Journal of Sound and Vibration (2000) **234**(1), 149–165
doi:10.1006/jsvi.2000.2863, available online at http://www.idealibrary.com on IDEAL®

NOISE ATTENUATION BY GREEN BELTS

A. K. Pal, V. Kumar and N. C. Saxena

Centre of Mining Environment, Indian School of Mines, Dhanbad, India

(*Received* 15 *June* 1999, *and in final form* 28 *January* 2000)

This paper outlines the results of noise attenuation investigations at eight planatation sites in Jharia (JCF) and Raniganj (RCF) coalfields in India. With a B&K Type 4224 noise source operated on spectrum I mode, the maximum total noise attenuation for *Leq* at 50 m depth of the green belt was found to be within 18·8–21·1 dB (A) in JCF and 18·7–21·0 dB (A) in RCF. Excess noise attenuation (*Leq*) exclusively due to green belts in JCF and RCF was 3·3–6·0 and 3·6–5·7 dB (A) respectively. Excess attenuation for higher frequencies (> 250 Hz) was more [> 4 dB (A)] than that for lower frequencies ($\leqslant 125$ Hz). Average trend of total noise attenuation (in percentage) at different depths of the green belt was evaluated to compute the minimum desired thickness of green belt for different locations in coal mining complexes. Based on characterization of the plantation sites and measured noise attenuation, a multivariable linear relationship was established for excess noise attenuation.

1. INTRODUCTION

Mitigation of environmental pollution caused by industrialization and urbanization in developing countries like India has emerged as one of the challenging tasks. Among the environmental pollutants, noise is considered to be a cause of the widespread occupational and community health problems in mining complexes. Adequate control measures have been taken in different countries, which mainly emphasize engineering control for major noise sources. Applicability of these measures is only possible in case of new mines or overall reconstruction of old mines. Since most of the Indian coalfields consist of a mix of old and new mines, it has so far not been possible to integrate the latest noise-control technologies in mine planning.

The recent trend is to develop green belts in and around the mining and urban areas to minimize ambient air and noise pollution. It has been regarded as one of the cheapest methods of pollution control in the developing countries. In managing noise, sound propagation in the environment has attracted the attention of acousticians and environmentalists. Research in this field is directed towards absorption of acoustic energy by the different structure in a plant community [1]. Plant leafs absorb acoustic energy by transferring the kinetic energy of the vibrating air molecules in a sound field to the vibration pattern of the leafs. Therefore, vibration energy is withdrawn from the acoustic field and part of this energy is lost by transfer to heat since leaf friction occurs in a vibrating plant [2]. Some pilot studies with Laser–Dopplex–Vibrometer System showed that when a sound field is present, vibration patterns exist over the leaf structures depending on the structure of the leaf. Vibration velocities at 100 dB sound pressure level are between 10^{-5} and 3×10^{-4} m/s. However, the exact mechanism of reflection, diffraction and absorption of sound waves around deciduous plant leaves is presently poorly understood [3].

0022-460X/00/260149 + 17 $35.00/0

The importance of different ground effects encountered in well-developed green cover due to formation of highly porous humus layer with lower flow resistivities is noticeable [4, 5]. Ground effect produces excess attenuation below 500 Hz. Excess attenuation at or above 1 kHz has been attributed to both scattering by trunks and branches and scattering and absorption by foliage [3, 5–7].

This paper highlights the results of the systematic noise-attenuation studies at eight plantation sites of Jharia and Raniganj coalfields (JCF & RCF respectively) [8].

2. CHARACTERIZATION OF PLANTATION SITES

Eight plantation sites, four each from JCF and RCF were selected keeping in view the following

- Already existing, well-developed plantation sites.
- Accessibility from the point of view of studies.
- A minimum width of 50 m.

2.1. METHODOLOGY

Standard quadrate method was used. Two to four quadrates of $10\,m \times 10\,m$ were considered. The following parameters were observed.

- Aerial height (AH).
- Diameter at breast height (DBH).
- Branchless lower trunk (BLT).
- Canopy branch cover (CBC).
- Vegetation density quantification through vertical light penetration and horizontal light penetration.

3. NOISE ATTENUATION STUDY

3.1. INSTRUMENTS USED

For noise monitoring, B&K Modular Precision Sound Level Meter (Type 2231) and B&K Noise Analyser (Type 2260) were used. Spectrum I mode of B&K sound source (Type 4224) was used as noise source. The following gives brief description of the salient features of sound source.

- Portable and robust instrument capable of producing high noise levels.
- Dimensions and weight:
  height: 480 mm,
  width: 380 mm,
  depth: 242 mm,
  weight: 18 kg.
- Deliverable sound power level
  0–118 dB, mains-operated,
  0–115 dB, battery-operated.
- Types of sound power spectrum:
  — wide band,
  — spectrum I,
  — spectrum II.

- Power supply:
  Mains-operated 100–240 V, 50–60 Hz,
  Built-in batteries — 10 Ni Cd cells
- Power consumption:
  65 W at full load.
- Recharging time using mains supply: 14 h.

3.2. NOISE LEVEL PARAMETERS MONITORED

MaxL—Maximum root mean square (RMS) level: This indicates the sound pressure level (SPL) exceeding 10% of the monitoring time.

Leq—The energy-equivalent sound level which equals the constant SPL whose acoustic energy is equivalent to the acoustic energy of a fluctuating sound over some time interval.

3.3. MONITORING PROCEDURE

A systematic noise attenuation study at different plantation sites of JCF & RCF was conducted using B&K sound source (Type 4224) during 1997–98 (monsoon season). A green belt upto 50 m in width was considered for monitoring. Ambient sound level in terms of *MaxL* and *Leq* was determined at the border line, 10, 20, 30, 40 and 50 m within the green belts. With noise source (placed on ground at about 10 m from the border line) in operation, noise level parameters were monitored in a similar fashion and the average noise levels were determined. The noise-monitoring instrument was set on a tripod at a height of 1·5 m from the ground.

Frequency spectrum analysis (1/1 octave band) was conducted to evaluate frequency-wise attenuation at different distances from the source in the green belts.

Meteorological parameters, i.e., wind speed and direction, humidity and temperature were also monitored.

4. RESULTS AND OBSERVATIONS

4.1. GREEN BELT CHARACTERIZATION

Plantation composition and characteristics, etc., of the sites of JCF and RCF were as given in Tables 1 and 2. It was observed that Loudoha forest, Jhanjhra incline mine and Bera plantation sites had more diversified species. In terms of average density (plants/ha), Loudoha College site had the maximum. Average spacing between consecutive plants varied from 1·1 m × 1·0 m to 3·0 m × 1·5 m. Average canopy cover at different plantation sites also varied with respect to different species [9].

The ground cover of the sites was studied and dominant species were as stated in Tables 1 and 2. Vertical light penetration at 1·5 m above the ground and horizontal light penetration as observed are also shown in Tables 1 and 2.

4.2. NOISE ATTENUATION

The total noise attenuation for *MaxL* and *Leq* levels in spectrum 1 mode of B&K type 4224 noise source increased steadily with the increase of the width of green belt at all the

TABLE 1

Green belt characterization of the JCF plantation sites

Location/ parameter	Putki Balihari plantation area	Kustore plantation area	Bera plantation area	Simlabahal plantation area
1. Vegetation (%) characteristics				
Acacia auriculiformis	100·0	53·0	69·0	7·8
Cassia siamea	—	41·1	22·0	50·0
Leucaena leucocephala	—	—	—	42·2
Gmelina arborea	—	—	6·0	—
Dalbergia sissoo	—	5·9	3·0	—
2. Average density (No. of plants/ha)	2091	2100	4200	3200
3. Average spacing (m)	2·2 × 2·2	3 × 1·5	1·5 × 1·5	2 × 1·5
4. Average aerial height (m)				
Acacia auriculiformis	7·34	10·26	4·03	6·63
Cassia siamea	—	10·49	4·13	6·58
Dalbergia sissoo	—	10·50	3·60	—
Gmelina arborea	—	—	3·72	—
Leucaena leucocephala	—	—	—	9·33
5. Average branch-Less lower trunk (BLT) (m)				
Acacia auriculiformis	3·58	4·36	1·42	2·49
Cassia siamea	—	5·87	1·11	3·67
Dalbergia sissoo	—	2·20	1·70	—
Gmelina arborea	—	—	1·74	—
Leucaena leucocephala	—	—	—	4·63
6. Average diameter at breast height (cm)				
Acacia auriculiformis	7·55	8·06	4·85	6·22
Cassia siamea	—	9·84	4·53	8·47
Dalbergia sissoo	—	6·90	2·95	—
Gmelina arborea	—	—	4·74	—
Leucaena leucocephala	—	—	—	7·04
7. Average canopy branch cover (m)				
Acacia auriculiformis	3·84	6·13	2·68	3·55
Cassia siamea	—	4·65	2·99	2·93
Dalbergia sissoo	—	8·30	1·90	—
Gmelina arborea	—	—	1·98	—
Leucaena leucocephala	—	—	—	5·42
8. Dominant ground cover	*Oscimum sp.* *Eupatorium sp.* *Cassia tora*	*Oscimum sp.* *Tridex sp.* *Cynodon sp.*	*Oscimum sp.* *Tridex sp.* *Cynodon sp.* *Euphorbia sp.*	*Oscimum sp.* *Andropogon sp.* *Cynodon sp.* *Achyranthus sp.* *Indigofera sp.* *Evolvulus sp.* *Lantana camara*
9. Vertical light penetration (%) at 1·5 m above the ground	49·30	27·00	52·81	13·82
10. Horizontal light penetration (%) at				
10 m	85·3	87·9	45·0	86·2
15 m	—	—	36·0	75·9
20 m	56·0	62·0	33·0	63·8
25 m	—	—	10·0	51·7
30 m	24·9	34·5	—	37·9
35 m	16·3	20·7	—	—

TABLE 2

Green belt characterization of the RCF plantation sites

Location/ parameter	West Bengal Government Forest Dept. plantation site, Laudoha	Plantation site near Jhanjra incline mine	Plantation site near Laudoha College	Jhanjra Project plantation site
1. Vegetation (%) species				
Madhuca indica	51·7	15·4	—	—
Acacia auriculiformis	33·7	29·5	100·0	48·9
Shorea robusta	10·7	50·0	—	—
Terminalia arjuna	3·4	—	—	—
Cassia siamea	0·5	—	—	—
Eucalyptus globosus	—	3·9	—	47·8
Albizzia lebbek	—	1·3	—	—
Dalbergia sissoo	—	—	—	3·4
2. Average density (Plants/ha)	2372	2600	5900	5800
3. Average spacing (m)	2·1 × 2	2 × 1·92	1·5 × 1·1	1·5 × 1·12
4. Average aerial height (m)				
Madhuca indica	22·24	8·57	—	—
Acacia auriculiformis	21·59	6·79	10·35	13·44
Shorea robusta	23·16	7·52	—	—
Terminalia arjuna	12·78	—	—	—
Cassia siamea	14·70	—	—	—
Eucalyptus globosus	—	9·15	—	10·74
Albizzia lebbek	—	5·47	—	—
Dalbergia sissoo	—	—	—	4·78
5. Average branchless lower trunk (m)				
Madhuca indica	2·29	2·00	—	—
Acacia auriculiformis	4·34	1·52	1·76	3·72
Shorea robusta	3·35	1·89	—	—
Terminalia arjuna	2·47	—	—	—
Cassia siamea	3·92	—	—	—
Eucalyptus globosus	—	2·90	—	7·25
Albizzia lebbek	—	1·79	—	—
Dalbergia sissoo	—	—	—	1·69
6. Average diameter at breast height (cm)				
Madhuca indica	15·12	10·57	—	—
Acacia auriculiformis	14·36	8·70	4·85	5·21
Shorea robusta	15·47	8·50	—	—
Terminalia arjuna	8·67	—	—	—
Cassia siamea	20·80	—	—	—
Eucalyptus globosus	—	9·64	—	5·33
Albizzia lebbek	—	12·60	—	—
Dalbergia sissoo	—	—	—	3·22

TABLE 2—*Continued.*

Location/ parameter	West Bengal Government Forest Dept. plantation site, Laudoha	Plantation site near Jhanjra incline mine	Plantation site near Laudoha College	Jhanjra Project plantation site
7. Average canopy branch cover (m)				
Madhuca indica	19·98	6·58	—	—
Acacia auriculiformis	17·26	5·33	8·61	9·97
Shorea robusta	19·89	5·61	—	—
Terminalia arjuna	10·35	—	—	—
Cassia siamea	10·78	—	—	—
Eucalyptus globosus	—	6·25	—	3·49
Albizzia lebbek	—	3·68	—	—
Dalbergia sissoo	—	—	—	3·23
8. Dominant ground cover	*Cynodon sp. Andropogon sp. Croton sp. Euphorbia sp.*	*Oscimum sp. Andropogon sp. Cynodon sp. Evolvulus sp.*	*Tridex sp. Euphorbia sp. Evolvulus sp.*	*Oscimum sp. Andropogon sp. Cynodon sp. Evolvulus sp.*
9. Vertical light penetration (%) at 1·5 m above the ground	12·94	51·65	51·64	62·2
10. Horizontal light penetration (%) at				
5 m	79·3	48·3	40	58·6
10 m	58·6	37·9	17·2	24·1
15 m	55·2	27·6	14·4	20·7
20 m	41·4	17·2	5·2	6·9
25 m	37·9	6·9	—	—
30 m	31·0	—	—	—

plantation sites of JCF (Table 5) and was maximum at 50 m width of the green belt as seen in the summarized data given in Table 3.

A similar total noise attenuation pattern was observed for all plantation sites of RCF (Table 6). The maximum attenuation for both *MaxL* and *Leq* was at 50 m depth of the green belt as seen in the summarized data given in Table 4.

The noise attenuation in green belt was due to the combined effect of geometric spreading, plantation, ground cover and meteorological effect. Out of these, the first three are supposed to contribute maximum to noise attenuation, whereas the noise attenuation due to meteorological effect is supposed to be negligible. The ground effect, generally speaking, includes reflecting, scattering and absorption of sound waves.

Noise attenuation in open spaces with more or less similar ground cover and meteorological situation was monitored and it was used to evaluate excess noise attenuation exclusively by the green belts for all the plantation sites of JCF and RCF.

For all the plantation sites, the maximum excess noise attenuation for both *MaxL* and *Leq* was at 50 m depth of the green belt as seen in Table 7.

TABLE 3

Total noise attenuation at 50 m width in JCF

Plantation site	Spectrum I	
	MaxL dB (A)	*Leq* dB (A)
Bera	19·9	19·5
Simlabahal	20·0	20·9
Putki Balihari	21·0	21·1
Kustore	18·9	18·8

TABLE 4

Total noise attenuation at 50 m width in RCF

Plantation site	Spectrum I	
	MaxL dB (A)	*Leq* dB (A)
Loudoha college	22·1	20·5
Loudoha forest	18·5	18·7
Jhanjhra project	14·9	18·9
Jhanjhra incline	20·1	21·0

The average excess noise attenuation (*Leq*) was in the range 3·3–6·0 dB (A) at 50 m depth. This is due to the combined effect of the characteristics of the green belts. Since the noise source was placed on the ground and the Modular Precision Sound Level Meter on a stand, at a height of 1·5 m from the ground, the contribution of aerial height on excess attenuation seems to be negligible.

4.3. FREQUENCY SPECTRUM ANALYSIS

Frequency spectrum analysis for all the eight plantation sites of JCF & RCF showed that the dominant frequency range at border line was 125 Hz–1 kHz for spectrum I mode (Tables 9 and 10). The total attenuation for all the sites increased with the width of the green belt in most of the frequencies. The maximum total attenuation at a width of 50 m for certain frequencies was as seen in the data given in Table 8.

Frequency spectrum values in open space due to geometric spreading and ground cover were used to evaluate frequency-wise excess noise attenuation exclusively by the green belt for all the plantation sites of JCF and RCF (see Tables 9 and 10).

For all the cases, the excess attenuation was found to be varying with respect to different frequencies. For lower frequencies, i.e., up to 125 Hz, the excess attenuation was relatively less (within 3–4 dB). The maximum effective attenuation for certain higher frequencies was as given in Table 11.

TABLE 5

Average total noise attenuation characteristics in different plantation sites of Jharia Coalfield (*monsoon season*). *Noise Source*: *B&K Type* 4224 (*spectrum* 1 *mode*)

	Sound attenuation in dB (A)							
	Bera		Simlabahal		Putki Balihari		Kustore	
Location	*MaxL*	*Leq*	*MaxL*	*Leq*	*MaxL*	*Leq*	*MaxL*	*Leq*
At border line	0·0 (84·3)	0·0 (84·0)	0·0 (88·2)	0·0 (87·5)	0·0 (86·7)	0·0 (86·2)	0·0 (88·9)	0·0 (88·4)
At 10 m	3·9 ± 0·82	3·5 ± 0·76	7·0 ± 0·94	6·1 ± 0·84	3·1 ± 0·67	4·1 ± 0·57	3·8 ± 0·76	3·8 ± 0·59
At 20 m	8·6 ± 1·02	8·4 ± 0·97	10·9 ± 1·06	11·0 ± 0·98	8·5 ± 1·12	8·8 ± 1·07	8·1 ± 1·03	7·9 ± 1·09
At 30 m	12·5 ± 1·13	13·7 ± 1·13	14·0 ± 1·43	15·6 ± 1·21	12·3 ± 1·21	13·7 ± 1·21	11·8 ± 1·24	12·6 ± 1·19
At 40 m	17·6 ± 1·27	17·7 ± 1·28	17·7 ± 1·56	19·3 ± 1·32	16·1 ± 1·24	18·3 ± 1·20	16·7 ± 1·36	16·3 ± 1·30
At 50 m	19·6 ± 1·87	20·0 ± 1·41	20·0 ± 1·45	20·9 ± 1·45	21·0 ± 1·36	21·1 ± 1·32	18·9 ± 1·41	18·8 ± 1·39

Figure within ( ) indicates average noise level.

TABLE 6

Average total noise attenuation characteristics in different plantation sites of Raniganj Coalfield (monsoon season). Noise Source: B&K Type 4224 (spectrum 1 mode)

	Sound attenuation in dB (A)							
	Laudoha college		Loudoha forest		Jhanjhra project		Jhanjhra incline	
Location	*MaxL*	*Leq*	*MaxL*	*Leq*	*MaxL*	*Leq*	*MaxL*	*Leq*
At border line	0·0 (89·2)	0·0 (88·7)	0·0 (86·9)	0·0 (86·3)	0·0 (86·2)	0·0 (86·1)	0·0 (88·1)	0·0 (87·4)
At 10 m	1·8 ± 0·51	1·9 ± 0·52	3·9 ± 0·86	4·0 ± 0·84	3·3 ± 0·45	4·0 ± 0·48	7·1 ± 1·00	6·2 ± 0·98
At 20 m	7·6 ± 1·09	7·5 ± 1·06	8·4 ± 1·04	8·4 ± 1·06	8·1 ± 0·98	8·9 ± 0·96	11·0 ± 1·21	11·1 ± 1·17
At 30 m	11·5 ± 1·12	13·6 ± 1·14	12·4 ± 1·12	12·6 ± 1·14	12·0 ± 1·19	14·5 ± 1·20	14·1 ± 1·25	15·7 ± 1·21
At 40 m	16·6 ± 1·21	16·6 ± 1·19	16·7 ± 1·27	16·7 ± 1·30	14·0 ± 1·27	16·7 ± 1·34	17·8 ± 1·31	19·4 ± 1·32
At 50 m	22·1 ± 1·57	20·5 ± 1·47	18·5 ± 1·38	18·7 ± 1·37	14·9 ± 1·34	18·9 ± 1·41	20·1 ± 1·35	21·0 ± 1·38

Figure within ( ) indicates average noise level.

TABLE 7

Excess noise attenuation

Plantation site	Spectrum I mode	
	MaxL dB (A)	*Leq* dB (A)
1. *Jharia coalfield*		
Bera	6·2	4·9
Simlabahal	3·4	5·6
Putki Balihari	7·3	6·0
Kustore	4·8	3·3
2. *Raniganj coalfield*		
Loudoha forest	4·7	3·6
Jhanjhra incline	6·1	5·7
Loudoha college	7·9	4·9
Jhanjhra project	3·2	3·8

TABLE 8

Maximum total noise attenuation at a width of 50 *m for certain frequencies for spectrum I mode of noise source*

Jharia coalfield

Bera	Putki Balihari	Kustore	Simlabahal
125 Hz–20·5 dB	125 Hz–23·6 dB	125 Hz–23·7 dB	125 Hz–23·3 dB
250 Hz–21·1 dB	1 kHz–20·6 dB	1 kHz–20·3 dB	2 kHz–24·0 dB
1 kHz–20·7 dB	2 kHz–24·7 dB	2 kHz–23·9 dB	8 kHz–24·0 dB
2 kHz–23·3 dB	8 kHz–24·5 dB	8 kHz–23·9 dB	
8 kHz–21·5 dB	16 kHz–20·0 dB		

Raniganj coalfield

Loudoha college	Loudoha forest	Jhanjhra project	Jhanjhra incline
63 Hz–23·2 dB	125 Hz–23·4 dB	31·5 Hz–17·7 dB	31·5 Hz–21·1 dB
125 Hz–24·8 dB	2 kHz–24·5 dB	500 Hz–18·0 dB	125 Hz–23·5 dB
250 Hz–22·8 dB	8 kHz–24·5 dB	1 kHz–17·3 dB	2 kHz–24·2 dB
500 Hz–22·0 dB		8 kHz–18·2 dB	8 kHz–24·2 dB

4.4. STATISTICAL RELATIONSHIP

Excess noise attenuation values at a depth of 50 m of eight plantation sites of JCF and RCF using B&K Type 4224 noise source (spectrum I mode) were used to develop a statistical relationship through SPSS package as outlined below.

Dependent variable

X_1 = Excess noise attenuation (*Leq*) in dB (A)

TABLE 9

Frequency spectrum analysis of total noise attenuation (dB) at different plantation sites of JCF. Noise Source: B&K Type 4224 (*spectrum* 1 *mode*)

Particulars	1/1 octave band frequencies (Hz)									
	31·5	63	125	250	500	1K	2K	4K	8K	16K
1. *Bera plantation site*										
At border line	0·0 (55·7)	0·0 (65·0)	0·0 (78·3)	0·0 (81·0)	0·0 (81·0)	0·0 (78·1)	0·0 (76·8)	0·0 (73·7)	0·0 (60·2)	0·0 (45.6)
At 10 m	6·4 ± 0.43	4·9 ± 0·82	5·4 ± 0·71	5·4 ± 0·70	4·5 ± 0·62	3·5 ± 0·39	2·0 ± 0·30	2·2 ± 0·16	4·7 ± 0·40	3·2 ± 0·61
At 20 m	12·0 ± 0.63	7·6 ± 1·02	10·0 ± 0·95	8·7 ± 0·90	7·6 ± 0·87	9·9 ± 0·81	6·7 ± 0·84	6·8 ± 0·73	12·6 ± 0·82	8·7 ± 0·95
At 30 m	10·8 ± 0.81	12·8 ± 1·21	13·0 ± 1·12	13·4 ± 1·01	17·0 ± 1·32	16·1 ± 1·12	12·9 ± 1·01	10·2 ± 0·91	14·7 ± 0·95	11·2 ± 1·12
At 40 m	13·8 ± 0.82	14·7 ± 1·31	13·5 ± 1·52	17·2 ± 1·34	21·0 ± 1·62	17·8 ± 1·34	20·4 ± 1·1	12·8 ± 0·98	19·2 ± 1·24	13·0 ± 1·12
At 50 m	15·5 ± 0.98	17·9 ± 1·62	20·5 ± 1·72	21·1 ± 1·68	19·5 ± 2·34	20·7 ± 1·90	23·3 ± 1·53	15·4 ± 1·15	21·5 ± 1·45	16·3 ± 1·91
2. *Putki Balihari plantation site*										
At border line	0·0 (59·0)	0·0 (69·1)	0·0 (84·7)	0·0 (84·5)	0·0 (85·9)	0·0 (83·5)	0·0 (76·7)	0·0 (69·6)	0·0 (61·4)	0·0 (43.8)
At 10 m	12·4 ± 0.72	6·8 ± 0·83	6·4 ± 0·80	6·9 ± 0·81	5·2 ± 0·85	5·8 ± 0·63	1·0 ± 0·32	3·4 ± 0·41	6·7 ± 0·82	4·8 ± 0·80
At 20 m	14·6 ± 0.80	8·4 ± 0·96	12·2 ± 0·98	10·3 ± 0·89	9·3 ± 1·12	10·7 ± 0·88	7·2 ± 0·81	8·4 ± 0·83	14·4 ± 0·91	10·7 ± 1·0
At 30 m	17·1 ± 0.82	13·9 ± 1·21	14·9 ± 1·04	13·0 ± 1·15	14·1 ± 1·05	14·8 ± 0·92	13·0 ± 0·98	12·3 ± 0·99	16·4 ± 1·22	13·4 ± 1·21
At 40 m	8·9 ± 0.81	16·1 ± 1·12	20·0 ± 1·32	16·2 ± 1·38	17·0 ± 1·41	17·8 ± 1·36	19·6 ± 1·24	14·6 ± 1·12	22·0 ± 1·56	16·4 ± 1·42
At 50 m	21·0 ± 0.94	19·0 ± 1·43	23·6 ± 1·32	19·5 ± 1·41	17·7 ± 1·52	20·6 ± 1·48	24·7 ± 1·40	17·2 ± 1·38	24·5 ± 1·92	20·0 ± 2·32
3. *Kustore plantation site*										
At border line	0·0 (59·1)	0·0 (69·5)	0·0 (85·1)	0·0 (85·1)	0·0 (86·2)	0·0 (84·2)	0·0 (77·1)	0·0 (70·4)	0·0 (62·1)	0·0 (44.1)
At 10 m	11·9 ± 0.76	6·4 ± 0·80	5·9 ± 0·79	7·0 ± 0·83	4·1 ± 0·80	5·8 ± 0·62	0·9 ± 0·31	3·3 ± 0·29	6·9 ± 0·81	4·0 ± 0·84
At 20 m	14·0 ± 0.90	8·3 ± 0·98	10·9 ± 0·97	9·6 ± 0·85	8·9 ± 0·98	11·1 ± 0·99	6·8 ± 0·83	8·6 ± 0·80	14·3 ± 0·82	10·3 ± 1·12
At 30 m	16·3 ± 1.02	13·6 ± 1·32	14·7 ± 1·13	12·9 ± 1·20	13·4 ± 1·25	14·7 ± 1·33	12·6 ± 1·19	11·9 ± 1·24	16·3 ± 1·32	12·9 ± 1·37
At 40 m	18·0 ± 1.38	15·7 ± 1·42	19·6 ± 1·48	16·9 ± 1·51	16·4 ± 1·56	18·4 ± 1·28	18·9 ± 1·18	14·5 ± 1·31	21·9 ± 1·52	16·0 ± 1·36
At 50 m	20·2 ± 1.24	18·6 ± 1·52	23·7 ± 1·43	19·0 ± 1·44	17·1 ± 1·51	20·3 ± 1·50	23·9 ± 1·51	17·6 ± 1·52	23·9 ± 1·92	19·3 ± 2·31
4. *Simlabahal plantation site*										
At border line	0·0 (58·1)	0·0 (68·2)	0·0 (84·1)	0·0 (84·1)	0·0 (85·2)	0·0 (82·9)	0·0 (75·9)	0·0 (68·9)	0·0 (60·8)	0·0 (43.1)
At 10 m	11·9 ± 0.72	5·1 ± 0·82	6·2 ± 0·71	6·0 ± 0·73	5·2 ± 0·68	5·8 ± 0·61	0·8 ± 0·30	3·0 ± 0·31	6·8 ± 0·66	4·3 ± 0·64
At 20 m	14·2 ± 0.89	8·7 ± 0·98	11·6 ± 0·91	10·2 ± 0·81	9·1 ± 0·90	10·8 ± 0·79	7·0 ± 0·80	8·0 ± 0·81	12·7 ± 0·90	10·0 ± 0·92
At 30 m	16·2 ± 0.92	13·4 ± 1·10	15·3 ± 1·00	13·2 ± 1·12	14·4 ± 1·13	14·8 ± 0·99	13·8 ± 1·28	12·1 ± 1·31	16·0 ± 1·41	12·9 ± 1·35
At 40 m	18·0 ± 1.25	15·3 ± 1·32	20·0 ± 1·31	16·2 ± 1·22	17·1 ± 1·29	18·1 ± 1·30	19·1 ± 1·29	13·9 ± 1·35	22·6 ± 1·42	16·3 ± 1·30
At 50 m	20·9 ± 1.19	19·7 ± 1·89	23·3 ± 1·82	19·3 ± 1·90	17·4 ± 1·99	20·4 ± 1·52	24·0 ± 1·49	17·1 ± 1·42	24·0 ± 1·81	20·6 ± 2·1

Figure within ( ) indicates average noise level.

TABLE 10

Frequency spectrum analysis of total noise attenuation (dB) at different plantation sites of RCF. Noise Source: B&K Type 4224 (spectrum 1 mode)

Particulars	1/1 octave band frequencies (Hz)									
	31·5	63	125	250	500	1K	2K	4K	8K	16K
1. *Loudoha college plantation site*										
At border line	0·0 (57·7)	0·0 (72·4)	0·0 (88·9)	0·0 (86·6)	0·0 (90·1)	0·0 (82·0)	0·0 (77·0)	0·0 (75·0)	0·0 (59·5)	0·0 (43.1)
At 10 m	1·3 ± 0.31	6·6 ± 0·83	9·0 ± 0·80	5·0 ± 0·76	4·4 ± 0·57	1·0 ± 0·29	2·0 ± 0·57	2·6 ± 0·73	1·3 ± 0·31	1·9 ± 0·60
At 20 m	1·6 ± 0.42	10·1 ± 1·15	13·1 ± 1·16	9·4 ± 0·96	9·1 ± 0·92	5·9 ± 0·82	6·7 ± 0·79	8·3 ± 0·99	6·2 ± 0·89	7·5 ± 0·79
At 30 m	2·5 ± 0.61	14·3 ± 1·21	18·8 ± 1·20	14·1 ± 1·05	13·3 ± 1·01	9·2 ± 0·96	10·9 ± 1·19	13·2 ± 1·17	10·4 ± 1·02	11·9 ± 1·05
At 40 m	2·3 ± 0.86	18·5 ± 1·52	20·7 ± 1·47	18·5 ± 1·42	17·9 ± 1·32	13·9 ± 1·16	14·2 ± 1·98	16·9 ± 1·92	14·3 ± 1·86	15·3 ± 1·15
At 50 m	1·5 ± 0.62	23·2 ± 1·98	24·8 ± 2.15	22·8 ± 1·96	22·0 ± 1·99	18·2 ± 1·92	18·5 ± 2·1	20·5 ± 2·3	18·0 ± 2·06	20·0 ± 1·56
2. *Loudoha forest plantation site*										
At border line	0·0 (58·9)	0·0 (69·0)	0·0 (84·6)	0·0 (84·4)	0·0 (85·8)	0·0 (83·4)	0·0 (76·6)	0·0 (69·5)	0·0 (61·3)	0·0 (43.7)
At 10 m	12·2 ± 0.72	6·6 ± 0·81	6·2 ± 0·76	6·7 ± 0·78	5·0 ± 0·80	5·6 ± 0·57	0·8 ± 0·11	3·2 ± 0·35	6·5 ± 0·79	4·6 ± 0·70
At 20 m	14·4 ± 0.71	8·2 ± 0·90	11·1 ± 1·00	10·1 ± 0·98	9·1 ± 0·92	10·5 ± 0·90	7·0 ± 0·80	8·2 ± 0·82	14·2 ± 0·86	10·5 ± 1·00
At 30 m	16·9 ± 0.88	13·7 ± 1·21	14·7 ± 1·25	12·8 ± 1·27	13·9 ± 1·32	14·6 ± 1·02	12·8 ± 1·11	12·1 ± 1·20	16·2 ± 1·21	13·2 ± 1·37
At 40 m	18·7 ± 0.90	15·9 ± 1·27	19·8 ± 1·32	16·1 ± 1·34	16·8 ± 1·47	17·6 ± 1·37	19·4 ± 1·27	14·4 ± 1·12	21·8 ± 1·51	16·2 ± 1·50
At 50 m	20·8 ± 1.01	18·8 ± 1·21	23·4 ± 1·36	19·3 ± 1·27	17·5 ± 1·60	20·4 ± 1·56	24·5 ± 1·68	17·0 ± 1·27	24·3 ± 2·1	19·8 ± 2·3
3. *Jhanjhra project plantation site*										
At border line	0·0 (58·3)	0·0 (68·7)	0·0 (83·5)	0·0 (84·2)	0·0 (85·2)	0·0 (83·1)	0·0 (76·2)	0·0 (69·2)	0·0 (61·4)	0·0 (43.2)
At 10 m	12·1 ± 0.80	6·8 ± 0·62	5·4 ± 0·41	7·0 ± 0·52	5·0 ± 0·68	6·0 ± 0·34	1·0 ± 0·08	2·8 ± 0·42	7·2 ± 0·39	4·4 ± 0·37
At 20 m	14·1 ± 0.56	8·6 ± 0·90	10·3 ± 0·99	9·9 ± 1·05	9·1 ± 0·81	10·9 ± 0·76	7·1 ± 0·37	7·8 ± 0·67	14·2 ± 0·58	10·0 ± 0·58
At 30 m	16·4 ± 0.83	14·5 ± 1·20	13·7 ± 1·29	12·9 ± 1·37	15·6 ± 1·18	15·0 ± 1·05	13·0 ± 0·97	12·0 ± 1·05	16·2 ± 0·98	13·4 ± 0·87
At 40 m	17·5 ± 0.98	15·5 ± 1·32	14·8 ± 1·40	13·8 ± 1·42	15·4 ± 1·26	15·2 ± 1·20	13·1 ± 0·97	12·4 ± 1·26	17·3 ± 1·06	14·6 ± 0·98
At 50 m	17·7 ± 1.05	16·6 ± 1·32	16·3 ± 1·37	15·9 ± 1·42	18·0 ± 1·52	17·3 ± 1·36	14·2 ± 1·21	15·1 ± 1·50	18·2 ± 1·18	16·0 ± 1·02
4. *Jhanjhra incline plantation site*										
At border line	0·0 (58·2)	0·0 (68·3)	0·0 (84·2)	0·0 (84·2)	0·0 (85·3)	0·0 (83·0)	0·0 (76·0)	0·0 (69·0)	0·0 (60·9)	0·0 (43.2)
At 10 m	12·1 ± 0.72	5·3 ± 0·86	6·4 ± 0·82	6·2 ± 0·73	5·4 ± 0·62	6·0 ± 0·41	1·0 ± 0·05	3·2 ± 0·09	7·0 ± 0·60	4·5 ± 0·39
At 20 m	14·4 ± 0.80	8·3 ± 1·05	11·8 ± 0·98	10·4 ± 0·88	9·3 ± 0·68	11·0 ± 0·90	7·2 ± 0·83	8·2 ± 0·56	12·9 ± 0·67	10·2 ± 0·98
At 30 m	16·4 ± 1.02	13·6 ± 1·21	15·5 ± 1·17	13·4 ± 1·21	14·6 ± 1·22	15·0 ± 1·02	14·0 ± 1·05	12·3 ± 0·99	16·2 ± 1·27	13·1 ± 1·34
At 40 m	18·2 ± 1.01	15·5 ± 1·47	20·4 ± 1·42	16·4 ± 1·39	17·3 ± 1·40	18·3 ± 1·45	20·3 ± 1·32	14·1 ± 1·27	22·8 ± 1·49	16·5 ± 1·42
At 50 m	21·1 ± 1.27	19·9 ± 1·42	23·5 ± 1·45	19·5 ± 1·57	17·6 ± 1·97	20·6 ± 1·80	24·2 ± 1·67	17·3 ± 1·56	24·2 ± 1·92	20·8 ± 2·10

Figure within ( ) indicates average noise level.

TABLE 11

Maximum excess attenuation for certain frequencies. Spectrum I mode

Jharia coalfield

Bera	Kustore	Simlabahal	Putki Balihari
500 Hz–7·1 dB	4 kHz–6·8 dB	4 kHz–6·6 dB	2 kHz–6·0 dB
1 kHz–6·4 dB	8 kHz–6·6 dB	8 kHz–7·1 dB	4 kHz–6·6 dB
	16 kHz–6·8 dB	16 kHz–8·4 dB	8 kHz–7·4 dB
			16 kHz–7·6 dB

Raniganj coalfield

Jhanjhra project	Jhanjhra incline	Loudoha college	Loudoha forest
500 Hz–4·9 dB	4 kHz–6·7 dB	500 Hz–8·2 dB	4 kHz–6·4 dB
4 kHz–4·5 dB	8 kHz–7·3 dB	1 kHz–8·2 dB	8 Hz–7·3 dB
	16 kHz–8·5 dB	4 kHz–9·0 dB	16 kHz–7·4 dB
		16 kHz–7·8 dB	

Independent variables

X_2 = average density (number of plants/ha)
X_3 = average aerial height (m)
X_4 = average canopy branch cover (m)
X_5 = average diameter of the trunk at breast height (mm)
X_6 = vertical light penetration
X_7 = horizontal light penetration

Both vertical and horizontal light penetrations were considered to assess canopy and branching coverage of the green belt. Low values of vertical and horizontal light penetrations represent more dense green belt. For statistical analysis, suitable weightages were considered for these two parameters.

The following multivariable linear relationship was found in spectrum I mode of noise source:

$$X_1 = 4{\cdot}3160 + 3{\cdot}498 \times 10^{-5} X_2 - 0{\cdot}349 X_3 + 0{\cdot}1257 X_4 + 0{\cdot}1905 X_5 + 1{\cdot}1836 X_6 + 1{\cdot}3916 X_7 \quad (1)$$

The correlation coefficient and coefficient of determination were highly significant. Standard error estimate and analysis of variance justified the significance of relationship.

Equation (1) indicates that all the independent variables (except X_3) contribute directly towards the excess noise attenuation. Average density (X_2 = number of plants/ha) seems to have negligible effect [0·07–0·20 dB (A)] in the entire range of monitored values (2091–5900). This was due to the sound wave propagation through the gaps between the trees even with the maximum plantation density. The average aerial height (X_3) also does not contribute to the overall excess attenuation. This was due to the location of the noise source (on the ground) and the monitoring instrument (at a height of 1·5 m above the surface). Inspite of this, aerial height is found to contribute a negative effect, may be due to back reflection and scattering of some sound waves directed towards higher altitude. Out of the other four parameters, vertical light penetration (X_6) and horizontal light penetration (X_7) were found to contribute 0·95 and 1·25 dB (A) respectively at their maximum values.

TABLE 12

Validation of the statistical model

Plantation site	Parameter considered						Predicted effective noise attenuation at 50 m through model, dB (A)	Actual (observed) effective noise attenuation, dB (A)
	Av. density (plants/ha)	Av. aerial height (m)	Av. canopy branch cover (m)	Av. dia. of the trunk at breast height (mm)	Vertical light penetration at 1·5 m above ground	Horizontal light penetration at 20 m distance		
Using Noise Source (E&K Type 4224) in spectrum I mode								
Putki Balihari	2091	7·34	3·84	7·55	0·5	0·4	4·89	6·00
Kustore	2100	10·36	5·65	8·72	0·7	0·3	4·39	3·30
Bera	4200	4·02	2·68	4·71	0·4	0·6	5·60	4·90
Simlabahal	3200	7·74	4·03	7·69	0·8	0·3	5·10	5·60
Loudoha forest	2372	21·76	18·68	14·71	0·8	0·5	3·59	3·60
Jhanjhra incline	2600	7·51	5·68	8·98	0·4	0·8	5·79	5·70
Loudoha college	5900	10·35	8·61	4·85	0·4	0·9	4·64	4·90
Jhanjhra project	5800	11·87	6·65	5·20	0·3	0·9	3·81	3·80

The excess noise attenuation due to the green belt alone as evaluated using equation (1) was as shown in Table 12. These computed values are close to the actual excess attenuation as observed in the field investigations.

5. DISCUSSIONS AND CONCLUSIONS

Noise attenuation studies at various plantation sites of JCF & RCF during monsoon season indicated the following range of total and excess attenuations at 50 m width.

Total attenuation (*Leq*) : RCF : 18·7–21·0 dB (A).
JCF : 18·8–21·1 dB (A).

Excess attenuation (*Leq*) : RCF : 3·6–5·7 dB (A).
JCF : 3·3–6·0 dB (A).

This was due to the characteristics of the green belt.

Figures 1 and 2 show the summarized average noise attenuation (both total and excess, *Leq*) at the plantation sites of JCF and RCF. The total attenuation at different plantation sites of RCF increased linearly with the depth of the green belt, whereas the increasing trend of excess attenuation is less with the depth of the green belt. It is imperative to conclude that the main contributor to higher total attenuation at higher depth is the effect of geometrical spreading. A more or less similar trend was observed for the plantation sites of JCF (Figure 2).

Excess attenuation for higher frequencies (> 250 Hz) was more than that at lower frequencies (< 125 Hz).

From 84 to 89 dB (A) *Leq* levels at border line of the green belt due to B&K noise source (spectrum I mode), the average trend of total noise attenuation with the depth of green belt was as given below.

	JCF	*RCF*
10 m depth :	4·2–7·0%	1·6–7·1%
20 m depth :	8·9–12·6%	8·5–12·7%

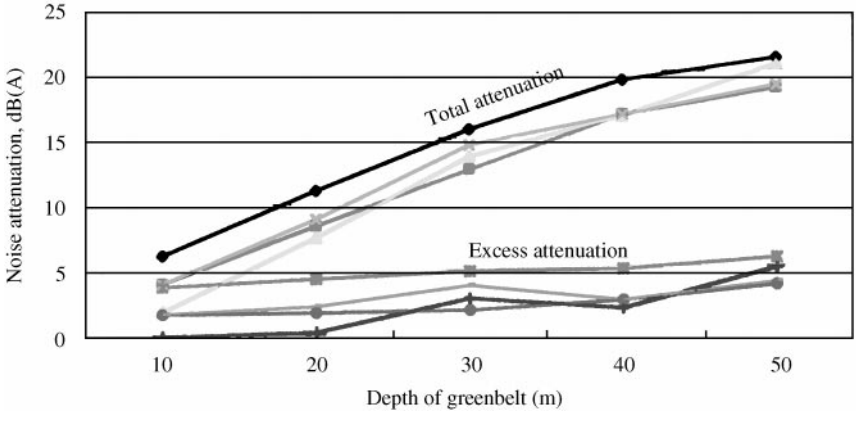

Figure 1. Noise attenuation at different plantation sites of RCF (monsoon) B&K noise source (spectrum I). —●—, Jhanjhra incline; —■—, Loudoha forest; —▲— Loudoha college; —×—, Jhanjhra project; —■—, Jhanjhra incline; —●—, Loudoha forest; —+—, Loudoha college; ——, Jhanjhra project.

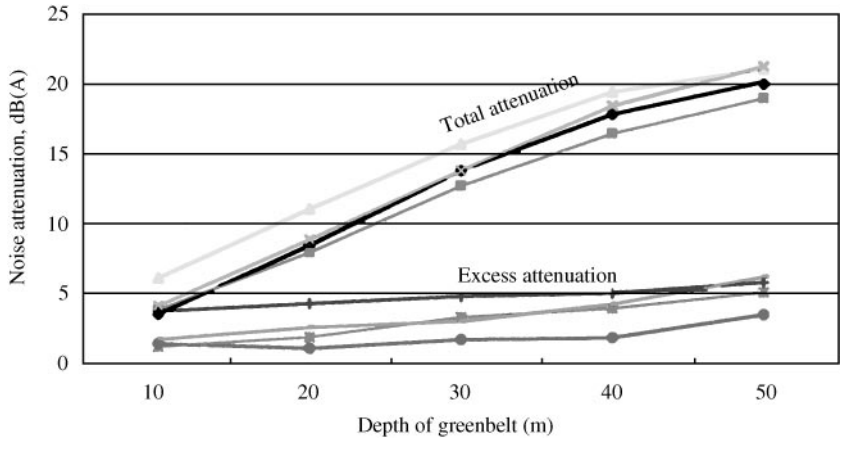

Figure 2. Noise attenuation at different plantation sites of JCF (monsoon) B&K noise source (spectrum I). Bera; , Kustore; Simlabahal; , Putki Balihari; , Bera; , Kustore; , Simlabahal; , Putki Balihari.

30 m depth : 14·2–17·8%	14·6–18·0%
40 m depth : 18·4–21·2%	18·7–22·2%
50 m depth : 21·3–24·2%	21·7–23·1%

Based on the average trend of total noise attenuation (%) at different depths of the green belt, the desired minimum thickness of the green belt computed for different locations of coal mining complexes is as given in Table 13.

A multivariable linear regression equation was established for assessing the excess noise attenuation for spectrum I mode of noise source (B&K Type 4224). This can be used for designing the green belts.

In order to strengthen the above findings, it is planned to conduct further studies with noise sources of different types and characteristics kept at different heights from the ground surface.

TABLE 13

Desired minimum thickness of green belts for different locations of coal mining complexes

Location	Observed noise level (*Leq*), dB (A)	Permissible norm, dB (A)	Desired minimum thickness of green belt (m)
Along road	75–80	65 (commercial area, daytime)	40
In colonies	60–65	55 (residential area, daytime)	30
Near opencast mines	70–80	75 (industrial area)	10
Near CHPs	80–90	75 (industrial area)	30
Near Shaft	80–87	75 (industrial area)	30
Near mine exhaust fan (low-frequency dominant situation)	85–92	75 (industrial area)	> 50

REFERENCES

1. M. J. M. MARTENS 1981 *Applied Acoustics* **14**, 167–189. Noise abatement in plant monocultures and plant communities.
2. M. J. M. MARTENS, J. A. M. VAN HUET and H. F. LINSKENS 1982 *Proceedings of Koninklijke Nederlandse Akademic Van Wetenschappen, Series C* **85**, 287–292. Laser interferometer scanning of plant leaves in sound fields.
3. M. J. M. MARTENS and A. MICHELSEN 1981 *Journal of the Acoustical Society of America* **69**, 303–306. Absorption of acoustic energy by plant leafs.
4. J. E. PIERCY, T. F. W. EMBLETON and G. DAIGLE 1979 *Journal of the Acoustical Society of America* **165**, J63. Excess attenuation or impedance of common ground surface characterized by flow resistance.
5. D. AYLOR 1972 *Journal of the Acoustical Society of America* **51**, 197–205. Noise reduction by vegetation and ground.
6. T. F. W. EMPLETON 1963 *Journal of Acoustical Society of America* **35**, 1119–1125. Sound propagation in homogenous deciduous and evergreen woods.
7. F. FRICKE 1984 *Journal of Sound and Vibration* **91**, 149–158. Sound attenuation in forest.
8. N. C. SAXENA, A. K. PAL, S. K. MAITI, V. KUMAR and G. C. THAKUR 1999 *Final report of coal science and technology*. Study of green belt regarding its noise attenuation and dust arresting capacity in coal mining areas.
9. A. K. PAL, V. KUMAR, G. C. THAKUR, S. K. MAITI and N. C. SAXENA 1998 *7th National Seminar on Environment at Indian School of Mines, Dhanbad*. Noise attenuation through green belt — a case discussion.