasis, on reducing waste and emissions by utilizing advanced construction materials[10,11,12].

A study conducted by the Institute for Regional Economic Studies in Saint Petersburg has shed light on the benefits of incorporating marble slurry into construction materials[13]. This study is in line with a discussed paper suggesting that the use of marble slurry can significantly decrease waste and pollution thereby promoting environmental sustainability. The research conducted in Russia illustrated the integration of marble slurry, into construction applications effectively diminishing the environmental impact of industrial waste.

#### China

The construction sector, in China has been actively investigating the incorporation of marble slurry into brick production. Research shows enhancements in both characteristics and environmental sustainability aspects. For instance, a study carried out in China delved into the utilization of grained cement slurry highlighting the significance of eco materials, in decreasing carbon emissions[14].

China, known for its brick production is grappling with environmental issues stemming from emissions produced by brick kilns. Recent research carried out at the Guangzhou Institute of Science and Technology underscores the importance of methods, in brick manufacturing. Their studies indicate that incorporating waste like marble slurry into bricks can lower emissions and enhance the structural integrity of the bricks[15]. This study aligns with the findings presented in the paper illustrating how using marble slurry can improve both the durability and eco friendliness of bricks.

Another research project in China investigated the impact of pollution on agriculture shedding light on how industrial emissions are negatively affecting crop health. This study, conducted in areas with emissions from brick kilns reinforces the necessity for sustainable practices as advocated in the aforementioned paper. The research revealed that implementing practices could notably decrease levels, in the environment safeguarding human health and agricultural output simultaneously.

#### Uzbekistan

Sustainable brick making projects, in Uzbekistan have been emphasizing the use of waste materials, like marble slurry found locally for construction purposes. This method tackles waste management problems while also offering an eco-alternative to address the scarcity of building materials.

Researchers, in Uzbekistan at the Turan Academy of Sciences and the Samarkand Institute of Economics and

Service have been actively studying methods for producing bricks. Their studies have involved testing types of waste materials from industries and agriculture such as parthenium biomass to improve brick quality and reduce emissions[16].

Moreover Uzbekistan has been grappling with air pollution caused by brick kilns, a challenge to that faced by Pakistan. Research has indicated that incorporating parthenium biomass and marble slurry into brick production can effectively address these pollution issue[17]. The willingness of brick kiln operators to embrace technologies has been examined, revealing challenges and opportunities consistent, with the findings presented in the aforementioned paper.

Fluoride enriched marble slurry and Parthenium weeds being incorporated into brick production is seen as a step, towards ecofriendly building methods. These components not improve the strength of bricks. Also play a role in managing waste and protecting the environment. Examples from countries, like Russia, China and Uzbekistan demonstrate how these sustainable practices have relevance and advantages.

**Brick Kilns Producing HF in Pakistan**

There is a significant threat of HF emitting from brick kilns in South Asia to agricultural crops in the region, particularly in Pakistan. These brick kilns are mostly located on or near the agricultural lands in peri-urban areas exposing crops directly to air pollution from these brick kilns because of tis close proximity. These brick kilns are poorly regulated by using low quality fuel to fire brick kilns that results in the release of carbon monoxide (CO), sulfur dioxide ($SO_2$), and HF. However, the HF is the most phyto-toxic pollutant compared to CO and $SO_2$. HF is emitted from clay when clay brick is backed above 950$^o$C in the kiln[7]. Upon the release in the air, it combines with hydrogen to form hydrogen fluoride.

Previous research has stated significant effects of HF damage to peri-urban crops in Pakistan by Ahmad[18]; Ahmad[19], Wahid[20] and Saleem[21].

**Marble slurry pollution in Pakistan**

Marble industry is the major contributor to waste water pollution in the industrial sector due to the excessive amount of water usage that results in releasing water in to the streams and rivers. The marble industry is on the rise in Khyber Pakhtunkhwa Province, Pakistan. The province contributes around 97% of the total marble produced in Pakistan because of which the province is facing major impacts on its environment. Marble industries is important for the province economy but is paying heavy price for the waste it is producing[22]. The marble industry produces solid and semi solid (slurry) waste. The slurry contains large volume of water with enough marble particles that is produced during mining, processing and polishing steps[23].

**Invasive Parthenium Weed**

Commonly known as *Parthenium hysterophorus* L., commonly known as parthenium weed that is a part of the *Asteraceae* family. It is a well-known weed that is found in all continents including Pakistan, India, Bangladesh, Southern China, Africa, Australia[24]. It is poses a major threat to humans, animals and other plants, which is responsible for agricultural losses, and have severe environmental problems[25]. Its evasiveness is because of its survival in arid hot regions that have much harsh environment[26] due to which it is adaptable to different environment, capable of germinating and growing around the year[27].

The aim of the study is to make a sustainable brick that contain marble slurry and parthenium waste as additives to reduce the environmental implications from marble and parthenium waste to reduce energy consumption and contribute to circular economy and sustainable agriculture, and to carry out a targeted survey of brick kiln vendors to determine their response of using these bricks.

## MATERIAL AND METHODS

**Project area**

A current study was conducted in the vicinity of brickilns fields near peshawar, which is located at 34$^o$01'N 71$^o$35'E in Pakistan at an elevation of 510m.

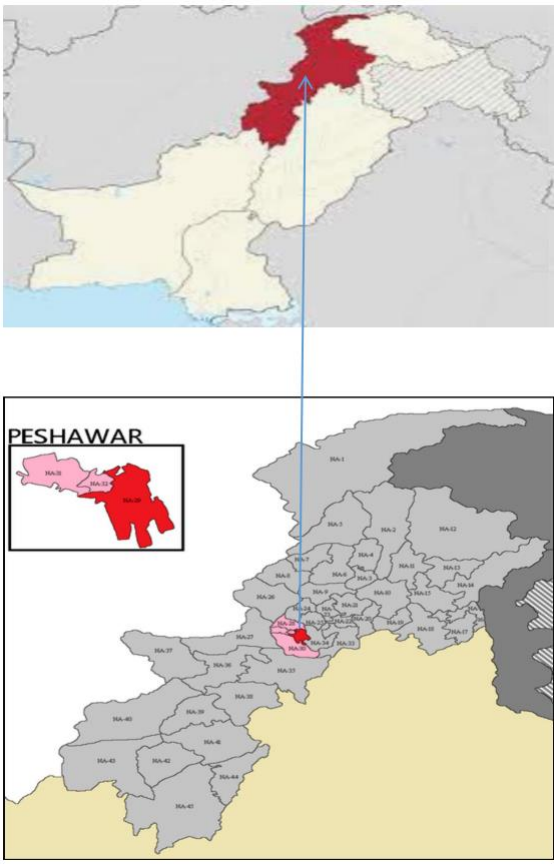



**Fig-1: Location of the study area in Peshawar Source: Google Maps (2024)**

The brick kilns are on the western side of Peshawar city, in 15 square kilometers. The area is mostly irrigated farmlands from nearby Warsak Dam. The cluster of brickilns in the are is due to the favourable composition of soil for brick making. Because of high market demand and high fuel prices, brick kilns owners use low quality fuel like used automobile oil and low quality coal that contribute to atmospheric pollution in the city.

**Preparation of bricks from slurry and parthenium additives**

In the current study, clay bricks were incorporated by varying percentages (5%, 10%, 15%, 20%, 30%, 40%, and 50% by weight) of marble slurry and parthenium biomass separately as initial additives. The marble slurry were obtained from marble factory situated on Warsak Road , Peshawar. The slurry were dried to get the powdered form. The total parthenium plant including roots was sun dried an cut in small pieces by chopping them with th help of a chopper. Both marble slurry powder and parthenium biomass were then mixed with clay bricks in a fixed proportion mentioned above. The procedure was conducted on a small scale at the University of Agriculture, Peshawar replicating on industrial procedure. With the help of stainless mold, the samples were molded by pressing to get into a rectangular shape with dimentions of 20×15×10mm. The newly made bricks were dried under sunlight for up to 3 days and were then kept in the furnace and subjected to splintering, by increasing the furnace temperature at 10°C/minute until the temperature reaches up to 950°C. The bricks remained there for 60 minutes at this temperature before lowering the temperature to cool it down. The chemical composition of bricks were determined by a wavelength dispersion X-ray fluorescence (XRF) spectrometer (Bruker AXS GmbH-S4 Pioneer, Germany) at UAP, Peshawar. The spectrometer contained a high-powered X-ray tube that have a rhodium anode and a 75µm beryllium window, which produces 4kW of power. Moreover, it also has 8 diffracting crystals, which allows Precise analysis because of the distinct d-spacing. The brick mechanical strength was analyzed using a 100–500 kN Universal Testing Machine made by Testometric Co. Ltd., UK. The conductivity (κ) and thermal diffusivity (α) of the bricks were determined by a transient plane source (TPS) method by Rehman and Maqsood[28]. The die-mentions were done by a calibrated Pt-100 thermometer.

**The Conversation survey**

The survey consisted of around 40 brick kilns, including the ventures of the brick kilns and local farmers. The survey conversation was regarding the particular types of fuel being used to fire the kilns and the related reasons for using these specific fuel. Are they using any modern technology to filter exhaustive gases from HF and other air pollutants? Are they willing to transfer their fuel combustion technology with an advance technique e.g. cleaner fuel or using marble slurry and agricultural wastes to reduce air pollution? Is there any systematic monitoring of air pollution in the brick kiln area? What threshold levels are set for HF and other toxic gases in Pakistan to assess their negative effects on local crops and fruit orchards by using advanced air quality monitoring system?

Moreover, they were asked about regular assessment and looking after of kiln equipment to satisfy optimal

performance and emissions gauge? Are there any buffer zones like tall tress to reduce the effects of brick kiln emission on crops? Which can reduce the HF impact's up to certain extent.

Determining the level of education of the farmers and how much they know about the negative impacts of HF on crops and fruit orchards? Which variety are grown well in these conditions? Are they willing to build greenhouse structure to shield their sensitive crops from the air pollutants? Will they be willing to change the planting schedule and sites to avoid peak hour emissions or vicinity to the brick kilns?

Devising strategy based on the results obtained from the conversation survey from local farmers and brick kiln ventures on how to reduce the emissions and protect sensitive crops from HF and other air pollutants. Determining the keen interest of the local farmers and community in monitoring atmospheric pollution and report any violations for strict implementation through local EPA.

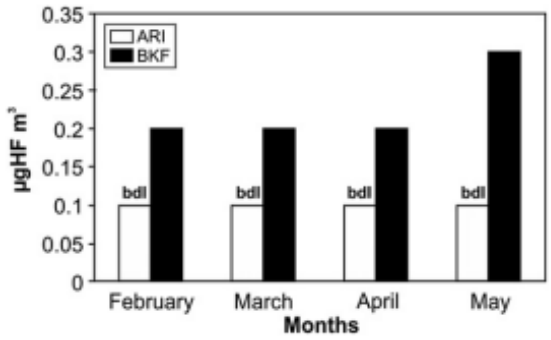
Will the comply with government regulated policies to encourage brick kiln vendors to embrace alternate/cleaner technologies by providing tax breaks, subsidies and grants?

## RESULTS AND DISCUSSION

### Fluoride content of the Soil

The total fluoride in the brick before firing were in the range between 180 to 241 µgF/kg, which lowered down to 75 to 106 µgF/kg after backing when the temperatures went above 900°C. around 70% of the fluoride was released in to the atmosphere during the brick backing process. The normal fluoride content of soil is around 500-1000 µgF/g that depends on the material of soil containing clay particles[29]. When the temperature rises above 900°C in the brick kiln then it released around 50% of the fluoride from the brick samples[30]. The fluoride concentration in the brick used for backing in this study was lower but the continuous use of hundreds of brick kiln round the year in Peshawar can contribute significantly to the overall HF concentration in the air that can damage crops significantly I the longer run as reported by Ahmad et al[18]. They documented the impacts of HF from brick kilns revealing HF concentration of 0.3 µg/m$^{-3}$ (Figure 2) that is still toxic enough to have negative impacts on vegetation in Peshawar.

**Figure 2: The atmospheric concentration of HF at different sites in Peshawar (Ahmad et al. 2012).**




### Chemical composition of marble slurry and parthenium biomass

The primary raw materials used in the brick industry, notably clay. The chemical composition of clay and marble slurry are given in Table-1.

**Table 1. shows the chemical composition (% weight) of clays and marble slurry used in the present study.**

| Substance | Clay | Marble Slurry |
|---|---|---|
| $SiO_2$ | 45.52 | 1.71 |
| $Al2O_3$ | 12.40 | 1.02 |
| $Fe_2O_3$ | 6.80 | 0.24 |
| CaO | 8.92 | 50.02 |
| MgO | 1.33 | 4.45 |
| LOI (Loss on ignition) | 12.31 | 42.3 |

Clay of Peshawar is mostly calcareous that contains around 6% of CaO by weight. Moreover, if the total concentrations of CaO, MgO, $Fe_2O_3$ and $TiO_2$ exceeds above 9% then the clay is deemed as low refractory. However, the total content of the above oxides is below 9% which term the clay as highly refractory. Chemical analysis of marble slurry collected from several factories on Warsak Road showed that it contains 42% organic matter, 1.71% Silica, 1.02% Alumina, 0.24 $Fe_2O_3$, 4.45% Magnesia and 50.02% lime (Table 1). Whereas, the bulk density ranged from 1.3 to 1.5 (gm.cc) and specific gravity was found to be between 2.93-2.88. Parthenium plant biomass, used as an additive or filling material in brick making which contains plant fiber (mainly cellulose) particularly for sustainable environment purpose as shown in Table 2.

**Table 2. Chemical analysis of Parthenium biomass (% weight)**

| Chemical Composition | % Weight |
|---|---|
| Cellulose | 37 |
| Hemicellulose | 27 |
| Lignin | 23 |
| Ash | 4 |
| Minerals (Si, Na, K) | 3 |
| Protein | 1 |

A number of test were carried out to assess the mechanical strength of the bricks have marble slurry and parthenium additives.

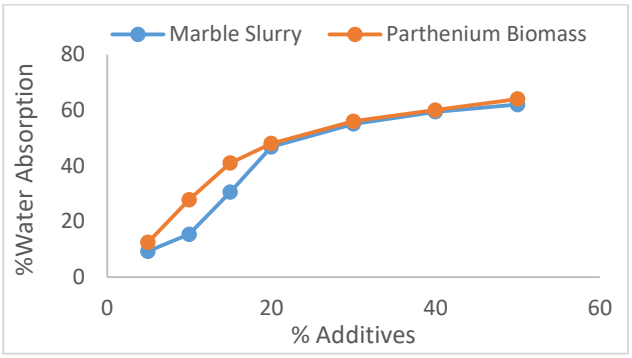
**Water absorption**

The local plain brick typically has water absorption of around 8 to 21%, mainly because of little variations in the raw material and manufacturing techniques[31]. But the good quality brick should not have absorbed water above 20% of its dry weight after being put under water for one whole day[32].

In the current research, the absorption of water by clay with marble slurry varied from 9 to 59% above 900C temperature and 11% to 36% with parthenium biomass addition, as depicted in Figure 3. It was witnessed that more that 15% of the additions of additives raises the level of water absorption above the threshold limit of 20%. This is due to the apparent porosity which is mainly linked to water absorption and is important for preventing water from incursion by The water absorption of the bricks that is directly linked to their apparent porosity, which is crucial for preventing water intrusion to ensure a solid internal structure.

Firing temperature must be raised to ensure the reduction of water absorption and density. Consequently, the porosity in fired specimens was a result of the combustion of additives during firing.

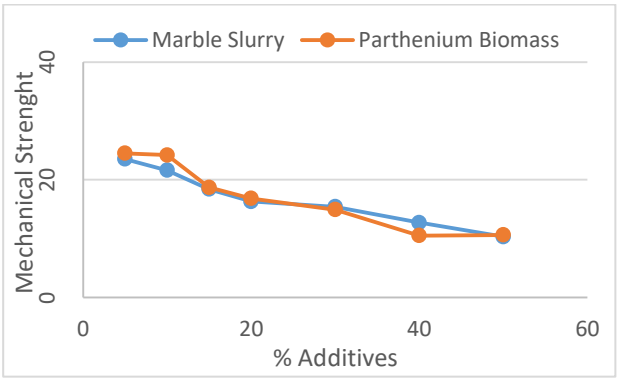
**Fig. 3: Effect of additives on the water absorption of the brick samples.**




**Mechanical strength**

the quantity of additives has affected the mechanical strength of the. Particularly, the mechanical strength of the bricks fired above 900°C lowered as the amount of marble slurry and parthenium biomass increased. The compressive strength of the bricks lowered from 23 to 10 MPa with an increase in marble slurry content from 5 to 50% by weight, and 24 to 10 MPa with a rise in parthenium biomass content from 5-50% by weight as shown in Figure 4. It is generally observed that in clay-based ceramic systems, strength tends to decrease as porosity increases.

**Figure 4: Variation in mechanical strength with the additives.**




The objective of the current study was to get a brick with high porosity and low density, and to utilize the marble slurry and parthenium weed as additives to remove HF from emitting it to the atmosphere and contribute to the circular economy. Too much addition of marble and parthenium waste to the brick can affect

the physical properties of the brick leading to unstable outcomes. Therefore, it is imperative to regulate the amount of additives to avoid antagonistic effects. An average brick should have a compression strength of around 25 MPa according to the British Standard Institution for average quality bricks[33]. The present study showed that by raising the content of either marble slurry and parthenium biomass in brick can also impede its permeability and mechanical strength, which is important for a good quality brick. However, the addition of around 20% marble slurry and parthenium biomass can give enough mechanical stability that will not surpass above 20MPa that is under the permissible limit of 25MPa for a quality brick. Therefore, we can add 15-20% of these additives in brick making. The mean weight of a brick is around 3kg in South Asia that can utilize about 200-600gm of marble slurry and parthenium biomass material as additives in a single brick making.

**Conversation survey with brick kiln owners & farmers**

Most owners of brick kilns are aware of the pollution that their current methods of operating the brick kilns are causing to the environment. In order to keep brick production costs to a minimum, they frequently use low quality fuel. It's interesting to note that none of them had ever heard of adding additives made from agricultural waste to clay bricks, so they all stuck to their traditional methods. More than 60% of the brick kiln vendors were not willing to use marble slurry and parthenium as additives as it might affect the quality and toughness of the brick. But when they were provided evidence of the benefits they can brick to the environment with compromising on the quality of the bricks, their thinking moved on the positive side.

The brick vendors were also reluctant despite their interest in the new brick technology as they wanted necessary training's for their employees operating the brick kiln and also providing workshop and training about the environmental pollution and sustainable environment to utilize these additives to lower the energy consumption and harmful emissions from the brick kilns. The owners were very happy about the lower cost of manufacturing by using these additives in brick because of high fuel prices.

The brick vendors asked the local government to give them financial benefits like tax waiver and incentives for adopting to this new method and there should be a good mechanism for collecting Agri and marble waste by the help of local farmers. The main point will be how much this advanced method can lower the fuel costs that will lure other brick kiln owners to follow the step.

Moreover, the owners also requested for giving recognition in form of certificates to those brick kilns that are using this sustainable method to reduce environmental pollution, which will encourage other brick kiln vendors to embrace this technique and contribute to circular and green economy.

The current research is in line with the UN-SDGs, specifically to SDG 11,12 and 13 as it has a substantial positive effect on development of viable cities and communities by using marble and agricultural waste for sustainable production and consumption and also addressing main issues of climate change by using energy efficient methods.

**Conclusion and Recommendations**

The current study emphasizes on the importance of embracing sustainable management techniques to enhance eco-friendly consumption to promote green economy. It was concluded that utilizing marble slurry waste it can reduce HF emission as it will capture fluoride inside the clay brick and Agro-industrial byproducts, like parthenium biomass addition to brick making. This intern will lower the negative impacts of on the environment and will promote economic and social advantages. Future studies should emphasize to investigate further possibilities of these practices by scaling up and applied in other regions and manufacturing industries to reduce the emissions and stop climate change.

## ACKNOWLEDGMENT

The research is financed as part of the project “Development of a methodology for instrumental base formation for analysis and modeling of the spatial socio-economic development of systems based on internal reserves in the context of digitalization” (FSEG-2023-0008).

## CONFLICT OF INTERESTS

None.

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