Global Population Trends and Projections

Devki Desai, Paul Mello, Priyanka Moorthy, and Vamsi Chalamolu

San Jose State Univeristy

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Abstract

The census has been the most crucial form of data collection for all of human history dating back as far as the Babylonians who used it to determine how much food they needed to survive. Today this data extends to demographics, geopolitical influence, and understanding the unnatural phenomenon that is climate change. Through exploration of the World Bank's census data we intend to develop a better understanding of the patterns and trends present in human life in an attempt to demonstrate relationships between countries and continents while also building models to offer predictions on future populations. We find that our regression models tend to predict future populations with statistically significant accuracy while classification by continent proves to be far trickier.

1 Introduction

Population studies are the most ancient methods of examining a populations' size, structure, and development over time. Researchers have applied statistical examinations on this type of data to explore mortality, fertility, and their associative factors such as poverty, employment, culture, migration, and religion. This often results in sweeping changes and action by giving people an understanding of where the modern population is trending towards. Many factors play an important role in developing these projections and predictions including climate change, health services, education, and future well-being. Having this information can better equip governments and individuals to prepare for the future.

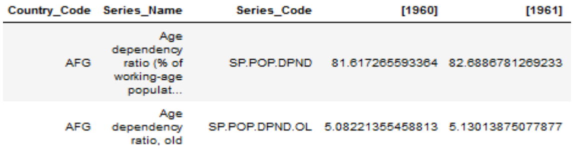
The World Bank collects and interprets census data in a way that allows them to extrapolate and make predictions based on trends over the past 80 years. These predictions are often accurate outside of sudden or unseen global changes. The data set we will be using is broken down into many pieces consisting of continent information, country information, and time intervals. A group columns which act as series names describes what the remaining data in row contains, and many more columns with data from 1960 - 2050 which contain the numeric observations collected.

The focus of this paper aims to use the World Bank's population estimation data to comprehend global population trends by analyzing the data in unique and interesting ways, while also devising and developing models which can aid in furthering our understanding. We incorporated regression and classification based algorithms into our analysis in order to develop models which provided an additional complexity of knowledge. This will be coupled with supplementary analysis, such as principal component analysis, in an attempt to extract any important years which may have altered the course of history within the past few decades. We hope that through our exploration we will see interesting patterns emerge, be able to make our own predictions and classifications, and shed some light on why these trends are occurring.

2 Methods

The World Bank provides an easy and accessible way to download historic, current, and future data projections directly from their main website. The data we worked with is broken down into three distinct categories consisting of Country, Series, and Time. The country section contains a list of all recognized countries on the planet as well as continental, age, and economic based data that is pooled together. The series section contains a list of all the relevant data information that can be extracted from each of the individual countries. Finally, the time section contains a yearly interval from 1960-2050. For our purposes we elected to download all the data available; However due to limitations in their servers, we were only able to download a grand total of 2.5 million cells for our analysis. As a result we downloaded every country and time, but chose to remove percentage based data from the series section as that could be derived from the totals if needed.

The data we downloaded is laid out in the following manner. The first few columns consist of continents and country identification. Following these are a series of descriptions which elaborate on what the remaining observations in the row entail. These series consist of a variety of data points from age dependency, to net migration, and population totals. Each country contains an ordered list of 90 of these series types which are followed by ground truth data from 1960-2020 and predicted observations from 2021-2050. The following figure demonstrates a small subsection of Afghanistan's data with many additional columns hidden after 1961.



Country_Code	Series_Name	Series_Code	[1960]	[1961]
AFG	Age dependency ratio (% of working-age populat...	SP.POP.DPND	81.617265593364	82.6886781269233
AFG	Age dependency ratio, old	SP.POP.DPND.OL	5.08221355458813	5.13013875077877

Figure 1: Inital Data

As there are many series and many countries, it is imperative to mention that low income and war torn countries often have significantly more missing data. As a result, there may be a bias in some of our models, depending on the data series we are working with, which appear to favor higher income and stable countries.

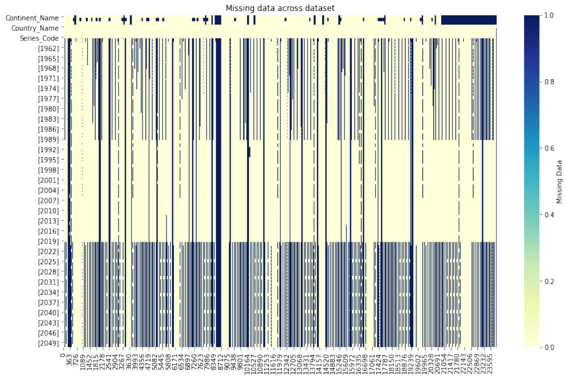


Figure 2: Missing Data

Our methods for analysis have been divided into many different components. Our first action was to collect and preprocess the data. Missing data was handled on a case by case basis where the missing observations may be pruned or cleaned as necessary. Following this preprocessing we subdivided the data into the appropriate data frames which will allow access to specific series, such as total population by country. Through this subdivision, visualization of the data was easily accessible. Below we can see a heat map of the world, which demonstrates current population totals of the most recent year.

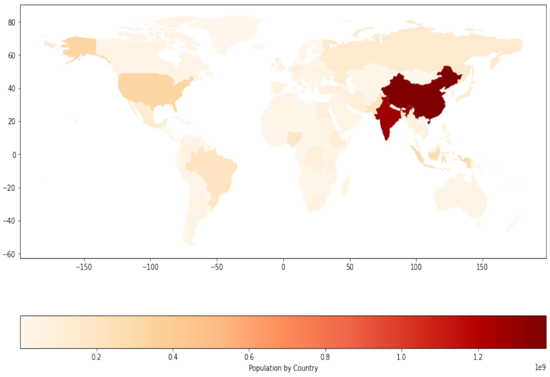


Figure 3: Heat Map of World Population Today

Once this visualization was completed we began conducting our methods of analysis to make predictions, categorize, and show relationships within the data. The two most notable methods we used consisted of regression and classification. Other methods such as clustering have been performed as well. Each of these methods were used to interpret and understand if there were any underlying patterns inherent in the data we could not easily identify. Regression consists of an analysis which can help estimate relationships between dependent variables and one or more independent variables. This can help us model the trends within our data and make predictions about where a population is moving towards in the next few years. Classification is consistent with creating an understanding of relationships between groups by identifying and assigning categories to some dependent data. Both of these methods of analysis have provided key insights into making comparisons about the nature of the relationships between countries, not only by continent, but by global comparison as well.

Once these methods of analysis were compiled and completed we needed to create adequacy checks to demonstrate the accuracy of these respective models. We were able to create interesting plots which demonstrated our findings and our models. One method of analysis called principal component analysis (PCA) allowed us to see far deeper into the data than we previously could. PCA refers to reducing the dimensionality of a data set while retaining as much information about the data as possible. This is incredibly useful for our purposes because it allowed us to condense country and continent data down to a more manageable size. Additionally, the process paved the way for interpreting what years are contributing to our data's variation the most. This is an important step as it helped develop an understanding regarding important years containing big shifts in the global populations trends.

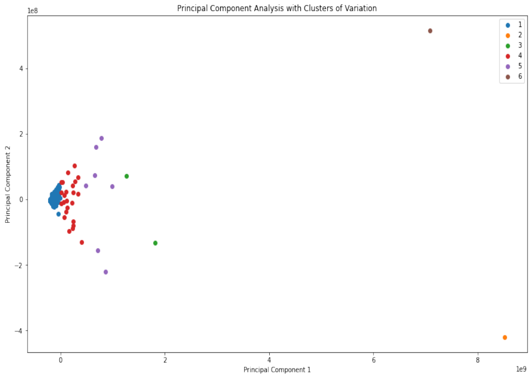


Figure 4: Conducting PCA on Population Totals

Here we demonstrate PCA by reducing our population totals data from 1960-2020 into a single two dimensional plot with their associated K-Means clusters as determined by our model. K-Means clustering is a method where we can partition the data into multiple categories based on their distance from a centroid which is iteratively updated until all data points are accounted for. We can see that most of the data is clustered into a tight spread which fans out with a few outliers forcing their own clusters. This provides a wealth of information as we can see how our population trends appear to be mostly the same. Continuing through this line of analysis into the apparent outliers, we were able to narrow them down to two specific countries, China and India. These countries have seen an immense population growth over the past century.

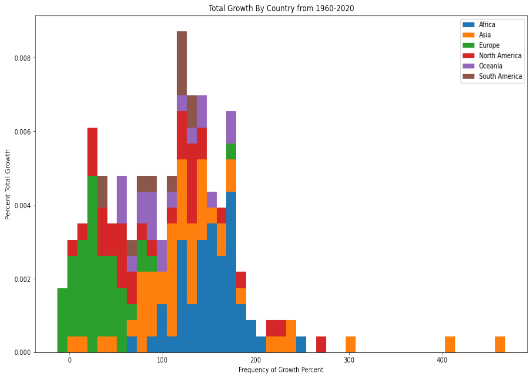


Figure 5: Continental Frequency Growth by Country

As demonstrated above these two countries have seen an explosion of growth likely due to their sudden and rapid economic expansion. In addition to this information we saw that, in nearly every clustering attempt, the data was best sectioned off into six distinct parts which mimics continent quantities. Further data mining demonstrated this to be a coincidence rather than a correlation.

Another method of analysis we conducted was regression. Regression can provide us with a way to model and predict future population trends. The following graph is an example of one of our regression models

REGRESSION MODEL GRAPH INCORPORATION

TALK ABOUT WHAT WAS DONE TO MAKE IT LIKE THAT SUCH AS DESCRIBING WHAT WE SEE AND WHY ITS INTERESTING

Due to the nature of this data set and our proposed work we expected to run into many different limitations and challenges. We handled combining, separating, and cleaning these individually created data frames, but due to the importance of the census data not much needed to be done to pre-process and prepare the data. Most of the effort and challenges came from developing the proper data frames and have a thorough understanding of what section of the data was relevant for our work. We did not run into many challenges in our modeling either because each data series we selected had a significant majority of data present.

Our parameters were hyper-dependent on what series we desired to extract and our goals for prediction or classification. These series included population totals, net migration, life expectancy, and deaths under 5 years old. For nearly every series we used, our data consisted of each observation from 1960-2020, and then depending on specific analysis goals we would add 2021-2050 as projected data. Having projected data was pivotal in being able to test our models. The strength of these parameters are apparent in that they provide consistent and unflinching data regarding population trends on a country by country basis. If a country has some data, they are overwhelmingly likely to have all the data necessary. However, the opposite can be stated as well such that, any country which tends to have missing data often has a significant portion of data missing.

Additionally, our approach to the data is most likely flawed due to the complex nature of populations. Much of the initial planning we developed had to be adjusted or removed as we noticed we could not accurately or statistically prove that our assumptions about the data were correct. One example of this short coming was a lack of data for North America, simply put there are few countries in North America and thus few opportunities to train and classify the data properly. If we were to conduct this analysis again we would likely attempt to incorporate many more training styles such as K-Fold cross validation. K-Fold cross validation is a method to iterate over training and testing sets by partitioning the data into multiple different sets. This allows for additional accuracy because of an increase in training data.

Finally, we conducted analysis and interpreted the results of our methods in a fashion that provided a clear and concise summary of our findings. We will cover this experimentation, analysis, and its interpretations in the following section.

3 Experiments & Analysis

In developing our experiments and analysis there were many models and visualizations that offered key and interesting insight about the series it described. A few of these highlights can be found in the appendix section of this paper. These figures visualize and represent a broader range of modeling and help interpret our population data. However, for now in this section we will specifically highlight two examples which excited us.

Through our initial exploration of the data we discovered interesting trends around population totals. We found that, on average, western continents appear to have significantly less population growth within the past century, by in one case approximately 5x. The following graphic demonstrates this sheer difference in growth.

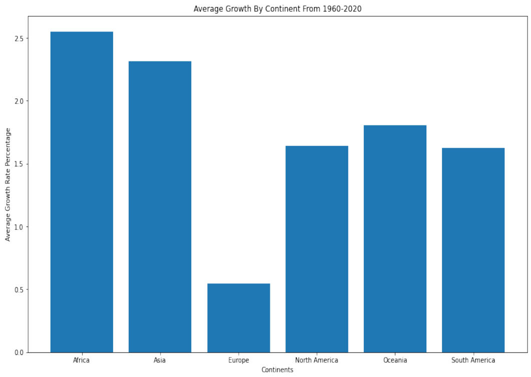


Figure 6: Growth Totals by Continent

As a result of this visual we elected to dive deeper into potential reasons for this discrepancy and found many potential justifications. According to the National Institute of Health, there are many factors which are contributing to these declines in western countries[1]. They cite increasing access to contraceptives, a rise in female education, and soaring housing prices as key factors to the decreasing growth rate and thus decreasing population. They expand on this by explaining that unlike Europe, the Americas and Oceania have largely been unaffected due to a lack of time passing. Once generational equilibriums standardize we expect to see a gradual decline. For example, the Americas have not seen this slowdown in growth like Europe has, due, in large part, to most couples of child bearing age choosing to wait later in their life for economic stability before having kids. This process will repeat over a few more generations and inevitably result in the Americas of tomorrow appearing as modern Europe, in regards to growth trends.

Further research and analysis of this declining trend in fertility rates have been forecasted by the Lancet Project. They have demonstrated that by the year 2100 fertility rates will decrease from an average of 2.30 to 1.66[2]. Resulting in one of the lowest global growth rates in modern human history. Specifically, we will see that some western countries, especially those in Europe, may see a 50 percent decline in their population totals[2]. Despite this drastic decline The United States will continue to gradually increase in population over the next century. From this new found understanding we began exploring other sections of the data in an attempt to pin down if there were any relevant factors contributing to this increase despite growth rates decreasing.

Through further data manipulation and visualization we came across an interesting statistic regarding net migration by continent. It seems that, due to economic prosperity in the west, migrants are moving in disproportionate numbers from Asia to Europe and North America.

Images/NET MIGRATION.png

Figure 7: Net Migration by Continent

On a yearly basis this difference alone does not make for a huge impact. However, overtime these migration trends can make a significant mark on the population at large. We suspect that the growing number of immigrants coming to western countries may result in a sizeable increase in population. We believe that the demographic of those making such a trip are primarily young and able bodied workers. Looking at global news reports regarding migrants on the borders of European countries only furthers this notion and demonstrates its relevance.

Evidence suggests that as global population continues to increase these migration patterns will persist[2]. The defining question then becomes if or when will the population decrease. Through population trend visualization we noticed a gradual but evident decrease in the total population year after year. Meaning there maybe an inflection point where the population will begin to decrease as a direct result of declining growth rates.

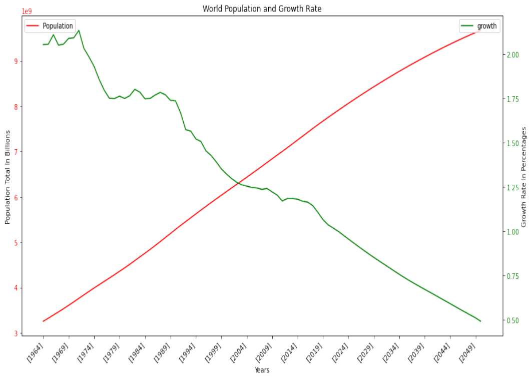


Figure 8: Population Growth Rates and Totals

This graph demonstrates two important notions about the global population. It must be noted that any data past 2020 is simply the projected data based on estimations. Firstly, average world growth rates are projected to fall below the crucial level of "replacement births" around 2020. This means that less kids will be raised when compared to fertile adults. Secondly, population totals will begin to gradually slow down around the start of the 2030's. Consequently, we can extrapolate that within a few decades after 2050 we will likely see an inflection point the population will begin to decline.

This is only exacerbated when we consider the increasing life expectancy of humanity. As we can see below, the average life time has increased from the early 1960s significantly.

This means we expect to see an aging population that refuses to die, lower birth rates, and an increase from modern population totals. A grim reality, but one we can prepare for today thanks to these estimated projections.

Images/LIFE EXPECTANCY TOTALS.png

Figure 9: Average Life Expectancy by Year

4 Comparisons

5 Conclusions

Population trends continue to increase on both a continental and global scale. We suspect that the global population is likely to peak somewhere around the middle of the century before a rapid decline due to low fertility and growth rates. We have analyzed a significant amount data and created relevant visualizations which demonstrate these defining features to be unavoidable in our near future. As a result, we can confidently say we have shed some light on the data and its subsequent meaning. While we were successful in developing statistically significant models to predict future population trends by continent we can not be certain our analysis is accurate given the scope of this paper. We hope that countries will take these trends seriously as they prepare for the near future; Not only for the sake of their own people, but for the common welfare of our planet.

References

[1] G. Nargund. Declining birth rate in developed countries: A radical policy re-think is required. *Facts, Views, Vision in OBGyn*, 2009.

[2] Prof Stein Emil Vollset, Emily Goren, Chun-Wei Yuan, Jackie Cao, Amanda E Smith, and Thomas Hsiao. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the global burden of disease study. *The Lancet*, 396(10258), July 2020.

World Bank Data:
https://databank.worldbank.org/reports.aspx?source=Health%20Nutrition%

20and%20Population%20Statistics%3A%20Population%20estimates%20and%20projections#

World Bank Data Description:
https://data.worldbank.org/indicator/

National Institute of Health:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4255510/

The Lancet Project:
https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30677-2/fulltext

Our Repository:
https://github.com/devkisdesai/CMPE255-Team-6-Project-Fall-2021-