Global Demographic Analysis and Population Visualization – Case Study

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1. Introduction

This case study focuses on analyzing global demographic patterns using a publicly available dataset from the United Nations Population Division [?]. The study examines population growth, fertility, mortality, life expectancy, migration, and age distribution across countries and regions. The objective is to generate informative visualizations and derive insights that can guide policy-making and demographic planning.

2. Problem Statement

Countries around the world experience diverse demographic trends. Some face rapid population growth, straining resources and infrastructure, while others experience stagnation or decline, often with an aging population. Fertility rates, mortality, and migration patterns are the key factors influencing these trends. The main questions are:

- Which countries are growing fastest, and which are declining?
- How do fertility, mortality, and migration affect population growth?
- Are there correlations between development level, employment, and demographic trends?
- What patterns exist in age distribution and gender balance across regions?

3. Objectives

The objectives of this case study are:

- Identify population trends across countries and regions.
- Examine drivers of population change: birth rates, death rates, and migration.
- Highlight demographic patterns such as median age, life expectancy, and sex ratios.
- Understand the potential reasons for trends in population growth or decline.
- Provide a foundation for future predictive analysis and visualization.

4. Scope and Background of Dataset

This study covers:

- All countries and regions globally, using the UN World Population Prospects dataset[1].
- Demographic indicators such as total population, fertility, mortality, life expectancy, migration, and age/sex distribution.
- Time-based comparisons focusing on population changes over recent years.

5. Visualizations

5.1. Figure 1: Total Fertility Rate by Country

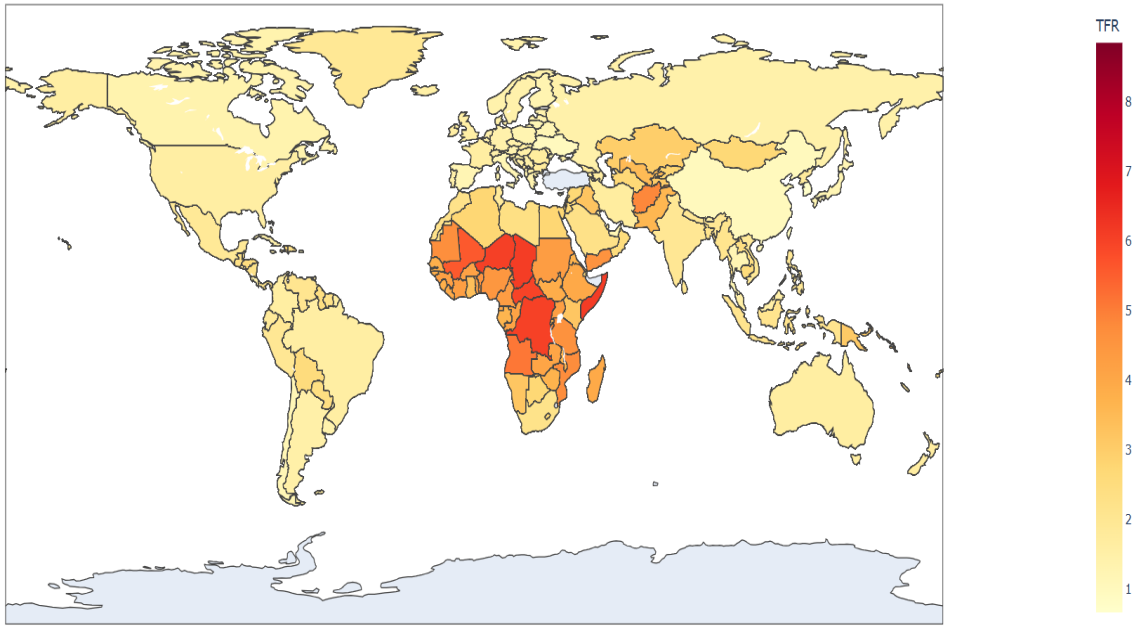

Fig. 1: Choropleth map showing Total Fertility Rate (TFR) across countries.

The choropleth map of Total Fertility Rate clearly shows strong regional contrasts in global fertility patterns.

Top 10 Highest TFR Countries:

- Somalia – TFR: 6.13
- Chad – TFR: 6.12
- Niger – TFR: 6.06
- Democratic Republic of the Congo – TFR: 6.05
- Central African Republic – TFR: 6.01
- Mali – TFR: 5.61
- Middle Africa – TFR: 5.51
- Angola – TFR: 5.12
- Burundi – TFR: 4.88
- Afghanistan – TFR: 4.84

Top 10 Lowest TFR Countries:

- China, Macao SAR – TFR: 0.66
- China, Hong Kong SAR – TFR: 0.72
- Republic of Korea – TFR: 0.72
- Saint Barthélemy – TFR: 0.8
- China, Taiwan Province of China – TFR: 0.87
- Singapore – TFR: 0.94
- Puerto Rico – TFR: 0.94
- Ukraine – TFR: 0.98
- Holy See – TFR: 1.0
- China – TFR: 1.0

The choropleth map of Total Fertility Rate clearly shows strong regional contrasts in global fertility patterns. The highest TFR values appear across Sub-Saharan Africa, where countries like Niger, Chad, Somalia, and the Democratic Republic of Congo show deep orange-red shading, indicating fertility levels above five children per woman. These high rates are linked to limited access to family planning, younger maternal age, higher child dependency, and cultural norms favoring larger families. In contrast, most of Europe, East Asia, North America, and Australia exhibit very low fertility, typically between 1 and 2 children per woman. These lower levels align with delayed marriage, higher education and workforce participation among women, and the rising cost of raising children. Middle fertility regions, including parts of South Asia, the Middle East, and North Africa, fall between these extremes and represent societies transitioning from high to moderate fertility. The hover information reinforces these patterns, showing that high fertility countries have higher crude birth rates and younger childbearing ages, while lowfertility regions exhibit the opposite. Overall, the map highlights the uneven pace of demographic transition worldwide and the contrasting population pressures different regions face.

5.2. Figure 2: Global Net Migration Analysis (1950–2023)

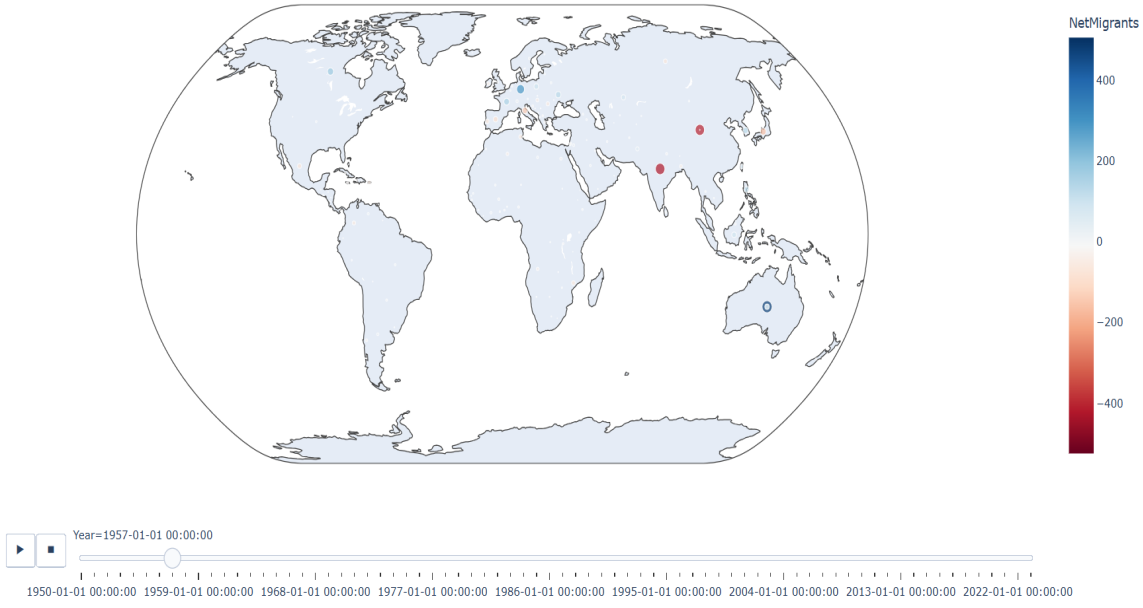

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Fig. 2: Scatter map showing global net migration inflows (positive) and outflows (negative) by country and region. Marker size represents migration intensity, color indicates direction.

This analysis examines global net migration trends, highlighting countries and regions with the highest inflows and outflows of people. The size of markers represents migration intensity, while color indicates direction: positive values for immigration and negative for emigration. Temporal trends reveal how migration patterns have shifted over time. High-income regions such as the United States, Germany, Australia, Canada, and Western Europe consistently attract the most immigrants, with top regions including High-income countries, More developed regions, and Europe/Northern America/Australia/New Zealand. These areas benefit from economic opportunities, political stability, and social infrastructure. At the country level, the USA, Germany, and Australia/New Zealand lead in total net immigration. In contrast, emigration is highest from lower-income or less developed regions. The top emigration regions include Low-and-middle-income countries, Middle-income countries,

and Less developed regions, while countries like Syria, Venezuela, and various lower-middle-income countries contribute most to population outflows. Migration from these regions is often driven by conflict, economic instability, or lack of opportunities. Yearly trends show fluctuations, with spikes in emigration during crises or geopolitical events, such as in 1994, 2007, 2015, and 2022. Europe, Northern America, and Australia/New Zealand remain major immigration hubs, whereas Africa, South Asia, and Latin America generally experience net population loss. Overall, global migration reflects a combination of economic, political, and humanitarian factors. Highincome regions gain population through immigration, while lower-income countries experience outflows, shaping global demographic patterns. The top 15 regions and countries clearly highlight where migration pressures are most significant, providing insight into global population movements over the past seven decades.

5.3. Figure 3: Crude Birth Rate, TFR, and Mean Age at Childbearing Scatter Plot Matrix

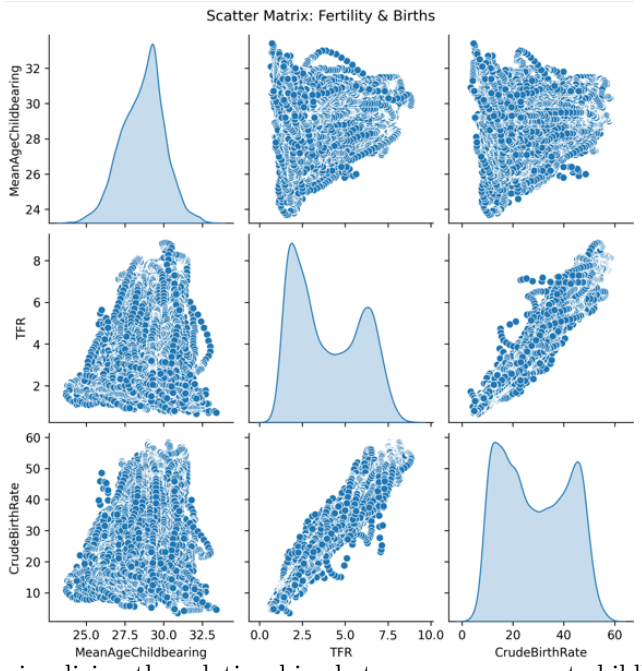

Fig. 3: Scatter matrix visualizing the relationships between mean age at childbearing, total fertility rate (TFR), and crude birth rate. Diagonal plots show kernel density estimates of individual variables, while off-diagonal plots show pairwise correlations.

This scatter matrix visualizes the relationships between mean age at childbearing, total fertility rate, and crude birth rate. Each plot shows pairwise correlations, while the diagonal displays kernel density estimates to illustrate the distribution of individual variables. This allows identifying trends, patterns, and potential outliers across countries.

The plots indicate a negative correlation between mean age at childbearing and fertility rates: countries where women have children later tend to have lower TFR and crude birth rates. Conversely, regions with younger average maternal age typically show higher fertility and birth rates. The strong correlation between TFR and crude birth rate reflects that higher fertility directly increases the number of births relative to the population.

Overall, the scatter matrix highlights that maternal age is a key factor in fertility patterns, while fertility and crude birth rates are closely linked. This visualization provides a clear overview of demographic trends and helps identify countries with unusual reproductive patterns.

5.4. Figure 4: Cluster Correlation Matrix

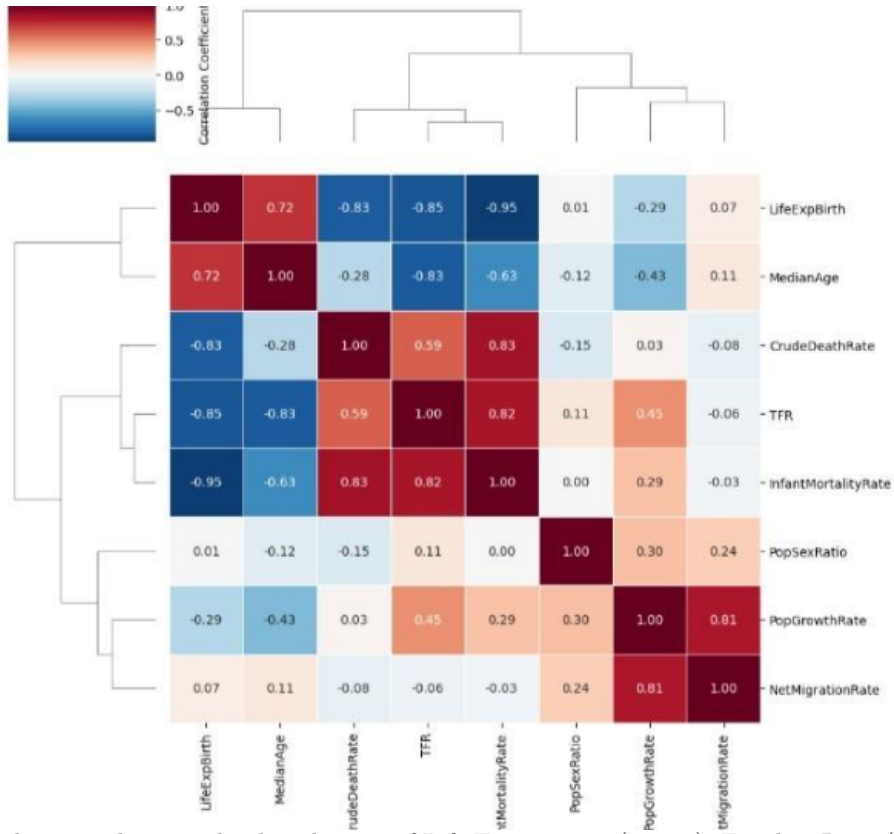

Fig. 4: 3D visualization showing the distribution of Life Expectancy (y-axis), Fertility Rate (x-axis), and Population (z-axis) and their relationships.

It can be observed that population is highest in regions where fertility rates are moderate and life expectancy is high. Very low or very high fertility tends to correspond with smaller populations. High life expectancy alone isn't enough; it's the balance with fertility that creates population peaks. Real country points show that most nations cluster near these optimal conditions. The visualization highlights clear demographic spots where both factors align.

- Aging-Demography Cluster: Median age shows strong negative correlation with fertility rate (-0.85) and infant mortality rate (-0.95), indicating that older populations correspond with lower birth rates and better child survival outcomes.
- Fertility-Mortality Link: Total Fertility Rate (TFR) and infant mortality rate show moderate positive correlation (0.62), suggesting higher fertility often coexists with higher infant mortality.
- Growth Dynamics: Population growth rate correlates positively with net migration rate (0.81), highlighting migration's significant role in population changes.
- Demographic Transition Pattern: The strong negative correlation between median age and infant mortality (-0.95) exemplifies classic demographic transition theory, where aging societies achieve better child survival rates.
- Independent Factors: Population sex ratio shows weak correlations with other indicators, suggesting it operates relatively independently in demographic systems.

5.5. Figure 5: Demographic Landscape 2023

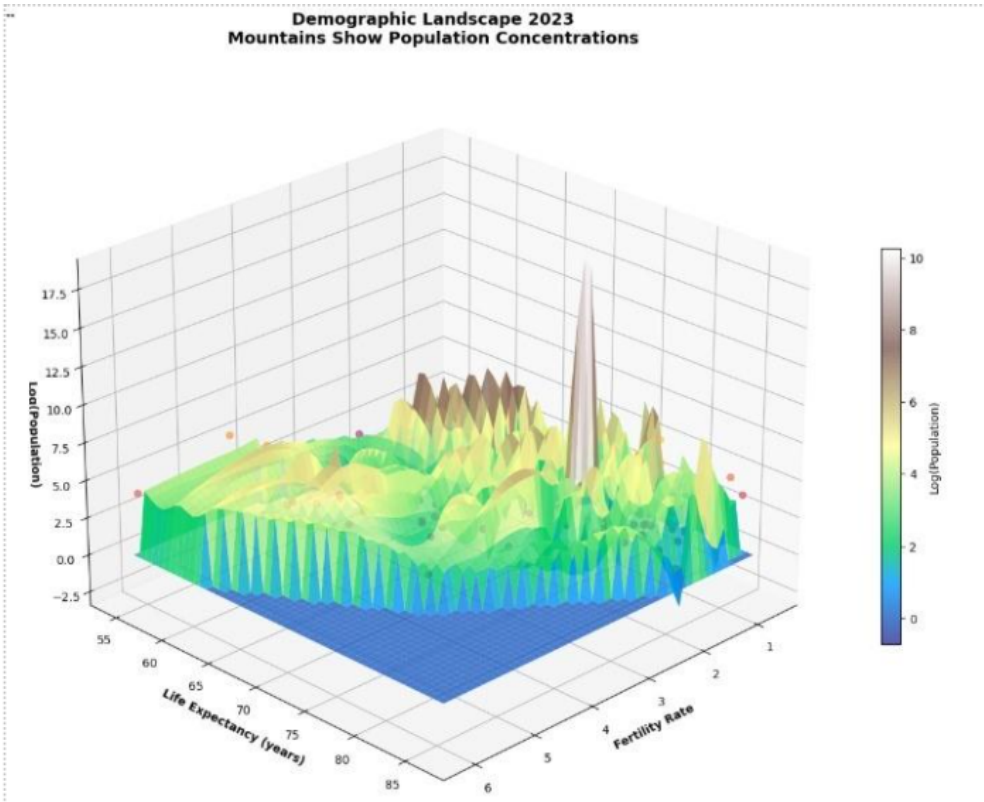

Fig. 5: 3D visualization showing the distribution of Life Expectancy (y-axis), Fertility Rate (x-axis), and Population (z-axis) for 2023.

Insights: It can be observed that population is highest in regions where fertility rates are moderate and life expectancy is high. Very low or very high fertility tends to correspond with smaller populations. High life expectancy alone isn't enough; it's the balance with fertility that creates population peaks. Real country points show that most nations cluster near these optimal conditions. The visualization highlights clear demographic spots where both factors align.

- Optimal Demographic Zone: Population peaks occur where moderate fertility rates (approximately 2-3 children per woman) combine with high life expectancy (70+ years), creating the most favorable conditions for population sustainability.
- Development Spectrum: The visualization clearly shows the demographic transition continuum, with low-fertility, high-longevity developed nations at one end and high-fertility, lower-longevity developing nations at the other.
- Population Voids: Extremely high fertility regions (above 4-5) rarely achieve high life expectancy, while very low fertility regions (below 1.5) show population decline despite longevity advantages.
- Regional Clustering: Geographic patterns emerge where similar development levels create demographic clusters, with European nations concentrated in low-fertility zones and African nations in high-fertility regions.
- Sustainability Challenge: The sparse middle ground indicates few countries successfully maintain replacement-level fertility while achieving high life expectancy, highlighting global demographic imbalances.

5.6. Figure 6: Hexbin Plot of Migration vs. Population Growth

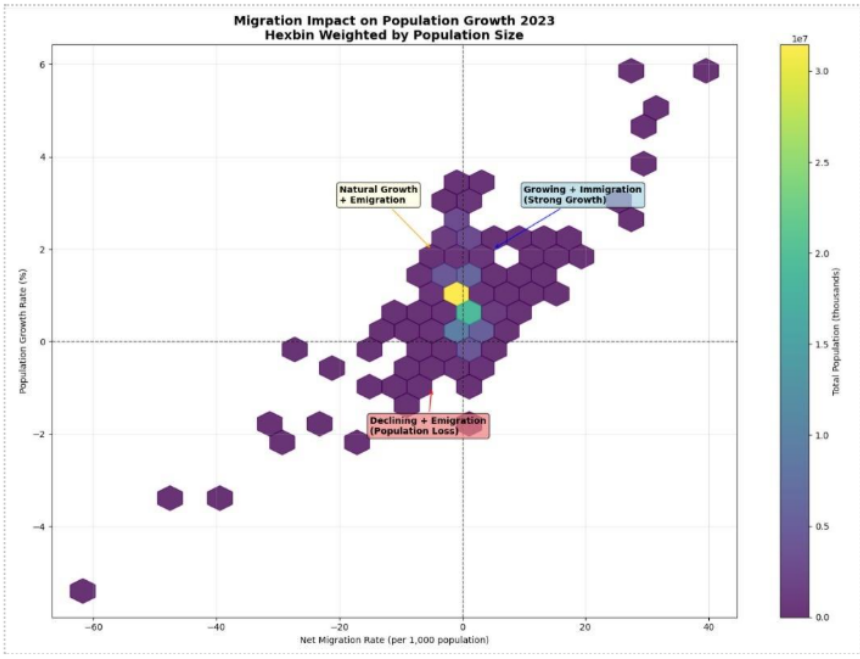

Fig. 6: Hexbin plot showing the relationship between net migration rates and population growth, weighted by population size.

Explanation: This hexbin plot analyzes the relationship between net migration rates and population growth across countries, weighted by population size. Each hexagon represents a cluster of countries with similar migration and growth patterns, with color intensity showing total population affected. The plot is divided into quadrants by zero-growth and zero-migration reference lines, revealing four distinct demographic regimes. Insights: Countries in the top-right quadrant combine immigration with natural increase for strong growth, demonstrating successful population strategies in nations like Canada and Australia. The top-left quadrant shows developing nations maintaining positive growth despite emigration, indicating high fertility offsets population loss. Bottom-left countries face both natural decline and emigration, representing severe demographic stress in regions like Eastern Europe. Most of the world's population clusters in slightly positive migration/growth areas, suggesting moderate, sustainable demographic patterns prevail globally.

- Migration-Driven Growth: The strong positive correlation (0.81 from Figure 4) is visually confirmed, with dense hexbin concentrations showing migration as a primary driver of population growth in many developed nations.
- Demographic Resilience: Countries in the top-left quadrant demonstrate how high natural growth can compensate for emigration losses, typical of many developing economies with youthful populations.
- Double-Demographic Challenge: The bottom-left quadrant reveals nations experiencing both net emigration and natural population decline, creating accelerated population shrinkage and aging.
- Population Weighting Significance: The intensity scaling by population size reveals that despite numerous countries in extreme quadrants, most of the global population resides in moderate migration/growth zones.
- Policy Implications: The quadrant distribution suggests successful demographic policies either focus on attracting migrants (right quadrants) or sustaining natural growth (top quadrants),

with the most challenging scenarios in the bottom-left.

5.7. Figure 7: Comprehensive Mortality Life Expectancy Metrics Hierarchy

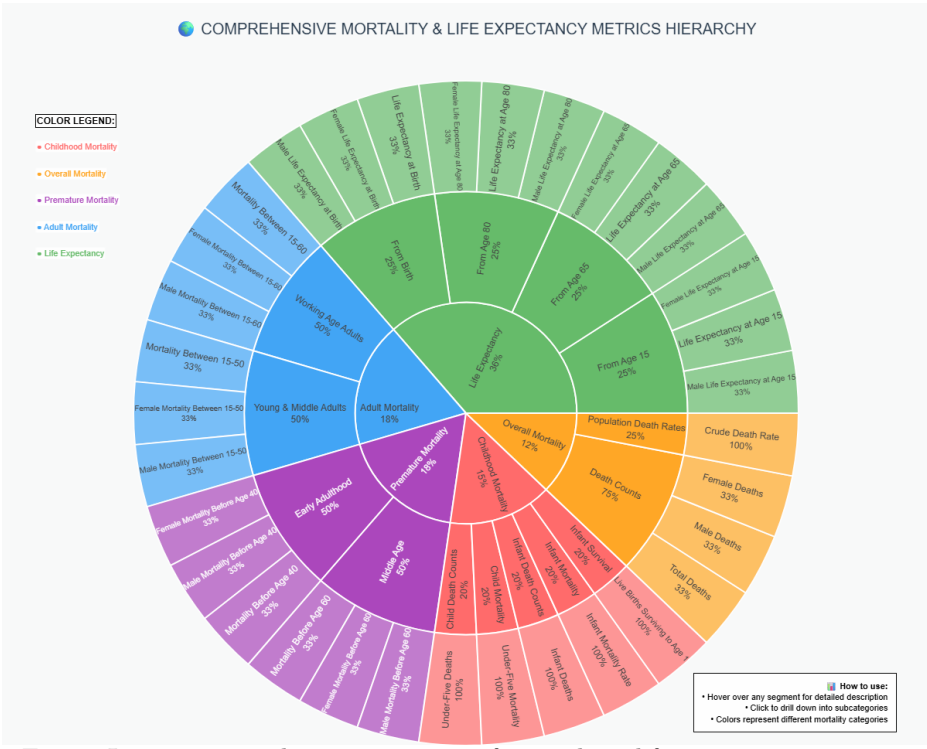

Fig. 7: Interactive sunburst taxonomy of mortality life-expectancy metrics.

- This sunburst groups mortality and life-expectancy metrics into five big categories (Childhood Mortality, Overall Mortality, Premature Mortality, Adult Mortality, Life Expectancy) and shows the hierarchy and relative metric counts. It's an interactive, qualitative navigator for a complex mortality dataset — excellent for exploring where specific indicators live in a taxonomy and for drilling down into specific measures or age bands.
- Life Expectancy occupies one major wedge with sublevels for ages (birth, 15, 65, 80) — showing the dataset emphasizes multiple conditional life-expectancy measures.
- Child mortality grouping: Infant and under-five metrics are grouped and visually distinct (red), highlighting infant survival metrics as a focused subdomain.
- Premature adult mortality: Purple/blue wedges show layered age-cut mortality (before 40, before 60, 15–50, 15–60). This signals good granularity for working-age mortality analyses (policy relevance for workforce productivity).
- Color coding: Clear mapping between policy themes (childhood, adult, premature, overall, life expectancy) — helps nontechnical audiences quickly grasp categories.
- Normalization note: You compute a mean-based normalized coloring; be careful — visuals may understate/overstate importance if distributions are skewed. Consider median or percentile normalization for heavy-tailed metrics.
- Use case: Great for exploratory presentation and for directing users to time series or maps for any clicked metric.
- Limitation: Sunburst shows taxonomy count/importance but does not convey trends or magnitudes over time — combine with the trellis to show dynamics.

5.8. Figure 8: Pakistan Development Profile (Radar / Spider Chart)

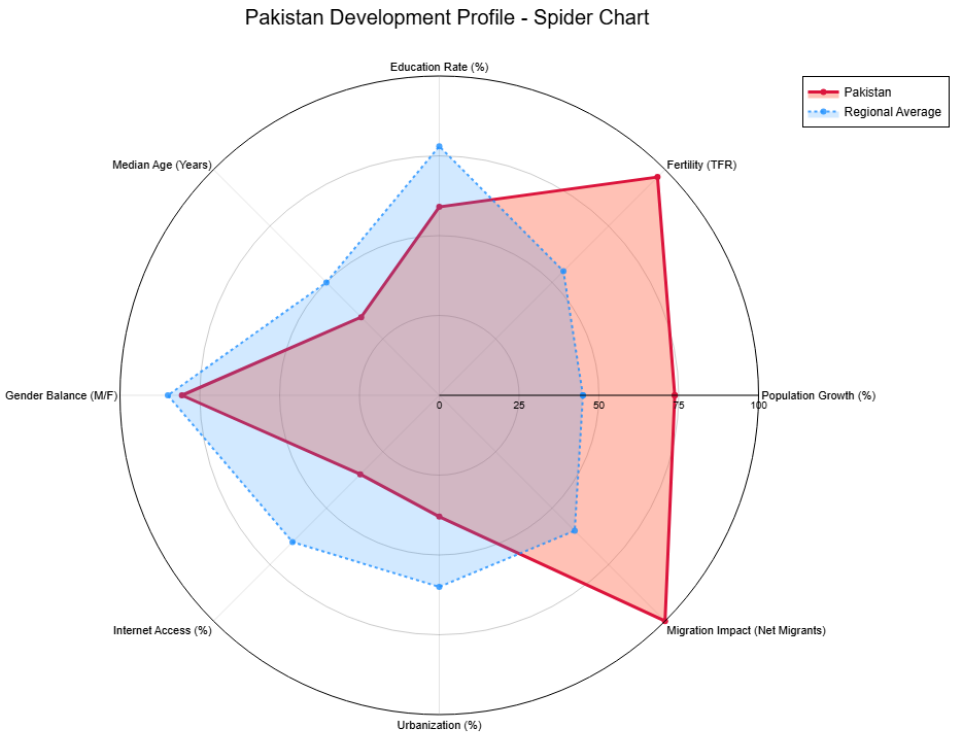

Fig. 8: Radar chart comparing Pakistan (red) against a regional average (blue dotted) across multiple development metrics.

- The radar compares Pakistan (red) vs an encoded "regional average" (blue dotted), normalized to a 0–100 radial scale to allow heterogeneous metrics (fertility, internet access, urbanization, migration) to be visually comparable.
- High fertility migration impact: Pakistan's radar spikes strongly on Fertility (TFR) and Migration Impact, indicating youthful/high-growth demographic pressure — important for dependency ratios, schooling, and jobs.
- Lower human capital infrastructure indicators: Education rate (Pakistan 59% vs regional 78%), internet access (35% vs 65%), and urbanization (38% vs 60%) are visibly lower — key development gaps.
- Gender balance: Pakistan shows a relatively high gender balance score, suggesting sex ratio is not the primary issue compared to education and access metrics.
- Population growth: Pakistan's population growth is relatively high versus the regional average, reinforcing the fertility finding.
- Normalization caveat: Different metrics are scaled 0–100 with varying input ranges (e.g., TFR scaled 1–7). Legends/notes should state normalization rules to avoid misinterpretation.
- Policy implication: Prioritize digital access and education to leverage the demographic dividend; otherwise, high fertility + low education may slow human capital improvements.
- Cross-visual context: Pakistan's high fertility + low education/internet (spider) aligns with trellis time series patterns (Fig. 9) for less-developed regions, showing later fertility decline, lower internet penetration, and lower life expectancy initially.

5.9. Figure 9: Demographic Trends Over Years (Trellis Time Series, Top 5 Regions)

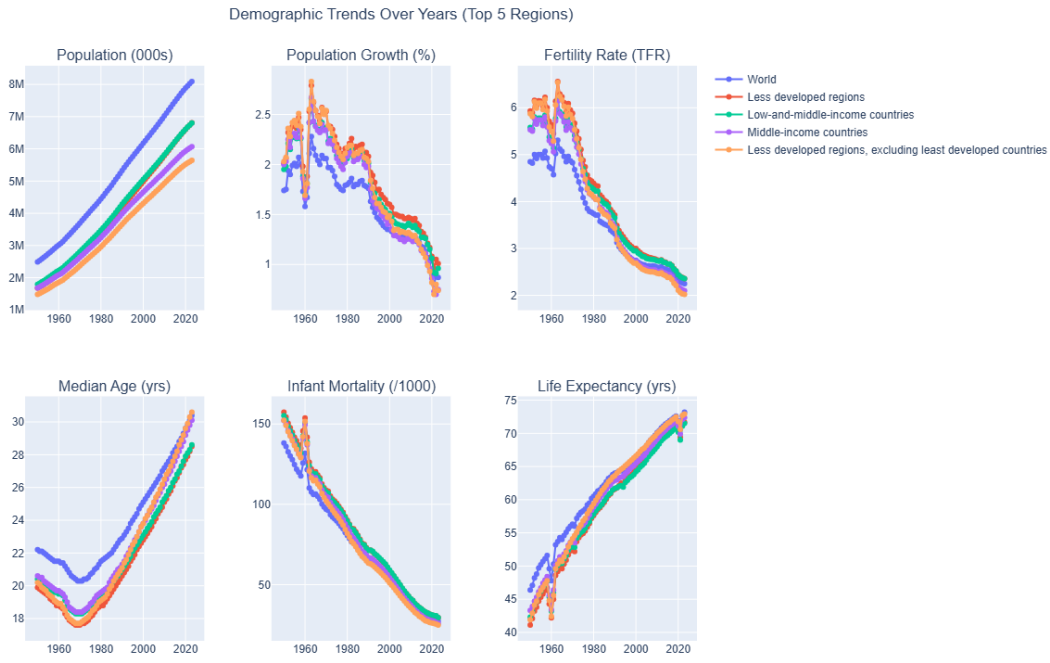

Fig. 9: Grid of time series showing population, population growth rate, fertility, median age, infant mortality, and life expectancy for top 5 regions from mid-20th century to present.

- Tracks global and regional trajectories: rising populations, declining fertility and mortality, rising median age and life expectancy. Regional differences remain visible (e.g., less-developed regions lag in life expectancy and started declines later).
- Population: Steady increase since 1950 across regions; world population rises fastest, low/middle income regions catch up but remain below world totals per capita.
- Population growth rate: Peaks in mid-1960s–1970s then long-term decline; less-developed regions experienced higher peaks and later declines.
- Fertility (TFR): Declines for all groups from >5–6 children per woman to 2–3; greatest absolute declines in less-developed regions.
- Median age: Increasing sharply since 1980s/1990s; less-developed regions show later rise but have been catching up.
- Infant mortality: Major, sustained decline from >100 per 1000 to <30 — public health success across all groups.
- Life expectancy: Smooth rise from 40s to 70s; improvements across regions with some gaps remaining.
- Anomalies/spikes: Temporary fertility/pop-growth spikes in the 1960s/70s due to cohort/war/economic shocks; should be annotated if relevant.
- Policy view: Regions in later stages face aging and require pensions/healthcare planning; earlier stages should invest in education, job creation, and urban planning to realize a demographic dividend.
- Cross-visual context: The trellis shows how metrics evolved over time, complementing the spider (Fig. 8) which shows Pakistan's relative position. The dataset's granularity (sunburst, Fig. 7) allows targeted time series on any selected metric (e.g., infant mortality by region or

male/female life expectancy at 65) — powerful for policy briefs.

5.10. Figure 10: Parallel Coordinates Plot—Multivariate Demographic Profiles Across Countries

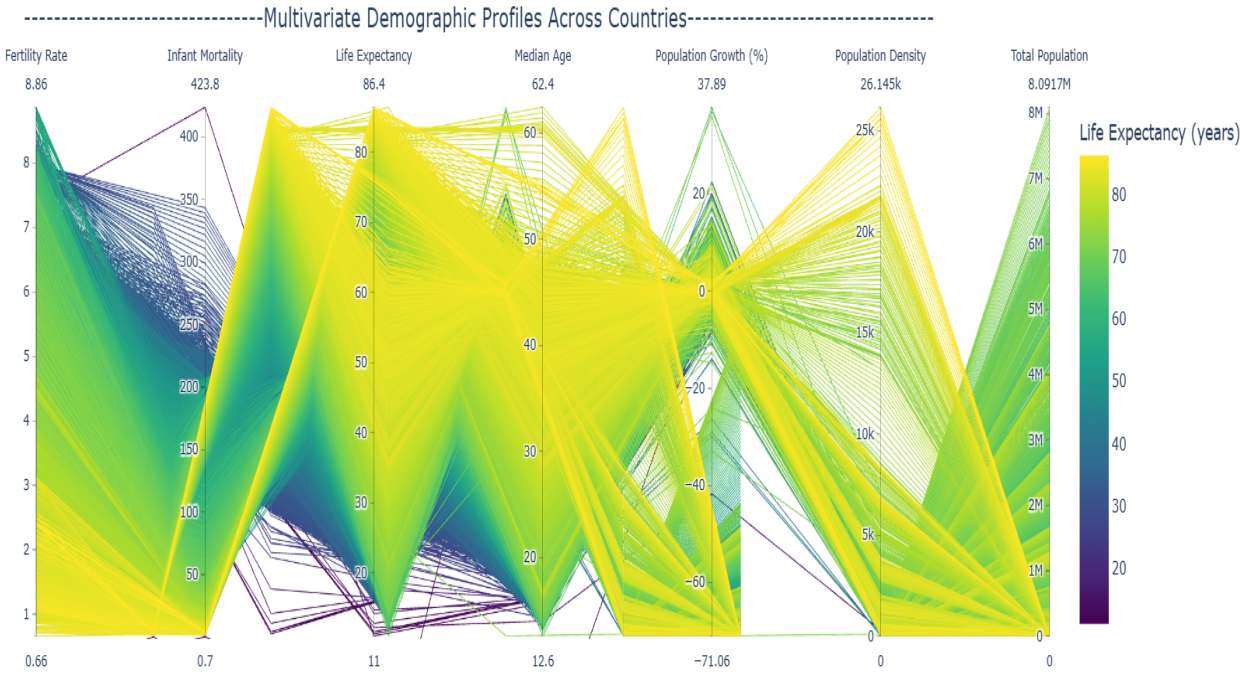

Fig. 10: Parallel coordinates plot visualizing seven key demographic indicators across countries, including fertility rate, infant mortality, life expectancy, median age, population growth, population density, and total population. The color scale represents life expectancy, allowing clear identification of demographic patterns, trends, and contrasts between higher- and lower-development profiles.

- The plot shows relationships among key demographic indicators across countries.
- Countries with higher fertility rates tend to have lower life expectancy and higher infant mortality, reflecting less developed health and social systems.
- Infant mortality is strongly negatively correlated with life expectancy; high infant mortality countries rarely have high life expectancy.
- Median age separates developed and developing countries: higher median ages correspond to lower fertility, lower infant mortality, higher life expectancy, and often negative/zero population growth.
- Population growth varies widely: high-growth countries usually have young populations and high fertility; low or negative growth occurs in older populations.
- Population density shows no universal correlation with life expectancy; variations reflect geographic and economic differences rather than developmental status.
- Total population does not show a strong direct relationship with life expectancy, indicating size alone is not a predictor of health outcomes.
- Overall, the plot highlights clusters: high-fertility, low-life-expectancy countries; low-fertility, high-life-expectancy countries; and a mixed group influenced by density or growth anomalies.

6. Conclusion

This case study provides a comprehensive analysis of global demographic patterns using the United Nations Population Division dataset. Key insights include:

- Fertility patterns show stark regional contrasts, with Sub-Saharan Africa exhibiting the highest Total Fertility Rates, while Europe, East Asia, and North America show the lowest.
- Migration trends reveal high-income regions gain population via immigration, whereas lower-income regions often experience net outflows.
- Maternal age is a critical determinant of fertility, with later childbearing associated with lower fertility and birth rates.
- Life expectancy, fertility, and population distribution demonstrate clustering consistent with the demographic transition model.
- Pakistan's development profile shows high fertility and migration impact with lower human capital indicators such as education, internet access, and urbanization, aligning with broader patterns observed in less-developed regions.
- Temporal trends from trellis time series indicate declining fertility and infant mortality globally, rising median age, and increasing life expectancy, highlighting ongoing demographic transitions and aging populations.
- Multivariate analyses (parallel coordinates and cluster plots) confirm relationships among fertility, mortality, median age, population growth, and density, revealing distinct country clusters and developmental disparities.

Overall, the combination of sunburst, trellis, radar, and multivariate visualizations offers a powerful framework for exploring, interpreting, and communicating complex demographic data.

7. Future Work

Potential avenues for extending this analysis include:

- Forecasting demographic indicators (TFR, population growth, median age) using time series or Bayesian models.
- Constructing age-pyramid animations and regional projections to visualize population structure dynamics.
- Expanding comparative country-level analyses using correlation or regression models to quantify the impact of development indicators on life expectancy and fertility.
- Adding spatial visualizations such as choropleths for mortality, life expectancy, and internet access to capture geographic variation.
- Interactive dashboards linking sunburst metrics to trellis time series or maps for real-time policy exploration.
- Cluster analyses to identify groups of countries sharing similar demographic trajectories and challenges.

8. Limitations

- Visualizations rely on normalized scales; radar/spider charts may under- or over-emphasize differences depending on chosen scaling method.
- Sunburst visualizations illustrate taxonomy and counts but do not convey temporal dynamics; trend interpretation requires complementary time series.
- Dataset coverage and quality vary by country and year; some metrics may be missing or interpolated.
- Aggregated metrics (e.g., rates vs counts) can mask underlying heterogeneity within regions or subpopulations.

Acknowledgments

The authors thank the United Nations Population Division, World Bank, and WHO for making their data publicly available, enabling this analysis and visualization effort.

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