Comprehensive Clean Air Action Plan for Gaya

बिहार सरकार

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Executive Summary

The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, launched the National Clean Air Programme (NCAP), which proposes strategies to reduce air pollution. The NCAP identifies 122 non-attainment Indian cities [cities that violate the National Ambient Air Quality Standards (NAAQS)]. Gaya—one of the five most polluted cities in the world, in terms of particulate matter (PMs) (WHO, 2018) — has also been identified as one of the non-attainment cities under NCAP. In this context, a clean air action plan was prepared under which an emission inventory was developed for Gaya. Gaya Clean Air Action Plan identified source-specific Control Measures (CMs) and performed a Techno-Economic Assessment (TEA) on the CMs. This helped to identify technically and economically feasible solutions/technologies to reduce pollution levels in Gaya. Moreover, several focused group discussions with various stakeholders were also conducted to understand the pollution landscape in the city and workshops were conducted as a part of the study, to discuss and validate the findings.

The emission inventory was developed to estimate the total emission load from various polluting sources of the city. The research team conducted dispersion modelling using the emission inventory, which was projected for the year 2030 using various scenarios. Surveys were conducted to collect data and to substantiate the emission load.

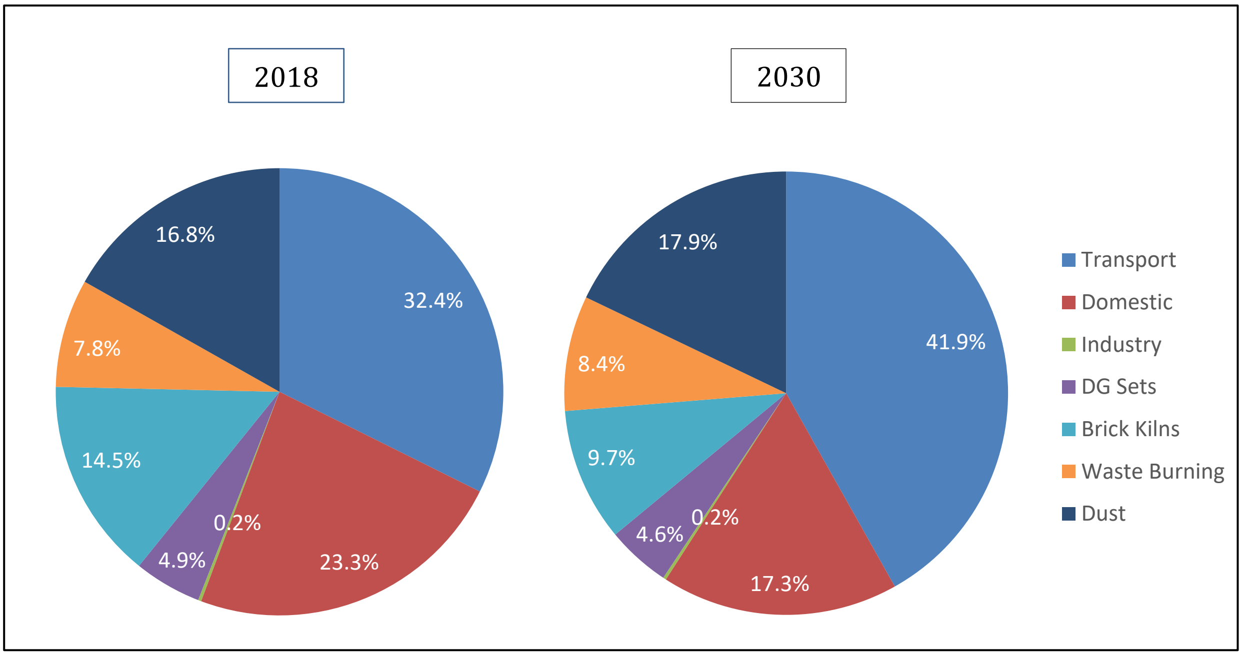

Figure 1: PM 2.5 Emission share: 2018 vs 2030 (BAU)

The study estimated that the total PM2.5 emission load for 2018 is around 10,000 tonnes/year and is estimated to reach around 16,000 tonnes/year in 2030, under the business-as-usual (BAU) scenario. Figure 1 presents the sectoral share of emission under BAU scenario. Emission from transportation sector was found to be the most, contributing to 42% of the total PM2.5 emission load, followed by dust (including road dust and construction dust), domestic (including heating, cooking, and lighting), and brick kilns contributing 18%, 17% and 10% respectively in 2030. The concentrations levels of PM2.5 is expected to reach from 69.3 μg/m^3

in 2018 to 91.7 μg/m^3 by 2030. Estimated mortality due to air pollution in the BAU scenario would touch 550 deaths/year in 2030 from 270/year in 2018.

To identify source-specific CMs, pollution determinants for various sectors such as transportation, domestic, industry, open waste burning, DG sets, construction, and road dust were identified. Existing policies along with these determinants were considered while developing CMs.

Transportation:

PM2.5 emissions from transportation sector are estimated to increase by 95% by 2030 from the baseline emissions (2018). Increasing the mode share of public transportation, promoting the use of EV/CNG vehicles, strict enforcement of PUC norms, and incentivising the installation of Diesel Particulate Filters (DPF) are few of the measures that are likely to improve the existing transportation scenario and reduce pollution levels in Gaya.

Industries:

The Bihar government has mandated the brick industry to adopt cleaner technologies (zigzag) as fixed chimney kiln technology was contributing more to the pollution level. Effective implementation of the zigzag technology would reduce the emission load from brick kilns by 40%. Gaya is also home to several stone crushers, implementing stricter norms on such industries will help control pollution from the industries sector.

Solid-waste management:

By ensuring effective waste collection and disposal strategies, 90% of the emissions from open waste burning could be reduced. It was estimated that the city would generate around 300 tonnes per day (TPD) of solid waste by 2030. Gaya would need an additional 120 TPD of composting plants and 35 TPD dry-waste collection centres for proper waste management by 2030. The Gaya municipality would require at least INR 28 crore (capital cost) for installing these plants.

Domestic:

The domestic sector contributed to around 23% of the total PM2.5 emission load in 2018, and is estimated to be one of the major polluting sectors in 2030. Incentivising the use of induction stoves/ smokeless *chulhas* and increasing the penetration rate of LPG cylinders would help reduce emissions from the domestic sector. The government would have to invest around INR 1.5 crore in the form of incentives to increase the LPG penetration rate. The government will also incur an excess of INR 4 crore as incentives to increase the refuelling rate of the LPG cylinders.

Capacity building:

To further strengthen the existing monitoring infrastructure in Gaya, the state government should consider installing additional Continuous Ambient Air Quality Monitoring (CAAQM) stations for the effective measurement and monitoring of pollution levels. This could help identify pollution hotspots and prepare appropriate strategies accordingly.

Scenario analysis:

Three scenarios were created based on the CMs and their emission-reduction potential. These scenarios had varying levels of compliance vis-à-vis the suggested CMs. These scenarios focussed on high (scenario 1), medium (scenario 2), and low (scenario 3) emission-reduction potential of CMs. The reduction in mortality rates for the different pollution-reduction scenarios were estimated on the basis of PM reduction between 2018 and 2030.

The study estimated that under high-, medium-, and low emission-reduction scenarios, the PM2.5 emission level can be reduced by 58%, 44%, and 33% respectively with reference to the BAU scenario in 2030, as described in Figure 2. Under the high emission-reduction scenario, the city would save at least 1,100 lives by 2030.

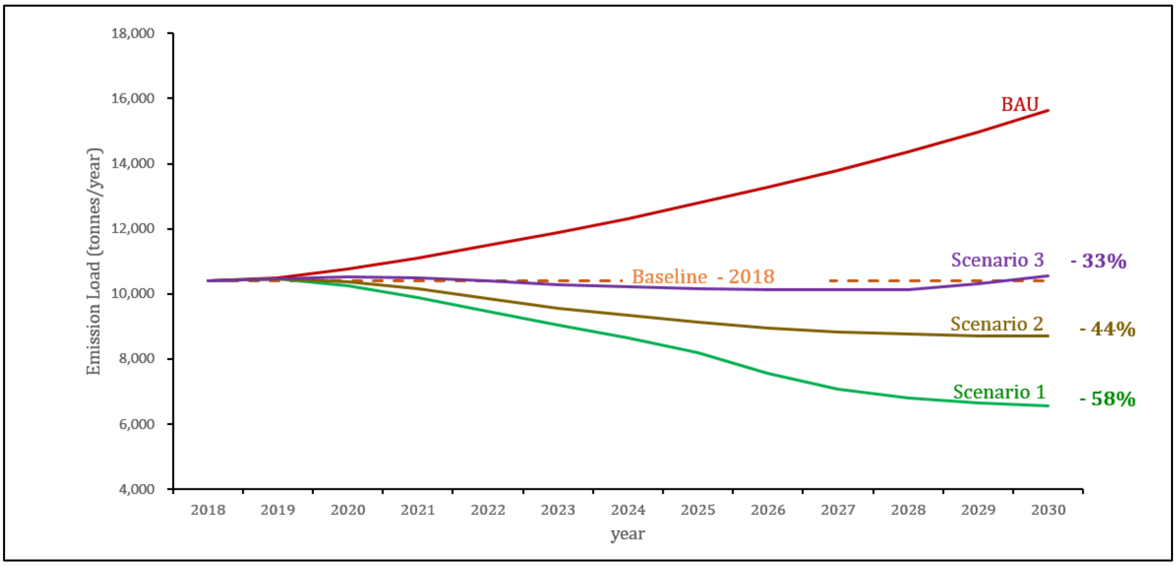

Figure 2: Scenarios: emission-reduction potential

Based on the study conducted by the consortium partners, the Bihar State Pollution Control Board (BSPCB) suggests that the state government and concerned line departments should implement the following CMs, which would result in maximum pollution reduction:

- Introduce EVs / CNG vehicles in the city
- Efficient solid-waste management strategies
- Decrease the use of solid fuel by increasing the penetration and refuelling rate of LPG
- Converting fixed chimney kilns to zigzag kilns

It is necessary for the government to work closely with citizen groups to sensitise them about the effects of air pollution. Existing policies like traffic regulations, construction-and-demolition waste management rules, and construction of road pavements are a few of the measures that could be implemented with immediate effect by the line departments.

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Abbreviations

AAQ	Ambient Air Quality
AQI	Air Quality Index
As	Arsenic
BaP	Benzo(a)Pyrene
BAU	Business as Usual
BC	Black Carbon
BCR	Benefit Cost Ratio
BSPCB	Bihar State Pollution Control Board
BSRTC	Bihar State Road Transport Corporation
C_6H_6	Benzene
CAAP	Clean Air Action Plan
CBA	Cost Benefit Analysis
CMVA	Central Motor Vehicles Act
CMs	Control Measures
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
CRF	Concentration Response Function
D.O.T	Department of Transport
DALYs	Disability Adjusted Life-years
DG Sets	Diesel Generator Sets
DPF	Diesel Particulate Filter
EF	Emission Factor
EI	Emission Inventory
ER	Excess Risk
EV	Electric Vehicle
FAME	The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FCK	Fixed Chimney Kiln
G-CAAP	Gaya Clean Air Action Plan
GMC	Gaya Municipal Corporation
GBD	Global Burden of Disease
GDP	Gross Domestic Product
HHK	Hybrid Hoffman Kiln
IGSC	Indira Gandhi Science Complex
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LPG	Liquid Petroleum Gas
LULC	Land Use and Land Cover
MLH	Mixing Layer Height
MoEFCC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
MSME	Ministry of Micro, Small and Medium Enterprises
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NAMP	National Air Quality Monitoring Programme

NCAP	National Clean Air Programme
NGT	National Green Tribunal
NH_3	Ammonia
Ni	Nickel
NMVOCs	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
O&M	Operation & Maintenance
O_3	Ozone
OC	Organic Carbon
Pb	Lead
PM	Particulate Matter
PMUY	Pradhan Mantri Ujjwala Yojana
PUC	Pollution Under Control
PV	Photovoltaic
RSPM	Respirable Small Particulate Matter
SBPDCL	South Bihar Power Distribution Company Limited
SIAM	Society of Indian Automobile Manufactures
SO_2	Sulphur Dioxide
SPCB	State Pollution Control Board
SWM	Solid Waste Management
TCO	Total Cost of Ownership
TEA	Techno-Economic Assessment
TPD	Tonnes Per Day
VOC	Volatile Organic Compounds
VSBK	Vertical Shaft Brick Kiln
WHO	World Health Organisation

1. Gaya: Current Pollution Landscape

Air pollution is a critical challenge that India faces. Massive population and rapid economic growth place significant pressure on the environment and, in turn, on the quality of the air. Gaya is one of the fastest developing cities of Bihar, with its economic growth propelled by Small and Medium-sized Enterprises (SMEs) and tourism. However, this city has been placed among the five worst polluted cities in the world, in terms of particulate matter (PM) (WHO, 2018). The major sources contributing to the deteriorating air quality of Gaya city are transportation, brick kilns, and dust emission from road re-suspension (Urban Emissions, 2019). In this context, a Clean Air Action Plan (CAAP)—backed by research-based evidence—is required to precisely determine the air pollution levels and identify the sources, and thus help formulate policies towards air pollution mitigation.

1.1 Overview

Gaya is located in the extreme south of Bihar at 24.7914° N, 85.0002° E. The population of Gaya city is 575,987 with decadal growth rate around 20.92% for 2001-2011 (Census, 2011). The area of Gaya city is 90.17 sq. km.

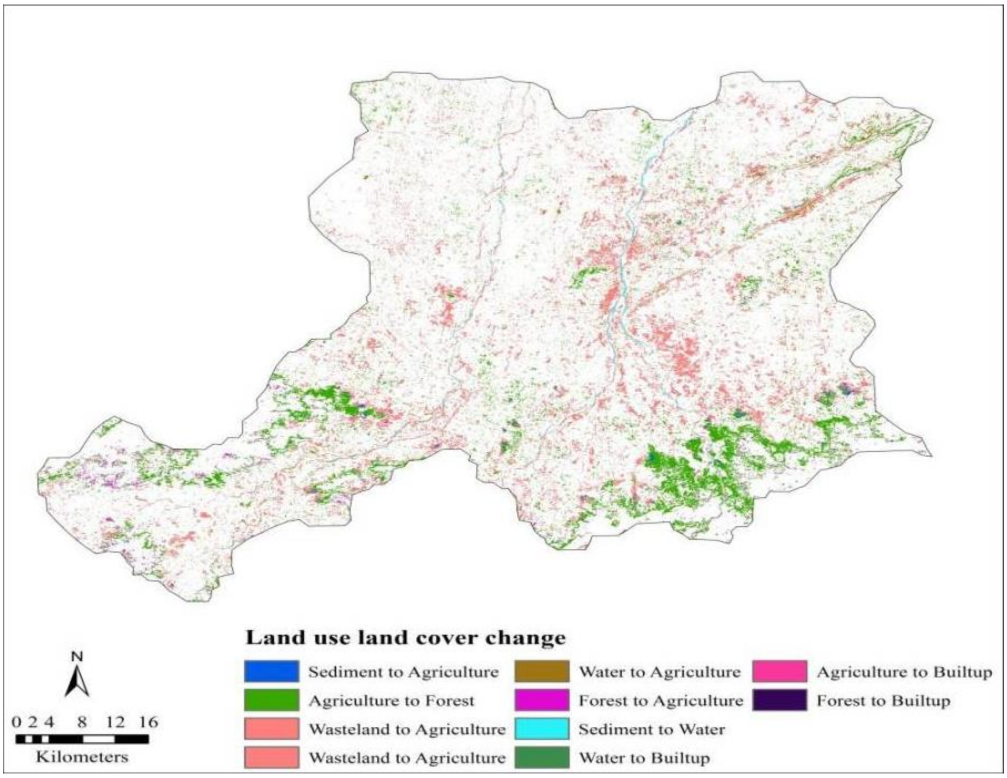


Figure 3: Land use and land cover change pattern of Gaya district (1989-2010).

Source: Sen and Kumar, 2013

The Gaya district is surrounded by Jahenabad and Nalanda in the north, Aurangabad in the west, Nawada in the east and the state of Jharkhand in the south. Figure 3 presents the land use and land cover change pattern of Gaya district from 1989 to 2010. In last two decades, forest and agricultural lands have shrunk by 5.81% and 2.07% respectively whereas water bodies such as ponds, lakes etc. and built-up[1] area have increased by 1.58% from 1989 to 2010 in Gaya district (Sen and Kumar, 2013).

1.2 Air quality levels and its comparison to national standards

The chief factor for deteriorating level of air quality in Gaya city is the PM in the atmosphere. Figure 4 depicts that PM2.5 is significantly higher than National Ambient Air Quality Standard (NAAQS) whereas levels of CO, O_3, SO_2, and Benzene remain fairly below NAAQS. However, NO_2 is almost touching the NAAQS (CPCB, 2019) due to heavy inflow of traffic. Since Gaya is an old and unplanned city, traffic congestion is a common sight, because of the higher vehicular burden.

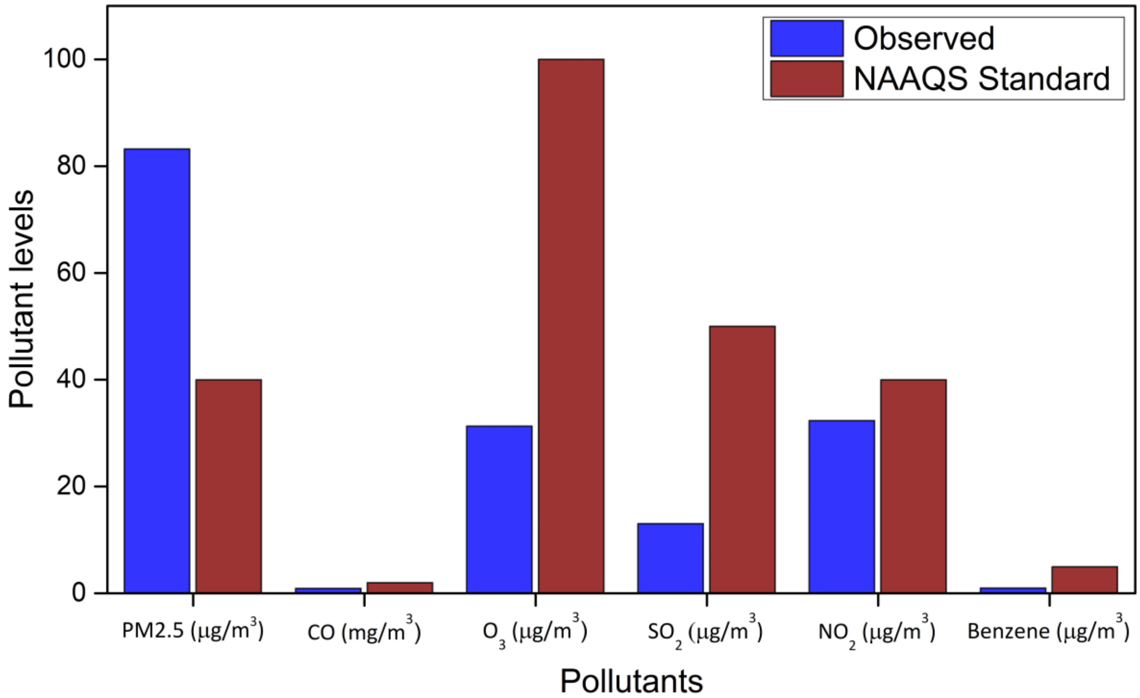


Figure 4: Pollutant levels in Gaya: observed (2019) vs NAAQS

Source: CPCB, 2019

1.3 Impact on public health, environment, and economy:

Air pollutants including PM can induce several health distresses among people (The Global Burden of Disease, 2010). Number of patients suffering from asthma and tuberculosis registered in Government facilities increased from 216 in 2016-2017 to 349 in 2017-2018 in Gaya city (IDSP, 2018). The current total number of patients of acute respiratory disease registered in Government hospitals in 2018 is 19076 (IDSP, 2018). PM can trigger a number of pulmonary and respiratory ailments. Outdoor air pollution and human health has been commonly linked with chronic obstructive pulmonary disease, respiratory diseases, cerebrovascular disease, ischemic heart disease, and cancers of trachea, bronchitis, and lung (The Global Burden of Disease, 2010). However, there is a lack of research evidence to establish relationship between air pollution and public health for any region including Gaya.

[1] Built-up area is part of urban agglomeration that includes building and non-building structures such as residential, commercial, transportation etc.

Additionally, air pollution has severe effect on the environment. Acid rain, eutrophication, haze, ozone depletion, crop and forest damage, global climate change, and impact on wild life are major impacts on environment due to air pollution (Department of Environmental Protection, 2016). Since air pollution has been linked with crop damage, it also has significant impact on agricultural productivity. Around 100,000 tonnes of wheat and 30,000 tonnes rice have been observed to be lost in yield in Bihar due to NOx, VOCs and other pollutants (Beig, 2014).

Besides the impact on human health and environment, air pollution has the potential to also slow down the economy of a country. The Global Burden of Disease (2016) has reported that more than one million of premature deaths were caused by outdoor air pollution in India in 2016. The cost of premature death accounted for USD 800 billion in India in 2016 (OECD Insights, 2017 and OECD, 2017). Air pollution also increases the cost incurred on the economy due to increased number of lost work days and falling labour productivity. In addition, loss in agricultural yield may also trigger increased cost to the economy. According to projection of OECD Insights (2017), the estimated market cost due to air pollution on Indian economy would increase by USD 280 billion by 2060 (based on purchasing power parities exchange rates in 2005). The number of premature deaths per million population due to air pollution has increased from 814 in 2000 to 832 in 2015 in India (OECD, 2017). As the number of premature deaths and cost per death is projected to increase significantly, the social cost for the deaths due to air pollution would also increase by 15 to 33 times by 2060 (OECD Insights, 2017).

1.4 Need for developing a city-specific clean air action plan

Sectorial control measures need to be formulated for better understanding of their contribution to city's pollution. Furthermore, these measures need to be implemented by the district administration of Gaya under the guidance of the Bihar State Pollution Control Board (BSPCB). Hence, well designed evidence-based research study is required to generate data and suggested measures. Continuous air quality monitoring, development of a baseline emissions inventory, and techno-economic assessment would be able to provide evidence-based strategic planning and help design implementation strategies to mitigate air pollution. In this regard, Ministry of Environment, Forest and Climate Change (MoEFCC) has launched National Clean Air Programme (NCAP), under whose purview 122 non-attainment cities of India (including Gaya) are included. The city-specific CAAP for Gaya is one giant leap towards achieving NCAP goals.

1.5 Scope of the study

The main objective of this study is to develop a comprehensive clean air action plan for the city of Gaya to tackle the challenge of increasing air pollution in Gaya. BSPCB will adopt the suggested strategic plans of the study, based on the findings. The study is primarily aimed at identifying the sources of air pollution in Gaya and preparing a comprehensive list of control measures (CMs). CMs and policy recommendations will be designed, considering the inputs from the district administration of Gaya and the line departments.

2. Air Pollution Scenario

2.1 Existing policies/interventions in the state of Bihar

Some of the existing set of policies and interventions, guided by national compliances and regional-level policies, are stated below:

- *National Air Quality Monitoring Programme (NAMP):* The government is executing a nation-wide air quality monitoring programme called the National Air Quality Monitoring Programme (NAMP). In this regard, the BSPCB has set up an online air quality monitoring system at the District Administration office, Gaya[2].
- BSPCB has instructed all brick kiln owners in Bihar to adopt cleaner technologies. In this regard, BSPCB has issued the closure of 46 brick kilns in Gaya and Muzaffarpur which have been violating the rules of environmental protection (BSPCB, 2018)[3]. Additionally, a task force for monitoring conversion of brick kilns to zigzag and other cleaner technologies has been constituted[4].
- *Central Motor Vehicles Act (CMVA):* As per CMVA, electric rickshaws have been permitted to ply in Gaya city in an effort to curb air pollution[5].
- District administration has imposed penalties on the commercial eateries using coal as fuel. Additionally, provision of subsidies for using LPG instead of coal as fuel would be ensured by Gaya Municipal Corporation (GMC)[6].
- GMC has been conducting awareness programmes on impacts of waste burning and have started imposing a fine on waste burning. Apart from these, GMC has also been focussing on capacity building to help reduce the biomass & waste burning in the city[6].
- GMC has taken concrete steps towards proper solid waste collection, segregation, and disposal/treatment. GMC has also set up an incineration plant to manage the solid waste load of the city[6].
- District administration, Gaya has also taken a decision to impose ban on diesel vehicles older than 15 years through stringent PUC and fitness checks[7].
- There are huge numbers of stone crushers in Gaya which contribute significantly to overall PM level in the city. In this regard, district administration of Gaya has ordered mandatory water sprinkling to reduce PM at the site of stone crushers[6].
- Covered transportation of construction materials and covering of construction sites has been mandated by District Administration, Gaya[6].
- Improvised cremation[8] in Gaya has been proposed under Ganga Action Plan by GMC[5].

[2] National Clean Air Program (NCAP) – India, Ministry of Environment, Energy and Climate Change, New Delhi. http://www.indiaenvironmentportal.org.in/files/file/NCAP.pdf

[3] Magicbricks, BSPCB issues closure notice to over 50 brick kilns in Muzaffarpur and Gaya. https://content.magicbricks.com/property-news/other-cities/bspcb-issues-closure-notices-to-over-50-brick-kilns-in-muzaffarpur-gaya/110329.html

[4] BSPCB, Notice regarding brick-kilns. http://www.bspcb.bih.nic.in/int_5.12.19.pdf

[5] The Motor Vehicles (amendment) Bill, 2015, bill no. 37 of 2015. http://www.lamp.prsindia.org/sites/default/files/bill_files/Motor_Vehicles_%28A%29%2C_2015_0.pdf

[6] Information provided by GMC during the meeting on 'CAAP for Gaya'

[7] Information provided by District Administration of Gaya during the meeting on 'CAAP for Gaya'.

[8] Improvised crematoria designs are more eco-friendly in nature. These crematorium consumes less wood than the traditional crematoria designs. There are improvised crematoria designs that run on electric/CNG as well.

The Government of Bihar and district administration of Gaya are making efforts to combat air pollution, but more effective and prudent actions must be undertaken by all stakeholders, including citizens, to achieve better air quality.

2.2 Pollution landscape in the country

The major pollutants considered for any emission inventory in a city are PM2.5, PM10, Black Carbon (BC), Organic Carbon (OC), NOx, CO, VOCs, SO_2, and CO_2 (Guttikunda et al., 2014). The major sources of emissions are transport, domestic, open waste burning, on-road dust, industries, brick kilns, DG sets, and outside contribution[9]. Transportation is considered to be a major source of emission, containing Particulate Matter, NOx, SOx, Volatile Organic Carbons (VOCs), and other hydrocarbons. The construction of buildings and roads can produce significant amounts of PM10 and NO_2 through the process of land clearing, operation of diesel engines, demolition, burning, and working with toxic materials. In addition, industrial emissions also significantly contribute to regional air pollution. Since Gaya is one of the developing cities in Bihar, developmental processes such as urbanisation, industrialisation, construction, transportation, and other anthropogenic activities have increased. This contributes significantly to the city's overall pollution profile.

Moreover, global contributions of sources (51 countries including India) have been studied by Karagulian et al. (2015). Source contribution of PM2.5 for India in comparison with global scenario has been represented in Figure 5. Emissions from traffic contribute up to 37% in India, which is higher than the contribution from traffic in other countries (25%). Natural sources such as dust and sea salt also have a higher contribution in India (21%) as compared to other countries (18%). However, domestic fuel-burning contributes as much as 16% in India, which is lower than other countries. Industries contribute to only 4% of the total pollution load in India, which is significantly lower than contribution from industries (15%) in other countries.

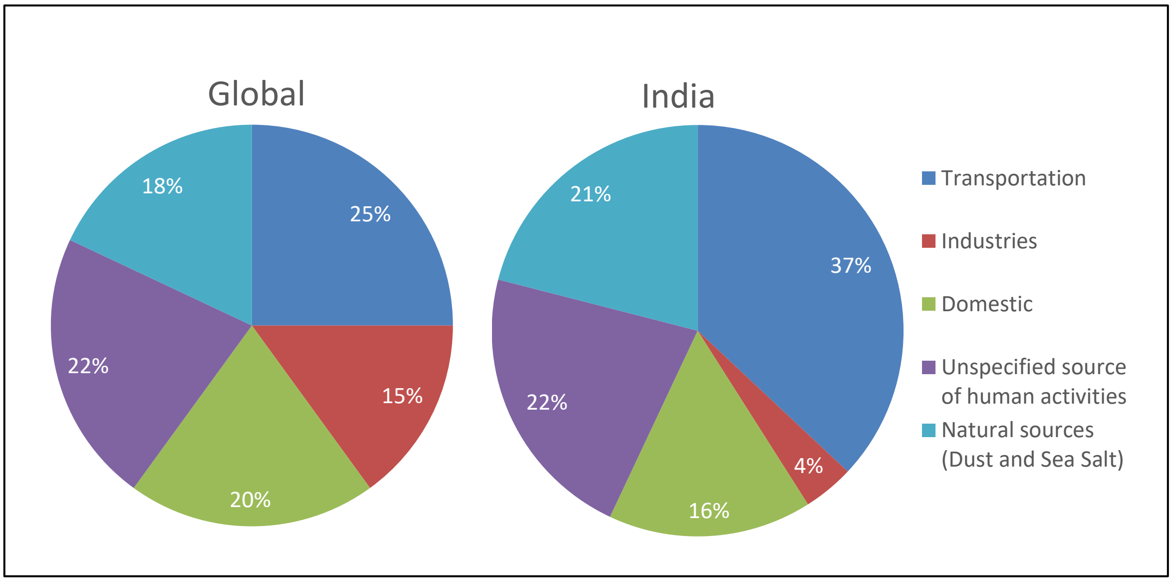


Figure 5: Source contribution of PM2.5 emissions

Source: (Karagulian et al., 2015)

[9] Outside contribution – Emissions from outside the air shed region.

2.3 Emission inventory

An emission inventory (EI) accounts for the total emission load from various polluting sources in a given geographical area, within a particular time frame. An EI helps identify the most polluting sources in a city/state/region. It is also used to estimate and project future emissions for various pollution control/reduction scenarios (ACAP, 2017).

There is very limited information that can be accessed to conduct EI studies in Indian cities. Guttikunda et al. (2019) details the model for conducting such studies in various cities of India and the resources accessed for various sectors. There are studies (such as Guttikunda et al., 2014) that discuss the uncertainties, gaps, and pathways for various sectors.

2.3.1 Methodology

EI for Gaya city was developed for the airshed area of 30 km X 30 km for the year 2018. Various pollutants such as PM2.5, PM10, NO_x, CO, SO_2, CO_2, and non-methane volatile organic compounds (NMVOCs) were considered in the EI. Although an inventory of NH_3 emissions was not prepared, NH_3 emission data was extracted from the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) (http://www.htap.org/), 2012 and the data was used after linear extrapolation. The EI was developed to estimate emissions from the transport sector, domestic and commercial cooking, space heating, diesel generator (DG) sets, solid waste burning, industries, aviation, and dust from different activities (construction and road). The developed EI was also projected for the year 2030 under the business-as-usual (BAU[10]) scenario.

The EI was prepared by considering the various activities (A) in a sector that contribute to the total pollution load in a city/state/region. Activities (A), when multiplied by their respective emission factors (EF), provide an estimate of the emission load of any particular activity. This emission load is distributed in a 1 km X 1 km unit of area in Gaya. The sector-specific methodology for estimating the emission has been provided in the following sections. The model details and the architecture are detailed in Guttikunda et al. (2019).

EI looks at pollutants at the source and does not include remote effects of pollutants or the effects of meteorology on pollutant concentration. Dispersion modelling has been used to address this gap.

[10] It is assumed that there are no serious interventions by the government to control emissions

Emissions from transportation:

For the *transportation sector*, the ASIF (Schipper et al., 2000) principles were used to estimate the emissions.

$$E_T = A * S_i * I_i * F_{ij} \quad \textbf{(2.3.1.1)}$$

Where,
E_T - Emissions from transportation
A - Total travel activity,
S_i - Vector of modal share[11],
I_i - Energy intensity of each mode (i),
F_{ij} - Sum of each fuel (j) in mode (i); the emission factors[12] mentioned below are used to convert fuel used into emissions.

The method mentioned above have been applied for all modes of transportation. The vehicle exhaust emissions factors are adjusted by vehicle type, deterioration of vehicle engine with age (corroborated with the PUC data from the city), fuel type, and local congestion levels. A database of average emissions factors for fleets is available in Goel and Guttikunda (2015) and can also be accessed at http://www.urbanemissions.info/publications.

The emission estimated from the transportation sector is adjusted for traffic congestion. The methodology for estimating the congestion rates in the city is based on the extracts from google maps direction application programming interface (API).

To substantiate the methodology, a transportation survey was conducted at various petrol pumps in Gaya in 2019, which helped us understand the vehicle characteristics (mode share, age, and fuel use).There are evaporative emissions also at the fuel stations, which add to the VOC totals. Fuel sales information was also gathered as a part of this exercise.

According to the data provided by the transport department, Bihar Government, the in-use vehicular population in Gaya district is around 286,293 as of 2018. Of the total registered fleet, two-wheelers (73%) are the dominant ones. While projecting emissions for future years the vehicle growth rate is assumed from the national road transport emission study based on the sales projection numbers from Society of Indian Automobile Manufactures (SIAM), New Delhi India.

Emissions from road dust resuspension:

Vehicular movement on the road triggers resuspension of dust. The on-road resuspension of dust is classified as non-exhaust PM emissions. The dust emissions are also linked to the local meteorology in the chemical transport model, to suppress any overestimation of resuspension during the rains. The resuspension of dust is dependent on the weight of the vehicle, silt load[13], road surface type, and average rainfall. Data from geographic information systems (GIS) helped us understand and identify the types of road (paved/unpaved) in Gaya.

[11] Modal Share – Percentage of travellers using a particular mode of transportation.
[12] Emission Factor – Mass emitted for vehicle km travelled
[13] Silt load – Amount of dust present per unit area on the road

Emissions from industry:

Primary information pertaining to industries was extracted from the annual survey of industries, while the information on industries' emissions was estimated based on fuel consumption (Ministry of Statistics and Program Implementation[14]). This has been corroborated with the information provided by line departments. Google Earth imagery for every grid in air shed area was used as a reference to locate the industries. Besides the traditional manufacturing industries, there are brick kiln clusters around the city. The brick manufacturing includes a) land clearing[15] for sand and clay, b) combustion of fuel for baking bricks, c) the operation of diesel engines on site, and d) transportation of the end product to various parts of the city. It was found that the brick manufacturers use conventional technology - fixed chimney kiln (FCK).

Figure 6: Emission from a brick kiln

Emissions from domestic sector:

Domestic-sector emissions are based on fuel consumption (coal, wood, kerosene, and LPG) estimates for cooking, heating, and lighting. Grid-level fuel usage in households was estimated based on census statistics[16]. According to the data provided by the Gaya municipality, at least 21% of the households are using non-LPG stove for cooking and heating. Apart from LPG, fuels such as coal, biomass, and agricultural waste are used in slum areas, restaurants, and areas outside the municipal boundary. Gridded population data was obtained from the "Gridded Population of the World and Global Rural and Urban Mapping Project (GRUMP)" (2010)[17]. It is

[14]Ministry of Statistics and Programme Implementation, Government of India, @ http://mospi.nic.in/Mospi_new/site/India_statistics.aspx?status=1&menu_id=43

[15] Land Clearing - The process of removing trees, stumps, brush, stones and other obstacles

[16] Household energy usage in India, Database maintained by the Institute for Financial Management and Research, Chennai, India @ http://www.householdenergy.in

[17] GRUMP (2010) - Gridded Population of the World and Global Rural and Urban Mapping Project. Center for International Earth Science Information Network (CIESIN) of the Earth Institute, Columbia University, New York, USA @ http://sedac.ciesin.columbia.edu

assumed that while high-density areas (highly urban areas) most likely utilise LPG, low-density areas utilise a mix of fuels. The LPG consumption rates based on census 2011 for the domestic sector were adjusted based on surveys (Jain et al., 2018; Jain et al., 2015) and reports on new LPG connections provided by Bihar state (MoPNG & www.data.gov.in).

Emissions from waste burning:

Figure 7: Emission from waste burning

Garbage burning in residential areas emits a substantial amount of pollutants and toxins (Guttikunda and Jawahar, 2014). Waste burning is the most challenging source and also the most uncertain for estimating the emissions load. Despite government authorities having banned solid-waste burning, citizens continue to violate the regulation. The amount of emission from waste burning is estimated using the equation (2.3.1.2) below.

$$E_{WB} = W_b * F \tag{2.3.1.2}$$

Where,
E_{WB} - Emissions from waste burning
W_b- Quantity of waste burnt (Estimated after adjusting the total amount of waste processed)
F - Emission factor
Anthropogenic activities increase with increase in population. And hence population growth rate (Census data) was considered while estimating emissions from the domestic sector, construction activities, brick demand, diesel usage in the generator sets, and open waste burning.

Dispersion modelling

Dispersion modelling is performed to understand the physical and chemical transformation of air pollutants over a geographical area. Advection of the pollutant refers to a kind of physical transformation that depends on the topography of the area, meteorological conditions, and the pollutant's wet and dry deposition. Area-specific meteorology plays an important role as it influences the transport and vertical mixing of pollutants. There are different types of dispersion models available, based on complexity and computational needs. Comprehensive Air Quality Model with Extensions (CAMx) dispersion model was used to simulate the air quality parameters for Gaya.

The 3D meteorological parameters from Weather Research and Forecasting (WRF), along with the estimated emissions load of each of the grid points, act as inputs to the model. Pollutant concentration is the model output. Concentration is the amount of pollutant matter present in a unit volume of ambient air. It is generally expressed in microgram per cubic meter ($\mu g/m^3$) or parts per million (ppm). Concentration values are important, as they help identify changes in air pollutant concentrations over time. These values are also the basis for evaluating the effectiveness of existing control measures and a way of identifying the sources of possible problems for the future (Brimblecombe, 2011). The detailed model formulation and meteorological parameters considered in the study can be accessed from Guttikunda et al. (2019).

2.3.2 Results

It was found that sectors like transport, domestic fuel consumption, open garbage burning, road and construction dust, industries, DG sets, and aviation are contributing to the total pollution load in Gaya. Emission such as black carbon, NO_x, CO, SO_2, CO_2, PM2.5, PM10, and non-methane volatile organic compound (NMVOCs) emissions were estimated for all the sectors contributing to the city's pollution (See Annexure B).

The PM2.5 sectoral emission loads were estimated for 2018, based on the primary and secondary data collected for different sectors. The sectoral emission loads were also projected until 2030, based on the growth rates of different sectors.

Figure 8 presents PM2.5 emissions projected for the period between 2018 and 2030 (under the BAU scenario) from various sectors contributing to pollution in the city. The year 2018 is considered as the base year for the emission estimation. The total PM2.5 emission load for 2018 was estimated to be around 10,000 tonnes/year. The transportation sector (32%), and the domestic sector (23%) which includes cooking, heating, and lighting, contribute around 55% of the total emissions, followed by dust (17%), which includes road and construction dust, and brick kilns (15%).

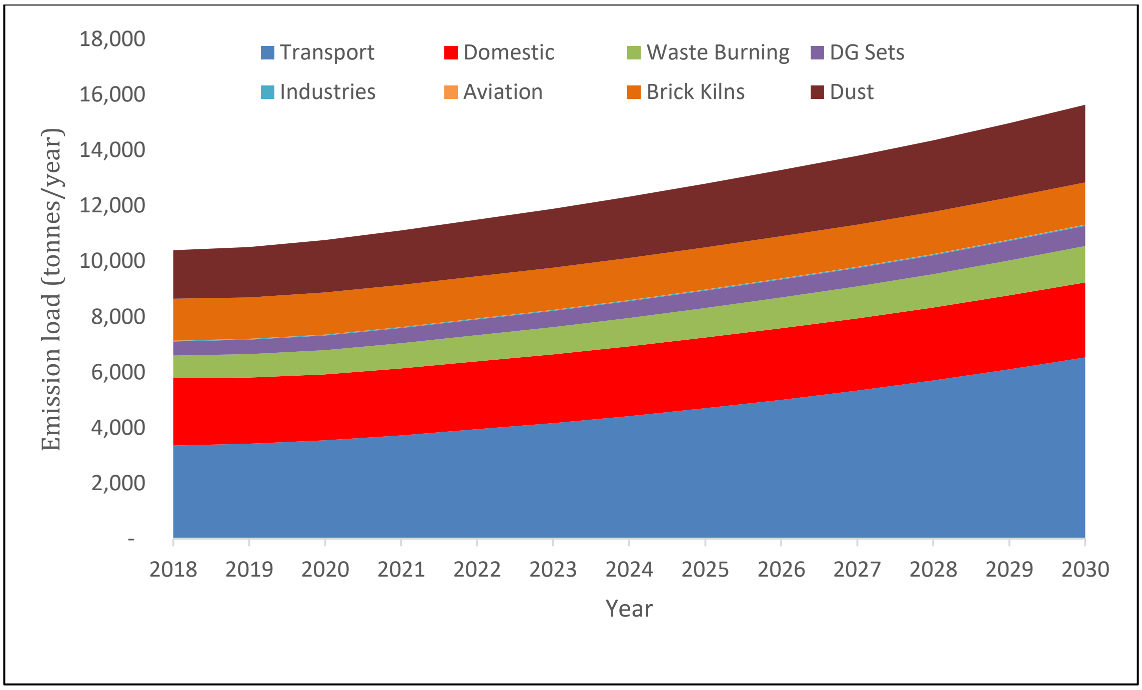


Figure 8: PM2.5 emissions (BAU)

The total PM2.5 emission is estimated to reach around 16,000 tonnes/year in 2030, in which the emissions from the transportation sector (42%), dust (18%), and domestic sector (17%) are expected to contribute the most, followed by brick kilns (10%). Based on estimates, PM2.5 emissions from the transportation sector will increase by 95% in 2030 from 2018 levels. The increase in emissions load from the transportation sector is mainly attributed to vehicular and economic growth. Figure 9 presents the grid wise PM2.5 emissions for Gaya during 2018. It was observed that the majority of the pollution hotspots are located inside the city.

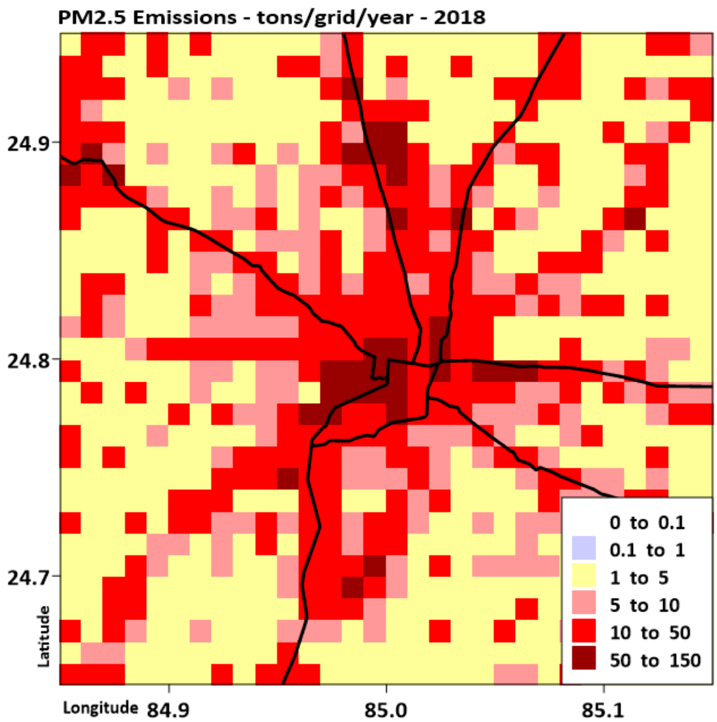


Figure 9: Grid level PM2.5 emissions (BAU-2018)

The emission load for the city does not include PM2.5 emitted outside the boundary, the influence of weather parameters (rainfall, wind speed, atmospheric mixing height, etc.), and the generation of secondary PM by atmospheric chemistry. In order to incorporate such factors, dispersion modelling is used to determine the concentrations levels in the city.

Figure 10 presents the estimated PM2.5 concentration share in Gaya during 2018 and 2030 under the BAU scenario. By 2030, outside contribution[18] to the total concentration level will be maximum with 33%, followed by transportation with 31% share in the total concentration levels in the city. Under BAU scenario it appears that transportation and domestic sectors (heating) will have the maximum impact and hence need serious interventions in terms of policies and mitigation measures to reduce the pollution level. The PM2.5 concentration of Gaya is expected to reach 91.7 µg/m³ in 2030 from 69.3 µg/m³ in 2018.

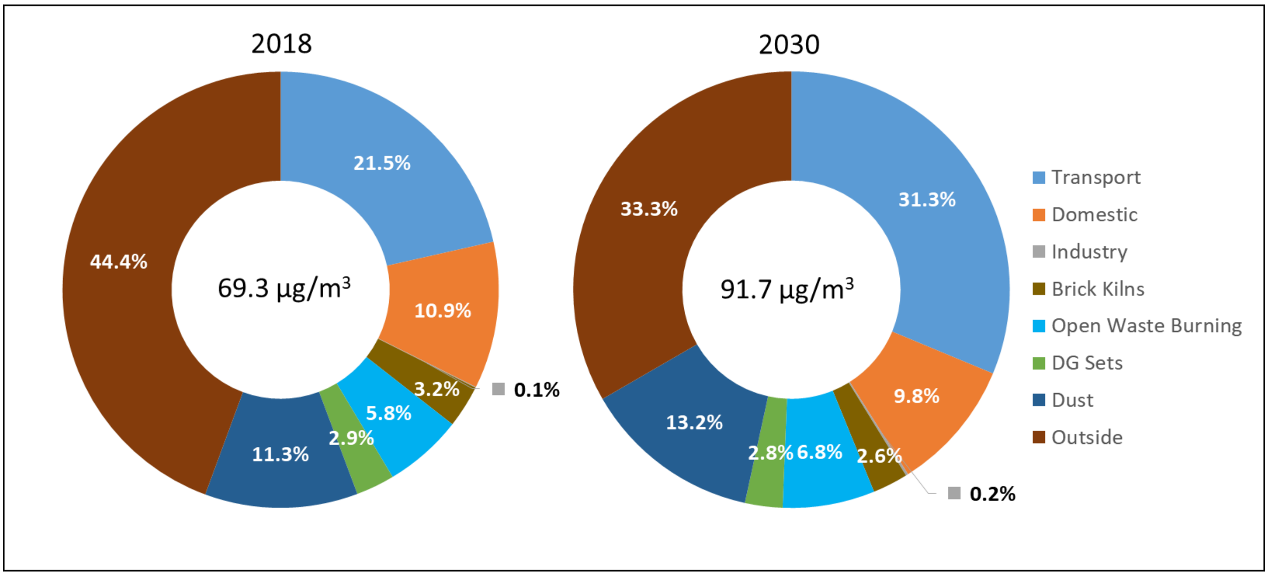
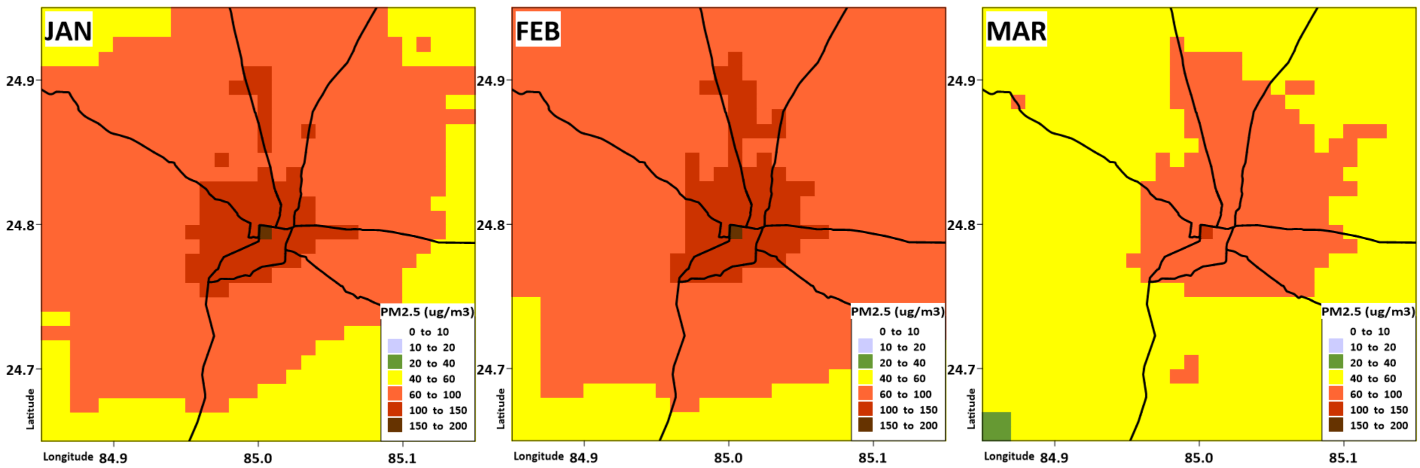


Figure 10: PM2.5 concentration share: 2018 vs 2030 (BAU)

Figure 11 presents monthly estimates of PM2.5 concentration levels in Gaya for 2018 (BAU). It is observed that the concentration levels are high (well over 60 µg/m³) during the winter months (November, December, January, and February), while for rest of the months the air is relatively clean.



[18] Outside contribution – Emissions from outside the considered boundary. This represents most of the non-urban activities outside the city limits, mostly dominated by cooking and heating (in the absence of any big industries).

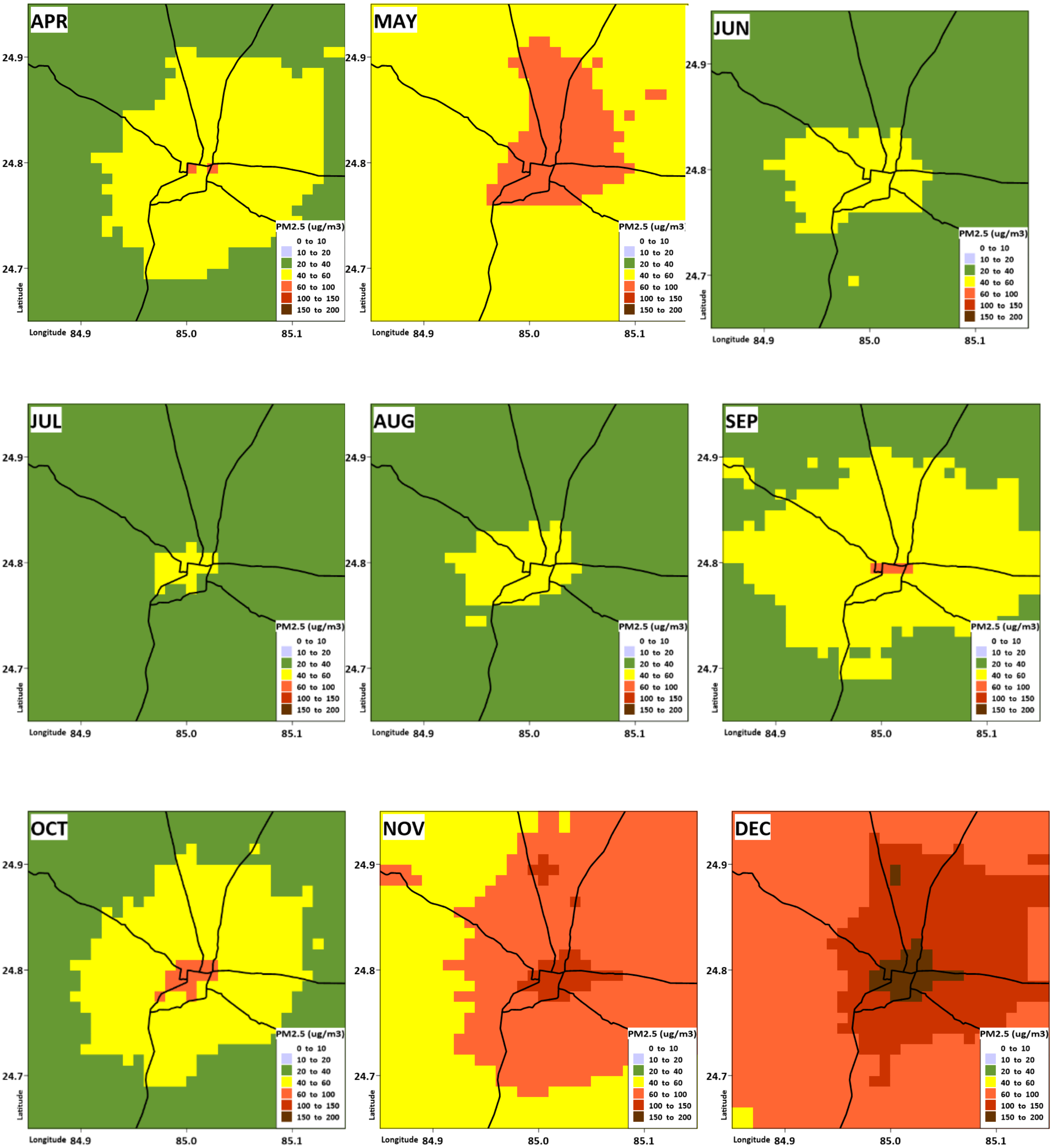


Figure 11: PM2.5 monthly concentration levels (BAU-2018)

3. Sector-Specific Control Measures

The pollution in Gaya city is predominantly anthropogenic in nature. Mainly tail pipe emissions from transportation sector, industrial emission (stone crushers, manufacturing and fabrication industries), dust from construction and demolition activities, and household emission (cooking and heating) contribute to the city's pollution load. Reducing the pollution load of the city will require curbing emissions from these sectors. A list of sector-specific CMs were identified to reduce emission from the sectors.

3.1 Comprehensive list of control measures.

A comprehensive list of sector-specific CMs was prepared for an effective action plan for the city. Figure 12 presents the various sector-specific determinants which were selected for identifying the CMs. The determinants were selected based on the present and existing scenario of the various sectors in the city of Gaya.

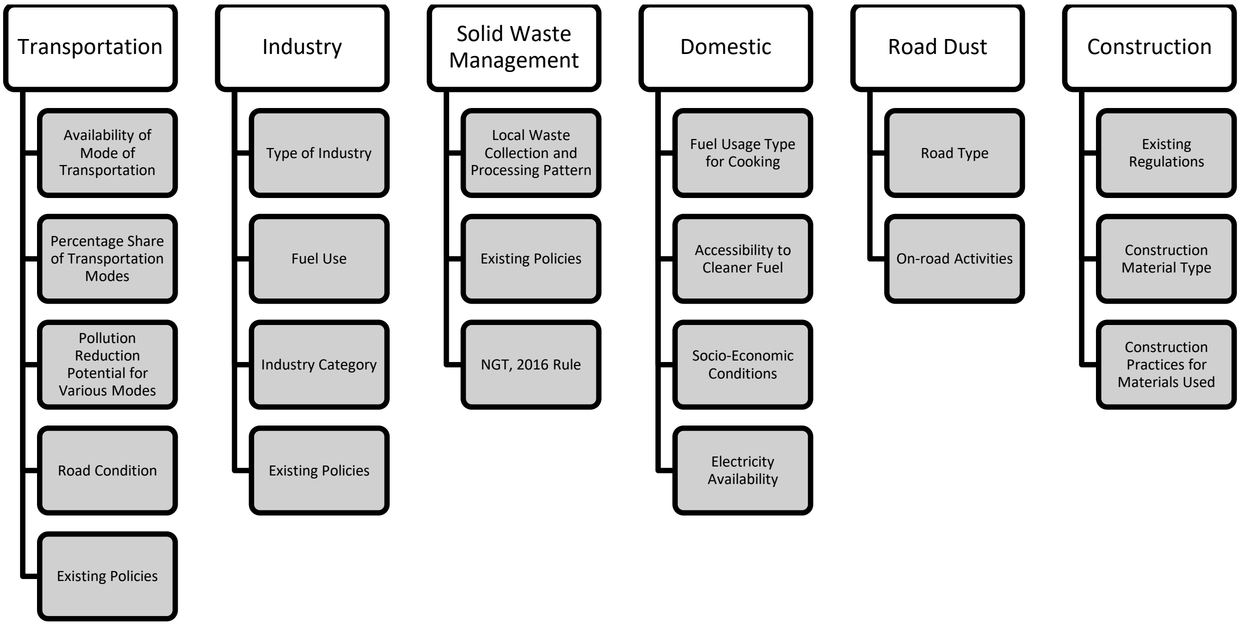


Figure 12: Determinants for source-specific CMs

Transportation Sector: To identify CMs for the transportation sector, determinants such as the existing mode of transportation (i.e., bus, car, auto rickshaw, 2-wheelers, and non-motorised transport) and modes of transportation used by the public were considered. Moreover, factors such as road condition (road width, paved/unpaved roads) and the pollution-reduction potential of various modes of transportation were considered while determining the CMs. Existing and upcoming emission-reduction policies were also examined to identify CMs.

Industrial Sector: Various determinants were considered for suggesting the CMs, such as type of industries (brick kiln, metal fabrication, smelting, and others), fuel use (biomass, coal, CNG, and diesel), and categorisation (red, orange, green, and white). Apart from the above mentioned determinants, the existing and upcoming policies relating to air pollution were considered while selecting the CMs.

Solid Waste Management (SWM): The sector is governed by various factors such as:-

- Door-to-door waste collection / Collection from local dumping place
- Frequency of collection
- Waste segregation
- Types and quantity of waste processing (if any)

When attempting to determine CMs for solid waste, the aforementioned factors along with central and state policies of waste management and National Green Tribunal (NGT) rules–2016 (ban on any type of waste burning) were taken into account.

Domestic Sector: Determinants such as the fuel used for cooking/heating (LPG and wood), availability and accessibility to cleaner fuel, socio-economic conditions, and fuel for lighting purpose (because of non-availability of electricity) were taken into account for identifying CMs.

Road Dust: Determinants such as types of road (paved or unpaved), on-road activities (number and type of vehicles plying), and construction activities near the roads, green covers around the roads, and potholes were considered while determining the CMs.

Construction Sector: CMs were selected based on the central and state governments' existing rules and regulations on pollution reduction. The construction practices (transportation and storage of material) exercised in the city also helped define the CMs.

The determinants helped us identify CMs for various sectors contributing to pollution. The policies introduced by the state and central governments—such as the introduction of BS-VI vehicles and fuel (by the central government), and the introduction of increased LPG use for cooking under the Pradhan Mantri Ujjwala Yojana (PMUY)—were taken into account for determining the CMs.

It was important to understand the various line departments' capability to implement the identified CMs. For this, multiple focussed group discussions were conducted with the line departments and the necessary data was collected (Annexure D).

A comprehensive list of CMs was proposed based on the polluting sectors and their contributions. Implementation timelines for the CMs (short-, medium-, and long-term) were also suggested based on the availability of infrastructure and the existing policy framework of the various line departments. A Benefit-Cost Ratio (BCR) of the CMs was estimated to help line departments prioritise implementation strategies. The CMs were shortlisted by BSPCB, after deliberations with various line departments, based on the BCR and the implementation time.

The short-listed CMs for TEA are listed in Table 1. Detailed list of CMs adopted by BSPCB for Gaya city is attached in Annexure A. The list of CMs mentioned in Annexure A has been sent for NGT compliance.

Table 1: Shortlisted control measures for TEA

City name:- Gaya						
S. no.	**Sectors**	**Action Points**	**Technology/Infrastructure Requirement (TR/IR)/ Methods (M)/ Outcome (OC)**	**BCR[19]**	**Implementation Period (Short term – 6 months, Medium term- <2 yrs. Long term – >2 yrs.)**	**Implementation Agency**
1	Transportation	Complete ban on 2-stroke autos and replacing them with EVs	TR—E-rickshaws OC—Reduction of emission load from autos	High	Medium-Long	Dept. of. Transport (D.O.T)
		Strict implementation of PUC check (every 6 months) and better PUC check infrastructure and management (increase the no. of PUC centres and proper calibration of instruments)	OC—With better PUC infrastructure and strict pollution norms emission from private and public vehicles will decrease	Medium	Medium	
		Incentivising the use of cleaner fuels - (CNG/LPG) for private vehicles and electric vehicles	TR—Proper infrastructure to increase the adoption rate of cleaner fuels OC—Reduction of emission load from private vehicles which switch to Electric/CNG/LPG-based vehicle from petrol/diesel -based vehicles	Medium	Medium	
		Installation of Diesel Particulate Filter (DPF) in all the diesel vehicles	M—Installing DPF filters to existing diesel vehicles OC—Reduction of emission load from diesel vehicles	Medium	Medium	
		Increase parking facilities near railway stations, religious spots, educational institutions, and Govt. offices.	M—Improvement in infrastructure at hotspots OC—Reduction in traffic congestion will facilitate faster vehicle movement and reduce tail-pipe emissions	Medium	High	GMC
2	Industry	Shifting of stone crushers away from the city area (min 10km away from the city outskirts)	Incentive to owner for relocating outside the city. Land availability for shifting to new location OC – Reduction of emission load from stone crushers.	Medium	Medium	Bihar State Pollution Control Board (BSPCB) Dept. of Industries (Bihar)
		Adapting new technologies for brick kilns	Adapting zigzag technology	Low	Medium	

[19] Lives saved and cost incurred is the deciding factor for categorising CMs into high, medium, and low for BCR. The categorisation scale of BCR varies for all the CMs listed.

3	**Solid Waste Management**	Installing waste composting plants at city level	M—Composting plants OC—Composting waste/garbage will reduce the emission load from garbage burning	Medium	Medium	GMC
		Recycling centres for dry waste	M—Recycling centres for dry waste OC—Proper disposal of dry waste will reduce the emission load from garbage burning	Medium	Medium	
4	**Domestic**	Increasing the LPG connections in low-income strata	M—Increase in LPG connection OC—Reduction in emission load	High	Medium	BSPCB GMC
		Introduction of improved *Chulhas* (low emission *Chulhas*)	M—Identifying areas where *Chulhas* were being used Procuring the *Chulhas* OC—Reduction in emission load	Medium	Medium	Food And Civil Supplies Department GMC
		Replacing kerosene with an alternate fuel	M—Procuring solar lanterns OC—Reduction in emission load	Medium	Medium	Food And Civil Supplies Department
		To mandate roof-top solar panel for power back up and solar water heating	TR—Solar panels and other technological requirements OC—Reduced electricity demand	Low/ Medium	Medium	Bihar Renewable Energy Development Agency (BREDA) GMC
		Promotion of the use of prefabricated blocks for building construction	OC—Reduction in emission load from dust	Low/ Medium	Medium	BSPCB, GMC
5	**Road Dust**	To take appropriate action to remove road dust/silt regularly by using mechanical sweepers	M—Mechanical sweeping, Identifying the road stretch with high silt content, & Procuring the mechanical sweepers OC—Reduction in resuspension of dust	High	Medium	GMC

4. Methodology - Techno-Economic Assessment (TEA) of the CMs

4.1 Techno-economic assessment

Techno-Economic Assessment (TEA) is a framework to analyse the economic and technical performance of a process, service or product. Technical feasibility analyses the effectiveness of a particular technology, whereas the economic feasibility analyses the cost incurred (capital, operational, maintenance, and salvage value, etc.) and the benefits achieved in the form of lives saved due to better air quality. TEA was performed for all the shortlisted CMs identified (Table 1) in each sector.

The following sections describe the sector-specific TEA and the technologies considered for emission reduction and policy solutions.

4.1.1 Transportation

Gaya district's road network is well connected to the rest of the state. However, Kumar and Sen (2015) states that only 17% of the total road network is either highways/district roads, rest is village roads. The study also highlights that over 40% of the population resides in area where they have to travel at least three kilometres to access a surface road[20]. Kumar and Sen (2015) also states that there is big scope for improving the existing transportation infrastructure in Gaya. Adding to this, Gaya does not have an efficient public transportation system. People often prefer either their own vehicle or auto rickshaws for their transportation needs.

Following CMs were considered for Gaya city under the transportation sector to help reduce pollution levels.

Control measure 1: Ban on registration of two-stroke autos

Proposed measure: "Registration of two-stroke autos will be banned; Old two-stroke autos to be replaced with Electric-Rickshaws"

Two-stroke autos use a mixture of oil and gasoline and tend to emit more pollutants into the atmosphere compared to four-stroke autos. Though the percentage share of two-stroke autos operating in Gaya is low, the proportion of toxic air pollutants emitted by two-stroke autos is more than twice that of four-stroke autos (Thakur et al., 2018). Potential technologies that could replace the existing two-stroke autos were identified. A cost beneift analysis (CBA) was performed by comparing the shortlisted technologies using their Total Cost of Ownership (TCO) (estimated using equation 4.1.1.1) and potential benefits that these technologies could offer in terms of pollution reduction and additional revenue. It was estimated that the major component of the TCO of auto rickshaws is the operation and the maintance cost. Table 2 lists the technological options and key parameters considered for replacing two-stroke autos.

[20] Surfaced road – Road covered with any type of cement concrete or bituminous surface

$$TCO = \frac{C + (F * L * D) + [(O + M) * L * D] - S}{L * D} \quad \textbf{(4.1.1.1)}$$

Where,

C - Initial Capital cost (INR);
F - Fuel cost (INR/km);
L - Lifetime of the considered vehicle (yrs.);
D - Distance travelled by the vehicle in a year (km/yr.);
O & M – Operation and Maintenance cost (INR/km); Includes battery replacement cost
S - Salvage Value (estimated resale value of an asset at the end of its useful life)
Battery replacement costs are included in the O&M cost.

Table 2: Key parameters for technologies considered - Autos

Parameters	Two-Stroke Autos	CNG	Electric
Capital cost (INR Lakhs)	1	1.5	2
Fuel efficiency	18-20 km/l	20-22 km/kg	0.15 kWh/Km
Fuel cost (INR/km)	4.2	2.6	1.0
TCO (INR/km)[21]	9.5	6	2.5

Control measure 2: PUC check (every 6/12 months) and better PUC check infrastructure and management

Proposed measure: "To open PUC centres at each petrol pump, and policies like 'No PUC No fuel' shall be enforced"

Rogers et al. (2002) suggests that with effective polices and efficient PUC centres, the level of emissions from automobiles will decrease. The total number of PUC centres that need to be installed in the city are estimated considering a) the cost to install (equipment cost and the registration fee) and operate (salary and other recurring costs) a PUC centre, b) no. of vehicles operating, c) average cost to get a PUC certificate, and d) % of vehicles to receive a PUC certificate.

A Cost Benefit Analysis (CBA) was performed by identifying the total costs (Capital and O&M cost) incurred and the benefits (based on emission reduction as a result of vehicles getting PUC certified) achieved to identify the effectiveness of the CM. The equipment needed to open a PUC centre: smoke meter, 4-gas analyser, and a personal computer. In addition to this, training of staff is also necessary.

Key Facts:

- Total no. of PUC centres in Gaya – 6 (Operational)

Control measure 3: Incentivising the use of cleaner fuels (CNG/LPG) and electric vehicles for private use

Proposed measure: "Provide incentives to people to buy CNG/LPG/electric vehicles"

There are policies and plans such as Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) and National Electric Mobility Mission Plan (NEMMP), which promote the use

[21] Estimated from (Center for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP).Indian Institute of Science, 2012)

of electric vehicles in India. However, the number of people who have received subsidies under FAME schemes in Gaya is very less in comparison with other cities – only 1.3% of the total vehicles have been sold under FAME scheme in Bihar[22]. Under this control measure, the number of vehicles to get incentives were estimated based on the growth rate of EV registration in Gaya and it was assumed that at least 10%–12% of the cars will be retrofitted with CNG/LPG kit

The cost incurred for implementation of this CM considered the incentives for the consumers. The government should also bear the cost of promotional activities focused towards increasing the adoption rate of CNG/LPG/electricity-based vehicles. These fuels, as a replacement of diesel, could lead to reduced emissions. The benefits achieved by implementing the CMs, in terms of potential lives saved (using the difference in emission load), has been estimated.

Control measure 4: Installation of Diesel Particulate Filter (DPF) in vehicles

Proposed measure: "Create mandates and provide subsidies to diesel vehicles (trucks) to install DPF"

Gaya is currently undergoing rapid urbanisation, a lot of construction activities are taking place in and around the city. This has increased the number of trucks currently operating in the region. Gaya is home to several stone crushers and trucks/trailers, which run on diesel fuel, and are used to carry sand from such industries. These heavy-goods vehicles use diesel fuel. Emissions from these heavy-goods vehicles are relatively high, compared with other modes of transportation.

The installation of DPF filters will help reduce emissions from these vehicles by at least 70% (Tsai et al., 2011) and (CARB-USEPA, 2015). However, Installation of DPF will increase the CO_2 emissions from the engine. Pollution caused by diesel vehicles can be curbed using the available filters (Preble et al., 2015). The kind of filters that could be installed in vehicles were identified by taking into account the availability of filters, the vehicle type, and the efficiency of the filters. The capital cost of the filter, the recurring maintenance cost and the pollution-reduction factor of the filter were used to determine an efficient option. Installing a DPF in a truck is expensive, and does not provide any additional benefit to the driver. The major focus will be on trucks that are older than 10 years. Around 8% of the total trucks that are registered in Gaya are older than 10 years. It was assumed that at least these trucks will be incentivised to install DPF filters by 2023

Control measure 5: Efficient parking facilities near hotspots

Proposed Measure: "Parking facilities will be constructed near traffic hotspots. This will help in reducing vehicles parked at unauthorised spaces"

Gaya is an old and unplanned city with narrow roads, leading to traffic congestion. Inadequate parking spaces near hotspots, slow moving vehicles, etc., add an extra burden to the congestion levels in the city. Introduction of parking lots near hotspots and effective implementation of parking rules will help GMC to reduce the number of vehicles that are parked at illegal spaces,

[22] As per data accessed from https://www.fame-india.gov.in/

thereby reducing the overall congestion levels in the city. Locations where vehicles are parked at unlawful places were identified as a part of the transportation survey.

4.1.2 Industry

The economy of Gaya is heavily dependent on SMEs and tourism industries. Besides that, Gaya is also an important industrial hub, and home to several brick kilns, stone crushers, and agricultural units.

Considering the various types of industries present in Gaya, the following CMs are proposed for reducing pollution levels.

Control measure 1: Adapting efficient technologies for brick kilns

Proposed measure: "Create mandates to convert fixed chimney kilns to advanced technologies"

Despite legal mandates from the Bihar government to adopt zigzag technology in kilns, several brick kilns still use fixed chimney kilns (FCK). Shifting to zigzag technology will help improve the city's air-quality levels. The cost of conversion from FCK to zigzag kilns was estimated by considering the capital cost and opportunity cost (based on productivity loss during the days spent on shifting). Meanwhile, the benefits were estimated in terms of the additional revenue generated (based on improvements in product output), savings in fuel (based on fuel efficiency), and lives saved (based on emission-reduction potential).Table 3 presents the list of parameters (Iqbal, 2016) considered for adopting the improved technology for emission reduction in brick kilns.

Table 3: Key parameters considered - Adapting new technologies for brick kilns

Retrofitting Parameters	Induced zigzag kiln	Natural zigzag kiln	Existing FCK kilns
Capital required (INR lakhs)	25	27	-
Days required to shift technologies	60	90	-
Coal consumption (tonne) per lakh bricks	12	12	16
Product output	70-80%	70-80%	50 – 60%
Total annual savings (INR lakhs)	44	44	-
Additional requirements	Draught fan	Chimney	-

Control measure 2: Shifting of stone crushers away from the city area (min 10 km away from the city outskirts)

Proposed measure: "Create mandates to shift stone crushers away from the city"

Apart from brick kilns, several stone crushers are operational around the city. The cost incurred in implementing this CM is estimated using the capital cost incurred by the owner to move their stone crushing unit to a remote place, and the benefits achieved are estimated by lives saved (estimated using the emission reduction potential).

Figure 13: Suspended dust near a stone crusher unit

4.1.3 Solid-Waste Management

Gaya generates around 184 tonnes of waste per day. The collection efficiency of waste here is one of the best amongst the Indian cities. However, only 35% of the waste in the city gets segregated. Only around 10% of the waste that is generated gets treated, while rest gets accumulated in a landfill. Waste generated every year is estimated using the equation (4.1.3.1)

$$S_n = G * P_n \qquad \textbf{(4.1.3.1)}$$

Where,

S_n – Solid waste generated for year n;
G – Per capita waste generated (Per capita waste generated to increase by 1% (Shekdar, 1999));
P_n – Projected population at year n;

Key facts:

- Total municipal waste generated in a day: 184 TPD
- Installed capacity: 12TPD of Aerobic Composting Plants
- Waste composition: Compostable: 75%; Recyclable: 20%; Non-Compostable: 5%
- Segregation Level: <33%; Collection efficiency:95%

Control measure: Installation of composting plants at the city level, recycling centres for dry waste and waste to energy plants.

Proposed measure: "To increase the treatment capacity of solid waste at the city level"

There are several efficient solid-waste composting methods, such as vermicomposting, windrow composting, anaerobic digestion, and stack pile composting (CEDINDIA, 2011). The windrow composting (production of compost by piling up compostable waste in long rows) technique is economically attractive and technically simple. This technology can be operated at a centralised level and is likely the most suitable composting technology that could be implemented in Gaya.

Various composting methods were shortlisted for implementation in Gaya. While selecting the composting method, a few variables were taken into consideration, such as (a) land-use pattern, (b) solid-waste composition, (c) use of compost, and (d) cost required to install composting plants for the waste generated in Gaya.

The capacity of composting plants and dry-waste collection centres that need to be installed every year was estimated by projecting the solid waste generated, taking into account the population growth and the segregation level.

Cost of implementing this control measure was estimated by taking into account the capital cost (land cost, machineries, etc.), O&M (salary, maintenance of machineries, etc.), awareness activities, and more.

Studies suggest that a proper solid-waste management plan could reduce the amount of waste being burnt, which in turn may lead to improved air quality in the city (Guttikunda and Jawahar, 2014). In other words, the benefits of these control measures are directly linked to the potential emission reduction from waste burning. The overall benefits of implementation was estimated keeping in mind the revenue generated (sale of fertilisers and recyclable materials), along with the potential lives saved as a result of emission reduction. Table 4 presents the key parameters for the technologies considered. Capital costs include the buildings, machinery, and construction cost of the plant. It is assumed that the land required to build the plant will be arranged by the municipality.

Table 4: Key parameters for the methods considered - SWM

Parameters	Windrow composting[23]	Dry waste collection centres[24]
Segregation required	Yes	Yes
Implementation time (year)	< 1	1 – 2
Capital required (Per-tonne) (INR Lakhs)	9	15
O&M cost (Per-tonne) (INR Lakhs)	2.3	9
Output	Fertilisers	Reusable/Recyclable materials

Authors estimates based on (CEDINDIA, 2011) and (Chandran and Narayanan, 2016)

4.1.4 Domestic

In 2015, across India, residential biomass burning was the largest individual contributor (24%) to the deaths attributable to PM2.5 (GBD MAPS Working Group, 2018). Solid fuels that are burned for cooking purposes are also a major contributor to indoor air pollution. Evidence suggests a strong link between indoor air pollution and asthma, tuberculosis, cancer etc.

[23] Estimated price for the year 2011
[24] Estimated price for the year 2019

(Kurmi et al., 2012). Infants and children are more vulnerable because of the immaturity of their respiratory defence mechanisms. As per the data provided by the Gaya municipality, at least 21% of the households use *Chulhas* for cooking.

Key facts:

- People use *Chulha* even if they have LPG connection (Fuel used in *Chulha* is available for free/cheap rate)
- Roof top area in government buildings: 3,063,398 sq. feet

Control measure 1: To mandate roof-top solar panel for power back up and solar water heating.

Proposed measure: "Focuses on incentivising the installation of solar panels in independent houses and installation of solar panels in government buildings.

Industries and local shops often switch to DG sets when there is a power outage. With the introduction of solar panels, the installed power generation capacity of Gaya will increase, reducing the use of DG sets. Government should also focus on incentivising the installation of solar panels at houses/government buildings.

Installation of a 1KW solar plant costs around INR 70,000 – INR 75,000 and government will be providing an incentive of around 30%[25] for the same. Cost incurred by the government for implementation of this CM is estimated using the incentives that will be provided to the general public for installation of the solar PVs on their rooftops and the cost incurred by the government to build rooftop panels at government buildings.

Control measure 2, 3 and 4: Introduction of improved Chulhas *(low-emission* Chulhas*), induction stoves, increased LPG connections in low-income strata, and use of solar lanterns*

Proposed measure: "Focus on subsidising the cost of smokeless Chulhas*, induction stoves and new LPG connections, and promote solar lanterns within the economically lower strata of society"*

As per the data provided by the Gaya municipality, LPG penetration rate in Gaya is around 80%. 21% of the households still use *Chulhas* for cooking. By increasing the number of LPG connections and refuelling rate of LPG cylinders, and using smokeless *Chulhas* or induction stoves, it is assumed that the dependency on solid fuels like wood and biomass will decrease. The emissions level from these solid fuels is higher than that of the emissions from LPG or smokeless *Chulhas* (Singh, 2009). The cost for implementing this control measure was estimated by taking into account the incentives (Annexure C) that will be provided to the citizens. This will motivate people to switch to smokeless *Chulhas*/induction stoves or to adopt LPG connections. The benefits of implementation were estimated by taking into consideration the percentage of emission reduction caused by the implementation of these CMs.

The electrification level in Gaya is around 100%; however, there are households in Gaya which are still dependent on kerosene for lighting purposes. By promoting the use of solar lanterns in these households, it is assumed that kerosene usage will decrease.

[25] As per the information retrieved from MNRE

4.1.5 Road Dust

Traditionally, all the roads and sidewalks in Gaya city are swept manually. This method, however, is considered highly inefficient as dust swept from the roads is left on the roadside, with dust getting suspended in the atmosphere while sweeping as well. This dust gets re-suspended due to vehicular movement (Kuhns et al., 2008). The Bihar government needs to implement stringent norms to collect roadside dust to curb the resuspension of dust. The installation of mechanical sweepers and end-to-end road pavement could help achieve the goal.

Control measure: Regular removal of road dust/silt using mechanical sweepers

Proposed measure: "Introduction of mechanical sweepers to control road dust emissions"

Roadside dust can be removed using mechanical sweepers currently available in the market. However, to select a suitable mechanical sweeper for Gaya, various parameters were considered like (a) road surface condition, (b) content of the debris, (c) area to be swept, and (d) frequency of sweeping. A CBA was performed to check the financial feasibility of the sweeper, considering the key parameters (Kuehl et al., 2008) mentioned in Table 5.

Table 5: Key parameters considered - Mechanical sweeper

Parameters	**Mechanical Sweeper (MS)**	**Regenerative-Air Sweeper (RAS)**	**Vacuum-Assisted Sweeper (VAS)**
Capital cost (INR lakhs)	40	48	80
O & M cost per km (INR)	68	31	34
Life (Yrs.)	10	12	14

The total number of mechanical sweepers required is estimated using the equation (4.1.5.1) below

$$M_n = L_r/(S * R) \qquad \textbf{(4.1.5.1)}$$

Where,

M_n – Total no. of mechanical sweepers required
L_r – Total length of the roads considered (km)
S – Average speed of the mechanical sweeper (km/hr)
R – Average operational time of the mechanical sweeper (hr)

4.2 Health benefits

Long-term exposure to small particles [10 microns or less in diameter (PM2.5 & PM10)] has been associated with increased mortality and morbidity over time (Srinivasan et al., 2018). When PM concentrations reduce, the related mortality and morbidity levels also go down. The reduced PM concentration helps project the associated health benefits in monetary terms. The clean air action plan's focus was to estimate the mortality avoided due to reduction in PM2.5 concentration levels.

The following method was adopted to estimate the mortality avoided annually (Pope et al., 2014)

$$M = \Delta\ PM2.5 * E_p * \Delta ER * B_d \qquad \textbf{(4.2.1)}$$

Where,

- M – Mortality avoided annually
- $\Delta\ PM2.5$ – Change in PM2.5 concentration levels in 60 km X 30 km grid
- E_p - Exposed Population – Population of Gaya
- B_d - Baseline death rate (national mortality rate)
- ER (excess risk) – Supra-linear Concentration Response Function (CRF) considered on the basis of global burden of diseases (GBD) assessments. $ER\ (excess\ risk) = 0.4 \times \{1 - \exp\ [-0.03\ (PM2.5)^{0.9}\ ]\}$

The method establishes a relationship between the change in PM2.5 concentrations and the mortality avoided. According to a study by Pope et al. (2014), the excess risk function can follow either a supra-linear form (rate of change of risk decreases with higher pollution concentration levels) or a linear form (risk increases at the same rate irrespective of pollution levels). However, recent studies consolidated that the ER or the CRF is more likely to be supra-linear at higher levels of exposure (Burnett et al., 2014) (Pope et al., 2014). This implies that the marginal benefits of pollution reduction at lower concentration levels are higher than the benefits in highly polluted areas. Figure 14 describes the difference between the supra-linear curve and the linear curve.

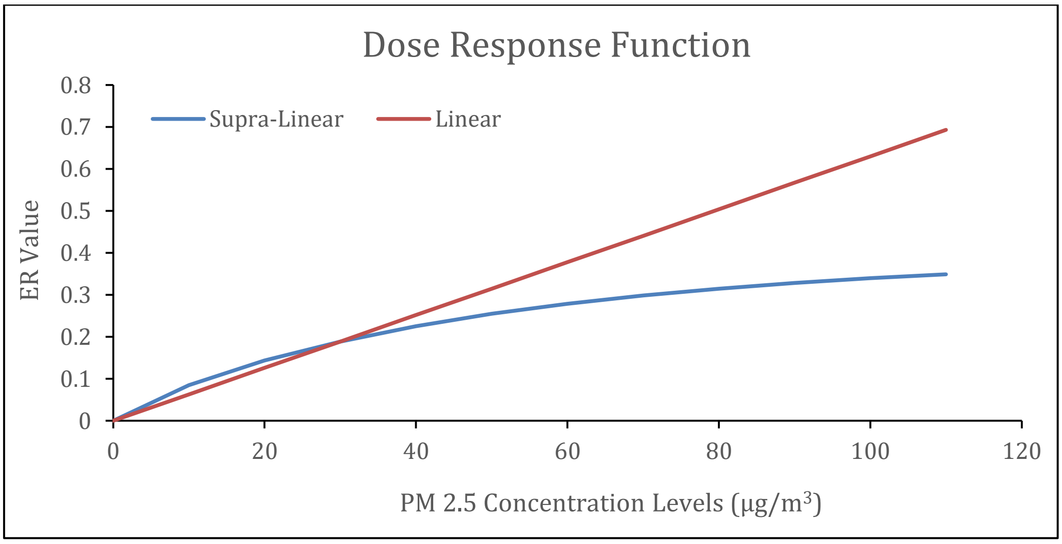


Figure 14: Supra-linear and linear form of ER function

5. Results and Discussion

As per the study, the total emission load is increasing by 50% (Chapter 2.3.2) under the BAU scenario. Sectors such as transportation, waste burning, and domestic are contributing to this increase in the emission load. Based on these emission concentrations, various scenarios (combination of CMs) were developed with varying levels of pollution reduction targets till 2030. Emission reduction scenarios for the sectors considered in the study have been described in detail below.

5.1 Sector: Transportation

Control measure 1: Ban on registration of two-stroke autos

Under this CM, registration of two-stroke autos will be banned and incentives will be given to two-stroke autos so that the owners can replace their vehicles with E-rickshaws. Introduction of electric autos will help improve the current transportation scenario in Gaya along with helping the municipality to control air pollution.

Key Considerations:

- Total no.of. two-strokes to receive incentive: 6192
- Incentives – As per FAME scheme; Time period: 5 years.

The cost incurred and the benefits achieved under this CM is given in Table 6 below

Table 6: Economic analysis - Replacing two-stroke auto with EV-based autos

Cost and benefits	2019-2022	2023-2025	2026-2030
Cost incurred (INR Cr.)	38	-	-
Total mortality saved (no.)	1	4	16

The study estimates that the adoption of E-rickshaws will reduce the pollution levels. However, barriers such as technology, manufacturing capacity, affordability, and driver acceptance have a major impact on the adoption rate of E-Rickshaws (CapaCITIES, 2018) Therefore, considering the varied and substantial potential benefits offered by E-Rickshaws (emission reduction, cost involved, etc.), the government should focus on building new infrastructure and educating drivers to boost the adoption rate.

Control measure 2: PUC check (every 6 months) and better PUC check infrastructure and management

At present, according to CPCB protocol, all vehicles must undergo a PUC check once a year. The existing PUC check system needs to be revised and the number of PUC centres and the infrastructure must be improved.

Under this control measure, it is proposed that 17 new PUC centres be set up with proper monitoring mechanisms and adherence to CPCB protocols. The total number of vehicles having valid PUC certificate will increase by at least 30% (TERI, 2017). We have assumed that with proper monitoring mechanism, at least 30% of the vehicles that are plying in Gaya will have a valid PUC certificate. Table 7 presents the total cost incurred for setting up the PUC centres, the operational cost (includes the manpower required, electricity charges etc.,) and the estimated mortality saved under this scenario. Around 1.6% of the total emissions from the transportation sector could be reduced under this control measure. This reduction in emissions would help save at least 13 lives by 2030.

Table 7: Economic analysis - PUC scenario

Cost and Benefits	2019-2022	2023-2025	2026-2030
Capital cost (INR Cr.)	0.64	-	-
Operational cost (INR Cr.)	0.95	0.83	1.63
Total mortality saved (no.)	1	3	9

The mere introduction of new PUC centres will not help/encourage vehicle owners to ensure that their vehicles are in a good condition. Initiatives like "No PUC, No fuel" must be introduced and public awareness about the impact of air pollution must also be escalated.

Delhi has good PUC infrastructure; the city also has proper regulations in place. However, studies indicate (TERI, 2017) that fewer than 30% of vehicles in Delhi have a valid PUC certificate. Lack of public awareness and acceptance is one of the main reasons for these abysmal numbers. Therefore, it is important for various government departments to create public awareness about the importance of vehicle maintenance.

Control measure 3: Incentivising the use of Electric Vehicles and cleaner fuels (CNG/LPG) for private vehicles

To bring about any kind of policy change and implement any regulation on ground, people must be provided with regulations that incentivise them to adopt the suggested change. Hence, for people to use clean fuel and electric vehicles, a proper incentive-provision channel must be created.

Under this scenario, incentives will be provided to:
- Private vehicle owners who are motivated to retrofit their vehicles with CNG/LPG kit
- Owners purchasing new vehicles that use clean fuel

India already operates schemes that provide incentives to vehicle owners who purchase electric vehicles. Unfortunately though, limited knowledge about these schemes is available with the beneficiaries in Gaya. One of the major reasons for less beneficiaries is the lack of awareness about the available schemes and lack of infrastructure.

The burden of cost for implementing this control measure falls on the government. Under this CM, individuals will be provided incentives only till 2022. It is assumed that around 100 new electric vehicles will be registered by 2022 and around 1,400 vehicles will be retrofitted with CNG kits. It is estimated that around 2% of the total emissions from transportation sector can be reduced by this measure. The estimated cost and benefits for the same are listed in Table 8 below.

Table 8: Economic analysis - Incentivising private vehicles

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.) – EVs	1	0	0
Incentives (INR Cr.) – CNG	1.4	0	0
Total mortality saved (no.)	1	4	13

Control measure 4: Installation of DPF Filters in vehicles.

Diesel vehicles emit pollutants that are harmful to human health (New Hampshire Department of Environmental Services, 2014). These emissions can be reduced by retrofitting diesel vehicles with DPF (CARB-USEPA, 2015). BS6 complaint vehicles will come with pre-installed particulate filters and is expected to hit the roads soon. However, in view of the existing registered vehicles, this CM suggests that trucks older than 10 years should have DPF installed. The major focus is on trucks registered in Gaya. However, transportation department should also promote the installation of DPFs in trucks plying in cities close to Gaya.

It was estimated that this scenario would reduce the transportation sector's emissions by around 10%, which would help the government save around 62 lives by 2030. Table 9, presents the total cost incurred (incentives) and the lives saved.

Table 9: Economic analysis - Installation of DPF

Cost and Benefits	2019-2022	2023-2025	2026-2030
Incentives (INR Cr.)	4	0	0
Total mortality saved (no.)	4	9	49

Technologies like (a) selective catalytic reduction (SCR) for NOx emission reduction, (b) DPFs for PM reduction, and (c) diesel oxidation catalyst (DOC) for CO & hydrocarbon (HC) reduction (Preble et al., 2015) already exist in the market. Since the primary focus is on reducing the levels of PM, it is recommended that the focus should be on installation of DPFs in diesel vehicles that are older than 10 years.

Control measure 5: Efficient parking facilities near hotspots

Major hotspots where traffic gets congested due to parking of vehicles at no parking places were identified as a part of the transportation survey. Introduction of parking lots that are accessible and affordable will encourage people to utilise such lots. Under this control measure, we are proposing to install three parking lots with capacity to handle 20026 cars near 1) Station Road, 2) Kachahari chowk, 3) Kashinath more. This would cost the GMC around INR 60 Cr.

5.2 Sector: Industry

Control measure 1: Adapting new technologies for brick kilns

This control measure recommends the conversion of all the existing FCKs to zigzag technology. Most importantly, the capital cost required to retrofit FCKs to zigzag technologies is much lower than other advanced technologies like Vertical Shaft Brick Kilns (VSBK) and Hybrid Hoffman Kilns (HHK). This control measure will help to reduce 40% of emissions from the brick kilns sector, saving around 73 lives by 2030.

Table 10 presents the cost of retrofitting all brick kilns from FCK to zigzag technology in Gaya.

Table 10: Economic analysis - Brick kilns

Method	Induced zigzag kiln	Natural zigzag kiln
Additional cost incurred (INR Cr.)	8	8
Additional maintenance cost /yr. (INR Cr.)	0.5	-
Savings /yr. (INR Cr.)	7.5	7.5
Total mortality saved (no.)	73	73

Control measure 2: Shifting of stone crushers away from the city area (min 10 km away from the city outskirts)

There are no stone crushers inside the city. However, stone crushers on the outskirts emit enormous amount of suspended particles into the atmosphere. Hence, government should

[26] Assumption based on existing parking lots in tier 2 cities.

enforce norms such as transportation of the produced sand with proper cover, green covers at the premises, etc., to control emissions.

5.3 Sector: Solid-waste management

Control measure: Installation of composting plants at city level, recycling centres for dry waste.

Gaya generated around 184 tonnes of solid waste per day in 2018. Considering the population growth and per-capita waste generation, the city will produce around 290 TPD of waste by 2030.

Key considerations:

- Per capita waste generation to increase by 1% annually, waste composition to remain constant
- Gaya's segregation levels to reach at least 70% by the end of 2030
- It is assumed that setting up a proper solid-waste management plan will reduce the solid-waste burning practices in Gaya
- A composting plant of capacity 50 TPD will be installed in 2021, 40 TPD in 2024, and an additional capacity of 30 TPD will be installed in 2027
- Dry waste collection centre of capacity 10 TPD will be installed in 2021, 15 TPD in 2024, and an additional capacity of 10 TPD will be installed in 2027.

Composting plants capacities and number of dry waste collection centres required were determined by considering the waste segregation level, the collection efficiency, and the projected waste generated per year. Table 11 presents the total cost incurred and benefits under this scenario.

Table 11: Economic analysis - SWM

Cost And Benefits		2019-2022	2023-2025	2026-2030
Composting plants	Capital cost (INR Cr.)	8	7	6
	Operational cost (INR Cr.)	5	11	31
Dry waste collection centres	Capital cost (INR Cr.)	2	3	2
	Operational cost (INR Cr.)	2	7	21
Total mortality saved (no.)		7	22	99

Under this scenario, we have assumed that the amount of waste that is burned will decrease with the proposed solid-waste management plan. By achieving a segregation level of 70% and with sufficient waste treatment capacity, to treat the collected waste, it is estimated that around 90% of the emissions from burning wastes will be reduced. This could save around 128 lives as a result of reduction in pollution levels.

Household-level waste segregation and waste collection are key to developing an efficient solid-waste management system (Bhushan et al., 2018). A proper waste-collection mechanism ensures safe transportation and treatment of the generated waste. Therefore, 100% waste collection needs to be ensured alongside boosting the installation and capacities of solid-waste treatment facilities.

5.4 Sector: Domestic

Control measure: Reducing the usage of solid fuels.

The problem of solid fuel burning can be reduced by increasing LPG connections and replacements of traditional *Chulhas* with advanced *Chulhas* and induction stoves. This, in turn, will result in reducing the domestic sector's emissions.

Scenario Creation:

Considering the percentage of people (Jain, 2017)) willing to switch to LPG from traditional *Chulha* and the cost of solid fuel, we considered two scenarios. Under this control measure, we assumed that at least 70% of the households that are using *Chulha*s will get incentives to either switch to LPG or smokeless *Chulha*/induction stoves.

Table 12 presents the cost incurred and the benefits achieved under this scenario. The smokeless *Chulhas* cost around INR 750-2500 in the market. In order to achieve desired reduction in pollution from the sector, the government should provide incentives to the citizens. This incentive will range from INR 750-2500 based on the cost of the *Chulhas* available in the market. Incentive of INR 1600 will be provided to people who get new LPG connection and three LPG cylinders at a subsidised rate will be given to the beneficiaries.

Table 12: Economic analysis - Domestic sector

Cost And Benefits	2019-2022	2023-2025	2026-2030
Incentives(INR Cr.) – New LPG connection	0.36	0.34	0.53
Incentives(INR Cr.) – Subsidised Cylinders	0.41	0.99	2.88
Incentives(INR Cr.) – Smokeless *Chulha*/ Induction stoves	2.77	0.35	0.29
Total mortality saved (no.)	15	37	86

Scenario: Solar PV on government building, institutions, industries, and households.

Solar rooftop potential of Gaya in government building is around 23 MW[27]. DG sets are widely used in industries, hospitals, institutions, mobile towers and by local vendors. Under this scenario, we have considered that with increase in power generation, it is expected that installation of solar rooftops will help to decrease the use of DG sets. Government would incur around INR 175 Cr for installation of solar rooftops in government buildings.

5.5 Sector: Road dust

This measure proposes end-to-end road pavement, strict compliance of existing policies, and the introduction of mechanical sweepers. This can help reduce suspended road dust particles.

Key considerations:

- Total length of road in Gaya: 160 km
- No of mechanical sweepers to be employed on major roads : 1 - 2

It is estimated that at least 2 regenerative air sweepers will be required to cover the major roads in Gaya. This will cost around INR 1 crore. Additional measures such as strict implementation of construction regulations and end-to-end road pavement could help the

[27] As per data provided by GMC

government save 110 lives in 12 years. In addition to deploying mechanical sweepers, government should also focus on creating green buffers along the roads. This will help in controlling the resuspension of dust considerably.

5.6 Scenario analysis

The previous section discussed individual interventions and the associated costs and benefits of various CMs. The study also looked into three combination scenario analysis for emission reduction. These scenarios were considered by clubbing various CMs in three buckets of high-emission reduction, medium-emission reduction, and low-emission reduction potentials. The section below details 1) the assumptions considered, 2) the estimated change in pollution levels, and 3) the costs and the benefits.

Scenario combination 1: High emission reduction potential measures combination

This scenario is designed to achieve maximum emission reduction (best case scenario) by 2030. All the high emission reduction CMs/technologies from various sectors were clubbed. The interventions under each scenario have predefined targets, described in chapter 6.

Few of the major interventions in this scenario are 1) to increase percentage share of electric transportation, 2) conversion of all the brick kilns and other industries to clean fuel technology, 3) maximising the use of LPG for cooking needs.

Scenario combination 1 – Assumptions

- Complete ban on two-stroke auto rickshaw registration and replacement of existing two-stroke auto rickshaws with E-rickshaws
- At least 30% operating vehicles to have valid pollution under control (PUC) certificates
- Up to 8% of the trucks to have DPF installations
- Brick kilns to adopt zigzag technology by 2023 and promotion of prefabricated bricks
- Waste treatment capacity – composting plants: 120 TPD & dry-waste collection centres: 35 TPD
- Installed solar rooftop capacity – 23MW
- At least 70% of the traditional *Chulhas* are replaced by smokeless *Chulhas*/ induction stoves
- LPG penetration rate – 90%
- Electrification level – 95%
- No of mechanical road sweepers -2

It is estimated that the total emission load (PM2.5) will reduce by 58% by 2030 with respect to the BAU scenario (Figure 18). A major reduction in PM2.5 emissions in sectors like DG sets (91%) and open waste burning (91%), followed by brick kilns (76%) and transport sector (63%) is expected by 2030, under this scenario.

Figure 15 presents the estimated emissions for Scenario 1.

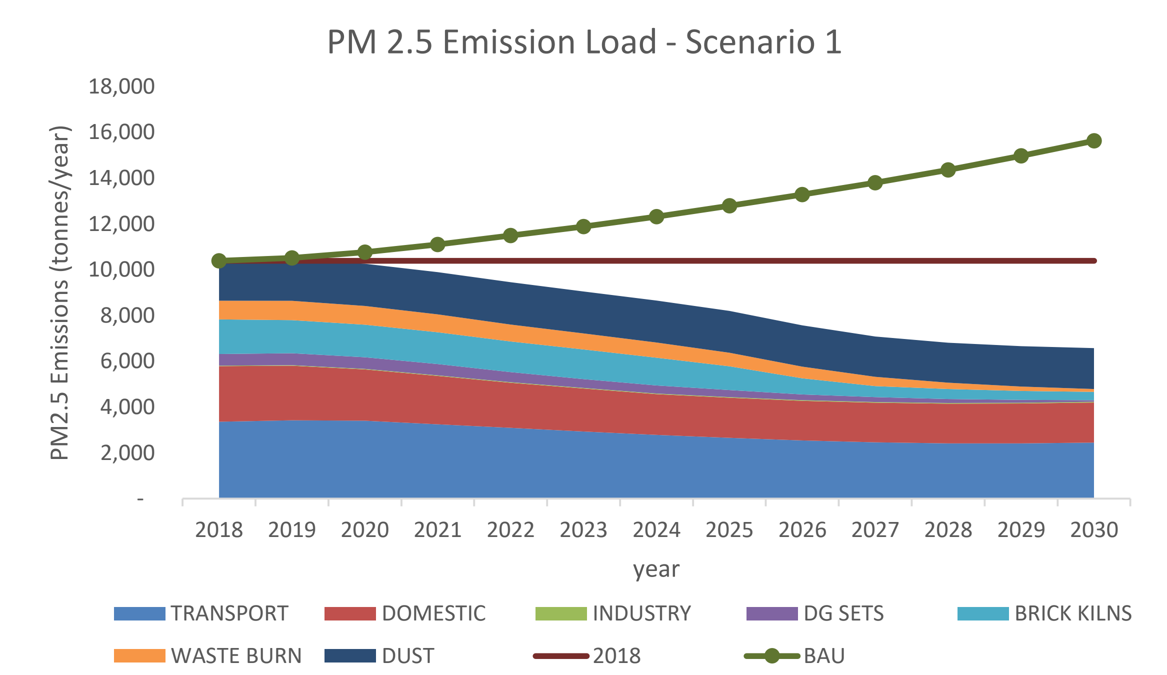


Figure 15: PM2.5 emissions scenario 1

Introduction of solar PV and improvement in the existing power sector infrastructure will decrease pollution from DG sets. Gaya would also have enough installed solid-waste-treatment capacity to treat all of the waste generated, essentially curtailing the burning of open waste.

Though all the brick kilns are expected to shift to advanced technologies, they are likely to continue contributing to the total emission load, given that they are located within the city. Hence, expecting 100% pollution reduction from the brick kilns sector is unrealistic.

Scenario combination 2: Medium emission reduction potential measures combination

CMs/technologies with medium-level pollution reduction potential have been grouped under this scenario. It has the potential to reduce the PM2.5 emissions load by 44% by 2030 with respect to the BAU scenario (Figure 16)

Scenario combination 2 – Assumptions

- Registration for two-stroke autos are banned completely and all the existing two-stroke autos are replaced by E-Rickshaws
- At least 30% of the vehicles that are plying Gaya to have a valid PUC certificate
- At least 6% of the trucks to have a DPF installed in them
- Brick kilns that are present in Gaya are shifted to natural zigzag kiln
- Waste treatment capacity – composting plants: 70 TPD & dry-waste collection centres: 25 TPD
- Installed solar rooftop capacity – 20 MW
- At least 50% of the traditional Chulhas are replaced by smokeless Chulhas /induction stoves
- LPG penetration rate – 87%
- Electrification level – 90%
- No of mechanical road sweepers -1 -2

The contributors to this PM2.5 emission reduction are expected to come from sectors like DG sets (75%), transport sector (60%), and followed by brick kilns (54%). Figure 16 presents the estimated emissions for scenario 2.

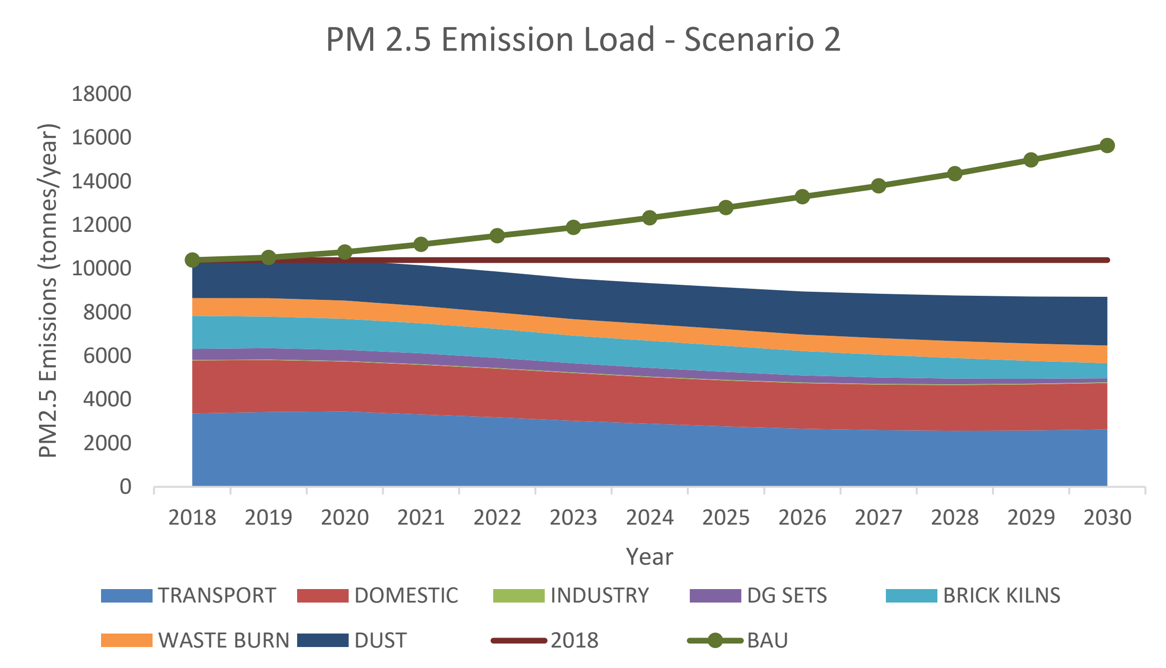


Figure 16: PM2.5 emissions scenario 2

Although scenario 2 is similar to scenario 1, it has slightly relaxed targets under each sector. As a result, emissions reduction from each sector is relatively less compared to the first scenario. However, the transportation sector's emission reduction in both scenarios is nearly the same. This is mainly because, in both the scenarios, the number of vehicles (for public transportation) released remains almost the same; only the type of technology used varies.

Scenario combination 3: Low emission reduction potential measures combination

This scenario groups all the CMs that a government can implement without any major investments or technology change. Measures such as the introduction of buses - with the majority of new buses being diesel, the implementation of existing rules such as the banning of two-stroke auto-rickshaws, the shifting to zigzag kilns that use clean technology, etc., will help reduce pollution immediately.

Scenario combination 3 – Assumptions

- Registration for two-stroke autos is banned completely
- At least 10% of the vehicles that are operating in Gaya to have a valid PUC certificate
- Brick kilns that are present in Gaya are shifted to natural zigzag kiln
- Installed solar rooftop capacity – 20 MW
- Waste treatment capacity – composting plants: 50 TPD & dry-waste collection centres: 25 TPD
- At least 30% of the traditional Chulhas are replaced by smokeless Chulhas/induction stoves
- LPG penetration rate – 85%

- Electrification level – 80%
- No of mechanical road sweepers –1

This scenario has the potential to reduce PM2.5 emissions load by 33% by 2030 with respect to the BAU scenario. Figure 17 presents the estimated emissions for the scenario 3.

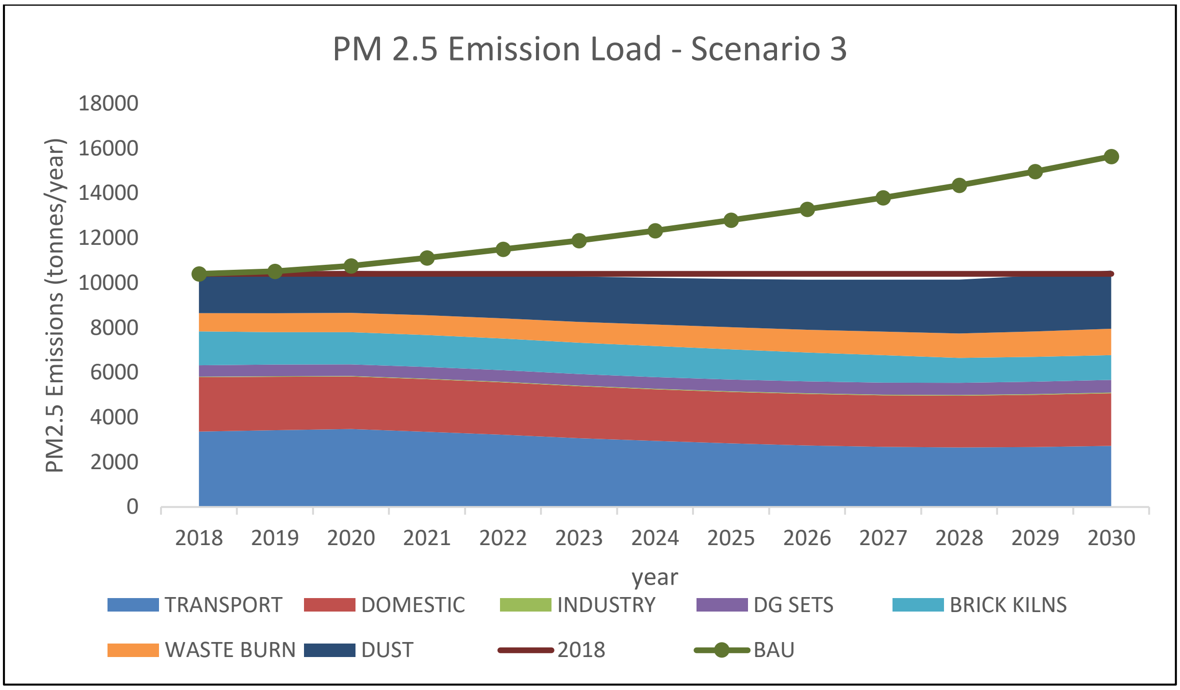


Figure 17: PM2.5 emissions scenario 3

Economic analysis: scenario combination 1 vs scenario combination 2 vs scenario combination 3

Figure 18 presents the total PM2.5 emission load for high, low, and medium-pollution reduction scenarios with respect to baseline (2018) and the BAU scenario. High-pollution reduction scenario would result in pollution reduction of 58%. The medium and low-pollution reduction scenarios would result in pollution reduction by 44% and 33% respectively.

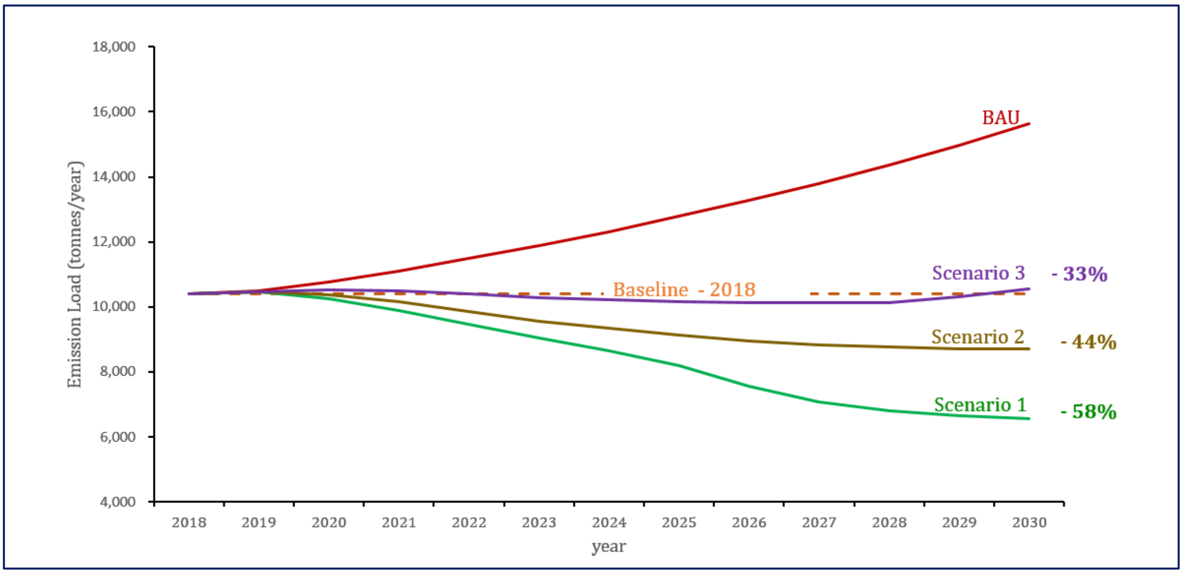


Figure 18: Pollution reduction potential scenarios

Table 13 presents the estimated cost incurred and the potential lives saved under each scenario. The transportation and solid waste management sectors require a larger budget allocation. It is because these sectors need additional machines, vehicles, and new infrastructure to improve the existing practices. However, for other sectors, the cost is either in the form of incentives and implementation cost or is borne by the private players. Hence, the government's cost burden is reduced.

The cost incurred (INR 463 crore) and the lives saved (1101) for scenario 1 is high in comparison to the other two scenarios as described in Table 13. The costs and benefits have been estimated over a period of 11 years (2019 – 2030).

Table 13: Economic analysis (scenario 1 vs scenario 2 vs scenario 3)

Sectors	**Private Owners**	**Departments**	**Cost Incurred (INR Cr.)**		
			Scenario Combo 1	**Scenario Combo 2**	**Scenario combo 3**
Transport		Traffic Police	1	1	1
	Private		3.5	2	2
		D.O.T[28]	44	43	42
		GMC[29]	60	40	40
Industry	Stone Crushers		0	0	0
	Brick kilns		8	6	4.2
SWM		GMC[30]	108	77	54
Domestic		FCS[31]	12	10	7
Solar Rooftop		SBPDCL	175	150	75
Road Dust		UD	1	1	0.5
		BSPCB	0.4	0.4	0.4
		GMC	50	25	15
Lives Saved (No.)			1101	844	613
Total			463	355	241

28 Includes incentives provided for EVs, CNGs, DPFs.
29 Includes cost incurred to build parking lots
30 Includes capital cost of the waste management plants and additional vehicles for efficient waste management
31 Includes incentives provided for new LPG connection, incentives to shift to smokeless *chulha*/ induction stoves and subsidised cylinders.

6. Recommendations, Implementation Strategy, and Target Setting

Air-pollution management needs a collaborative approach from all concerned departments across Gaya. Various measures suggested in the study and existing policies must be implemented for effective reduction of the city's pollution levels. The formation of a project management and audit unit is also vital in ensuring the time-bound implementation of policies and CMs. Appropriate indicators to measure the effective implementation of the CMs and progress of the implementation strategy need to be devised.

Based on the techno-economic assessment of the shortlisted CMs for the city of Gaya, the following policies are recommended:

1. *Gaya should introduce green public transport (EVs/CNG):* Diesel autos are the only public transportations modes that are available to the people of Gaya. Old two-stroke autos should be phased out and replaced with electric auto rickshaws. Such measures will help reduce tail-pipe exhaust to a major extent.

2. *Vehicle fitness certificate and PUC certificate should be made mandatory for fuel refilling:* Tailpipe emission from poorly maintained vehicles is much higher than that from vehicles that are well-maintained and serviced on a regular basis. By introducing policies like "No PUC, No Fuel", vehicle owners will be more inclined to get their vehicle serviced.

3. *Trucks (diesel) plying in Gaya must be retrofitted with DPF.* This will cut down tailpipe emission loads by around 60% to 80%.

4. *Mandate city-wide cap on coal and diesel (industrial) use, and revise/reduce the cap every four years:* Industrial pollution is one of the major contributors to air pollution in Gaya. The city must set a cap on coal and diesel usage for industrial use. This will encourage industry owners to adopt clean fuels (CNG/electric). A review/reduction of the cap every five years will help reduce industrial pollution to a great extent.

5. *Open dumping of solid waste should be penalised and the municipality should not collect waste if it has not been segregated at the household level:* GMC should ensure 100% door–to-door collection of municipal solid waste. GMC should also develop a mechanism to penalise people who dump their solid waste in open sites. These steps will ensure that waste is collected and treated properly. GMC also needs to develop measures and campaigns to encourage segregation of waste.

6. *Financial incentives (as reduced electricity unit cost) should be provided for houses with grid-connected rooftop photovoltaic systems (RTPV):* Gaya's residents should be encouraged and rewarded for setting up grid-connected RTPV. Unit price of electricity consumption can be reduced, based on the solar power generation capacity and household consumption patterns.

7. *LPG distributors should be encouraged to provide 100% door-to-door LPG distribution service:* A robust supply infrastructure (or more LPG distributors) must be set up to ensure door-to-door supply. Increasing the number of LPG distributing centres and workforce will ensure proper door-to-door supply and reduce the use of solid fuel.

8. *Gaya's city civic body should ensure end-to-end paving of the city's roads:* Dust on roads must also be removed to ensure road-dust suppression. The above mentioned

measures along with road-side and a green belt will prevent, to a large extent, dust collection on roads.

9. *The Gaya administration should also focus on installing advanced monitors that track source contributions effectively:* Such monitors can assist policymakers with the necessary data to take source-specific actions.

10. *A health study should be commissioned to fill the gaps on details about air-pollution–related illness:* This would help the health sector strengthen its public communications on air pollution and health.

6.1 Roadmap, time frame and essential levers of the plan

This section describes the recommendations, targets, and strategies that should be adopted to ensure effective implementation of the suggested CMs. This section also discusses the various existing schemes in accordance with the suggested CMs. These schemes could be a potential source to financially support the related CMs.

Sector: Transportation

Transportation is one of the major contributors to pollution, contributing 30% to the total pollution concentration in Gaya. Reducing transportation sector emissions can be a complex process. Table 14 presents the strategies to be followed for implementing CMs.

Table 14: Strategic roadmap - Transportation sector

S. No	Strategy	Similar Funding Schemes	Targets			Implementing agency
			2022 (Short term)	2025 (Medium term)	2030 (Long term)	
CM 1	**Complete ban on 2-stroke autos and replacing it with CNG-based vehicle or EV**					
1.1	Ban on 2-stroke autos	-	Complete Ban			D.O.T
1.2	Replacing existing two-stroke autos with EV-based autos	-	100%			
1.3	Setting up scrapping centres for old autos (No)	-	1	-	-	
CM 2	**PUC check (every 6 months) and better PUC check infrastructure and management**					
2.1	Setting up PUC centres (No)	-	17			Private owners
2.2	Spreading awareness	-	Awareness programmes			
CM 3	**Incentivising the use of cleaner fuels (CNG/LPG) and electric vehicle for private vehicles**					
3.1	Setting up of incentives for different types of vehicles	FAME	Incentives mechanism already in place			D.O.T
CM 4	**Installation of DPF filters in diesel vehicles**					
4.1	Installation levels of DPFs (in trucks)	-	8 - 10%	-	-	D.O.T
CM 5	**Efficient parking facilities near hotspots**					
5.1	Installation of parking lot (No)	-	3	-	-	D.O.T

Awareness programmes with a wide public outreach need to be created for promoting acceptance for new modes of transportation.

Sector: Industry

Unlike the transportation sector, emission reduction from the industry sector is directly associated with the kind of technology this sector uses. Policies that enable industries to adopt advanced technologies and fuel need to be enforced. Audit systems need to be set up to monitor the emission from industries. Table 15 lists the strategies that should be followed to ensure implementation of the CMs mentioned above.

Table 15: Strategic roadmap - Industry

S. No	Strategy	Targets 2022 (Short term)	2025 (Medium term)	2030 (Long term)	Implementing Agency
CM 1	Adapting New Technologies for Brick Kilns				
1.1	Conversion of FCKs to zigzag Technology	100%			BSPCB & Dept. of Industries (Bihar)

Sector: Solid-waste management

Open waste burning contributes to around 8% of the total emission in Gaya. Studies suggest that an efficient solid-waste management system can reduce the amount of waste burnt. Table 16 presents the targets and strategies that should be followed to achieve maximum pollution reduction from the solid-waste sector.

Table 16: Strategic roadmap - Solid-waste management

S. No	Strategy	Targets 2022 (Short term)	2025 (Medium term)	2030 (Long term)	Implementing Agency
CM 1	Introduction of Composting Plants and dry waste collection centre				
1.1	Setting up laws/ Incentivising mechanism to improve segregation at household level	Awareness programs and policy initiatives to increase the segregation level			GMC
1.2	Level of segregation	50%	65%	70%	
1.3	Installation of composting plants (TPD)	50	40	30	
1.4	Installation of dry-waste collection centre (TPD)	10	15	10	

The government should establish stringent regulations to control waste burning during the winter. It is observed that roadside dwellers burn leaves and dry waste to dispose them and generate heat to shield themselves from the cold in winters. Therefore, alternative solutions for roadside dwellers need to be provided to discourage them from burning waste.

Sector: Domestic

Wood and biomass (solid fuel) usage for cooking is a major contributor to domestic sector emissions, which can be reduced either by increasing LPG connections or by introducing smokeless *Chulhas*/induction stoves. Table 17 details the various targets and strategies that can help ensure the highest levels of pollution reduction from the domestic sector.

Table 17: Strategic roadmap - Domestic sector

S. No	Strategy	Similar Funding Schemes	Targets 2022 (Short term)	2025 (Medium term)	2030 (Long term)	Implementing Agency
CM 1	**Introduction of improved *Chulhas* (Smokeless *Chulhas*)**					
1.1	Setting up incentivising mechanism	Unnatt *Chulha* Abhiyan (UCA)		-		Food And Civil Supplies Department, GMC
1.2	Replacement of traditional *Chulhas* (%)		50%	+15%	+15%	
CM 2	**Increasing the LPG connections in low-income strata**					
2.1	Setting up new LPG refuelling centre (No.)	PAHAL, Ujjwala Yojana	20	+5	+5	Food And Civil Supplies Department
2.2	Increase the LPG penetration rate (%)		85%	87%	90%	
CM 3	**Solar Rooftops**					
3.1	Increasing the Solar Rooftop capacity	Solar Energy Subsidy Scheme	23 MW	-	-	Bihar Renewable Energy Development Agency (BREDA)

Sector: Road Dust

Construction activities, resuspension of dust, unpaved roads, transportation of uncovered material, and uncoordinated roadworks are some of the activities that result in the increase of suspended particles in the atmosphere. Because the sources of road dust are linked to activities of various departments, it is important to have a coordinated approach among various departments to reduce the emission from suspended particles.

Mechanical sweepers need to be adopted and end-to-end road pavements should be constructed to control the resuspension of dust. The strategy that should be followed, under this sector, is described in Table 18.

Table 18: Strategic roadmap - C&D and road dust

S. no	Strategy	Targets 2022 (Short term)	2025 (Medium term)	2030 (Long term)	Implementing Agency
CM 1	**To take appropriate action to remove road dust/silt regularly by using either mechanical sweepers / road paving**				
1.1	Addition of new mechanical sweeper of capacity 5-8 tonne (no.)	2	0	0	GMC

Communication and implementation strategy

A task force committee with representation from various line departments needs to be formed, to monitor and implement the CMs. The air-quality monitoring committee should keep a check on the functioning of the task force committee. The task force committee should be headed by the Chief Secretary of the state. The main objective of the committee will be "to reduce the emissions levels in Gaya region to the target set by NCAP".

The committee should meet every quarter to discuss the a) implementation status of the CMs, b) new policy changes, and c) required future steps. The respective representatives from line departments should coordinate the implementation strategies within their departments within the stipulated time.

Alongside other stakeholders and funders, various available schemes at the central level need to be considered for creating the corpus needed to implement the action plan.

6.2 Emergency response actions

Despite our best efforts, there may be episodes where pollution levels may increase drastically due to anthropogenic and natural phenomena.

To control this unexpected increase in pollution levels, CMs are suggested in Table 19. These measures, if implemented on an emergency basis, could safeguard our environment.

Table 19: Emergency response action plan

Severe Pollution (ambient PM2.5 concentration values of 250µg/m3 and above)	**Agency Responsible/ Implementation Agency**
Temporarily stop all construction activities	Bihar State Pollution Control Board (BSPCB)
Temporarily shut down brick kilns, and hot mix plants	BSPCB
Temporarily shut down schools and colleges	
Very Poor Pollution (ambient PM2.5 concentration values of 121-250µg/m3)	**Agency Responsible/ Implementation Agency**
Increase frequency of mechanised cleaning of the road and sprinkling of water on the unpaved section of the road	Gaya Municipal Corporation (GMC)
Increase public transport frequency and restrict operation of diesel autos	Department of Transport, Govt. of Bihar
Increase parking fee 3-4 times the current value	GMC
Strict vigilance and no tolerance for visible emissions—stop operations of visibly polluting vehicles by putting heavy fines	Traffic police
Stringently enforce all pollution control regulations in brick kilns and industries	BSPCB
Moderate to Poor (ambient PM2.5 concentration values of 61-120µg/m3)	**Agency Responsible/ Implementation Agency**
Strict vigilance and enforcing of PUC norms	Traffic police
Stop burning of solid waste	GMC, and BSPCB
Periodic mechanised sweeping and water sprinkling on the unpaved roads	GMC

6.3 Way forward

Development plays an important role in shaping a city's economy. Although Gaya has grown as a major tourist attraction in Bihar and is home to new industries, this growth has come at the cost of its deteriorated air quality levels. Unfortunately, the resultant increase in air pollution has had tremendous health impacts and is not sustainable for the future. Gaya's rising air-pollution levels require immediate adoption and implementation of relevant mitigation measures. Various environmental consequences and the social well-being of the inhabitants have to be considered while implementing the mitigation measures. Apart from this, future infrastructural development and growth for the city should be planned only after evaluating the impacts and consequences of the potential environmental damage.

Our study indicates that the mortality benefits [value of a human life—around INR 2.8 crore (Madheswaran, 2007) of implementing CMs that focus on improving environmental quality far outweigh the costs. Such measures could end up saving hundreds of lives and prevent insurmountable environmental damage.

Gaya administration has already initiated actions on enforcing fines on waste burning, ban on plastic, etc., Proactive action from the state government in implementing the suggested CMs will help improve the quality of air in the city.

To make any plan effective on the ground, it is important to take citizens and communities into confidence. By creating awareness and advocacy plans, we can create an ecosystem that will help implement the strategies in a time-bound manner. Additionally, it is of the utmost importance to build capacity of the line departments and make citizens the champions of the cause—to ensure a good quality of life for the future.

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Appendix:

Annexure A: Clean Air Action Plan submitted to NGT by BSPCB

S. No	Sector	Action Points	Technology/Infrastructure Requirement (TR/IR)/ Methods (M)/ Outcome (OC)	Implementation period (Short – 6 months, Med- <2 yrs.), Long – (>2 yrs.)	Implementation Agency	Time Target for Implementation
1	Transportation	Restriction on plying and phasing out of 15 year old commercial diesel driven vehicles[32]*	M—Policy reforms OC—Reduction In black carbon emissions	Medium	Transport Dept. Govt. of Bihar	December 2019
		Complete ban on 2-stroke autos and replacing them with CNG based vehicle or EV	TR—E-rickshaws OC—Reduction of emission load from autos	Medium		December-2019
			TR—CNG based autos OC—Reduction of emission load from autos			
		PUC check (every 6 months) and better PUC check infrastructure and management (Hon'ble Supreme court of India in W.P.(C) no 13029/1985 said that pollution testing centres should be set up within premises of all petrol pumps)	OC—With better PUC infrastructure and strict pollution norms emission from private and public vehicles will decrease	Medium		December-2020
		Incentivising the use of cleaner fuels - electric vehicle and (CNG/LPG) for private vehicles	TR—Proper infrastructure to increase the adoption rate of cleaner fuels OC—Reduction of emission load from private vehicles which switched to	Medium		December-2021

[32] Subject to clearance from Honourable High court

			electric/CNG/LPG based vehicle from petrol/diesel based vehicles			
		Installation of Diesel Particulate Filter (DPF) in all the diesel vehicles[33]	M—Installing DPF filters to existing diesel vehicles OC—Reduction of emission load from diesel vehicles	Medium	Transport Dept. Govt. of Bihar	December-2020
		Good traffic management including re-direction of traffic movement to avoid congestion.	TR—Policy intervention OC—Reduction in emission due to non-congestion	Medium	Traffic police	December 2020
		Demarcated lanes for E rickshaws plying for public commuting	TR- Policy intervention OC- Reduction in emission due to non-congestion	Short	Traffic police	Immediate
		Monitoring of Vehicle fitness	M—Audit systems OC—Reduction in emission	Short-Medium	Transport & Traffic dept.	December 2019
		Checking on fuel adulteration	M—Audit systems OC— Reduction in emission	Short	District Administration & Oil companies	April 2019
		Periodic calibration test of vehicular emission monitoring instrument.	M—Audit systems OC—Reduction in emission	Short	BSPCB & Transport	April 2019
		Complete ban of carriage transport, heavy vehicles, during peak hours (8:00 -11:00 am & 5:00 - 8 pm). (Arranging alternate routes to all carriage transports between)	OC—Reduction in peak hour traffic will facilitate faster vehicle movement and reduce tail- pipe emission	Short	Traffic police	April 2019

[33] Policy decision – MV Act doesn't have provision for installing DPF.

		Launch drive against any vehicle with visible smoke coming out of it and ensure strict compliances				April 2019
2	**Industry**	Adapting new technologies for Brick kilns	Adapting Cleaner technology	Medium	Bihar State Pollution Control Board (BSPCB) Dept. of Industries (Bihar)	December 2019
		Shifting of polluting industries like stone crushers away from the city area (min 10km away from the city outskirts)	M—Regulatory requirements 1) Incentive to owner for relocating outside the city OC—Reduction in emission load from stone crushers	Long		December 2021
		Ban on polluting industries	M—Regulatory requirements	Short		June 2019
3	**Biomass & Garbage Burning**	Check stubble burning	M—Regulatory as well as awareness sensitisation OC—Reduction in emission from stubble burnings	Medium	Dept. Of Agriculture	December 2020
		Ensure segregation of waste at source and daily collection of segregated waste	OC—Reduction in emission load from garbage burning	Medium	GMC	Immediate
		To create separate zone to handle solid waste, C&D waste and other waste in the city	OC—Reduction in emission load from garbage burning			
		Identify garbage burning locations and strict enforcement of NGT (2016) rules regarding prohibition of garbage burning.	OC—Reduction in emission load from garbage burning			
		Promoting waste composting plants at city level				
		Recycling plants for dry waste.				
4	**Domestic**	Increasing the LPG connections in low income strata. To mandate LPG/Biogas in commercial eateries.	M—Increase in LPG connection OC—Reduction in emission load	Medium	Food And Civil Supplies Department	December 2020

		Ensuring uninterrupted electric supply within the city.	OC—Reduction in total emission load from kerosene lamps (as power cut backup will not be required)	Medium	South Bihar Power Distribution Company Limited	December 2019
		Ensure easy availability of affordable cleaner cooking fuels (LPG in urban areas & biogas in rural areas)	M—Improvement in LPG/Bio gas infrastructure	Medium	Food & Civil supplies Dept.	December 2020
		To mandate LPG/biogas in commercial eateries and promote induction cookers				
		Introduction of improved *Chulhas* (low emission *Chulhas*)	1) Identifying areas for using *Chulhas* 2) Procuring the *Chulhas* OC – Reduction in indoor emission load			
5	**Construction & Demolition**	Construction materials should be transported in covered vehicles	OC—Reduction in emission load from dust	Short	Traffic Police & Gaya District Administration	Immediate
		To mandate facility of tar road inside the construction site for movement of vehicles carrying construction material	OC—Reduction in emission load from dust	Medium	GMC	December 2019
		Promotion of the use of prefabricated blocks for building construction	OC—Reduction in emission load from dust	Long		December 2020
		Strict enforcement of CPCB guidelines for construction (use of green screens, side covering of digging sites, etc.)	OC—Reduction in emission load from dust	Short	BSPCB	Immediate
		Demolition & construction sites should be covered from all sides	OC—Reduction in Road dust	Short	GMC	Immediate
		Restriction on storage of construction materials along the road.	OC—Reduction in road dust	Short	GMC	Immediate
6	**Road Dust**	To take appropriate action to remove road dust/silt regularly by using mechanical sweepers	Mechanical sweeping Identifying the road stretch with high silt content Procuring the mechanical sweepers	Medium	GMC & Urban Development Dept.	December 2019
		End to end road pavement	OC—Reduction in resuspension of dust	Medium	GMC	

		Creating green buffer along the roads.	M—Improvement in infrastructure		& Urban Development Dept.	
		Urban Greening including vertical garden				
7	**DG Sets**	Initiate steps for installation of combined de NOx – particulate filter in all DG sets	M —Procuring the filters and identifying the DG sets which need to be retrofitted with filters	Medium	BSPCB	immediate
		Introduction of DG sets which use clean fuel	OC —Reduction in emission load from DG sets	Medium		
		Incentivising the use of clean fuel (CNG/LPG) based generator set	OC —Reduction in emission load from DG sets	Medium		
8	**Strengthening of AAQ monitoring**	Installation of four CAAQMS at Gaya. Two CAAQM stations under CSR funds of Central Public Sector Undertaking (CPSU) through CPCB at Eco-Park. Two CAAQM stations under State Govt. financial assistance.	OC—Proper evidence on sectoral contributions with primary baseline surveys to update the emissions inventory. OC—Efficient monitoring	Short	BSPCB	June 2019
		Source apportionment study (Dispersion +Receptor) Modelling	OC—Identification of pollutants	Medium	BSPCB	December 2019
9	**Public Awareness**	Issue of advisory to public for prevention and control of air pollution	OC—Awareness and better implementation of policy	Short	BSPCB & Dept. of Environment, forest & Climate Change	Immediate
		Launch public awareness programme campaign to control air pollution	OC—Through awareness, public participation for air pollution reduction will increase	Short	BSPCB GMC & Dept. of Environment, forest & Climate Change	Immediate
10	**Others**	Compliance of guidelines on DG sets and action against violation	TR—DPF (Diesel Particulate Filters installation) OC—Reduction in black carbon	Short	BSPCB & GMC	Immediate
		Help line to oversee non compliances on aforesaid issues.	OC—Awareness and better implementation of policy	Short	BSPCB & GMC	Immediate

		Hospital incinerators for bio-medical incineration	OC—Reduction in bio-hazardous materials being dumped in to the landfill	Short	BSPCB GMC Dept. of Health (Govt. of Bihar)	Immediate
		City wise cap on coal use	OC—Reduction in coal consumption will reduce the emission load	Medium	BSPCB Food And Civil Supplies Department	December 2019
		Polluter pay principle	OC—Will act as a deterrent against polluters	Medium	BSPCB	December 2019
		Transportation of municipal solid wastes, construction materials, and debris in covered system.	M—Monitoring of implementation OC—Minimisation of road dust	Short	GMC	Immediate
		Immediate lifting of solid wastes generated from de-silting and cleaning of municipal drains for its disposal.	M—Monitoring of implementation OC—Minimisation of road dust	Short	GMC	April 2019

Annexure B:

Total emissions for the Gaya region for the base year 2018 (Tonnes)

	PM2.5	PM10	BC	OC	NOx	CO	VOC	SO_2	CO_2
Transport	3,358	3,535	1,352	1,080	5,065	45,267	12,783	82	11,89,276
Cooking	1,023	1,077	119	443	110	12,671	1,318	326	1,33,673
Lighting	117	123	112	1	0	16	1	11	3,829
Heating	1,286	1,354	169	705	141	13,462	2,168	89	45,881
Open Waste Burning	815	858	61	491	20	3,915	789	21	5,220
Construction Dust	850	4,814	-	-	-	-	-	-	-
DG sets	507	534	298	95	4,757	1,264	121	48	2,16,086
Industry - Light	23	24	8	5	18	34	3	6	2,048
Aviation	5.7	6.7	1.5	2.7	607.8	752.4	248.4	41.8	1,34,331
Brick Kilns	1,513	1,528	431	652	757	20,388	2,399	454	76,725
Industry - Heavy	-	-	-	-	-	-	-	-	-
Road Dust	898	5,987	-	-	-	-	-	-	-
Total	**10,396**	**19,840**	**2,551**	**3,474**	**11,476**	**97,768**	**19,830**	**1,079**	**18,07,067**

Total emissions for the Gaya region for the year 2030 (Tonnes)

	PM2.5	PM10	BC	OC	NOx	CO	VOC	SO_2	CO_2
Transport	6,533	6,877	2,365	2,160	7,868	91,555	29,679	23	22,63,910
Cooking	1,088	1,145	133	470	114	13,901	1,394	396	1,69,403
Lighting	117	123	112	1	0	16	1	11	3,838
Heating	1,494	1,573	197	821	164	15,585	2,496	102	51,181
Open Waste Burning	1,313	1,382	98	792	32	6,309	1,271	34	8,412
Construction Dust	1,294	7,330	-	-	-	-	-	-	-
DG sets	727	765	427	136	6,814	1,810	174	69	3,09,535
Industry - light	35	35	12	7	27	51	5	9	3,063
Aviation	11	12.5	2.6	5.2	1,186	1,454	475	82	2,62,732
Brick Kilns	1,520	1,535	433	655	761	20,490	2,411	457	77,108
Industry - Heavy	-	-	-	-	-	-	-	-	-
Road Dust	1,503	10,020	-	-	-	-	-	-	-
Total	**15,635**	**30,800**	**3,780**	**5,047**	**16,965**	**1,51,171**	**37,905**	**1,183**	**31,49,183**

Annexure C: Sector wise formulas, data considered, and assumptions

Key macro-economic variables

Variable	Value
Inflation Rate (CPI)	4.30%
Average Person per household	5.9
Population (2018) (Lakhs)	5.7
Population (2030) (Lakhs)	8.0

Sector: Transportation

Vehicle characteristics in Gaya (2018)

Total vehicle fleet: 2,86,293

Vehicle type	% share
Truck	5%
Bus	1%
Car	4%
Taxi	2%
Jeep	2%
Three-wheelers	7%
Two-wheelers	73%
Tractor	4%
Trailer	3%

Source: Data from Transportation Department

Incentives provided to autos

Autos	EV
Incentives (INR)	61000

Incentives provided to buy CNG/LPG/Electric vehicles (FAME scheme)

Type	Incentive (INR)
Electric Vehicles	As per the FAME scheme
CNG retrofitting	30000

Sector: Industry

Brick kilns in Gaya

Brick Kilns in Gaya	
Total	33
Operational	17

Sector: Solid Waste management

1) Waste Composition

Compostable	Recyclable	Non- Compostable
75%	20%	5%

2) Projected solid waste generation

Projected values		
Year	**Projected Population**	**Solid waste Generation (TPD)**
2018	5,70,160	184
2019	5,89,347	192
2020	6,08,534	200
2021	6,27,721	209
2022	6,46,907	217
2023	6,66,094	226
2024	6,85,281	235
2025	7,04,468	244
2026	7,23,655	253
2027	7,42,842	262
2028	7,62,028	272
2029	7,81,215	281
2030	8,00,402	291

3) Proposed waste segregation level

	Assumptions	Estimates		
Year	**Proposed waste segregation level**	**Segregated compostable waste (TPD)**	**Segregated recyclable waste (TPD)**	**Non compostable + Unsegregated (TPD)**
2018	0	0	0	184
2019	35%	45	12	135
2020	40%	54	14	132
2021	45%	63	17	128
2022	50%	75	20	122
2023	55%	86	23	117
2024	60%	97	26	112
2025	65%	109	29	105
2026	65%	115	31	108
2027	70%	128	34	100
2028	70%	133	35	104
2029	70%	140	37	104
2030	70%	145	39	107

4) Proposed waste treatment plants (TPD)

Year	Addition of new Composting plants	Composting Plant Capacity	Addition of new Dry Waste Collection centres	Dry Waste Collection Centre	W2E Plants
2018	0	12	0	0	0
2019	0	12	0	0	0

2020	0	12	0	0	0
2021	50	62	10	10	0
2022	0	62	0	10	0
2023	0	62	0	10	0
2024	40	102	15	25	0
2025	0	102	0	25	0
2026	0	102	0	25	0
2027	0	102	0	25	0
2028	30	132	10	35	0
2029	0	132	0	35	0
2030	0	132	0	35	0

Sector: Domestic

Incentives provided

CMs	Incentives provided (INR)
New LPG connection	1600
Smokeless *Chulha*	750 – 2500
Purchasing a cylinder	300

Annexure D: Data requirement form

S. no	Sector	Concerned Departments	Data Required
1	Transportation	Transport Department, Govt. of Bihar	1) Number of vehicles (buses/ Autos (2 strokes, E-Rickshaw and 4 strokes)/ two wheelers/ Cars/taxis/heavy vehicles) plying in Gaya 2) Vehicles registration details for the past 15 years (yearly data for all vehicles) 3) Number of new buses proposed for public transportation in the city (if any) and type of buses 4) Total number of existing and proposed charging infrastructure for EVs.
		Bihar State Pollution Control Board (BSPCB)	1) Number of Pollution Under Control (PUC) centres (operational and non-operational centres) 2) Year of calibration (last) for the PUC units
		Bihar State Food & Civil Supplies Corporation Ltd.	1) Total number of existing and proposed charging/ fuelling infrastructure for CNG/LPG 2) Number of parking facilities (public/private) that are available in the city and their vehicle parking capacity 3) Number of petrol stations carrying out fuel adulteration
		Gaya Municipal Corporation (GMC)	1) Number of petrol pumps and the amount of fuel sold and types of fuel sold 2) Total road length in the city, types of road, and road width

2	Industries	BSPCB, Bihar Industrial Area Development Authority (BIADA)	1) Total no. of industries in Gaya (segregated based on industry type/ fuel used/ location-inside city/ outside city, emission details if monitored by BSPCB) 2) Total number of brick kilns in Gaya (segregated based on technology used/ fuel they use/ location-inside city/outside city) 3) List of metal fabrication industries that use clean technologies 4) Number of industries that meet the standards set by CPCB 5) List of industries with waste disposal facilities, their waste treatment technology, and their treatment capacities 6) An estimate on the total number of DG sets (industrial) that are used in Gaya 7) Average running hours
3	Diesel Generator Sets		1) Estimate of number of DG sets used for commercial and domestic purpose 2) Average running duration (hrs/day) 3) Capacity of the DG sets (KVA)
4	Health	Health Department, Govt. of Bihar	1) Total number of respiratory health diseases registered in various hospitals (details for at least one year) 2) Average cost that is spent on one person on respiratory health diseases 3) Average number of days a person stays in a hospital for cases related to respiratory health diseases
		BSPCB	1) Total number of hospitals with incineration facility (Total/Operational) 2) Amount of medical waste that is generated in Gaya hospitals (tonnes/day) 3) Number of medical waste processing units
5	Solid Waste Management	BSPCB, GMC	1) Total solid waste generated in the city (tonnes/day)-domestic 2) Total solid waste collected and treated per day 3) Total waste burned on daily basis 4) Total number of solid waste treatment plants (composting/ recycling/ waste to energy plants) in Gaya and their treatment capacity. 5) Total amount of waste that is (generated by the industries (tonnes/day)/ treated by the industries (tonnes/day)/ disposed by the industries (tonnes/day))
6	Domestic, Institution & Commercial.	GMC, BSPCB	1) Total urban, rural, and slum population in the city 2) Number of slums inside the city 3) Mode of cooking and fuel used by the slum people (biomass burning, *Chulhas*, dung cakes etc.) 4) Total number of households that use *Chulhas*. 5) Percentage of households that have access to electricity 6) Type of fuel used in households (cooking-LPG, kerosene, and lighting-electricity. kerosene for lamps etc.)

7	Road side Vendors/Eateries		1) Total number of roadside vendors that use DG sets 2) Type and amount of fuel used for (cooking / DG sets)
8	Others	Finance Department, Govt. of Bihar	Average income of a person in Gaya
		GMC	Average land cost in Gaya