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Energy efficient brick kilns for sustainable environment

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ABSTRACT

Bricks are one of the most commonly used materials in building construction. In recent decades, rapid urbanization has led to an increase in construction activities, hence the usage of bricks as well. However, the conventional brick kilns are not energy efficient and the emissions from the brickfields are severely polluting the environment. Therefore, comprehensive investigation is crucial for sustainable development of brick manufacturing industries. In this study, brick burning techniques, types of fuel, energy consumption, emitted pollutants, and their environmental effects in the context of the southern region of Bangladesh have been presented. Qualitative and quantitative data were collected from the Greater Khulna region along with secondary sources. From an analysis of the collected data, some suggestions on the use of energy efficient brick kilns and a comparative study of the various kilns are formulated in the paper. The study has found that conventional brick kilns (such as the Clamp method and Bull Trench Kilns) are energy inefficient and environmentally harmful. The study compared key parameters of various brick kilns and concludes that for smaller investors the vertical shaft brick kiln provides a feasible solution, whereas the hybrid Hoffman kiln is a better choice for big investors.

Keywords: Brick kilns; Environmentally friendly; Energy efficient; Air pollution; Sustainable brick industry; Greenhouse gas emissions

1. Introduction

Environmental pollution is a major concern nowadays. Among others, atmospheric pollution is widely considered as a severe problem that may cause health effect to population in highly populated and anthropized areas [1]. Bangladesh is one of the most densely populated countries in the world having population around 149 million [2] and is considered as a more vulnerable country for air pollution. From current United Nation (UN) reports, about 25% of Bangladesh's present populace resides in urban regions. This percentage is increasing day by day and to keep pace with the rate of urban population

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growth, building and construction activities are rapidly expanding in urban areas. In accordance with the increasing demand of construction, bricks are considered one of the most essential materials for sustainable infrastructure development in this region. In urban areas, brick consumption has risen substantially. Khulna City, situated in the southern part of Bangladesh, is the third largest city in the country and considered as one of the megacities and statistical metropolitan areas of Bangladesh. This city has an urbanization rate of 65.08%. The proportion of households having masonry walls in Khulna division is among the highest in Bangladesh at 13.14% [3].

The Greater Khulna region has a high concentration of brickfields to meet the demands of construction in this area. These brickfields are a source of several major environmental pollutants and cause severe air pollution [4,5]. Starting in the early nineties, a number of efforts to disseminate cleaner brick burning technologies have failed [6–9]. A huge amount of energy have been wasted in this process where energy is the most sensitive and important issue for the Asian countries as well as for the whole world [10–15].

As stated by the Department of Environment and the Brick Manufacturers Association, the total number of brickfields in Bangladesh is about 6,000. Around 280 brickfields are operating in the Greater Khulna region, of which 180 are registered and 100 are unregistered. The unregistered brickfields burn their bricks using the conventional Pazawah or Clamp method and are mainly dependent on wood for fuel [16]. About 72 tons of wood fuel are required to burn one hundred thousand bricks [17]. This is one of the main causes of deforestation [18] in this area, which is where the world's largest mangrove forest, Sundarban, is situated.

Most of the registered brickfields have traditional Bull Trench Kilns (BTKs), which use low- grade coal (63%) with wood fuel (37%) [17] to fire bricks. Low-grade coal, wood fuels, and fossil fuels emit greenhouse gasses, such as CO_2, CH_4, CO, N_2O, NO_x, and NO [19–23]. The pollution from BTKs, largely in the form of particulates, has reached alarming proportions [16,24–26]. This problem is further compounded by the fact that these BTKs operate during the dry season when the problem of dust pollution reaches its peak [27]. Serious pollution levels are readily discernible from the thick black plumes that emanate from the chimneys and the dismal state of the vegetation in the vicinity of the kilns (Fig. 1). Various health hazards are reported by the local population and it is suspected that these diseases might be resulted through the emissions from these traditional brick kilns [28,29]. General health problems faced by inhabitants of the areas surrounding the kilns are headaches, fatigue, dizziness, respiratory problems, eye irritation, chest pain, cardiovascular and lung diseases, bronchitis, premature mortality, and other problems.

Fig. 1. Pollution from traditional brick kilns.

Most of the brickfields of this region are located on the fringes of Khulna, Bagerhat, and Satkhira (three districts in Greater Khulna). This paper aims to portray the fuel consumption scenario, the emission categories, the levels of pollution, and the effect of pollutants on the surrounding localities. It also appraises alternative energy efficient approaches to control pollution from brick kilns and explores the broader implications of large-scale and small-scale brick kilns in a developing country like Bangladesh. A comparative breakdown of existing kiln technologies is addressed in this research. Finally, a number of proposals are put forward for more energy efficient and environmentally friendly (green) brick production in this region.

2. Fuel consumption in brickfields

Brickfields produce some of the highest emissions of greenhouse gases in Bangladesh as they burn huge amounts of coal and wood fuel [24]. As a result of wood being used as a fuel in this industry, deforestation has become a major problem in the Greater Khulna region, as well as in Bangladesh as a whole. Burning of wood fuel except bamboo is illegal (Government of Bangladesh [30]), but biomass, mainly firewood and rice husk, continue to be the main energy sources for brick firing [31]. The pattern of energy consumption in the brickfields of the Khulna and Satkhira districts is shown in Table 1.

Around 180 registered brickfields are located in the coastal region of Bangladesh (97 in Satkhira, 78 in Khulna, and 5 in Bagerhat). At this juncture, the

Table 1
Pattern of energy consumption in brickfields

Fuel type	To burn 0.1 million bricks (tons)
Coal	30
Wood fuel	18
Crude oil	0.0416
Tush	0.1
Truck tire	10 (pieces)

largest unit can produce 5–6 million bricks per year and smaller units can produce 1.5–2.0 million bricks per year, averaging 3.0 million per year overall. These registered brickfields use wood fuel along with coal.

The unregistered brick manufacturers are located in the coastal rural region of Bangladesh, mainly in the Bagerhat and Satkhira districts. Their average production is 0.5 million bricks per year. Most of these undocumented brickfields do not use any kiln. They rely on the primitive Pazawah or Clamp method and depend mainly on wood fuel for brick burning. The unregistered brickfields use more wood fuel than the registered brickfields and in a less controlled way (Table 2).

3. Pollutants emitted from brickfields

Wood fuels and fossil fuels are responsible for the emission of greenhouse gases, such as CO_2, CH_4, CO, N_2O, NO_x, and NO [23,32,33]. Therefore, brick industries are significant sources of greenhouse gases as they use wood, coal, and oil as fuels for high temperature brick burning [34]. The combustion of clay and fuels in the process of making bricks produces dioxins and furans as byproducts. These dioxins are chlorine rich and persist for years together, and are self-transportable from one place/country to another. They are also bioaccumulative because of their strong affinity for fats, and thus increase manifold in toxicity along the food chain, causing harm to the lives of the hosts [35,36]. Ahmed and Hussain [37] studied the pollutant loads, particularly of SO_2 and particulate matter, within regions where brick kilns were clustered in Bangladesh. They found that particulate matter was a major pollutant in these regions.

Table 2
Wood fuel consumption in Greater Khulna

Type	No. of brickfields	Production (million)	Wood fuel required (*t*/ million)	Wood fuel consumed (*t*)	Deforested round wood (m^3)
Registered	180	3.0	1.8	97,200	433,512
Unregistered	100	0.5	7.2	36,000	160,560
Total	280	3.5	9.0	133,200	594,072

Table 3
Total greenhouse gas emissions from brick burning in brick kilns

	Fuel type	Fuel used kilo tons (kt)	Emissions (tons)						
			CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Greater Khulna	Coal	162	314,341.3	34	4.75	1,787	268	68	15,390
	Wood	133.2	423,517.53	59.94	7.99	199.80	3,996	99.90	532.80
	Crude oil	0.245	749.8999	0.020	0.0062	2.0658	0.1033	0.0001	19.6000
	Total		738,608.73	93.96	12.75	1,988.87	4,264.10	167.90	15,942.4
Bangladesh	Coal	1,800	3,492,681	376.74	52.7436	19,854.2	2,976.24	753.48	171,000
	Wood	1,260	4,006,246.86	567	75.6	1890	37,800	945	5,040
	Crude oil	2.288	7,003.147	0.192	0.0579	19.292	0.9646	0.0005	183.04
	Total		7,505,931	943.9	128.40	21,763.4	40,777.2	1,698.48	176,223

Note: NMVOC—Non-methane volatile organic compounds.

In relation to the standard toolkit prescribed by the United Nations Environment Program, under well-controlled processes 0.2 μg toxic equivalents (TEQ) of dioxins and furans are emitted as byproducts into the air during the production of each ton of bricks. As per this emission rate, if each brickfield in the Greater Khulna region produces an average of 3.0 million bricks, which is equivalent to 4,091 tons/y, then a single brickfield emits a total of 818 μg TEQ dioxins and furans per year, polluting the air within a 4 km radius (Table 3).

4. Emission concentrations

The impact of pollution on the environment can be estimated through checking the level of pollution in the affected environment [38]. This study estimates the pollution levels in the affected environment of the Greater Khulna region and compares them with WHO air quality standards. A survey was conducted in the affected region to determine any other effects of the pollution from the brickfields. The study was conducted in "Koiya" of Khulna district and "Tala" of Satkhira district. In both places, the stack height of the kilns was generally 80 ft (Table 4).

Pollutant concentrations are higher during winter [27]. This is due to meteorological factors like low temperatures and less or stagnant wind in winter. Kavak Akpinar et al. [39] have shown a relationship between air pollutant concentration and the meteorological factors such as relative humidity, pressure, and temperature. Such conditions do not allow pollutants to disperse easily and high concentrations of the pollutants buildup in neighboring areas. The local inhabitants around brickfields are continuously exposed to high concentrations of pollution during the brick-burning season. The continuous inhalation of this poisonous air puts them at risk of developing serious respiratory diseases [19].

5. Dependency of emissions on fuel

This study found that the emission of different pollutants is dependent upon the type of fuel used for brick burning (Fig. 2). Wood fuel emits far more carbon rich pollutants than other fuels [40]. In the brickfields of the Greater Khulna region, the consumption ratio of coal to wood fuel is 55:45. Although the rate of wood fuel used is lower than that of coal, more carbon-containing pollutants were emitted from wood fuel burning than from coal [17]. This is graphically shown in Fig. 2.

Table 4
Pollution concentrations—WHO standards vs. concentration in Greater Khulna

		Coastal region of Bangladesh (μg/m^3)[a]	
Pollutant	WHO Standards (μg/m^3)	December	April
SO_2	100	3,000	1,000
NO_x	150	300	125
PM-10	150	300	125

[a]Concentrations around 400 m from source and are 24 h average concentrations.

6. Impact on health and environment

Brick burning in the traditional way causes both short-term and long-term impacts on the environment and on human health [41]. Short-term impacts include severe air pollution from the emission of smoke and the pollution of soil and nearby water bodies with byproducts and wastage produced by the brick kilns [42]. These have a negative effect on vegetation and fish production [43].

As for long-term impacts, this study observed that the people of the surrounding areas, especially the infants and the elderly, suffered from various respiratory and skin diseases.

6.1. Impact on workers

The brick manufacturing season is usually from October–November to March–April (six months continuously), which coincides with the dry winter season. Brickfield workers are therefore transitory and mainly reside around the site during the manufacturing season. Most of the workers spend nearly all of their time in the kiln. They even stay there at night. As a result, these workers are exposed to huge

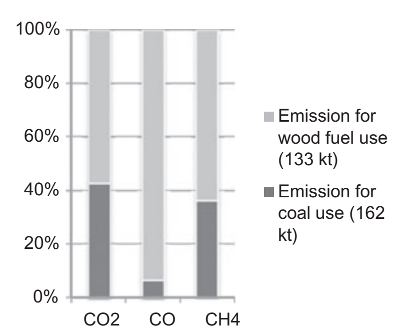

Fig. 2. Comparison of the emission of carbon-containing pollutants from different fuels due to brick burning in Greater Khulna.

amounts of heat and smoke round the clock, which causes respiratory problems and dizziness. One of the most serious effects on workers is black lung disease.

Workers who work outside the kiln also face health problems. These workers are mainly engaged in carrying raw materials like coal into the kiln. While carrying coal, they inhale huge amounts of particulate matters as dust. As a result, they also suffer from respiratory problems.

In that locality, it was found that most of the brickfield workers suffered from headaches (75% of the workers responded) during the brick manufacturing season. They also suffered from dizziness and fatigue (30% and 60%, respectively). The workers also claimed that the dizziness was during the months of brick manufacturing. The fitness level of the workers decreased with increasing job duration.

6.2. Impact on local vicinity

It was found in the villages of that coastal area that the people suffered from respiratory problems due to the pollution from brick kilns. They also suffered from other health problems due to the high concentrations of SO_2, NO_x, and PM-10. However, the people were not aware of the harmful pollution they were exposed to; rather they considered such health problems as a part of their lives. This was why a huge percentage of the respondents (33%) thought that they were not facing any problems. About 44% of the people recognized that they had some pollution related problems and 23% were confused about their exposure. The problems noted were headaches, fatigue, dizziness, respiratory problems, eye irritation, chest pain, cardiovascular and lung diseases, bronchitis, premature mortality, and others.

Dioxins and furans are two highly toxic and deadly substances produced as byproducts in the process of brick burning. They have many adverse effects on human health and the environment, and, as they are highly persistent toxic substances, their toxic effects are magnified manifold. No study has been conducted on dioxins and furans in this region despite the presence of a significant brick manufacturing industry. They cause abnormally functioning thyroids and other hormone system malfunctions, feminization of males and masculinization of females, compromised immune systems, behavioral abnormalities, neurobehavioral impairment including learning disorders, a shortened period of lactation in nursing mothers, endometriosis, increased incidence of diabetes, tumors and cancers, and gross birth defects. Other effects include loss of appetite, weight loss, nausea, headache, liver and renal damage, cardiac arrhythmias, allergic conjunctivitis, and retinal angiopathy.

6.3. Particulate matters

A major pollutant emitted from brickfields is suspended particulate matter (SPM). By increasing the stack height of kilns, the concentration of these pollutants could be reduced in the areas surrounding brickfields (Fig. 3). It is estimated that while 60 ft high stacks lead to concentrations of pollutants that exceed the WHO standards (100 for SO_2, 150 for Particulate Matter and NO_x) (WHO, 1999), increasing the stack height to 120 ft leads to well-controlled concentrations. Fig. 3 shows the comparison for concentrations from stacks of different height in December, 2003. It shows that SO_2 concentrations decreased by increasing the stack height to 120 ft but could not be completely controlled. However, NO_x and PM-10 concentrations were well-controlled by increasing the stack height to 120 ft.

7. Policies to control pollution

Brick kilns are one of the major sources of pollutant emission in Bangladesh. There is a wide scope to improve the traditional brick manufacturing process. The major issues involved in improving the brick making process to make it more environmentally friendly are improving the combustion efficiency of existing kilns, upgrading kilns to newer and more efficient designs, upgrading the design of the chimney to emit lower levels of hazardous pollutants, and upgrading the technology of the overall process. The methods used to upgrade technology are usually capital intensive in this industry. In contrast, improving combustion efficiency can be achieved with relatively little cost in many kilns. Promoting cleaner production in this industry requires extensive understanding of changes in brick making technology. There are several possible policy options that can be implemented in the Greater Khulna region.

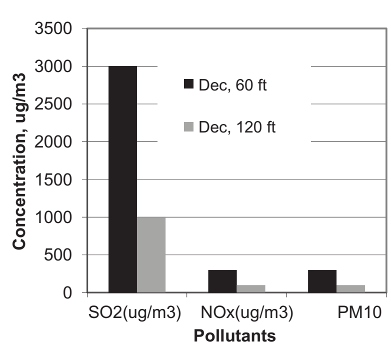

Fig. 3. Comparison of pollutant concentrations when stack height is increased from 60 to 120 ft.

7.1. Social awareness and public motivation

The inhabitants of the areas near brickfields are already aware of the pollution caused by emissions from traditional brick kilns. The owners and manufacturers of the bricks are also beginning to recognize these matters. A good number of BTK owners converted their kilns into 120 ft fixed chimney kilns (FCKs) when the government declared in 2004 that BTKs would not be permitted to operate the next brick manufacturing season and that licenses would only be issued to FCKs and Zigzag kilns.

Local leaders and respected members of the community should take up the responsibility of discouraging unregistered brickfields from operating Clamp or Pazawah brick kilns and also the use of BTKs with movable chimneys. Documentary films on the devastating health risks and environmental damage of the pollution from brickfields can promote awareness among brickfield owners, brickfield workers, and the general public. Documentaries can also inform the people about alternative cleaner technology for making bricks and the importance and usefulness of such technology.

7.2. Indirect economic incentives

Extra taxes can be imposed on very low grade, high sulfur coal, which is less energy efficient. This could deter brick manufacturers from using this type of coal due to its higher price. The government should take extra initiatives and grant subsidies for importing superior quality coal like special less volatile coal. The use of special less volatile coal produces less ash and volatile matter. Moreover, this type of coal has high calorific value, which helps to produce quality bricks in energy efficient brick kilns and thus to also reduce particulate emissions.

Consumers also have a responsibility to stop environment polluting brick manufacturing practices. They can boycott brickfields which produce the most pollutants and cause the most damage to the surrounding environment. Such policies will force brick manufacturers to reevaluate their use of brick kilns that cause high levels of pollution.

7.3. Improving the existing technology

BTKs (Fig. 4) are the most common type of kiln in this region. It is difficult to convert this kind of kiln overnight into a cleaner and more energy efficient kiln due to high initial costs. The existing technology can be improved by making some minor changes to the kiln to make it comply with existing standards. Most current BTKs have movable metallic chimneys. These movable chimneys can be replaced with fixed chimneys, which are more environmentally friendly.

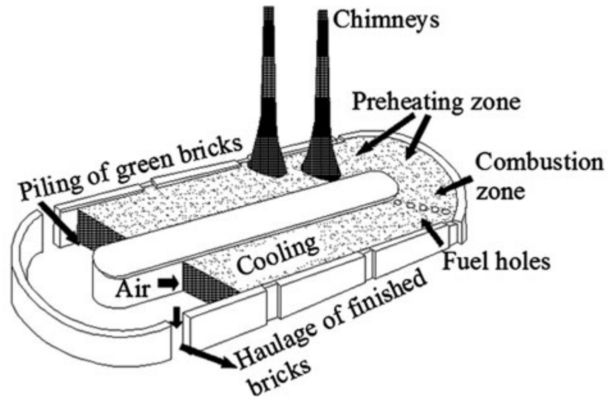

Fig. 4. Schematic diagram of a BTK.

From the technical point of view, several low-cost ways to increase efficiency and to reduce waste and pollution in brick making are as follows:

7.3.1. Pile up fuel mass around bricks to ease preheating

Compact fuel mass can be added with the bricks all through the kiln. Sawdust or coal powder can be blended with the green brick mass or solid fuel can be used as fuel channels in various stages of the kiln. This creates a combustion zone in the kilns which progressively shifts upward and utilizes the residual heat in the lower chamber to heat up the combustion air. For drying or preheating the green or crude bricks, the residual heat of the flue gas is utilized.

7.3.2. Better wither of brick prior to firing

Amount of fuel required can be reduced by increasing the drying time period. Uniform drying all through the brick stacks lessens imperfect burning of bricks.

7.3.3. Enhance airflow mechanism

For better combustion of the brick, the airflow speed and direction needs to be well organized. This efficiency can be improved by sealing all air leaks and managing kiln opening size.

7.3.4. Shift to natural gas fuel

Recently, a number of new gas fields are found in different locations of Bangladesh. This creates a possibility to use the natural gas to burn the brick which will eventually generate less pollution to the environment. In addition, the production quality and speed will be improved well.

7.4. Upgrading of the BTK design

The following steps can also be adopted to upgrade the existing technology.

(1) The conventional BTK process could be improved by inserting limestone scrubbers for decreasing sulfur dioxide discharge and installing filters aimed at embedded particulate elimination.
(2) Mixing and pulverizing fuels prior to burning along with providing insulation to the brick kiln would result in higher energy efficiency as well. Low sulfur coal and natural gas could be a good alternative of the conventional solid wood fuel and inferior quality coals.
(3) The chimney should be designed to provide the required draught for the combustion of fuels and the transfer of heat from the cooling zone to the firing zone and then to the preheating zone.
(4) To supplement the chimney, the flue ducts could be designed to provide the least amount of resistance to the flue gases.
(5) A gravitational settling chamber could be provided below the chimney to arrest SPM.
(6) Space for valves should be provided in the flue lines as this will fulfill the requirements of the factory's standard.

8. Introducing modern energy efficient kilns

There are several categories of energy efficient brick kilns. In Bangladesh, FCKs, Zigzag kilns, and Hoffman kilns are in operation. However, there are some other options for clean and energy efficient brick production, such as the vertical shaft brick kiln (VSBK) and the hybrid Hoffman kiln (HHK).

The VSBK is a fuel-efficient kiln, consuming 20–30% less fuel than BTKs and FCKs [44]. The VSBK is also simple to construct and operate, and has proven to be ideal for rural areas. For the same production capacity, a VSBK needs about 25–30% of the land required by a BTK. VSBKs are not affected by variations in weather. They can be operated even during the monsoon. Unlike other traditional kilns, VSBKs have roofs (Fig. 5), which offers protection from the rain and allows operations to continue round the year. Most other brick kilns can operate only five to six months in a year. Modularity in construction and flexibility in production are important attributes of this technology. Additional shafts (with production capacities of 2,000– 5,000 bricks per day) can be easily added or operated according to the demand for bricks. The VSBK has been tested and proven successful in China. In India and Nepal it has enjoyed limited success. There was one effort to construct a VSBK in Bangladesh, but it was not successful due to a lack of adequate technical and financial support, and properly experienced manpower.

It is worth mentioning that to develop a model brick making factory to manufacture high quality, technically sound, and marketable solid bricks. As advancement of the record of UNDP-GEF [45], a comparative assessment has been conducted based on actual experiences in China with necessary modifications for adaptation in Bangladesh. The study combines the technology of a highly efficient kiln, the

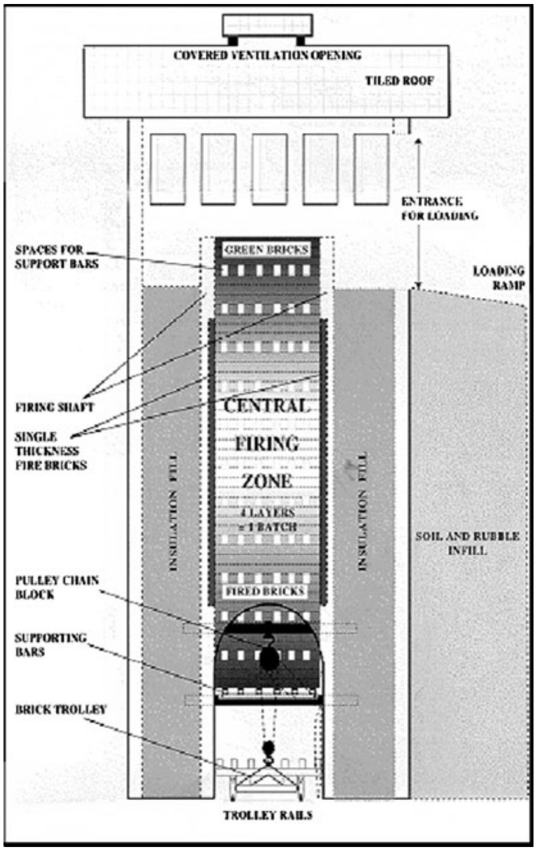

Fig. 5. Schematic diagram of a VSBK [46].

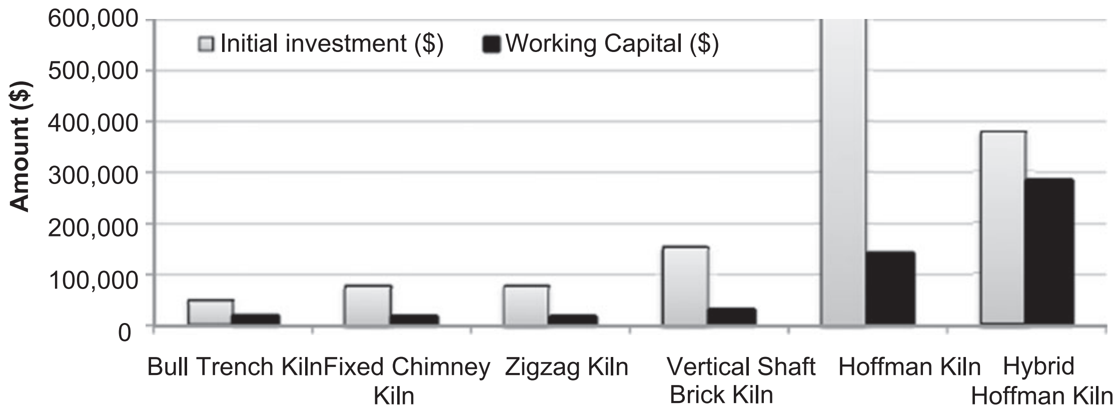

Fig. 6. Comparative assessment of different types of kiln's expenditure.

HHK, with a unique technique for forming green bricks. Granulated coal is injected for internal combustion. This approach results in lower energy usage, the highest quality bricks, and reduced pollution. Bricks of any size, shape, and pigmentation can be produced at this factory with minor modifications.

All bricks are intended to be of uniform quality and meet international standards for strength, quality, and appearance. Fig. 6 represents the comparison of initial cost and working capital of different kilns. Among those kilns, Hoffman kiln requires more initial investment, whereas the HHK demand additional budget as working capital to run their manufacturing process smoothly. On the contrary, if we consider the fuel consumption of those kilns, BTK along with FCK and Zigzag kiln incinerate more fuel than the other types of kilns (Fig. 7(a). The HHK has demonstrated the least consumption of fuels among the kilns, which, on the other hand produces more bricks than others (Fig. 7(b). VSBK and HHK appear with a reduction of environmental pollution, whilst the traditional BTK seems to be severe polluting. BTK, FCK, and Zigzag kiln can only operate their manufacturing process during the dry season from November to April, though VSBK and HHK operate their production round the year. Quality of bricks and wastage during production is also considerably superior in the case of VSBK and HHK.

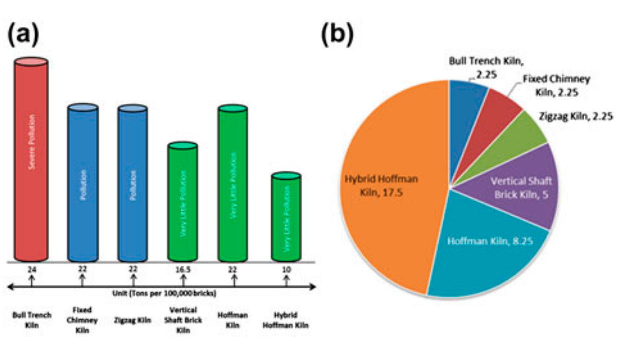

Fig. 7. (a) Fuel consumption and pollution level; (b) annual production of bricks (in million) of various kilns.

9. Conclusion

In the Greater Khulna region, environmental degradation and health risks in urban communities have become more severe with the added pollution from brick kilns that use traditional brick burning methods. This paper has explored data on the consumption of different types of fuels and the emission of various pollutants from the brickfields of the Greater Khulna region, and the impact of this pollution on the environment and on human health. In addition, the research presents several ways to reduce pollution from brickfields, such as increasing social awareness, providing economic incentives, improving existing technology in sustainable manner, and replacing traditional kilns with more modern energy efficient kilns. Following conclusions have been drawn from the study:

(1) Both small and large investors exist in the brick manufacturing industry in the Greater Khulna region. Entrepreneurs who are capable of a large investment can run the newer HHK. Smaller investors can choose to operate VSBKs. This kiln requires less investment but it is energy efficient, less polluting, and ensures smooth production throughout the year.

(2) Law enforcement agencies should be more wary of unregistered brickfields, of which

there are a large number. Unregistered brickfields pay less attention to environmental laws meant to make brick production more energy efficient and environmentally friendly.

(3) Replacing existing kilns overnight with more modern and efficient kilns may have a negative impact on the national economy. A great number of the people who are involved in the brick making process may fall jobless and consumers will have to buy bricks at a higher price. This may have an undesirable influence on the rapid growth of urbanization. Hence, a period of gradual transition from the existing technology to more efficient and environmentally friendly alternatives should be set up.

(4) The government should consider offering supplementary initiatives and granting subsidies for importing better grades of coal, such as special less volatile coal. An open platform should be established to facilitate interaction between manufacturers, law enforcement agencies, and stakeholders to popularize the adoption of green technology for brick manufacturing.

(5) Brick making is a profitable business in the Greater Khulna region. To fulfill the growing need for bricks in urban areas, more and more brickfields are being constructed, leading to more pronounced levels of environmental pollution. For sustainable development in this region, new initiatives from government bodies, foreign donors, local populace, and research organizations are expected to introduce further energy efficient and less polluting brick kilns which can make these techniques more accepted among brick manufacturers.

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