

Geography 374

Statistics in Geography

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Term Paper

The Mean Correlation Between Population and CO₂ Growth

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1.0 Introduction

In 2016, Antarctica measured a record high of 400 PPM (Parts Per Million) of Carbon Dioxide in the atmosphere, for the first time in 4 million years.¹ Most recently, in February 2017, the North Pole recorded an unusual temperature of +2°C in the midst of winter.² As the human population has grown at an exponential rate, the resultant rates of consumption and emission have followed a similar trend across the globe. Scientists have claimed that the increase in atmospheric Carbon Dioxide concentrations beyond a threshold of 450 PPM will ‘lock-in’ the effects of Climate Change, making it an irreversible problem.³

As the directly proportional relationship between atmospheric Carbon Dioxide concentration and Global Temperatures is now better understood, there has been an increase in awareness about Climate Change across the globe. While we have developed new technologies and taken numerous measures to reduce consumption and mitigate emissions, the outcome has been nominal. Coping with Climate Change is not just about reducing our ecological footprint, but also the number of feet. Hence, it is imperative to study the relationship between Population Growth and Carbon Dioxide Concentrations mathematically in order to better understand trends and predict future changes. Therefore, in keeping with Neo-Malthusian theories, understanding this correlation better would assist population control advocates in justifying the need for anti-natalist policies. In order to analyze the relationship between Human Population Growth and Carbon Dioxide Concentrations, a Correlation and Regression analysis was performed on annual measurements of each variable, from a period of 1960 to 2016.

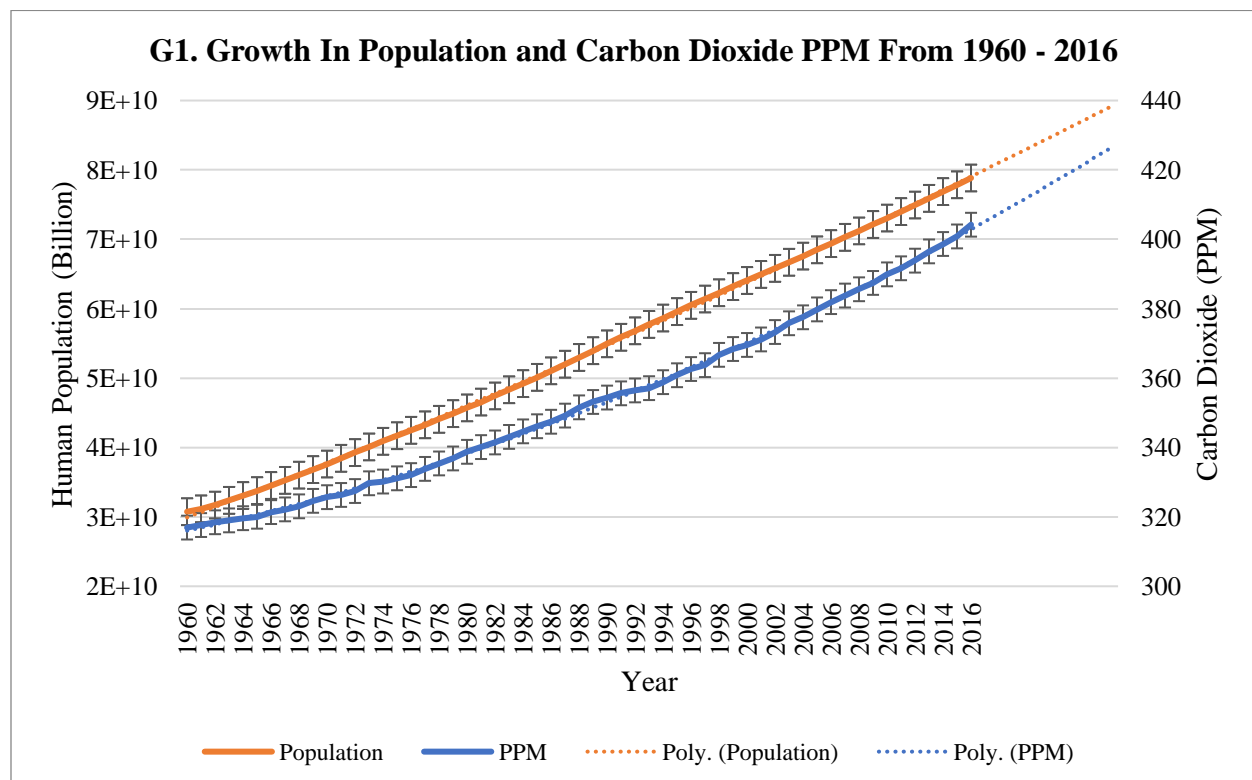
¹ Kahn, Brian. “Antarctic CO2 Hit 400 PPM For First Time in 4 Million Years.” *Climate Central*

² Samenow, Jason. “North Pole Surges above Freezing in the Dead of Winter, Stunning Scientists.” *The Washington Post*

³ Harvey, Fiona. “World Headed for Irreversible Climate Change in Five Years, IEA Warns.” *The Guardian*

2.0 Data Analysis

The Global Population Dataset⁴ was procured from the World Bank Database while the Atmospheric Carbon Dioxide Concentration Dataset⁵ was obtained from the National Oceanic and Atmospheric Administration Database. A majority of the data analysis was performed on Microsoft Excel, using the Data Analysis plug-in. Both the datasets were annual measurements and were hence trimmed to a range of 57 years, from the year 1960 to 2016. As evident from Graph 1, these were both directly proportional and grew exponentially when plotted on a time series graph. Therefore, the best statistical inferential analysis for this dataset was deemed to be a Correlation Regression Analysis. The Human Population was determined to be the independent variable as it is what dictates the variation in the resultant CO₂ emissions.



⁴ "Historic World Population Total." *The World Bank*

⁵ "ESRL Global Monitoring Division - Global Greenhouse Gas Reference Network - ESRL Co2 Trends RSS" NOAA

Hence, the hypotheses for this analysis were:

$H_0: \rho = 0$ - There is no correlation between *Population Growth* and *CO₂ Concentrations*.

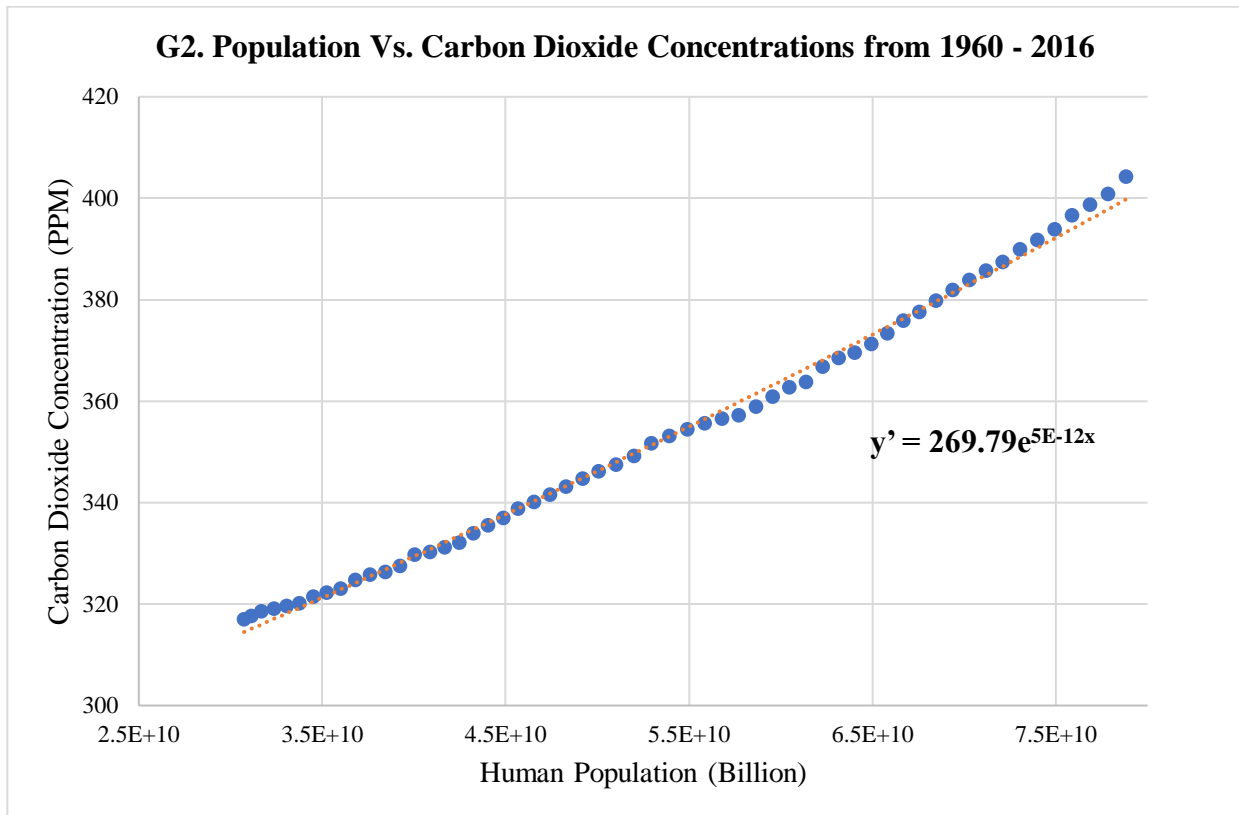
$H_1: \rho \neq 0$ - There is significant correlation between *Population Growth* and *CO₂ Concentrations*.

Before performing any mathematical computations, the data was first plotted on a scatter plot; looking at the highly significant relationship, it was deemed that a regression analysis could be performed. First, the Pearson's Correlation Co-efficient was computed to validate the visually determined significance mathematically. Next, keeping in mind that this was a two-tailed test, a Significance of Correlation Coefficient Test was performed to determine whether the relationship between the two variables was actual correlation or just coincidence.

The Residual Plot yielded a pattern that was non-random with a u-shaped curve. Hence, several transformations were applied in order to normalize it. However, with no change in the plot, it was concluded that a non-linear model was most appropriate for the given dataset. Finally, the Equation of the Line of Best Fit was derived in order to understand the trend and allow for future predictions. To determine how well it approximated the relationship, the Co-efficient of Determination, r^2 was calculated as well.

3.0 Results

The results of the Correlation and Regression analysis were as anticipated. Graph 2, is a scatter plot with the independent variable, Human Population on the x-axis and the dependent variable, Carbon Dioxide Concentration on the y-axis. Visually, it appears to be a Strong Positive Linear Correlation.



3.1 Pearson's Correlation Coefficient

With statistical computation, a r -value (Pearson's Correlation Coefficient) of 0.996 was calculated, suggesting a Strong Positive Linear Correlation. Given that $\rho \neq 0$, the null hypothesis was rejected. Hence, there was enough evidence to assume a strong correlation between Human Population Growth and increasing Carbon Dioxide Concentrations in the atmosphere.

3.2 Significance of r Test

Next, a Significance of r Test was performed to conclude whether there was an actual significant correlation between the variables, or whether the value of r was due to coincidence. As this was a two-tailed test, the Table I⁶ method was used with an Alpha Level (α) of 0.01 and a r -value of 0.996. Next, the Degrees of Freedom were determined to be 55 ($n-2$ i.e. $57-2$). Finally, using Table I, a Critical Value of ± 0.339 was calculated. Hence, because $r > C.V.$, i.e. $+0.996 > +0.339$, the decision to reject the null hypothesis was validated, confirming a significant relationship of correlation between the two variables.

3.3 Line of Regression and Approximation

As the value of the correlation coefficient was significant, the next step was to determine an equation for the Regression Line. The equation derived was $y' = 269.79e^{5E-12x}$ - It was a non-linear, exponential relationship. The Coefficient of Determination r^2 was 0.992, meaning the regression line approximated the data points really well mathematically.

3.4 Residual Plot

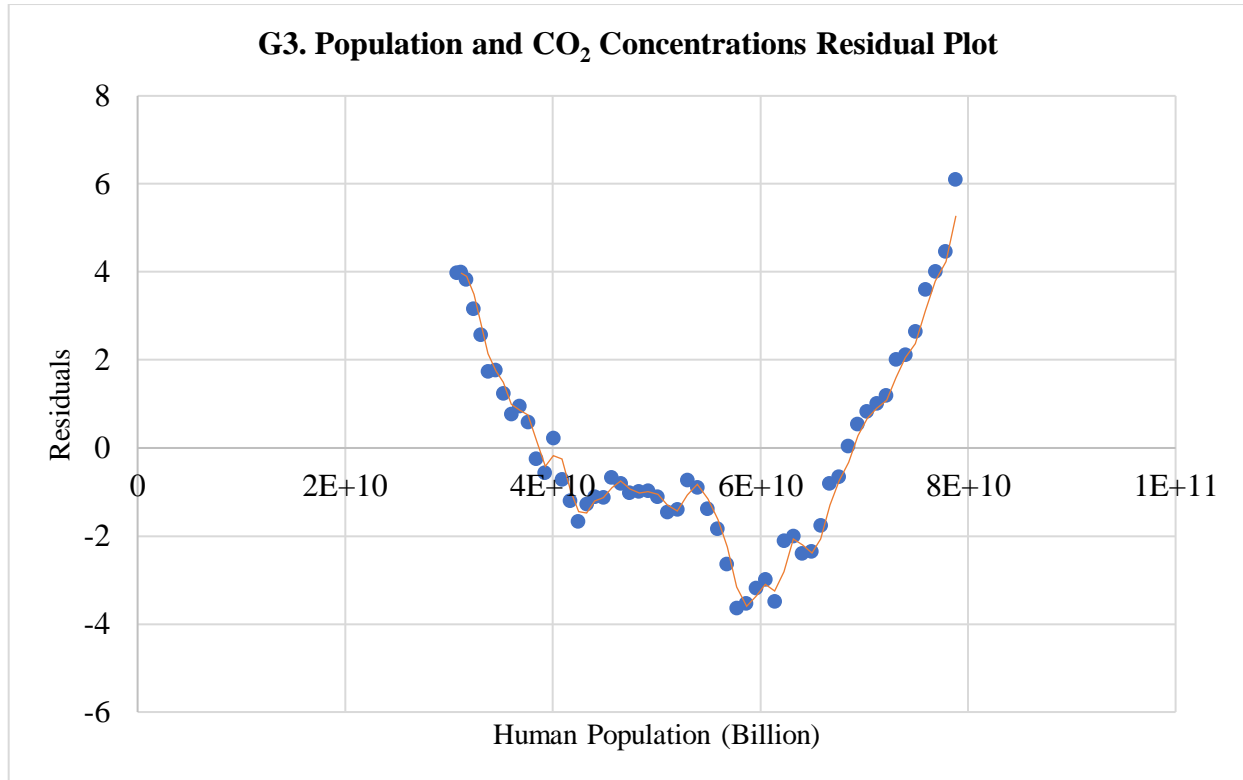
Residuals describe the difference between the actual y value and the predicted value y' based on the line of best fit it plots. Hence, the smaller the variation in a residual plot, the greater the accuracy in prediction by the equation of regression⁷. Graph 3 is the residual plot for this dataset. As evident from the graph, the plot followed a very unusual pattern. In order to normalize it several transformations such as using reciprocals, logging, and square rooting were applied to the dataset.⁸

⁶ Bluman. *Elementary Statistics: A Brief Version*. 7th ed. Appendix A

⁷ "Residual Plot: Definition." *Stat Trek*

⁸ "Data Transformations." *Fmwww.bc.edu*

However, the residual plot remained the same and hence it was concluded that a non-linear model was most appropriate for the given dataset.



3.4 Trends

This statistical analysis, made evident the correlated and directly proportional relationship between the exponentially growing Human Population and the resultant Carbon Dioxide Concentrations in the atmosphere.

4.0 Discussion

It is mathematically known that the human population has grown exponentially.⁹ Hence, with an increase in number of people, their needs and impact on the planet have increased at an exponential rate as well. This explains why the Equation of Regression was exponential. The non-linear residual plot only further confirmed that the equation of regression $y' = 269.79e^{5E-12x}$, was a reliable estimation.

In accordance with the growth curve $y' = 269.79e^{5E-12x}$ the y-intercept, 269.79 PPM is the initial value given the value of $x = 0$. Interestingly enough, the actual amount of CO₂ in the atmosphere before the Industrial Revolution was around 280 PPM¹⁰ (Image 1) while the human population in the 1800's was close to a billion¹¹, meaning the equation is a truthful approximation.

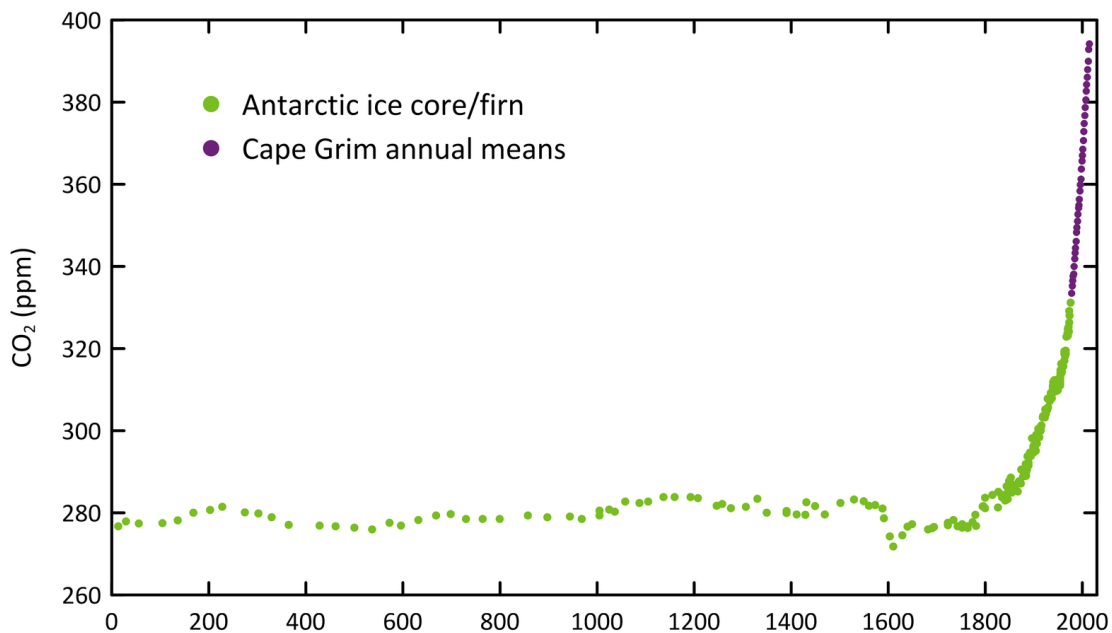


Image 1. Historic Carbon Dioxide Concentrations in the Atmosphere¹²

⁹ Vandermeer, John. "How Populations Grow: The Exponential and Logistic Equations." *Nature News*

¹⁰ "ESRL Global Monitoring Division News Items." *NOAA Earth System Research Laboratory*

¹¹ "World Population to Hit Milestone With Birth of 7 Billionth Person." *PBS*

¹² CSIRO. "Ice Measurements Show the Rise of CO₂ since 1800 - A New Peak for Carbon Dioxide Levels" *World Economic Forum*

However, in keeping with theories of Limits to Growth, *“Exponential growth models of physical phenomena only apply within limited regions, as unbounded growth is not physically realistic. Although growth may initially be exponential, the modelled phenomena will eventually enter a region in which previously ignored negative feedback factors become significant or other underlying assumptions of the exponential growth model, such as continuity or instantaneous feedback, break down”*.¹³ Meaning, that with respect to the Earth’s Carrying Capacity, a(n) (un)natural limiting factor will eventually alter this trend of growth. Widely known as the Malthusian Catastrophe Theory, the anticipated Limit to Growth will ensure, *“a forced return to subsistence level conditions once population growth has outpaced agricultural production”*.¹⁴ Implying that the ‘Earth’s inability to serve’ the exponentially growing population’s exponentially growing demands, will eventually limit population size and hence change the growth model. In the meantime, in spite of how well science has understood this current relationship, there still is a negligible possibility for the existence of a lurking variable; which a further study should to attempt identify. However, it would be nearly impossible to identify it given the interconnectedness and complexity of today’s world systems.

Hence, from this analysis, it can be concluded that there currently exists a direct cause-and-effect relationship between the variables. Implying that an increase in Human Population leads to an increase in the Carbon Dioxide emissions and therefore it’s atmospheric concentrations. Meaning that the proposition that humans have exploited the planet to cater to their needs, creating an ecological imbalance with irreversible damage, stands true. Ironically enough, for an enduring existence of humanity, we are in urgent need of population control measures.

¹³ “Exponential Growth.” *Wikipedia*

¹⁴ “Malthusian Catastrophe.” *Wikipedia*

5.0 Works Cited

- Bluman. *Elementary Statistics: A Brief Version*. 7th ed.
- CSIRO. "Ice Measurements Show the Rise of CO₂ since 1800 - A New Peak for Carbon Dioxide Levels" World Economic Forum, 2015, <https://www.weforum.org/agenda/2015/03/a-new-peak-for-carbon-dioxide-levels/>.
- "Data Transformations." *Fmwww.bc.edu*, 2017, fmwww.bc.edu/repec/bocode/t/transint.html.
- "ESRL Global Monitoring Division - Global Greenhouse Gas Reference Network." *ESRL Co₂ Trends RSS*, NOAA, 2017, www.esrl.noaa.gov/gmd/ccgg/trends/data.html.
- "ESRL Global Monitoring Division News Items." *NOAA Earth System Research Laboratory*, 1 Oct. 2005, www.esrl.noaa.gov/gmd/news/7074.html.
- "Exponential Growth." *Wikipedia*, Wikimedia Foundation, 31 Mar. 2018, en.wikipedia.org/wiki/Exponential_growth.
- Harvey, Fiona. "World Headed for Irreversible Climate Change in Five Years, IEA Warns." *The Guardian*, Guardian News and Media, 9 Nov. 2011, www.theguardian.com/environment/2011/nov/09/fossil-fuel-infrastructure-climate-change.
- "Historic World Population Total." *The World Bank*, 2017, data.worldbank.org/indicator/SP.POP.TOTL.
- Kahn, Brian. "Antarctic CO₂ Hit 400 PPM For First Time in 4 Million Years." *Climate Central*, 15 June 2016, www.climatecentral.org/news/antarctica-co2-400-ppm-million-years-20451.
- "Malthusian Catastrophe." *Wikipedia*, Wikimedia Foundation, 31 Mar. 2018, en.wikipedia.org/wiki/Malthusian_catastrophe.
- "Residual Plot: Definition." *Stat Trek*, 2018, stattrek.com/statistics/dictionary.aspx?definition=residual_plot.
- Samenow, Jason. "North Pole Surges above Freezing in the Dead of Winter, Stunning Scientists." *The Washington Post*, WP Company, 26 Feb. 2018, www.washingtonpost.com/news/capital-weather-gang/wp/2018/02/26/north-pole-surges-above-freezing-in-the-dead-of-winter-stunning-scientists/?utm_term=.3cdb5c2b1d2c.
- Vandermeer, John. "How Populations Grow: The Exponential and Logistic Equations." *Nature News*, Nature Publishing Group, 2010, www.nature.com/scitable/knowledge/library/how-populations-grow-the-exponential-and-logistic-13240157.
- "World Population to Hit Milestone With Birth of 7 Billionth Person." *PBS*, Public Broadcasting Service, 27 Oct. 2011, www.pbs.org/newshour/show/world-population-to-hit-milestone-with-birth-of-7-billionth-person.