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ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF COAL-FIRED PAYRA THERMAL POWER PLANT

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ABSTRACT
Coal-based thermal power plants are essential for meeting the growing energy demands of developing countries like Bangladesh. However, their environmental impact, particularly on agriculture and ecosystems, raises serious concerns. This study assesses the environmental consequences of the Payra Thermal Power Plant in the Kalapara region, focusing on air, water, and soil quality, as well as agricultural productivity and biodiversity. This study analyzed key pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NOx), particulate matter (PM), and heavy metals from fly ash, and their impact on soil fertility, crop yield, and aquatic biodiversity. Additionally, greenhouse gas emissions such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) contribute to climate change and local air pollution. Field data were collected through air and water quality monitoring, soil analysis, and structured farmer surveys within a 9 km radius of the plant. The findings indicate a decline in agricultural output, contamination of water bodies, and disruptions in fish populations, particularly the economically significant Ilish fish. The study highlights the urgent need for mitigation strategies, including advanced emission control technologies, sustainable waste management, and stricter environmental regulations, to minimize ecological degradation while maintaining energy production.

Keywords: *Coal-fired Power Plants, Environmental Impact, Agriculture, Ecosystem, Air Pollution, Greenhouse Gas Emissions, Mitigation Strategies.*

1. INTRODUCTION
Rapid industrialization and the growing demand for electricity in developing countries like Bangladesh have led to an increasing reliance on coal-fired power plants. Among them, the Payra Thermal Power Plant (PTPP) is one of the largest coal-based power generation facilities in the country, playing a crucial role in meeting national energy needs [1]. However, coal combustion is associated with significant environmental consequences, including severe air, water, and soil pollution due to the release of sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), and toxic heavy metals from fly ash [2]. These pollutants contribute to acid rain, soil degradation, and respiratory diseases, posing threats to local agriculture, ecosystems, and human health [3,4].
Coal-fired power plants are the largest contributors to global CO_2 emissions from power generation, accounting for approximately 75% of such emissions [5]. In addition to carbon dioxide (CO_2), coal combustion releases potent greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), which have significantly higher global warming potential than CO_2 [6]. These emissions contribute to climate change, leading to rising temperatures, altered precipitation patterns, and an

increased frequency of extreme weather events [7]. Bangladesh, being a low-lying country, is particularly vulnerable to sea-level rise and climate-induced disasters, making the regulation of coal emissions a pressing concern [8].

Environmental degradation is becoming increasingly evident in the Kalapara region, where the PTPP is located. Elevated levels of SO_2 and NO_x emissions have led to acidification of soil and water bodies, directly impacting agricultural productivity [9]. Farmers in the region have reported declining crop yields, particularly for staple crops such as paddy and coconut, which are vital to the local economy [10]. Acid rain, caused by SO_2 and NO_x emissions, reduces soil pH, damages plant tissues, and disrupts nutrient absorption, further worsening agricultural decline. Additionally, untreated wastewater discharge and thermal pollution from the plant have affected aquatic ecosystems. Heavy metals such as arsenic, mercury, and cadmium from coal ash contaminate local rivers, posing risks to fisheries and public health [11]. Ilish fish populations, a key economic and dietary resource, have declined due to increased water toxicity and temperature fluctuations caused by thermal pollution [12]. Fly ash deposition on surrounding farmland has further led to reduced crop yields and declining soil fertility [13,14].

Despite global concerns regarding coal-fired power plants, limited localized research has been conducted on the environmental effects of the PTPP in Bangladesh [15]. While broader studies have documented the negative consequences of coal energy on air and water quality, agriculture, and public health, the specific case of the PTPP's impact on the Kalapara region remains underexplored [16,17]. Despite these known impacts, limited localized research has examined the specific consequences of the PTPP on agriculture, ecosystems, and livelihoods in the Kalapara region. This study aims to fill this gap by analyzing air, water, and soil pollution levels, assessing their effects on agriculture and biodiversity, and proposing mitigation strategies to balance energy production with environmental sustainability.

2. METHODOLOGY

This study assesses the environmental impacts of the PTPP in Kalapara, Bangladesh, by evaluating changes in air, water, and soil quality and their effects on agriculture and biodiversity. The research followed a mixed-methods approach, combining field data collection, laboratory analysis, and structured surveys to ensure a comprehensive environmental assessment.

Table 2.1: Villages affected by the PTPP.

SL	Village Name	SL	Village Name
1	Madhu Para	9	Calta Buniya
2	Garad Kha	10	Champapur
3	Sikander Khali	11	Golbaniya
4	Tia Khali	12	Dholai
5	Dhan Khali	13	Moricbuniya
6	Ful Tali	14	Londa
7	Lalua	15	Nishanbariya
8	Banati	16	Neshan baria

A 9 km radius around the power plant was selected as the study area, covering agricultural villages such as Madhupara, Garad Kha, Sikander Khali, and Banati (Table **2.1**), where environmental degradation has been reported since the plant's operation.

Figure 2.1: The geographic distribution of the PTPP and the nearby agricultural villages that have experienced environmental impacts, including changes in crop yields and ecosystem balance.

The study employed random and purposive sampling techniques to collect air, water, and soil samples from affected locations. In addition, structured interviews and surveys were conducted with local farmers and fishermen to assess the socio-economic impacts of environmental pollution.

Figure 2.2: The PTPP. (a) Side View and (b) Above View.

Air quality monitoring was conducted using stationary and portable sensors placed at five locations within the study area. Concentrations of key air pollutants—SO_2, NO_x, PM (PM2.5 and PM10), and CO_2—were measured following the National Ambient Air Quality Standards (NAAQS) and World Health Organization (WHO) guidelines [18,19]. Air sampling was performed for three months, with data collected every six hours to account for variations in pollution levels during different times of the day.

Water samples were collected from two major rivers near the PTPP—Andharmanik River and Golachipa River, as well as from irrigation canals supplying local farmlands. Sampling followed EPA Method 200.7 for detecting heavy metals (arsenic, mercury, cadmium) and ISO standards for testing pH, dissolved oxygen (DO), temperature, and total suspended solids (TSS) [20]. Samples were analyzed in a laboratory to determine pollutant concentrations. Additional seasonal sampling was conducted during the monsoon to account for variations in rainfall-related pollutant dispersion.

Soil samples were collected from farmlands within a 5 km radius of the power plant to assess the impact of fly ash deposition and acid rain on agricultural productivity. Samples were taken from the top 50 cm of soil, following ISO 10390:2005 for pH measurement and ISO 11666:1995 for heavy metal analysis [21,22]. Standard soil fertility indicators, including organic matter content, nitrogen (N), phosphorus (P), potassium (K), and heavy metal contamination, were assessed. Farmers in the affected villages were interviewed using a structured survey questionnaire to collect crop yield data from the past three years, allowing a comparative analysis of yield decline linked to pollution exposure.

Water temperature measurements were taken at multiple points along the Andharmanik River using digital temperature loggers to evaluate the impact of thermal pollution on local aquatic ecosystems. Water temperature variations were measured at multiple locations and compared to pre-operation levels, using IEA thermal discharge guidelines [23]. The study also investigated changes in Ilish fish populations, a key economic resource, by analyzing fishermen's catch records from the past five years and conducting interviews with local fishery experts.

The study included structured household surveys and interviews with 200 residents from affected villages to evaluate the health impact of air pollution exposure. The survey was based on WHO Air Quality Guidelines for Public Health and included questions on respiratory illnesses (asthma, bronchitis), cardiovascular diseases, and skin conditions [24]. Additional data were collected from local health clinics to assess trends in respiratory illnesses over the past five years.

To examine the socio-economic impact, occupational shifts and income loss among farmers and fishermen were analyzed using pre- and post-plant data. Changes in poverty levels were evaluated based on the Bangladesh Bureau of Statistics (BBS) classification of income groups [25].

3. RESULTS AND DISCUSSION

3.1 Socio-Economic Impacts on Employment, Poverty, Displacement, and Crop Productivity

The Payra coal-based thermal power plant falls under the union Dhankhali, with 26,073 individuals within its 9 km radius. According to the statistics, there were 13,023 males and 13,048 females, who comprised 5,859 families in total. The following table presents the occupational categories of these individuals before and after the establishment of the thermal power plant.

Table 3.1: Occupational categories before and after the establishment of the PTPP.

Indicator	Before Plant (%)	After Plant (%)
Agriculture	30	12
Agriculture Laborer	7	4
Wage Laborer	6	3
Shopkeeper	1	4
Commerce	4	9
Transport	1	9
Construction Labor	4	8
Government Employee	3	7
Fisherman	8	6
Unemployed	3	1
Others	33	37

Around 40 percent of Bangladesh's population lives just above the upper poverty line. The power station project may influence the poverty situation due to the generation of higher incomes, improved communications, and health facilities. However, the project's acquisition of lands may have adverse effects on the economic well-being of the relocated people. The table below indicates the reasons for measuring poverty pre- and post-the establishment of the plant.

Table 3.2: Poverty in Power Plant Areas

Indicator	Before Plant (%)	After Plant (%)
Very High	2	5
High	1.5	18
Medium	10	22
Low	25	12
Very Low	23.5	10
No Comment	38	33

The power plant extends over 1,000 acres in Dhankhali village on the banks of the Andharmanik River. This acquired land has displaced 130 families, which have a population of 516. The government has arranged accommodation for people who lost their homes due to the construction of the power plant. Housing accommodation has been provided to a total of 100 families under the Rehabilitation Scheme.

The stack emissions of SO_2 and NOx from the PTPP have immensely contributed to impacting the fertility of farmland in the surrounding villages. The incident of acid rain due to the combined effect of atmospheric moisture and pollutants has caused more harm because of soil acidification, thus degrading productive capacity. As may be observed from Table 3.3, the staple crops of paddy, watermelon, and sweet potatoes immediately started showing a decline in yield. Aman rice has fallen from 4.5 metric tons per hectare to 3 metric tons per hectare.

Table 3.3: Agricultural productivity before and after PTPP Operations

Crop	Before (metric tons/hectare)	After (metric tons/hectare)
Aman rice	4.5	3
Watermelon	30-35	20-25
Sweet potato	10-12	8-9
Green chili	1.5	0.9

Apart from acid rain, heavy metals such as arsenic and cadmium deposited in their fly ash have worsened the condition of the soil and affected crop cultivation. The farmers in the locality are concerned about the crops, their size has reduced drastically. Deposits of toxic heavy metals like arsenic and cadmium in fly ash have exacerbated soil pollution, restricted crop growth, and reduced its quality. Md. Joynal Farazi, a local farmer, also documented an increase in the amount of fly ash deposits as one of the major reasons for the sudden decline in the yield of gourds, which he has cultivated for over a decade.

3.2 Impact on Air, Water, and Soil Quality

The study findings reveal significant environmental and socio-economic impacts of the PTPP on air, water, and soil quality. The data collected from field measurements, laboratory analysis, and structured surveys provide a comprehensive assessment of pollution levels and their consequences.
Air quality analysis showed a substantial increase in SO_2, NO_x, PM2.5, and CO_2 levels within the study area. The recorded SO_2 concentration near the PTPP averaged 65 µg/m³, exceeding the National Ambient Air Quality Standard (50 µg/m³) [18]. Similarly, NO_x levels reached 80 µg/m³, surpassing the national threshold of 53 µg/m³. The presence of PM2.5 and PM10 exceeded WHO-recommended air quality limits, indicating a potential risk of respiratory diseases among local populations [19]. The correlation analysis between SO_2 and PM2.5 levels ($r = 0.72$, $p < 0.05$) suggests that coal combustion emissions significantly contribute to fine particulate matter pollution.
Water quality assessment revealed contamination of surface water bodies, particularly in the Andharmanik and Golachipa Rivers, due to thermal discharge and heavy metal accumulation. The measured water temperature increased by 3.5°C compared to pre-operation levels, exceeding the International Energy Agency (IEA) thermal pollution limit of 2°C [23]. Heavy metal analysis detected arsenic (As: 0.048 mg/L), mercury (Hg: 0.0023 mg/L) and cadmium (Cd: 0.017 mg/L), all of which surpass WHO drinking water quality limits [26]. The contamination has led to a decline in Ilish fish populations, with fish catch data indicating a 45% reduction in the last three years. Fishermen reported increasing occurrences of fish kills and deformities, suggesting bioaccumulation of heavy metals in aquatic species.
Soil quality analysis highlighted acidification and heavy metal contamination, impacting agricultural productivity. The average soil pH decreased from 6.2 to 4.8, indicating significant acidification due to SO_2 and NO_x emissions leading to acid rain. Heavy metal concentrations in soil samples showed elevated levels of arsenic (4.2 mg/kg), cadmium (2.8 mg/kg), and lead (6.1 mg/kg), exceeding FAO permissible limits for agricultural soils [27]. Crop yield data showed a 33% decline in paddy production, while coconut and watermelon yields decreased by 27% and 21%, respectively, compared to pre-PTPP levels. Farmers identified fly ash deposition, acid rain, and irrigation water contamination as primary causes of yield reduction.

3.3 Environmental Impact on Local Vegetation and Ecosystems

The local ecosystems around the PTPP—aquatic environment—and rivers, mainly the Andharmanik and Golachipa Rivers, have been contaminated with pollutants coming from the plant. These rivers are highly important to the local biodiversity because these rivers host the Ilish fish, which is the most economically valuable fish in the locality. The research found that the discharge of untreated wastewater with heavy metals like mercury and lead causes a sharp decrease in the population of fish. The fishermen also continued to say that the fish yield had dropped from 9,000 tons to 4,500 tons per year and was ruining their means of living. Thermal pollution, an increase in river water temperature by as much as 3.5°C, further disrupts aquatic life since it promotes changes in breeding cycles and oxygen levels within the water, which the water living creatures depend on for survival.

Figure 3.1: View of the Andharmanik river near the PTPP showing reduced fish activity due to pollution from the thermal power plant.

Both fly ash and acid rain appear to have affected vegetation in villages surrounding PTPP. Copies of coconut and palm trees, on which the local economy is dependent, show signs of distress: yellow falling leaves and low fruit production are cases reported by farmers. Increase in atmospheric particulate matter—mainly from fly ash—has deposited a coating on tree leaves that interferes with photosynthesis, leading to poor health in trees. Sufia Begum, a resident of Madhupara, stated that "*Coconut tree yields have dramatically decreased since the power plant began operations.*" Figure 3.2 shows that coconut trees within the power plant area show signs of stress from fly ash deposition, while trees located in remote areas from the power plant remain unaffected.

The plant emissions have been blamed for climatic changes in the region, such as local people reporting an increase in temperatures over the summer periods. This increase in temperature agrees with the heat produced when coal is burned at high temperatures inside the plant, producing large quantities of heat into the atmosphere. This study observed that the average summer temperature of villages within the 10 km radius of this plant increased by 1.5°C. This increase in temperature, caused by pollution, has already begun to alter microclimates critical for the unique biodiversity inside the region. Such changes are highly vulnerable to vegetation and wildlife. The higher temperatures are also associated with a high rate of evaporation, which might in itself affect soil moisture and, in turn, further inhibit agricultural productivity.

Figure 3.2: Impact of fly ash deposition on different types of trees. (a) Trees within the power plant area and (b) Trees in remote areas from the power plant.

Table 3.4: Changes in Local Temperature Before and After Power Plant Operations

Period	Average Summer Temperature (°C)
Before 2020	31.5
After 2020	33.0

3.4 Public Health Impacts

A health impact assessment revealed a significant rise in respiratory diseases among residents living within a 9 km radius of the PTPP power plant. Health clinic records indicate a 38% increase in asthma and chronic bronchitis cases over the past three years. Survey data showed that 35% of respondents—particularly children and the elderly—experienced respiratory symptoms, aligning

with high PM2.5 levels recorded near the PTPP. Statistical analysis found a significant association ($p < 0.01$) between PM2.5 exposure and respiratory illness prevalence.
In addition to respiratory issues, 12% of respondents reported skin conditions, likely linked to exposure to heavy metals in water and soil. Residents attribute these health problems to prolonged exposure to airborne pollutants, particularly particulate matter. Md. Zahid Parvez, a local teacher, noted, *"Many children in the village are developing asthma-like symptoms that were not as common before the power plant's construction."*

Table 3.5: Reported Health Issues in Villages Near the PTPP.

Health Issue	Percentage of Affected Population (%)
Respiratory illnesses	35
Skin diseases	12
Mental health issues	8

3.5 Mitigation and Recommendations

To mitigate the environmental damage caused by the PTPP, several measures can be implemented:

a. Installation of Advanced Emission Control Technologies: Flue Gas Desulfurization (FGD) can be fitted to reduce SO_2 emissions. Low-NOx burners also considerably reduce harmful emissions.
b. Fly Ash Management: Safe containment and recycling systems, such as using fly ash in building materials, would lower the level of contamination of the soil and air in the surroundings.
c. Wastewater Treatment: The easy installation of advanced wastewater treatment plants would prevent heavy metals from entering rivers and affecting aquatic ecosystems.
d. Public Health Monitoring: Periodic health checkups need to be conducted in the affected villages, and medical facilities need to be established, providing expertise in respiratory and skin-related diseases.

4. DISCUSSION

The findings confirm that coal-fired power plants contribute to severe environmental degradation and public health risks, aligning with previous studies conducted in Bangladesh and South Asia [10,13]. The significant increase in SO_2 and NO_x emissions directly correlates with air quality deterioration and acid rain formation, leading to soil acidification and agricultural decline [11]. These findings are consistent with studies from India, where coal-based emissions have caused extensive environmental damage in rural farming regions [28].
The presence of heavy metals in water bodies and their bioaccumulation in fish species are major concerns, as they pose long-term health risks to human populations [29]. The 45% reduction in Ilish fish populations suggests that thermal pollution and heavy metal contamination are disrupting aquatic ecosystems, similar to findings from industrial areas in Vietnam and Indonesia [30].
The observed increase in respiratory diseases and cardiovascular conditions aligns with previous epidemiological studies linking PM2.5 exposure to adverse health outcomes [19]. The strong correlation between air pollution levels and respiratory illnesses underscores the need for urgent mitigation strategies, such as the implementation of Flue Gas Desulfurization (FGD) systems and low-NOx burners to reduce emissions.

The study's socio-economic findings indicate that coal-fired power plants can lead to economic instability, particularly in communities dependent on agriculture and fisheries. Similar patterns have been observed in other regions where coal plants have displaced traditional livelihoods, increasing poverty and migration rates [16]. The decline in agricultural output and fishery resources highlights the pressing need for compensation programs, alternative employment opportunities, and stricter environmental regulations to mitigate socio-economic disruptions.

5. CONCLUSIONS

The PTPP, one of Bangladesh's largest coal-based power plants, has significantly contributed to environmental degradation in the surrounding region. Emissions from coal combustion—including toxic fly ash and greenhouse gases—have polluted air, water, and soil, threatening agricultural productivity, biodiversity, and public health. Heavy metals such as arsenic, mercury, and lead have contaminated local ecosystems, reduced crop yields, and compromised food security. Additionally, untreated wastewater and thermal discharge have disrupted aquatic life, particularly in the Lalua River, affecting livelihoods dependent on fisheries. These cumulative impacts endanger both the ecological balance and the socio-economic well-being of nearby communities. Urgent and coordinated policy interventions are essential to reduce emissions, manage industrial waste, and protect environmental and human health. Sustainable energy strategies must be prioritized to balance power generation with long-term ecological resilience.

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