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Quantification and Forecasting of Plastic Waste in Gorakhpur City, India

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Abstract

Plastic pollution is one of the biggest environmental threats faced by human society, especially in cities like Gorakhpur, which have minimal resources for waste management but a very high amount of waste that keeps on increasing day by day. The purpose of this research is to determine the total amount of plastic waste (PW) generated in Gorakhpur city and forecast plastic waste generation. The snowball sampling method was used for collecting data. Various interviews and site visits were conducted to collect data on plastic waste. Then collected data was analysed and, assuming a linear increment of plastic waste generation in Gorakhpur, forecasting was done. After completing the calculation and analysis, the found result shows that approximately 74,25,086 kg of plastic waste was collected by Gorakhpur Nagar Nigam, and the total generated plastic waste in Gorakhpur is 99,08,222 kg, or 12.92 kg per capita in 2021. The rate of increase in the generation of plastic waste is 217g per capita per year and if things don't change, then in the year 2030 plastic waste can reach up to 14.87 kg per capita in Gorakhpur. Also, assuming exponential growth and Holt's damped trend (with a damped factor of 0.85), we get per capita plastic waste of 21.97 kg and 13.84 kg per capita in the year 2030, respectively. These results show the severity of the plastic waste management problem. Part of the problem is that much macro-scale research has been conducted on the national level in the past, but it can't provide solutions to the local problems related to plastic waste, such as rapid urbanization, geographical features, weather conditions, lack of resources, etc. So more targeted research like this needs to be conducted. The results of this research will help the administration to design better, more efficient, and effective waste management techniques and systems.

Keywords: Plastic waste management, plastic waste, municipal solid waste, pollution, snowball sampling method

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INTRODUCTION

Due to its extensive usage, resilience, and environmental persistence, plastic garbage is a major environmental hazard on a global scale. Developing practical management and mitigation solutions for plastic waste's environmental impact requires an understanding of its chemical makeup. Ethylene monomers combine to form the polymer known as polyethylene (PE). Because of its affordability, adaptability, and chemical and moisture resistance, it is one of the most often used polymers. PE is used in many different products, such as bottles, containers, plastic bags, and packaging materials.

A thermoplastic polymer derived from propylene monomers is called polypropylene (PP). It is renowned for having great flexibility, heat resistance, and strength. PP is used in home items, textiles, automotive components, and packaging. Poly Vinyl chloride (PVC) monomers are the starting point for the synthetic polymer PVC. Depending on the additives employed during manufacture, it may be either stiff or flexible. PVC is used in clothes, medical equipment, electrical insulation, and building components (such as pipes and window frames). Poly Styrene (PS) monomers make up the polymer known as polystyrene. It has good insulating qualities and may be clear or foamed. PS is used in insulating materials, disposable utensils, and food packaging (such as foam cups and take-out containers). Ethylene glycol and terephthalic acid are combined to create PET, a polyester polymer. It is recyclable, translucent, and light. Packaging films, food containers, polyester fibres for clothing and textiles, and beverage bottles are common uses for producing PET. One polymer that is produced when polyols and isocyanates react is polyurethane. Depending on how it is formulated, it may be either stiff or flexible. PU is utilised in automobile components, adhesives, coatings, furniture cushioning, and foam insulation. To improve their qualities, plastic goods often include additives like plasticizers, flame retardants, and antioxidants. There is a chance that some of these compounds may seep out of the plastic and endanger both the environment and human health. Persistent Organic Pollutants (POPs): Dioxins and PCBs, two examples of POPs that may adsorb and accumulate from the environment, can be found in plastic garbage. These substances may bioaccumulate in the food chain and are persistent and harmful. Microplastics: Through mechanical and chemical processes, plastic trash may fragment into tiny particles known as microplastics. When dangerous contaminants, such as microplastics, are absorbed by aquatic species, they may find their way into the food chain and endanger the health of both people and animals. Greenhouse Gas Emissions: The extraction and processing of fossil fuels, which are used as raw materials and energy sources in the plastics manufacturing process, is the main way that the manufacture, usage, and disposal of plastics contribute to greenhouse gas emissions.

A comprehensive strategy is needed to address the negative effects of plastic waste on the environment and human health. This strategy must include trash reduction, recycling and reuse, the creation of alternative materials, and regulatory interventions to control the manufacturing and disposal of plastics. Governments, businesses, communities, and people must work together to successfully address the worldwide problem of plastic pollution.

Plastic has been an important factor in the improvement and enhancement of the quality of human life for more than half a century, and it is now an inseparable and essential component of our lives as a result of the numerous ways in which it can be utilised, including in the fields of packaging, automotive, industrial appliances, healthcare, textiles, construction, communication materials, and many more [1-4]. It is now abundantly obvious that the issue of marine plastic pollution poses a threat not only to biodiversity but also to the food chain and, as a consequence of this, to both human and animal heath as well as animal welfare [5]. Scientists, producers, and policy officials have all turned their attention to this issue because the proof of the damage that improper management of plastic items in the environment has had [6,7]. The invention of plastic is one of the most significant events in human civilization. It was known as the wonder material at that time as it had all the properties such as flexibility, mouldability, toughness, hardness, high strength-to-weight ratio, resistance to chemicals and electricity, water resistance, transparency, ease to manufacture and processing, ductility and the most important one, durability [8]. Plastic can last for thousands of years easily and all of this without any major drawbacks, such as corrosion, toxicity, creep, brittleness, etc. Due to this, from 2 million tonnes in 1950, production of plastic reached 378 million tonnes in 2019 and total production crosses the 9.2 billion tone mark in 2017 [9].

The generation and growth opportunities for the plastic industry in a country like India are particularly distinct and enormous due to the diverse consumer base that represents varied climate zones, eating habits, and standards of living. There is a 16% annual growth in consumption of plastic products in India [10,11]. India is one of the greatest users of plastic items in the world, and the country produces around 9.4 million tonnes of garbage from plastic products each year [12]. More than 4 million people are employed in the country's plastic sector, which now consists of 15 big polymer plants, about

30,000 production units, and over 7,000 recycling units [13,14]. As a result of India's position as the world's third biggest economy in terms of purchasing power parity, behind only the United States and China, the plastics sector is poised to see significant growth in the not-too-distant future [15]. At the moment, the average annual use of plastic by an Indian is between 8 and 11 kg, which is quite a bit less than the average consumption of plastic worldwide. Consumption levels are 38 in China, 50–65 in Europe, and 68–109 in the USA in kilogrammes per capita per year, with a global average of 28 kg per capita per year [16,17]. This rise may be further pushed by other programmes, being supported by the government, such as Make in India, Skill India, Digital India, and the Swachh Bharat Abhiyan. These phrases translate to "Make in India," "Skill India," "Digital India," and "Swachh Bharat Abhiyan" [18,19].

But after only 30 to 40 years of widespread use, plastic has become the single most harmful and dangerous substance for our environment and society. The durability of plastics becomes its biggest drawback. Because compared to other materials such as paper bags, glass, food products, etc., the degradation time of plastic is very high, meaning it cannot decompose by itself. A study conducted by academics from the University of California, Santa Barbara, and others found that only 9% of plastic waste delivered between 1950 and 2015 was universally recycled, 12% was burned, and 79% ended up in landfills, seas, and other bodies of water [20].

According to a report, if plastic waste keeps going at the current rate, then by 2050 there will be more plastic in the ocean than all the fish by weight [21]. A major threat to civilisation today is microplastics. Plastic smaller than 5 mm is known as microplastic, but it contains all of its properties, such as durability and non-degradability [22]. Microplastics are now entering our food chain. It may obstruct or deceive organisms' gastrointestinal tracts, causing them to believe they don't need to feed, resulting in starvation. A pilot project in 2018 first found the presence of microplastics in the human digestive system. But according to the latest research, scientists have now found traces of microplastics in human blood [23]. Chlorinated plastics such as polyvinyl chloride can release chemicals and contaminate the surrounding soil, which can further pollute groundwater and ecosystems. According to new research, not only macro plastics but also microplastics are contaminating our soil and microbial ecosystem [24]. Plastics come in all shapes and forms, containing various additives, resins, and chemical groups, so without proper treatment and disposal, they can cause problematic conditions for surrounding ecosystems. For cities like Gorakhpur, waste management is a critical problem due to its rapid urbanisation and population growth. Per capita waste generation is increasing and plastic is one of the most significant components of solid waste [25]. Also, due to the increase in income, the effect of COVID-19, and changes in consumer behaviour, demand for plastic keeps on increasing. Due to COVID-19, the momentum of the campaign to reduce the use of plastic has slowed down significantly. Use of plastic in the form of personal protective equipment, sanitizer, other medical equipment, and single-use plastic saw a huge increase in demand during this time [26]. The development and characterization of eco-friendly rubber composite materials using Sansevieria cylindrica fibres offer a promising alternative to conventional plastics, aligning with the global push towards sustainability and effective plastic waste management. This composite material leverages the natural properties of Sansevieria cylindrica fibres, which are known for their high tensile strength and biodegradability, to create a product that not only reduces reliance on synthetic polymers but also mitigates plastic waste [27]. The advent of fully biodegradable "green" composites represents a significant leap forward in addressing the pervasive issue of plastic waste. These materials, derived from renewable resources and designed to decompose naturally, offer substantial environmental benefits over conventional plastics [28]. The introduction of abaca fibre into structural polymer composites represents a promising advancement in the realm of sustainable materials, offering a viable solution to the growing issue of plastic waste [29]. The integration of natural fibres and nanocellulose into bio composite applications offers a promising route to reducing plastic waste and promoting sustainability. By selecting appropriate fibres and optimizing processing techniques, it is possible to create high-performance, eco-friendly materials that meet the demands of various industries [30]. The innovative use of hemp waste combined with mycelium-grown matrices to develop bio-composites presents a promising approach to addressing plastic waste issues. This sustainable technology leverages agricultural by-products and natural fungal growth to create eco-friendly materials that can potentially replace traditional plastics [31].

RESEARCH SIGNIFICANCE

To tackle all of these problems, a combined effort of each and every stakeholder involved in the problem is needed. Therefore, we have set 2 clear goals in this research for tackling the plastic waste problem, which are as follows:

1. To collect the amount of plastic waste generated in the city.
2. Assess the current situation and forecast the amount of plastic waste that will be generated in the future.

For designing an appropriate or suitable plastic waste management system some necessary data is required which is not available. This research aims to collect and analyse that data so that a better, more efficient and effective waste management system can be created.

RESULTS & DISCUSSION

The research is mainly conducted in 3 parts as follows.

- In this part, all the primary and secondary data are collected through various techniques.
- Then the collected data is analysed and then forecasting is done.
- In the final step, the current situation of Gorakhpur is assessed and a solution based on the current condition is provided.

Data collection is started from Nagar Nigam, Gorakhpur. After that, for collecting other data, the Snowball Sampling technique was used. With the help of these techniques data on plastic waste is collected from various scrap dealers across Gorakhpur City. Some secondary data is also collected from some government websites such as Central Pollution Control Board. After collecting these data total amount of plastic waste generated in Gorakhpur is determined. Then with the help of previous data available from the Central Pollution Control Board, forecasting of plastic waste generated in Gorakhpur is being done using simple linear regression techniques, Holt's damping trend method.

Study Area

Gorakhpur city is one of the major cities in eastern Uttar Pradesh having coordinates 26.7606° N, 83.3732° E. The current population of the city is about 673446 as per census 2011 and its population is increasing day by day. The city suffering from the problem of plastic waste and the disposal practices (Figure.1-2) If an effective waste management system is successfully proposed for this city, then it can be effectively applied to the other cities in the country too(Table 1-5).

Table 1. Details of Gorakhpur City (Source- Nagar Nigam, Gorakhpur).

Name of City/Town	**Gorakhpur**
Population (as per Census 2011)	673446
Area (in square km)	147
Number of households in the City/Town	146075
Number of wards in the City/Town	70
Coordinates	26.7606° N, 83.3732° E

Data Collection Techniques

The techniques involved in collecting data are very much important. Most of the data is collected by the snowball sampling method. It is a non-probabilistic method of data collection or survey. If the technique involved is appropriate the result that we will get is fruitful. All the technique used for collecting data is mentioned below:

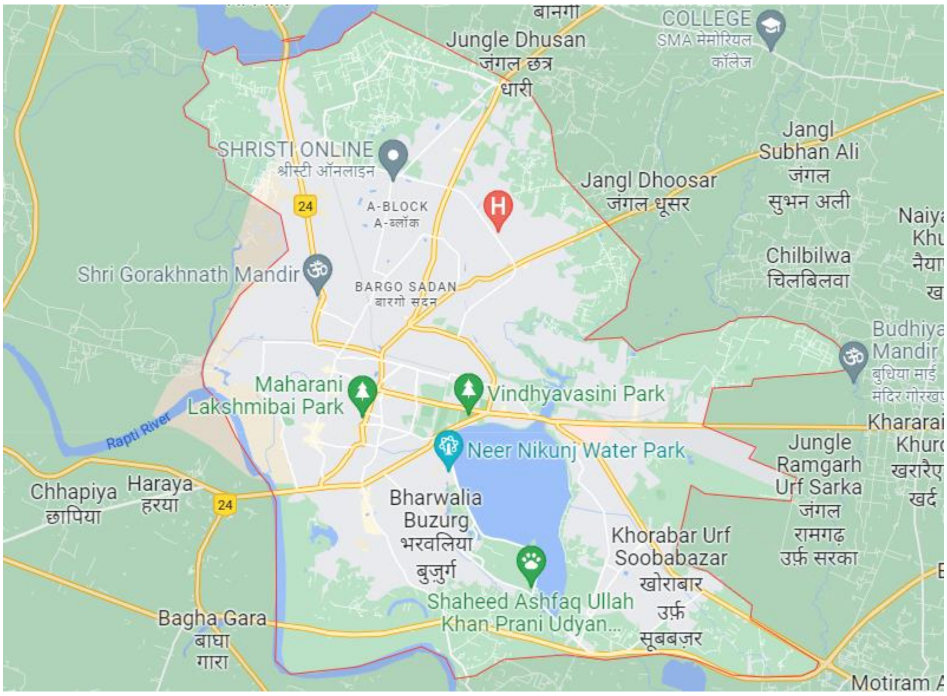

Figure 1. Map of Gorakhpur City (Source- Google Maps).

Interview method

The interview method is one of the most important methods in primary data collection. It is a process in which people collect data from the respondents by asking them a set questionnaire easier. By this method, we get the opinions of the individual respondent sent as well as the society. We talk on to one to the respondent regarding waste disposal practices, waste management, waste generation, and recycling in ample time.

Observation method

This is also one of the most important methods and needs utmost supervision. All the answers told during the interview by the respondent might not be correct. There might be a hypothetical and exaggerated answer. It may be possible that they might not want to give all the answers, the reason can be many, like shyness, illiterate, telling stories instead of realities, etc. the data that comes out may be dramatically different from the data in reality. Thus, observations help the researcher to see all the activities in front of his eye and do a thorough analysis. The researcher has to collect data as much as possible to capture the real scenario of waste management. This is the main data collection technique for this thesis study.

Collection of Data

The collection of data starts from Nagar Nigam, Gorakhpur. After conducting various interviews and surveys we came to know that there is no data available on PW separately. Only data on Solid Waste is available. So, to find out the amount of plastic waste we have to find the approximate percentage of plastic waste in total solid waste. To find out the percentage of plastic waste we have used annual reports for 2019-20 of municipal solid waste and plastic waste. With the help of these reports, we have calculated the average percentage of Plastic Waste in Municipal Solid Waste in India.

The total amount of collected PW is divided by the total collected MSW. So, we finally get 6.3% as the average percentage of plastic waste present in municipal solid waste.

Now we can easily calculate the amount of PW with the help of provided data on the total generated and collected municipal solid waste in Gorakhpur by Nagar Nigam.

Table 2. Determination of Average Percentage of Plastic Waste in MSW in 2019-20 [25].

State	SW Generated (TPD)	SW Collected (TPD)	SW Collected (TPA)	PW Collected (TPA)	Percentage PW to SW
Andhra Pradesh	6766	6140	2241100	46222	2.062
Arunachal Pradesh	286	224	81599	2721	3.335
Assam	1271	922	336680	24971	7.417
Bihar	4334	3695	1348675	41365	3.067
Chhattisgarh	1650	1650	602250	32850	5.455
Goa	189	180	65839	26068	39.594
Gujarat	14496	10755	3925575	408201	10.399
Haryana	5232	4809	1755212	147734	8.417
Himachal Pradesh	393	354	129210	13683	10.590
Jammu & Kashmir	1519	1465	534597	74826	13.997
Jharkhand	2189	1847	674294	43332	6.426
Karnataka	12258	10011	3654015	296380	8.111
Kerala	3521	1880	686200	131400	19.149
Madhya Pradesh	7980	7193	2625445	121079	4.612
Maharashtra	22945	22779	8314448	443724	5.337
Manipur	265	192	70226	8293	11.809
Meghalaya	153	119	43504	5043	11.592
Mizoram	348	313	114245	7909	6.923
Nagaland	306	256	93404	565	0.605
Odisha	2209	2123	775005	45339	5.850
Punjab	4478	4414	1611092	92890	5.766
Rajasthan	6659	6476	2363704	51966	2.198
Sikkim	75	75	27229	69	0.253
Tamil Nadu	14228	13955	5093575	431472	8.471
Telangana	9285	9270	3383550	233655	6.906
Tripura	411	381	138992	32	0.023
Uttarakhand	1611	1481	540586	161148	29.810
Uttar Pradesh	14468	13955	5093575	25203	0.495
West Bengal	13980	12062	4402630	300236	6.819
Andaman Nicobar	121	115	41975	387	0.922
Chandigarh	450	450	164250	6746	4.107
DDDNH	184	191	69715	1948	2.794
Delhi	10471	10467	3820298	230525	6.034
Lakshadweep	33	33	11881	46	0.387
Puducherry	580	517	188705	11753	6.228
TOTAL	165343	150749	55023279	3469781	6.306

Table 3. Data of Plastic Waste Collection in Gorakhpur (Source- Nagar Nigam, Gorakhpur)

Plastic Waste Collected by Nagar Nigam, Gorakhpur				
Generated SW (TPD)	**Collected SW (TPD)**	**% PW to SW**	**Total PW (TPD)**	**zTotal PW (TPA)**
351	322.9	6.3	20.3427	7425.086

By assuming 6.3% as amount of PW present in MSW, we get the plastic waste collected by Nagar Nigam Gorakhpur in 2021 as 7425 tones.

Table 4. Amount and location of different Plastic Waste collection centres in Gorakhpur City.

Data Collection of Plastic Waste in Gorakhpur City (Urban)			
Collection Point	***Time (Year)***	***P. W. (Kg)***	***P.W. (kg/year)***
Nagar Nigam (Gorakhpur)	1	7425085	7425085
Nagar Nigam (Raid)	2	22400	11200
Dev Plastic (Dharmshala Bazar)	1	105328	105328
Material Recover Facility (Netaji Subhaschadra Bos Colony)	0.25	12424	49696
Shri Mahavir Polypet (Lakhimpur Bargadwa)	1	357948	357948
Rapti Traders (Lachhipur Bargadwa)	1	329684	329684
Ahasun Traders (Lachhipur Bargadwa)	1	490687	490687
Krishna Traders (Prem Nagar Colony, Khorabag)	1	1138594	1138594
Total			9908222

Table 5. Per Capita Plastic Waste Generated in Gorakhpur (2021).

Per Capita Plastic Waste Generated in Gorakhpur (2021)		
Total PW (kg)	**Population of Gorakhpur City (worldpopulationreview.com)**	**Per Capita PW (Kg/Person)**
9908222	766646	12.924

By taking 6.3% as percentage of PW in MSW, Gorakhpur generates 7425085 kg of PW and overall, 9908222 kg of PW in 2021, or 12.92 kg per capita per year.

Analysis of Data

For the forecasting of plastic waste in Gorakhpur, we use trend analysis of the increase in the amount of plastic waste in India. Table 6 contains the previously available data on PW collected in India from 2012 to 2020 by the Central Pollution Control Board. With the help of Table 6-7, we plot an X-Y scatter chart and, by using simple linear regression and exponential regression, we get trend curves. The slope of the linear trend line and the power of the exponential trend curve represent the average rate of increase in plastic waste yearly [32].

Linear regression

By fitting a line to observed data, it helps to explain the relationship between the variables. While logistic and nonlinear regression models employ a curved line, linear regression methods do not. You may estimate a dependent variable's change as an independent variable or set of independent variables changes using regression.

The formula for linear regression equation is given by:
$y = a + bx$
a & b can be calculated by given formula:

$$b= [n \sum xy-(\sum x)(\sum y)]/[n\sum x^2-(\sum x)^2]$$

$$a= [\sum y-b(\sum x)]/n$$

Where x & y are variables for which we will make a regression line.

a = Y-intercept value of the line. b = Slope of the line.

X = First data set value Y = Second data set value

Table 6. Annual Report of Plastic Waste in India [33].

State	2012 (TPA)	2013 (TPA)	2014 (TPA)	2015 (TPA)	2016 (TPA)	2017 (TPA)	2018 (TPA)	2019 (TPA)	2020 (TPA)
Andaman Nicobar	0	2555	9	2737	0	365	0	1850	387
Andhra Pradesh	28888	243820	243820	128480	128480	82863	0	66314	46222
Arunachal Pradesh	0	0	0	38	15	0	6	3787	2721
Assam	0	1116	240	0	24010	24030	0	32277	24971
Bihar	0	0	0	0	0	2280	2280	68903	41365
Chhattisgarh	5548	5840	4818	0	0	7300	12775	6000	32850
Chandigarh	0	4964	0	0	8383	21517	0	11715	6746
Daman Dip	0	0	0	0	0	0	0	1947	1948
Delhi	0	251850	0	0	0	232732	0	224810	230525
Goa	415	1643	118	104	106	477	0	32580	26068
Gujarat	0	251796	251797	265568	269295	271092	269808	356873	408201
Haryana	0	55480	50332	0	0	23370	0	68735	147734
Himachal Pradesh	202	107	2326	1004	0	255	0	3672	13683
Jammu Kashmir	0	11748	0	4164	6243	0	27870	34367	74826
Jharkhand	16691	81030	75817	35262	35853	0	0	51454	43332
Karnataka	0	77247	77247	0	129600	419600	0	272776	296380
Kerala	109500	50370	27794	0	0	0	0	133316	131400
Madhya Pradesh	16887	23400	22974	27764	30884	50457	61037	72327	121079
Maharashtra	1045	10950	587285	0	469098	21420	0	409630	443724
Manipur	0	4380	5475	25	30	0	24	12454	8293
Meghalaya	0	4599	4015	14	14	13	15	1263	5043
Mizoram	0	1682	45625	45625	6396	0	0	13	7909
Nagaland	0	0	0	0	0	0	14052	268	565
Odisha	0	0	897	1871	27860	6890	12092	90139	45339
Puducherry	0	4927	0	16425	0	9252	0	8433	11753
Punjab	31000	0	378	43282	48073	163423	54066	119414	92890
Rajasthan	182	0	0	0	0	0	0	104704	51966
Sikkim	0	1668	0	0	0	102	0	6	69
Tamil Nadu	0	205724	0	0	150323	79115	0	401091	431472
Telangana	0	0	243820	123005	120961	0	0	183014	233655
Tripura	0	10950	11680	33	0	30	28500	26	32
Uttar Pradesh	0	0	0	93598	130777	152493	206733	254401	161148
Uttarakhand	0	0	0	0	3016	0	0	31093	25203
West Bengal	0	200750	0	0	0	0	0	300236	300236
Total	212370	1510609	1658480	791013	1591433	1571093	691276	3361907	3471755
Population (World Bank)	1265780243	1280842119	1295600768	1310152392	1324517250	1338676779	1352642283	1366417756	1380004385
Per Capita Plastic Waste	0.168	1.179	1.280	0.604	1.202	1.174	0.511	2.460	2.516

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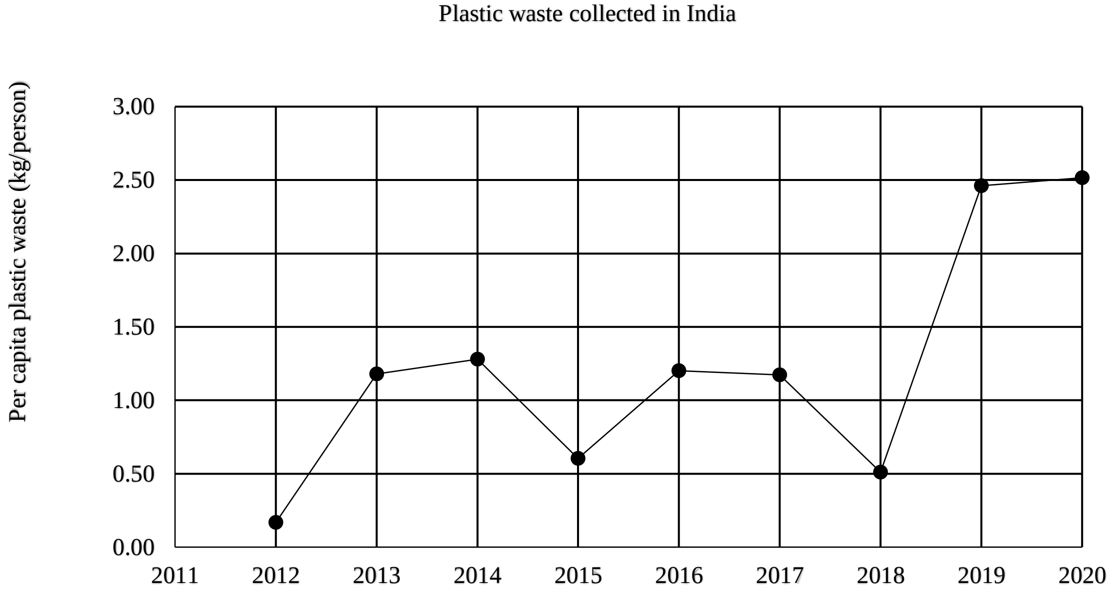

Figure 2. Yearly plastic waste collected in India

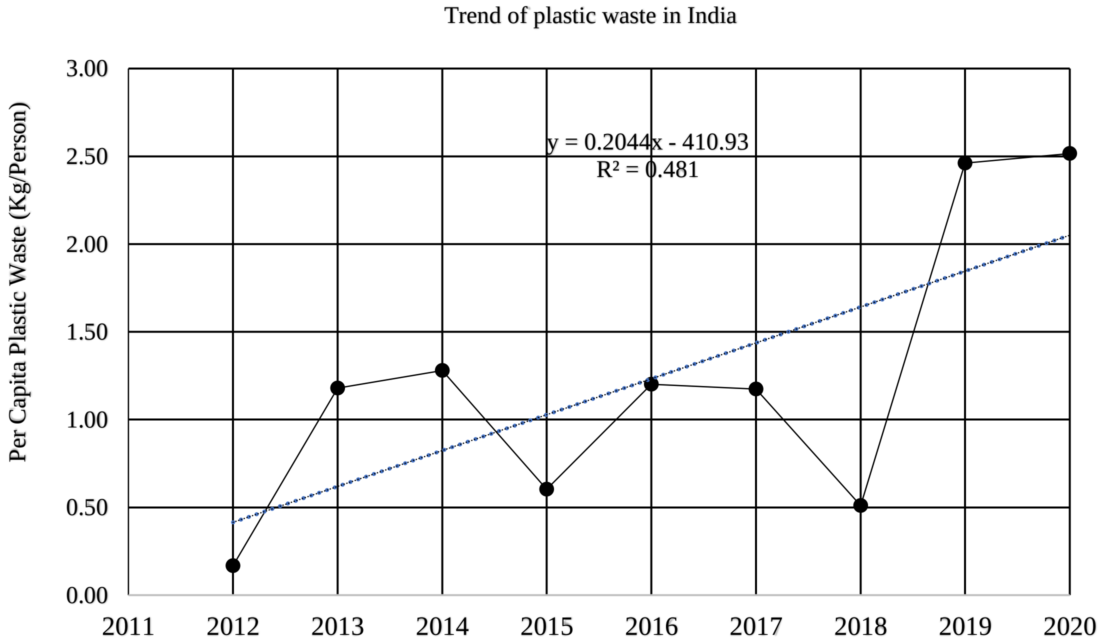

Figure 3. Trend analysis of plastic waste collected in India

From the analysis, we get the slope of the trend line in figure 3 as 0.204, which represents the rate of increase in PW in India at 0.204 kg or 204 g per person per year. And for the exponential trend curve in Figure 4, we get a power of exponent of 0.197, which also represents the rate of increase of plastic waste.

Note- But in the available Table 6, we can see that lots of data is missing. For many years, many states were not able to submit the plastic waste collection data, but previously they had submitted the data. This means that generated and collected plastic waste in these states was not zero in that year. So, to rectify this error, we have replaced the missing data in Table 6 with the average of all the previously submitted data by the state. Calculations are as follows, and all the replaced values are highlighted.

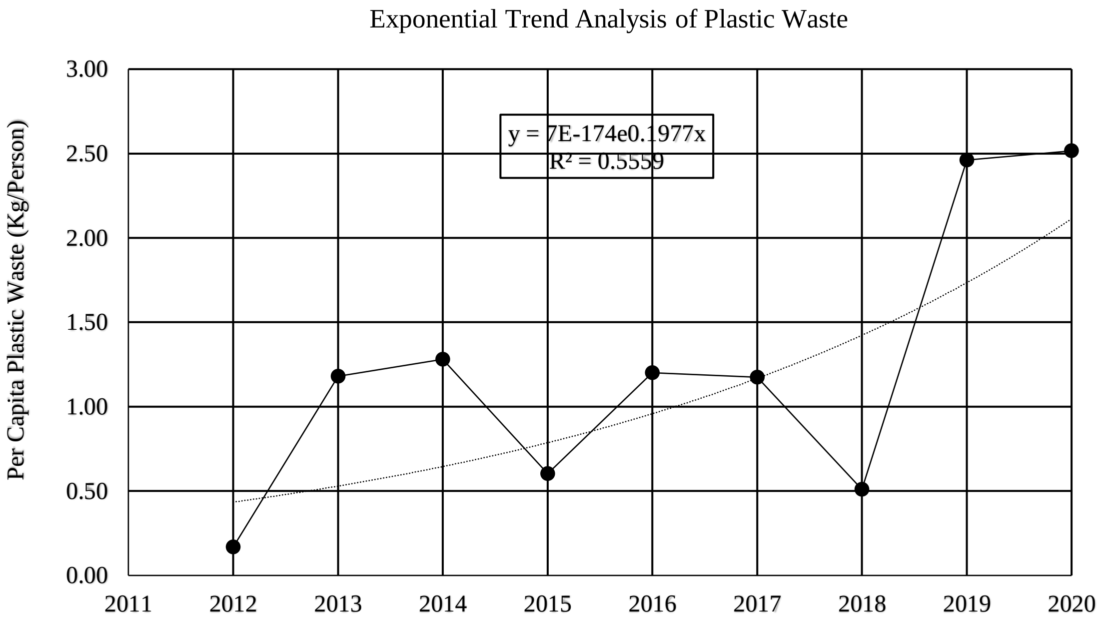

Figure 4. Exponential Trend Analysis of Plastic Waste collected in India.

Table 7. Corrected Annual Report of Plastic Waste in India.

State\Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Andaman Nicobar	0	2555	9	2737	1325	365	1165	1850	387
Andhra Pradesh	28888	243820	243820	128480	128480	82863	142725	66314	46222
Arunachal Pradesh	0	0	0	38	15	10	6	3787	2721
Assam	0	1116	240	452	24010	24030	8308	32277	24971
Bihar	0	0	0	0	0	2280	2280	68903	41365
Chhattisgarh	5548	5840	4818	5402	5402	7300	12775	6000	32850
Chandigarh	0	4964	2482	2482	8383	21517	6638	11715	6746
Daman Dip	0	0	0	0	0	0	0	1947	1948
Delhi	0	251850	125925	125925	125925	232732	143726	224810	230525
Goa	415	1643	118	104	106	477	477	32580	26068
Gujarat	0	251796	251797	265568	269295	271092	269808	356873	408201
Haryana	0	55480	50332	35271	35271	23370	33287	68735	147734
Himachal Pradesh	202	107	2326	1004	910	255	801	3672	13683
Jammu Kashmir	0	11748	5874	4164	6243	5606	27870	34367	74826
Jharkhand	16691	81030	75817	35262	35853	48931	48931	51454	43332
Karnataka	0	77247	77247	51498	129600	419600	125865	272776	296380
Kerala	109500	50370	27794	62555	62555	62555	62555	133316	131400
Madhya Pradesh	16887	23400	22974	27764	30884	50457	61037	72327	121079
Maharashtra	1045	10950	587285	199760	469098	21420	214926	409630	443724
Manipur	0	4380	5475	25	30	1982	24	12454	8293

Meghalaya	0	4599	4015	14	14	13	15	1263	5043
Mizoram	0	1682	45625	45625	6396	19866	19866	13	7909
Nagaland	0	0	0	0	0	0	14052	268	565
Odisha	0	0	897	1871	27860	6890	12092	90139	45339
Puducherry	0	4927	2464	16425	5954	9252	6504	8433	11753
Punjab	31000	31000	378	43282	48073	163423	54066	119414	92890
Rajasthan	182	182	182	182	182	182	182	104704	51966
Sikkim	0	1668	834	834	834	102	712	6	69
Tamil Nadu	0	205724	102862	102862	150323	79115	106814	401091	431472
Telangana	0	0	243820	123005	120961	97557	97557	183014	233655
Tripura	0	10950	11680	33	5666	30	28500	26	32
Uttar Pradesh	0	0	0	93598	130777	152493	206733	254401	161148
Uttarakhand	0	0	0	0	3016	603	603	31093	25203
West Bengal	0	200750	100375	100375	100375	100375	100375	300236	300236
Total	212370	1541791	1999478	1478611	1935831	1908760	1813293	3361907	3471755
Population (World Bank)	1.266E+09	1.281E+09	1.296E+09	1.31E+09	1.325E+09	1.339E+09	1.353E+09	1.366E+09	1.38E+09
Per Capita Plastic Waste	0.168	1.204	1.543	1.129	1.462	1.426	1.341	2.460	2.516

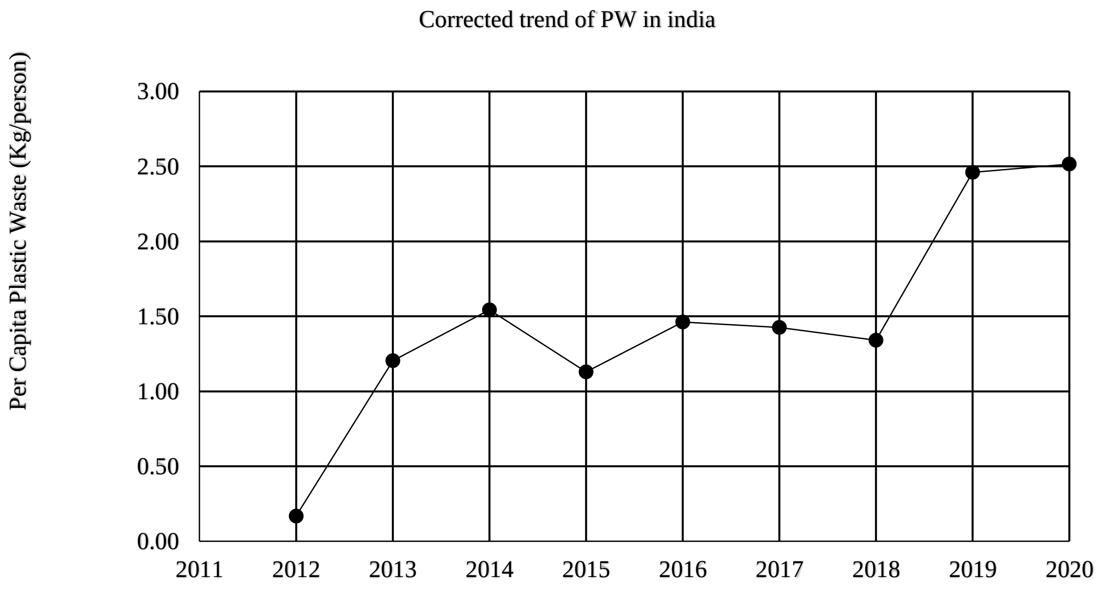

Figure 5. Corrected data of Plastic Waste collected in India

By correcting the available data in Table 8 of the Central Pollution Control Board, for the linear trend line in Figure 5-6, we get the average rate of increase in plastic waste in India from 204 g per person per year to 217 g per person per year. The corrected trend line has an R^2 value of 0.713, which is higher than the previous trend line's R^2 value. It means that the corrected trend line is better at predicting trends compared to the previous one. Similarly, in the exponential trend curve in Figure 7, we get the power of exponent as 0.215, which is higher than the previous value with a higher R^2 value of 0.7136.

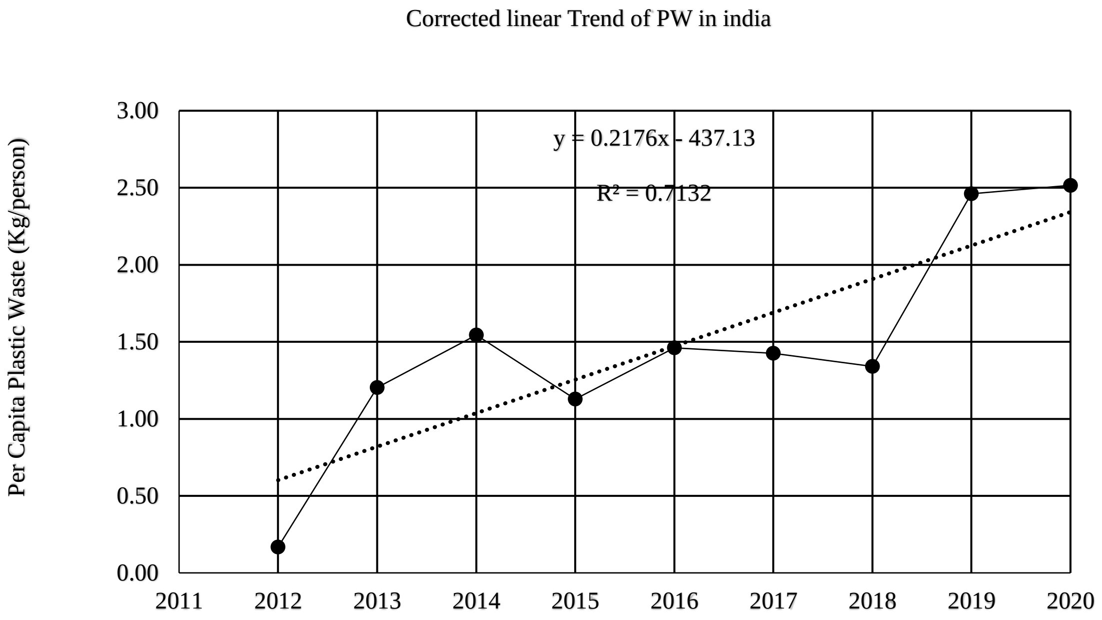

Figure 6. Corrected trend analysis of plastic waste collected in India.

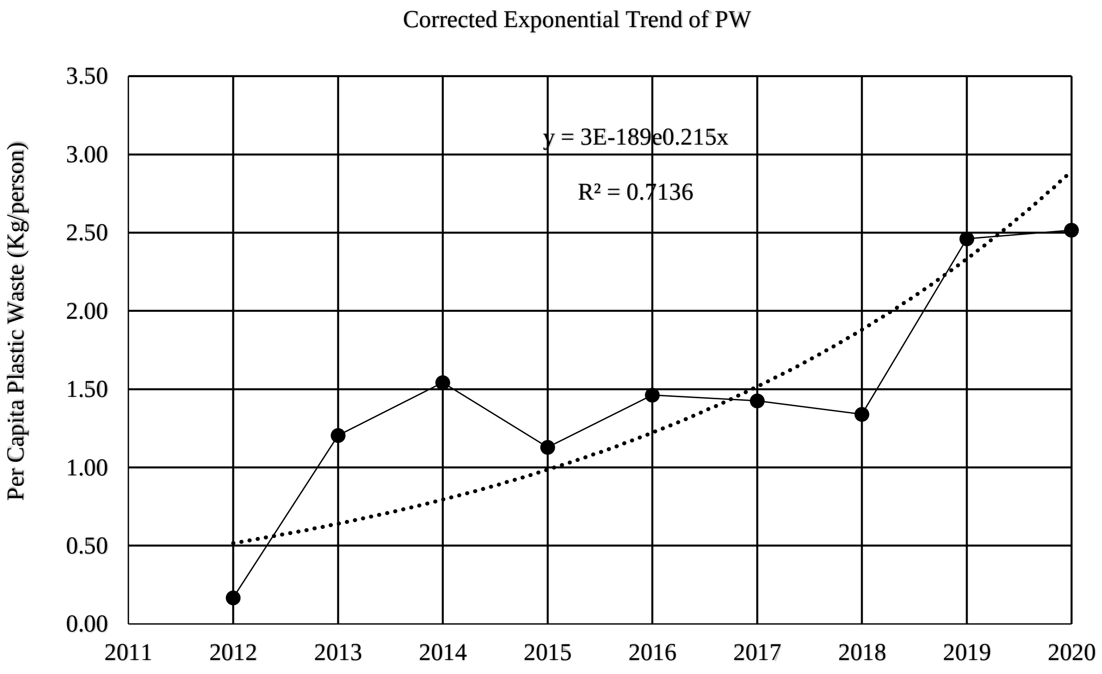

Figure 7. Corrected exponential trend analysis of Plastic Waste collected In India

By conducting various surveys, interviews, and visiting sites, we have collected that the total amount of plastic waste generated in Gorakhpur in 2021 is 99,08,222 kg, of which 74,25,086 kg of plastic waste is collected by the Municipal Corporation of Gorakhpur as municipal solid waste. Plastic waste makes up 6.3% of the total collected municipal solid waste. This means that this 74,25,086 kg of plastic waste is mixed with other types of waste such as organic, household waste, biomedical, hazardous domestic, construction, demolition, etc., which makes it extremely hard to separate or segregate from other waste. Assuming the current population of Gorakhpur in 2021 as 7,66,646 (source-worldpopulationreview.com), we have calculated the per capita plastic waste generation in Gorakhpur to be 12.92 kg in 2021 which is very high compared to the national average.

With the help of the Annual Report on Implementation of Plastic Waste Management 2016 (2012–2020) in Table 6, we have performed a trend analysis that represents the average increment in plastic waste generation in India throughout these years. By calculating, we get an average yearly 204 g per capita increment in plastic waste in India, as shown in Figure 3. However, the available data contains numerous inconsistencies. For many years, states have not submitted data on plastic waste, which creates gaps in submitted reports [34] So, to rectify those errors, we have replaced the missing data with the average of previously available data for that state in Table 7. Then again, the trend analysis of the report has been performed by the linear regression method, the exponential increase method, and Holt's damping trend method. Now we have the rate of increase of plastic waste in India at 217 g per capita per year in Figure 6. This corrected trend line has an R^2 value of 0.731, which is greater than the value of 0.481 of the previous noncorrected trend line. Similarly, in Figure 7 we have the exponential equation as $y = 3E\text{-}189e^{0.215x}$ with an R^2 value of 0.7136. The R^2 value represents how well the data fits the regression model. The value of R^2 varies from 0 to 1. The data should be as close to 1 as possible. For Holt's damping trend, we have taken the damp factor as 0.85. The damp factor ranges from 0 to 1, but usually it is taken between 0.8 and 1 [35]. Depending upon the situation, the damp factor is taken. A smaller damp factor provides a higher variation between the base line and the damped trend line.

With the help of available, collected, and analysed data, we can now forecast the amount of plastic waste that will be generated in the future in Gorakhpur City. Assuming a constant rate of increase in plastic waste of 217 g per person for calculating the total amount of plastic waste generated in a single year, we only need to multiply the per capita plastic waste by the current population. Similarly, we are also forecasting with the help of the exponential increase method and Holt's damping method by taking the power of exponent as 0.215 and Holt's damping factor as 0.85, respectively.

Table 8. Future amount of Plastic Waste generated in Gorakhpur.

Per Capita Plastic Waste up to 2030 in Gorakhpur										
Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Linear Increase	12.92	13.14	13.35	13.57	13.79	14.01	14.22	14.44	14.66	14.87
Exponential Increase	12.92	13.28	13.73	14.30	14.99	15.86	16.94	18.27	19.92	21.97
Holt's Damped Trend	12.92	13.10	13.25	13.38	13.49	13.59	13.67	13.74	13.79	13.84

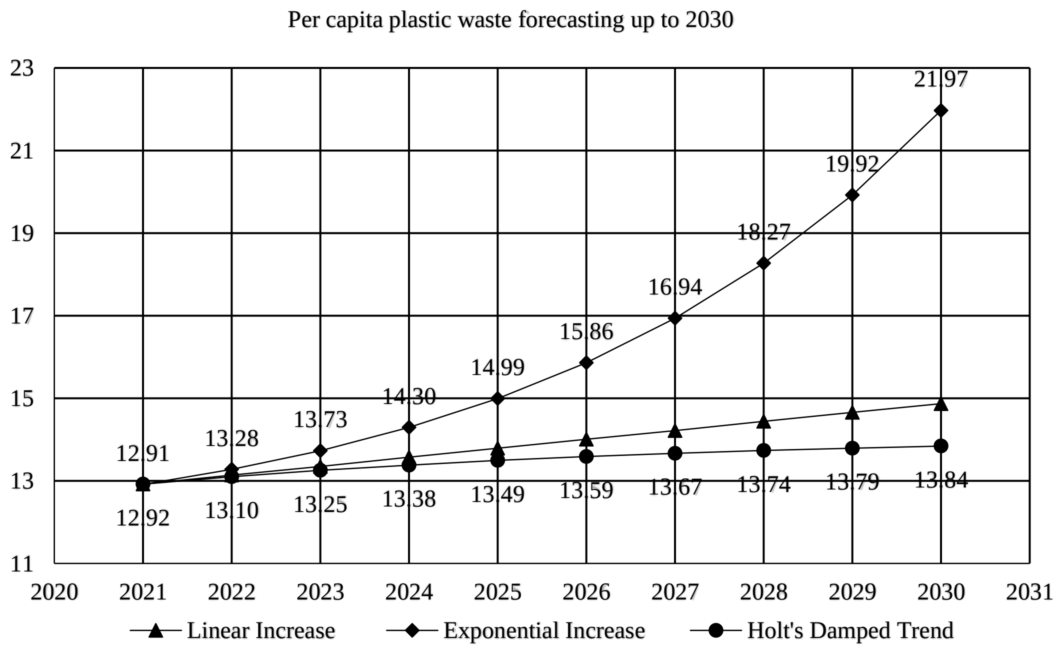

Figure 8. Future amount of plastic waste generated in Gorakhpur.

As shown in Figure 8, up to 2030, per capita plastic waste generation in Gorakhpur will increase from 12.92 kg to 14.87 kg per person assuming a linear increase in plastic waste, will increase to 21.97 kg per capita assuming an exponential increase, and finally can reach up to 13.84 kg per capita by assuming the Holt's damping method with a damp factor of 0.85. It means the stress on waste management is going to increase drastically, and if nothing is done, then this plastic can cause various environmental and health-related problems in the city. All this calculation is done assuming the rate of plastic waste is increasing. Among the given 3 methods, the linear increase in per capita plastic waste is possible when the current situation remains unchanged, but the total amount of plastic waste generated will increase more rapidly because both the population and per capita rate are increasing, so the results of the exponential increase are more likely to be true. The result of Holt's damping method can only be true if major steps like banning single-use plastic, heavy taxation of the plastic production industry, etc. are taken [36-40].

Plastic waste generated in Gorakhpur is divided into mainly two categories. The first is the plastic waste by Nagar Nigam, and the second is collected by ragpickers, where some small amount lies here and there. Plastic waste collected by rag pickers is mostly recycled because they only collect PET and HDPE plastic. These types of plastic have high recyclability [41-45]. Due to their high recyclability in the secondary market, they have a high value (approximately 8–12), and the ragpicker gets some income. The price of this plastic waste also depends on its condition. Plastic that is free from dirt, dust, and filth has a higher value compared to dirty plastic, as its processing will be easier. So approximately 25,00,000 kg (and more as there are many scrap dealers' data is not collected) of the collected plastic waste gets recycled. Also, according to Nagar Nigam, Gorakhpur processes 30% of the waste collected by them. 30% of plastic waste is either disposed of or recycled.

Table 9. Percentage Recycling of Plastic Waste in Gorakhpur.

Percentage Recycling of Plastic Waste						
PW Collected by MNC (kg)	**Processing Rate (%)**	**Processed PW (kg)**	**PW scrap (kg)**	**Total Recycled (kg)**	**Total PW (kg)**	**% Recycled PW**
7425085	30	2227526	2471937	4699463	9908222	47.43

According to the calculation, approximately 47%, or 47,00,000 kg, of total generated plastic waste in Gorakhpur in 2021 was either recycled or disposed of. The recycling rate is high compared to the Indian average. But the recycling rate could be higher as we are not able to reach all the scrap dealers and all the scrap dealers did not provide their data. After interviewing various plastic waste dealers and researching, it is observed that all types of plastic, such as LDPE, PP, PS, Polystyrene, PVC, and especially multi-layered plastic waste, are not collected by ragpickers as they don't have any value in the secondary market. This is mainly because it is extremely hard and expensive to recycle this type of plastic waste, and even after recycling, the finished material is highly degraded in quality.

CONCLUSIONS

This manuscript aims to identify the overall amount of plastic waste generated in Gorakhpur and forecast its amount up to 2030, based on the surveys, findings and results provide a suitable solution for plastic waste problem in cities like Gorakhpur. It can be concluded that due to the rapid urbanization, increase in per capita income, and rapid population growth the amount of plastic waste generated in Gorakhpur city is very high and keep on increasing.

By conducting the research, we came to know that approximately 75,00,000 kg of plastic waste is collected by the Municipal Corporation of Gorakhpur and approximately 99,00,000 kg, or 12.92 kg per capita of total plastic waste, is generated in Gorakhpur in 2021. Based on the annual report submitted by the Central Pollution Control Board from 2012 to 2020, it is determined that the average national per capita increase in plastic waste generation per year is 217 grams. That is what we assumed as the rate of increase in plastic waste in Gorakhpur. With the help of this data, we have predicted that in the year 2030, plastic waste per capita will increase by up to 15 kg in Gorakhpur.

For collecting data, various surveys and interviews have been conducted as there is no data available online or in the public domain. When the research started, it was expected that Gorakhpur would have higher per capita plastic waste compared to the national average, but after conducting the research, we came to know that it is higher than expected, approximately four times higher than the national average. The approach to forecasting was very simple. With the help of previously available data, trend analysis is performed in Excel. This analysis gives us the rate of increase in per capita plastic waste in India. After that, by assuming all other factors remain the same, we have taken a linear increment in per capita waste generation in Gorakhpur up to 2030. It is the simplest, easiest, and most efficient way of forecasting. The result clearly illustrates the large amount of plastic waste and its increment. But the assumed rate of increase in plastic waste could be different on the ground. So, research is needed on this topic.

FUTURE SCOPE

This research has been able to answer many questions, but many questions still remain to be answered. At the same time, there is a lot of scope for improvement in the methods adopted and some of these improvements are as follows.

- One of the most important future scopes is to characterise plastic waste based on the resin used to produce it such as PET, HDPE, PP, PS, Polystyrene, PVC, LDPE, etc.
- Many scrap dealers in Gorakhpur have not participated in this research, either because the researchers have not been able to reach them or because the scrap dealers have not shared the data. So, more research with a bigger data sample needs to be conducted.
- This is the first and one of the kinds of research that needs to be rectified, such as data collection method, trend analysis method, calculation of the rate of increase, and mathematical model of forecasting.
- More such research needs to be done in different states and districts.

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