

Full Length Research Paper

Impact of emissions from brick industries on soil properties, agricultural crops and homegardens in Chittagong, Bangladesh

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Received 2 August 2021; Accepted 2 November 2021

This study was conducted in the Chittagong district of Bangladesh to explore the impact of emissions from brick kilns on crop yields from agricultural lands which were located at distances of 100, 101-500, 501-1000, and 1001-2000 m from brick kilns. The survey was conducted by using a semi-structured questionnaire during the period from January to March 2019. It also included soil sampling on farmlands located at distances of 0, 150, and 300 m from brick kilns to evaluate impact of brick kilns on the soil properties of agricultural fields. On the other hand, the impact of emissions from brick kilns on the yield of crops and fruits from agricultural lands and home gardens was tested at distances of <100, 101-500, 501-1000, and 1001-2000 m from brick kilns. In total, 14 fixed chimney kilns and four zigzag kilns were randomly selected in the Raozan Upazila, which operated yearly during the period from October to April. Moreover, a total of 72 respondents were randomly interviewed to evaluate their opinions on the impacts of brick industries on their crop production. Results showed that although regulations exist which prohibit clay removal from depths >0.30 m. However, in practice, brick industries collect clay from depths of 0.9 to 2.4 m. For all distances of farmlands from brick industries to human settlements, the available P, K and MC in soil varied significantly. The farmland areas, soil fertilities, crop yields, and status of fruit production all increased significantly while the quantity of fertilizers used in agricultural fields and periods of land leasing decreased with increasing distances from brick industries. These relationships affected attitudes, as people living further from brick industries were more positive towards these industries than people living closer to brick kilns. Therefore, government should provide subsidized credit loans to reduce the impacts caused by the pollution.

Key words: Emissions, brick, crops, soil, Bangladesh.

INTRODUCTION

Bricks are becoming a significant building material in both urban and rural areas of Bangladesh as the demand for

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bricks is steadily rising at an annual rate of approximately 5.3% (BBS, 2011). The total number of households in Bangladesh is 31.7 million, of which 26.1% are using bricks as construction material, while 73.9% are using mud or unburned bricks, tin (CI sheets), wood, straw, bamboo, polythene, plastic, and canvas (BBS, 2011). The fired clay bricks are the major demand for materials used as major building blocks for all infrastructure projects such as roads, bridges, and buildings. There are approximately 6,335 brick manufacturing kilns in Bangladesh (BUET, 2007) and the total brick production in Bangladesh is estimated to be over 17 billion bricks annually with an estimated sale value of approximately US\$ 1.2 billion (ESMAP, 2011).

Negative environmental impacts of brick industries over the environment with respect to air quality, soil conditions, and in particular, on vegetation have been indicated in many studies (Fatima, 2011; Gupta and Narayan, 2010; Guttikunda, 2009; Guttikunda et al., 2013; Le and Oanh, 2010). The brick industry in Bangladesh is one of the largest coal users in the country and therefore the industry has been considered to be one of the most extreme sources of air pollution due to its carbon emissions (Elampari et al., 2010). The gas-based Hoffmann kilns and coal-based zigzag kilns, which represent only a few percent of all kilns in Bangladesh, are relatively effective in keeping the surrounding environment clean compared to the fixed chimney kiln (World Bank, 2008). The fixed chimney kiln dominates the brick sector of Bangladesh and many studies have reported that fuel consumption, particulate emissions, and greenhouse gas emissions are the highest for fixed-chimney kilns (BUET, 2007; ESMAP, 2011). Different studies have revealed that considerable areas of productive and potential agricultural lands have been rented out to the brick industry (Bhanarkar et al., 2002; Parvez et al., 2019) and the removal of fertile topsoil for clay renders the land infertile (Avinash, 2008; Rajonee and Uddin, 2018; Tripathi and Gautam, 2007). Moreover, the release of harmful gases from brick kilns to the environment changes nitrogen cycle and other natural processes, which results in decreasing fertility and nutrient contents in the soil (Das, 2015) and reduces overall soil quality (Krishna and Govil, 2007) as well as decreases both the organic carbon content and water holding capacity (Guttinkunda, 2009). As a result the yield of the crop decreases (Agrawal et al., 2003; Bisht and Neupane, 2015; Gupta and Narayan, 2010; Ozolincius et al., 2005; Rajput and Agrawal, 2005). Moreover, dust deposition on plant leaves hampers photosynthesis which also reduces agricultural crops yields (Agrawal et al., 2003; Begum et al., 2013; Bisht and Neupane, 2015; Emberson et al., 2001; Guttinkunda, 2009; Kumar and Thambavani, 2012).

The negative impact of pollution on the surrounding environment from brick industries varies with increasing

distance from the pollutant source (Hassan et al., 2012; Ismail et al., 2012). Thus, it is important to test the hypothesis that location, in this case, the distance of human settlements from a brick kiln, is an important factor to understand the magnitude of environmental degradation caused by brick kilns. Therefore, it was predicted that the attitudes of local residents living adjacent to a brick industry would be negative because they understand that they are paying a high cost and receiving few benefits from such industries (Boholm and Löfstedt, 2004). If such infrastructural development initiatives are not sustainable, conflicts may arise between the local people and the development partners (Gillingham and Lee, 2003; Roe and Elliott, 2006). Human attitudes towards the presence of a brick industry near human settlements have not been studied in Bangladesh. This study therefore attempts to explore the impacts that such industries have on the surrounding environment with respect to soil quality as well as crop yields from agricultural lands and home gardens, and the attitudes of local people towards brick industries. The information gained from this study will be helpful in formulating an effective policy to halt the environmental degradation caused by brick industries in human settlements. This is the novelty of this study.

This study was undertaken in the Raozan Upazila (that is, sub-district) of the Chittagong district during the period of January to March, 2019 to achieve the following specific research hypotheses: (i) consumption of raw materials for energy production in brick kilns and also for the production of raw bricks used in brick industries is produced by raw materials from its vicinity, (ii) land leasing status of the surrounding farm lands after the removal of topsoil from agricultural lands is declining, (iii) the negative impact of brick kilns on the soil properties of agricultural lands located at different distances from the boundaries of brick industries is declining with distance, (iv) the negative impact of emissions from brick kilns on the yields of different crops being produced on farmlands and home gardens are declining at different distances from the boundaries of brick industries, and (v) the attitudes of local people towards brick industries are becoming more positive with distance from the brick industry.

MATERIALS AND METHODS

Study site selection

Based on information provided by the Department of Environment (DoE) in Bangladesh (2019), the Chittagong district harbours approximately 321 brick manufacturing units. To explore the preliminary information regarding the brick industries of the Chittagong district, secondary data were collected from the DoE in January 2019. During the selection of a study site for the present research, two criteria were considered. The first criterion was the

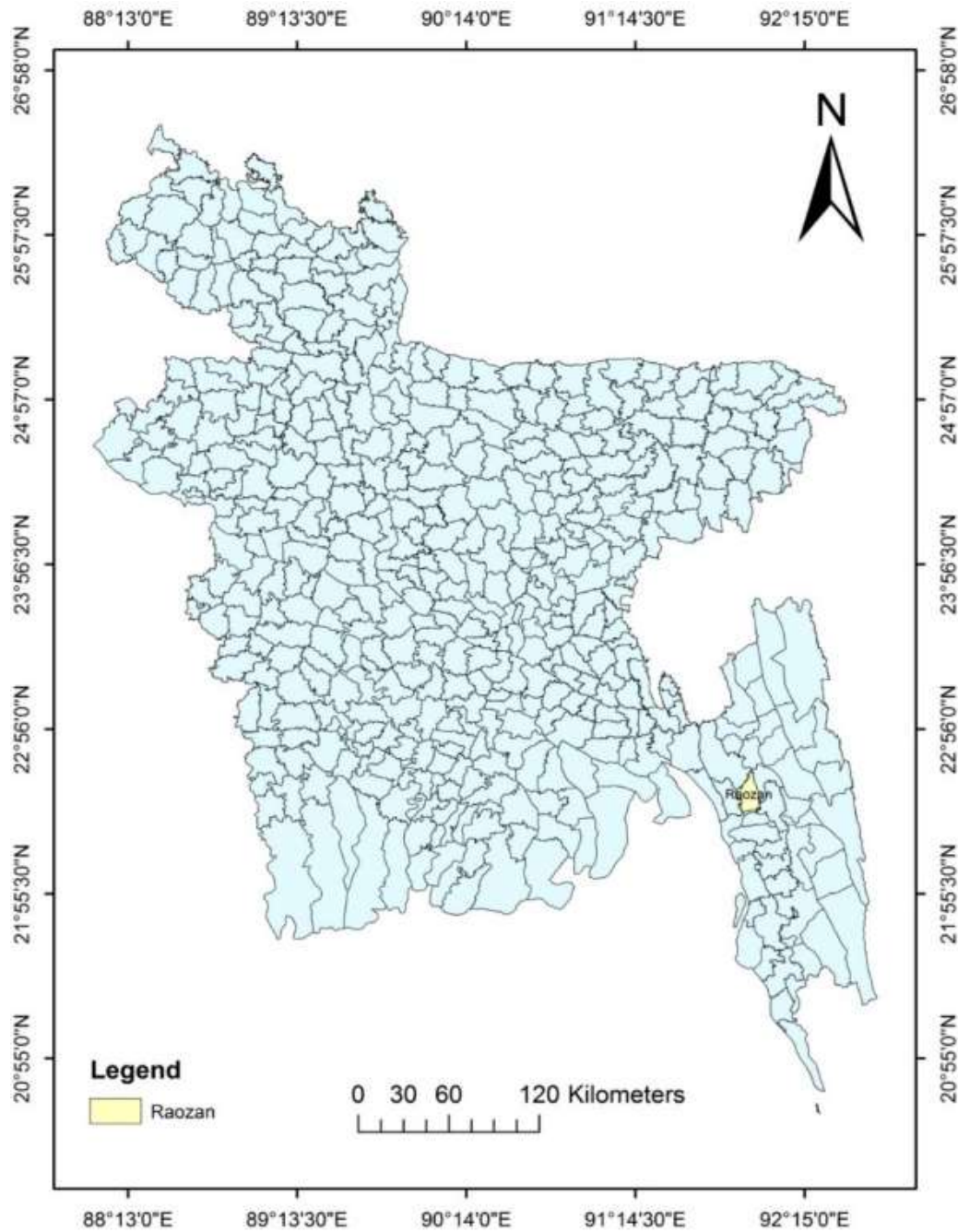


Figure 1. Location of Raozan Upazila (yellow mark) in the Bangladesh map.

presence of both fixed-chimney kiln and zigzag kiln technologies in the sampling area. It is notable that fixed-chimney kilns have been used more widely for brick production across the country than zigzag kilns. Moreover, the emissions of particulate matter and CO₂ per 100,000 bricks caused by these kiln technologies are very high compared to other kiln types. The other criterion was that farmlands and home gardens would be present within 100 m and beyond and up to 2 km from brick industries in the study area. The findings of the reconnaissance survey revealed that both fixed-chimney and

zigzag kiln technologies are common in the Raozan Upazila and the proportion of farmlands and home gardens within 0.1 km of brick industries with agricultural crops was higher in Raozan compared to other locations in the Chittagong district (Figure 1). The brick industries of the Raozan Upazila were primarily located within the unions of Dabua and Raozan Sadar. Prior to conducting the final field survey, the questionnaire was revised based on challenges or limitations that were identified in the reconnaissance survey.

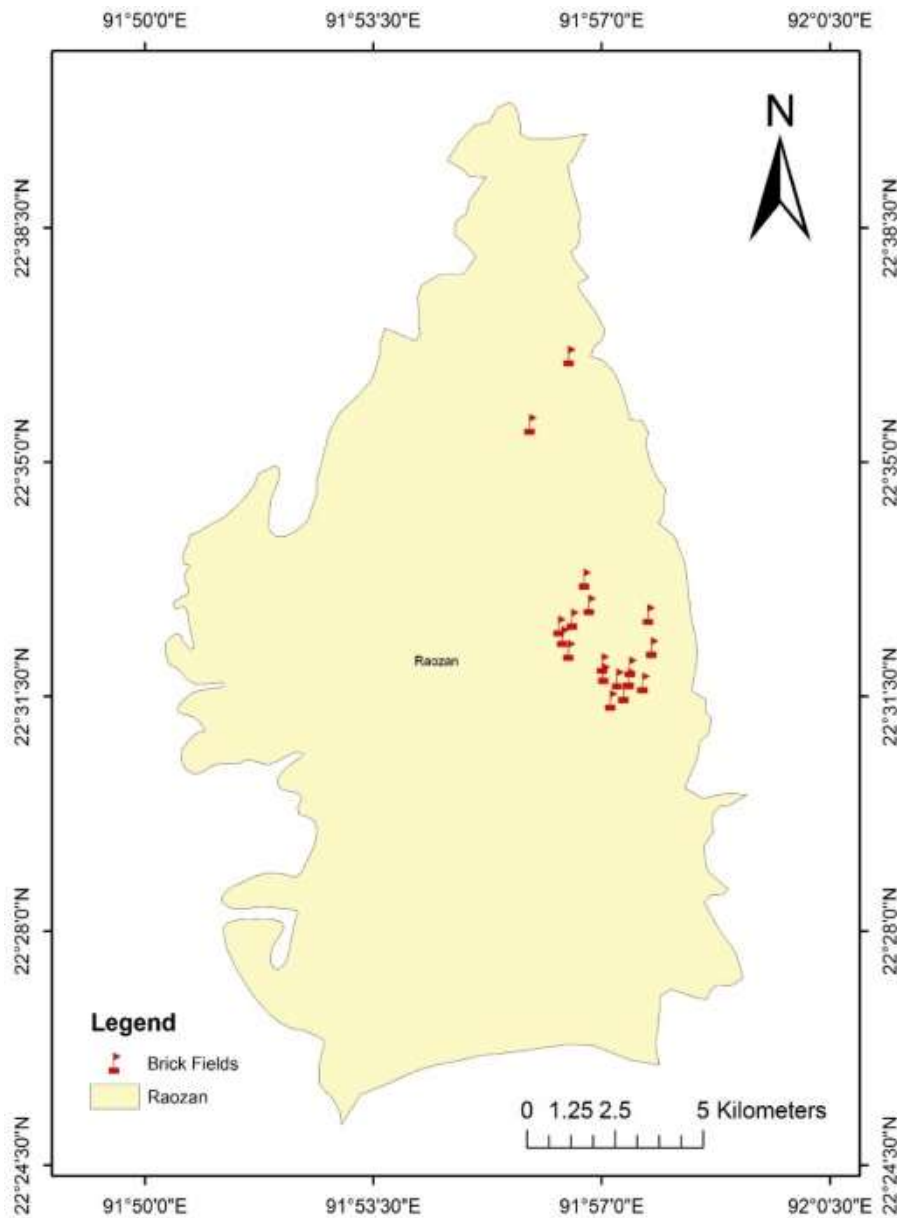


Figure 2. Location of brick industries surveyed (flag marked) in Raozan Upazila.

Collection of secondary data

Prior to fieldwork, several attempts were made to collect secondary data from the Department of Environment (DoE), Chittagong district. The secondary information included the names of brick industries located in the Raozan Upazila with contact details for the owners. A literature review using different scientific journals, proceedings, websites, and newspapers was also conducted to collect secondary information regarding the nature of brick kilns in Bangladesh as well as their impacts on the surrounding environment. Moreover, different documentaries on brick industries, which were broadcast on different Bangladeshi TV channels, were also considered when collecting secondary information related to

the impacts of brick kilns on the environment.

Collection of primary data

Fieldwork addressing various brick industries was conducted from January to March 2019. Prior to the field visits, we contacted by telephone a total of 39 brick industry owners who were located in the Raozan Upazila and made appointments for data collection. Of the 39 owners, 31 showed enormous interest in assisting this study. Thereafter, 18 out of 31 industries were randomly selected for surveys by using a semi-structured questionnaire (Figure 2). The questionnaires included the following information such as

production of bricks per year; types and quantities of raw materials for energy production in brick kilns, what kinds of raw materials were used to produce raw bricks, with their quantities, and collection times. In addition, landowners were asked about the leasing status for the removal of topsoil by brick industries from agricultural lands.

To measure the impacts of brick industries on the surrounding localities, a total of 62 crop fields were selected randomly at different distances from less than 100 m to 2 km for each of the brick industries. The questionnaire included information regarding the distance of farmlands from the brick industries; status of agricultural activities [e.g. areas of cultivated land and production quantities for each of the cultivated crops, annual investments [that is, seed cost, quantity and costs of applied fertilizers, and other costs (e.g. ploughing, labour, and irrigation, and crop-specific earnings)].

To understand the attitudes of local people towards the impacts of brick industries in their locality, a total of 72 randomly selected respondents were interviewed using a semi-structured questionnaire at different distances from brick industries. The questionnaire collected information related to socioeconomic and demographic features; for example, the respondent's sex (that is, male or female), age, occupation (that is, agriculture, business, housewife, or student), education (that is, illiterate, \leq primary, secondary, higher secondary, and above higher secondary education), household size, monthly family income, distance of home garden and farmland from the brick industry, yield of crops compared with the previous years, production status of horticultural crops and forest plants in and around the homestead, and a set of statements related to the attitude of respondents towards the presence of the brick industry in their locality. These statements were as follows: the brick industry reduces the productivity of crops and fruits (that is, agree, do not know, or disagree), agriculture is less profitable than leasing lands to the brick industry (that is, agree, do not know, or disagree) and the government should ban brick industries near human settlement zones (that is, agree, do not know, or disagree). Typically household heads, which primarily are males, were interviewed. However, in their absence, any member who was willing to participate (primarily housewives) was interviewed. Open-ended questions were asked at the end of the structured portion of the survey to collect as much information as possible.

Determination of pH, MC (Moisture Content), OC (Organic Carbon), and total N (Nitrogen), P (Phosphorus), and K (Potassium) of soil samples

To understand the impact of brick industries on land degradation, this study measured soil properties from collected soil samples. Soil samples at a depth of 0-15 cm were collected from farmlands by using a soil probe and spade at distances of 0, 150, and 300 m from the boundaries of eight brick industries. A total of 24 composite soil samples (that is, five soils samples were mixed together for each plot) from 24 plots (that is, 8 plots from each distance) were collected randomly from farmlands. Afterward, the collected soil samples were transferred into sealed and labelled plastic bags for laboratory analyses. In the laboratory, the collected soil samples were air-dried and we removed external substances. Next, the samples were passed through a sieve to remove gravel, small stones, and coarse roots. The sieved samples were then preserved and later analysed to measure the values of various physicochemical properties such as pH, moisture content, organic carbon, total N, available P and K. The determination procedures are as the following.

Moist soil pH was determined at 1:2 soil-water ratios by a digital

pH meter (n=3). For the determination of field moisture, the soil samples were dried in an oven at 105°C for 8 h. Soil moisture content was then calculated using the formula (Equation 1):

$$\text{Field moisture (\%)} = \{(W_2 - W_3) / (W_3 - W_1)\} \times 100 \quad (1)$$

where W_1 = weight of petridish, W_2 = weight of petridish + field moist soil, and W_3 = weight of petridish + dry soil.

Soil organic C was determined by the chromic acid-H₂O₂ method of Degtjareff method according to Walkley and Black (1934). Soil organic C (%) was calculated by using following formula:

$$\text{Organic C (\%)} \text{ in soil} = \frac{(B-T) \times f \times 0.003 \times 1.3 \times 100}{W} \quad (2)$$

where B = Amount of N FeSO₄ solution required in blank experiment, T = Amount of N FeSO₄ solution required in blank experiment with soil, f = Strength of N FeSO₄ solution (from blank experiment), and W = Weight of soil taken.

Total N was determined by micro-Kjeldahl digestion method (Jackson, 1973). Total N (%) was enumerated according to the formula:

$$V_1 S_1 = V_2 S_2 \quad (3)$$

where V_1 = in ml 0.1 N Na₂CO₃ solution taken, S_1 = Strength of 0.1 N Na₂CO₃ solution, V_2 = in ml prepared HCL solution required for titration, and S_2 = Strength of prepared HCL solution.

Next Total N (%) was determined by using the formula:

$$\text{Totla N (\%)} = \frac{1.4 \times N \times (T-B) \times V_1}{V_2 \times W} \quad (4)$$

where N = Normality of standard HCL, T = in ml standard HCL required to titrate the extract distillate, B = in ml standard HCL required to titrate the blank distillate, V_1 = Total volume for distillation, V_2 = in ml extract taken, and W = Weight of soil in g.

Available P was determined spectrophotometrically according to the stannous chloride (SnCl₂) reduced molybdophosphoric blue colour method (Jackson, 1973). Available P (%) was then calculated by using the formula:

$$\text{Available P (\%)} = \{(R \times P \times V_1 \times 1000 \times V) / (V_2 \times W)\} / 10^4 \quad (5)$$

where R = Spectrophotometer reading (absorbance), P = in mg phosphorus per unit of absorbance, V = Volume made for colour development, V_1 = Total volume of extract (ml), V_2 = in ml extract taken for colour development, and W = Weight of soil taken in g.

Finally, the available K content of the soil was quantified using a Jenway PFP7 flame photometer according to Jackson (1973).

Data analyses

The data were analysed using SPSS version 16.0 (SPSS, Chicago, USA). The differences between variables were explored using a χ^2 (Chi-squared) test of independence and a one-way ANOVA (analysis of variance). Stepwise linear regression analyses were performed to analyse the relationships among multiple variables.

RESULTS

Production of brick industries

Of 18 brick industries, approximately 78% were

Table 1. Soil properties at different distances from brick kilns in Raozan Upazila.

Soil property	Distances of farm land from the boundary of brick industry (m)				Optimum value for agriculture**	*F	df	p
	0 (n = 8)	150 (n = 8)	300 (n = 8)	Mean				
Organic carbon (%)	1.01±0.21	0.85±0.04	1.01±0.12	0.96±0.15	1.00 - 2.00	3.19	2	0.06
Total N (%)	0.07±0.01	9.86±26.32	0.085±0.008	3.34±15.26	0.27 - 0.36	1.10	2	0.35
P (mgkg ⁻¹ soil)	48.7±3.45	18.4±6.32	16.4±1.56	27.83±15.63	22.50 - 30	144.87	2	0.0001
K (cmol/l)	0.17±0.03	0.14±0.02	0.12±0.13	0.15±0.03	0.27 - 0.36	8.57	2	0.002
Moisture content (%)	7.46±4.34	9.48±2.41	13.26±2.60	10.07±3.95	20.00 - 25.00	6.6	2	0.006
Soil pH	5.70±0.16	5.40±0.05	4.95±0.08	5.35±0.33	6.50 - 7.50	97.7	2	0.0001

*ANOVA-tests of differences (mean ±SD) among various distances from the brick field. **SRDI 2002.

constructed with a fixed-chimney kiln while the remaining industries used zigzag kilns. The total annual production of bricks for the 18 industries was 79.8 million bricks with a mean of 4.4 million bricks per year for each industry which accounted for 0.5% of the total annual brick production of the country (e.g. 17 billion). The annual brick production per industry ranged from 1.6 to 6.0 million and the mean annual production for each industry also varied substantially between the types of brick kiln used ($F = 14.9$, $df = 1$, $p \leq 0.001$). The mean annual brick production for fixed-chimney kilns (4.8 ± 0.71 million) was higher than the production from zigzag kilns (3.1 ± 1.1 million).

Consumption of raw materials for energy production in brick kilns

Fuelwood and coal are the major types of raw materials consumed by brick kilns to produce energy for burning green bricks. Both fuel wood and coal are used in fixed-chimney kilns while only coal is used in zigzag kilns. Total annual consumption of fuelwood and coal by the 18 brick kilns was 27,055 and 9,030 t, respectively.

Raw materials for the production of raw bricks used in brick industries

Three different materials e.g. clay, sand, and water are essential for producing green bricks. It was stated here that clay is collected throughout the year except during the rainy season. The mean amount of clay required by each industry was $11,775.1 \pm 2070.2$ m³/year while the amount of sand was 578.1 ± 114.9 m³/year.

Land leasing status for the removal of topsoil from agricultural lands

Approximately 50% of the clay used was collected from

agricultural land while 22% from uncultivated uplands and 28% came from both agricultural and uncultivated uplands. Regulations exist which prohibit clay removal from depths >0.30 m but in practice, brick industries collect clay from depths of 0.9 m to 2.4 m (mean±SD: 1.6 ± 0.4 m). However, when land owners were asked 'Have you leased the land to a brick industry for the collection of clay?', 47.2% of the respondents said, "yes" ($n = 34$) and their responses to the aforementioned question differed significantly ($\chi^2 = 42.13$, $df = 3$, $p \leq 0.0001$) based on different distances from the boundary of a brick industry (e.g. ≤ 100 m: 100.0%, 101-500 m: 66.7%, 501-1000 m: 16.7%, and 1001-2000 m: 5.6%). Respondents who leased land to brick industries gave different reasons for leasing land such as, financial insolvency (55.8%), unproductive agricultural land (11.8%), and steeply sloping land-not suitable for agriculture (32.4%). Most respondents (47.1%) leased land to brick industries for 1 year while 32.4% leased for 3 years and 20.6% for 5 years. The period of leasing land to brick industries varied significantly with the distances the respondents lived from brick industries ($\chi^2 = 34.0$, $df = 6$, $p = 0.0001$). The respondents who lived within 100 m of brick industries leased land from 3 years (61.1%) to 5 years (38.9%) while the respondents who leased land for one year lived farther away.

Assessment of farmland soil properties

Organic carbon

The soil organic carbon content of farmlands varied considerably with the distances between farms from brick industries (Table 1). In this study, the organic carbon contents of farm soils at 150 m distance from brick kilns were lower than the optimum range prescribed by SRDI (2002), however, the organic C of soil measured at two other distances (e.g. 150 and 300 m) satisfied the optimum range (Table 1).

Total N

The total soil N content in farmland also varied substantially with distance from brick industries (Table 1). The contents of this material for farms located between 0 and 150 m distances from brick kilns increased, but decreased between 150 and 300 m distances and ranged below the optimum level as prescribed by SRDI (2002), as shown in Table 1.

Available P

For all three distances of farmlands from brick industries to human settlements, the available P for farmlands varied significantly (Table 1). The P contents in farm soils were low at 0 m but gradually decreased at the 150 and 300 m distances between farmlands and brick kilns. Table 1 shows that the content of this nutrient at 0 m was higher and lower at 150 and 300 m, and it was lower than the optimum range as mentioned by SRDI (2002).

Available K

The available K levels in farm soils gradually decreased significantly with increasing distances of farmlands from brick kilns (Table 1); however, all values were lower than the optimum range, as provided by SRDI (2002).

Moisture content

The moisture content also significantly increased in farm soils with increasing distance between farmlands from brick industries (Table 1). However, at all three distances, the values were lower than the optimum range mentioned by SRDI (2002).

Soil pH

For all three distances of farmlands from brick industries, the soil pH levels of the farmlands also decreased significantly with increasing distance between farmlands and brick industries (Table 1); however, all values were lower than the optimum range presented by SRDI (2002).

Demographic and socioeconomic features of local communities near brick industries

The proportions of male and female respondents were 65.3 and 34.7%, respectively (N = 72). Approximately 32% were illiterate, whereas almost 31% had schooling up to the primary level, 22% had schooling up to the

secondary level, 7% had schooling at the higher secondary level, and more than 8% had schooling above the level of secondary education. The average farm size was approximately 0.9 ha, but the size of farms increased significantly with increasing distance from the industry: at ≤ 100 m (0.7 ± 0.4 ha), 101-501 m (0.8 ± 0.4 ha), 501-1000 m (0.9 ± 0.5 ha) and 1001-2000 m (1.1 ± 0.5 ha) ($F=9.5$, $n = 72$, $df = 3$, $p = 0.05$). Similarly, the average family income of respondents per month was approximately 447 USD, but income increased with increasing distance from the brick industry: at ≤ 100 m (227.5 ± 86.6 USD), 101-501 m (468.9 ± 283.1 USD), 501-1000 m (470.5 ± 225.5 USD), and 1001-2000 m (617.9 ± 322.1 USD) ($F = 7.7$, $n = 72$, $df = 3$, $p = 0.0001$).

Impact on agricultural crop yields from farmlands

A total of eight different crops were recorded in agricultural farms at all distances up to 2 km from brick industries. These crops are boro rice, amon rice, chili, potato, pumpkin, sajna, mustard, and tomato. The areas of cultivated land allocated for each crop (Figure 3) and annual yields of different agricultural crops per hectare (Table 2) varied remarkably with the distances between farms and brick industry boundaries. The farm areas allocated for each cultivated crop were smaller closer to brick industries but gradually became larger with increasing distances between agricultural farms and brick industries (Figure 3). The yields (t/ha) of different agricultural crops are also increased with increasing distances between farms and brick industry boundaries (Table 2).

The yield of agricultural crops from farmlands compared with previous years varied considerably with the distance from the brick industry (Table 3). More than 60% of respondents reported that the yields of boro rice, potato, pumpkin, and tomato were reduced compared with previous years, whereas more than half of respondents reported that the yield of amon rice, chili, sajna, and mustard crops were the 'same as before' (Table 3). The proportion of individuals who claimed that the production had been reduced was higher among those who owned farmland and lived closer to brick industries than those who owned farmland farther from brick kilns (Table 3). The net annual profit per hectare for farmland activities increased with increasing distance from brick industries (Figure 4).

Impact on the yield of horticultural and forest plant species in home gardens

The home garden consisted of perennial and semi-perennial crops, including coconut, areca nut, litchi, jackfruit, papaya, mango, banana, guava, and Indian

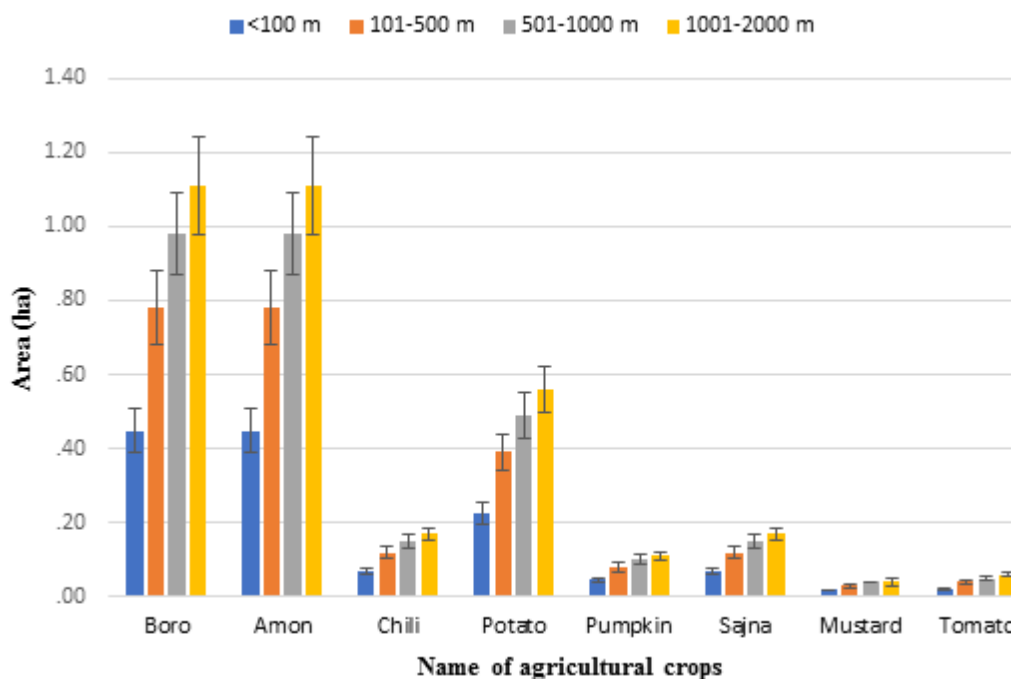


Figure 3. Size of cultivated land (ha) allocated for different crops located at different distances from the brick industry in Raozan Upazila.

Table 2. Production (t/ha) status of agricultural crops at different farms located at various distances from brick industries in Raozan Upazila.

Crop	Distances of agricultural field from the boundary of brick industry (m)				Standard range** (yield/ha)	*F	df	p
	<100 (n=10)	101-500 (n=16)	501-1000 (n=18)	1001-2000 (n=18)				
Boro	5.3±0.2	5.7±0.2	6.2±0.2	6.8±0.1	7 - 8	270.6	3	0.0001
Amon	6.2±0.1	6.5±0.1	6.8±0.1	7.2±0.1	7 - 8	110.4	3	0.0001
Chili	1.3±0.2	1.8±0.2	2.3±0.1	2.9±0.1	3.0 - 3.2	284.6	3	0.0001
Potato	9.0±0.1	10.5±0.1	12.0±0.1	13.7±0.1	25 - 30	237.1	3	0.0001
Pumpkin	38.2±0.1	42.0±0.1	45.9±0.1	49.8±0.1	40 - 50	146.1	3	0.0001
Sajna	7.5±0.1	7.6±0.1	7.9±0.1	8.3±0.1	-	80.4	3	0.0001
Mustard	1.0±0.1	1.1±0.1	1.4±0.1	1.7±0.1	1.5 - 1.8	53.6	3	0.0001
Tomato	1.0±0.1	1.1±0.2	1.4±0.1	1.7±0.1	85 - 90	53.6	3	0.0001

*ANOVA-tests of differences (mean ±SD) among various distances from the brick field.

** Source: DAE, Raozan Upazila, Chittagong.

plum. In addition, forest tree species such as mangium (*Acacia mangium*) and mahogany (*Swietenia mahagoni*) were also planted in home gardens. More than half of the respondents reported that the yield of both the horticultural crops and forest plants in their home garden was 'same as before', but the responses varied considerably with the distance from the brick industry (Table 4). None of the respondents located within 500 m of brick industries reported that the yield of crops in their home gardens was the 'same as before'. More than 95%

of those residing within 500 m from an industry reported that dust deposition on plant leaves was the major problem impacting the growth of horticultural plants than those living in other distances.

Quantity of fertilizers applied in agricultural field to improve soil fertility

Farmers apply fertilizer to their agricultural fields to

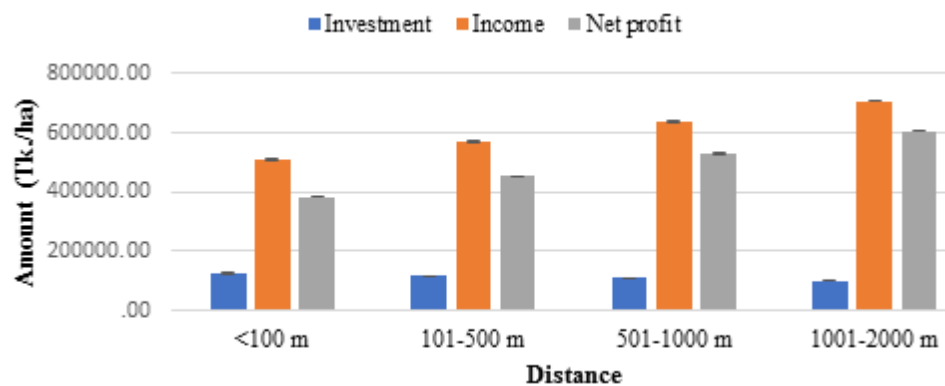


Figure 4. Total investment (Tk/ha), total income (Tk/ha), and net profit (Tk/ha) of farms located at different distances from the brick industry in Raozan Upazila.

Table 3. Respondents (%) opinion regarding the production status of agricultural crops in their fields located at different distances from the brick industry in Raozan Upazila.

Crop	Production status	Distance of agricultural field from the boundary of the brick industry (m)				Total (n = 62)	Statistics		
		<100	101-500	501-1000	1001-2000		* χ^2	df	p
Boro	Reduce	100.0	100.0	61.1	11.1	62.9	36.0	3	0.0001
	Same as before	0.0	0.0	38.9	88.9	37.1			
Amon	Reduce	70.0	31.3	44.4	11.1	35.5	10.6	3	0.014
	Same as before	30.0	68.8	55.6	88.9	64.5			
Chili	Reduce	80.0	68.8	55.6	5.6	48.4	20.2	3	0.0001
	Same as before	20.0	31.3	44.4	94.4	51.6			
Potato	Reduce	100.0	93.8	66.7	16.7	64.5	29.5	3	0.0001
	Same as before	0.0	6.3	33.3	83.3	35.5			
Pumpkin	Reduce	100.0	93.8	66.7	22.2	66.1	26.1	3	0.0001
	Same as before	0.0	6.3	33.3	77.8	33.9			
Sajna	Reduce	90.0	56.3	55.6	5.6	46.8	20.9	3	0.0001
	Same as before	10.0	43.8	44.4	94.4	53.2			
Mustard	Reduce	60.0	100.0	33.3	5.6	46.8	32.5	3	0.0001
	Same as before	40.0	0.0	66.7	94.4	53.2			
Tomato	Reduce	100.0	100.0	50.0	22.2	62.9	29.4	3	0.0001
	Same as before	0.0	0.0	50.0	77.8	37.1			

* χ^2 tests of independence for different distances from the brick industry.

improve soil fertility. The amounts of chemical and organic fertilizer used also varied considerably with the distances between farms and the boundaries of brick industries (Table 5). In this study, it was found that the

use of fertilizers per hectare of farmlands decreased with increasing distance from brick industries. The quantity (kg/ha) of urea was higher in farmlands within a 100 m distance from brick industries compared to those farms

Table 4. Respondents (%) opinion regarding the yield of horticultural and forest plant species in their home gardens located at different distances from the brick industry in Raozan Upazila.

Tree	Production status (no. of respondents)	Distance from the boundary of the brick industry to human settlement (m)					Statistics		
		<100	101-500	501-1000	1001-2000	Total	* χ^2	df	p
Coconut	Reduce (n=19)	100.0	100.0	14.3	0.0	38.8	41.8	3	0.0001
	Same as before (n=30)	0.0	0.0	85.7	100.0	61.2			
Areca nut	Reduce (n=12)	100.0	100.0	22.2	0.0	32.4	29.9	3	0.0001
	Same as before (n=25)	0.0	0.0	77.8	100.0	67.6			
Litchi	Reduce (n=3)	100.0	100.0	0.0	0.0	27.3	11.0	3	0.012
	Same as before (n=8)	0.0	0.0	100.0	100.0	72.7			
Jackfruit	Reduce (n=25)	100.0	100.0	6.3	0.0	43.1	54.2	3	0.0001
	Same as before (n=33)	0.0	0.0	93.8	100.0	56.9			
Papaya	Reduce (n=32)	100.0	100.0	16.7	0.0	49.2	55.0	3	0.0001
	Same as before (n=33)	0.0	0.0	83.3	100.0	50.8			
Mango	Reduce (n= 30)	100.0	100.0	11.1	0.0	46.9	56.9	3	0.0001
	Same as before (n=34)	0.0	0.0	88.9	100.0	53.1			
Banana	Reduce (n=29)	100.0	100.0	11.1	0.0	46.0	55.8	3	0.0001
	Same as before (n=34)	0.0	0.0	88.9	100.0	54.0			
Guava	Reduce (n=27)	100.0	100.0	5.6	0.0	43.5	58.2	3	0.0001
	Same as before (n=35)	0.0	0.0	94.4	100.0	56.5			
Indian plum	Reduce (n= 15)	100.0	100.0	23.1	0.0	34.9	32.8	3	0.0001
	Same as before (n=28)	0.0	0.0	76.9	100.0	65.1			
Mangium	Reduce (n=26)	100.0	100.0	0.0	0.0	41.9	62.0	3	0.0001
	Same as before (n=36)	0.0	0.0	100.0	100.0	58.1			
Mahagoni	Reduce (n=10)	100.0	100.0	0.0	0.0	29.4	34.0	3	0.0001
	Same as before (n=24)	0.0	0.0	100.0	100.0	70.6			

* χ^2 tests of independence for different distances from the brick industry.

Table 5. Quantity of fertilizers (kg/ha) used in agricultural field located at different distances from the brick industry in Raozan Upazila

Fertilizer	Distance of agricultural field from the boundary of brick industry (m)					*F	df	p
	<100 (n=10)	101-500 (n=16)	501-1000 (n=18)	1001-2000 (n=18)	Mean (n=62)			
Urea**	312.7±16.8	264.1±13.3	247.0±18.0	200.2±12.3	248.4±39.4	218.5	3	0.0001
Bio-fertilizer	213.0±12.9	176.6±9.0	171.8±15.0	141.1±23.1	170.8±28.6	42.3	3	0.0001
Muriate of potash**	86.0±9.1	67.6±4.1	65.3±4.5	40.9±11.5	62.1±17.2	77.6	3	0.0001
Dung	218.1±15.5	185.2±9.0	167.2±14.0	144.1±19.2	173.3±28.7	62.9	3	0.0001

*ANOVA-tests of differences (mean ±SD) among various distances from the brick field. **Chemical fertilizer.

Table 6. Respondent's (%) opinion regarding the brick industry based on location at various distances from the brick industry in Raozan Upazila.

Statement	Opinion	Distance from the boundary of brick industry to human settlement (m)				Total (n=72)	Statistics		
		<100	101-500	501-1000	1001-2000		* χ^2	df	p
Brick industry reduces the productivity of crops and fruits	Disagree	16.7	33.3	44.4	72.2	41.7	16.4	6	0.012
	Don't know	0.0	0.0	0.0	5.6	1.4			
	Agree	83.3	66.7	55.6	22.2	56.9			
Agriculture is less profitable than leasing land to the brick industry	Disagree	0.0	5.6	72.2	77.7	38.9	46.5	6	0.0001
	Don't know	0.0	0.0	11.1	5.6	4.2			
	Agree	100	94.4	16.7	16.7	56.9			
Govt. should ban brick industry near human settlement zone	Disagree	5.6	11.1	16.7	55.6	22.2	28.5	6	0.0001
	Don't know	0.0	0.0	0.0	16.6	4.2			
	Agree	94.4	88.9	83.3	27.8	73.6			

* χ^2 tests of independence for different distances from the brick industry.

Table 7. Linear regression analysis of attitudes towards the brick industry in Raozan Upazila.

Independent variable	Brick industry reduces the productivity of crops and fruits		Agriculture is less profitable than leasing land to brick industry		Govt. should ban brick industry near human settlement zone	
	t	p	t	p	t	p
Constant	-0.025	ns	1.135	ns	3.58	0.001
Distance lived from brick field	-4.236	0.0001	-10.758	0.0001	-5.667	0.0001
Gender	-3.98	0.0001	-0.743	ns	-2.743	0.008
Monthly family income	0.961	ns	2.794	0.007	2.465	0.016
Household size	0.848	ns	-0.867	ns	-2.336	0.023
Occupation	1.667	ns	2.66	0.01	-0.522	ns
Education	0.782	ns	1.416	ns	-0.298	ns
Age	1.955	0.05	1.41	ns	0.384	ns
R ²	0.473	0.0001	0.666	0.0001	0.542	0.0001

ns = Not significant.

located at greater distances. Similarly, the quantities of bio fertilizer, muriate of potash and dung per hectare of farmland also decreased with increasing distances from brick industries (Table 5).

Attitudes of local people towards brick industries

Brick industries reduce the productivity of crops and fruits

More than half of the respondents agreed that the brick industry reduces the yield of crops and fruits in their farmlands and home gardens (Table 6), and these

responses varied significantly with the distance that the respondents lived from brick industries. Those living within 100 m of brick industries experienced higher crop and fruit reductions than those living farther from brick kilns. A stepwise linear regression analysis using the opinion that the brick industry reduces the productivity of crops and fruits as a dependent variable was tested against eight independent variables (Table 7); only three of the variables were significant contributors to the variation. The variables that significantly explained variation in the response to this statement were the distance that the respondent lived from the brick industry, gender, and age. The other independent variables were not significant. All independent variables explained 47.3%

of the variation in the opinions related to this statement. The respondents who lived closer to the brick industry, male respondents, and older respondents agreed more with the statement.

Agriculture is less profitable than leasing land to brick industry

More than half of the respondents agreed that agriculture was less profitable than leasing land to the brick industry, and the response varied significantly with the distance that respondents lived from brick industries (Table 6). The respondents who lived within 500 m of a brick industry agreed more with the statement than those who lived farther from brick kilns. A stepwise linear regression analysis of the variation in the attitudes of respondents that agriculture is less profitable compared with leasing land to the brick industry (as a dependent variable) was tested against eight independent variables; only four of these variables were significant contributors to this variation. The variable explaining most of the variation in this response was the distance that the respondent lived from the brick industry. Monthly family income was the second most important predictor. The third significant predictor was the occupation of the respondent, and the fourth significant predictor was the medical expenses of respondents (Table 7). The other independent variables were not significant. All the independent variables explained 66.6% of the variation in attitudes related to this statement. Respondents who lived closer to the brick industry, who were financially more solvent, and who were non-farmers agreed more with the statement. Finally, respondents who had lower costs related to medical treatment agreed more with the statement than those who had higher medical costs.

Government should ban brick industries near human settlement zones

More than 70% of the respondents agreed that the government should ban brick industries near settlement zones, but this response varied significantly with the distance that the respondents lived from brick industries (Table 6). The respondents who lived within 1000 m were more likely to agree with banning a brick industry in their locality than those who lived more than 1000 m away. A stepwise linear regression analysis examined the variation in the attitudes of respondents regarding whether the government should ban brick industries near settlement zones (as a dependent variable) was tested against eight independent variables (Table 7); only four variables were significant contributors to this variation. The variable explaining most of the variation in this attitude was the distance that the respondent lived from

the brick industry. Gender was the second most important predictor. The third most significant predictor was monthly family income. Household size was the fourth significant predictor. Occupation, costs of medical treatment, education, and the age of the respondent were not significant predictors. All independent variables explained 54.2% of the variation in attitudes related to this statement. Males, those who were more financially solvent, and smaller households were more likely to agree with banning brick industries in their locality.

DISCUSSION

The brick sector presently is mostly grown by little modification of existing kilns in kiln design. The construction costs of fixed-chimney kilns are relatively lower than those for coal-based zigzag kilns (Sarker et al., 2020). Therefore, current fixed-chimney kiln owners are unlikely to adopt modern technologies in their industries. As a result, old manufacturing technology increases the pollution of the brick sector in Bangladesh. In Bangladesh, the brick industry uses various types of energy such as fuelwood, coal, and natural gas. Natural gas is the cheapest energy type for the brick industry but it was banned for use by the non-mechanized brick industry (Sarker et al., 2020). Fuelwood can also be a cheap fuel and has also been banned as a source of energy to reduce deforestation in Bangladesh. Coal is also widely used but there appear to be problems with coal quality. The price of coal was gradually increased while the quality of coal was decreased (pers. com. with kiln owners in 2019). Although Bangladesh produces high-quality coal with low sulfur content (e.g. less than 0.5%), nearly all of it is used in the coal based power plant, but during non-operational periods of the power plant, local coal becomes available for brick kilns (World Bank, 2008).

Clay is the main raw material for producing green bricks and in many cases, clay is obtained from the agricultural land (Sarker et al., 2020). Topsoil removal has a direct impact on agricultural crop production through reduced soil fertility status (Brunel et al., 2011). Topsoil can be removed and set aside to be returned after clay removal, which is an option with minimal impact on agriculture (FAO, 1993). However, in practice, this is often not done in many cases, as was observed in the study area. Therefore, the land is often not suitable for agriculture (Asgher and Singh, 2003; Biswas et al., 2018).

Organic carbon is an important soil property which improves soil structure, enhances aeration and water penetration, increases water holding capacity, and supplies nutrients for plant growth (Almendo-Candel et al., 2018). Organic carbon levels greater than 0.8% are regarded as good quality for soils (Yaseen et al., 2015).

However, the present study revealed that the organic C levels in the soils near brick kilns were poor but gradually improved with increasing distance from the kilns. Organic carbon variations are directly related to surface soil removal processes (Bisht and Neupane, 2015). Moreover, the soil pH ranged from 4.9 to 6.2 within the study site and indicated the presence of toxic substances, which causes problems for normal plant growth (ESF, 2020). Soil pH levels affect the availability of primary nutrients such as N, P, and K to plants and the maximum availability of primary nutrients is found in a pH range of 6.5 to 7.5 (Yaseen et al., 2015).

Water absorption is another factor which determines soil quality. If water is lost from the soil, then soil quality deteriorates (Bisht and Neupane, 2015). The water holding capacity of soil influences crop growth, rotting, and the ability to supply water to crops during dry periods (Debnath et al., 2012). When soil loses more water, its infiltration capacity declines (Assadi et al., 2011, Bisht and Neupane, 2015). However, in the present study, the moisture content values across distance show an increasing trend with increasing distance from brick chimneys or kilns.

As hypothesized, in this study, it was found that crop production was much lower near the brick industry and that local people complained that dust deposition on the leaves of plants was the major problem affecting the growth of horticultural plants. Although plant species vary in their sensitivity to pollutants (Jacobson and Hill, 1970), this study showed that plants in the immediate vicinity of brick kilns were more vulnerable. Particulate matter emissions during brick production consist of dust and accumulations of particulates on the plant surfaces and can, with time, cause plant vulnerabilities to pathogens and pests (Emberson et al., 2001). Exposures to dust pollution stress provoke significant reductions in photosynthesis in most plants (Kumar and Thambavani, 2012). This effect may alter plant growth and production (Assadi et al., 2011; Begum et al., 2013; Kondo and Sugahara, 1978).

The difference in opinion regarding the presence of a brick industry in their area was strongly influenced by the respondents' socioeconomic status and demographics. However, the most significant factor was as hypothesized, the distance that they lived from the borders of the industry. Thus, the distance between the home garden or agricultural land and the brick industry was the primary factor shaping the attitudes of people to the presence of brick industries in their area. The distance between the brick industry and human settlements is an important determinant of the severity of the environmental problems associated with the brick industry. Under such conditions, there may be a conflict between the local people and the owners of the brick industry, which can lead to unstable development initiatives. To address this problem, the availability of

subsidized credit loans could be initiated by the Bangladesh government to reduce the impacts caused by the pollution. The government could also provide economic incentives to brick industries for the production of new wall materials and the use of alternative raw materials. Finally, the existing policies and regulations regarding a traditional high-polluting kiln (e.g. a fixed chimney kiln) should be implemented by the Bangladesh Department of Environment, particularly for those industries that are located near large human population centres.

Conclusion

Bricks are becoming an important building material in both urban areas and rural areas of Bangladesh. With the increase in population, the demand for bricks for construction has increased dramatically following the establishment of the brick industry. The negative impacts of pollution from a brick industry on the surrounding environment decrease with the increasing distance from the source of air pollutants (*that is*, the brick kiln). As hypothesized, this study shows that the pollution caused by brick industries influences the attitudes of the local people towards this industry, and these attitudes vary with the distance from the industry. The attitudes of the local people living near the adjoining brick industry are that it reduces crop production. Therefore, government should upgrade its brick sector to save valuable natural resources, reduce air pollution, and increase energy efficiency. Adopting gas-based, cleaner technologies is hampered by serious energy shortages and land scarcity. The government has already banned the use of fuelwood and fixed-chimney kilns. However, the development of the brick industry guided by the Bangladesh government should move towards transforming traditional brick making technologies (e.g. fixed-chimney kilns) to cleaner kilns (e.g. hybrid Hoffman kilns and vertical shaft brick kilns) in addition to exploring globally available alternative raw materials.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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