SOCIAL COST OF AIR POLLUTION FROM THERMAL POWER STATIONS IN WEST BENGAL

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Executed by: **Chittaranjan National Cancer Institute (CNCI),** Kolkata

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INTRODUCTION AND OBJECTIVE

Thermal power plants are the principal generators of electricity in India. They produce 59.2% of electric power in the country. As on July 2003, there were 83 coal-based power-generating plants in India, with a total production of 62,880.9 MW (CPCB, 2006). Several other plants are coming up in rapid succession. West Bengal ranks 10th in power generation among the Indian states and Union territories. It has a total installed capacity of 5,411 MW of which coal-based thermal power units contribute 5053 MW (93.4% of total), hydroelectric 179 MW, gas 100 MW and diesel 12 MW (Ministry of Power, April 3, 2006).

Coal is predominantly used as fuel for electricity generation in the country as it is readily available. India has 7% of world's coal reserve and ranked third in production of coal (348 million ton in 1997). However, combustion of coal emits a wide spectrum of chemicals into the environment, and some of these chemicals such as respirable particulates, oxides of nitrogen and sulfur, transitional metals and hydrocarbons are potentially harmful for human health. An estimated 240 million tons of coal with 35-45% of ash content is consumed annually by the thermal power plants in India. It has been calculated that 4,24,650 tons of carbon dioxide, 3311 tons of SO_2 and 100 million tons of ash are generated daily from these plants (Table 1; CPCB, 2006). Emissions of CO_2, SO_2 and particulate matter from coal-based power plants represent 82%, 89% and 82% of total emissions of these pollutants, respectively, from the industrial sector. No wonder, coal-based thermal power plants are considered as major contributors to ambient air pollution.

Table 1. Emissions of pollutants from coal-based thermal power plants in India

Pollutant	Emission (Tons/day)
Carbon dioxide	424650
Particulate matter	4347
SO2	3311
NOx	4966

Source: Central Pollution Control Board (CPCB), 2006

Since many of these pollutants are hazardous for human health, emissions from coal-based thermal power plants can impair the health of their employees as well as people living nearby. Besides, the emissions can inflict damage to the crops and forests, ecosystem, building materials, biodiversity and can mediate atmospheric changes including global warming because of the presence of significant amount of green house gases (such as CO_2) in emissions (Deluchi et al., 2002).

Against this backdrop, economists analyze the relevant social costs and benefits on the presumption that one should not adopt policies whose social cost exceeds social benefits (USEPA, 1997). For social cost calculation of air pollution, a multi-step damage-function method is generally employed in which one estimates the relationship between policy and emissions, emissions and air quality, air quality and exposure, exposure and physical damage, and physical damage and its monetary value (Deluchi, 2002). All these steps, particularly the valuation step is uncertain and as a result estimates of social cost of air pollution are highly variable.

Although social cost estimation is important from economic and social aspects and from the point of policy decisions, no attempt has ever been made in India to a significant extent to calculate the social cost of thermal power generation. In view of this, the present study was undertaken by Chittaranjan National Cancer Institute (CNCI), Kolkata in association with The Energy Research Institute (TERI), New Delhi with the encouragement, active help and support from West Bengal Electricity Regulatory Commission (WBERC) to estimate the social cost of thermal power generation in the state of West Bengal.

OBJECTIVE OF THE STUDY

To determine the financial consequences of the changes in disease profile and the environment associated with emissions from thermal power generation plants in West Bengal.

CHAPTER-2

STUDY PROTOCOL

In order to investigate the impact of air pollution from power generating plants on human health, we followed stratified random sampling procedure under the general plan of Simple Random Sampling Without Replacement (SRSWR) method. To enrol the participants we organized health camps at different thermal power stations, areas adjacent to these power plants and far-away rural areas of West Bengal (Plate 1).

Participants

A total of 1,412 adults were recruited for this study conducted during 2007. They included 1,363 males (96.5%) and 49 females ((3.5%) aged between 21 and 59 years (median age 41 yr). The participants were clustered into 4 groups (Table 2):

i. Employees of thermal power plants

A total number of 671 men working in Bandel, Kolaghat and Bakreswar thermal Power stations under West Bengal Power Development Corporation Limited (WBPDCL) aged between 28-59 years (median age 42 yr) volunteered for this study.

ii. Employee's family members residing in power plant townships

Thirty-two adults (male 11, female 21, median age 39 yr) residing in Bandel and Bakreswar thermal power plant township but not employed in these plants were also enrolled.

iii. Residents of areas adjacent to power plants

A total number of 382 participants (median age 42 yr) were recruited from areas within 10 km radius of the three thermal power plants.

Plate 1 : Emission of black smoke from Kolaghat Thermal Power Station (6 x 210MW) (a), Bandel Thermal Power Station (4 x 80 + 1 x 210) (b)

iv. Reference (control) group

As reference, 327 apparently healthy subjects, median age 41 yr, from the rural areas of Birbhum, Hooghly and East Medinipur districts of West Bengal were enrolled (Table 2). The villages were more than 10 km away from the nearest thermal power plants.

Table 2. Participants of health impact study

Area	Male	Female	Total
Thermal power station employees			
1. Bandel Thermal Power station	137	0	137
2. Kolaghat Thermal Power station	226	0	226
3. Bakreswar Thermal Power station	308	0	308
Sub- total	671	0	671
BkTPP/BTTP employee's family members residing within plant	11	21	32
Residents of areas within 10 km of power plants			
1. Mecheda, East Medinipur	134	2	136
2. Kachujor, Sadaipur, Birbhum	54	6	60
3. Hetampur, Birbhum	112	8	120
4. Bansberia, Hooghly	65	1	66
Sub- total	365	17	382
Residents of far away areas (Reference group)			
1. Panskura, East Medinipur	128	3	131
2. Tantipara, Birbhum	84	6	90
3. Polba, Hooghly	104	2	106
Sub- total	316	11	327
Total	**1363**	**49**	**1412**

Inclusion and exclusion criteria

Employees of thermal power stations, their family members residing in staff quarters in power plant township, people residing within 10 km radius of power plants and from far away places were included. Subjects under treatment for tuberculosis, cancer, and serious heart, lung or kidney ailments were excluded.

QUESTIONNAIRE SURVEY FOR THE PREVALENCE OF RESPIRATORY SYMPTOMS

We assessed respiratory health of the subjects through questionnaire survey for respiratory symptoms (Plate 2). For this, we have developed a modified, structured respiratory questionnaire based on the respiratory questionnaire of British Medical Research Council (BMRC, Cotes, 1987), the American Thoracic Society (ATS) and National Heart and Lung Institute (NHLI) Division of Lung Diseases (DLD) questionnaire (ATS-DLD-78-C; Ferris, 1978).

Plate 2: Research team in action doing Questionnaire survey (a) and lung function tests at Bakreswar Thermal Power Project (b)

PULMONARY FUNCTION TESTS BY SPIROMETRY

Lung function tests by spirometry were performed with informed consent of the participant (Plate 2). The tests were done according to the methods suggested by the American Thoracic Society (1995) using a portable, electronic spirometer (Spirovit SP-1, Switzerland). The following spirometric parameters were recorded for analysis:

- Forced vital capacity (FVC), i.e. the volume of air in liters that can be maximally forcefully exhaled

- Forced expiratory volume at 1 second (FEV_1), i.e. volume of air (in liter) that is forcefully exhaled in one second.

- Ratio of FEV_1 to FVC (FEV_1/FVC), expressed as percentage

- Forced expiratory flow at 25-75% ($FEF_{25-75\%}$) or maximal mid-expiratory flow rate (MMEF), which is the average expiration flow rate during the middle 50% of the FVC

- Peak expiratory flow rate (PEFR) – the peak flow rate during expiration

The abnormalities that could be detected by spirometry tests are obstruction, restriction and combined type of lung function deficits. In *obstructive lung diseases* such as emphysema or chronic bronchitis, the FEV_1/FVC ratio is less than 70% of predicted. In *restrictive lung disease*, the FVC is reduced to less than 80% of predicted value based on height, weight, gender, age and ethnicity. In *combined lung disease* both FVC and FEV_1/FVC ratio are decreased below 80% and 70% respectively.

DETECTION OF CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD)

Field surveys were conducted with the help of a structured and validated questionnaire. COPD was initially diagnosed on the basis of symptoms of chronic bronchitis (presence of cough and expectorations on most of the days for at least three months in a year for two consecutive years or more). Confirmation of diagnosis and further classification of COPD were based on spirometric measurements following the criteria of Global Initiative for Chronic Obstructive Lung Diseases (GOLD) which are as follows (Pauwels et al., 2001; Table 3):

Table 3. GOLD diagnosis of Chronic Obstructive Pulmonary Disease (COPD)

Stage	Severity	Spirometric value	Symptom
I	Mild	FEV_1/FVC <70% FEV_1 70-79% of predicted	With or without chronic symptoms like cough, sputum expectoration, dyspnea
II a	Moderate	FEV_1/FVC <70% FEV_1 51-69% of predicted	"
II b	Severe	FEV_1 /FVC <70% FEV_1 30-50% of predicted	"
III	Very Severe	FEV_1 /FVC <70% FEV_1 <30% of predicted	Chronic respiratory failure

ASSESSMENT OF CELLULAR LUNG REACTION TO AIR POLLUTION

Sputum samples were collected from reference group, population within 10 km of three thermal power plants and power plant workers (Plate 3). Smears were made on clean glass slides from the non-transparent high viscosity part of each sample. Papanicolaou staining was done following the procedure of Hughes and Dodds (1966). Under light microscope at least 20-50 high power fields at 400x magnification were observed and the total and differential sputum cell counts were scored. Staining for non-specific esterase, a marker enzyme for macrophages was done by Fast Blue B method for counting of alveolar macrophages (AM; Oliver et al., 1991). Perl's Prussian blue reaction was done to identify deposition of ferric iron (hemosiderin) in AM, by the method of Pearse (1985).

Diagnosis of hypertension

Arterial blood pressure (BP) was measured by a sphygmomanometer in subject with empty bladder and in resting conditions. Hypertension was diagnosed on the basis of Seventh Report of the Joint Committee on the Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC-7, 2003; Table 4, Plate 3).

Table 4. Classification of blood pressure according to JNC-7

BP Classification	Systolic BP (mmHg)		Diastolic BP (mmHg)
Normal	<120		<80
Pre-hypertension	120-139	or	80-89
Stage 1 hypertension	140-159	or	90-99
Stage 2 hypertension	≥160	or	≥100

Plate 3 : Health camp being organized at Bakreswar Thermal Power Project. The employees are being checked for hypertension (a) and change in sputum cytology (b)

QUESTIONNAIRE SURVEY FOR NEUROBEHAVIORAL SYMPTOMS

A neurobehavioral symptom questionnaire, adopted from the subjective symptom questionnaire accompanying the World Health Organization Neurobehavioral Core Test Battery (WHO, 1986), Wechsler's memory scale (Wechsler, 1945) and 21-item Beck depression inventory (Beck et al., 1961) was administered to thermal power plant workers, local people and control (reference) subjects. The Beck's depression inventory (BDI) includes 21 parameters:

Sadness, Pessimism, Sense of failure, Dissatisfaction, Guilt, Expectation of punishment, Dislike of self, Self-accusation, Suicidal ideation, Episodes of crying, Irritability, Social withdrawal, Indecisiveness, Change in body image, Retardation, Insomnia, Fatigability, Loss of appetite, Loss of weight, Somatic preoccupation, and Low level of energy.

Highest score on response to each question related to the above parameters was 3, and a total score of 5-9 was normal; 10-18: mild to moderate depression; 19-29: moderate to severe depression; and 30-63: severe depression (Beck et al., 1961).

In addition, the questionnaire focused on other symptoms like burning sensation in extremities (feeling of burn in distal and terminal portions of the body such as hand and foot), tingling (repetitive moving pin prick-like sensation), numbness (temporary loss of sensation), vertigo (an illusionary sensation that the body or surrounding environment is revolving), and dizziness (sensation of unsteadiness with a feeling of movement within the head, giddiness). A five-point rating scale using simple and clear words like 'never', 'rarely', 'sometimes', 'frequently' and 'very frequently' was used in the questionnaire to elicit a better response for these symptoms. Afterwards, answers like 'never' and 'rarely' were considered as absence of that symptom, while responses like 'sometimes' frequently' and very frequently' were recognized as having such symptoms.

AIR QUALITY DATA

Data on the concentration of ambient air pollution with respect to RSPM (respirable particulate matter with an aerodynamic diameter of less than 10 µm, i.e. PM_{10}), oxides of nitrogen (NOx) and sulfur (SOx) in study areas during and preceding months of this study were obtained from different thermal power stations. Air quality data of rural areas of West Bengal was measured by real-time particulate pollutant concentration in air by portable, battery-operated laser photometer (DustTrak™ Aerosol monitor, model 8520, TSI Inc., MN, USA). The instrument contains 10-mm nylon Dor-Oliver cyclone, operates at a flow rate of 1.7 liter/min and measures particle load in the concentration range of 1µg-100 mg/m^3. We measured PM with the aerodynamic diameter of less than 10 μm (PM_{10}). The monitor was calibrated to the standard ISO 12103-1 A1 test dust. The monitoring was carried out 8 hours/day. The efficiency of real-time aerosol monitor and reliability of data are well recognized (Kim et al., 2004; Zhu et al., 2005).

LIFE-YEARS LOST

We compared the life years lost of two populations - the reference population of minimally exposed to air pollution from thermal power stations and local residents and employees of Bandel, Bakreswar and Kolaghat plants. We followed the life-table approach for calculation of person-years lost. The demographic data of 2001 Census were used. The population was divided into 15 five-year cohorts and the current age-specific death rates were compared. The economic impact was calculated based on daily wages and 'willing to pay' approach.

STATISTICAL ANALYSIS OF DATA

The collected data were processed and analyzed in EPI info 6.0 and SPSS (Statistical Package for Social Sciences) software, and expressed as mean ± standard deviation. Generalized estimating equations (GEE), more specifically generalized linear model (GLM), were used to examine the relationship between respiratory symptoms and possible confounders like PM_{10} levels. Data were stratified according to age, sex, religion, SES, PM_{10} levels etc, adjusting for continuous as well as discrete variables. For categorical variables Chi-square test was done. When the number of degrees of freedom was close to the total degrees of freedom available, conditional logistic regression model was followed. The step-up conditional logistic regression model was developed using variables that were significantly associated with the outcome variable (for example; presence of a respiratory symptom) in univariate analysis. Moreover, odds ratio and 95% confidence interval as calculated from logistic regression models were used to determine the degree of association between exposure and outcome. $p<0.05$ was considered as significant.

CHAPTER - 3

RESULTS

Demographic characteristics of reference group, employees of power plants and their family members residing inside the plants, and people residing thermal power plant-adjacent areas who took part in this study are compared and presented in Table 5. It is evident that both groups were comparable with respect to age, sex, BMI, religion, smoking and food habit. But they differed with respect to fuel use at home and income.

Table 5. Comparison of demographic characteristics of the participants

Characteristics	Reference group (n=327)	Participants from plant -adjacent areas (n=382)	Thermal plant employees & family (n=703)
Median age in year	41	42	41
Gender (%): Male	96.6	95.6	97.0
Female	3.4	4.4	3.0
Median BMI in kg/m^2	21.3	21.8	22.1
Tobacco smoking/chewing habit (%)			
Current and ex-smoker	11.3	10.3	12.1
Chewer	10.1	10.7	12.8
Regular use of alcohol (%)	2.5	1.9	2.4
Level of education (% individuals)			
Up to 5 years' of schooling	69.4	71.7	63.2
10 years' of schooling	15.3	19.1	24.0*
Graduate	13.8	8.4*	8.5*
Postgraduate	1.5	0.8*	4.3*
Religion (%) : Hindu	91.7	88.5	90.3
Muslim	8.3	11.5	9.7
Food habit (%)			
Vegetarian	1.5	1.6	1.4
Mixed	98.5	98.4	98.6
Cooking fuel use at home (%)			
LPG	33.9	21.2*	57.3*
Kerosene, coal, biomass	66.1	78.8*	42.7*
Average family income/month (Rs.)	2100	2250	4800*

* $p>0.05$ compared with reference group

AIR QUALITY

Comparison of the PM_{10} level of reference areas with that of thermal power plants revealed significantly higher concentrations in the latter (66.5 ± 7.2 [SD] vs. 95.7 ± 14.7μg/m^3 in power plant-adjoining areas and 135.7 ± 24.8 μg/m^3 inside power plants, p<0.001).

PREVALENCE OF UPPER RESPIRATORY SYMPTOMS (URS)

Sinusitis, rhinitis (runny or stuffy nose), sore throat and common cold with fever were the most prevalent upper respiratory symptoms (URS). In general, 40.1% power plant employees had experienced one or more of these URS in the past 3 months. In comparison, 16.2% of reference group and 33.5% of people living near the power plants had URS (Table 6). The difference in the prevalence of URS between reference and other two groups was significant (p< 0.05) in Chi-square test. Prevalence of each of the five symptoms under URS is presented in Table 6.

Table 6. Prevalence (%) of upper respiratory symptoms in past three months

Symptom	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)	OR (95% CI) Plant vs. reference
Sinusitis	4.0	6	7.5	1.22 (0.93-1.57)
Runny or stuffy nose	3.1	7.5	9.5	1.62 (1.19-2.19)*
Sneezing	2.4	4.5	8.5	1.77 (1.20-2.34)*
Sore throat	5.2	11.1	17.5	2.68 (1.37-5.58)*
Common cold & fever	8.0	16.0	19.5	1.87 (1.54-3.61)*
URS, total	**16.2**	**33.5**	**40.1**	**1.59 (1.32-1.91)***

OR, odds ratio; 95% CI, 95% confidence interval; More than one symptom was present in many subjects; *, p<0.05

PREVALENCE LOWER RESPIRATORY SYMPTOMS (LRS)

Recurrent dry cough, cough with phlegm (wet cough), wheeze, breathlessness on exertion and chest discomfort were the major lower respiratory symptoms (LRS) encountered. The prevalence of LRS was significantly higher (p<0.001) among the power station workers in comparison with age- and sex-matched rural controls (Table 7).

Table 7. Prevalence (%) of lower respiratory symptoms in past 3 months

Symptom	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)	OR (95% CI) Plant vs. reference
Dry cough	5.8	7.3	16.5	1.80 (1.29-2.50)*
Cough with phlegm	10.4	16.0	19.9	2.00 (1.47-2.75)*
Wheeze	1.5	5.3	5.8	2.39 (1.62-3.55)*
Breathlessness	4.9	12.6	22.4	2.19 (1.61-2.98)*
Chest discomfort	7.6	10.3	15.9	2.13 (1.46-3.13)*
LRS, total	**13.8**	**27.7**	**34.3**	**1.97 (1.62-2.40)***

More than one symptom were present in many subjects; *, $p<0.05$

In multivariate logistic regression analysis, the level of PM_{10} in ambient air was found to be positively associated with the prevalence of LRS even after controlling potential confounders like smoking, education and income (OR=1.42, 95% CI 1.22-1.63). In conditional logistic regression analysis taking LRS prevalence during PM_{10}level of 50-75 $\mu g/m^3$ as baseline (OR=1), odds ratio of 2.90 with 95% CI 2.05-4.16 was found when PM_{10} level in ambient air crosses the level of 150 $\mu g/m^3$. The prevalence of respiratory symptoms was highest in Bandel (BTPS) and lowest in Bakreswar thermal power plant (BkTPS; Table 8).

Table 8. Comparison of the prevalence (%) of respiratory symptoms among the employees of different thermal power plants

Type of symptom	BTPS	KTPS	BkTPS
URS (%)			
Employees	48.2	42.0	36.4
Local people	42.4	38.2	26.6
LRS (%)			
Employees	44.5	37.2	28.9
Local people	33.3	29.4	24.4
Overall (%)			
Employees	46.3	39.6	32.6
Local people	40.9	36.8	25.0

ASTHMA, HEADACHE, EYE AND SKIN PROBLEMS

The prevalence of physician-diagnosed asthma, recurrent headache, eye and skin irritation in past 3 months was significantly higher ($p<0.001$) among employees of thermal power plants and people living within 10 km of these plants compared with reference group. The prevalence of asthma, headache, eye and skin problems was highest in Bandel and lowest in Bakreswar thermal power plant (Table 9, Figure 1).

Table 9. Prevalence (%) of bronchial asthma, headache, eye and skin problems among workers of thermal power stations and local population

Type of ailment	Ref (n=327)	Local people (n=382)			Power plant employees and residents of townships (n=703)		
		BTPS	KTPS	BkTPS	BTPS	KTPS	BkTPS
Asthma	2.4	4.5	3.7	2.2	5.1	4.9	4.2
Headache	7.3	18.2	19.8	11.1	43.1	30.9	26.3
Eye irritation	2.5	10.6	9.5	3.3	24.8	14.6	8.1
Skin problem	4.3	15.1	11.0	4.4	19.7	17.3	13.6

*, p<0.05 compared with reference group (ref)

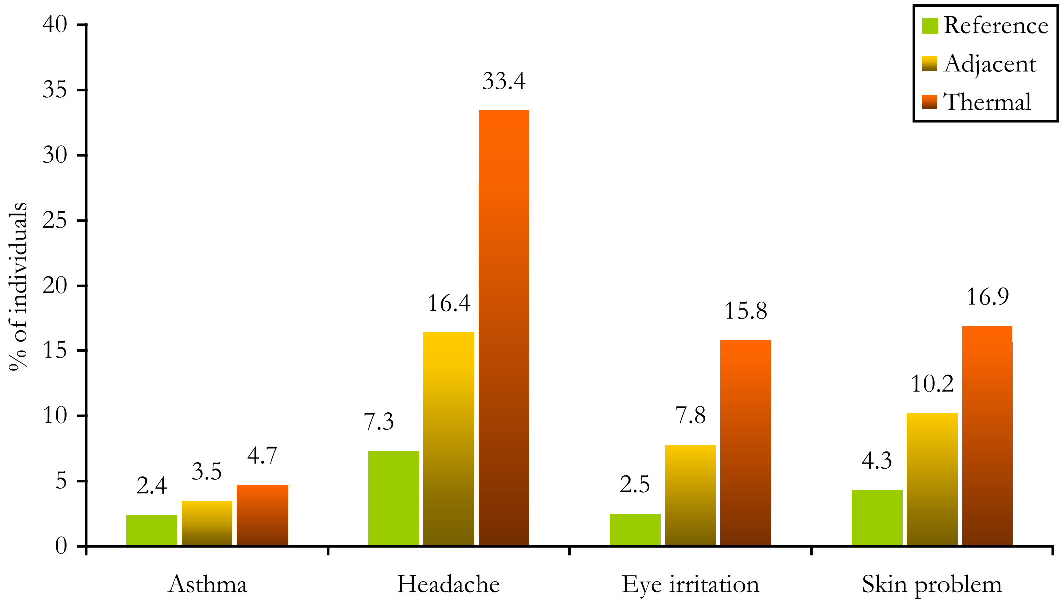


Figure 1: Prevalence (%) of bronchial asthma, headache, eye and skin problems among workers of thermal power plants and local population

LUNG FUNCTION

Compared with reference group, power plant workers and local population had poor lung function. Lung function was reduced in 42.1% workers, 31.5% of local people in contrast to 19.6% of reference group (p<0.001). Moreover, the severity of lung function reduction was more intense among plant workers and local populace (Table 10). Restrictive type of lung function deficits was predominant in all three groups (Figure 2). Among the three power stations, the prevalence of lung function impairment was highest among employees and local people of BTPS, and lowest in BkTPS (Figure 4)

Of all the potential confounders, particulate air pollution was most intimately associated with lung function decrement. A strong negative correlation was found between PM_{10} level and lung function measurements. The correlation was strongest for FVC (rho value 0.74, $p<0.0005$), followed by PEFR (rho=0.66, $p<0.0005$), and FEV_1 (rho=0.62, $p<0.0005$). After controlling potential confounders like age, gender, BMI, education and income, logistic regression analysis confirmed that particulate pollution (PM_{10}) was positively associated with lung function deficits (OR=1.63, 95% CI 1.22-2.89). Conditional regression analysis reaffirmed this finding.

Table 10. Prevalence of reduced lung function

Type of lung function deficits	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)
Persons (%) with lung function deficits	19.6	31.5*	42.1*
Type of impairment (%)			
Restrictive	15.0	22.1*	25.6*
Obstructive	4.0	6.9*	12.8*
Combined	0.6	2.5*	3.7*
Magnitude of lung function reduction			
Mild	9.8	17.1*	18.9*
Moderate	8.0	11.9	14.9*
Severe	1.8	2.5*	8.3*

*, $p<0.05$ compared with reference group

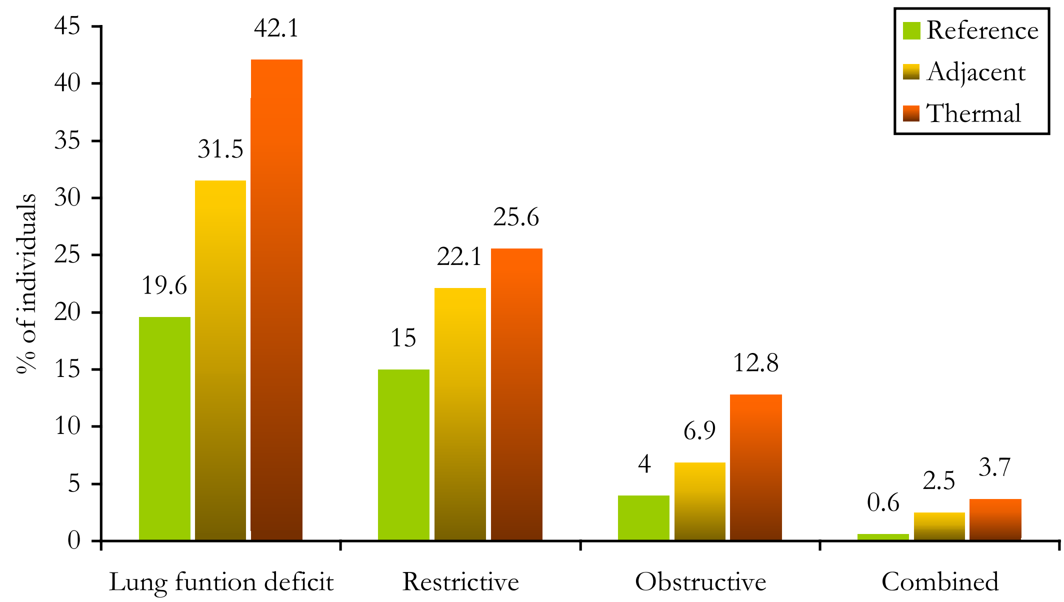


Figure 2: Prevalence of reduced lung function

PREVALENCE OF COPD

Chronic obstructive pulmonary disease (COPD) is a disease state characterized by airflow limitation that is not fully reversible. It is the fourth leading cause of death after heart diseases, cancer and stroke in USA and Europe. In the present study, 4% of thermal power plant workers and 2.3% of local people had COPD compared with 1.2% of reference group, indicating 3.3-times more relative risk among the workers (Table 11, Figure3). PM_{10} level showed significant positive correlation with COPD (rho=0.452). Therefore, the changes can be attributed in part to PM_{10} emitted from these plants. The prevalence of COPD among employees and local people was highest in BTPS, and lowest in BkTPS (Figure 4)

Table 11. Prevalence (%) of chronic obstructive pulmonary disease (COPD)

Group	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)
Overall	1.2	2.3*	4.0*
Stage-I	0.6	1.1*	1.7*
Stage-IIa	0.3	0.8*	1.1*
Stage-IIb	0.3	0.4	0.7*
Stage-III	0	0	0.4

*, $p<0.05$ compared with reference group

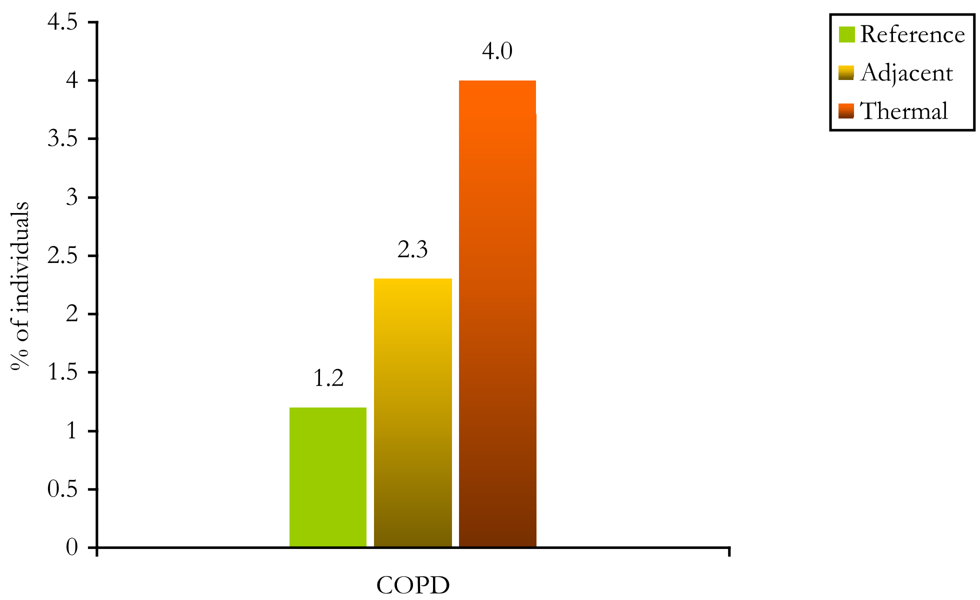


Figure 3: Prevalence (%) of chronic obstructive pulmonary disease (COPD)

Among the three thermal power stations, the prevalence of lung function impairment and COPD was highest in Bandel and lowest in Bakreswar thermal power plant (Table 12, Figure 4).

Table 12. Comparison of the prevalence (%) of reduced lung function and chronic obstructive pulmonary disease (COPD) among the employees and local people of different thermal power plants

	BTPS	KTPS	BkTPS
Reduced lung function (%)			
Employees	49.6	44.2	38.0
Local people	39.4	35.3	25.5
COPD (%)			
Employees	5.8	4.4	2.9
Local people	4.5	2.2	1.6

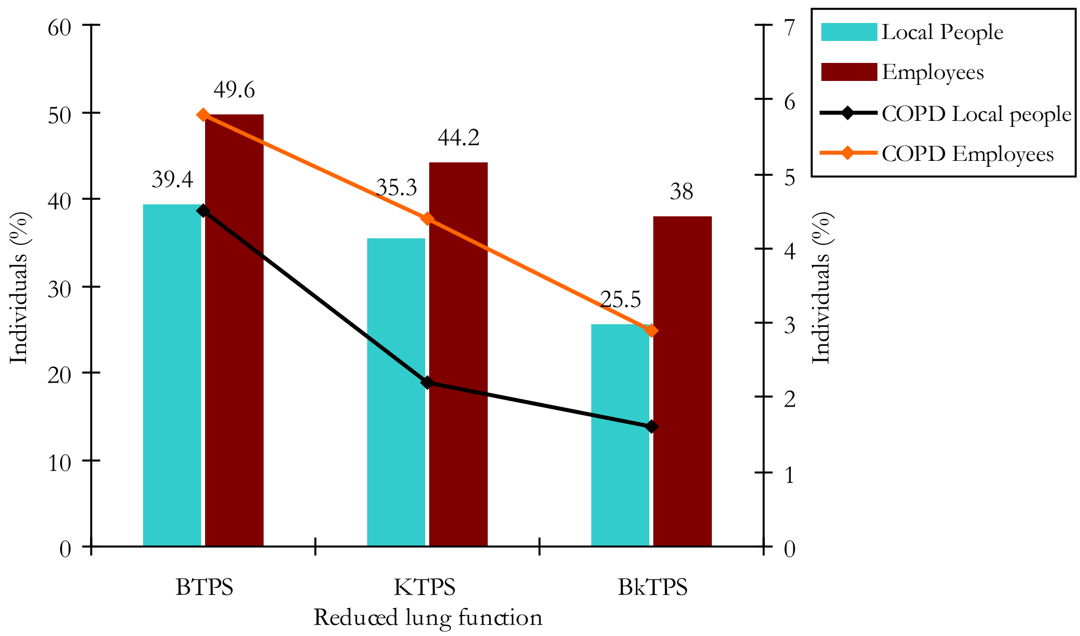


Figure 4: Comparison of the prevalence (%) of reduced lung function and chronic obstructive pulmonary disease (COPD) among the employees and local people of different thermal power plants

CELLULAR CHANGES IN LUNGS AND THE AIRWAYS

Inflammation of the lung and airways

Compared with controls, Pap-stained smears of sputum samples of power plant workers were more cellular and contained significantly increased number ($p<0.05$) of lung defense cells such as neutrophils, lymphocytes, eosinophils and alveolar macrophages (Table 13). Moreover, the AMs were heavily loaded with particles, and were larger in size. Remarkable increases in the number of these cells engaged in lung defense suggest inflammatory changes in the lung and airways (Plate 4, 5, 6).

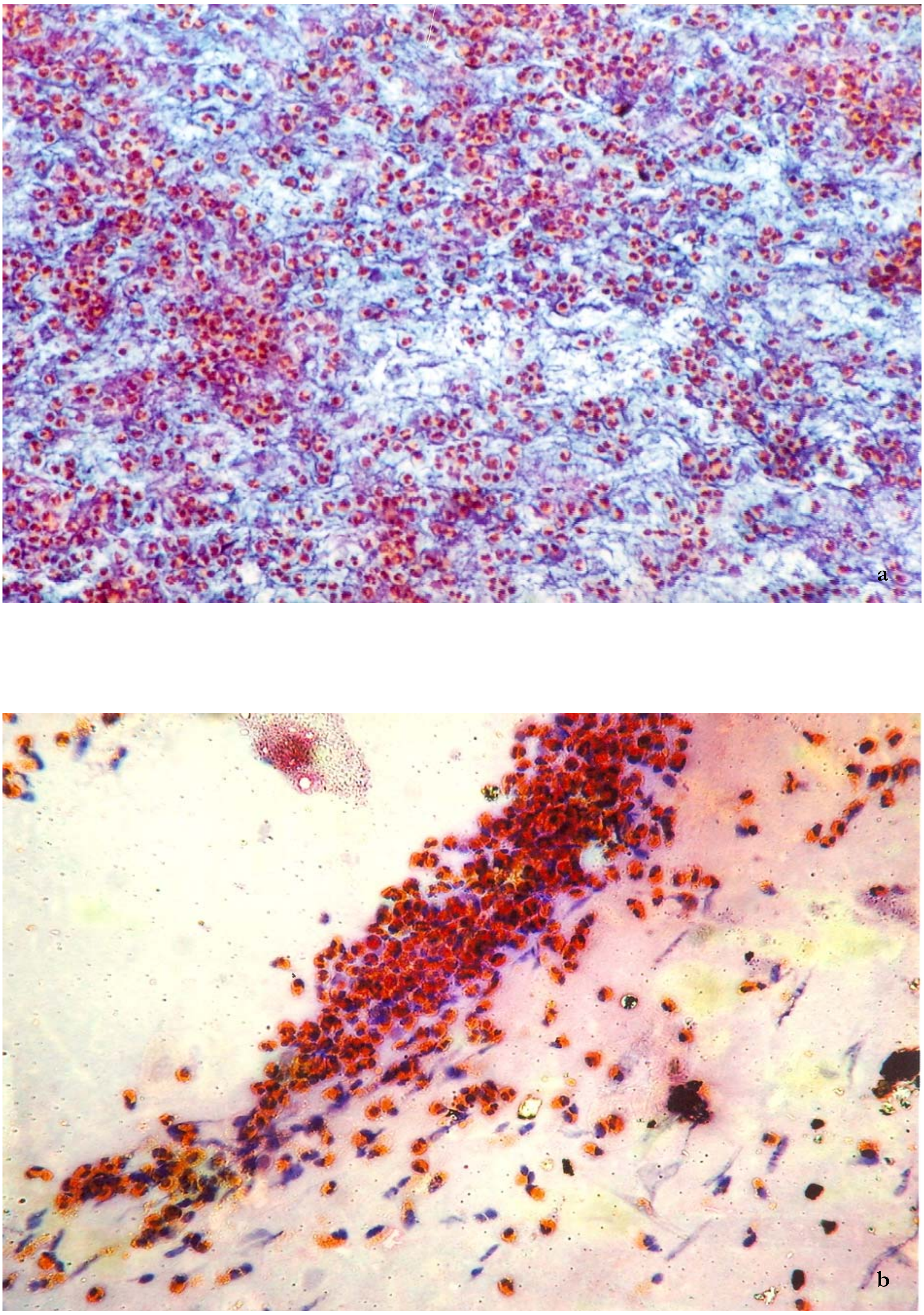


Plate 4 : Photomicrographs of sputum showing neutrophilia (a) and eosinophilia (b) among employees Bandel Thermal Power Station [Papanicolaou-stained, x 200 (a), x 400 (b)]

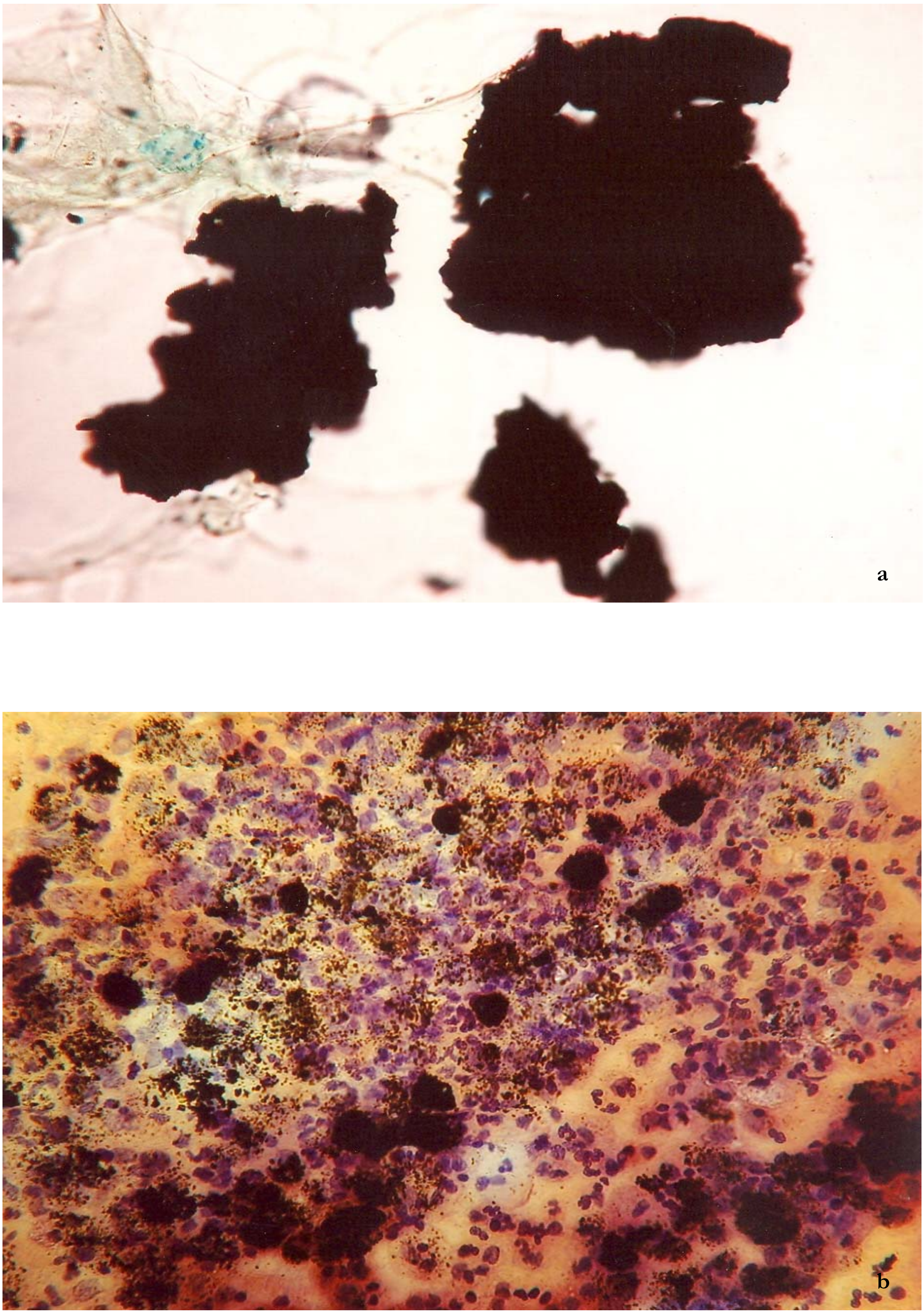


Plate 5 : Photomicrographs of sputum samples of employees of coal handling plant of Bakreswar Thermal Power Project showing massive deposition of particulate pollution in their airways [Papanicolaou-stained, x 400 (a), x 400 (b)]

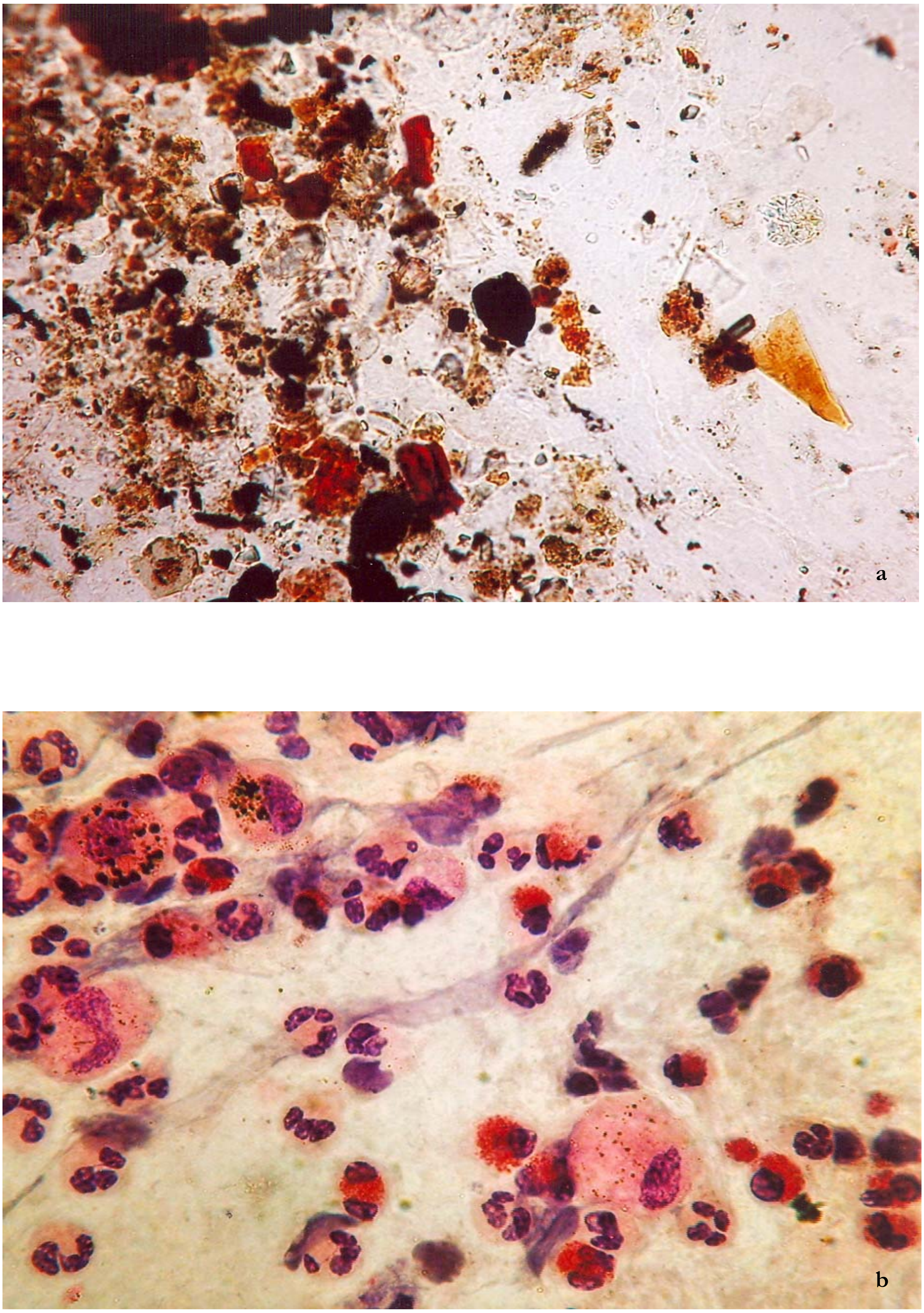


Plate 6 : Photomicrographs of sputum samples of employees of Kolaghat Thermal Power Station showing deposits of mineral dust in the lungs (a) and as a consequence, Mast cells accumulation (red stained) in the airways (b) [Papanicolaou-stained, x 400 (a), x 1000 (b)]

Table 13. Number of inflammatory cells (mean ±SD) in sputum

Cell type	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)
Neutrophil/hpf	29.8± 5.6	36.2 ± 5.5*	48.1±7.6*
Eosinophil/hpf	0.6±0.2	1.3± 0.6*	3.3±1.6*
Lymphocyte/hpf	2.9±1.3	3.3± 2.4	4.7±2.5*
AM/hpf	6.9±1.6	9.6± 1.8*	12.9±2.6*

hpf, high power field of microscope (x400); *, p<0.05 compared with reference group

Early changes towards cancer

Two important cytopathological findings in sputum of thermal power plant workers were greater incidence of metaplasia and dysplasia of bronchial epithelial cells (Figure 5, Plate 7). The changes, recognized as early steps towards cancer development, were positively correlated with ambient PM_{10} level. The prevalence of metaplasia and dysplasia was highest in Bandel and lowest in Bakreswar thermal power plant (Table 14). In BTPS, the excess of dysplasia among local people was 4.25 - 0.70 = 3.55%. In KTPS and BkTPS the excess prevalence of airway cell dysplasia was 3.4% and 1.5% respectively.

Table 14. Comparison of the prevalence (%) of metaplasia and dysplasia of airway epithelial cells among the employees of different thermal power stations

Parameter	Reference	Local people			Power plant employees		
		BTPS	KTPS	BkTPS	BTPS	KTPS	BkTPS
Metaplasia	6.2	21.2*	19.9*	11.1*	36.5*	31.0*	19.8*
Dysplasia	0.70	4.25*	4.10*	2.2*	8.0*	6.2*	3.9*

*, p<0.05 compared with reference group

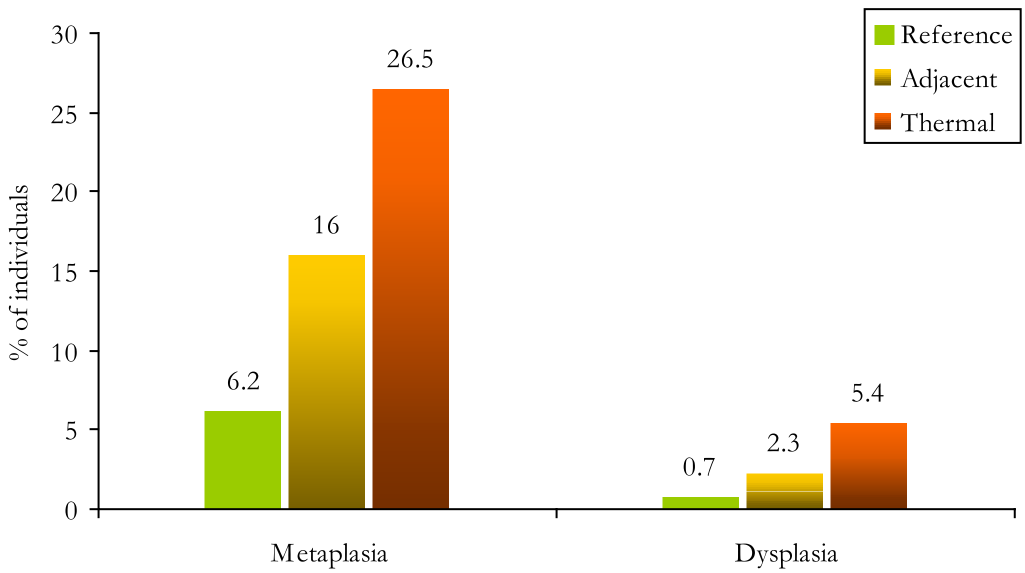


Figure 5: Prevalence (%) of metaplasia and dysplasia of airway epithelial cells

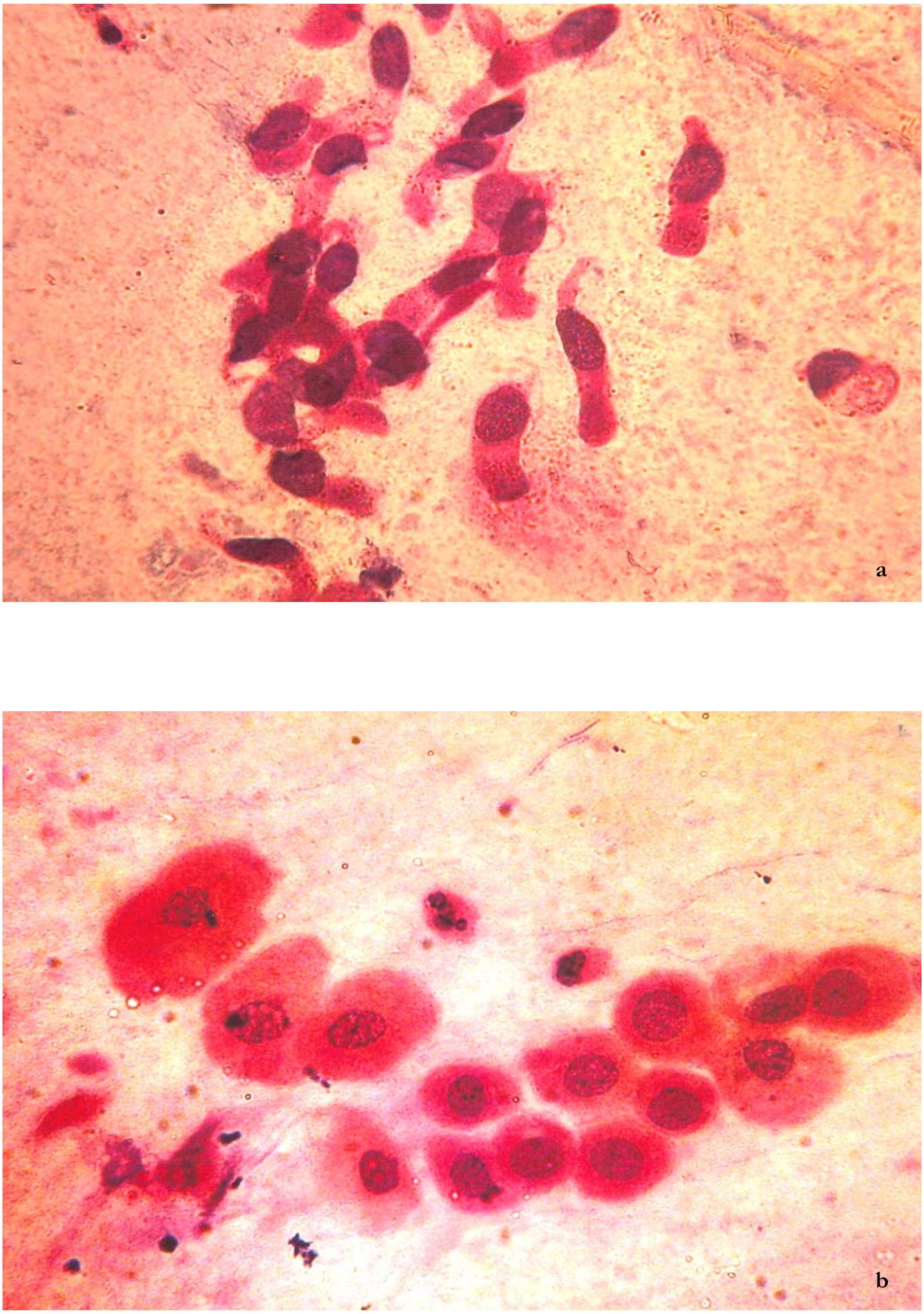


Plate 7 : Photomicrographs of sputum samples showing aggregates of columnar epithelial cells (a) and squamous metaplasia (b), suggesting injury to the airway wall and early cellular changes towards carcinogenesis, respectively (x 1000)

Hemorrhage in lung

Results showed that 29% of AM of plant workers and 17% of AM of people living near power plants had iron deposits compared with 8% of iron-laden macrophages in sputum of control subjects (Plate 8). Abundance of iron-containing macrophages in sputum of the workers may suggest covert pulmonary hemorrhage. This could be detrimental to the lung because excessive accumulation of iron, especially in unbound, 'free' form, facilitates the generation of potentially toxic hydroxyl radicals from less reactive superoxide and hydrogen peroxide via Fenton and Haber-Weiss reaction (Mateos et al., 1998). The consequence would be tissue injury. Moreover, iron in certain forms promotes the development of cancer (Hueper and Payne, 1962).

PREVALENCE OF HYPERTENSION

Overall, hypertension was present in 36.1% thermal power station workers and 20.2% of people living within 10 km of power plants compared with 9.5% of reference group. More importantly, 16.7% and 11.8% of the former two groups respectively had both systolic and diastolic hypertension compared with only 2.6% of reference group (Table 15, Figure 6). Hypertension was most prevalent in BTPS and least in BkTPS (Table 16, Figure7).

Table 15. Prevalence (%) of hypertension in thermal power plant workers

Hypertension	Reference (n=327)	Adjacent (n=382)	Power plant (n=703)
Only systolic	4.4	4.6	2.7
Only diastolic	2.5	3.8*	16.7*
Systolic plus Diastolic	2.6	11.8*	16.7*
Overall	9.5	20.2*	36.1*

*, p<0.05 compared with control

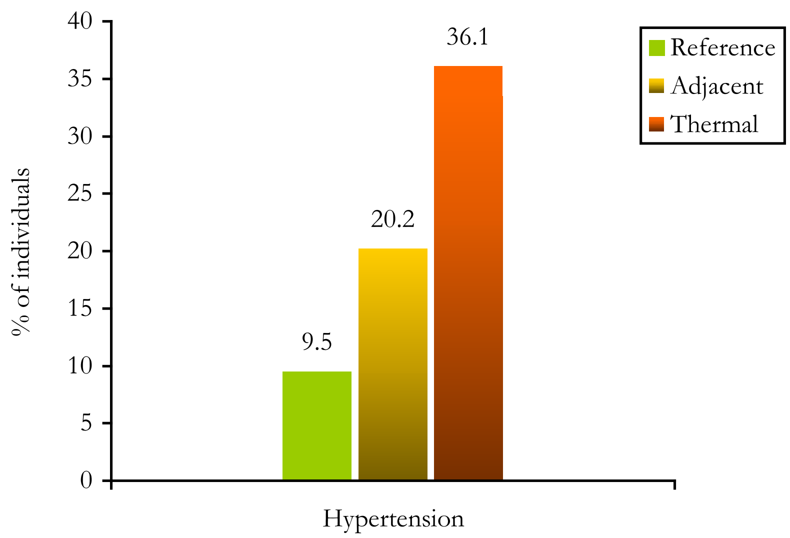
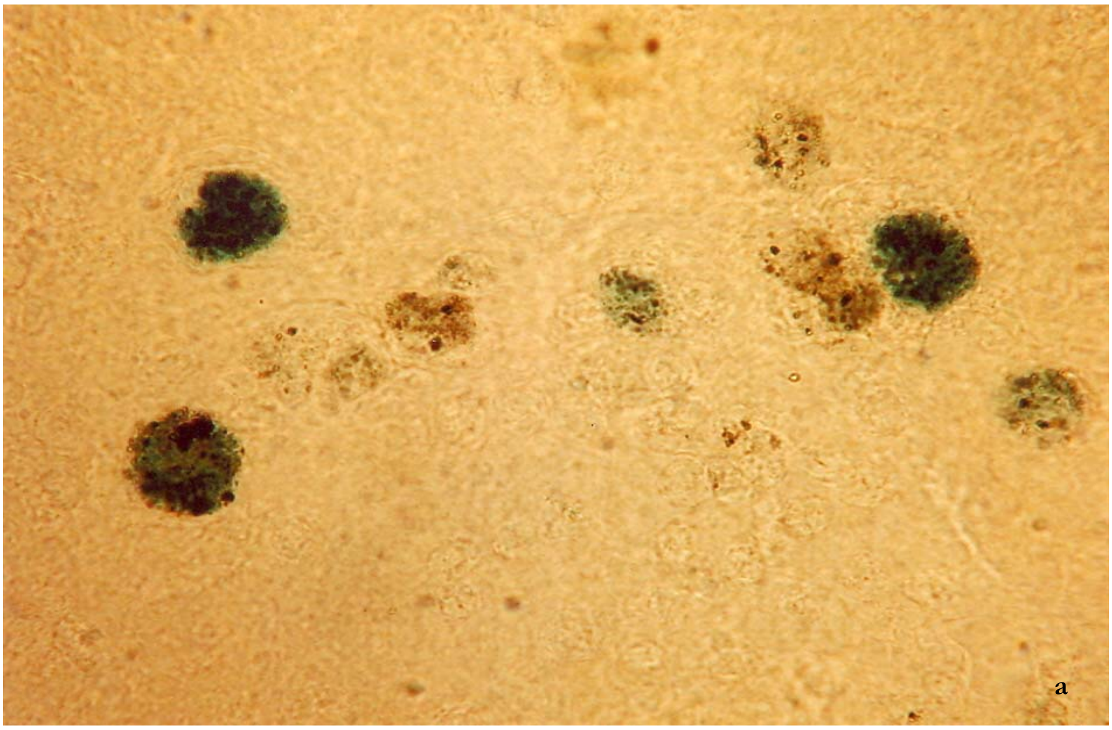


Figure 6: Prevalence (%) of hypertension in thermal power plant workers



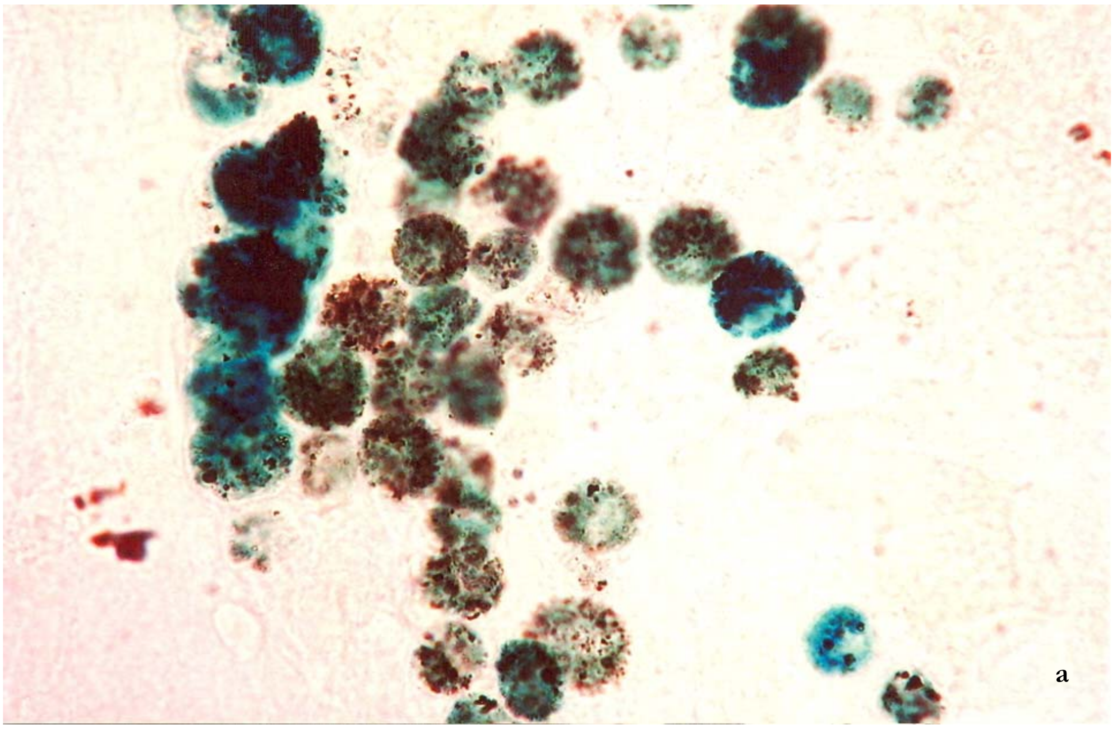


Plate 8 : Photomicrographs of iron-laden alveolar macrophages, blue stained among control subjects and employees of Kolaghat Thermal Power Plant (b). Note the abundance of these cells among the employees indicating microscopic hemorrhage in their lungs [PPB reaction, x 1000]

Table 16. Prevalence (%) of hypertension in different thermal power plants

Hypertension	Bandel	Kolaghat	Bakreswar
Employees (%)	50.4*	39.8*	28.2*
Local people (%)	33.3*	25.0*	11.7*

*, p<0.05 compared with a reference value of 9.5%

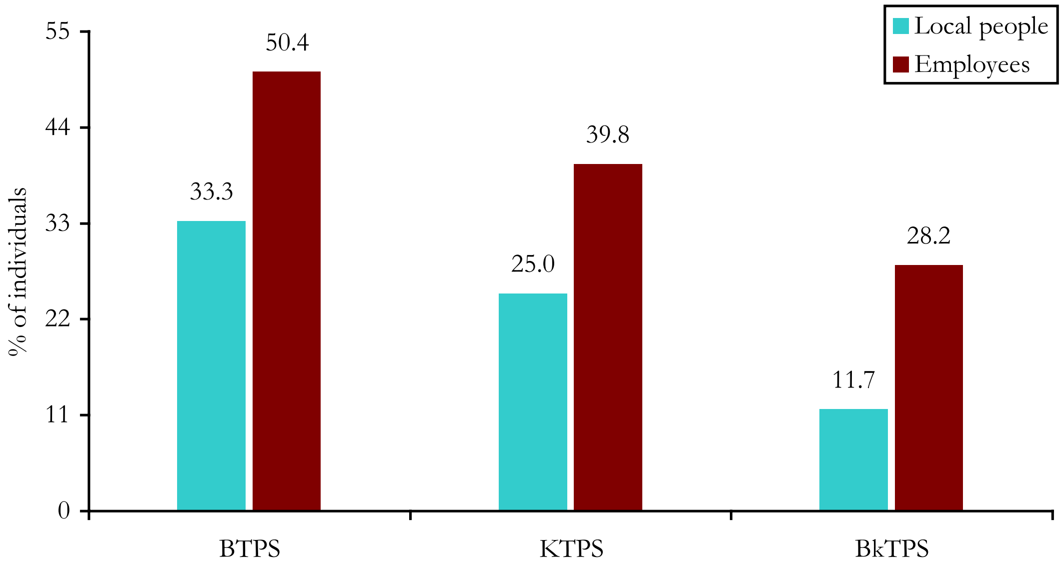


Figure 7: Prevalence (%) of hypertension in different thermal power stations

DEPRESSION AND OTHER NEUROBEHAVIORAL SYMPTOMS

A remarkably increased prevalence of depression was found among thermal power plant workers, and to some extent in nearby population when compared with that of control (reference). Compared with 23.2% of reference group with different grades of depression, 48.6% of power plant employees and 35.6% of nearby population had depression. Moreover, 13.1% of employees had severe depression compared with 3.6% of reference group (Table 17).

Table 17. Prevalence (%) of depression among Thermal power plant workers

Depression	BDI Score	Reference (n=327)	Local people (n=382)	Power plant workers (n=671)
Absent	5 – 9	76.8	64.4*	51.3*
Mild to moderate	10 –18	14.5	19.3	18.1
Moderate to severe	19 –29	5.0	10.6*	17.4*
Severe	30 – 63	3.6	5.4*	13.1*
Overall depression	10-63	23.2	35.6*	48.6*

Results are expressed as percentage of individuals; BDI, 21-question Beck's depression inventory; *p<0.05 compared with control in Chi-square test

Depression was most prevalent among the workers of BTPS (73.7%), and least in BkTPS (35.7%). Likewise, people residing within 10 km radius of BTPS had highest prevalence of depression (60.6%) compared with local people of KTPS (36.8%) and BkTPS (25.6%) [Table 18, Figure 8].

Table 18. Prevalence (%) of depression in different thermal power plants

Depression	BTPS	KTPS	BkTPS
Employees (%)	73.7*	55.3*	35.7*
Local people (%)	60.6*	36.8*	25.6

*, $p<0.05$ compared with a reference value of 23.2%

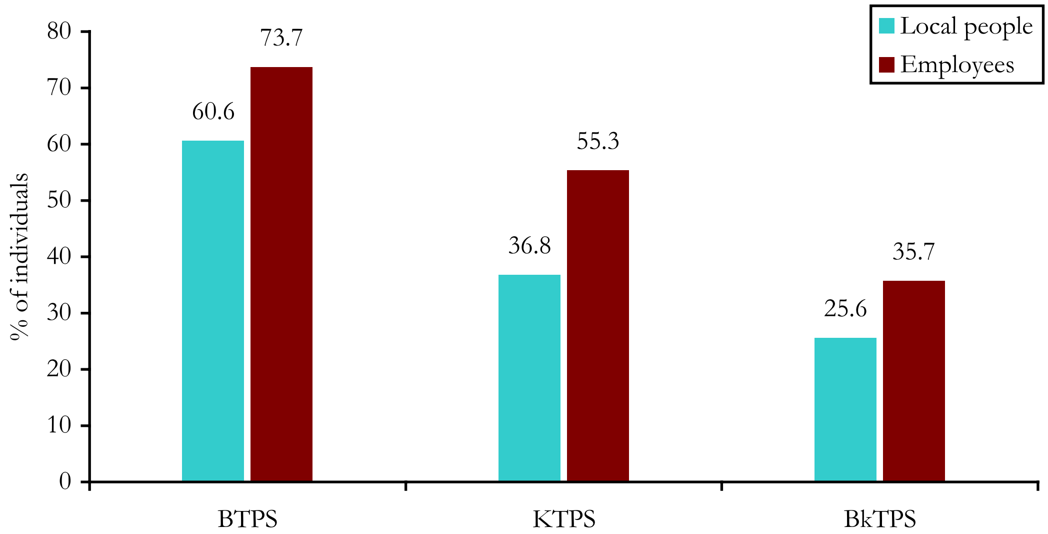


Figure 8: Prevalence (%) of depression in different thermal power plants

Besides depression, burning sensation in extremities, anxiety, drunken feeling, inability to concentrate, transient loss of memory, reduced sense of smell, and sleep disturbance were more prevalent among employees of thermal power plants and people residing near these plants ($p<0.05$, Table 19).

Table 19. Prevalence of neurobehavioral symptoms

Symptom	Reference	Local people	Plant workers
Burning sensation in extremities	1.5	6.8*	14.5*
Vertigo/dizziness	3.4	11.0*	17.6*
Palpitation	10.4	9.2*	18.2*
Anxiety	7.3	12.3*	28.6
Drunken feeling	2.1	2.9	6.5*
Inability to concentrate	6.1	8.4*	42.9*
Transient loss of memory	13.5	21.5*	42.4*
Reduced sense of taste	1.5	2.3*	6.4*
Reduced sense of smell	1.5	4.2*	7.8*
Feet numbness	7.6	9.2*	15.4*
Disturbed sleep	2.4	4.7*	14.8*

n, number of subjects; *, $p<0.05$ compared with control in $\chi 2$ test

Increased prevalence of neurobehavioral symptoms seen in thermal power station workers could be the fall-out of possible neurological changes, because behavior is the outcome of multiple mechanisms within the brain and changes are sensitive indicators of nervous system dysfunction. The changes could be partially attributed to air pollution (Sirivelu et al., 2006). Some studies have shown brain damage and Alzheimer's- like changes following sustained exposures to high level of air pollution (Calderon-Garciduenas et al., 2004). Air pollution can adversely affect psychological health of the people; exposures to increased levels of some air pollutants are associated with psychiatric symptoms, including anxiety and changes in mood, cognition and behavior (Lundberg, 1996). Toxic air pollutants including carbon monoxide interfere with the development and adult functioning of the brain causing impairment of memory, learning ability, attention and concentration (Amitai et al., 1998). It is now well established that ultrafine particles present in combustion products cross the alveolar-capillary barrier, reach the blood stream, and influence the activities of all vital organs including the brain. It is possible therefore that ultrafine particles emitted during coal burning have played a role in mediating neurobehavioral changes among employees and people living near coal-based thermal power stations.

SUMMARY OF THE FINDINGS

In summary, we found significant increase ($p<0.05$) in the prevalence of respiratory symptoms, asthma, lung function deficits, skin and eye problems, headache, hypertension, COPD, lung inflammation, depression and other neurobehavioral symptoms, and early cellular changes towards carcinogenesis among employees and local residents of thermal power stations. The findings have been summarized in Table 20.

Table 20. Summary of the health impact of emissions from Bandel, Kolaghat and Bakreswar thermal power plants in West Bengal. Results are expressed as percentage of affected persons

Parameter	Ref group	Local people	TPP employees	Change Ref vs. local	Change Ref vs. TPP
Respiratory symptoms	15.6	30.9*	37.6*	2-fold rise	2.4-fold rise
Asthma	2.4	3.2*	4.6*	1.3-fold rise	1.9-fold rise
Headache	7.3	15.6*	30.7*	2.1-fold rise	4.2-fold rise
Eye irritation	2.5	6.9*	13.4*	2.8-fold rise	5.4-fold rise
Skin problem	4.3	8.6*	15.6*	2-fold rise	3.6-fold rise
Reduced lung function	19.6	31.5*	42.1*	1.6-fold rise	2.1-fold rise
Lung inflammation	19.0	29.8*	30.6*	1.6-fold rise	1.6-fold rise
COPD	1.2	2.3*	4.0*	1.9-fold rise	3.3-fold rise
Hypertension	9.5	20.2*	36.1*	2.1-fold rise	3.8-fold rise
Metaplasia	6.2	15.9*	26.5*	2.6-fold rise	4.3-fold rise
Dysplasia	0.7	3.5*	6.0*	5-fold rise	8.5-fold rise
Depression	23.2	35.6*	48.6*	1.5-fold rise	2.1-fold rise

*,$p<0.05$ compared with control

When the findings of three thermal power stations were compared it was found that health impairments were most noticeable among employees and local people of Bandel, followed by Kolaghat and Bakreswar thermal power stations (Table 21).

Table 21. Comparison of health impact of emission from Bandel, Kolaghat and Bakreswar thermal power stations. Results are expressed as percentage of affected persons

Parameter	BTPS		KTPS		BkTPS	
	Local	Workers	Local	Workers	Local	Workers
Respiratory symptoms	40.9	46.3	36.8	39.6	25.0	32.6*
Asthma	4.5	5.1	3.7	4.9	2.2	4.2*
Headache	18.2	43.1*	19.8	30.9*	11.1	26.3*
Eye irritation	10.6	24.8*	9.5	14.6*	3.3	8.1*
Skin problem	15.1	19.7	11.0	17.3*	4.4	13.6*
Reduced lung function	39.4	49.6*	35.3	44.2*	25.5	38.0*
COPD	4.5	5.8	2.2	4.4*	1.6	2.9*
Hypertension	33.3	50.4*	25.0	39.8*	11.7	28.2*
Metaplasia	21.2	36.5*	19.9	31.0*	11.1	19.8*
Dysplasia	4.2	8.0*	4.1	6.2*	2.2	3.9*
Depression	60.6	73.7*	36.8	55.3*	25.6	35.7*

*, $p<0.05$ compared with corresponding local population

CHAPTER-4

ECONOMIC IMPACT OF ILLNESS ATTRIBUTABLE TO AIR POLLUTION FROM THERMAL POWER STATIONS

For social cost calculation of thermal power generation, it is necessary first to calculate the impact of air pollution on health of the people who are directly engaged in power generation and residing in and around power plants, because the pollutants are emitted into the air and travel a long distance before it is deposited on the earth's surface. In view of this, we have calculated the impact among power plant employees, their family members residing within plant areas and residents of surrounding areas. As reference group we included people from rural areas of the districts of West Bengal where the plants are situated in order to make social variables at par. As expected, the health impact of thermal power plant emissions was most noticeable among the workers, followed by the local people. They had higher prevalence of respiratory symptoms, lung function decrement, pulmonary inflammation and neurobehavioral problems (Table 15). After controlling potential confounding factors such as age, gender, active and passive smoking, tobacco chewing habit, education and family income in multivariate logistic regression analysis, the health impairments were positively associated with pollutants emitted from these plants. Recent study has identified $PM_{2.5}$ (Bernstein and Abelson, 2005) and inorganic metallic dusts (Pb, Cd, Zn, Ni) present in $PM_{10}/PM_{2.5}$ fractions (Balachandran et al., 2000) as the most dangerous pollutants for mediating health impairment. These pollutants are ubiquitous because they are largely derived from coal combustion during electricity generation and are transported over long distances and readily penetrate indoors (Pope 2004). Since the investigations were carried out simultaneously in thermal power plant and reference areas, seasonal variation was also negligible. Respiratory symptoms reflect underlying problems in the airways and the alveoli. Therefore, greater prevalence of respiratory symptoms among the thermal power plant workers may suggest elevated frequency of airway and alveolar damage.

Externality / Adder

The environmental impact in monetary value is usually termed 'externalities'. An externality exists if two conditions are met. First, some positive or negative impact is generated by an economic activity and it is imposed on third parties. Second, for a negative impact no compensation is paid to the sufferer by the generator of the externality. In power generating and energy circle, externality is usually expressed as cents or milli-euros (or paisa in Indian scenario) per kilowatt hour (kWh). This is known as an 'adder'. An adder is the unit externality cost added to the standard resource cost of energy. Therefore, if a thermal power generating station costs 'x' paisa to produce a unit of electricity, the final social cost of it will be (x + y) paisa, where y is the externality adder.

WTP

One of the important components used during cost estimation is "Willingness to pay" (WTP). It is based on a subject's income and perceptions of physical, mental and social well being. Individuals who underestimate the health effects are willing to pay less than they would if they were fully informed (Delucchi et al. 2002). We constructed a model that includes emissions from the plants, size of the exposed population, their income and WTP. Most of the casual/contractual workers employed in the power plants who participated in this study and the local population did not have health insurance. We used the contingent valuation method to assess the maximum willingness to pay (WTP) for health related problems. In our estimate we found that they were willing to spend 1 to 20% of their income for treatment of the diseases directly or indirectly associated with air pollution exposures.

PUBLIC HEALTH EXTERNALITIES VIS-À-VIS POWER GENERATION

1. Respiratory illness

Presence of respiratory symptoms in an individual generally indicates underlying respiratory illness. Respiratory infections and consequent respiratory symptoms are inversely correlated with body's immune defense against airborne pathogens. Air pollution markedly reduces body's immunity resulting in greater susceptibility to infections. Therefore, significant rise in the prevalence of respiratory symptoms among plant employees and local people could be attributed, to a great extent, to pollutants released into air from the power plants.

Table 22. Population living near thermal power stations

Area	Population density* per km^2	Estimated population within 10 km radius (314 km^2)
Bandel TPS	4682	1470148
Kolaghat TPS	2132	669672
Bakreswar TPS	584	183532

*Based on Census of India, 2001

A person requires antibiotics to control bacterial infections (wet or dry cough, sore throat etc.), antihistamine for sneezing and runny nose, and antibiotic or anti-fungal drugs for sinusitis. The cost of such treatment will be a minimum of Rs. 500 (Rs. 300 for medicine, 100/- doctor's fee, and 100/- for laboratory tests). Therefore the cost of treatment among the local population attributable to the activities of BTPS will be: 374887 x 500 = Rs. 187443500/- per year (Table 23). On the other hand, cost of treatment for respiratory symptoms among employees of BTPS will be 563 x 500 = Rs. 2,81,500 per year. The total cost for treatment of respiratory illness in workers and local people of BTPS will be Rs. 187725000/- per year. Similarly, the annual cost of treatment for respiratory symptoms will be Rs. 73424500 and Rs. 9304000 per year for KTPS and BkTPS, respectively (Table 23).

Table 23. Minimum cost of treatment (in rupees) for respiratory illness other than COPD among workers and people living near thermal power stations

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
Excess prevalence (%)	25.5	21.8	10.0
Number of affected persons	374887	145988	18353
Cost of treatment per year @ 500/- per person	187443500	72994000	9176500
Number of employees	1800	3500	1450
Excess prevalence (%)	31.3	24.6	17.6
Number of affected persons	563	861	255
Minimum cost of treatment/yr	281500	430500	127500
Total medical cost (for local people plus employees) per year	187725000	73424500	9304000

2. COPD

COPD (chronic bronchitis and emphysema) is a progressive, life-threatening disease. It is not fully reversible, i.e. not always curable. It is common among 40 year-plus people. The minimum cost of treatment for COPD is estimated as Rs. 400 as doctor's fees (4 visits) + 2000 for diagnostic tests + 5000 for medicine; Total = 7400 per year. Accordingly, the medical cost of treatment for COPD among 40 year + local people of BTPS is calculated as Rs. 107699600/- per year. For the workers it will be Rs. 347800/- per year. Therefore, the annual cost of treatment for COPD in employees and local people of BTPS is estimated as Rs. 108047400/- (Table 24). Similarly, the total medical cost due to COPD is expected to be Rs. 15377200/- and Rs. 1768600/- per year for KTPS and BkTPS, respectively (Table 24).

Table 24. Cost of treatment (in rupees) for COPD among workers of thermal power stations and people living nearby

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
40-plus age group (30% of total)	441044	200901	55059
Excess prevalence (%)	3.3	1.0	0.4
Number of affected persons	14554	2009	220
Cost of treatment per year @ 7400/- per person	107699600	14866600	1628000
Number of employees	1800	3500	1450
40-plus age group (45% of total)	810	1575	653
Excess prevalence (%)	5.8	4.4	2.9
Number of affected persons	47	69	19
Minimum cost of treatment/yr	347800	510600	1,40,600
Total medical cost (for local people plus employees) per year	108047400	15377200	1768600

3. Headache

Headache has multiple etiology, exposure to air pollution is just one of them. Cost of treatment for each person is usually Rs. 100. Accordingly, medical cost is calculated as Rs. 16024600/- and Rs. 77,600/- per year for local people and employees of BTPS, respectively (Table 25). In total, an estimated 161022 people employed and residing within 10 km of BTPS may suffer from headache and the total cost of treatment will be Rs. 16102200/- per year for BTPS. Similarly, the cost of treatment of headache for local people and employees of KTPS and BkTPS were calculated and presented in Table 25 & 26).

4. Diseases of the eye

A rise in eye problems has been recorded in employees and local people of thermal power plants. Total cost of diagnosis and treatment of corneal ulcers in South India is Rs. 2300/- (Prajna et al. 2007). We understand that not all cases of eye irritation were as serious as corneal ulcers, and the medical cost for these problems will be around Rs. 200 (100/- for medication and 100/- as doctor's fee). Therefore the cost of treatment will be 200 x [29770 + 446] = Rs. 60,43,200 per year for employees and local people of BTPS (Table 25 & 26). Similarly, the cost of treatment for other two power stations is summarized in Table 25&26.

5. Dermatological problems

Excess skin problem was recorded in plant employees as well as in local people. The cost of diagnosis and treatment will be around Rs. 200 (100/- for medication and 100/-

as doctor's fee). Total cost of treatment per year for local people and the employees is tabulated in Table 25 and 26.

Table 25. Minimum cost of treatment for headache, asthma, eye and skin problems among workers of thermal power stations and people living nearby

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
Headache, excess prevalence (%)	10.9	12.5	3.8
Affected persons	160246	83709	6974
Cost of treatment @ Rs.100 /yr	16024600	8370900	697400
Eye irritation, excess prevalence (%)	8.1	7.0	0.8
Affected persons	119081	46877	1468
Cost of treatment @ Rs.200 /yr	23816200	9375400	293600
Skin problems excess prevalence (%)	10.8	6.7	0.1
Affected persons	158776	44868	183
Cost of treatment @ Rs.200 /yr	31755200	8973600	36600
Asthma excess prevalence (%)	2.1	1.3	0
Affected persons	30873	8705	0
Cost of treatment /yr @1400/-	43222200	12187000	0
Employees of power plants	1800	3500	1450
Cases of headache	776	1082	381
Cost of treatment/yr	77600	108200	38100
Cases of eye problems	446	69	19
Cost of treatment /yr	89,200	13,800	3800
Skin problems	355	606	197
Cost of treatment /yr	71000	121200	39400
Cases of Asthma/yr	92	172	61
Cost of treatment /yr	128800	240800	85400

6. Asthma

Bronchial asthma is a costly, chronic disease and the correlated social impact is ever increasing. On an average, a person spends Rs. 1400 (cost of medicine Rs. 1200 + doctor's fee Rs. 200) per year. Since asthma can affect both adults and children, more frequently the latter, all the population seemed vulnerable. Total cost of treatment per year for asthma in local people and the employees is tabulated in Table 25 and 26.

Table 26. Cost of treatment for headache, asthma, skin and eye problems

Illness	Affected population (employees + local people)			Cost of treatment /person/ year (Rs.)	Total cost per year (Rs.)		
	BTPS	KTPS	BkTPS		BTPS	KTPS	BkTPS
Headache	161022	84791	7355	100	16102200	8479100	735500
Eye irritation	119527	46946	1487	200	23905400	9389200	297400
Skin problems	159131	45474	380	200	31826200	9094800	76000
Asthma	30965	8877	61	1400	43351000	12427800	85400

7. Hypertension

We found remarkable higher prevalence of hypertension among power plant employees and local people when compared with that of reference group. In all three thermal power plants, particularly in Bandel, a sizeable number of employees were under treatment and were using anti-hypertension drugs regularly. Hypertension is intimately associated with air pollution particularly the fine ($PM_{2.5}$) and ultrafine (diameter less than 0.1 micron) particles that migrate from lungs to other organs through circulation. Therefore, significant rise in the prevalence of hypertension among plant employees and local people could be attributed in part to particulate pollutants released into air following combustion of coal. Alternatively, job stress and anxiety could have played a role in inducing hypertension among the employees.

Hypertension is a chronic disease that requires regular medication and doctor consultation. A person requires a yearly medication of at least Rs. 1440 (@120/- per month) plus doctor's fee of Rs. 200 (2 visits) and laboratory tests (ECG and others) of Rs.200. Therefore, minimum treatment cost = Rs. 1440 + Rs. 200 +Rs. 200 = Rs. 1840 per person per year.

Hypertension is usually prevalent in 40-plus age group although younger people could also be affected. The total number of affected persons in this age category was calculated as 108959 among local people and 253 among the employees of BTPS. The minimal cost of treatment for hypertension in BTPS will be Rs. 20,09,50,080/- per year (Table 27). Similarly, the annual cost will be Rs. 5,79,36,080in KTPS and Rs. 24,36,160 in BkTPS (Table 27). This is a conservative estimate, because the costs ranged from US $ 485-622 (Rs. 25,000-30,000/-) for hypertension even in developing nations of Latin America (Arredondo et al. 2005).

Table 27. Minimal cost of treatment for hypertension among workers of thermal power stations and people living nearby

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
40-plus age group (30% of total)	441044	200901	55059
Excess prevalence (%)	23.8	15.5	2.2
Number of affected persons	104968	31139	1211
Cost of treatment per year @ 1840/- per person	193141120	57295760	2228240
Number of employees	1800	3500	1450
40-plus age group (45% of total)	810	1575	653
Excess prevalence (%)	31.3	24.6	17.6
Number of affected persons	253	387	115
Minimum cost of treatment/yr	465520	712080	211600
Total medical cost (for local people plus employees) per year	193606640	58007840	2439840

8. Depression and neurobehavioral problems

Depression was most evident among people aged 40 years and above. The minimum cost of treatment has been calculated as Rs. 1000 per year (100 x 5 = 500 as doctor's fee plus 500 for medicine). The total medical cost for this problem has been calculated in Table 28.

Table 28. Cost of treatment (in rupees) for depression and neurobehavioral problems among workers of thermal power stations and people living nearby

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
40-plus age group (30% of total)	441044	200901	55059
Excess prevalence (%)	19.2	13.6	9.0
Number of affected persons	84680	27322	4955
Cost of treatment per year @ Rs.1000/- per person	84680000	27322000	4955000
Number of employees	1800	3500	1450
40-plus age group (45% of total)	810	1575	653
Excess prevalence (%)	30.8	29.0	21.6
Number of affected persons	249	457	141
Minimum cost of treatment/yr	249000	4,57,000	1,41,000
Total medical cost (for local people plus employees) per year	84929000	27779000	5096000

9. Cancer

We found an excess of 3.55% dysplasia of airway cells in local populace of BTPS. Presence of this condition does not necessarily indicate development of cancer, but it strongly suggests an increased risk of cancer in the airways. If we assume that one out of 10 people with dysplasia will ultimately develop cancer in 40+ age group people, then the number of cases will be 0.355% of 1441044 = 1566. Similar calculation among BTPS employees will lead us to an excess incidence of 6 cases per year (Table 29).

For cancer of the airways including lung cancer, treatment options are usually chemotherapy and radiotherapy especially in the advanced stages of the disease. For this, approximately Rs. 2.5 lakh for therapy, Rs. 5000 as doctor's fees and Rs. 25,000 for diagnostics are required. Hence the annual cost will be a minimum of Rs. 2.8 lakh for each case. Health cost due to excess cancer incidence in three thermal power stations is summarized in Table 29.

Table 29. Cost of treatment (in rupees) for lung cancer among workers of thermal power stations and people living nearby

Variable	BTPS	KTPS	BkTPS
Population within 10 km radius	1470148	669672	183532
40-plus age group (30% of total)	441044	200901	55059
Excess prevalence (%)	0.35	0.34	0.15
Number of affected persons	1566	687	86
Cost of treatment per year @ Rs. 2.8 lakh per person	438598029	192284398	23990033
Number of employees	1800	3500	1450
40-plus age group (45% of total)	810	1575	653
Excess prevalence (%)	0.73	0.55	0.22
Number of affected persons	6	9	1
Minimum cost of treatment/yr	1680000	2520000	280000
Total medical cost (for local people plus employees) per year	440278029	194804398	24270033

CHAPTER-5

SOCIAL COST OF THERMAL POWER GENERATION IN WEST BENGAL

The cost of treatment for the diseases attributable to emissions from three thermal power stations investigated in this study is summarized in Table 30. It is evident that the estimated cost is maximal in BTPS (Rs.112.9 crore/yr) and minimum in BkTPS (Rs.4.4 crore /yr). In KTPS, the cost is calculated as Rs. 40.8 crore per year (Figure 9). Besides greater emissions due to relatively old technology and lower chimney height, higher population density within 10 km radius of BTPS appeared to be a contributing factor to highest medical cost in this power station.

Table 30. Minimal cost of treatment of illness related to emissions from Bandel, Kolaghat and Bakreswar thermal power plants in West Bengal

Illness	Cost of treatment per year (rupees) for employees and local people		
	BTPS	**KTPS**	**BkTPS**
Respiratory illness	187725000	73424500	9304000
COPD	108047400	15377200	1768600
Headache	16102200	8479100	735500
Eye irritation	23905400	9389200	297400
Skin problems	31826200	9094800	76000
Hypertension	193606640	58007840	2439840
Asthma	43351000	12427800	85400
Depression and neurobehavioral	84929000	27779000	5096000
Lung cancer	440278029	194804398	24270033
Total	**112,97,70,869**	**40,87,83,838**	**4,40,72,773**

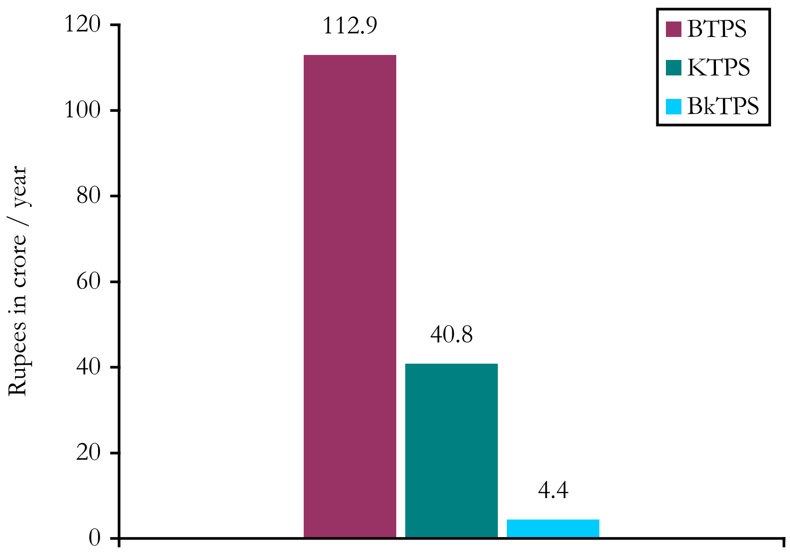


Figure 9. Cost of medical treatment for diseases attributable to air pollution from coal-based thermal power stations in West Bengal

Other expenses associated with medical treatment

In essence, the cost of treatment of health problems among employees and local people attributable to air pollution from three aforesaid coal-based thermal power station will be a minimum of Rs. 158.1 crore per year. To this will be added

- Cost of transportation for attending hospital/doctor's chamber for the patient and attendant (s)
- Cost of special diet needed for the patient
- Cost of the loss of daily earnings of the patient and attendant (s)

As a conservative estimate, we may add 30% to the cost of treatment on account of these conditions. Therefore the total medical cost for these three thermal power stations will be:

Rs. 158.1 crore + Rs. 47.4 crore = **Rs. 205.5 crore per year**

Value of Life-Year Lost (VOLY)

Mortality effect from air pollution generally affect the elderly whose willingness to pay (WTP) to avoid premature death is substantially less. But in India air pollution causes a large number of premature deaths among children of the poorer section of the society by increasing the chances of bacterial and viral infections through compromising body's immunity. For example, 51% of tuberculosis cases in the villages can be attributed, in part, to air pollution. Therefore parents of these children will be willing to pay more to avoid or treat life-threatening illness in their children. Although concrete data are lacking in this regard, a conservative estimate puts the figure in the tune of Rs. 200 lakh per year for a population of 100,000 (Pandav et al, 1997). Accordingly, the VOLY of three power plants is calculated and presented in Table 31.

Table 31. Value of Life-Year Lost (VOLY)

Parameter	BTPS	KTPS	BkTPS
Affected population within 10 km radius	1470148	669672	183532
VOLY @ Rs. 200,00,000/- per 100,000 population per year	29,40,29,600	13,39,34,400	3,67,06,400

Total financial implication of diseases attributable to emissions from three thermal power stations

The total medical cost for illness attributable to emissions from three thermal power stations investigated in this study has been calculated as Rs. 176.27 crore/yr for BTPS, Rs. 66.53 crore/yr for KTPS and Rs. 9.40 crore/yr for BkTPS (Table 32, Figure 10) .

Table 32. Overall cost of treatment of illness related to emissions from Bandel, Kolaghat and Bakreswar thermal power stations

Parameter	Health cost for employees and local people		
	BTPS	KTPS	BkTPS
Treatment cost (Rs./yr)	1129770869	408783838	44072773
Associated cost @ 30% (Rs/yr)	338931261	122635151	13221832
VOLY (Rs/yr)	294029600	133934400	36706400
Overall (Rs /yr)	**176,27,31,730**	**66,53,53,390**	**9,40,01,005**

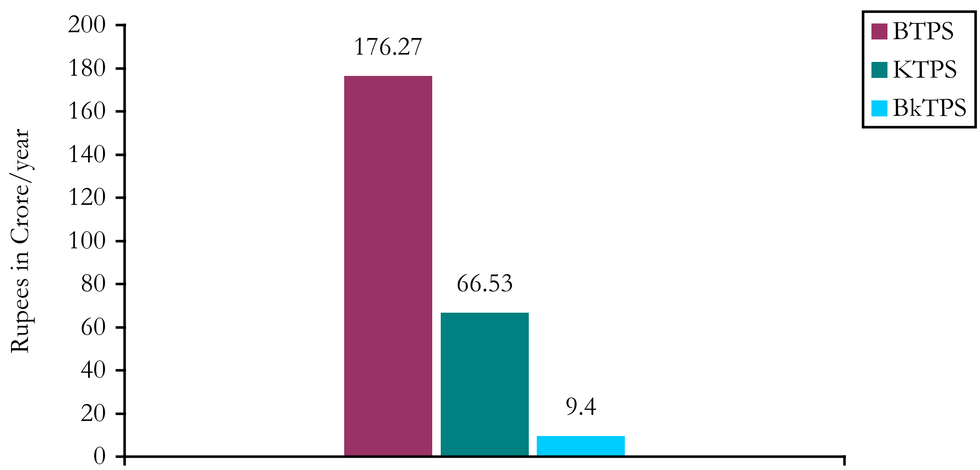


Figure 10. Total financial implication of diseases attributable to air pollution from coal-based thermal power plants in West Bengal

Cost of Global Warming

Global warming is another important externality of thermal power generation. Global warming from green house gasses (GHGs) emitted from thermal power plants adversely affects health, agriculture, water supply, sea level, ecosystem and biodiversity. An important point in this regard is that the location of GHG emissions is irrelevant to the marginal damages caused since GHGs mix with other gases in the atmosphere soon after they are emitted. India being a signatory to **Kyoto Protocol** is especially concerned about global worming.

Quantifying the marginal damages of green house gasses emissions is a highly uncertain affair. Different GHGs with different residency times in the atmosphere and with different heat-trapping properties can be compared at an equivalent basis using Global Warming Potential (GWP) concepts.

The estimate is approximately (Venema and Barg, 2003):

26 Canadian dollars per Ton CO_2-eq
= 26 x 40 = **1040 Indian rupees per Ton CO_2-eq**

Table 31. Cost of global warming from carbon dioxide emission from Bandel, Kolaghat and Bakreswar thermal power plants in West Bengal

Parameter	BTPS	KTPS	BkTPS
Average generation per day (U)	5921244	20310706	11456263
CO_2 emission (Ton/year)	2098875.7	9044357.5	3755019.4
CO_2 emission (Ton/day)	5750.34	24779.1	10287.7
Cost of global warming per day @ Rs. 1040 per Ton CO_2-eq	**59,80,358**	**257,70,224**	**106,99,232**

*Ref. Perspective Plan of WB Power Sector, 2006

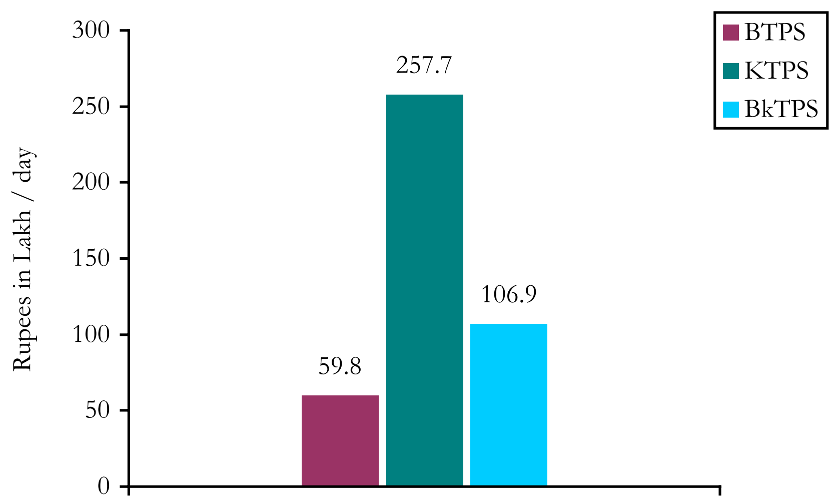


Figure 11. Cost of global warming from carbon dioxide emission

HEALTH COST PER UNIT POWER GENERATION

We have calculated the overall social cost taking into account the total health cost and cost of global warming due to carbon dioxide emission. We then calculated the health and social cost per unit of power generation.

The health cost per unit of power generation was 81.5 paise in BTPS, 8.9 paise in KTPS and 2.2 paise in BkTPS (Table 32, Figure 12). Compared with Bakreswar, therefore, the health cost/Unit was 37-times higher in Bandel, and 4-times more in Kolaghat.

Table 32. Conservative estimate of total environmental cost of generation from thermal power plant (in rupees)

Parameter	Thermal power stations		
	BTPS	**KTPS**	**BkTPS**
Health cost per year (Rs.)	1762731730	665353390	94001005
Health cost per day (Rs.)	4829402	1822886	257537
Cost of global warming /day	5980358	25770264	10699208
Average generation (Unit per day)	5921244	20310706	11456263
Energy sent out (in Unit) per day	5287671	18178082	10336986
Cost of global warming /U	1.131	1.417	1.035
Health cost/ Unit	0.815	0.089	0.022
Social cost per unit (Rs.)	1.947	1.507	1.058

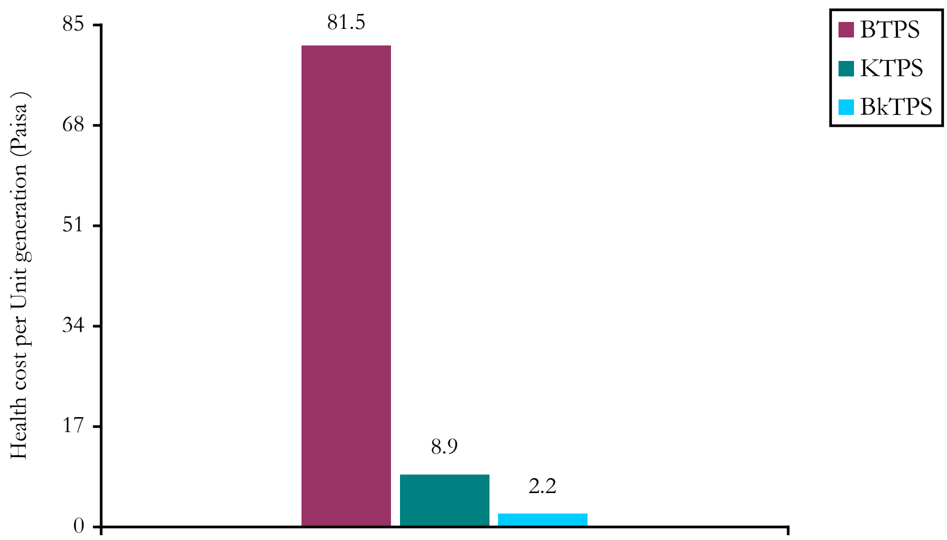


Figure 12. Comparison of health cost per unit generation of electricity from three thermal power stations

SOCIAL COST PER UNIT POWER GENERATION

The overall social cost per unit power generation was 194.6 paise in Bandel, 135.8 paise in Kolaghat and 95.6 pase in Bakreswar (Table 32, Figure 13). Compared with Bakreswar, therefore, the social cost per Unit power generation was 1.9-times higher in Bandel and 1.4-times higher in Kolaghat thermal power station.

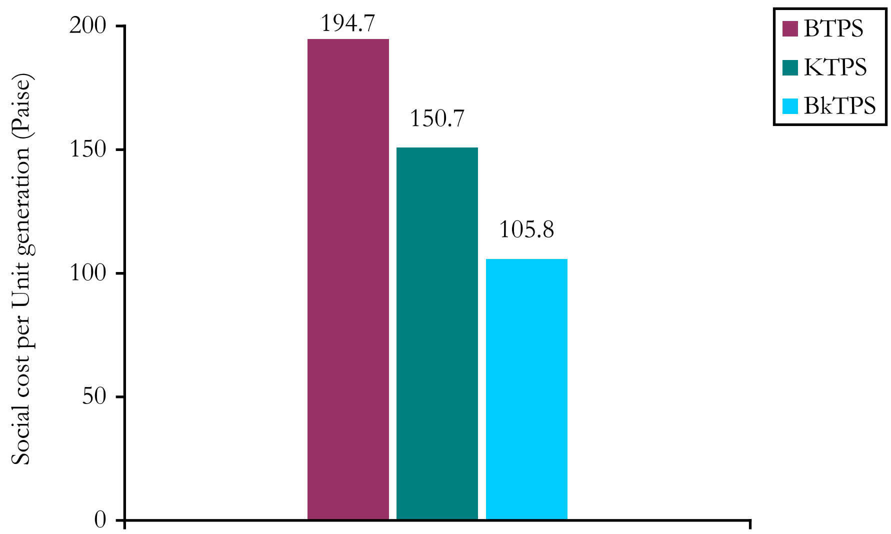


Figure 13. Comparison of social cost of power generation in three thermal power stations of West Bengal

CHAPTER-6

COMPARISON OF SOCIAL COST AMONG THERMAL POWER STATIONS IN WEST BENGAL

The health impact of air pollution emitted by different thermal power plants varies due to a number of variables including population density in the nearby areas, technology and emission pattern and quantum. As far as the health effect is concerned, respirable particulate matter with an aerodynamic diameter of less than 10 micrometer (PM_{10} or PM in short) is universally recognized as most important mediator (Pope, 2004). Therefore, we calculated the health cost in terms of PM emission from individual thermal power plants and the results are incorporated in Table 33. Then we used this value along with the cost of global warming due per Ton-eq of CO_2 emissions for calculation of Social Cost of other thermal power plants.

We have clustered the existing thermal power plants of the state under WBPDCL broadly into three categories:

- **Group-I**: Plants running on relatively old technology and with lower chimney height and hence having higher emission and lesser dispersal of pollutants; e.g. Bandel, Santaldih, DPL, New Cossipore, Dishergarh , Waria and Chinakuri thermal power stations.

- **Group-II:** Plants running on relatively new technology and having higher chimney height; e.g. Kolaghat, Titagarh and Southern thermal power stations, and

- **Group III:** Thermal power plants running on advanced technology; e.g. Bakreswar, Budge budge, Mejia, Sagardighi, Santaldih (new unit) and DPL (new unit).

We have compared the Health and Social cost of these power stations taking BTPS as representative of Group-I, KTPS for Group-II and BkTPS for Group-III.

COMPARISON OF HEALTH COST IN DIFFERENT THERMAL POWER STATIONS

The results, presented in Figure 14-16 and Table 33 revealed highest health cost in Group-I and lowest in Group-III. In Group I, health cost was highest (Rs. 5.897/Unit) in New Cossipore, followed by Waria (Rs. 4.075/U), Disergarh (Rs. 1.607/U) and DPL 1-2 (Rs. 1.0132/U). On the other hand, Santaldih (old) has the lowest health cost (12 paise/Unit) in Group-I (Figure 14).

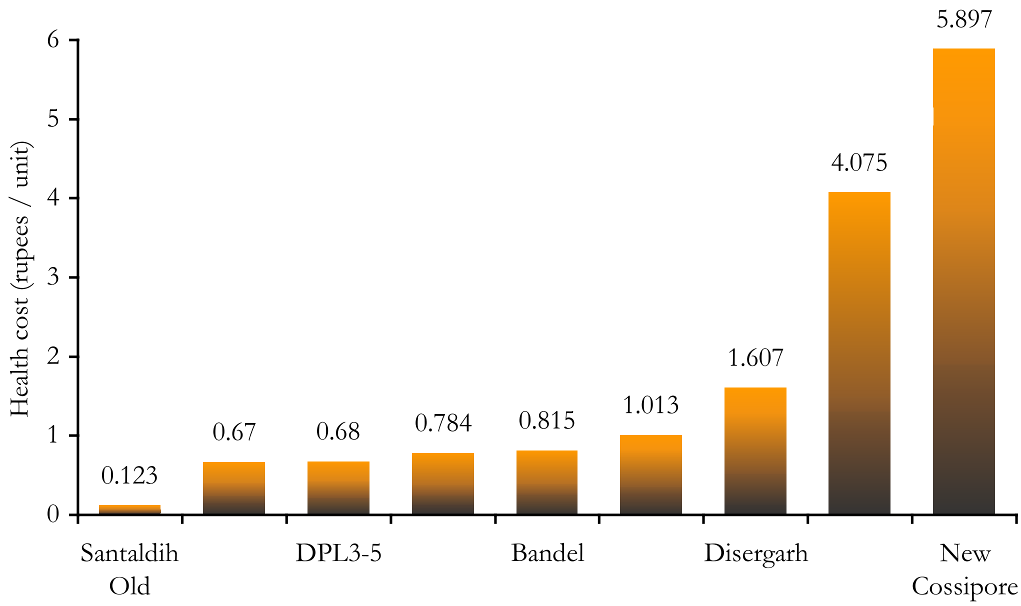


Figure. 14. Health cost (Rupees per Unit) of power generation of coal-based thermal power stations of West Bengal running on relatively old technology and with lower chimney height

In Group II, highest health cost (Rs. 1.141/Unit) was in Southern TPS, followed by Titagarh (93 paise/Unit) and Kolaghat (9 paise /Unit) [Figure 15]. In Group III, highest health cost was in DPL-7 (13 paise/Unit), followed by Budge budge (12 paise/Unit). The remaining power stations- Sagardighi, Santaldih, Mejia and Bakreswar had a low health cost of 2 to 3 paise per Unit (Figure 16).

Therefore, of all the thermal power stations, highest health cost was recorded in New Cossipore (Rs. 5.89/U) and lowest in Bakreswar (2 paise/U).

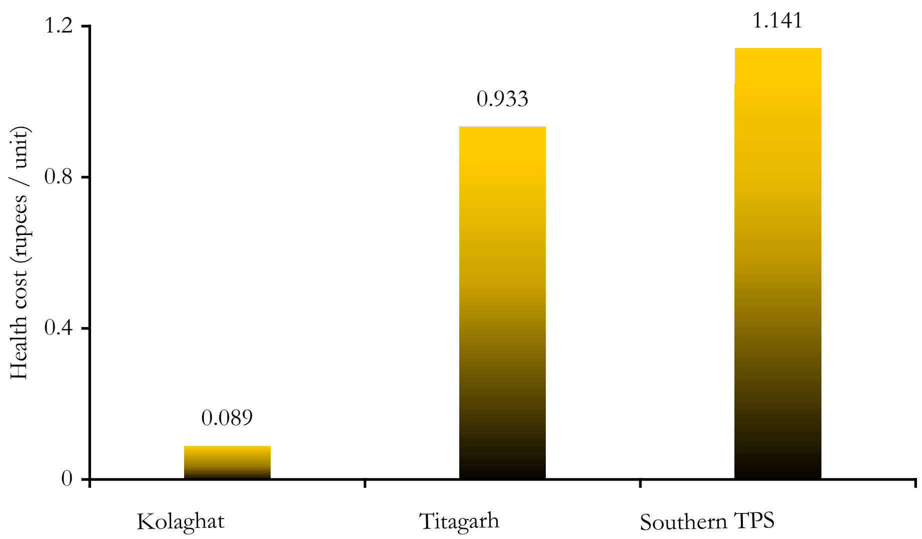


Figure 15. Health cost (Rupees per Unit) of power generation of coal-based thermal power stations of West Bengal running on relatively new technology and with higher chimney height

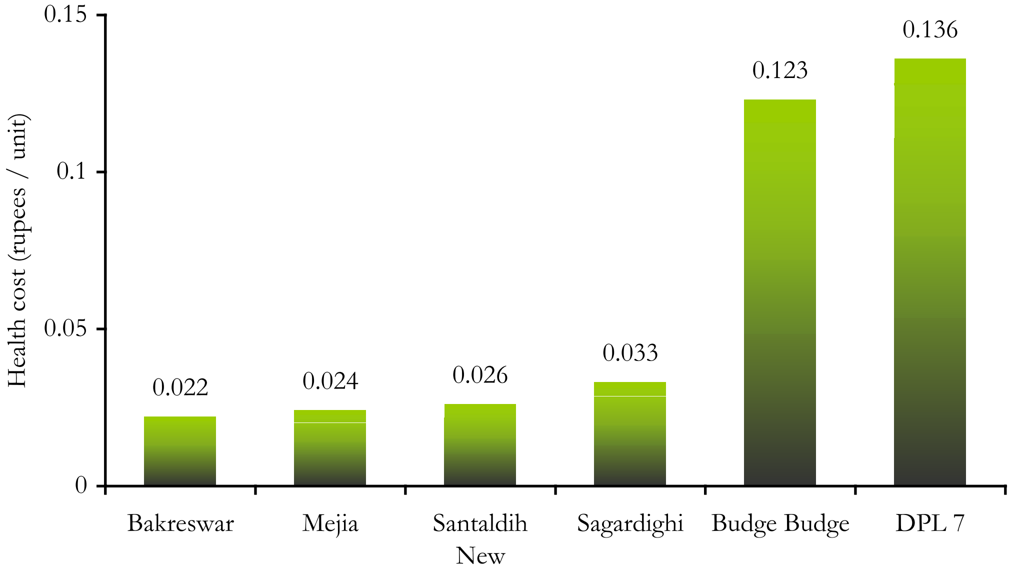


Figure 16. Health cost (Rupees per Unit) of power generation of coal-based thermal power stations of West Bengal running on advanced technology and with higher chimney height

COMPARISON OF OVERALL SOCIAL COST IN DIFFERENT THERMAL POWER STATIONS

As in case of health cost, higher social cost was recorded in thermal power stations belonging to Group-I and lower in Group-II and Group III (Fig. 17-19, Table 33). In Group I, social cost was highest (Rs. 7.559/Unit) in New Cossipore, followed by Waria

(Rs. 5.231/U), Dishergarh (Rs. 3.585/U), Chinakuri (Rs. 2.813/U), and DPL 1-2 (Rs. 2.648/U). On the other hand, Santaldih (old) has the lowest social cost (Rs. 1.622/Unit) in Group-I (Figure 17).

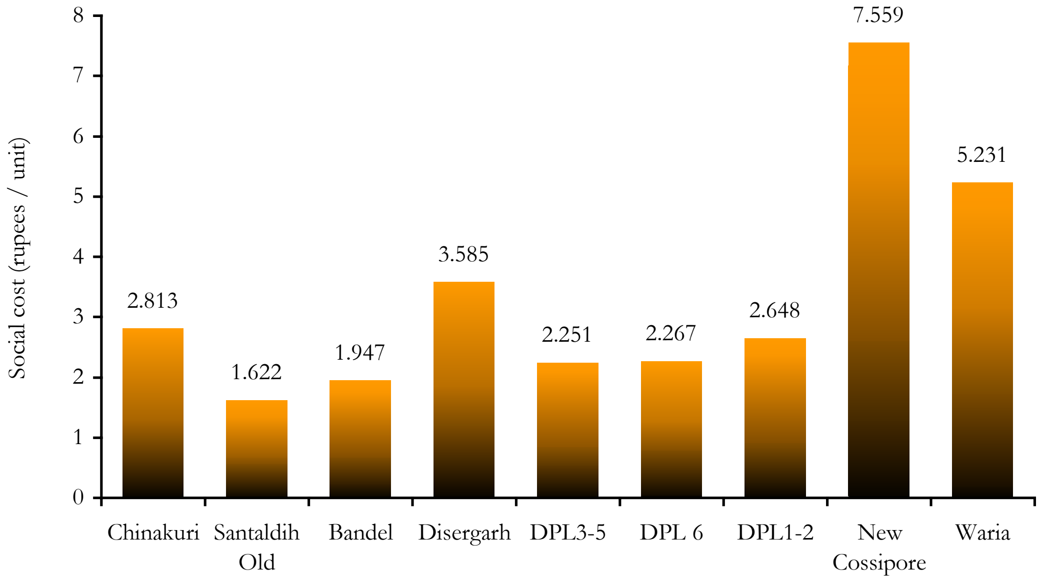


Figure 17. Social cost of thermal power generation in plants with old technology and lower chimney height

In Group II, highest social cost (Rs. 2.422/Unit) was in Southern TPS, followed by Titagarh (Rs. 2.121/Unit) and Kolaghat (Rs. 1.057 /Unit) [Figure 18].

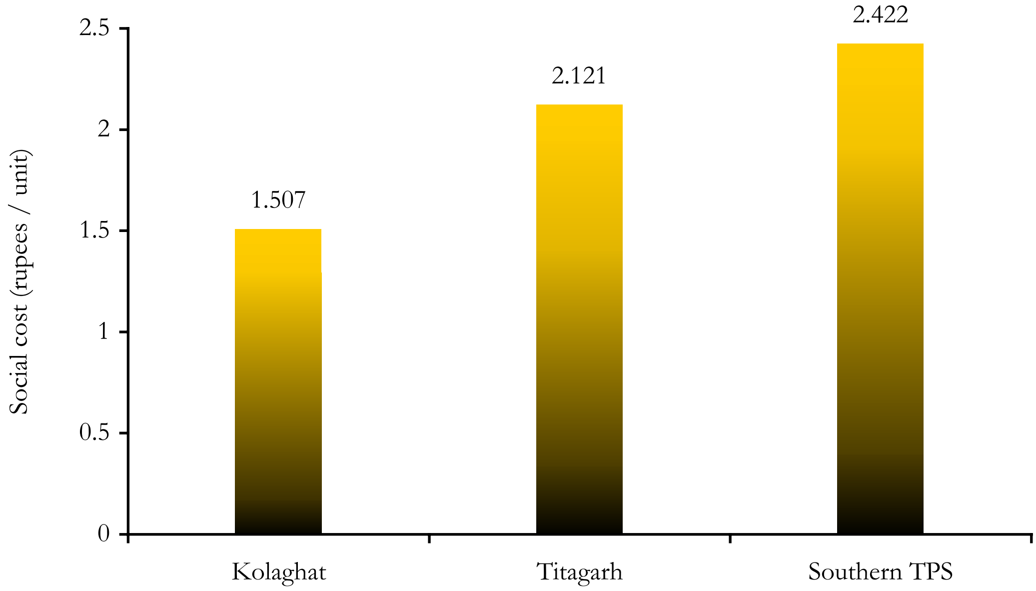


Figure 18. Social cost of thermal power generation in plants with relatively new technology and higher chimney height

In Group III, social cost was highest in Mejia (Rs. 1.312/Unit), followed by Budge budge (Rs. 1.282/Unit) and Bakreswar (Rs. 1.058/U). On the other hand, lowest social cost was recorded in Sagardighi (89 paise/U) [Figure 19].

Therefore, of all the thermal power stations, highest social cost was recorded in New Cossipore (Rs. 7.559/U) and lowest in Sagardighi (89 paise/U).

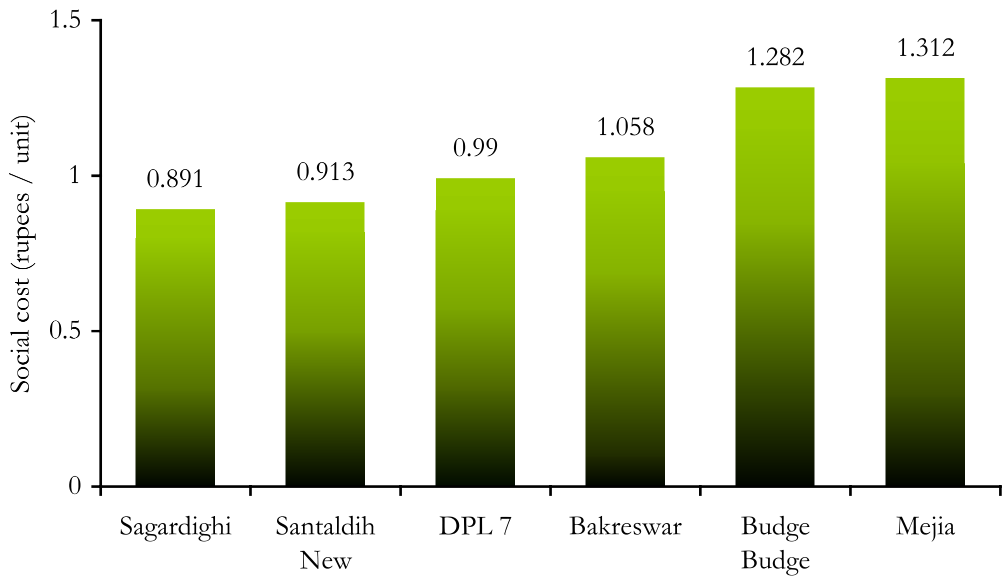


Figure 19. Social cost of thermal power generation in plants with advanced technology and lower chimney height

Table 33. Social cost of coal-based thermal power generation in West Bengal

Thermal Power Station	Annual Sent Out (MU)	Auxiliary Energy Consumption in %	Annual Generation (MU)	PM Emission (g/U)	Average Generation U/day	CO2 Annually in Ton	Cost of global warming for CO2 in Rs.	Affected Population in 10 Km radius (NO)	Health Cost/Unit/Person in Rs.	Health cost in Rs./Unit	Social cost/Unit in Rs.
Bandel	1930	10.7	2161.254199	0.2049	5921244	2098875.7	1.1310004	1470148	0.0000005548	0.815606	1.947
Santaldih-old	1167	14.41	1363.477042	0.52	3735554	1681167.2	1.4982124	214664	0.0000005775	0.123962	1.622
Santaldih-new	1693.965	9	1861.5	0.112	5100000	1443705.8	0.8863548	214664	0.0000001225	0.026297	0.913
DPL1-2	147.4			5.13	288000	231626.3	1.6342694	1114672	0.0000009095	1.013764	2.648
DPL3-5	1174			0.98	4158000	1772441.4	1.5701354	1114672	0.0000006106	0.680617	2.251
DPL-6	502	9.19	2007.92864	0.85	1980000	770606.8	1.5964762	1114672	0.0000006012	0.670181	2.267
DPL-7	2043.927	8.5	2233.80000	0.109	6120000	1677156.1	0.8533780	1114672	0.0000001225	0.136549	0.99
New Cossipore	438	8.79	480.2105032	2.74	1315645	699666.7	1.6613091	7998208	0.0000007373	5.89748	7.559
Chinakuri	190	9.16	209.1589608	2.15	573038.2	255592.3	1.3990313	1128832	0.0000006949	0.784425	2.183
Disergarh	42	13.33	48.45967463	12.27	132766.2	79861.5	1.9775239	1128832	0.0000014237	1.607118	3.585
Waria	1836.70902	11	2063.718	5.19	5654022	2039691.7	1.1549349	4458688	0.0000009141	4.07564	5.231
Kolaghat	6635	10.5	7413.407821	1.1	20310706	9044357.5	1.4176536	669672	0.0000001340	0.08975	1.507
Titagarh	909	8.91	997.9141508	0.14	2734011	1037830.7	1.1873971	7542376	0.0000001238	0.93341	2.121
Southern	1636	9.27	1803.15221	0.26	4940143	2014121	1.2803703	7998208	0.0000001427	1.14156	2.422
Bakreswar	3773	9.77	4181.536074	0.13	11456263	3755019.4	1.0350438	183532	0.0000001225	0.02248	1.058
Budge Budge	3455	9.04	3798.372911	0.26	10406501	3851550.1	1.1593668	797248	0.0000001543	0.123	1.282
Mejia	4126.23	10.94	4633.090052	0.47	12693397	5110298.3	1.2880305	156688	0.0000001543	0.02417	1.312
Sagardighi	4065.516	9	4467.600	0.109	12240000	3354312.2	0.8580669	272532	0.0000001225	0.03339	0.891

CONCLUDING REMARK

The economic and financial cost of a product, such as electricity, is often not its full cost because environmental costs are usually neglected. The costs constitute a loss of social welfare due to their negative impacts on human health, ecology and our environment par se. The health cost is rarely counted in the price of the goods or services produced when the coal is burned for production of electricity. Buyers of coal-based electricity is therefore paying less than it's real cost, and society bears the burden of this loss of social welfare.

This study is the first in India to use regional scale source-receptor modeling to quantify the air quality, public health and environmental externalities associated with coal-based thermal power generation. Unlike financial accounting, social cost estimation can never be precise, because the science that links pollution emissions to human diseases and environmental degradation is incomplete. We still do not know the precise mechanism by which pollutants interfere with normal functions of our body and the ecosystem that sustain us. Research in techniques for valuating the economic worth of the services that our ecosystem provides may in time reduce these uncertainties.

Emission from thermal power plants was associated with an increase in the prevalence of respiratory symptoms, lung function reduction, COPD, inflammation of the airways, covert pulmonary hemorrhage, hypertension, and early cellular changes towards malignancy and neurobehavioral symptoms. Fortunately, most of these health impairments are reversible.

The results of this study can be considered as a first time conservative estimate since a large number of known impacts (such as ozone and crop damage, CO and hospital admission for heart diseases, acid deposition and fish yield loss etc.) could not be evaluated because neither the data nor the damage function were available. Still, we found the social cost is substantial and highly significant. Therefore, concerted efforts should be made by all concerned for reduction of pollutant emission from thermal power plants in order to safeguard the physical and mental health of the employees and local population.

CHAPTER-7

RECOMMENDATION

1. Epidemiological studies have identified PM_{10} and $PM_{2.5}$ as the principal mediators of health hazards of air pollution from combustion of coal during thermal power generation. Therefore, we recommend monitoring of both PM_{10} and $PM_{2.5}$ in ambient air at the power plants and nearby areas (within 10 km radius) at regular basis.

2. Ozone is one of the most harmful pollutants. It is not directly emitted but it is formed in complex photochemistry of oxides of nitrogen and hydrocarbons in the atmosphere. Only a limited amount of information is available for photochemical air pollution in the country. We recommend monitoring of ozone concentration in all thermal power stations and adjoining areas. Meteorological variables like wind speed should be taken into account during monitoring days.

3. Volatile organic compounds like benzene, and polycyclic aromatic hydrocarbons such as benz(a)pyrene are potential cancer-causing agents emitted during combustion of coal. Considering their adverse health impact coupled with absence of a threshold level for their carcinogenicity, these two compounds should be monitored regularly in order to minimize their emissions to protect public health.

4. Recent published works have identified transition metals adsorbed on particulates as the main source of oxidative stress that mediate most of the health effects of air pollution. Therefore, we recommend regular monitoring of iron, copper, nickel, chromium and manganese in ambient air within thermal power stations and in adjoining areas.

5. We recommend epidemiological study in all thermal power plants at regular intervals to detect and analyze the health effects of air pollution, because apparently small or infrequent effects spread over large populations can have important public health consequences as air pollution often acts in synergy with other agents to cause or exacerbate serious diseases.

6. Recent studies in the West have emphasized the need to explore the effect of ambient air pollution on the cardiovascular system because most people die due to air pollution exposures from diseases of the heart. Unfortunately, very little is known about this problem in India. We found a very high prevalence of hypertension among workers, especially in BTPS and KTPS. Therefore, we recommend a comprehensive study on the effects of chronic air pollution exposures on cardiovascular system of people employed in thermal power plants and living nearby.

7. Biological markers of air pollution exposure and effect are now available. Notable examples are alveolar macrophage response and sputum cytology for respiratory toxicity; platelet activity, fibrinogen and C-reactive protein for cardiovascular effects; urinary excretion of trans,trans-muconic acid for benzene exposure; and micronucleus assay for genotoxicity. We recommend use of these biomarkers in all future epidemiological studies on health impact of air pollution from thermal power stations.

8. We propose establishment of biomedical and toxicological laboratories in existing health care facilities in all thermal power stations.

9. We found neurobehavioral problems among a large section of the employees. Besides air pollution, job stress could have contributed significantly to these conditions. In order to reduce stress and strain, we propose recreational activities in the plants at regular intervals and paid holidays and free travel for the employees and their dependants once in a year.

10. From the economic point of view, the total cost of control measures should be measured in terms of total benefits to the society. The monetary benefits of reducing illness and premature mortality associated with even a small change in air pollution exposure may be important for cost-benefit analysis in air pollution mitigation programs.

11. Mass awareness campaigns should be widely promoted through educational and information programs involving local bodies, voluntary organizations, students, trade unions and others educating people about air pollution control measures taken up by the authority.

CHAPTER-8

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