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Climate Change Threat in Jaipur: Mitigating and Sustainable Attributes Through Carbon Footprint Reduction

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Abstract

Challenges of climate change are significantly increasing on a forward time scale. Such a phenomenon is predominantly seen in urban sectors where population is rapidly increasing, thereby resulting in extensive resource consumption leading to release of significant carbon footprint. An attempt has been made in the present paper by the authors initially to assess the carbon footprint of Jaipur, Rajasthan on a backward and forward time scale partly to suggest mitigating measures and partly to link it with carbon credit schemes for achieving circular economy and providing sustainability. Research on assessment of carbon footprint has been done primarily on population, resource consumption in the form of LPG, power, and automobile, sewage, solid waste, housing, industry, other miscellany sources and secondly predicting on futuristic time scales of 1931, 1941 and 1951. Carbon footprint of automobile sector is done individually in respect of 2-wheelers, 4-wheelers, buses, goods vehicles, and other vehicles and predicted estimations done for the years 1931, 1941 and 1951. The mitigating measures particularly in the form of green infrastructure or urban forestry are evaluated to achieve towards d neutrality and link with carbon credit schemes to achieve circular economy and infuse sustainability. Although tropical rainforests are considered as one of the most important ecosystems used for the mitigation of the climate change, but it is quite far and away. The authors also attempted to assess the extent of green infrastructure required to achieve 30,50,70,90, and 100 percent carbon footprint reduction.

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INTRODUCTION

Climate change is an increasing global challenge leading towards rising temperatures and Un-predictable weather patterns coupled with environmental degradation. Urban areas, being hubs of human activity, contribute significantly to climate change due to high energy consumption, transportation emissions, and waste generation, resulting in elevated carbon footprints. Utilizing these footprints in the mitigating measures of climate change and sustainable urban development is a matter of challenge [1].

From last 70 years one of the significant

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changes worldwide include predicted climatic changes leading to global warming. One of the complex global challenges is climate change which is examined over different parameters including ecological, environmental, socio-political, and socio-economical dimensions [2–3]. It includes an overall increase in the temperature worldwide [4–6]. The different problems related to the climate of the earth intensified with the beginning of industrial revolution [7]. The devastating outcome of industrial revolution can be brought under control if immediate steps are taken. There is a large variety of natural and environmental disaster occurrence with the increase in the timeline, resulting in a lot of damage and loss of lives. Over the last decade there was a loss of 60,000 lives approximately around the world due to natural disasters [8]. The rapid increase in the temperature has very recognizable impact on the urban areas of the different continents [9–10]. Weather patterns which lead to extreme consequences like extinction of planted species include increase in the glacier melting, increase in the mercury contamination and lack of natural resources (such as ground and surface water) [11].

There is a drastic deterioration in the coastal ecosystem which leads to serious consequences like increase in temperatures, outbreak of diseases due to insects, health related serious issues and severe seasonal and lifestyle changes [12–13]. Due to noticeable lack in environmental knowledge and government's lack of commitment towards environment, which is clearly visible by the absence of a proper legislation the climate change has risen to a matter of serious public concern. Due to 2 to 3% increase of mercury level in the environment there will be a drastic transformation visible in the rainfall patterns and will have serious results visible by the end of 2050 [14].

LITERATURE REVIEW

Certain major environmental problems worldwide include extreme weather conditions, air pollution, increasing sea levels and spreading diseases due to major climate changes have become one of the primary issues to be addressed by the different countries worldwide [15]. The key cause behind such consequences is carbon dioxide emission. Henceforth, it has become one of the demanding steps to find a feasible carbon footprint calculation technique to provide a better sustainable environment [16]. Quantitative analysis of carbon footprint calculations not only helps to explore certain concentrated areas and the amount of carbon emissions but also helps to take certain mitigating measures and to keep a periodic check on it (Table 16).

As per the Paris agreement, the countries at the 21st meeting who are parts of the United Nations Framework on Climate Change agreed in the establishment of long term aims related to temperature including control of global average temperature [17] (limiting it to not more than 2^0C) and the actual temperature (limiting it to not more than 1.5^0C). China responded to the Paris Agreement by promising to reach its carbon peak by 2030 and to attain carbon neutrality by 2060. At the same time, USA intends to reduce the carbon emission by 50–52% taking 2005 benchmark into consideration (Table 17). Lastly, taking the agreement into consideration Japan has also decided to reduce the carbon emissions by 46% by within the time span from the year 2013 to 2030. Lastly, the European Union also did decide to reduce carbon emissions by 55% by 2030, considering 1990 to be the benchmark [18] (Table 18).

The California Climate Action Registry (CCAR), United States and The Climate Registry (TCR) are the most prominent and common resources which are used to calculate and define Carbon footprints. Although CCAR reports only CO_2 emissions, TCR also reports greenhouse gas emissions as well. Carbon footprint inventories can be defined as "Tiers". The "Tier 1" is related to direct emission of Carbon Dioxide (emissions directly from, firms, factories and vehicles). "Tier 2" refers to the carbon dioxide emissions related to the energy input of the organization [19].

CASE STUDY

About Jaipur

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Jaipur is known for its many rose-colored buildings, which earned it the nickname "The Pink City". Because pink is a symbol of friendliness, the city was painted pink in 1876 to greet Queen Victoria of Britain. Rajasthan, located in the northwest region of India, has Jaipur as its capital and most populous city. According to the 2011 census, the city has a population of 3.1 million residents. In 1727, Maharaja Sawai Jai Singh founded the fortified city to succeed the nearby Amber (currently known as Amer, which is now part of Jaipur)as the capital of the princely kingdom of Jaipur (formed by the Rajput in the 12th century CE).(Figure 1) The city is surrounded by hills except to the south. In the late 20th and early 21st centuries, Jaipur had rapid population growth, doubling between 1991 and 2011 (Table 19).

With significant air, rail, and road connections, Jaipur is both a commercial trading hub and a well-liked tourist destination. Engineering and metalworking, handloom weaving, distilling, glass, hosiery, carpets, blankets, shoes, and pharmaceuticals are among the industries. The production of jewellery, enamel, metalwork, printed fabrics, stone, marble, and ivory carving are among Jaipur's well-known arts and crafts.

Population of Jaipur

The population data of Jaipur during decades was collected from Census report, Govt. of India and reflected (Table 1). It would be evident from the said table that the population of Jaipur in the year 1951 was 0.65 million, which was increased to 4.1 million (estimate) in the year 2021, an increase of 630 percent during a span of 70 years.

Figure 1. Pictoral representation of Hawa Mahal.

Table 1. Showing population data of Jaipur during 1951–2011.

S.No	Year	Population
1	1951	3,07,000
2	1961	4,16,000
3	1971	6,44,000
4	1981	10,29,000
5	1991	15,40,000
6	2001	23,44,000

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7	2011	30,74,000

(Source: Census report 2011)

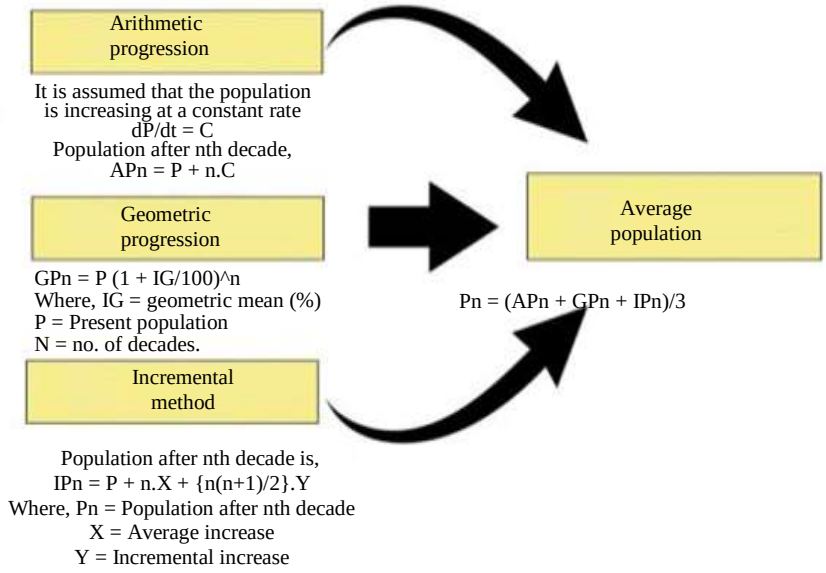

Figure 2. Geometrical increase method (or geometrical progression method).

Table 2. Showing the projected population from 2021–51.

YEAR	Arithmetic mean method	Geometric mean method	Incremental increase method	Average population
2021	35,35,167	40,30,988	36,59,367	37,41,841
2031	39,96,334	52,85,903	43,68,934	45,50,390
2041	44,57,500	69,31,493	52,02,700	55,30,564
2051	49,18,667	90,89,384	61,60,667	67,22,906

Population Projection

An attempt has been made to forecast the population of Jaipur for the years 2031, 2041, and 2051 through primarily three methods and then taken an average. The three methods of projection are thereby showcased here below:

Arithmetical Increase Method

This method of calculation is applicable for mostly old large and metropolitan cities. To go-ahead with the calculation, it is necessary to assume the increase rate of population is constant. Therefore, dP/dt = C, which states that rate of change of population with respect to time is constant. Henceforth, Population projection after nth decade will be Pn= P + n.C (Table 2) (Figure 2).

Table 2–Showing the average projected population(from 2021 – 51) from arithmetic mean, geometric mean and incremental increase method

In this method of calculation of population projection, the percentage increase in population is assumed to remain constant every decade. (as shown in table 2) This technique of population projection calculation is mostly applicable for newly developed industrial towns, specially in the first two decades when they are in the verge of development as this method gives values which is higher as compared to other two calculative methods. The projected population of the nth decade 'GPn' can be estimated as:

GPn = P (1+ IG/100) n

Where IG = geometric mean (%) P = Present population N = no. of decades.

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Incremental Increase method

This method of projected population calculation is a modified version of arithmetic progression method and is applied in large towns where there is a scope of expansion and the growth rate of population is in an increasing order. To start, the decadal growth increase is determined using historical population data, and then the average of this increase is added to the current population, along with the average growth rate (as shown in table 2).

Hence, the population after the nth decade is

$IPn = P+ n.X + \{n (n+1)/2\}.Y$

Where Pn = Population after the nth decade X = Average increase Y = Incremental increase

CARBON FOOTPRINT METHODS

Calculating the carbon footprint of a city like Jaipur involves assessing the total greenhouse gas (GHG) emissions produced by the city. The sources of carbon emissions include energy consumption (electricity), transportation, waste management, industrial processes and so on. The CO_2-equivalent (CO_2e) emissions through different GHGs (e.g., methane, nitrous oxide), determined by their global warming potential is used to calculate CO_2-equivalent (CO_2e) emissions (Table 3)

STEPS TO CALCULATE CARBON FOOTPRINT

Data Collection

Collect relevant data related to activities contributing to carbon emissions, such as energy consumption, transportation usage, industrial activities, fuel consumption, and population statistics.

Emission Factors

The carbon footprint of different countries has been estimated based on population. The carbon dioxide emissions around the world are primarily dependent on the population and the oil producing capacity of any country.(Table 6) Thus, it is being observed that the oil producing countries worldwide like Qatar, Kuwait, United Arab Emirates, Bahrain, and other Middle East countries are responsible for a major carbon dioxide emission around the world (Table 7).

As per the emission database for Global Atmospheric Research (EDGAR), CO 2 Emissions from Fuel Combustion – IEA, World Population Prospects: The 2024 Revision – United Nations Population Division, the emission factor of CO 2 per capita basis for few selected countries are reflected as per (Table 4)

Table 3. Data needs to be collected on the following sectors for Jaipur as reflected in table below.

S.N.	Components	Carbon footprint in kg/ton of MSW
1	Waste Management	*Solid waste:* Total waste generated and methods of waste disposal (landfill, incineration, recycling). *Waste-to-energy:* If any waste is converted to energy, emissions can vary based on the process used.
2	Transportation	*Vehicle fleet:* Total number of vehicles (cars, buses, trucks) in the city. *Fuel type:* Data on the fuel consumption (petrol, diesel, CNG) and vehicle type (private, public transport, freight). *Public transport:* Energy consumption and emissions from buses, metro, etc. *Mode Share:* Percentage of people using personal vehicles vs public transportation
3	Energy Consumption	*Residential and commercial energy use:* Energy consumption for electricity and heating in homes, buildings, and industries. *Sources of energy:* Break down the energy mix, such as coal, natural gas, renewable energy (solar, wind), etc.
4	Industry and Commercial Sector	*Industrial emissions:* Emissions from factories, cement plants, textile industries, and other manufacturing units. *Commercial buildings:* Emissions from office spaces, hotels, shopping malls, etc.
5	Agriculture and	*Farming activities:* Emissions from fertilizers, pesticides, livestock, etc.

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	Land Use	*Land use changes:* Deforestation, urban sprawl, or changes in land use can affect the carbon footprint.
6	Building and Infrastructure	*Construction:* Emissions from building materials like cement, steel, and construction activities. *Energy use in buildings:* Residential, commercial, and public sector energy use, especially from air conditioning, heating, and lighting.

Table 4. Carbon footprint (Carbon Dioxide emission) of few selected countries.

S.no	Country	CO_2 emissions (per capita tons)	Population (2022)	CO_2 emissions (tons, 2022)
1	China	8.89	1,425,179,569	12,667,428,430
2	United States	14.21	341,534,046	4,853,780,240
3	India	1.89	1,425,423,212	2,693,034,100
4	Russia	13.11	145,579,899	1,909,039,310
5	Japan	8.66	124,997,578	1,082,645,430
6	Germany	8.01	84,086,227	673,595,260
7	South Korea	12.27	51,782,512	635,502,970
8	Saudi Arabia	18.89	32,175,352	607,907,500
9	Canada	14.99	38,821,259	582,072,950
10	Australia	15.01	26,200,984	393,162,550
11	Kazakhstan	12.27	20,034,609	245,886,290
12	United Arab Emirates	21.36	10,242,086	218,799,350
13	Kuwait	23.99	4,589,511	110,119,570
14	Qatar	35.48	2,892,455	102,617,980
15	Palau	76.41	17,759	1,357,050

***(Source:** Emission data compiled from EDGAR (Emissions Database for Global Atmospheric Research), CO_2 Emissions of All World Countries Report, European Commission Joint Research Centre (JRC), 2022, along with population data for 2022.*

Table 5. Emission factors of Carbon footprint from municipal solid waste considered worldwide.

S.N.	Components	Carbon footprint in kg/ton of MSW	Tons of CO_2/capita/year
1	Waste incineration without sorting:	7130 kg CO_2eq/t of MSW	Emits the most
2	Post-sorting incineration:	800 kg CO_2eq	Less than pre-sorting incineration
3	Land filling:	781.05 kg CO_2 eq./t MSW	A significant source of GHGs
4	Waste source classification	-	Reduces carbon emissions
5	Material separation and recovery processes:	-	Improves carbon footprint
6	Biological treatments for the organic fraction:	-	Improves carbon footprint
7	Electricity consumption	-	Increases carbon footprint
8	Anaerobic digestion	-	Emits less than half the environmental impacts of aerobic composting
9	Integrated anaerobic digestion and recycling	-	Has the highest avoided CO2 eq. emissions

***(Source:** Compiled and adapted from published literature on municipal solid waste (MSW) carbon footprint, including studies on waste incineration, landfill emissions, anaerobic digestion, recycling, and life-cycle assessment approaches.*

Table 6. Emission factors of carbon footprint from municipal sewage considered worldwide.

S.no	Components	Carbon footprint in kg/ton of sewage	Tons of CO_2/capita/year
1	Wastewater treatment works	0.51–1.14 kg CO_2-eq/m^3	-
2	National average plants	0.88 kg CO_2 eq/m^3	-
3	Current Plant technology	0.44–0.54 kg CO_2 eq/m^3	-

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4	Upgraded plants	0.17 kg CO_2 eq/m^3	For an upgraded plant, the carbon footprint can be reduced significantly.
5	Wastewater treatment	0.29–1.18 kg CO_2 eq/m^3	-

(***Source:***Compiled and adapted from published literature on life-cycle assessment and carbon footprint analysis of wastewater/sewage treatment systems worldwide.

Also, the emission Factors from municipal solid waste (as shown in Table 5), municipal sewage (as shown in Table 8), Liquid petroleum gas (as shown in Table 6), Transportation (diesel and petrol), electricity and industrial processes (as shown in Table 7) worldwide.

CARBON FOOTPRINT FORECAST FOR JAIPUR

Forecasting of Carbon Footprint of Jaipur During Different Decades Because of Population

An attempt has been made to estimate roughly the carbon footprint of Jaipur during different decades based on population figures. As shown in table 6 above, the carbon footprint of India is 1.89 in the year 2022. The population is forecasted for the years 2031, 2041 and 2051 and the emission factors have been assumed 20, 30 and 40 percent more during these years respectively due to excessive overall development, increased standard of living, housing, infrastructure, increased energy consumption and population etc.

Similarly, emission factors considered on decreasing trend for the early decades in the range of 10 to 50 percent due to less development (Table 8). The predicted figures of carbon footprint during different decades have been reflected in Table 8.

Forecasting of Carbon Footprint of Jaipur During Different Decades Based on Municipal Solid Wastes (MSW)

Firstly, the quantity of municipal solid wastes that are being generated per day based on the population (2011–51) in kilograms has been calculated. Then an attempt has been made to estimate the carbon footprint on account of municipal solid waste generated in Jaipur during different decades, the details of which have been reflected in Table 9. It would be seen from the said table that the carbon footprint during the year 2011 is given below:

Forecasting of Carbon Footprint of Jaipur During Different Decades Based on Sewage Generated

To calculate the carbon dioxide emission, firstly the amount of total water consumption has been calculated with the help of projected water consumed per person per day and total projected population. This helps in the calculation of total projected sewage generation per day (Table 10).

An attempt has also been made to estimate the carbon footprint on account of sewage generated in Jaipur during different decades, the details of which have been reflected in table. It would be seen from the said table that the carbon footprint during the year 2011 is 86394.77 Tons/year which is increased to 249410.4005 tons/year by the year 2051 (Table 11).

Table 7. Emission factors of carbon footprint from electricity, transport and industrial process and LPG.

S.N.	**Components**	**Carbon footprint in kg/ton**	**Tons of co_2/capita/year**
1	Electricity	0.9 kg CO_2/ kWh energy consumption	Coal based electricity
2	Transport	2.3 kg CO_2 per liter of petrol	-
3		2.7 kg CO_2 per liter of diesel.	-
4	Industrial process	0.8 kg CO2/ kWh energy consumption	
5	LPG	One gallon of LPG emits 12.52 pounds (5,680 grams) of CO_2 when combusted	LPG has a lower carbon footprint than gasoline and diesel fuel

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(Source: Compiled and adapted from international greenhouse gas emission factor databases and energy-related carbon footprint literature.

Table 8. Carbon footprint of Jaipur during different decades based on population.

S.No	Year	Population	Tons of CO_2/capita/year	Total tons of CO_2
1	2011	30,74,000	2.41	7399135.005 = 7399135
2	2021	37,41,841	2.73	10200819.01 = 10200819
3	2031	45,50,390	5.65	25730834.74 = 25730835
4	2041	55,30,564	6.06	33538885.43 = 33538885
5	2051	67,22,906	6.58	44214543.42 = 44214543

Table 9. Carbon footprint from municipal solid waste generated in Jaipur during different decades.

S.N.	Year	Quantity of MSW generated (in Kg / day)	Quantity of MSW generated (in tons/year)	Emission Factor (in Kg of CO_2/ Ton of MSW)	Total tons of CO_2 (in Tons / Year)
1	2011	2459200	8,97,608	781.05	701031.8 = 7,01,032
2	2021	3367656.9	12,29,195	781.05	960001.1 = 9,60,001
3	2031	4550390	16,60,892	781.05	12,97,157
4	2041	6083620.4	22,20,521	781.05	17,34,227
5	2051	8067487.2	29,44,633	781.05	22,99,758

Table 10. Sewage generated in Jaipur during different decades.

S.N.	Year	Total water consumed (in liters/person/day)	TOTAL WATER CONSUMED (in Liters/ Day) (as per population)	TOTAL SEWAGE GENERATED (in Kg/Day)
1	2011	125	384250000	26,89,75,000
2	2021	135	505148535	35,36,03,974.5
3	2031	145	659806550	46,18,64,585
4	2041	155	857237420	60,00,66,194
5	2051	165	1109279490	77,64,95,643

Table 11. Carbon footprint from sewage generated in Jaipur during different decades.

S.N.	Year	Quantity of sewage generated (in m^3/year)	Emission factor (CO_2 in Kg / m^3 of sewage)	Total amount of CO_2 (in Tons / Year)
1	2011	98175875	0.88	86394.77 = 86395
2	2021	129065450.7	0.88	113577.6 = 113578
3	2031	168580573.5	0.88	148350.9 = 148351
4	2041	219024160.8	0.88	192741.3 = 192741
5	2051	283420909.7	0.88	249410.4 = 249410

Table 12. Carbon footprint from LPG consumption in Jaipur during different decades.

S.N.	Year	LPG Consumption (in Tons / Year)	Emission Factor of LPG to CO_2	Total amount of CO_2 (in Tons / Year)
1	1951	1922.26125	1.5	2883.391875 = 2,883
2	1961	8255.769289	1.5	12383.65393 = 12,384
3	1971	19995.49325	1.5	29993.23988 = 29,993
4	1981	45050.09097	1.5	67575.13646 = 67,575
5	1991	76989.51893	1.5	115484.2784 = 1,15,484
6	2001	145185.0692	1.5	217777.6038 = 2,17,778

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7	2011	511223.9102	1.5	766835.8653 = 7,66,836
8	2021	797012.133	1.5	1195518.2 = 11,95,518
9	2031	969233.07	1.5	1453849.605 = 14,53,850
10	2041	1178010.132	1.5	1767015.198 = 17,67,015
11	2051	1431978.978	1.5	2147968.467 = 21,47,969

Forecasting of Carbon Footprint of Jaipur During Different Decades Based on Liquid Petroleum Gas Consumption

An effort has been made to calculate Liquid Petroleum Gas consumption in Jaipur during different decades starting from 1951 and predicting consumption up to the year 2051. The consumption figures collected from 1951 to 2011 and thereafter predicted to be the years 2021, 2031, 2041 and 2051 (Table 22). The consumption figures are predicted in the categories of domestic, transport, commercial and industrial. For domestic consumption, it is assumed that 15 cylinders of 14.2 kg each may be consumed/ year on the presumption that subsidiary is allowed to individual consumers to such a limit (Table 21).

It would mean that 213 kg of CNG is consumed annually by individual consumers. Such a population equivalent consumption is equally considered to be consumed in transport, commercial and industrial sectors (Table 12). The consumption figures and carbon footprint are reflected in Table 12.

Forecasting of Carbon Footprint of Jaipur During Different Decades Based on Petrol/Diesel Consumption (From the Automobile Sector)

For the carbon footprint calculations firstly, the data of the total registered two – wheelers, four wheelers, buses, goods vehicles under Road transport authority of Jaipur are being collected from the year 1951 – 2011 and then the total registered vehicles for 2021 – 51 is being projected (Table 13). Then, the distance covered by each vehicle all the above-mentioned ones) per day is assumed, with the help of which the total distance covered by each vehicle per day is calculated (Table 15).

Table 13. Total registered two and four wheelers, buses, goods and other vehicles in Jaipur during different decades

YEAR	Total registered Two - wheelers	Total registered Four - wheelers	Total registered Buses	Total registered Goods vehicles	Total registered Other vehicles
1951	88	520	111	268	13
1961	92400	1747.5	322.5	948.75	236.25
1971	587100	4575	625	2300	1137.5
1981	2624400	10750	1500	5150	8300
1991	14209600	27600	3000	12600	23800
2001	38555000	102400	9600	43200	84000
2011	101812400	272000	22000	100000	170000
2021	1641130.286	310,783	25,127	114,247	194,284
2031	1846260.571	349,566	2,705,689	128,495	218,568
2041	2051390.857	388,349	3,563,546	142,742	242,852
2051	2256521.143	427,131	4,693,392	156,990	267,135

(Source: Rajasthan Transport Department, Statistical year book 2020–21)

Table 14. Assumed distance covered per two and four wheelers, buses, goods and other vehicles per day in Jaipur during different decades

Year	Assumed distance covered per Two - wheeler/day (in	Assumed distance covered per Four - wheeler/day (in	Assumed distance covered per Buses /day	Assumed distance covered per Goods vehicles /day (in	Assumed distance covered per Other vehicles /day (in

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	Kms.)	Kms.)	(in Kms.)	Kms.)	Kms.)
1951	10	10	20	20	20
1961	12	12	22	22	22
1971	14	14	24	24	24
1981	15.5	15.5	26	26	26
1991	17	17	30	30	30
2001	18	18	32	32	32
2011	20	20	35	35	35
2021	22	22	37	37	37
2031	25	25	40	40	40
2041	27	27	42	42	42
2051	30	30	45	45	45

Table 15. Total distance covered by two and four wheelers, buses, goods and other vehicles per day in Jaipur during different decades

YEAR	Total distance covered by 2 -wheelers/day (in Kms)	Total distance covered by 4 -wheelers /day (in Kms)	Total distance covered by Buses /day (in Kms)	Total distance covered by Goods vehicles (in Kms)	Total distance covered by Other vehicles (in Kms)
1951	880	5200	2220	5360	260
1961	5940	20970	7095	20872.5	5197.5
1971	54075	64050	15000	55200	27300
1981	376650	166625	39000	133900	215800
1991	2257600	469200	90000	378000	714000
2001	10094400	1843200	307200	1382400	2688000
2011	28720000	5440000	770000	3500000	5950000
2021	36104860	6837226	929699	4227139	7188508
2031	46156525	8739150	108227560	5139800	8742720
2041	55387557	10485423	149668932	5995164	10199784
2051	67695630	12813930	211202640	7064550	12021075

Table 16. Assumed average distance by two and four wheelers, buses, goods and other vehicles in per litre of petrol in Jaipur during different decades

Year	Name of the vehicle	Assumed average distance
1	Assumed average distance covered by 2 -wheelers in per litre of petrol (from the year 1951 – 2051)	20
2	Assumed average distance of 4 -wheelers in per litre of petrol (from the year 1951 – 2051)	20
3	Assumed average distance of Buses in per litre of diesel (from the year 1951 – 2051)	5
4	Assumed average distance of Goods vehicles in per litre of diesel (from the year 1951 – 2051)	5
5	Assumed average distance of other vehicles in per litre of diesel (from the year 1951 – 2051)	10

Table 17. Total petrol / diesel consumption by two and four wheelers, buses, goods and other vehicles in one day in Jaipur during different decades

Year	Total Petrol Consumption (in	Total Petrol Consumption (in	Total Diesel Consumption (in	Total Diesel Consumption (in	Total Petrol Consumption (in

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	l/day) (2 – wheelers)	l/day) (4 – wheelers)	l/day) (Buses)	l/day) (Goods vehicles)	l/day) (Other vehicles)
1951	35.2	433.3333333	222	536	26
1961	237.6	1747.5	709.5	2087.25	519.75
1971	2163	5337.5	1500	5520	2730
1981	15066	13885.41667	3900	13390	21580
1991	90304	39100	9000	37800	71400
2001	403776	153600	30720	138240	268800
2011	1148800	453333.3333	77000	350000	595000
2021	1444194.4	569768.8333	92969.9	422713.9	718850.8
2031	1846261	728262.5	10822756	513980	874272
2041	2215502.28	873785.25	14966893.2	599516.4	1019978.4
2051	2707825.2	1067827.5	21120264	706455	1202107.5

Table 18. Emission factor of two and four wheelers, buses, goods and other vehicles in Jaipur during different decades

Year	Name of the vehicle	Emission factor
1	Emission Factor of 2 wheelers (in kg CO_2/Litre of petrol) (from the year 1951 – 2051)	2.3
2	Emission Factor of 4 wheelers (in kg CO_2/Litre of petrol) (from the year 1951 – 2051)	2.3
3	Emission Factor of Buses (in kg CO_2/Litre of diesel) (from the year 1951 – 2051)	2.7
4	Emission Factor of Goods vehicles (in kg CO_2/Litre of diesel) (from the year 1951 – 2051)	2.7
5	Emission Factor of Other vehicles (in kg CO_2/Litre of diesel) (from the year 1951 – 2051)	2.7

*(**Source:** EDGAR)*

Table 19. Total Carbon footprint from 2 wheelers, 4 wheelers, buses, goods vehicles, other vehicles and total carbon footprint from all vehicles in Jaipur during different decades

Year	Carbon footprint in tons/year (2 – wheelers)	Carbon footprint (in tons/year) (4 – wheelers)	Carbon footprint (in tons/year) (Buses)	Carbon footprint (in tons/year) (Goods vehicles)	Carbon footprint (in tons/year) (Other vehicles)	Total carbon footprint from all Vehicles (in tons/year)
1951	29.550	363.783	218.781	528.228	25.623	1020
1961	199.465	1467.026	699.212	2056.985	512.214	4348
1971	1815.84	4480.831	1478.25	5439.96	2690.415	14113
1981	12647.91	11656.807	3843.45	13195.845	21267.09	57948
1991	75810.208	32824.45	8869.5	37251.9	70364.7	211991
2001	338969.952	128947.2	30274.56	136235.52	264902.4	847751
2011	964417.6	380573.33	75883.5	344925	586372.5	2199943
2021	1212401.199	478320.936	91621.836	416584.5485	708427.463	2907356
2031	1549936.11	611376.369	10665826.04	506527.29	861595.056	14195261
2041	1859914.164	733542.717	14749873.25	590823.412	1005188.713	18939342
2051	2273219.255	896441.186	20814020.17	696211.402	1184676.941	25864569

*(**Source:** Authors and Rajasthan Transport Department, Statistical year book 2020–21)*

Table 20. Amount of electric energy sold from 2011–21 and total projected electric energy to be sold from 2030–50 in Kilowatt (in different sectors) in Jaipur during different decades

Name of the type of Energy sold	(2011–12) (KWH)	(2021–22) (KWH)	(2030–2031) (KWH)	(2040–2041) (KWH)	(2050–2051) (KWH)
Domestic	1265433704	2301697971	2393888595	2486079219	2578269844
Non-domestic	704745621	981016162.3	1073206787	1165397411	1257588035
Streetlight	56902198	48237032.96	140427657.3	232618281.7	324808906.1
Agriculture					

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i. Metered	24644666	22934685.77	115125310.1	207315934.5	299506558.9
ii. Flat	42956667	0	92190624.38	184381248.8	276571873.1
iii. Nursery	15861	0	92190624.38	184381248.8	276571873.1
iv. Poultry	1043581	74549.05829	92265173.44	184455797.8	276646422.2
Industrial					
i. Small	85267951	71351838.81	163542463.2	255733087.6	347923711.9
ii. Medium	169305629	178210169.6	270400794	362591418.4	454782042.8
iii. Large	667913518	688052551.6	780243176	872433800.4	964624424.8
PHED					
i. Small	82553843	61256389.05	153447013.4	245637637.8	337828262.2
ii. Medium	2728172	3228455.167	95419079.54	187609703.9	279800328.3
iii. Large	41567450	76246370.78	168436995.2	260627619.5	352818243.9
Mixed Load	70575542	74016968.58	166207593	258398217.3	350588841.7
Total	82553843	61256389.05	153447013.4	245637637.8	337828262.2

*(**Source:** Authors , Jaipur Development Authority and Ministry of Housing and Urban Affairs)*

Table 21. Carbon footprint from the electricity generated from 2011–20 and total projected carbon footprint to be generated from 2030–50 in different sectors in Jaipur during different decades

Name of the type of Energy sold	**Carbon footprint in tons/year (2011–12)**	**Carbon footprint in tons/year (2021–22)**	**Carbon footprint in tons/year (2030–2031)**	**Carbon footprint in tons/year (2040–2041)**	**Carbon footprint in tons/year (2050–2051)**
Domestic	1138890.334	2071528.173	2154499.735	2237471.297	2320442.859
Non-domestic	634271.0589	882914.5461	965886.108	1048857.67	1131829.232
Streetlight	51211.9782	43413.32966	126384.8916	209356.4535	292328.0155
Agriculture					
i. Metered	22180.1994	20641.21719	103612.7791	186584.3411	269555.903
ii. Flat	38661.0003	0	82971.56194	165943.1239	248914.6858
iii. Nursery	14.2749	0	82971.56194	165943.1239	248914.6858
iv. Poultry	939.2229	67.09415247	83038.65609	166010.218	248981.78
Industrial					
i. Small	76741.1559	64216.65493	147188.2169	230159.7788	313131.3407
ii. Medium	152375.0661	160389.1527	243360.7146	326332.2766	409303.8385
iii. Large	601122.1662	619247.2965	702218.8584	785190.4204	868161.9823
PHED					
i. Small	74298.4587	55130.75015	138102.3121	221073.874	304045.436
ii. Medium	2455.3548	2905.60965	85877.17159	168848.7335	251820.2955
iii. Large	37410.705	68621.7337	151593.2956	234564.8576	317536.4195
Mixed load	63517.9878	66615.27172	149586.8337	232558.3956	315529.9575
Total	**2894088.963**	**4055690.83**	**5217292.697**	**6378894.564**	**7540496.431**

(Source: Authors and Jaipur Development Authority and Ministry of Housing and Urban Affairs)

Table 22. Total decadal carbon footprint of Jaipur from different sectors (from 2011–51)

Year	**Total carbon dioxide emissions**
2011	66,48,295
2021	92,32,144
2031	2,23,11,912
2041	2,90,12,220
2051	3,81,02,202

After that, based on the assumption of the average distance covered by all the above-mentioned

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vehicles in one litre of petrol or diesel, the total distance covered by the registered vehicles is being calculated (Table 14). Finally, with the help of the emission factor of carbon dioxide in one litre of petrol and diesel and the total distance covered by the registered vehicles (from 1951 - 2011), the total carbon footprint from all the vehicles from 1951–2011 is being calculated (Table 13).

Forecasting of Carbon Footprint of Jaipur During Different Decades Based on Electricity Consumption

The energy consumption data of Jaipur during 2011 and 2021 were collected from the state electricity authorities which were further predicted for 2031, 2041, and 2051 using different forecasting methods, the details of which are reflected in table 20 below. The carbon footprint from electricity consumption is the calculated multiplying energy consumption figures of different decades under different category usage with emission factor of 0.9 kg CO_2/ kwh. (Table 20) (Figure 3)

CARBON FOOTPRINT MITIGATION MEASURES

There are many ways to reduce carbon footprint, including using less energy, using renewable energy, and reducing waste (Table 23).

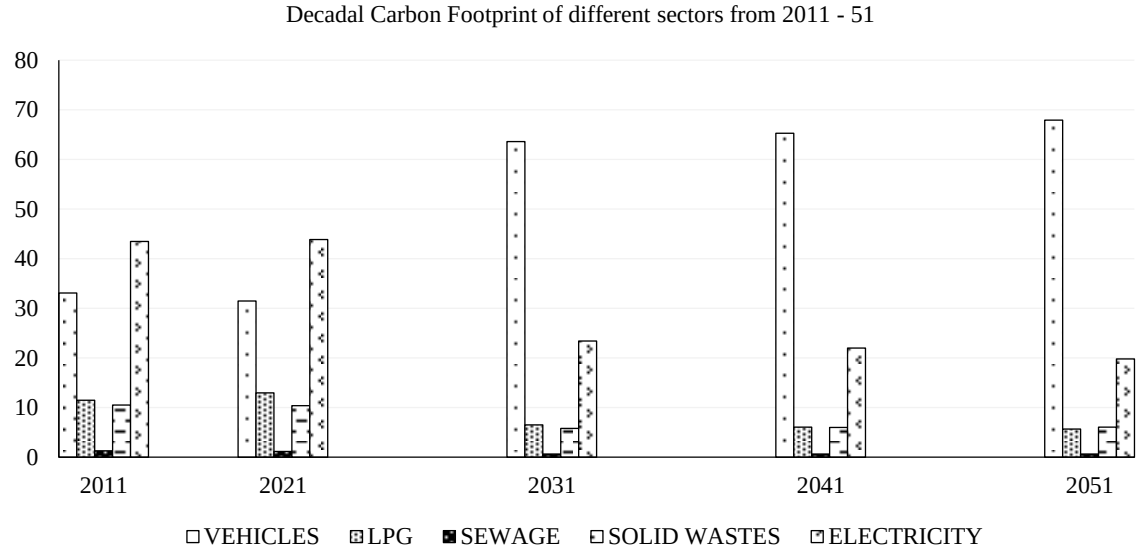

Figure 3. Percentage of carbon footprint from different sectors during different decades.
Showing the percentage of Carbon footprint generated from different sectors in Jaipur for 2011, 2021, 2031, 2041 and 2051

- Reduce energy use by insulating your home, using energy efficient appliances, reduce heating and cooling, turn off lights.
- Use renewable energy sources like solar, wind, and hydro power generate electricity with little to no greenhouse gas emissions.
- Switch from fossil-based fuels to renewable fuels.
- Reduce and Recycle waste

Other ways to reduce carbon footprint

- *Travel efficiently:* Travel by bicycle or public transportation when possible.
- *Plant trees:* Planting trees can help reduce your carbon footprint.
- Promote urban forestry and green infrastructure projects.

URBAN FORESTRY

One of the best solutions for the consequences of rapid climate change leading to global warming is

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to plant trees. Trees play a very vital role in the reduction of greenhouse gases particularly carbon dioxide (CO_2). Trees behave as natural filters used for absorption of carbon dioxide and conversion of it into oxygen, also stowing the remaining carbon as biomass. Trees are considered as one of the best storage areas for carbon dioxide. As they extract CO_2 from the atmosphere and then uses them for energy generation and for building up of tree tissues. Henceforth, the carbon generated from CO_2 are deposited in bark, stem, roots leaves and soil and the created oxygen is released back into the surrounding air. Thus, this proves that trees perform a very important role in stabilizing the climate along with cleaning of the atmosphere. In the context of global efforts to reduce greenhouse gas emissions, trees are a natural and relatively inexpensive way to absorb carbon dioxide. Studies indicate that forests can absorb up to 30% of global CO_2 emissions.Promoting the planting of new trees and protecting existing forests are therefore key actions in the fight against global warming.

Choosing the right tree species for reforestation and efforts to combat climate change is crucial. Not every tree absorbs carbon at the same rate. Species vary in terms of growth rate, lifespan, ability to store carbon in biomass and tolerance to harsh weather conditions. Below are some of the most effective tree species with high carbon sequestration capacity [20].

Table 23. Showing area of urban forest required in hectares for different percentage of carbon footprint reduction.

YEAR	Urban forest required in hectares for 30 percent reduction of carbon footprint	Urban forests, required in hectares for 50 percent reduction of carbon footprint	Urban forests, required in hectares for 70 percent reduction of carbon footprint	Urban forests, required in hectares for 90 percent reduction of carbon footprint	Urban forests, required in hectares for a 100 percent reduction of carbon footprint
2011	12470.452	20784.0871	29097.722	37411.35677	41568.17419
2021	17192.391	28653.986	40115.58038	51577.17477	57307.97197
2031	43366.575	72277.626	101188.6759	130099.7262	144555.2513
2041	56526.211	94210.352	131894.4933	169578.6342	188420.7047
2051	74518.893	124198.156	173877.4179	223556.6802	248396.3113

Figure 4. Pictoral representation of (a) Teak Forest and (b) Jackfruit tree.

- *Jackfruit: Artocarpus heterophyllus* - Absorbs 33,709 kg of CO_2 per year
- *Mango: Mangifera indica* Absorbs 25,404 kg of CO_2 per year
- *Indian rosewood: Dalbergia latifolia* Absorbs 11,084 kg of CO_2 per year
- *Teak: Tectona grandis* Absorbs 8,660 kg of CO_2 per year

The increase in carbon dioxide emissions in recent decades has been contributing significantly to global warming. This warming is leading to several negative consequences, such as extreme weather events, melting glaciers, rising sea and ocean levels and the destruction of ecosystems. In this context,

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trees play a key role in the fight against CO_2 emissions. Healthy Forests and green urban areas can make a significant contribution to reducing emissions, stabilizing the climate and protecting biodiversity. According to some studies, reforestation may be one of the most effective ways to counter the effects of climate change. The amount of carbon dioxide absorbed per hectare of urban forest depends on the type of trees, their age, and the location of the forest.

A hectare of trees can store around 50 tons of carbon, which is equivalent to about 80 tons of CO_2 in the atmosphere. The rate of carbon removal can range from 4.5 to 40.7 tons of CO_2 per hectare per year during the first 20 years of tree growth. A new University College London (UCL) study, published in Carbon Balance and Management, used publicly available airborne LiDAR (Light Detection and Ranging) data collected by the UK Environment Agency, combined with ground- based LiDAR measurements, to generate a map of carbon stored in an estimated 85,000 trees across the London Borough of Camden

According to the researchers, urban forests can contain as much carbon than tropical rainforests. They found that areas such as Hampstead Heath store up to 178 tons of carbon per ha, in comparison to the median value for tropical rainforests of 190 tons of carbon per ha. In the face of increasingly severe climate change, one of the simplest and most effective ways to combat global warming is to plant trees. Trees perform an irreplaceable function in reducing greenhouse gases, especially carbon dioxide (CO_2).(Figure-4) Each tree acts as a natural filter, absorbing CO_2 from the atmosphere and converting it into oxygen, while storing carbon in its biomass.Trees are one of the most efficient "stores" of carbon dioxide. During photosynthesis, plants take CO_2 from the air, which is then used to generate energy and build tree tissues. The carbon in CO_2 is stored in the wood, roots, leaves and soil, and the oxygen that is produced in the process is released into the atmosphere. This makes trees not only clean the air but also help stabilize the climate.

CONCLUSION

The carbon dioxide emissions around the world would primarily be dependent on the population and the oil producing capacity of any country. Thus, it is being observed that the oil producing countries worldwide like Qatar, Kuwait, United Arab Emirates, Bahrain, and other Middle East countries are responsible for a major carbon dioxide emission around the world. Apart from that, the high populous countries with high living standards around the world are also responsible for a large amount carbon dioxide emission which constitutes almost 3 times the global average per capita emission (for example, United States of America, Canada, and Australia). It can thus be concluded that the income of a country is directly proportional to the per capita carbon footprint. Increasing carbon footprint is directly related to climate change and such a change is significantly contributed by the urban sector. Around 70 percent of the global carbon footprint is contributed from these urban sectors and hence urban sectors are the significant causal factors of climate change.

An attempt has therefore been made to undertake a case study of an important city in the name of Jaipur which is also known as the pink city of India. The present research study deals with the assessment of carbon footprint of Jaipur during 2011 and 2021 and further predicted on a future time scale of 2031, 2041, and 2051 to evaluate the challenges of increasing carbon footprint in Jaipur and to timely suggest the mitigating tools. The authors of the present paper initially collected the population data from the National Census Department, Govt. of India for the years starting from 1951 and up to 2011. Such data is then predicted by using different population forecast methods and an average value is taken for the forecasted population during 2021, 2031, 2041, and 2051. Once the predicted population is available, similar predictions are made for the generation of municipal solid waste and sewage in Jaipur along with increasing vehicles, LPG, electricity consumption etc. The carbon footprint is then estimated using predicted values of these contributing attributes on a time scale of 2021-2051 coupled with population equivalent per capita footprint. The authors thereafter suggested a few mitigating measures but main emphasis on urban forestry along with the extent of

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urban forest needed in hectares to achieve 30, 50, 70, 90, and 100 percent carbon sequestration. Also, the suggestion includes some of the very efficient tree species which have a very high carbon sequestration ability.

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