DESCRIPTIVE STATISTICAL ANALYSIS ON PAPER, PLASTIC, AND GLASS RECYCLING IN ONTARIO, CANADA

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Abstract: The Ontario municipal solid waste generation and disposal rates increased noticeably from 1996 to 2010, partly due to the 16% increase in population. The province has adopted a number of waste management initiatives and programs to divert non-hazardous wastes from landfills and other disposal facilities. The key objective of the present study was to statistically analyze the recycling trends of paper, plastic, and glass wastes in Ontario. A detailed assessment program was developed in this study. Waste management programs from Waste Diversion Ontario and the Recycling Council of Ontario during the study period were investigated and discussed. Waste recycling data was collected from Statistics Canada, and verified from other literature. Descriptive statistical analyses were performed to examine the temporal variability of the waste recycling behaviours and practices. Regression analyses and Mann-Kendall (MK) tests were conducted to quantify the waste recycling trends. It is found that the waste recycling rates have increased significantly during the study period. Approximately 85% increases were observed for both paper and glass recycling. The trend analysis also showed significant increasing trends for all three waste materials. Plastic wastes exhibited the strongest trends with the highest MK statistic value (S = +26) and a 99% level of significance. The recycling trends of paper and plastic materials were found to be significant at 80% and 90% levels of significance, with S values of +8 and +12, respectively.

1 INTRODUCTION

In Ontario, the most populated province in Canada, current landfill space is decreasing, and no new landfills have been approved for over a decade (Mueller, 2013). The latest landfill in Ontario was approved in 1999. Hence, a number of recycling programs are needed to divert waste in order to reserve landfill space, and also for saving valuable land areas for other purposes such as agriculture. Due to the shortage of available waste disposal sites in Ontario, municipal solid waste (MSW) requires more efficient and environmentally responsive management (Feiock and Kalan, 2001). This can be done by diverting wastes from the landfills via recycling. Waste diversion minimizes the consumption of raw resources and energy, and generates profits for various waste recycling companies. Paper wastes are the most recycled materials among different types of municipal solid wastes. Paper wastes generally include newsprints, cardboard, boxboard, and mixed paper fibres. Other recyclable waste types are plastics, glasses, and different forms of construction and metal wastes.

The objective of this study was to statistically analyze the recycling trends of paper, plastic, and glass wastes in Ontario. First, a literature review was conducted on the recycling programs and diversion practices in Ontario. Second, the waste management data in Ontario during the study period was collected, verified and processed for paper, plastic, and glass wastes. Statistical analyses were performed over these data to examine the temporal variability, and to identify waste diversion trends. Finally, the results were used to assess the recycling trends of the wastes.

2 WASTE MANAGEMENT PROGRAMS

To manage MSW effectively, the Recycling Council of Ontario (RCO) and Waste Diversion Ontario (WDO) adopted several programs for reducing waste disposal at landfills by diverting wastes. These programs are outlined in Figure 1.

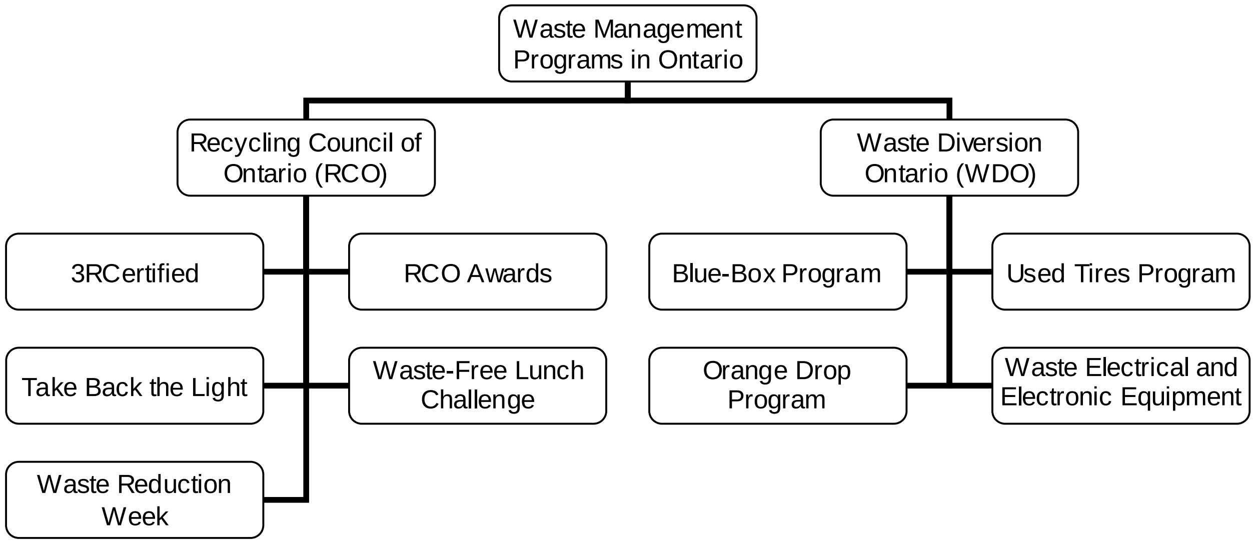

Figure 1: Waste management programs in Ontario

Among the aforementioned programs, the Blue-Box Program plays a major role in diverting paper waste and other valuable resources from landfills. Over 95% of Ontarians have access to curb-side recycling, and nearly 90% feel that the Blue Box Program is the main driver of their recycling habits (WDO, 2015). The accepted types of materials through the Blue Box Program are paper, glass, metal, and plastic. However, the types of materials accepted vary between municipalities. The collected materials are delivered to material recovery facilities. At this point, materials go through a series of mechanical and magnetic sorters. Similar materials are bulked together in bales, and shipped to processing facilities. The bales are broken down and transformed into raw materials, ready to be used in the manufacturing of new products. Waste Diversion Ontario has reported that almost 7 million tonnes of recyclable materials have been diverted by this program since 2004 (WDO 2015).

3 METHODOLOGY

A detailed assessment program was developed in this study. First, the Ontario waste data were collected for the study period of 1996 to 2010 (Statistics Canada, 1999, 2000, 2003, 2004, 2007, 2008, 2010, 2013). Following this, the descriptive statistical analysis and trend analysis were performed to investigate temporal variability and waste diversion trends in the province.

3.1 Statistics Canada Waste Survey and Data

The services provided by the Canadian waste management industry include: the collection and transportation of waste and materials destined for recycling (including composting); the operation of non-hazardous and hazardous waste disposal facilities; the operation of transfer stations; the operation of recycling and composting facilities; and the treatment of hazardous waste. Data collection for Statistics Canada Waste surveys is usually performed by mailing the questionnaires to different businesses and local governments. For example, a total of 1,353 businesses and local governments were contacted/participated in the 2010 waste survey (Statistics Canada, 2013). The companies' written responses are sent to Statistics Canada by mail. The questionnaires were addressed to a contact person who was either responsible for, or had knowledge of, the waste management operations of the survey unit. Follow-ups by fax and/or telephone were usually carried out after the return due date to remind respondents to return their questionnaires. Questionnaires were normally edited in two steps. Additional follow-ups were carried out to collect missing data and to correct inconsistencies. The Waste management industry survey coverage included waste that is formally managed by waste management firms or municipalities, and that were managed off-site (not at the point of generation). The data for the total amount of waste disposal does not include waste disposal in hazardous disposal facilities, or waste managed by the waste generator on-site. In this study, the data for waste diversion represent the materials prepared for recycling in public and private waste disposal facilities. Therefore, the amount of waste diverted can differ from the amount of waste recycled.

3.2 Statistical analysis

Linear regression analysis (Hess et. al, 2001) and Mann-Kendall tests (Brix, 2010) have been widely used for detecting and estimating linear trends in environmental and solid waste management data. These techniques were applied in this study using recycling data for paper, plastic, and glass wastes.

3.2.1 Regression analysis

Linear regression is a parametric statistical procedure for analyzing trends in data over time. Linear regression finds the straight line, called the least squares regression line (LSRL) that best represents observations in a bi-variate data set. Given a random sample of observations (X), the regression line is estimated by:

[1] $$\mathrm{Y} = \mathrm{b}_0 + \mathrm{b}_1\mathrm{X}$$

Where b_0 and b_1 are constant. The coefficient of determination (r^2) is interpreted as the proportion of the variance in the dependent variable that is predictable from the independent variable. ($0 \leq r \leq 1$)

[2] $$\mathrm{r}^2 = \left\{\left(\frac{1}{\mathrm{N}}\right)\frac{\sum(\mathrm{x_i} - \mathrm{x})(\mathrm{y_i} - \mathrm{y})}{(\mathrm{s_x} - \mathrm{s_y})}\right\}^2$$

The confidence interval analysis was also performed for the linear model in regression analysis. Confidence intervals (CI) provide an estimated range of values calculated from a given set of data that is likely to include an unknown population parameter. A very wide CI suggests that more data should be collected before anything definite can be said about the unknown parameter. CI are typically stated at the 95% confidence level in applied practice. However, when presented graphically, CI can be shown at several confidence intervals, such as 50%, 95% and 99%. In this study, confidence intervals are stated at the 95% confidence interval.

3.2.2 Mann-Kendall test

The Mann-Kendall test is a non-parametric statistical procedure to analyze trends in data over time. This test can be used with data sets which include irregular sampling intervals and missing data. The Mann-Kendall statistic (*S*) measures the trend in the data. Positive values indicate an increasing trend over time, whereas negative values indicate a decreasing trend over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend). Data for performing the Mann-Kendall Analysis should be in temporally sequential order. The first step is to determine the sign of the difference between consecutive sample results. Sgn(x_j - x_k) is an indicator function that results in the values 1, 0, or –1 according to the sign of x_j - x_k where j > k. The function is calculated as follows:

[3] $$\mathrm{sgn}(\mathrm{x_j} - \mathrm{x_k}) = 1, \mathrm{if}\ (\mathrm{x_j} - \mathrm{x_k}) > 0$$

[4] $$\mathrm{sgn}(\mathrm{x_j} - \mathrm{x_k}) = 0, \mathrm{if}\ (\mathrm{x_j} - \mathrm{x_k}) = 0$$

[5] $$\mathrm{sgn}(\mathrm{x_j} - \mathrm{x_k}) = -1, \mathrm{if}\ (\mathrm{x_j} - \mathrm{x_k}) < 0$$

The Mann-Kendall statistic (S) is defined as the sum of the number of positive differences minus the number of negative differences, or as follows:

[6] $$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}\left(x_j - x_k\right)$$

Variance of the Mann-Kendall statistic (S) is calculated as follows:

[7] $$VAR\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum t_p\ \left(t_p - 1\right)(2t_p + 5)\right]$$

Where q is the number of tied groups and t_p is the number of data values in the p^{th} group. The standard normal variate z is computed by using following equations:

[8] $$z = \frac{S-1}{\sqrt{VAR(S)}}\ , \text{if } S > 0$$

[9] $$z = 0\ , \text{if } S = 0$$

[10] $$z = \frac{S+1}{\sqrt{VAR(S)}}\ , \text{if } S < 0$$

The probability density function for a normal distribution is given by the following equation:

[11] $$f\ (z) = \frac{1}{\sqrt{2\pi}}\ e^{-\frac{z^2}{2}}$$

The confidence level is the complement of the respective level of significance (i.e. it gives an indication whether the revealed statistical trend is significant or insignificant). The level of significance is obtained from the value of the probability function in percentage. For practical use of the trend, higher confidence level values (80%, 95% and 99%) are generally used to represent significant trends, and vice-versa. In this study, a value of 80% or higher was considered a significant confidence level for the trends obtained from the Mann-Kendall test.

4 RESULTS AND DISCUSSION

Figure 2 shows the population and disposal of non-hazardous waste in Ontario during the study period. The population increased by about 17% from 10.75 million to 12.58 million from 1996 to 2010. The total amount of waste disposed increased by about 33% from 6.9 million tonnes to 9.2 million tonnes, with an average of 8.7 million tonnes of waste disposed per year. The increased population accounts for the increase in waste disposal. It should be noted that this total amount of waste mentioned above is not limited to the total amount of the selected three wastes (papers, plastics, and glasses), but includes all other types of municipal solid waste. The temporal variability shows a significant increasing trend from 1996 to 2002, and a stable rate thereafter (2002-2010). The significant increasing trend of disposed waste in earlier years (1996-2002) led the Government of Ontario to pass the Waste Diversion Act, 2002 on June 27, 2002 (Gerretsen, 2008). This act was an important step towards effective use of landfill space, resource conservation, and recycling through waste diversion. As mentioned previously, current landfill space is decreasing in Ontario, and a new landfill has not been approved for over a decade. This

Waste Diversion Act, with its aggressive diversion plans and strategies, was a demand at the time, since these acts came as a result of chronic shortages of municipally-owned waste disposal capacity (Garkowski and Hostovsky, 2011).

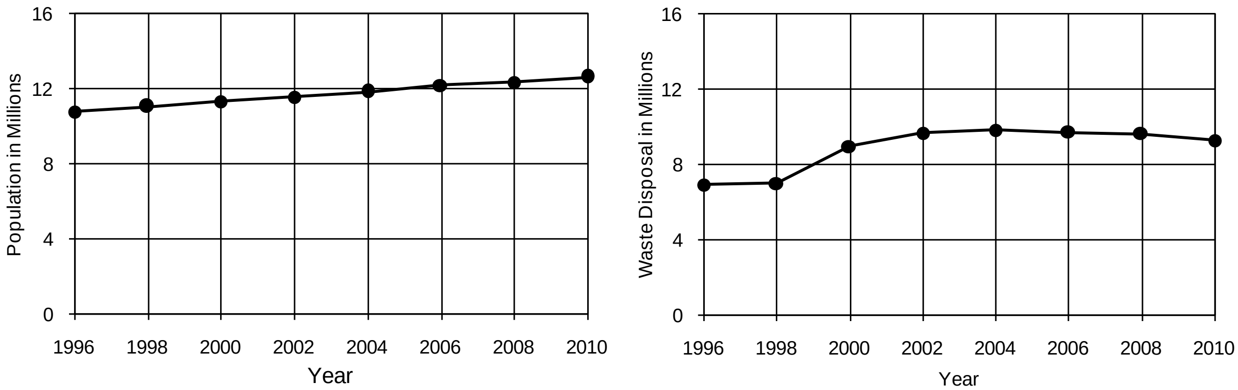

Figure 2: Population waste disposal in Ontario during 1996-2010.

Papers and related products are widely recycled by Ontarians. Figure 3 plots the results of statistical analysis of paper waste during 1996 to 2010. The paper waste data gives an increasing trend in the regression analysis with a positive slope in regression line and a correlation value (r^2 = 0.35). The 95% confidence interval for the linear regression line was plotted by filling the area between upper limit and lower limit (see the shaded area). The upper limits and lower limits were derived from 5,000 iterations using an automated procedure. All reported values of paper diversion were found within the CI limit of regression line except for 2002. Though a lower correlation value (r^2 = 0.35) was observed in the regression analysis, the derived linear model may be used to quantify paper waste diversion due to the reported values plotting within the 95% confidence interval. The increasing trend observed from regression analysis was reconfirmed by the Mann-Kendall (MK) test with a positive MK statistic value S = +8. The probability density function was found to be 0.81, which means the trend from the MK test is significant at an 81% level of significance. Overall, the amount of paper waste diversion was increased from 0.6 million tonnes to 1.1 million tonnes, which means per capita paper waste diversion increased from 5.50 kilograms to 8.75 kilograms per year. However, the increase in the total amount of paper waste diversion does not necessarily indicate effective waste management programs, since this can be the result of a number of other influencing factors.

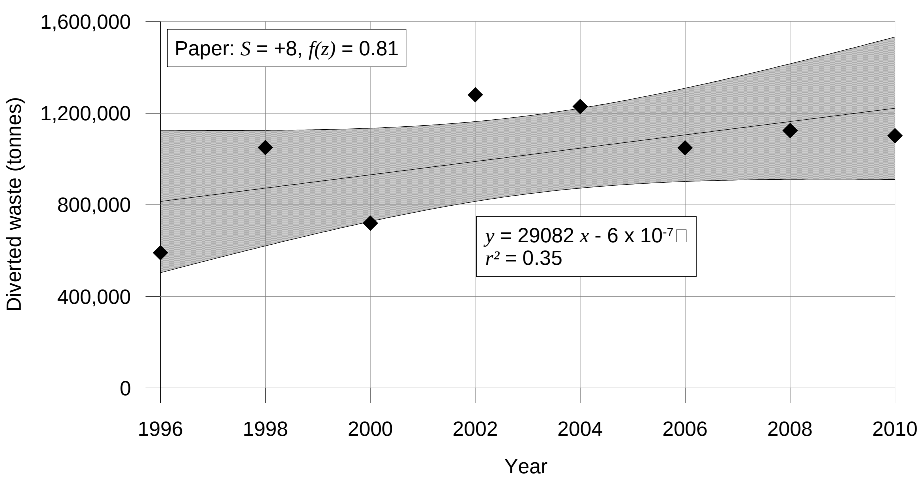

Figure 3: Statistical analysis of paper waste during 1996 to 2010

Figure 4 shows the results of statistical analysis of plastic waste diversion during the study period. Once again, an increasing trend was observed in the regression analysis with a positive slope in the regression line. Nonetheless, a higher correlation value (r^2 = 0.90) was observed in this case. Likewise, all reported values of diverted plastic waste were found within the 95% confidence interval limit of regression line, except for the value in 2008. Therefore, the derived linear model can be used to quantify the diverted waste within a 95% confidence level. The increasing trend observed from regression analysis was verified by the Mann-Kendall (MK) test, with a higher positive MK statistic value S = +26. The probability density function was found to be 0.99, which means the trend from the MK test is significant at 99% level of significance. Overall, the amount of plastic waste diversion was increased from 13 thousand tonnes to 80 thousand tonnes, which makes per capita waste diversion increase from 0.1 kilograms to 0.6 kilograms per year.

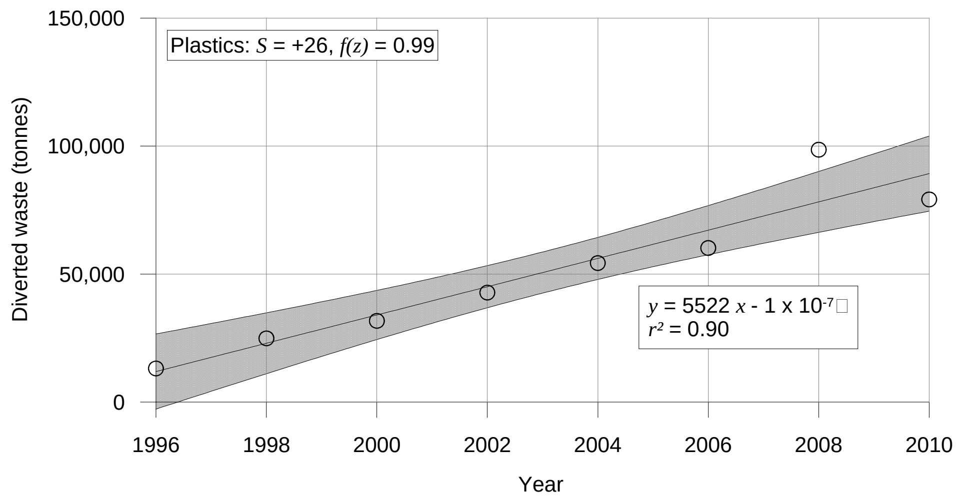

Figure 4: Statistical analysis of plastics waste during 1996 to 2010

Figure 5 shows the results of statistical analysis of glass waste diversion from 1996 to 2010. The glass waste data gives an increasing trend in the regression analysis with a positive slope in the regression line, and a correlation value (r^2 = 0.38). The 95% confidence interval for the linear regression line was plotted by filling the area between the upper limit and lower limit.

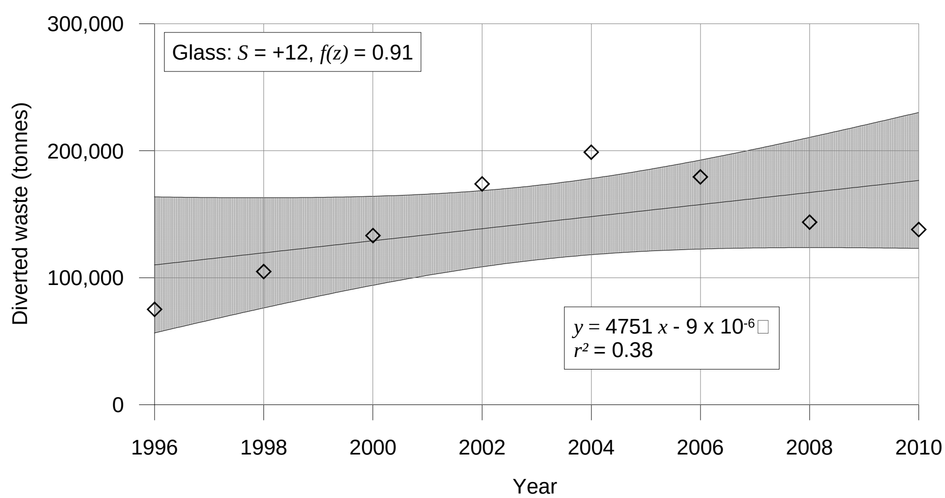

Figure 5: Statistical analysis of glass waste during 1996 to 2010

Most of the reported values of diverted glass waste were found within the confidence interval limit of regression line except the values for 2002 and 2004. Though a lower correlation value (r^2 = 0.38) was observed in the regression analysis, the derived linear model may be used to quantify the diverted waste because the reported values fall within the 95% confidence interval. The increasing trend observed from regression analysis was reconfirmed by the Mann-Kendall (MK) test with a positive MK statistic value of S = +12. The probability density function was found to be 0.91, which means the trend from the MK test is significant at a 91% level of significance. Overall, the amount of glass waste diversion was increased from 75 thousand tonnes to 138 thousand tonnes, which means that per capita waste diversion increased from 0.7 kilograms to 1.1 kilograms per year.

Table 1 summarizes the results of the statistical analysis. As described earlier, all wastes exhibited increasing trends in waste diversion. The plastic waste diversion showed the strongest increasing trend with a higher regression correlation value (r^2 = 0.90), and MK trend test statistic value (S = +26). Paper and glass waste diversion have a similar increasing trend, wherein the regression correlation values (r^2) range from 0.35 to 0.38, and MK trend test statistic value ranges from +8 to +12. All parameters showed a value of 80% or higher as their level of significance for the trends obtained from the Mann-Kendall tests (Table 1), which means that the trends of all parameters were found to be significant.

Table 1: Summary of statistical analysis

Waste Parameter	Linear regression model	r^2	S	z	$f(z)$	Trend	Level of Significance
Paper[1]	$y = 29{,}082\,x - 6 \times 10^{-7}$	0.35	+8	0.87	0.81	Increasing	81% (significant)
Glass	$y = 4{,}751\,x - 9 \times 10^{-6}$	0.38	+12	1.36	0.91	Increasing	91% (significant)
Plastics	$y = 5{,}522\,x - 1 \times 10^{-7}$	0.90	+26	3.09	0.99	Increasing	99% (significant)

Note:[1] Paper waste includes newsprint, cardboard, boxboard, and mixed paper fibres.

Figure 6 provides a comparison of waste diversions using a clustered column chart for the waste parameters. As expected, paper waste was observed to have highest diversion rate when compared to glass and plastic wastes.

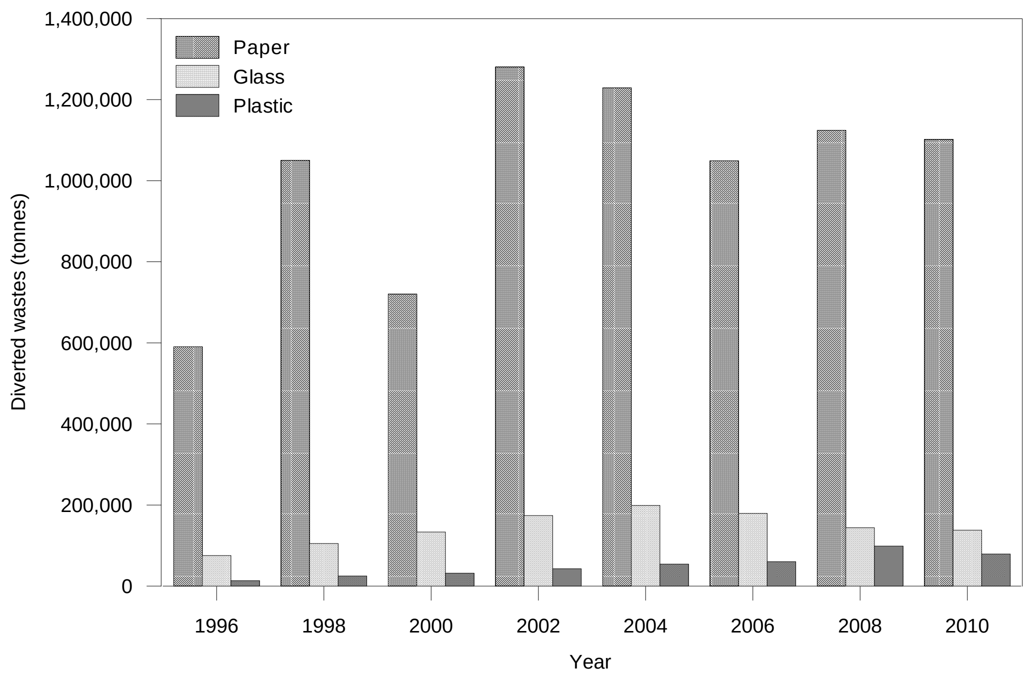

Figure 6: Comparison of waste diversions using clustered column chart

During the study period, the average amount of paper waste diversion per year (1.01 million tonnes) is about twenty times higher than plastic (143.3 thousand tonnes) waste diversion, and seven times higher than glass (50.6 thousand tonnes) waste diversion. The years 2002 and 2004 showed the highest amount (about 1.5 million tonnes) of waste diversion in total (summation of the selected waste parameters), with about a 10% increase from 1996. The per capita waste diversion for the selected three waste parameters increased from 6.3 kilograms per year in 1996 to 13.0 kilograms per year in 2002. The data suggests that the WDO diversion programs (created in 2002 through the Waste Diversion Act) may be partly responsible for the improvement of the diversion rates.

5 CONCLUSIONS

This study provides a baseline for paper, plastic, and glass recycling in Ontario, Canada. The main conclusions of this research are summarized as follows:

- The amount of total waste disposed (all types of MSW) in Ontario increased by about 33% from 6.9 million tonnes to 9.2 million tonnes. The average waste disposal per year was about 8.7 million tonnes during the period between 1996 to 2010.
- All selected waste types (paper, plastic and glass) exhibited increasing trends in waste diversion. The plastic waste diversion showed the strongest increasing trend with a higher regression correlation value (r^2 = 0.90), and MK trend test statistic value (S = +26). Paper and glass waste diversion have a similar increasing trend: the regression correlation value (r^2) ranges from 0.35 to 0.38, and the MK trend test statistic value ranges from +8 to +12.
- Paper waste was observed to have the highest diversion when compared to glass and plastic wastes. During the study period, the average amount of paper waste diversion per year (1.01 million tonnes) is about twenty times higher than plastic (143.3 thousand tonnes) waste diversion, and seven times higher than glass (50.6 thousand tonnes) waste diversion.
- The years of 2002 and 2004 showed the highest amount (about 1.5 million tonnes) of waste diversion in total (summation of the selected waste parameters). The amount of waste diversion for the selected parameters increased by 10% and per capita waste diversion increased by about 100% from 1996 to 2004.

6 ACKNOWLEDGMENTS

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