ESTIMATING AND FORECASTING THE AMOUNT OF MOBILE PHONE AS WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) GENERATED FROM NEPALESE HOUSEHOLDS

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ABSTRACT

This study is the first attempt to estimate the amount of e-waste in Kathmandu, Nepal. The total number of e-waste coming into its End-of-Life (EoL) depends on the disposal behavior of people. In this study, we comprehensively map the disposal behavior of people in Kathmandu Metropolitan City (KMC), the capital city of Nepal to dispose their mobile phones through questionnaire survey. Imports and exports statistics, life span of equipment in each process and Material Flow analysis is used to develop a model in order to estimate and forecast the generation of e-waste (mobile phone waste) from households of KMC. In 2017, 78,748 units of mobile phone will be generated as e-waste, out of which 26.81% will directly reach to Landfill, 33.80% will be dealt by scrap dealers, 25.49% will reach to retail or repair shops, and 15.62% will be stored in KMC's households. This study will help the policy makers and experts working in this field to prepare the sustainable plan for e-waste management in Nepal.

Keywords: Disposal behavior, end-of-life, Kathmandu, material flow analysis, mobile phone.

INTRODUCTION

Electronic waste, e-waste or Waste Electrical and Electronic Equipment (WEEE) are commonly used terms to cover all types of electrical and electronic equipment (EEE) and their parts which have been considered no more useful and discarded as waste by its owner without intention of reuse [1]. Rapid advancement of technology, rising demands, shorter life span, higher consumption and obsolesence rate are the major reasons resulting higher percentage of e-waste in municipal waste stream. One of the fastest growing wastes is the discarded electronic products which are increasing day by day and occupying larger volume in the current waste stream [2]. The end-of-life (EoL) of electric and electronic products refers to time when it no longer satisfies its initial consumer [3]. The study done by Widmer, Oswald-Krapf [4] reported that metals (60%) are the dominant constituent present in e-waste followed by plastics (15%), CRT and LCD screens (12%), metal-plastic mixtures (5%), pollutants (3%), PCBs (2%), cables 2% and others (1%). But, it is difficult to generalize the typical composition of entire e-waste stream due to the presence of diverse range of materials and compositon varies upon equipment. Increasing rate of waste formation, use of potentially hazardous substances and valuable resources, and the environmental impacts related to end-of-life of electronic products are the key issues which makes e-waste as special waste stream [5]. It is reported that globally about 50 million tons of e-waste is being discarded and 12 million tons of that by Asian countries [5]. E-waste is 1-3% of total municipal waste in the world but in developing countries the quantity of e-waste generation is only 1-2% of total municipal waste [5] which is very low in comparison to the e-waste generated by European Union countries which is 8% by volume of total municipal waste [6]. It is reported that due to lack of management of such type of waste about 75% of the old electronic goods are just stored at households or stores [7]. Kiddee, Naidu [8] reported that due to less ecological friendly behavior of e-waste and their short life, about 80% of them from developed countries are being exported to developing countries, which is the major problem for developing countries. Thus, it is important not only to quantity the amount of e-waste imported to the developing countries but also with the quantity of hazardous chemicals associated with those waste.

In order to design proper policy and disposal facility or treatment technology for e-waste management, the inventory of e-waste in any country, city or region forms the basis. The detailed literature review done on generation and estimation of quantities of e-waste by Perez-Belis, Bovea [9] concluded that the standardize method for estimation of e-waste is lacking in different countries. The accuracy in e-waste estimation and forecasting is thus required to analyze the size of problem and thus plans and policies could be made accordingly. Significant quantities of e-waste is produced form residential, commercial and industrial sectors but equipment that are commonly used in each sectors are different. The generation of e-waste varies from country to country or even within country because the time taken by any equipment to reach its EoL depends on disposal behavior of consumer [10].

In Nepal, most of the cities are already facing various waste management challenges due to lack of proper policies and infrastructure and e-waste is not considered as big problem or is not even considered as waste due to the low volume of its generation. But, the increasing amount of EoL electronics in capital area, i.e. in Kathmandu valley, is considered as emerging concern [11]. In this study, we comprehensively map the behaviour of people living in households of Kathmandu metropolitan city (KMC), the capital city of Nepal, to dispose their mobile phones, identify the life span associated with each process by doing questionnaire survey and systematically estimates the generation of e-waste (mobile phone waste) by using Material Flow Analysis (MFA). MFA serves as an decision making tool for appropriate e-waste management which is used to connect the pathways of e-waste form its source to its intermediate or final destinations, in space and time [8]. The e-waste mentioned onwards indicates the mobile phone waste. This study is the pioneer study done to estimate the amount of e-waste in Nepal. The main objective of this study is to establish a model to estimate and forecast the amount of mobile phone waste generated by households of KMC by identifying different flows, processes and life span associated with different processes.

METHODOLOGY

The systematic procedure followed to conduct the MFA is listed below.

Selection of substance/equipment

For this study, mobile phone is selected to estimate the generation of mobile phone as e-waste as it is very common equipment that is being used in Nepalese households. Mobile phones have shorter life span compared to other equipment thus tends to reach to its EoL disposal option faster than other equipment.

System definition in space and time

The system is defined as per the administrative region, in this case, households of Kathmandu Metropolitan City (KMC), the capital city of Nepal is selected as the system to study. The main advantage of selecting capital city is that the political and administrative stakeholders are within this boundary and the results of MFA can be easily implemented within the administratively defined regions which will serve as basis to construct, amend or implement the policy regarding e-waste management.

Sample size

The required sample size of households to carry out the questionnaire survey is calculated by using Eq. 1.

$$\text{ss}=\frac{z^2(p(1\text{-}p))}{d^2} \tag{1}$$

where, ss= sample size, z = z-value taken as 1.96 for 95% confidence interval, d = confidence interval or margin of error expressed as decimal, taken as 5% or 0.05 and p= true proportion which is unknown, taken as 0.5. The most conservative way of handling this uncertainty is to set the value of p at the proportion that would result in the highest sample size, which occurs at p=0.5 [12]. Eq. 1 is used for infinite population, but the number of households is known, thus, modified as Eq. 2 for finite population correction [13].

$$\text{New ss}=\frac{\text{ss}}{1+\frac{\text{ss}-1}{\text{H}}} \tag{2}$$

where, New ss= new sample size after finite population correction and H=number of households. In 2011, the number of households in KMC, H=254,292 [14]. The sample size is calculated as: 384. Thus sample size of 400 is selected to carry out this research. Similar research done by Alavi, Shirmardi [15] also obtained 384 as their sample size for the population of 293,000 households in Iran. According to the literature, sample size of 400 is adequate for the population more than 5000 [16].

Identification of relevant flows and processes

According to Brunner and Rechberger [17], flow is the transfer of material from one process to another and process is the transformation, transport or storage of materials. To develop a model in order to calculate the e-waste generation, the possible flows of e-waste following different intermediate processes to its EoL and life span associated with each process are investigated through questionnaire survey and presented in Fig. 1.

From our findings, the average life of new mobile phone (L_N), i.e. can be used without any maintenance is found to be 2.50 years. After that, consumer's preference to choose either intermediate processes or EoL options to dispose their used equipment (U), i.e. mobile phone, is investigated. It is found that there are two intermediate processes, repair and reuse (Re) and temporary storage (TemS) in households which extends the time period of mobile phone to reach to any EoL options.

The average period for which consumer prefer to repair and reuse their mobile phones before choosing temporary storage in households or any EoL options is found to be: L_{Re}=0.95 years. Repair and reuse is very common process done with any EEE in developing countries like Nepal because, it is economic to repair and reuse rather buying new one. It is found that people temporarily store their mobile phones due to various reason like: waiting for better resell price, scrap dealers visits less often in their households, can be used by their children, etc. The average period for which people temporarily store their mobile phone before choosing any EoL options is found to be L_{St}=2.62 years.

It is found that there are four EoL options to dispose the mobile phones: shops (Sh), store in house (StH), throw with other municipal waste which reach to the landfill (Lf) and give to scrap dealers (SD). Shops are also considered as one of the EoL option because as per the definition by StEP [1], mobile phone that is discarded by its owner without intention of reuse is considered as e-waste. Those shops mainly repair shops and retail shops either purchase old phones or exchange old phones with new one. If they can repair the old phones, it is sold to the users again as second hand product; else they keep on storing the phone hoping that some parts would be useful for repairing other phones in future. Repair shops are considered as special type of user [11] because they are receiving significant quantity of e-waste and also importing significant amount of mobile phone parts for repairing. Thus, the flow from which mobile phone is coming back to the households as second hand phone from the shops process is also neglected. It is found that consumers are storing their e-waste for long time in one of the corners of their house for the reasons like: don't have any resell value and don't take much space, having no idea about how to deal with such waste and having some kind of attachment with their old equipment. Thus, e-waste in this EoL option will be accumulated year by year. Landfill and scrap dealers are other two EoL options for disposal of mobile phones.

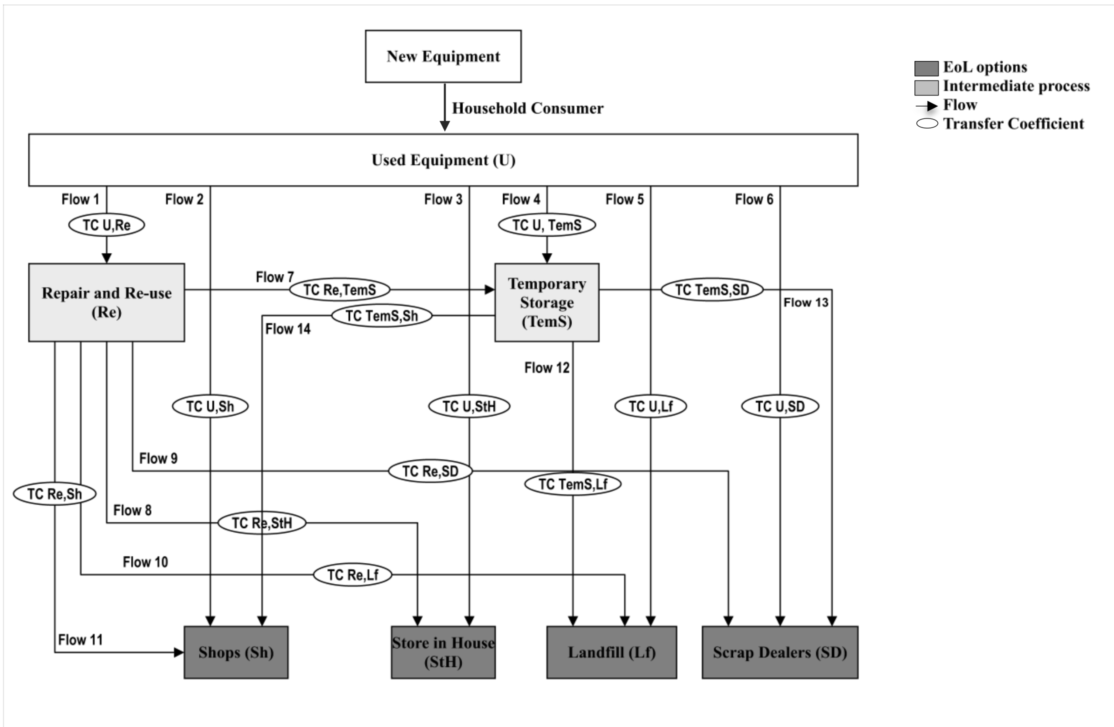

Figure 1. Disposal behavior of mobile phones

Determination of rate of substance flows

The term transfer coefficient (TC) is used to divide the flows when a process has multiple outputs. Thus, TC indicates the proportion by which it leaves the one process to another process. The sum of TCs leaving a process should always be 1.00 [17]. Consumer uses their new mobile phone without repairing for 2.5 years (L_N) and their used equipment (U) tends to go to two intermediate processes, Re and TemS and four EoL process Sh, StH, Lf and SD. $TC_{U,Re}$ indicates the proportion of the equipment reaching to process 'Re' form the process 'U' which is found to be 0.7675. Similarly, TCs for other flows is found to be: $TC_{U,Sh}$=0.1, $TC_{U,StH}$=0.0250, $TC_{U,TemS}$=0.050, $TC_{U,Lf}$=0.050 and $TC_{U,SD}$=0.0075. TCs to divide the flow of intermediate process 'Re' are: $TC_{Re,TemS}$=0.2932, $TC_{Re,StH}$=0.1433, $TC_{Re,SD}$=0.2801, $TC_{Re,Lf}$=0.1726 and $TC_{Re,Sh}$=0.1107. Similarly, TCs to divide the flow of intermediate process 'TemS' are: $TC_{TemS,Lf}$=0.4535, $TC_{TemS,SD}$=0.5364 and $TC_{TemS,Sh}$=0.1091. Using these TCs and lifespans of each process, equations are developed in order to estimate the total generation of e-waste from the households of KMC.

RESULTS AND DISCUSSION

Assessment of total flow

In order to assess the total number of e-waste coming to its EoL in year Y, first of all, sales statistics is used to produce a best fit curve. The sales data, i.e. total number of mobile phone put into the market, can be calculated by Eq. 3 where I(Y) and P(Y) represents the import and production of the equipment in current evaluation year respectively, whereas E(Y) represents export of the equipment in current evaluation year.

$$S(Y) = I(Y) + P(Y) - E(Y) \tag{3}$$

The annual foreign trade statistics is available in the website of Department of Customs, Ministry of Finance, Government of Nepal from fiscal year 2007/2008 to fiscal year 2015/2016. Fiscal year in Nepal starts from Mid-July and ends on Mid-June. Table 1 represents the statistical import of mobile phone for whole country. Since, Nepal is not producing and exporting any mobile phones; P(Y) and E(Y) are neglected. Data for fiscal year 2010/11 is missing in the website.

Table 1. Statistical Import and Export of Mobile Phone

Fiscal Year	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Import	583,503	601,601	1,098,702	-	1,936,695	2,193,549	3,171,985	3,353,009	4,990,487

Source: [18]

In order to calculate the generation and forecast the future trend of e-waste by mobile phone, linear regression is performed to obtain the best fit curve for the above data. The best fit curve is shown in Fig. 2 and best fit equation is given in Eq. 4 with coefficient of determination R^2=92.54%.

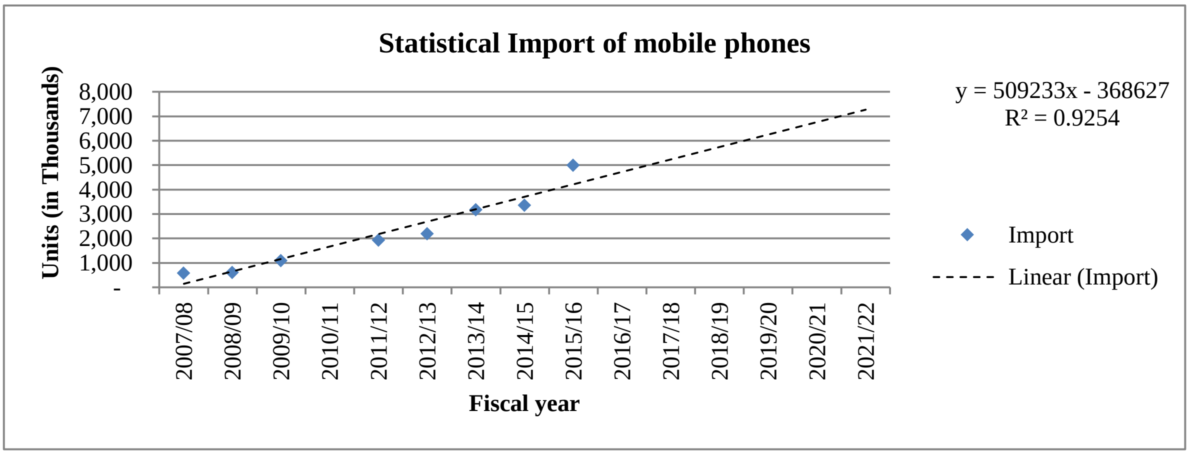

Figure 2. Statistical Import of mobile phones

$$y = 509233x - 368627 \tag{4}$$

In order to calculate the amount of e-waste generated from KMC in year 'Y', Eq. 3 is modified by doing population balance and given by Eq. 4.

$$y = [509233x - 368627] * \frac{P_{KMC,Y}}{P_{N,Y}} \tag{5}$$

where, $P_{KMC,Y}$ = Population of KMC in year 'Y' and $P_{N,Y}$=Population of Nepal in year 'Y'. For that, statistical population data of Nepal and that of KMC is taken from Review [19] and is forecasted by using regression method. Dashed line in Fig. 3 and Fig. 4 shows the trend of population increment in Nepal and KMC respectively. The equations used to forecast the population is given in respective figures. Table 2 shows the forecasted population of KMC and Nepal from 2017-2022.

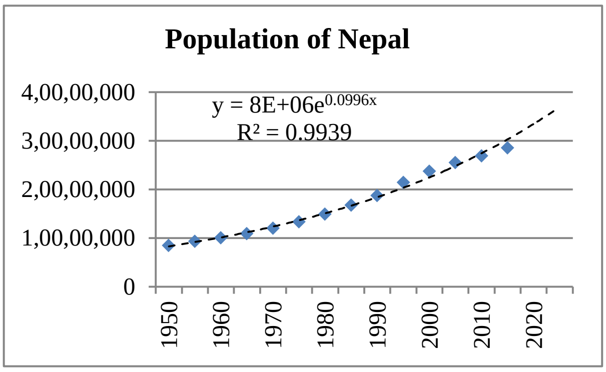

Figure 3. Population of Nepal

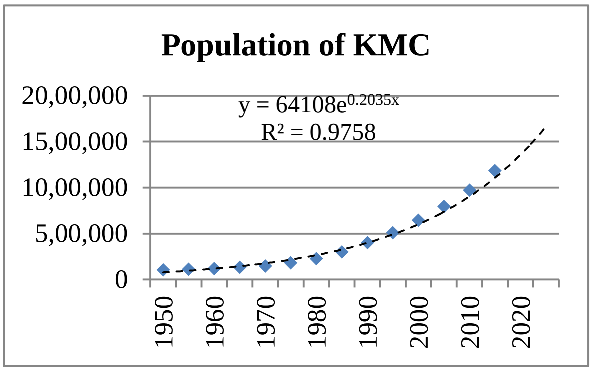

Figure 4. Population of KMC

Table 2. Forecasted population of KMC and Nepal

Year (Y)	2017	2018	2019	2020	2021	2022
Population of KMC (P_{KMC})	1,201,071	1,250,963	1,302,928	1,357,051	1,413,422	1,472,135
Population of Nepal (P_N)	33,571,636	34,247,088	34,936,130	35,639,036	36,356,083	37,087,558

By modifying Eq. 5 and balancing it with TCs and Life spans from the results from MFA, equations to calculate the amount of e-waste reaching to its four EoL options are formed. There are altogether two flows that reach upto first EoL option Store in House (StH). Thus, it will have two equations represented by Eq. 6 and Eq. 7. Consumer first use their mobile phone for 'L_N' period until the process Used Equipment(U), following Flow 1 with $TC_{U,Re}$ to next intermediate process Repair and Reuse (Re). In this process mobile phone spends 'L_{Re}' period and follow Flow 8 with $TC_{Re,StH}$ to reach to the EoL option Store in House. Thus, by balancing with respective TCs and lifespans of the flows and processes reaching to EoL 'Store in house', Eq. 6 and 7 are formed.

$$y_1(Y) = TC_{U,Re} * TC_{Re,StH} * [509233 * (Y\text{-}2008\text{-}L_N\text{-}L_{Re})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \tag{6}$$

$$y_2(Y) = TC_{U,StH} * [509233 * (Y\text{-}2008\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \tag{7}$$

And, $\sum_{i=1}^{2}(y_i)$ = total units of e-waste generated in year 'Y' that will be stored in HHs.

Similarly, Eq. 8, Eq. 9, Eq. 10 and Eq. 11 represents the equations to estimate the amount of e-waste that reach to the other EoL disposal option 'Landfill'.

$$y_3(Y)=TC_{U,Re} * TC_{Re,TemS} * TC_{TemS,Lf} * [509233* (Y\text{-}2008\text{-} L_N - L_{Re}\text{-} L_{St})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (8)$$

$$y_4(Y)= TC_{U,Re} * TC_{Re,Lf} * [509233 * (Y\text{-}2008\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (9)$$

$$y_5(Y)=TC_{U,TemS} * TC_{TemS,Lf} * [509233* (Y\text{-}2008\text{-}L_N\text{-}L_{St})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (10)$$

$$y_6(Y)= TC_{U,Lf} * [509233 * (Y\text{-}2008\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (11)$$

And, $\sum_{i=3}^{6} (y_i)$ = total units of e-waste generated in year 'Y' that will reach to the landfill.

Similarly, Eq. 12, Eq. 13, Eq.14 and Eq. 15 represents the equations to calculate the amount of e-waste that reach to other EoL option 'Scrap dealers'.

$$y_7(Y)=TC_{U,Re} * TC_{Re,TemS} * TC_{TemS,SD}* [509233* (Y\text{-}2008 \text{-}L_N\text{-}L_{Re}\text{-}L_{St})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (12)$$

$$y_8(Y)=TC_{U,Re} * TC_{Re,SD}* [509233*(Y\text{-}2008\text{-}L_N\text{-}L_{Re})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (13)$$

$$y_9(Y)=TC_{U,TemS} * TC_{TemS,SD} * [509233* (Y\text{-}2008 \text{-}L_N\text{-}L_{St})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (14)$$

$$y_{10}(Y)=TC_{U,SD} * [509233* (Y\text{-}2008\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (15)$$

And, $\sum_{i=7}^{10} (y_i)$ = total units of e-waste generated in year 'Y' that will reach to the scrap dealers.

Similarly, Eq. 16, Eq. 17, Eq.18 and Eq. 19 represents the equations to calculate the amount of mobile phone (e-waste) that reach to other EoL disposal option 'Shops'.

$$y_{11}(Y)=TC_{U,Re} * TC_{Re,TemS} * TC_{TemS,Sh}* [509233* (Y\text{-}2008\text{-}L_{St}\text{-}L_{Re}\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (16)$$

$$y_{12}(Y)=TC_{U,Re} * TC_{Re,Sh} * [509233*(Y\text{-}2008\text{-}L_{Re}\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (17)$$

$$y_{13}(Y)=TC_{U,TemS} * TC_{TemS,Sh} * [509233* (Y\text{-}2008 \text{-}L_N \text{-}L_{St})\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (18)$$

$$y_{14}(Y)=TC_{U,Sh} *[509233 * (Y\text{-}2008\text{-}L_N)\text{-}368627] * (P_{KMC,Y}/P_{N,Y}) \quad (19)$$

And, $\sum_{i=12}^{14} (y_i)$ = total units of e-waste generated in year 'Y' that will reach to the shops.

The total e-waste generation is given by: $\sum_{i=1}^{14} (y_i)$ (20)

By using above equations, quantity of e-waste going into different EoL options is calculated. Total e-waste generation by households of KMC and the quantity that will be generated in the future is presented in the Fig. 5.

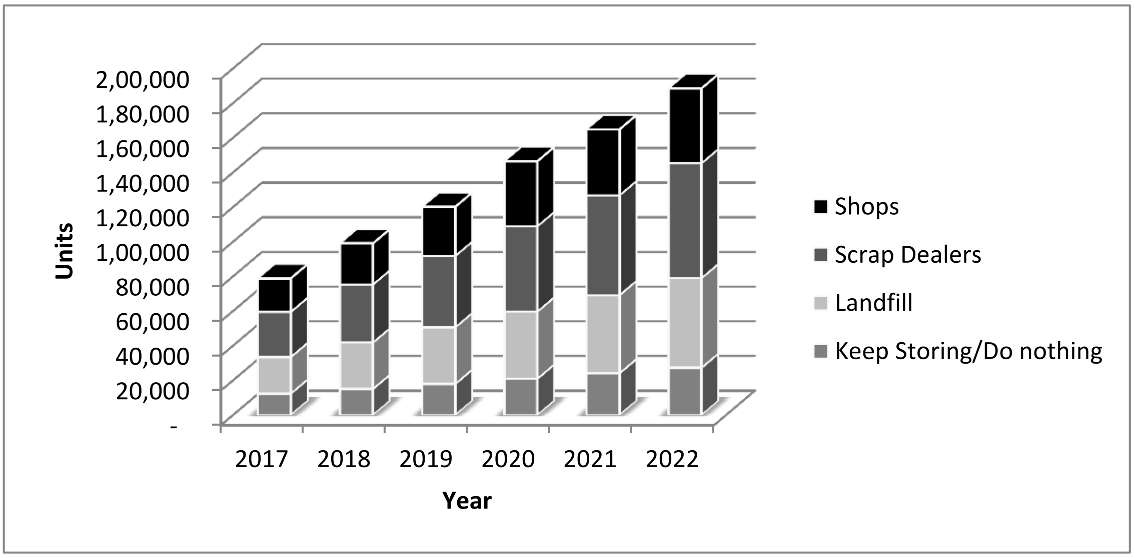

Figure 5. Quantity of e-waste generation by KMC

In 2017, i.e. Y=2017, total units of mobile phone generated as e-waste from KMC's households is: 78,748 in which 12,295 units will remain in KMC's households for unknown time because mobile phone requires small storage space and also people don't want to give/sell their mobile phone to others at low price. This amount of waste remains uncollected and remains within the households accumulating every year but still accounted as e-waste because it is discarded by its owner without intention of reuse. Whereas, 21,115 units will reach to the landfill site mixing up with other common municipal waste and ends up without treatment. Similarly, 26,053 units will be dealed by scrap dealers, who are the only informal recyclers dealing with e-waste in Nepal. Scrap dealers mainly dismantle the parts and sell valuables. The non-selleable parts are discarded by them with other type of waste ending up in the Landfill which increase the amount of e-waste reaching the landfill site. And, remaining 19,286 units will reach to retail or repair shops via exchange or selling of old mobile phones. That kind of shops either resell the mobile phone as second hand product (if applicable) or keep on storing them for the parts that could be useful in future to repair other mobile phones. The unused and parts also end up in the Landfill.

LIMITATIONS

In this study, only the quantity of mobile phone entering into the market from registered flow is considerd to estimate the e-waste generation neglecting the second hand mobile phones entering into the market from different shops and also neglecting unregistered flows like: individual carrying mobile sets while returning back from foreign countries. Life spans of each processes are taken constant so as to forecast the generation of e-waste in future.

CONCLUSIONS

The study affords the detailed understanding of the flows and process by which mobile phones reach to its EoL-both qualitatively and quantitatively in KMC. The collection of e-waste for further treatment is poor in KMC as only 33.08% is collected by informal sectors, i.e. scrap dealers and 42.43% remains uncollected from which 26.81% reach to the landfill and 15.62% will be stored in households. Remaining 25.49% reach to the shops which accounts almost one fourth of e-waste generated, thus generation of e-waste by these kind of shops should be studied separately. This systematic quantification will help the policy makers to understand the size of the problem in order to make the sustainable management plan timely. The procedure developed is supposed to help the study of generation of e-waste by other equipment too and for other places also.

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