Health risk assessment of emissions from brick kilns in Tando Hyder, Sindh, Pakistan using the AERMOD dispersion model

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Received: 27 March 2020 / Accepted: 16 June 2020 / Published online: 26 June 2020
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Abstract

Pakistan has more than 18,000 brick kilns and produced about 45 billion bricks every year. Brick making in Pakistan is a traditional small-scale and unmanaged industry. Coal is a major source of fuel for brick kilns. In Pakistan, urbanization, in terms of building construction has increased by 10% per year from 2015 to 2020. That growth has increased demand of building construction stock by 80% which causes an increased production of building materials and bricks. This increase in demand for bricks will increase the consumption of coal used in brick manufacturing. Therefore, there is an urgent need to assess the health risk to people living near brick kilns. This study assesses the health risk due to the emission of air pollutants from brick kilns. Two non-carcinogenic pollutants (i.e., SO₂ and Hg) and three carcinogenic pollutants (i.e., As, Cd and Cr) were selected for this health risk assessment. Both short-term and long-term health impacts were assessed. The AERMOD air dispersion model was used for predicting ground-level concentrations within a 10 km radius of the brick kilns. Non-carcinogenic health risk assessments indicate adverse health impacts from short-term concentrations, while long-term concentrations are within acceptable limits. Carcinogenic health risks also indicate adverse health effects from short-term concentration, while only As and Cr cause adverse health impacts from long-term concentration and exposure. The findings of this study show that a detailed assessment of the health effects caused by emissions from all of the brick kilns and ambient air concentration with meteorological conditions should be carried out.

Keywords Brick kiln · Emission rate · AERMOD · Health risk assessment · Tando Hyder Pakistan

1 Introduction

Clay fired bricks are widely used as a building material in Pakistan. Clay fired bricks are mainly produced by small-scale entrepreneurs in villages and rural areas. This informal, small-scale industrial sector, employs an unregulated and unlicensed industrialized process without controls for air pollution, which leads to environmental and human health impacts [1, 2].

Pakistan is the 3rd largest brick producer in South Asia, followed by India and Bangladesh. Pakistan has around eighteen thousand brick kilns throughout the country

producing more than 45 billion bricks every year [3, 4]. These kilns employ more than a million workers [5] and 115,000 horses, donkeys and Mules [4]. Coal is the main fuel used for brick kilns. In addition to coal, various types of biomass (i.e., rice husk, firewood, and cow dung) [1], plastic, waste oil, worn-out tires and other materials [2] are used for firing the bricks. In Pakistan and other developing countries, brick-making processes are less efficient in terms of energy utilization. Therefore, brick production leads to a high level of pollution. Air pollutants are not only emitted from the combustion of fuels, but the life

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cycle of brick manufacturing also contributes to a considerable amount of emissions [1].

In Pakistan, urbanization, in terms of building construction is growing at a rate of 10% per year in the years 2015–2020. In reality in the last 4–5 years, mega-city projects such as Bahria Town Karachi, DHA Karachi, Saima down town Hyderabad and Bahria town Nawabshah etc. have been started in several cities of Pakistan and are in the final stages of development. These expansions are causing an increase in demand for building construction stock. This requirement is expected to increase by 80% during these years [6], which is causing an increase in production of building materials and bricks. The rapid growth in brick manufacturing, and the environmental and human health aspects of making bricks have become serious concerns that need immediate attention.

Brick kilns emit various kinds of air pollutants, i.e., SO_2 , CO , CO_2 , NO_x , Hg, As, Cr, Cd, and Pb. These emissions are causing adverse effects in human health and are contributing to global warming. The use of coal and worn out tires for burning is an already provocative issue in the world, and various studies show an adverse effect on human health. The studied brick kilns received strong opposition from non-governmental organizations (NGOs) and the local residents of Tando Hyder. They claim that 55 brick kilns are there in Tando Hyder, which are burning coal, tires, rice husk, and plastic as a source of fuel. That has led to soil, water, and air pollution. That will cause serious effects on human health, i.e., gene alteration and birth defects; deadly effects are lung and skin cancer, heart attack, liver damage, and also destroy the natural environment [7].

Consequently, there is a serious need to assess the health risk to people living near the brick kilns of Tando Hyder, Sindh Pakistan. It is essential, due to an increase in the utilization of coal, worn-out tires, and plastic for the production of bricks to evaluate the health and environmental impacts caused by the emissions of coal-fired brick kilns. This study has never been published in Pakistan. However, research has been conducted in other countries, such as Nepal [8], Bangladesh [9], and India [1, 10]. Assessment of health risks is normally conducted with dispersion modeling, i.e., AERMOD [11], ADMS [12] and CALPUFF [13]. For the prediction of ambient air concentration at the particular receptor, the American meteorological society/environmental protection agency regularity model (AERMOD) has been accepted by the Pakistan environmental protection agency as a standard tool for the estimation of dispersion of air pollution. A similar exercise was reported in Malaysia [7] and Thailand [14]. AERMOD can be used to predict the transportation of numerous pollutants from a point and area source for SO_2 , PM and CO from brick kilns [11], and Hg, As, Cd from coal-fired power plants [7].

This study is particularly relevant to Pakistan and assesses human health risks associated with emissions from brick kilns. It includes three stages of assessment to determine the level of pollutants emitted from brick kilns. 1. To estimate pollution from the stack of the brick kiln 2. To predict ground-level concentrations using the dispersion model and compare with national and international guidelines 3. To estimate the health risk. In health risk assessment, three carcinogenic and two non-carcinogenic pollutants were selected for both short-term and long-term health risks.

2 An overview of Tando Hyder and brick kilns

Tando Hyder is a town in Hyderabad District and a rural part of Hyderabad Taluka. It is situated in north Sindh and has a subtropical climate with hot summers and cold winters [15]. It lies at $25^\circ 22' 60''$ N latitude and $68^\circ 25' 60''$ E longitude [16] and has a length of about 3.63 km [17]. According to the 2018 population census, the population of the Tando Hyder union is 13,444 [18]. There are 55 brick kilns in Tando Hyder, which have been selected for assessing the human health risk from exposure to pollutants emitted from these kilns. The selected 55 brick kilns were divided into 9 groups in which brick kilns with exact data were divided into individual six groups with its own name; owners of these brick kilns allowed us to show their data with their companies names. The remaining 49 brick kilns were divided into three groups based on the production of bricks for estimating emission rates and determining the basic design of stacks. The 1st group is composed of 19 brick kilns whose brick production rate was in the range of 3–4 Lac/month. The 2nd group is of 17 brick kilns whose brick production rate was 4–5.25 Lac/month. The 3rd group includes 13 brick kilns whose brick production rate was 5.25–6.5 Lac/month. Lac represents a specific number of bricks; it is equal to one-tenth of a million. Small-businessmen and owners of brick kilns in the study area used Lac for counting the bricks. The fuel used in brick kilns is coal. Basic information for the selected brick kilns is presented in Table 1.

3 Methodology

Figure 1 shows the methodological framework for this study. Estimation of emission rate was obtained by using the United States environmental protection agency (USEPA) AP-42 methods, and consumption of fuel for the brick kilns was obtained from a survey of brick kiln owners. Simultaneously AERMOD meteorological pre-processor

Table 1 Fuel consumption and design of brick kiln stacks

S#	Brick kilns	Stack height (m)	Stack exit diameter (m)	Average exit velocity (m/s)	Average exit temperature of flue gas (°C)	Fuel consumption (tons/year)
1	Abdul Aziz Brick Company	16.76	2.44	0.9	55.4	42
2	Samad Bricks Company	21.34	0.762	1.1	53.2	420
3	New Behram Bricks Company	16.76	1.524	0.95	48.5	1800
4	Nawab Brick Company	24.38	0.762	1.2	49.6	2700
5	Chamman Bricks Company	16.76	0.762	1.3	57.6	2700
6	Pak Brick Company	16.76	0.762	1.5	58.1	1620
7	Average of 19 brick kilns	17 ± 5.3	1.7 ± 0.31	0.9 ± 0.6	56 ± 18	–
8	Average of 13 brick kilns	21 ± 8.1	0.8 ± 0.25	1.1 ± 0.42	53 ± 16.24	–
9	Average of 17 brick kilns	25 ± 6.3	0.8 ± 0.33	1.2 ± 0.73	62 ± 24.53	–

Fig. 1 Methodological framework

(ARMET) and AERMOD terrain pre-processor (ARMAP) were used to preprocess the meteorological and terrain data into the readable form of AERMOD. Then, AERMOD was run to predict ground-level concentrations (GLC) of the five selected pollutants. Finally, GLC was used for assessment of the possible potential negative health effects.

3.1 Estimation of emission rate

Brick production is a small industry, consequently, there is lack of emission monitoring at the stack, because monitoring of emissions requires a large amount of financial support. Hence, estimated emission rate data is required for the simulation of ground-level concentrations.

Generally, the emission rate of air pollutants is estimated using Eq. 1. [19, 20]. The emission rate was estimated for SO₂, As, Cd, Hg and Cr as shown in Table 2.

$$E_i = \frac{EF_i \times AR}{365 \times 24 \times 3600} \quad (1)$$

where E_i emission rate of i th pollutant (g/s), EF_i emission factor of i th pollutant (g/kg), AR consumption of coal (kg/year).

A survey was conducted among different kiln owners about the type of fuel used and consumption of fuels; only six owners out of the 55 brick kiln owners provided information about the type and consumption of fuel; the remaining 49 owners provided information

Table 2 Estimated emission rates from different brick kilns stacks (g/s)

S#	Gases, metals and metalloids	Abdul Aziz Bricks Company	Samad Bricks Company	New Behram Bricks Company	Nawab Bricks Company	Chamman Bricks Company	Pak Bricks Company	Emissions from 19 brick kilns	Emissions from 13 brick kilns	Emissions from 17 brick kilns
1	SO ₂	0.008	0.008	0.035	0.052	0.052	0.031	0.74	0.924	0.84
2	As	9.5×10^{-6}	9.5×10^{-6}	4.1×10^{-5}	6.1×10^{-5}	6.1×10^{-5}	3.6×10^{-5}	1.8×10^{-4}	9.0×10^{-3}	6.5×10^{-4}
3	Cr	5.3×10^{-7}	5.3×10^{-7}	2.3×10^{-6}	3.4×10^{-6}	3.4×10^{-6}	2.0×10^{-6}	1.0×10^{-5}	9.5×10^{-5}	3.6×10^{-5}
4	Hg	6.4×10^{-7}	6.4×10^{-7}	2.7×10^{-6}	4.1×10^{-6}	4.1×10^{-6}	2.5×10^{-6}	1.2×10^{-5}	1.3×10^{-4}	4.4×10^{-5}
5	Cd	5.4×10^{-7}	5.4×10^{-7}	2.3×10^{-6}	3.5×10^{-6}	3.5×10^{-6}	2.1×10^{-6}	1.0×10^{-5}	9.2×10^{-5}	3.7×10^{-5}

about the total annual production of bricks and the type of fuel used. On the basis of that data, emission rates were estimated. According to the survey, coal is used as fuel in brick kilns. Emission factors of selected pollutants were taken from the United States environmental protection agency (US-EPA) AP-42 method and Jayaratne et al. (2018) [21] guidelines for brick kiln emission factors. Emission factors for Cd and As were taken from Jayaratne et al. (2018) and factors for SO₂, Hg and Cr were taken from the US-EPA AP-42 method. Emissions factors for SO₂, Hg, Cd, Cr, and As are 0.6, $4.75 \times E-5$, $4 \times E-05$, $3.9 \times E-05$ and $7 \times E-04$ g/kg, respectively [22]. In this study, SO₂ was selected for health risk assessment among SO₂, CO, CO₂ and NO_x because coal is a major source fuel for brick kilns and it contains a high amount of sulfur. Also SO₂ is selected because its short-term and long-term health risk assessment guideline are available.

3.2 AERMOD dispersion modeling process

AERMOD is based on the Gaussian equation; hence, it is also called the Gaussian plume steady-state model. It is used to simulate the dispersion of pollutants from point, area, and volume sources. It is proposed for a short-range domain of (50 km × 50 km) and suitable for both complex and simple terrain. The reason is that no chemical reaction occurs during the model simulation. Hence, in a short-range, the atmospheric reaction vary less and are considered insignificant. The AERMOD model requires three types of data (i.e., terrain, meteorological, and source data). According to the US EPA (2005) [23] modeling guidelines, 5 years of meteorological data is required for the prediction of ground level concentration (GLC). The most recent consecutive 5 years data is required. In this study, most recent 5 years data was used and was collected from the Hyderabad airport meteorological station, which is about 10 km from Tando Hyder. Breeze AERMET 7 was used for the conversion of meteorological data into the readable form for AERMOD. Figure 2 shows the season-wise 5 years of meteorological data on a wind rose for Tando Hyder. Terrain data with 90 m resolution in a DEM file was purchased from the Breeze Company for site topographical effects. AERMAP was used to convert DEM file data into AERMOD readable form. There are many locations in Tando Hyder and its surrounding area (i.e., Hyderabad, Husri and Tando Jam, etc.) where data was gathered. In this study, ten sensitive locations and one park as a tourist place were selected for health risk assessment within a 10 km radius of the brick kilns, as shown in Fig. 3. Of the ten, eight sensitive locations were from Hyderabad city, which is the fourth most populous city in Pakistan [18].

Fig. 2 Season wise meteorological data wind rose

3.3 Human health risk assessment

Human exposure of selected pollutants through inhalation was assessed for carcinogenic and non-carcinogenic health risks. Acute and chronic inhalation, which is a dose of pollutants for a short-term (1 h) and for a long-term (annual) [7]. From inhalation exposure of selected air pollutants for non-carcinogenic the health risk was evaluated by calculating hazard quotient (HQ) as given in Eq. 2. If the value of HQ is less than one, it means that the population is safe from selected air pollutant; if HQ is greater than one, it means that the population is not

considered safe and it may cause adverse health effects [7, 19, 23].

$$HQ = \frac{EC}{RfC} \quad (2)$$

where HQ hazard quotient, EC exposure concentration in $\mu\text{g}/\text{m}^3$, RfC reference concentration in $\mu\text{g}/\text{m}^3$.

RfC was obtained from the agency for toxic substances disease registry (ATSDR) and integrated risk information system (IRIS). The values of reference concentrations (RfC) for SO_2 and Hg are $28.2 \mu\text{g}/\text{m}^3$ and $0.3 \mu\text{g}/\text{m}^3$, respectively [24, 25]. The Hazard Index (HI) was used to evaluate overall

Fig. 3 Sensitive and tourist locations within a 10 km radius of the brick kilns

non-carcinogenic health risks caused by multiple pollutants. HI is calculated by the sum of HQ of the individual pollutants as shown in Eq. 3.

$$HI = HQ_1 + HQ_2 \quad (3)$$

where HI Hazard index, HQ hazard quotient.

Cancer risk from exposure of selected pollutants was calculated by using Eq. 4 [7, 26].

$$CR = EC \times SF \quad (4)$$

where CR cancer risk, EC exposure concentration in $\mu\text{g}/\text{m}^3$, SF slope factor for inhalation $(\mu\text{g}/\text{m}^3)^{-1}$.

The value of SF for calculating inhalation cancer risk is 4.29×10^{-3} , 1.8×10^{-3} and 1.2×10^{-2} for As, Cd and Cr as Cr VI, respectively [27].

4 Results and discussion

4.1 Evaluation of dispersion model results

Usually, wind in the study area is from the southwest, with occasional wind coming from the northeast and

northwest, as shown in Fig. 2. The average wind speed is 4.8 m/s. Figures 4 and 5 show the short-term and long-term concentrations of SO_2 , Hg, As, Cd and Cr, where short-term and long-term dispersion is based on maximal hourly and annual average, respectively. Short-term and long-term maximum ground level concentration (GLC) occurs within 1 km from the northeast and northwest direction of the emission source. Maximum short-term and long-term ground level concentrations most of the time are in the northeast direction, because mostly the wind blew in the southwest direction from the emission source. Among the ten discrete receptors, a school near the source of emissions in the northeast direction experienced the highest concentration in all cases. The maximum dispersion modeled concentration of both times is shown in Figs. 4 and 5 and Table 3. Ambient concentrations of pollutants emitted from brick kiln stacks were compared with Pakistan and other guidelines (Alberta, New Zealand and Arizona) and demonstrated that receptors within the vicinity of a 10 km radius of brick kilns measured acceptable and very low pollutants concentrations. Guidelines of other countries used as a reference because the Pakistan guidelines do not have specific ambient threshold limits for As, Hg, Cd, and Cr. However, the annual ground-level concentration

Fig. 4 Maximal hourly and annual average concentration of non-carcinogenic pollutants

of chromium (Cr) and hourly ground-level concentration of arsenic (As) exceeds the Arizona and Alberta guidelines for ambient air, respectively. Results suggest that further assessments are necessary to evaluate further possible potential adverse effects.

4.2 Non-carcinogenic risk

The HQs of Hg and SO₂ and HI by summing of HQs of both pollutants are calculated for the determination of short-term and long-term non-carcinogenic health risk, as shown in Table 4. HQs acquired due to short dispersion

of SO₂ causes potential adverse effects as HQs of short-term SO₂ were more than one (HQ = 1.86). While long-term dispersion of SO₂ shows no adverse health effects, as HQ was less than one (HQ = 0.192). It is indicated that an important role is played by the meteorological conditions in the reduction of health risk from air pollution. The acquired HQ of Hg shows that both short-term and long-term dispersion of Hg do not cause adverse effects to human health within 10 km from the studied brick kilns. In 2014 Mokhtar et al. conducted a similar health risk assessment study from the emissions of coal fired power plants located in Malaysia for Hg and SO₂. The hazard index (sum

Fig. 5 Maximal hourly and annual average concentration of carcinogenic pollutants

of more than one HQs) for short term and long-term risk was found to be 1.814 and 0.1009, respectively, and was less than present study [7]. In 2008 Cangialosi et al. also conducted a study for assessment of health risk caused by Hg, which shows $HQ = 6.1 \times 10^{-5}$ due to emissions from a municipal solid waste incinerator; these results were also less than our study [32].

4.3 Carcinogenic health risk

The cancer risk of As, Cd, and Cr are calculated to determine short-term and long-term carcinogenic human health risks and are presented in Table 5. Based on cancer risk, the possibility of cancer develops from short-term GLC of As, Cd, and Cr greater than the threshold limit of 1×10^{-4} to 1×10^{-6} . Conversely, the probability of cancer risk develops from long-term GLC of As and Cr when levels

are greater than the threshold limits of 1×10^{-6} , while long-term GLC of Cd indicated cancer risk was within acceptable limits among the people living within 10 km of the source of emissions. The meteorological condition could be a possible source of reduction in long-term carcinogenic health risks, as discussed early. The carcinogenic risk from our study of brick kilns was equal and higher than the studies conducted by Mokhtar et al. (2014) in Malaysia due to emissions from coal-fired power plants [7].

5 Conclusion

Dispersion modeling was simulated to estimate the pollutant ground-level concentrations being emitted from brick kilns. The comparison of GLC with national and international standards showed that, except for the long-term

Table 3 Estimated maximum concentration comparison with ambient quality standards

Pollutant	Maximal hourly average concentration ($\mu\text{g}/\text{m}^3$)	1-h ambient air guideline ($\mu\text{g}/\text{m}^3$)	Yearly average concentration ($\mu\text{g}/\text{m}^3$)	Annual ambient air guideline ($\mu\text{g}/\text{m}^3$)
<i>Non-carcinogenic</i>				
SO ₂	52.5	750 ^a	5.42	80 ^a
Hg	6.14×10^{-3}	1.5 ^b	2.58×10^{-4}	0.33 ^c
<i>Carcinogenic</i>				
Cr	4.49×10^{-3}	0.1 ^b	2×10^{-4}	8×10^{-5} ^b
As	4.23×10^{-1}	0.1 ^d	4.38×10^{-3}	0.01 ^d
Cd	4.35×10^{-3}	7.7×10^{-1} ^b	2.13×10^{-4}	5.6×10^{-4} ^b

^aPakistan National Ambient Air Quality Standards [28]

^bArizona Ambient Quality Standards [29]

^cNew Zealand Ambient Air Quality Standards [30]

^dAlberta Ambient Air Quality Guidelines [31]

Table 4 Evaluation of non-carcinogenic health effects of pollutants from studied brick kilns

Pollutant	Maximal hourly average concentration ($\mu\text{g}/\text{m}^3$)	Annual average concentration ($\mu\text{g}/\text{m}^3$)	RfC ($\mu\text{g}/\text{m}^3$)	Hazard quotient (HQ)	
				Short-term (1-h)	Long-term annual
SO ₂	52.5	5.42	28.2	1.86	0.192
Hg	6.14×10^{-3}	2.58×10^{-4}	0.3	2×10^{-2}	8.6×10^{-4}
Hazard Index (HI)				1.88	0.193

Table 5 Evaluation of carcinogenic health effects of pollutants from studied brick kilns

Pollutant	Maximal hourly average concentration ($\mu\text{g}/\text{m}^3$)	Annual average concentration ($\mu\text{g}/\text{m}^3$)	Unit risk factor for inhalation ($\mu\text{g}/\text{m}^3$) ⁻¹	Lifetime cancer risk (LCR)	
				Short-term (1-h)	Long-term annual
Cr	4.49×10^{-3}	2.0×10^{-4}	1.2×10^{-2}	5.4×10^{-5}	2.4×10^{-6}
Cd	4.35×10^{-3}	2.13×10^{-4}	1.8×10^{-3}	7.8×10^{-6}	3.83×10^{-7}
As	4.23×10^{-1}	4.38×10^{-3}	4.29×10^{-3}	1.8×10^{-3}	1.88×10^{-5}
Total				1.88×10^{-3}	2.16×10^{-5}

concentration of Cr and the short-term concentration of As, all pollutant concentrations are acceptable. Health risk assessment identified various levels of risks from short-term and long-term dispersion of pollutant emissions from brick kilns. Except for Hg, the short-term concentration of all carcinogenic and non-carcinogenic pollutants can cause potential adverse health effects and have the possibility to increase cancer risk in people living within a radius of 10 km. Laborers at brick kilns are at the highest risk, because the maximum ground level concentration of pollutants are within a 1 km vicinity of the brick kilns, while only As and Cr cause adverse health effects from long-term concentrations. However, authors of this study recommended that a detailed assessment of pollutant emissions from these same 55 brick kilns and the ambient air with meteorological conditions should be carried out as meteorology plays an important role in the reduction and deposition of pollutant at a particular location. Occupational health risk assessment is also recommended, since the results of dispersion modeling indicates laborers at brick kilns are exposed to higher concentrations. The authors of this research also recommend that legislation guidelines should be made for the construction, operation, and occupational hazards of brick kilns businesses.

Acknowledgements The authors of this study thank the US–Pakistan Centers for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering and Technology (MUET) Jamshoro, Sindh, Pakistan for providing the AERMOD model, air quality monitoring equipment, meteorological and terrain data. The authors also thanks six known and 49 anonymous brick kiln owners who provided information about the type and the amount of fuel consumed in the brick kilns. The authors also thanks to Prof. Rick Bereit for helping in improving the language of this paper.

Compliance with ethical standards

Conflict of interest The authors states that there is no conflict of interest.

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