SAFE AREA FOR RESIDENTIAL POPULATION TO RESIDE NEAR LIMESTONE MINING: A RISK MANAGEMENT APPROACH

Wilayah Aman Bagi Pemukiman Dekat Tambang Batu Kapur: Suatu Pendekatan Manajemen Risiko

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Abstrak. Di Sukabumi, batu kapur ditambang oleh penduduk setempat tanpa pengendalian bahaya yang memadai. Untuk mengestimasi risiko kesehatan akibat pajanan penambangan kapur dan menentukan lokasi aman untuk penduduk di sekitarnya, telah dilakukan analisis risiko kesehatan lingkungan untuk partikulat tersuspensi total (TSP) dan PM10 di Desa Padabeunghar, Kecamatan Jampang Tengah, Kabupaten Sukabumi. TSP dan PM10 diukur di lokasi penambangan dan di 10 tempat pemukiman dengan interval koaksial sekitar 500 m. Berat badan dan waktu kontak pemajanan diukur dari 110 orang penduduk lelaki dan perempuan dewasa yang dipilih secara acak dari 6.523 rumah tangga di sekitar lokasi penambangan. Estimasi risiko kesehatan, yang dinyatakan sebagai risk quotient (RQ), dihitung dari rata-rata asupan harian TSP dan PM10 dan dosis referensinya (RfC). Risiko kesehatan dianggap ada dan perlu dikendalikan jika RQ>1. Hasil estimasi menunjukkan bahwa hanya sekitar 9% penduduk Desa Padabeunghar yang aman dari risiko kesehatan oleh pajanan debu partikulat sepanjang hidup mereka. Dengan RQ gabungan yang berkisar 0,67 sampai 13, lokasi yang aman untuk dihuni berada mulai dari 4 km dari pusat pertambangan ke luar, sedangkan menurut baku mutu lingkungan udara ambien (PP 41/1999) lokasi aman mulai dari 3 km. Konsentrasi TSP dan PM10 yang terukur masing-masing 23-1.606 dan 10-175 μg/M3, sedangkan menurut rumusan manajemen risiko masing-masing 81 μg/M3 dan 57 μg/M3. Angka tingkat aman ini, yang lebih rendah dari ketentuan PP 41/1999 sebesar 90 μg/M3 untuk TSP, dapat dicapai dengan menurunkan laju penambangan dari 25 ton/hari menjadi 6,3 ton/hari, atau dengan memindahkan tungku pembakaran kapur ke lokasi yang lebih jauh dari pemukiman.

Kata kunci: *kapur, risk quotient, manajemen risiko, PM10, TSP*

Abstract. In Sukabumi limestone rock is exploited by local people without appropriate control measures. To estimate health risks from exposure to limestone mining and define safe area for residential population to reside, environmental health risk assessment has been conducted for total suspended particulate (TSP) and 10-μm aerodynamic diameter particulate matter (PM10) in Padabeunghar Village, Jampang Tengah District in Sukabumi Regency, West Java. TSP and PM10 were measured at the mining site and at 10 sampling sites with approximately 500-meter coaxial intervals. Body weight and contact time of exposure were measured from 110 adult male and female residents selected randomly from 6,523 households near mining sites. Health risk estimate, expressed as Risk Quotient (RQ), were calculated from TSP and PM10 average daily intakes and corresponding reference concentrations (RfC). Health risks are considered to exist and require control measure if RQs>1. It was found that only about 9% of the Padabeunghar residents are safe from particulate dust health risk over their life span. With combined RQ ranging from 0.67 to13, the safe location to reside is at >4 and so forth from the mining site, while according to Indonesian national ambient air quality standard (PP 41/1999) it begins from >3 km. TSP and PM10 concentrations were 23-1,606 and 10-175 μg/M3, respectively, while management option suggests 81 μg/M3 and 57 μg/M3, respectively. These safe levels are lower than the PP 41/1999 standard (90 μg/M3 for TSP) and might be achieved by reducing current mining rate of 25 ton/day to 6.3 ton/day, or by moving the limestone furnace to remote places.

Keywords: *Limestone, risk quotient, risk management, PM10, TSP*

INTRODUCTION

Limestone has been long well known as building material for brick, tile, and concrete since ancient time due to its hardness, durability, availability, and relatively accessible. Limestone is an important raw material for cement, quicklime (CaO), slaked lime ($Ca(OH)_2$), and non building material products such as additives and filler, soil conditioner and acid

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neutralizer, petroleum desulfurizer, abrasive, methane explosion suppressor in underground mine, and calcium supplementation for diet (Anonymous, 2005). In Indonesia, limestone rock is traditionally burnt to produce quicklime to be mixed with water and sand as cement-like slurry for stone and brick adhesive. Limestone is hard rock which mostly formed by marine sedimentation of dead plants and animals (Taylora and Wilson, 2003).

Sukabumi District in West Java has a lot of limestone deposits spreading out in many districts (Jeffrey and Lehrmann, 2008). For example, Jampang Tengah Sub-District in Sukabumi District roughly has 16 millions ton rock deposit distributed in 11 villages (Sukabumi, 2005). Of these, Padabeunghar Village has 4 millions ton rock, the highest deposit among the villages which is exploited intensively at 25 ton/day rate.

Limestone mining has been contributing to air pollution with particulate dusts, while burning its rock emits NO_2, SO_2, CO, and slaked lime dust. Respirable dust of limestone may contribute to the development of chronic obstructive pulmonary disease (COPD) (Mirzaee et al., 2008). In 2002, COPD has been the sixth major cause of death in the world. In Indonesia, epidemiologic surveillance in hospitals in West Java, Central Java, East Java, Lampung, and South Sumatra showed that 35% of non communicable disease is COPD, greater than asthma (33%) and lung cancer (30%) (PPM-PLP, 2004). In Jampang Tengah Sub-District of Sukabumi, monthly report 2005 of local Health Centre recorded 53 respiratory complaints among impacted residents, while from non impacted resident it was only 24 cases (Sukabumi, 2005). So far, Sukabumi Health Office has never conducted risk management program for limestone mining in Jampang Tengah.

Meanwhile, Directorate General of Disease Control and Environment Sanitation of Indonesian Ministry of Health has carried out health risk assessment study for limestone mining in Sukabumi, Cirebon, Tegal, Jepara, and Tulung Agung (Rahman et al., 2008). These assessment reported that the safe area to reside was likely >5 km away from the mining site. This study had only three sampling sites with only 30 respondents from each location, while the dusts were measured by conventional gravimetric technique. Due to small sample and narrow sampling sites, local anthropometric characteristic and activity pattern and environmental concentration of TSP and PM_{10}, by which daily intakes of TSP and PM_{10} were estimated, might not represent the real circumstances.

To better estimate health risk from exposure to particulate dusts, further health risk assessment has been conducted in Padabeunghar Village, Jampang Tengah Sub-District of Sukabumi District, West Java, with greater sample size and wider sampling sites. This study was intended to formulate management options by which the limestone mining can be continued without compromising adverse health consequences for prolong exposure.

METHODS

Study Design. This study employs environmental health risk assessment design as described elsewhere (EPA, 2005, WHO, 2009). It formally consists of hazard identification, exposure assessment, dose-response assessment, and risk characterization. Health risk characteristic was expressed as Risk Quotient (*RQ*) and was calculated by dividing life span average daily dose (*LADD*) of exposure to particulate dusts by corresponding reference concentration (*RfC*). *LADD* was calculated using Eq. (1)

$$LADD = \frac{C \times R \times t_{\mathrm{E}} \times f_{\mathrm{E}} \times D_{\mathrm{E}}}{W_{\mathrm{B}} \times t_{\mathrm{avg}}} \qquad (1)$$

Where *LADD* is daily intake for TSP or PM_{10} (mg/kg/day), *RfC* is reference concentration of TSP or PM_{10} (mg/kg/day), *C* is concentration of TSP or PM_{10} in ambient air (mg/M^3), R is inhalation rate (M^3/hour), t_E is exposure time (hour/day), f_E is exposure frequency (day/year), D_E is exposure duration (year; 30 year for lifetime residential default), W_B is body weight (kg), t_{avg} is averaging time of exposure (D_E × 365 day/year for non carcinogen). Based on calculated *RQ*s, management options were formulated by manipulating numerical values of intake variables in such a way that the *LADD* is equal to *RfC* as expressed in Eq. (2):

$$RfC = LADD = \frac{C \times R \times t_E \times f_E}{W_B \times t_{avg}} \quad (2)$$

Risk Agent Measurement. TSP and PM_{10} were measured by optical sensor devices using Micro Dust Sampler (Casella, UK). The measurements were conducted in April-June 2006 for 24-hour exposure from 06.00 am to 05.59.59 am local time and were recorded in one reading unit per second. The records were then grouped into 5-second reading resulting in 288 data points. Depending on distribution normality of the recorded data, arithmetic mean or median values of risk agents' concentrations were used for estimating *LADD*.

Site Description. Study area is located in Padabeunghar Village of Jampang Tengah Sub-District, District of Sukabumi, West Java (Figure 1). It consists of a number of kampongs and hamlets with total population of 66,547 in 16,652 households spreading out unevenly in 1,348,020 square km hilly area.

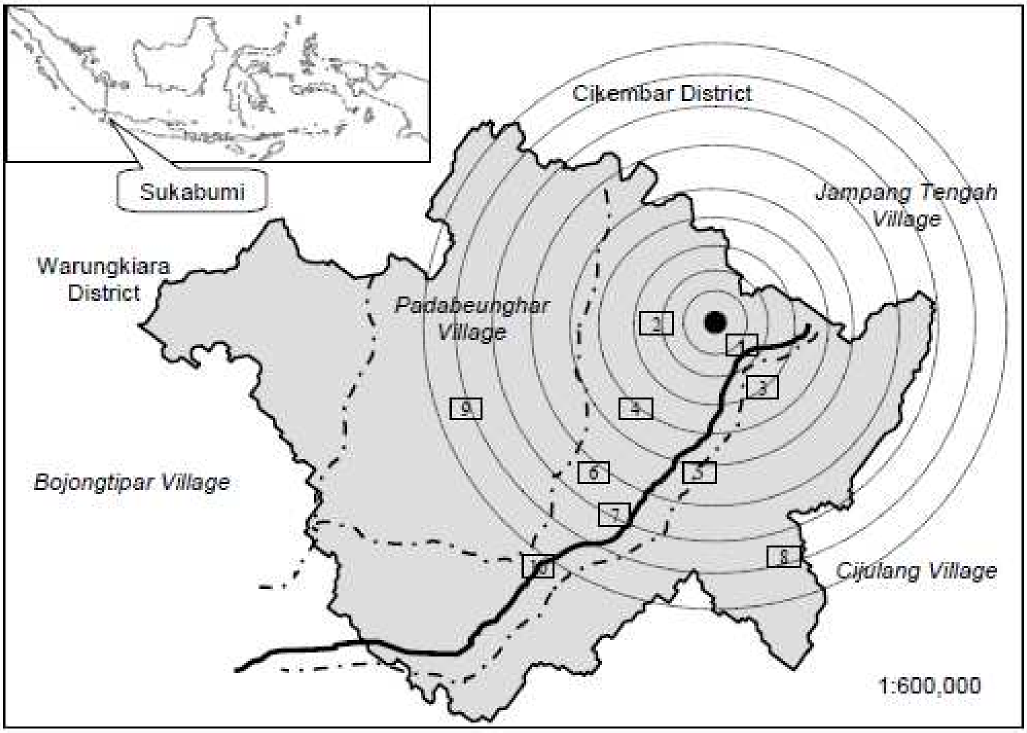

Figure 1. Map of study location indicating sampling locations at mining site (•), Bantarjati (1), Padabeunghar (2), Cisalak (3), Babakan (4), Ciembe (5), Lebakgede (6), Leuwipeundeuy (7), Neglasari (8), Panyindangan (9), and Ciwelit (10) for measuring TSP and PM_{10} and anthropometric survey in Padabeunghar Village, Jampang Tengah Sub-District, Distric of Sukabumi.

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Population and Sample. All adult people residing up to 5 km from the mining site were assigned as population at risk. Since this study assessed chronic health risk, study subjects were inclusively limited to (a) male and female, (b) have been resided in the study area ≥7 years, and (c) live continuously in the study ≥350 days per year. By these inclusion criteria, only 15,762 individuals were eligible as population at risk from 66,547 residents. Using population proportion sample size (Lwanga and Lemeshaw, 1998), a total of 110 respondents were drawn proportionally from 6,523 households in 10 kampongs and hamlets i.e. Bantarjati (5 of 203), Padabeunghar (20 of 810), Cisalak (13 of 527), Babakan (6 of 243), Ciembe (28 of 1,134), Lebakgede (3 of 121), Leuwipeundeuy (5 of 203), Neglasari (3 of 121), Panyindangan (18 of 729) and Ciwelit (9 of 364). Distance of these locations from mining site were 0 to 500 m, >500 m to 1,000 m, and so forth.

Anthropometric Exposure Factors. Anthropometric exposure factors were obtained directly from the surveyed respondents. Body weight was weighed using calibrated scale with 0.1 kg reading and rounded into 1.0 kg unit. Data on exposure time (t_E), frequency (f_E), and duration (D_E) were collected by interviewing respondents of how many hours they stay daily at home, how many days annually they leave home, and for how many years they have resided in the current home, respectively. R was derived from logarithmic curve of body weight versus adult inhalation rate for normal work activity y = 5.3ln(x)-6.9 where y = R (M^3/day) and x = W_B (kg) (Abrianto, 2004).

RESULTS

TSP and PM_{10} Concentration and Anthropometric Exposure Factors. TSP and PM_{10} concentration in 11 sampling sites and anthropometric exposure factors of 110 respondents including 25 mining workers are presented in Table 1.

Table 1. TSP and PM median concentration and anthropometric exposure factor characteristics (n = 110, including 25 mining workes) in Padabeunghar Village, Jampang Tengah Sub-District, District of Sukabumi, April-June 2006.

No	Location and Distance from Mining Site	Concentration (μg/M^3)		R^a (M^3/h)	W_B (kg)	t_E (h/d)	f_E (d/y)	D_E (y)
		TSP	PM_{10}					
A	Mining Site	1,604	1,091	0.60	56	8	350	25
B	Residence							
1	Bantarjati (0-0.5 km)	301	201	0.58	51	24	350	41
2	Padabeunghar (>0.5-1 km)	258	175	0.58	51	24	350	24
3	Cisalak (>1-1.5 km)	176	119	0.60	56	24	350	30
4	Babakan (>1.5-2 km)	164	111	0.53	41	24	350	23
5	Ciembe (>2-2.5 km)	129	87	0.60	56	24	350	34
6	Lebakgede (>2.5-3 km)	116	78	0.54	43	24	350	15
7	Leuwipeundeuy (>3-3.5 km)	76	51	0.56	47	24	350	37
8	Neglasari (>3.5-4 km)	62	42	0.58	50	24	350	32
9	Panyindangan (.4-4.5 km)	37	25	0.60	56	24	350	32
10	Ciwelit (>4.5-5 km)	23	10	0.89	57	24	350	23

[a]Calculated from logarithmic equation y = 5.3ln(x)-6.9 where y = R (M^3/day) and x = W_B (kg) (Abrianto, 2004).

Dose-Response Assessment. Dose-response relationship for particulate dust has not very well established. Non carcinogenic effects of dust in residential population are not adequate to derive *RfC* (EPA, 2002), although in occupational settings it contributes greatly to COPD (Hnizdo et al., 2002, Balmes et al., 2003, Trupin et al., 2003, Christiani, 2005, Meldrum et al., 2005, Mirzaee et al., 2008). Therefore, *RfC* of TSP and PM_{10} is not available in either Integrated Risk Information System database (IRIS,

2007) or Minimum Risk Level table (ATSDR, 2009), while NOAEL or LOAEL indicated in scientific papers has not been reviewed by competent agencies. Hence, for the present study the *RfC* is derived from US National Ambient Air Quality Standard (EPA, 1990b). Indonesia's ambient air quality standard (*Peraturan Pemerintah*, or PP, No. 41 of 1999, hereinafter referred to as PP 41/1999) cannot be employed since the default values of the anthropometric exposure factors are unknown. US NAAQS Primary Standard for PM_{10} is 50 µg/M^3 as annual arithmetic mean, whereas TSP standard could be 73.53 µg/M^3 (calculated as 1.47 × PM_{10} as described elsewhere (Petters et al., 2000). Using these values, Eq. (2) is employed to derive *RfC* of PM_{10} and TSP by substituting default values of EPA anthropometric exposure factors (EPA, 1990a, EPA, 1990b) (D_E of 30 years is applied as default lifetime non carcinogenic exposure, so the '30 year' is canceled out giving t_{avg} is only 365 day/year (Louvar and Louvar, 1998, Kolluru, 1996)):

$$RfC_{\mathrm{TSP}} = \frac{73.53\frac{\mu g}{M^3}\times 0.83\frac{M^3}{\text{hour}}24\frac{\text{hour}}{\text{day}}\times 350\frac{\text{day}}{\text{year}}}{70\text{ kg}\times 365\frac{\text{day}}{\text{year}}} = 0.02\text{ mg/kg/day}$$

$$RfC_{\mathrm{PM_{10}}} = \frac{0.05\frac{mg}{M^3}\times 0.83\frac{M^3}{\text{hour}}24\frac{\text{hour}}{\text{day}}\times 350\frac{\text{day}}{\text{year}}}{70\text{ kg}\times 365\frac{\text{day}}{\text{year}}} = 0.014\text{ mg/kg/day}$$

Exposure Assessment and Risk Characterization. Substitution of numerical values of variables in Table 1 into Eq. (1) gave *LADD* of TSP and PM_{10} for estimating *RQ*. Since TSP and PM_{10} have the same target organs and similar health consequences, *RQ* of TSP and PM_{10} could be also added to give combine *RQ*. Overall calculation outputs are presented in Table 2.

Table 2. Calculated life span average daily dose (*LADD*) and Risk Quotient (*RQ*) from exposure to TSP and PM_{10} of limestone mining in Padabeunghar Village, Jampang Tengah Sub-Distric , District of Sukabumi (n = 110)

No	Location (Kampong or Hamlet)	*LADD* (mg/kg/day)		*RQ* (unitless)		
		TSP	PM_{10}	RQ_{TSP}	$RQ_{PM_{10}}$	$RQ_{Combined}$
A	Mining Site	0.1178[a]	0.0911[a]	6.59	6.41	13.00
B	Residence					
1	Bantarjati	0.1114	0.0744	3.94	3.76	7.70
2	Padabeunghar	0.0570	0.0387	3.38	3.27	6.65
3	Cisalak	0.0434	0.0293	2.17	2.10	4.27
4	Babakan	0.0423	0.0287	2.44	2.36	4.8
5	Ciembe	0.0360	0.0243	1.59	1.53	3.12
6	Lebakgede	0.0186	0.0125	1.68	1.61	3.29
7	Leuwipeundeuy	0.0275	0.0185	1.04	1.00	2.04
8	Neglasari	0.0183	0.0124	0.83	0.80	1.63
9	Panyindangan	0.0100	0.0065	0.46	0.44	0.90
10	Ciwelit	0.0043	0.0019	0.41	0.26	0.67

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[a]Calculated from exposure to 8-hour in the mining site and 16-hour in the residence after work.

DISCUSSION

TSP and PM_{10} Concentration. The measured TSP and PM_{10} concentration has good agreement with previous measurements around furnace site i.e. 290-870 μg/M^3 in Jampang Tengah Sub-District, 560-780 μg/M^3 in Purabaya Sub-District, and 340-460 μg/M^3 in Cikembar Sub-District (Sukabumi, 2005) (see Fig. 1 for these sub-districts location). These concentrations are higher than the national standard (PP 41/1999: 90 μg/M^3 for TSP) for annual episode exposure (Indonesia, 1999).

Conservatively, a particular setting (such residence or work place) is usually considered as safe to reside if the contaminant concentration meets the legal standard. If this assumption is applied in the present study for annual exposure, the safe location to reside begins in Leuwipeundeuy (>3 to 3.5 km from the mining site) since the TSP concentration (76 μg/M^3) was lower than the PP 41/1999 standard. But, by the *RQ* values, Leuwipeundeuy is still unsafe. Unfortunately, PP 41/1999 dos not set out PM_{10} standard for annual exposure.

Anthropometric Exposure Factors. Body weight is one of variables responsible for adequacy of maximum contaminant level goal (MCLG) (EPA, 1990c) which can be legally passed as environmental standard. As expressed in Eq. (1), the lighter the body weight, the higher the intake and, therefore, the higher the health risk. Consequently, environmental standard based on 70-kg body weight (such as in the USA or European countries) is not suitable for Indonesia. So far, median value of body weight obtained from anthropometric survey in nine heavy-traffic big cities (n = 1,528) (Nukman et al., 2005), in Riau (n = 2,003) (Rahman et al., 2007) and in the previous limestone mining (n = 450) (Rahman et al., 2008) is 55 kg. In the present study body weight (Table 1) is closer to 55 kg than to 70 kg. Critical role of body weight in setting up health-based safe level for environmental standard is demonstrated in the management option formulation (see below).

In addition to body weight which is one of *LADD* denominators, inhalation rate and activity pattern are also critical. *R* can be determined by direct spirometric measurement of ventilation rate (VR) (Linn et al., 1993a, Linn et al., 1992, Spier et al., 1992, W C Adams, 1993, Linn et al., 1993b), by indirect measurement of heart rate (HR) (US-EPA, 1997), or by estimating energy expenditure from daily diet (Layton, 1993). In the present study, *R* was not measured directly from the study subjects but was calculated from logarithmic function of body weight (Abrianto, 2004). Reasonably, body weight determines energy expenditure which requires oxygen from inhaled air. While by logarithmic equation *R* is ranging from 0.54 to 0.89 M^3/hour (Table 1), energy expenditure estimate used by US-EPA gives 0.65 M^3/hour and 0.54 M^3/hour for adult male and adult female, respectively (US-EPA, 1997). Obviously, the energy expenditure-derived *R* is very close to the logarithmic-derived *R*. The later method even gives more opportunity for individual health risk estimates rather than single point estimates.

Meanwhile, assessing exposure to air contaminants is difficult as every person inhales air at different places in different length of periods. Besides, exposure time and frequency data in the present study are subjects to recall bias as the survey was conducted using recall rather than record technique. So, the calculated intakes may differ from real situations leading to less accurate *RQ* estimates. However, for human health protection, employing *RQ* is better than using the PP 41/1999 standard in which the exposure factors employed are unclear. In the absence of field data, using default values is common and acceptable (EPA, 1990a, Ricci, 2006).

Health Risk Characteristic. According to combined *RQ* values (Table 2) and Figure 2, safe location begins at Panyindangan (site 9) at >4 to 4.5 km from the mining site. It was not at Leuwipeundeuy (site 7) as defined by TSP level. By the *RQ* values, however, Leuwipeundeuy is still unsafe since its *RQ* of TSP is 1.38. It means that the existing legal standard is not adequate to protect human health risk from exposure to particulate dust. Since the population of Leuwipeundeuy and other 3 hamlets (Neglasari, Panyindangan, and Ciwelit, which are located more distant from the mining site) is 1,417 of total 15,762 individuals (see *Population and Sample* description above), only about 9% of total population of Padabeunghar Village could be safe from health risk from exposure to limestone mining dust. This situation is very critical that requires management options. Empirical finding as reported in 2005 by Jampang Tengah Health Centre confirm this necessity (Sukabumi, 2005). Management option formulation to solve the estimated health risk is described below.

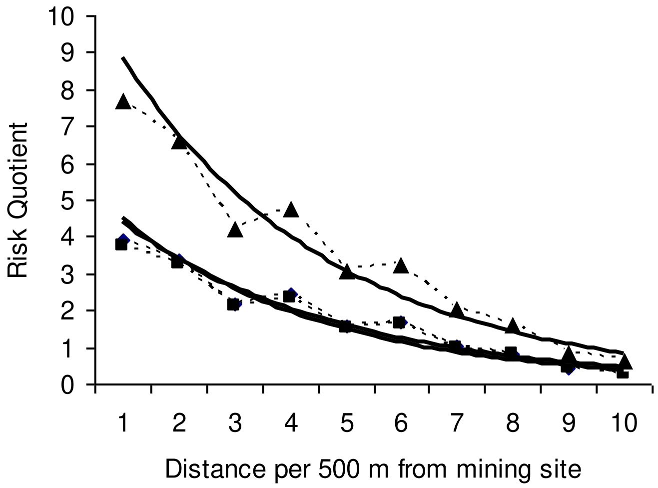

Figure 2. Observed (---) and exponential (–) trend line curves of RQ_{TSP} (■),RQ_{PM10} (♦), and $RQ_{Combined}$(▲) from the limestone mining site (0) to as far 5 km distance (11) in Padabeunghar Village, Jampang Tengah District of Sukabumi Regency.

Management Options. Risk management is especially required for *RQ*>1. It is mathematically formulated by adjusting numerical values of intake variables in such a way that the *LADD* is equal to *RfC* as expressed in Eq. (3) (rearranged from Eq. (2)).

$$C = \frac{W_B \times t_{avg} \times RfC}{R \times t_E \times f_E} \qquad (3)$$

Eq. (3) offers three management options: 1) reduce concentration (*C*), 2) shorten contact time (t_E or f_E or both), and (3) combination of 1) and 2). However, shortening contact time for residential population may not realistic as most of the residents spend their life almost 100% in their residence. So, reducing particulate dust concentration to safe level is more reasonable than shortening contact time. The following example calculates safe concentration of TSP over projected life span exposure for residential population in Bantarajati (site 1, as in Figure 1).

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$$C_{\mathrm{TSP}} = \frac{51\,\mathrm{kg} \times 365\,\dfrac{\mathrm{day}}{\mathrm{year}} \times 0.02\,\dfrac{\mathrm{mg}}{\mathrm{kg} \times \mathrm{day}}}{0.58\,\dfrac{\mathrm{M}^3}{\mathrm{hour}} \times 24\,\dfrac{\mathrm{hour}}{\mathrm{day}} \times 350\,\dfrac{\mathrm{day}}{\mathrm{year}}} = 0.076\,\mathrm{mg/M}^3$$

It shows that existing level of TSP (0.301 mg/M^3) is four-fold the calculated safe level. Using the same calculation, the safe level of TSP for 8-hour/day and 10-hour/day workers in the mining site is 0.243 mg/M^3 and 0.195 mg/M^3, respectively. Overall, the calculated safe levels for TSP and PM_{10} in the study area are ranging from 0.067 to 0.081 mg/M^3 and 0.047 to 0.057 mg/M^3, respectively. These values are lower than the PP 41/1999 standard for annual exposure duration for TSP (0.090 mg/M^3) but comply with 24-hour exposure for TSP (0.23 mg/M^3) and PM_{10} (0.15 mg/M^3). Unfortunately, most environmentalists misinterpret this standard as sampling period rather than *exposure episode* since the PP 41/1999 itself defines it as 'sampling time'.

If contact time reduction is chosen, only f_E and D_E are likely to be applicable. For residential population, exposure time (t_E) is not possible to reduce as most people stay at home daily for almost 24 hours. The following example calculates safe f_E and D_E at existing TSP concentration for residential population in Bantarajati using rearranged Eq. (3) and Eq. (2), respectively.

$$f_E = \frac{51\,\mathrm{kg} \times 365\,\dfrac{\mathrm{day}}{\mathrm{year}}\,0.02\,\dfrac{\mathrm{mg}}{\mathrm{kg} \times \mathrm{day}}}{0.31\,\dfrac{\mathrm{mg}}{\mathrm{M}^3} \times 0.58\,\dfrac{\mathrm{M}^3}{\mathrm{hour}} \times 24\,\dfrac{\mathrm{hour}}{\mathrm{day}}} = 86.3\,\mathrm{day/year}$$

$$D_E = \frac{0.02\,\dfrac{\mathrm{mg}}{\mathrm{kg} \times \mathrm{day}}\,51\,\mathrm{kg} \times 365\,\dfrac{\mathrm{day}}{\mathrm{year}} \times 30\,\mathrm{year}}{0.31\,\dfrac{\mathrm{mg}}{\mathrm{M}^3} \times 0.58\,\dfrac{\mathrm{M}^3}{\mathrm{hour}} \times 24\,\dfrac{\mathrm{hour}}{\mathrm{day}}\,350\,\dfrac{\mathrm{day}}{\mathrm{year}}} = 7.4\,\mathrm{years}$$

The above calculations show clearly that, based on existing TSP concentration, the safe exposure frequency and exposure duration are impossible to achieve. Both safe exposure frequency and safe exposure duration are only 25% of normally 350 day/year and 25% of projected 30 years life span, respectively. Therefore, in the present study reduction of particulate dust is primary option of risk management.

Assuming that limestone mining is exclusive source of particulate dust, those safe levels might be achieved by reducing the existing mining rate. As such, the mining rate should be reduced by factor of safe level of TSP, so,

$$\text{Reduced Mining Rate} = \frac{0.07\,\dfrac{\mathrm{mg}}{\mathrm{M}^3}}{0.31\,\dfrac{\mathrm{mg}}{\mathrm{M}^3}} \times 25\,\frac{\mathrm{ton}}{\mathrm{day}} = 6.31\,\mathrm{ton/day}$$

The calculated safe mining rate of 6.31 ton/day is only about 25% of the current rate. This scenario is also unacceptable as, due to less fertile soil, most people in the study area live on mining rather than on farming (Sukabumi, 2005). It therefore requires other reasonable control measures.

It is obvious that quicklime production generates more particulate dust than rock mining does, although quantitative data have not been available. Hence, one of possible solution to achieve the safe levels is by moving the furnace facilities to unoccupied or remote places. This option would be economically and socially cheaper than displacing people from the current residence. Land topography, dominant wind direction, and accessibility are of important factors for this management option implementation.

CONCLUSION

The present study gives prospective health risk estimates indicating safe area to reside at particular distance from the mining sites. It also provides managements options to minimize risks by reducing particulate dust concentration, although this scenario may not always be possible due to social and economic considerations. Surprisingly, national ambient air quality standard (PP 41/1999) is not adequate to protect human health from exposure to limestone mining dust for annual exposure. Local anthropometric exposure factors are undoubtedly responsible for this inadequacy. This issue has never been accounted for any environmental health legislation in Indonesia.

RECOMMENDATION

Despite important results, this study has some technical limitations leading to scientific issues. Recall bias in collecting personal exposure data may contributes to less accurate daily intake. It is therefore suggested to employ recorded exposure assessment technique using activity log book for at least one year survey. To give more benefits, it is also suggested to employ Public Health Assessment framework in future study where epidemiology study is integrated into health risk assessment. This will provide additional dose-response data that may contribute for establishing TSP or PM_{10} *RfC*, in addition to health risk characteristics and management options.

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