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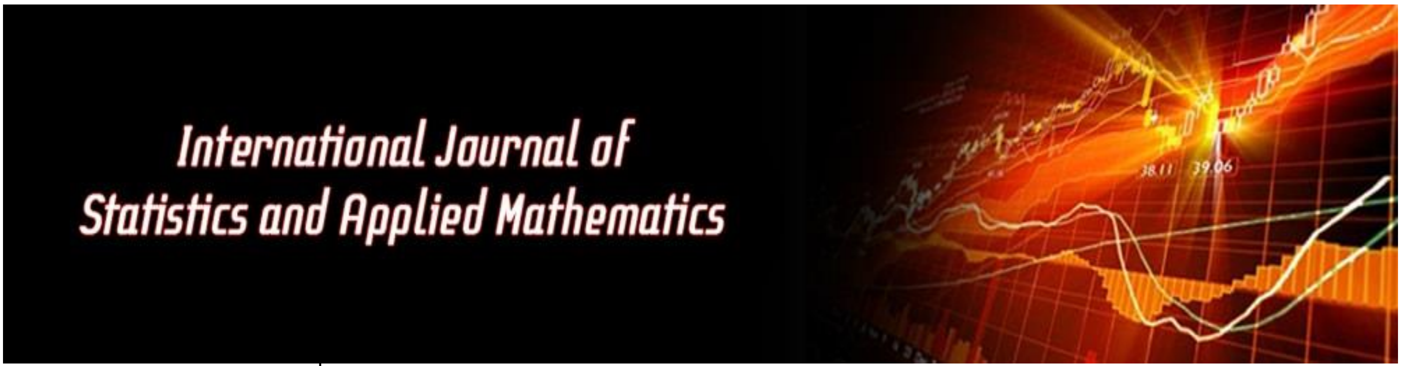

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Statistical modeling of electronic waste (e-waste) generated in India

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Abstract
Electronic Waste (e-waste) is one of the fastest growing waste streams in the country. Growth of Information and Communication Technology sector has enhanced the usage of the electronic equipment exponentially. Developing countries are facing enormous challenges related to the generation and management of E-waste which are either internally generated or imported illegally; India is no exception to it. Electronic wastes can cause widespread environmental damage due to the use of toxic materials in the manufacture of electronic goods. Hazardous materials such as lead, mercury and hexavalent chromium in one form or the other are present in such wastes. Due to the lack of sufficient facilities for the safe management of waste in developing countries, this waste is buried, burned in the open air or dumped into surface water bodies. E-waste disposal in landfills and incinerators does permanent damage to the atmosphere by water and soil pollution and air contamination. The aquatic organisms that live in the affected water bodies are highly exposed to these toxic, bio-accumulative, and persistent contaminants. This study presents an overview of generated e-waste in coming future using statistical modeling and analysis.

Keywords: Electronic Waste (e-waste), hexavalent chromium, statistical modeling and analysis

Introduction

E-waste or electronic waste is created when an electronic product is discarded after the end of its useful life. The rapid expansion of technology and the consumption driven society give results in the creation of a very large amount of e-waste. E-waste can be toxic, is not biodegradable and accumulates in the environment, in the soil, air, water and living things. E-waste can cause serious environmental problems due to toxic chemicals such as lead, mercury and arsenic that pollute our soil and water and disrupt our ecosystems and our health. The toxic materials from electronic devices are released into bodies of water, groundwater, soil and air, affecting both land and sea animals. When we throw out our e-waste they wind up in landfills, causing toxic materials to seep into groundwater.

When e-waste is exposed to the heat, toxic chemicals are released into the air damaging the atmosphere; this is one of the biggest environmental impacts of e-waste. Those toxic materials can then seep into the groundwater, affecting both land and sea animals. Open-air burning and acid baths being used to recover valuable materials from electronic components release toxic materials leaching into the environment. The main cause of e-waste is the rising demand for electronic products. Often, when electrical appliances break, consumers opt to purchase a replacement, more so if it is more economical than fixing the broken one. In other scenarios, the annual launch of new electronic gadgets encourages people to upgrade annually.

Current status of E-waste in India

India, has emerged as the world's second largest mobile market, is also the fifth largest producer of e-waste, discarding roughly 18.5 lakh tonnes of electronic waste each year (Lobo et. al., 2016) [16]. Telecom equipment alone accounts for 12% of the e-waste (Adhana, 2020) [5].

According to the Central Pollution Control Board, India generated 1.71 million metric tons of e-waste as compared to the worldwide e-waste generation which stood at 59.40 million metric tons (Kumar and Kumar, 2023) [13]. It is no secret that electronic dumps contain substantial quantities of toxic elements like lithium, mercury, arsenic, barium, cadmium, cobalt, etc. When broken or unwanted electronics are dumped in landfill, toxic substances like lead and mercury can leach into soil and water. Electronics also contain valuable non-renewable resources including gold, silver, copper, platinum, aluminum and cobalt. India processed 3.4 lakh tonnes of e-waste in 2020-2021 (Patel, 2021) [20]. According to CPCB, the generation of plastic waste per year is increasing by 3% and the generation of e-waste is even higher, with waste produced totaling 7.1 lakh tonnes in 2018-19 and 10.14 lakh tonnes in 2019-20 (Khan, 2023) [12]. Every year, there is a 31% increase. In 2021-22, of the 16, 01, 155 tonnes of e-waste generated, 5, 27, 131 tonnes (32.9%) were recycled. In 2020-21, 26.33% of e-waste was processed, while in 2019-20, the figure stood at 22.07% (Gupta, 2023) [10]. The main sources of electronic waste in India are the government, public and private (industrial) sectors, which account for almost 70% of total waste generation. The contribution of individual households is relatively small at about 15%; the rest being contributed by manufacturers (Rajya Sabha, 2011) [22].

Globally, consumers generated 44.7 million metric tons of e-waste in 2016. More than 44 million tonnes of electronic and electrical waste was produced globally in 2017, over six kilograms for every person on the planet. The world produced 44.7 million tonnes of electronic waste (e-waste) in 2016 (Baldé et. al., 2017) [1], enough to build nine great pyramids of Giza. This includes two million tonnes generated in India, which has one of the fastest growing electronics industries in the world. It is estimated that the total amount e-waste generated in 2014 was 41.8 million metric tonnes (Baldé et. al., 2014) [2]. It is forecasted to increase to 50 Mt of e-waste in 2018. According to the UN, in 2021 each person on the planet will produce on average 7.6 kg of e-waste, meaning that a massive 57.4 million tons will be generated worldwide India is now the world's third-largest source of e-waste, generating around 3.2 million tonnes annually (2019), behind only China (10 million tonnes) and the US (6.9 million tonnes) in 2021 (Geneva Environment Network, 2023) [7].

In India, Maharashtra produces maximum e-waste in the country followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab. Similarly Mumbai ranks first in generating e-waste followed by Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat and Nagpur. Mumbai produces 96,000 metric tonnes (MT) every year (Rajya Sabha, 2011) [22]. Urban India generates around 62 million tons of municipal solid waste every year. Mumbai and Delhi generate about 11,000 and 8,700 tonnes of solid waste per day, respectively (CPHEEO, 2020) [4]. Study done by KPMG and ASSOCHAM, stated that computer equipment stands for almost 70% of e-waste in India, and followed by telecom/phones (12%), electrical equipment (8%) and medical equipment (7%) (Patel & Balachandran, 2016) [19]. China is the largest importer and producer of electronic waste worldwide, generating more than 10 million metric tons (over 70% of all global e-waste) worth in 2019 (Vanessa et. al, 2020) [25]. This was followed by the United States where roughly seven million metric tons was produced. Ministry of Environment, Forest and Climate Change indicates that a staggering 10, 74, 024 tonnes (67%) of e-waste remained unprocessed. India ranks 177 amongst 180 countries and is amongst the bottom five countries on the Environmental Performance Index 2018, as per a report released at the World Economic Forum 2018 (Gupta, 2023) [10]. This was linked to poor performance in the environment health policy and deaths due to air pollution categories.

India's share in global hardware electronics production is about 3%. The share of domestic electronics production in India's GDP is 2.3%. India's share in global electronics manufacturing has grown from 1.3% in 2012 to 3.6% in 2020 (NEP, 2020). The domestic production of electronic items has increased substantially at a Compound Annual Growth Rate (CAGR) of 17%. Production profile for electronics in India (Annual Report MeitY, 2019–20, IBEF, 2023) [11] for electronic commodities like computer hardware, consumer electronics and mobile phones are given.

Table 1: Global market share of key product segments in 2020-21 (US$ billion)

540	**210**	**143**	**66**	**24**	**4**
Mobile Phone	IT Hardware	Consumer Hardware	Hearable & Wearable	LED Lighting	Evs

Literature Survey/Review

Electronic industry is the fastest growing industry. It contributes a lot in the economy of a country and fuels the market with new and latest products. In India, the volume of e-waste generated was 146,000 tonnes per year (Borthakur and Sinha 2013 [3]; Kumar & Karishma, 2016 [14]; Pathak, 2022) [21]. Gupta and Nikam (2009) estimated that approximately 80% of old electronic equipment and their parts are lying idle, discarded and not at all in use. The uncertainty of how to manage such a huge unused electronic waste has worsened the problem. Tyagi *et al.* (2015) [24] reported that by the end of 2016, 93.5 million tons of e-waste will be generated globally which was 41.5 million tons in 2011. In India the formalization process of handling the e-waste is in transition India is capable of handling only 4% of the generated e-waste. Sakshi Gupta (2020) stated that E-waste generation in 2005 was 1.47 lakh metric tons while in 2016 it was 20 lakh metric tons and it is growing 21% annually. Sixty-five cities in India generate more than 60% of the total e-waste generated in India. Ten states generate 70% of the total e-waste generated in India (Naik & Khan, 2020) [18]. Electronic Waste Management in India identified that computer equipment account for almost 70% of e-waste, followed by telecommunication equipment phones (12%), electrical equipment (8%) and medical equipment (7%) with remaining from household e-waste (Manish & Chakraborty, 2019) [17]. The study reveals that 35 million tone of e waste to be produced by 2021-22. E-waste contains 51 types of hazardous materials which is harmful to humans & environment (Kumar, 2018) [15].

In India only 4.5 lakes tons of e-waste were recycled every year which is a high gap between waste recycled and produced. This is effecting adversely to the climate and environment. E-waste collection, transportation, processing, and recycling are dominated by the informal sector. Due to low awareness and sensitization e-waste is thrown along with garbage which is collected and segregated by rag pickers. E-Waste contains reusable and precious material. The Environmental Protection Agency estimates that only 15-20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators. The recyclers use old and hazardous technologies and equipment to recycle/treat the e-waste. In India, the informal recycling sector employs mostly unskilled migrant labor and those from marginalized groups. Most people involved in informal recycling are the urban poor with low literacy levels, and hence have very little awareness regarding the hazards of E-waste and the recycling processes (Kumar & Karishma, 2016) [14].

Methodology

Detail and deep literature survey has been done for collection of secondary E-waste data. For literature survey different government agencies and ministry reports has been selected. For data analysis, ANOVA, curve fitting and trend analysis tools has been applied.

Data Analysis and Discussion

The paper is based on data collected through literature survey. The literature survey covers newspaper articles, magazine, e-books and e-papers. The graph of e-waste data collected through literature survey is given below in form of graph. The x and y axis of the graph shows year and generated e-waste respectively. Looking at the graph, it is clear that maximum e-waste has been generated in 2014 and 2016. Analysis of data generated between 2005 to 2022 shows that the trend of generated data holds power equation, which is $y = 1.482x^{0.984}$, with $R^2 = 0.829$ (Figure 1). The various errors SSE, MSE estimated are well within the directed limit for the confidence bounds of the 95%. The graph given below shows the best fit curves at 95% prediction bound. On the basis of power equation, when trend analysis was done in e-waste data, the trend of predicted e-waste (or predicted y) to be generated in future was found to be polynomial (Second degree parabola $y = 0.052x^2 + 0.752x + 2.249$ with $R^2 = 0.996$ within the directed limit for the confidence bounds of the 95% - Figure 2).

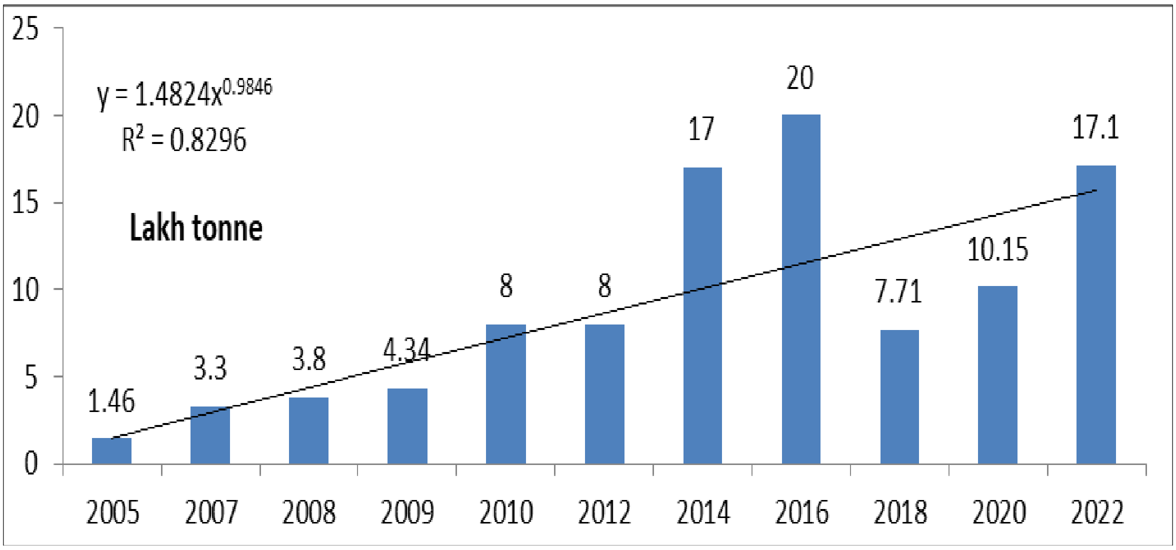


Fig 1: Trend of Generated e-Waste (In Lakh tone)

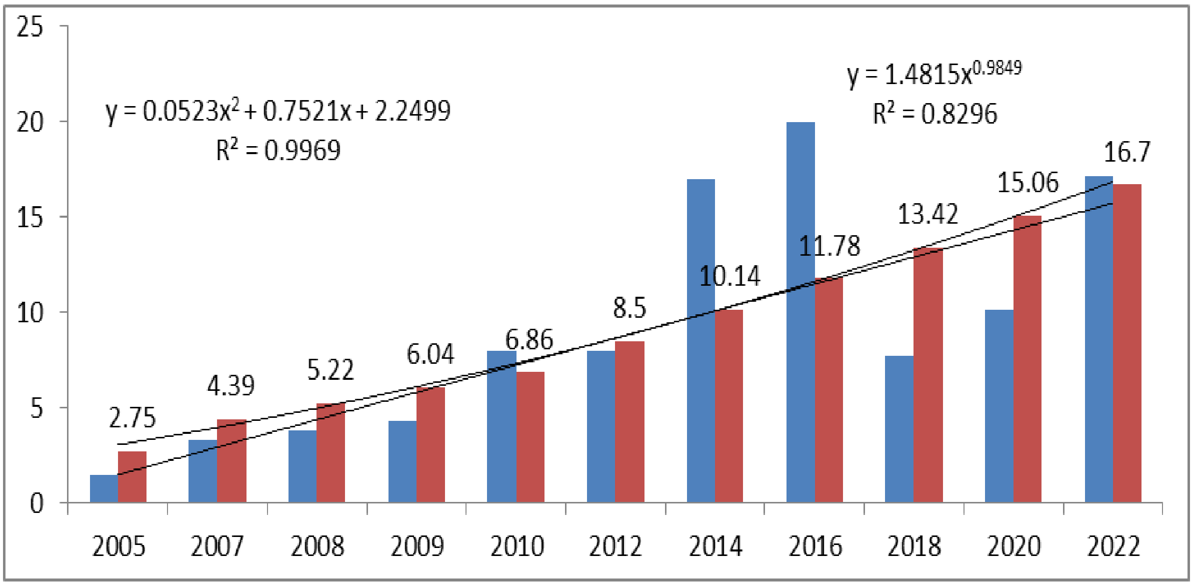


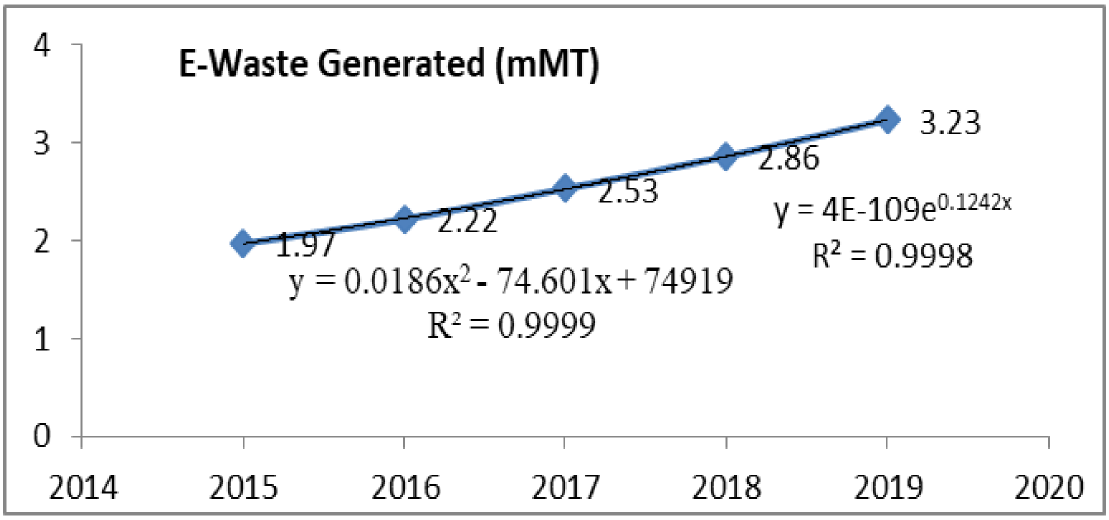
Fig 2: Trend of Predicted e-Waste (In Lakh tone)

The ANOVA analysis shows that the p value of the model is found 0.01024805. The p-value is used in correlation and regression analysis, which helps us identify whether the result is feasible and which data set from the result to work with. The p-values for the coefficients indicate whether the dependent variable is statistically significant. When the p-value is less than our significance level, we can reject the null hypothesis. Since this value is less than 0.05, we can conclude that the regression model as a whole is statistically significant. F is the F statistic or F-test for the null hypothesis. It is used to test the overall significance of the model. Significance F is the p-value associated with the overall F statistic. It tells us whether or not the regression model as a whole is statistically significant. The significance F is computed from the F value. Significance F is the P-value of F. Since significance F (0.009955915) is less than 0.05 (5%), it means our model is all right.

Table 1: ANOVA table of Generated e-Waste

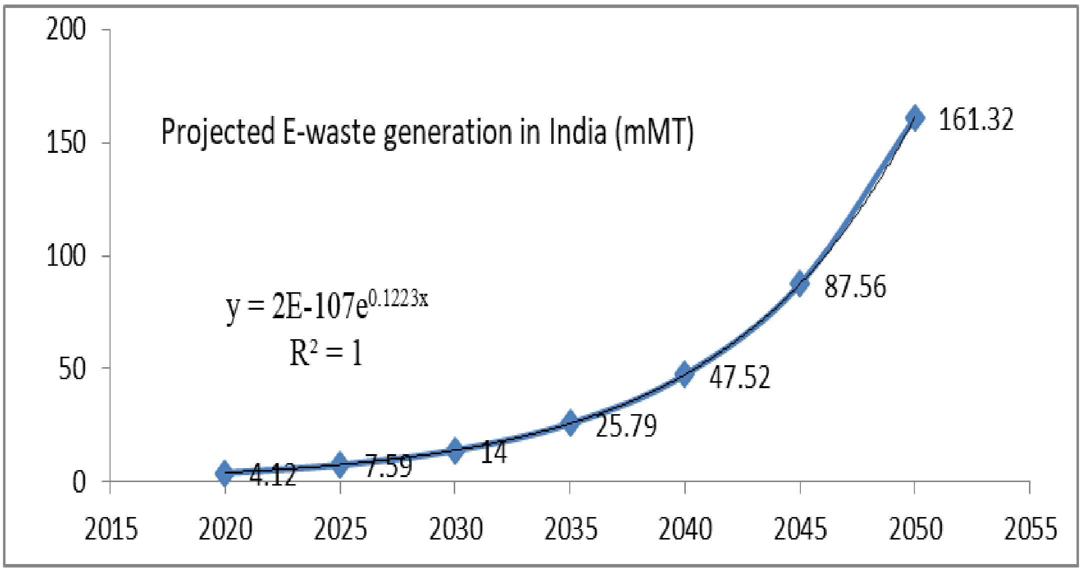
ANOVA			**Multiple R**	**0.540332948**
	T Stat	**P-Value**	**F**	**10.579389**
Intercept	-3.234528327	0.01024805	R Square	0.540332948
X Variable 1	3.252597264	0.00995591	*Significance F*	0.009955915

The e-waste data provided by CSE (2020) and data collected by us through literature survey are different. The model of e-waste data provided by CSE (2020) is given below (Figure 3). The trend analysis shows that the data provided by CSE (2020) follow two types of trend (1) exponential trend $y = 4E\text{-}10e^{0.124x}$ with $R^2 = 0.999$ and (2) second degree parabola $y = 0.018x^2 - 74.60x + 74919$ with $R^2 = 0.999$. The projected e-waste calculated provided by CSE (2020) is also given below in figure 4. The graph shows that the projected data follow exponential trend $y = 2E\text{-}10e^{0.122x}$ with $R^2 = 1$. The various errors for models estimated are well within the directed limit for the confidence bounds of the 95%.



Source: CSE, 2020 compiled from The Global E-waste Statistics Partnership

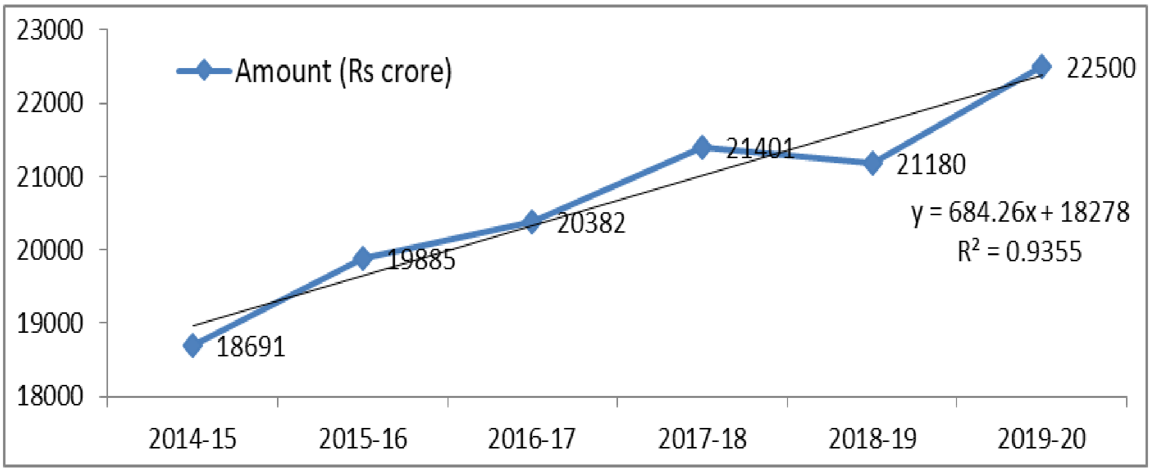
Fig 3: Trend of Generated e-Waste in India (in mMT)



Source: CSE, 2020

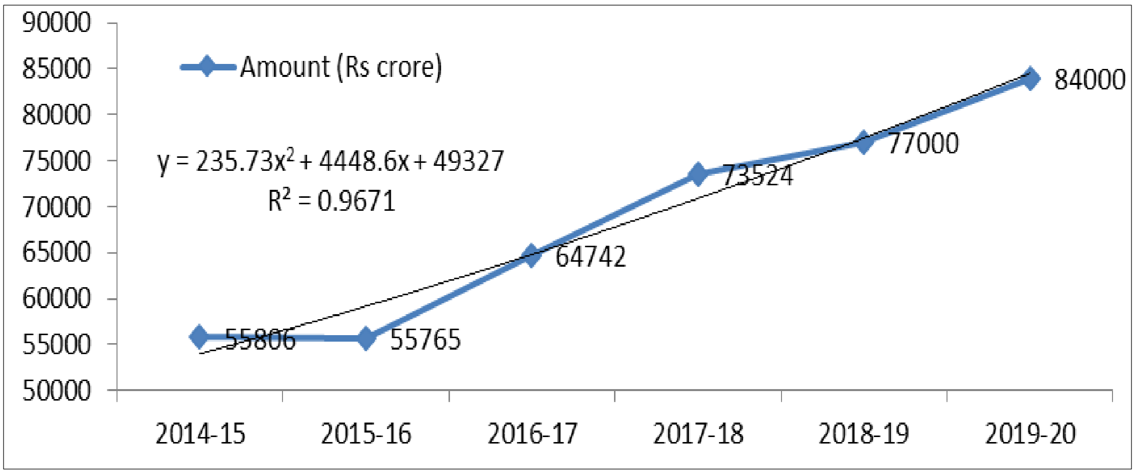
Fig 4: Trend of projected e-Waste in India (in mMT)

India's share in global hardware electronics production is about 3%. The share of domestic electronics production in India's GDP is 2.3%. Ministry of Electronics and Information Technology (MeitY), in its 2019–20 annual report, has provided data regarding production of electronics only in terms of revenue. The graph covers only electronic commodities like computer hardware, consumer electronics and mobile phones. The graph clearly depicts the linear and polynomial rise, especially in domestic production, of shorter lifespan equipment like computer hardware and mobile phones. The linear rise (equation) $y = 684.2x + 18278$, with $R^2 = 0.935$ is found for computer hardware, second degree parabola $y = 235.7x^2 + 4448.x + 49327$, with $R^2 = 0.967$ for consumer electronics and also polynomial rise for mobile phone $y = 1919.x^2 + 27148x – 9150$, with $R^2 = 0.998$ is noted between the year 2015-15 to 2019-20. The various errors for models are well within the directed limit for the confidence bounds of the 95%. The trend graph of computer hardware, consumer electronics and mobile phones is given below



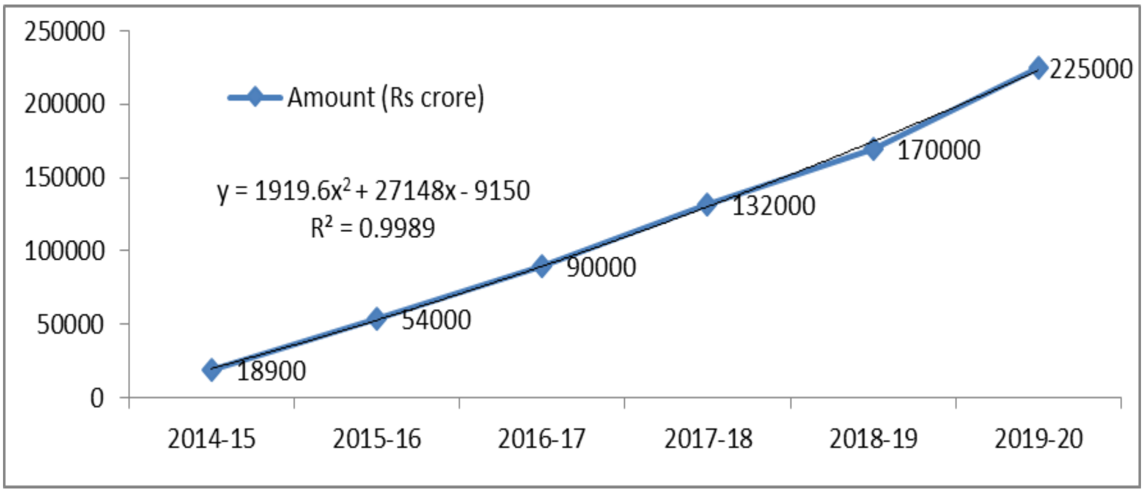
Source: CSE, 2020

Fig 5: Production profile for Computer hardware



Source: CSE, 2020

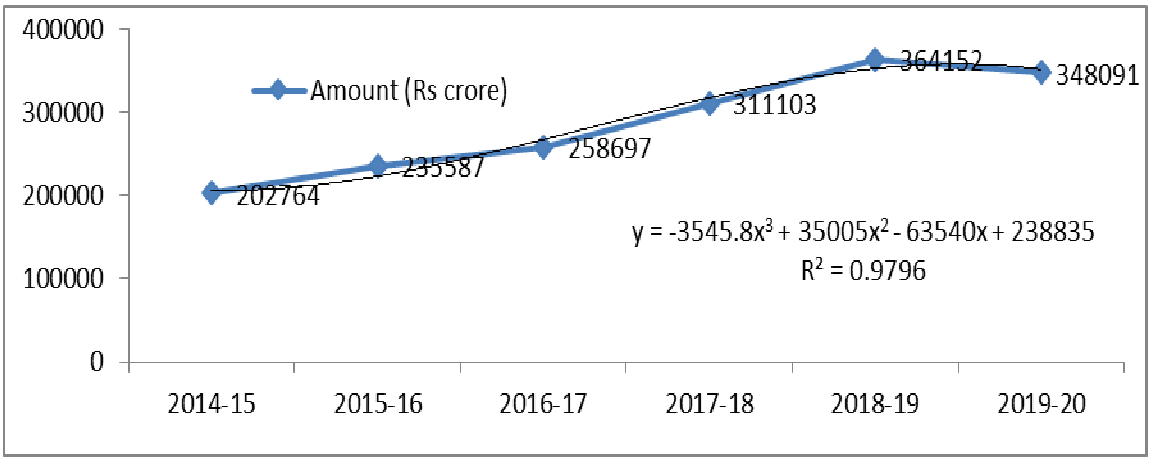
Fig 6: Production profile for Consumer electronics,



Source: CSE, 2020

Fig 7: Production profile for Mobile phones

Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 have banned the import of e-waste, except for refurbishment and re-exportation of second-hand goods. According to the latest Rajya Sabha report on the issue, titled E-waste in India, published in 2011, most ports are handicapped by lack of manpower and machinery in their efforts to stop import of e-waste into the country. Data from the Ministry of Commerce and Industry website indicates that the average share of electrical equipment in total imports is 9.62%. Import of EEE has been increasing at 12.3% annually in the last six years, with 2019–20 witnessing a negative growth.



***Source*:** CSE 2020, Deptt of Commerce (Ministry of Commerce & Industry)

Fig 8: Import profile of EEE in India

Conclusion

The generation of e-waste is a function of the amount of EEE used and discarded by citizens in a particular year. As the social strata changes, the consumption patterns, amount of consumption and rate of generation changes as well. MeitY conveyed to the Ministry of Environment, Forest and Climate Change (MoEF & CC) that only a national-level inventory of e-waste generation can be prepared. We need data that can be analyzed and interpreted to arrive at an estimate of electronic waste produced annually. This will help us strategize to tackle the menace of e-waste. Publishing data in the public domain will also create transparency with respect to generation, flow channels and methods of handling and disposal of potentially hazardous e-waste material. It is a positive sign that we want to position ourselves as a global manufacturing hub and it only increases the need for a robust data management system for handling of e-waste.

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