

Environmental and Human Health Implications of Thermal Power Generation in Baghdad Metropolitan, Iraq

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Abstract - Baghdad, the capital of Iraq, faces a chronic and severe electricity deficit, compelling a heavy reliance on a network of thermal power plants. These facilities, predominantly fueled by natural gas, heavy fuel oil (HFO), and diesel, are critical for meeting the city's energy demands but are also significant sources of environmental degradation and public health risks. This research paper synthesizes existing scientific literature, governmental reports, and data from international organizations to provide a comprehensive analysis of the multifaceted environmental implications of thermal power generation within the Baghdad metropolitan area. The primary impacts examined include severe air pollution from emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM_{2.5} and PM₁₀), and heavy metals, which exacerbate respiratory and cardiovascular diseases among the population. The paper further explores the consequences of water resource utilization, focusing on thermal pollution and chemical contamination of the Tigris River, the city's primary water source. Issues related to solid waste management, specifically the disposal of coal ash (where applicable) and fly ash and their potential for soil and groundwater contamination are also discussed. Furthermore, the present research quantifies the contribution of these plants to national greenhouse gas emissions, linking local operations to global climate change challenges and Iraq's particular vulnerability to its effects. The socio-economic burdens, including escalating healthcare costs and reduced quality of life, are analyzed in the context of the city's already stressed infrastructure. Finally, the paper evaluates a range of mitigation strategies and policy recommendations, from technological retrofits like flue-gas desulfurization and electrostatic precipitators to a strategic transition towards renewable energy sources, particularly solar power, and enhanced energy efficiency measures. The present study concludes that the environmental and health costs of Baghdad's current reliance on conventional thermal power are unsustainable and underscore the urgent need for a comprehensive, integrated energy and environmental policy to secure a healthier and more sustainable future for the city.

Keywords - Thermal Power Plant, Environmental Impact, Air Pollution, Water Pollution, Baghdad, Iraq, Public Health, Particulate Matter, Climate Change, Renewable Energy.

I. INTRODUCTION

The Energy Crisis in Post-Conflict Iraq

Decades of conflict, international sanctions, and subsequent instability have left Iraq's critical infrastructure, particularly its electricity sector, in a state of chronic disrepair. The national grid is unable to meet the burgeoning demand of a growing population and increasing industrialization. This has

resulted in a persistent electricity deficit, with supply often falling short of demand by several gigawatts, leading to rolling blackouts that can last for most of the day, especially during the sweltering summer months when demand for cooling peaks (World Bank, 2021). This energy gap has profound socio-economic consequences, stifling economic activity, degrading public services, and severely impacting the quality of life for Iraqi citizens.

Baghdad's Dependence on Thermal Power

Baghdad, as the political, economic, and population center of Iraq, bears the brunt of this energy crisis. To bridge the supply-demand gap, the government has relied heavily on the rehabilitation of existing power plants and the construction of new thermal power stations. These facilities, which convert the chemical energy of fossil fuels into electrical energy, form the backbone of the city's energy supply. The primary fuels used are natural gas, which is relatively cleaner but often in short supply, and heavy fuel oil (HFO) and diesel, which are more readily available but significantly more polluting (Ministry of Electricity, Iraq, 2022). While essential for keeping the city functioning, this heavy reliance on thermal power generation comes at a steep environmental and public health price, a cost that has been inadequately addressed in the national reconstruction agenda.

Objectives and Potential of the Review

This paper aims to systematically synthesize and analyze the available information on the environmental implications of thermal power plants operating in and around Baghdad. The central objective is to provide a holistic understanding of the complex interplay between energy production, environmental degradation, and public health in the Iraqi capital. The scope of this paper encompasses:

- Identification of the major thermal power plants and their operational characteristics.
- A detailed examination of the primary environmental pathways of pollution, including air, water, and soil.

- An assessment of the public health outcomes linked to emissions from these power plants.
- An analysis of the socio-economic burdens imposed by these environmental and health impacts.
- A critical evaluation of existing and potential mitigation strategies and policy frameworks.

This paper focuses specifically on the Baghdad governorate, recognizing its unique status as a high-density urban center with multiple large-scale power facilities in close proximity to residential areas.

II. THE ENERGY LANDSCAPE OF BAGHDAD

Understanding the environmental impact of power generation requires a clear picture of the sources involved. Baghdad's electricity is generated by a combination of large, state-owned power plants and a smaller number of private or captive generation units.

Major Thermal Power Plants in the Baghdad Governorate

The Baghdad governorate is home to several of Iraq's largest and most critical power facilities. These plants are often located in peri-urban areas, but their emissions can affect the entire metropolitan area due to prevailing wind patterns and the topography of the Tigris River valley

Table 1: Key Thermal Power Plants in the Baghdad Metropolitan Province

Sr. No.	Name of Plant	Approx. Capacity (MW)	Main Fuel	Location (District)	Operational Status
1	Al-Dora Power Plant	640	Natural gas, HFO	Karkh (South)	Active, aging
2	Al-Mansour Power Plant	320	Natural gas, Diesel	Karkh (West)	Active, aging
3	Al-Shuaiba Power Plant	200	Natural gas, HFO	Karkh (South)	Active
4	Al-Quds Power Plant	640	Natural gas	Rusafa (East)	Active
5	Baghdad South (Taji) Power Plant	1600	Natural gas, HFO	Taji (North)	Active, newer units
6	Al-Karama Power Plant	280	Natural gas, HFO	Rusafa (Northeast)	Active

[Source: Data compiled from Ministry of Electricity reports and international energy analyses, 2020-2023]

These plants vary in age, technology, and efficiency. Older plants like Al-Dora and Al-Mansour often operate with outdated combustion and pollution control technology, making them disproportionately high polluters per unit of electricity generated (IEA, 2021).

Fuel Profile and Combustion Technologies

The fuel mix is a critical determinant of the pollution profile. Natural gas is the preferred fuel, but its supply is inconsistent, forcing many plants to switch to heavy fuel oil (HFO) or diesel during shortages. HFO is a residual fuel with high sulfur content (often >3.5%), high viscosity, and significant concentrations of heavy metals like vanadium and nickel (Al-Hamdani et al., 2019). The combustion of HFO in boilers that are not specifically designed for it leads to incomplete combustion and higher emissions of SO_x, PM, and toxic metals. Most of Baghdad's plants are conventional steam turbine plants, which are inherently less efficient than combined-cycle gas turbine (CCGT) plants.

Capacity, Demand, and Operational Inefficiencies

While the installed capacity in the Baghdad region appears substantial, the actual output is often much lower due to a combination of factors: poor maintenance, aging infrastructure, fuel quality issues, and grid instability. Plants frequently operate below their rated capacity, and at inefficient load points, which increases fuel consumption and emissions per kilowatt-hour (kWh) of electricity produced (UNDP, 2022). This inefficiency is a key driver of the excessive environmental footprint of the sector.

Atmospheric Emissions and Air Quality Impacts

Air pollution is arguably the most direct and severe environmental consequence of Baghdad's thermal power plants. The combustion of fossil fuels releases a complex mixture of pollutants that have far-reaching effects on air quality, public health, and the environment.

Criteria Pollutants: SO_x, NO_x, and Carbon Monoxide (CO)

Sulfur Oxides (SO_x): Primarily sulfur dioxide (SO₂), SO_x emissions are directly linked to the sulfur content of the fuel. The combustion of HFO is the dominant source of SO₂ in Baghdad. Once released, SO₂ can react in the atmosphere to form fine sulfate particles and contribute to the formation of acid rain, which can damage buildings, vegetation, and aquatic ecosystems. Studies have shown that areas downwind of major power plants like Al-Dora exhibit SO₂ concentrations that frequently exceed World Health Organization (WHO) guidelines (Al-Jubouri & Hassan, 2021).

Nitrogen Oxides (NO_x): Comprising nitric oxide (NO) and nitrogen dioxide (NO₂), NO_x are formed during high-temperature combustion from both nitrogen in the fuel and in the air. NO₂ is a potent respiratory irritant that can exacerbate asthma and increase susceptibility to respiratory infections. It is also a key precursor to the formation of ground-level ozone (smog) and fine particulate matter (PM_{2.5}).

Carbon Monoxide (CO): A product of incomplete combustion, CO is a colorless, odorless gas that impairs oxygen delivery in the blood, posing a particular risk to individuals with cardiovascular disease. While modern, well-tuned plants have low CO emissions, inefficient operation and the use of poor-quality fuels can lead to elevated releases.

Particulate Matter (PM_{2.5} and PM₁₀):

Particulate matter is a mixture of solid particles and liquid droplets suspended in the air. PM is categorized by size: PM₁₀ refers to particles with a diameter of 10 micrometers or less, while PM_{2.5} refers to fine particles with a diameter of 2.5 micrometers or less. PM_{2.5} is particularly dangerous as it can penetrate deep into the lungs and enter the bloodstream.

Thermal power plants emit PM directly (primary PM) in the form of fly ash and soot, and they also contribute to the formation of secondary PM_{2.5} through atmospheric reactions of SO_x, NO_x, and ammonia. A 2020 study by the Iraqi Ministry of Health, in collaboration with the WHO, identified a strong correlation between days with high PM_{2.5} concentrations and spikes in hospital admissions for

acute respiratory conditions in Baghdad, with pollution hotspots located near the city's southern power plants (Ministry of Health, Iraq, 2020).

Heavy Metals and Toxic Pollutants

The combustion of HFO releases a suite of toxic heavy metals, including mercury (Hg), lead (Pb), cadmium (Cd), vanadium (V), and nickel (Ni). Mercury is a potent neurotoxin that can bioaccumulate in the food chain, posing a serious risk to fetal development and human health. Lead and cadmium are also highly toxic, causing a range of neurological, renal, and skeletal effects. These metals are often attached to fine particulate matter and can be transported over long distances before being deposited in soil and water (UNEP, 2019).

Contribution to Smog and Acid Rain

As mentioned, NO_x and Volatile Organic Compounds (VOCs) react in the presence of sunlight to form ground-level ozone, the primary component of smog. Baghdad's intense sunlight and high emissions make it highly susceptible to smog events, which cause respiratory irritation and damage vegetation. Furthermore, the high SO_x emissions from HFO combustion contribute to acid deposition, which can acidify soils and water bodies, leaching essential nutrients and mobilizing toxic metals like aluminum.

The Compounding Effect of Natural Dust Storms

Baghdad's air quality crisis is compounded by frequent and intense dust storms, particularly in the summer. These natural events inject massive amounts of coarse particulate matter (PM₁₀) into the atmosphere, often pushing Air Quality Index (AQI) readings into hazardous levels. The pollution from power plants adds to this baseline, creating a toxic mixture of dust and combustion-derived pollutants that places an immense burden on the population's respiratory system (Sissakian et al., 2022).

Hydrological Impacts: Water Use and Pollution

Thermal power plants are highly water-intensive facilities, posing a significant threat to Baghdad's water security and the health of the Tigris River ecosystem.

Cooling Water Intake and its Ecological Consequences

Most thermal power plants use a once-through cooling system, which draws large volumes of water from a source (the Tigris River), circulates it through the plant's condenser to absorb waste heat, and then discharges the heated water back into the source. This process has two major impacts:

Entrainment and Impingement: The intake structures can pull in small aquatic organisms (eggs, larvae, fish), killing them in the cooling system (entrainment). Larger organisms like fish may be trapped against the intake screens (impingement), leading to injury or death. This can alter the population dynamics and age structure of fish communities in the river (Al-Mansouri, 2018).

High Water Consumption: Once-through systems consume large amounts of water through evaporation. In a water-scarce region like Iraq, where the flow of the Tigris is increasingly threatened by upstream damming and climate change, this high level of consumption is unsustainable and creates conflicts with other water users, such as agriculture and municipal supplies.

Thermal Pollution of the Tigris River

The discharge of heated water raises the temperature of the receiving water body, a phenomenon known as thermal pollution. Elevated water temperatures decrease the solubility of dissolved oxygen (DO), which is critical for the survival of fish and other aquatic life. It can also increase the metabolic rate of aquatic organisms, making them more susceptible to disease, toxins, and stress. Studies on the Tigris near the Al-Dora and Al-Quds power plants have documented localized increases in water temperature of 5-8°C and corresponding decreases in DO levels below thresholds required to support a healthy fishery (Kadhumi, 2021).

Chemical Effluents and Wastewater Discharge

Beyond cooling water, power plants generate other wastewater streams, including boiler blowdown (water used to remove concentrated impurities from the boiler) and effluents from cleaning and

maintenance activities. This wastewater can contain high concentrations of dissolved solids, heavy metals (copper, iron, zinc from corrosion), and toxic chemicals (biocides, anti-scaling agents). If not properly treated before discharge, these effluents can contribute to the chemical contamination of the Tigris River, posing risks to both ecosystems and human health for those who rely on the river for drinking water or irrigation.

Solid Waste Generation and Land Contamination

The combustion of fossil fuels, especially HFO and coal (if used), generates significant quantities of solid waste, primarily in the form of ash.

Composition of Solid Waste: Fly Ash and Bottom Ash

Fly Ash: A fine, powdery material carried out of the boiler with the flue gases. It is captured by pollution control devices like electrostatic precipitators (ESPs) or baghouses. Fly ash is composed largely of silica, alumina, and iron oxide, but it can also be enriched in concentrated heavy metals like arsenic, lead, and mercury.

Bottom Ash: A coarser, granular material that collects at the bottom of the boiler furnace. It has a similar composition to fly ash but with larger particle sizes.

Current Disposal Practices and Associated Risks

In Baghdad, the management of this ash is a significant challenge. The common practice is to dispose of it in designated landfills or, in some cases, in uncontrolled ash ponds or open dumps. Many of these disposal sites lack adequate engineering controls, such as impermeable liners and leachate collection systems. This creates a high risk of environmental contamination.

Leaching of Heavy Metals into Soil and Groundwater

When fly ash is exposed to precipitation, water can percolate through the waste, leaching out toxic heavy metals and other soluble salts. This contaminated liquid, known as leachate, can then migrate through the soil and pollute underlying groundwater resources, which are a vital source of drinking water in many parts of the Baghdad

governorate. Surface runoff from ash dumps can also contaminate nearby surface water bodies and agricultural land, leading to the uptake of toxins by crops (Salih & Ali, 2020).

Land Use and Aesthetic Degradation

The large land areas required for ash disposal represent a significant loss of potentially useful land. Furthermore, open ash dumps can create dust problems on windy days, re-suspending fine particles and heavy metals into the air and creating a nuisance for nearby residents. This contributes to the overall aesthetic degradation of the urban and peri-urban landscape.

Contribution to Climate Change

While local air and water pollution are the most immediate impacts, Baghdad's power plants also play a significant role in the global crisis of climate change.

Greenhouse Gas Emissions: Carbon Dioxide (CO₂) and Methane (CH₄)

The combustion of fossil fuels releases vast quantities of carbon dioxide (CO₂), the primary greenhouse gas responsible for global warming. Thermal power plants are one of the largest point sources of CO₂ emissions in Iraq. In 2021, the electricity and heat production sector accounted for over 40% of Iraq's total GHG emissions (IEA, 2022). Additionally, leaks from natural gas extraction, processing, and transportation (fugitive emissions) release methane (CH₄), a greenhouse gas that is over 80 times more potent than CO₂ over a 20-year period.

Quantifying the Carbon Footprint of Baghdad's Power Sector

Estimating the exact carbon footprint of Baghdad's power plants is challenging due to data limitations. However, using emission factors for different fuel types, it is possible to make reasonable approximations. A plant burning HFO can emit over 100 kg of CO₂ per MWh of electricity generated, while a natural gas plant emits around 50-60 kg CO₂/MWh. Given the city's reliance on these fuels, it is estimated that the power sector in Baghdad emits

tens of millions of tons of CO₂ annually (Karbassi et al., 2021).

Feedback Loops: Climate Change's Impact on Energy Demand and Water Availability

Iraq is on the front lines of climate change, facing rising temperatures, more frequent and severe droughts, and increased water scarcity. These changes create dangerous feedback loops. Higher temperatures increase the demand for electricity for air conditioning, placing more strain on the power grid and leading to more fossil fuel combustion and emissions. Reduced water flows in the Tigris and Euphrates rivers threaten the cooling water supply for thermal power plants, potentially forcing them to reduce output or shut down, exacerbating energy shortages (UNDP, 2022).

Public Health Implications in Baghdad

The environmental degradation caused by thermal power plants translates directly into a heavy burden of disease for the residents of Baghdad.

Respiratory and Cardiovascular Morbidity and Mortality

Exposure to PM_{2.5}, NO₂, SO₂, and ozone is strongly linked to a wide range of adverse health outcomes. **Respiratory Effects:** These pollutants irritate the airways, causing or worsening asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Long-term exposure to PM_{2.5} can lead to reduced lung function and lung cancer. A 2021 epidemiological study in Baghdad found a statistically significant association between long-term exposure to PM_{2.5} from traffic and industrial sources (including power plants) and increased rates of childhood asthma (Al-Hashimi & Saeed, 2021).

Cardiovascular Effects: Fine particles can enter the bloodstream, triggering inflammation, oxidative stress, and endothelial dysfunction, which can lead to heart attacks, strokes, arrhythmias, and high blood pressure. The WHO estimates that air pollution contributes to millions of premature cardiovascular deaths globally each year, a proportion of which is attributable to power generation.

Neurological and Developmental Effects of Heavy Metals

Exposure to heavy metals like mercury and lead, even at low levels, can have devastating and irreversible neurological effects, particularly in children and fetuses. Mercury exposure can impair cognitive development, memory, and attention. Lead exposure can cause permanent intellectual disability, behavioral problems, and anemia. The deposition of these metals from power plant emissions onto soil and water creates pathways for human exposure through the food chain and contaminated water.

Vulnerable Populations: Children, the Elderly, and Outdoor Workers

The health impacts are not distributed equally. Children are more vulnerable because their lungs are still developing, and they breathe more air per unit of body weight than adults. The elderly and individuals with pre-existing health conditions (e.g., asthma, heart disease) are also at higher risk of severe outcomes. Outdoor workers, including traffic police, construction workers, and street vendors, face prolonged and direct exposure to polluted air.

The Burden on the Healthcare System

The health impacts of air pollution place an enormous strain on Baghdad's already fragile healthcare system. Increased hospital admissions, emergency room visits, and the need for long-term medication and care divert scarce resources away from other health priorities. The economic costs associated with treating these diseases, combined with the loss of productivity due to illness and premature death, represent a significant drain on the national economy (World Bank, 2021).

Socio-Economic Costs

The environmental and health impacts of thermal power plants extend beyond the realm of ecology and medicine, imposing significant socio-economic costs on Baghdad and its inhabitants.

Direct and Indirect Healthcare Costs

The direct costs include expenditures on doctor's visits, hospital stays, medications, and other medical

treatments for pollution-related illnesses. Indirect costs are often much larger and include lost workdays due to illness (absenteeism), reduced productivity while at work (presenteeism), and premature mortality, which cuts short an individual's productive working years.

Reduced Labor Productivity and Economic Output

The cumulative effect of a less healthy workforce is a measurable reduction in labor productivity and overall economic output. Furthermore, unreliable electricity supply forces many businesses and households to rely on private diesel generators, which are more expensive and polluting, increasing the cost of doing business and the cost of living.

Impact on Agriculture and Food Security

The deposition of pollutants like SO_x and NO_x can acidify soil, reducing its fertility and crop yields. The contamination of irrigation water with heavy metals and other chemicals poses a risk to food safety, as these toxins can accumulate in crops and enter the food chain, potentially causing long-term health problems for consumers.

Degradation of Quality of Life and Social Well-being

Constant exposure to noise from power plants, the visual blight of industrial facilities and ash dumps, and the inability to spend time outdoors due to poor air quality all contribute to a significant degradation in the overall quality of life. This can affect mental health, community cohesion, and the overall sense of well-being among Baghdad's residents.

Mitigation Strategies and Policy Recommendations

Addressing the environmental crisis caused by thermal power plants requires a multi-pronged approach that combines technological solutions, robust policy, and a strategic shift in the energy paradigm.

End-of-Pipe Technological Solutions

For existing plants, retrofitting with pollution control technologies is essential to reduce emissions.

Flue-Gas Desulfurization (FGD): Commonly known as "scrubbers," FGD systems can remove up to 95% of SO₂ from flue gases by reacting it with a sorbent, such as limestone or seawater.

Selective Catalytic Reduction (SCR) for NO_x Control: SCR systems inject ammonia into the flue gas over a catalyst, converting NO_x into harmless nitrogen gas (N₂) and water. This is the most effective technology for controlling NO_x emissions.

Electrostatic Precipitators (ESPs) and Baghouses for PM Control: ESPs use an electric charge to remove fly ash particles from the gas stream, while baghouses (fabric filters) act like giant vacuum cleaners. Both can achieve over 99% removal efficiency for PM.

Fuel Switching and Combustion Optimization

The most effective way to reduce emissions is to switch to cleaner fuels. Prioritizing the consistent supply of natural gas over HFO and diesel would lead to immediate and significant reductions in SO_x, PM, and heavy metal emissions. Investing in modern, high-efficiency combined-cycle gas turbines (CCGT) can also reduce fuel consumption and CO₂ emissions per unit of electricity generated.

Strengthening Environmental Governance and Monitoring

Technological solutions are only effective if they are implemented and monitored properly. This requires:

- **Stricter Emission Standards:** Updating and enforcing national air and water quality standards to align with WHO guidelines.
- **Continuous Emissions Monitoring Systems (CEMS):** Mandating the installation of CEMS at all major power plants to provide real-time data on emissions to regulators and the public.
- **Increased Transparency and Public Participation:** Making environmental data publicly available and creating channels for community input and grievance redressal.

The Path Towards Renewable Energy Integration

The long-term solution lies in transitioning away from fossil fuels.

Solar Energy Potential in Baghdad: Baghdad enjoys high solar irradiance, making it an ideal location for utility-scale solar photovoltaic (PV) power plants. Rooftop solar on residential, commercial and government buildings can also play a significant role in decentralizing power generation and reducing the load on the central grid.

Challenges and Opportunities for Grid Integration: Integrating intermittent renewables like solar requires grid modernization, investment in energy storage solutions (e.g., batteries), and the development of smart grid technologies to manage supply and demand.

Demand-Side Management and Energy Efficiency

Reducing electricity demand is as important as increasing supply. This can be achieved through:

- Energy Efficiency Standards: Implementing mandatory energy efficiency standards for appliances, buildings, and industrial equipment.
- Demand-Side Management Programs: Promoting practices like time-of-use electricity pricing to incentivize consumers to shift their consumption to off-peak hours.
- Public Awareness Campaigns: Educating the public about the benefits of energy conservation.

III. CONCLUSION

This paper has demonstrated that the heavy reliance on thermal power plants in Baghdad, while born of necessity, has created a severe and multi-faceted environmental crisis. The emissions from these plants are a primary driver of the city's dangerously poor air quality, contributing to a heavy burden of respiratory, cardiovascular, and other diseases. Their impact extends to the vital water resources of the Tigris River, through thermal pollution and chemical contamination, and to the land through the improper disposal of ash-laden with toxic heavy metals. Furthermore, these plants are a major contributor to Iraq's greenhouse gas emissions, exacerbating the global climate crisis to which the country is exceptionally vulnerable.

The environmental and public health costs are not abstract; they translate into tangible socio-economic burdens, including soaring healthcare costs, lost productivity, and a profound degradation in the quality of life for millions of residents. The current trajectory is unsustainable. Addressing this crisis requires an urgent and paradigm-shifting response. While retrofitting existing plants with pollution control technologies can provide some immediate relief, the only viable long-term solution is a comprehensive and strategic transition towards a cleaner, more diversified, and more resilient energy system. This involves a concerted national effort to harness Iraq's vast renewable energy potential, particularly solar power, coupled with robust policies for energy efficiency, strengthened environmental governance, and a firm commitment to prioritizing public health and environmental protection in energy planning. The future well-being of Baghdad and its citizens depends on the bold decisions made today to break the dependence on polluting fossil fuels and build a sustainable energy future.

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