

Mathematics in the Analysis of Demographic Data: The Case of Karbala City

Authors Names	ABSTRACT
<i>Hameed Hasan Obaid Anous Yasari^a</i> Publication date: 1/ 10 /2025 Keywords: <i>Applied mathematics, Population data analysis, Iraq, Karbala city, Demographic statistics, Mathematical modeling, Demography.</i>	This study reviews the role of mathematics in analyzing demographic data, focusing on Karbala City as a case study. It highlights how basic mathematical measures capture growth and density, while statistical models provide more accurate estimates of age structure and demographic change. Modern methods, including spatial analysis and machine learning, demonstrate strong potential for forecasting future trends. The review concludes that integrating traditional and modern tools, alongside improving data quality, is essential for supporting demographic policies in Iraq.

1. Introduction

Demographic data is also the single most critical input to designing and guiding economic and social policies -including urban zoning, resource planning and anticipating future demand. Converting the numbers into comprehensible terms – for example, growth or death rates, population density or age distribution – mathematical modeling and statistical methods help to interpret the underlying sense behind these data (Preston et al., 2001). With Iraq's increasing population rate, high internal/external migration levels and the outdated nature of data sources used in previous estimates, there is a critical need for updated estimates. The Karbala city is a typical example of these situations; it has an intense in-migration process and a fast-growing population with extreme religious beliefs which might have effect on urban development and the provision of public services 4,5(UN, 2021; CSO, 2022). Additional relevant methods in population processes, such as survival models and life-table and prediction models based on time series [^] have also been developed with the aid of mathematical modelling. Additionally, modern spatial analysis methods such as machine learning and traditional GIS have been utilized to analyze the population's spatial pattern and its potential redistribution (Weeks, 2011; Abdi et al., 2011). The aim of this article is twofold: - To show you how mathematics can be applied to a certain population through an example from Karbala- To clarify some of the disparities between our old tools and the new ones that we have started applying in this field, and what are these challenges facing math scientists or even decision makers toward implementing approaches for development based on math expertise.

2. Data Sources

We require population data as the denominator for any type of demographic study that uses statistical and mathematical methods. With regular reports on key indicators (population size, natural growth, age and sex structure, fertility and mortality rates), CSO is one of the most prominent sources of official data in the Iraqi context (CSO 2022). Both scientists and decision-makers are using these numbers as their most important premise. United Nations estimates also help us by allowing comparative data between Iraq and other countries in the region to be explored as well as future population estimates which can aid to anticipate urban trends of growth and public service pressures (United Nations, 2021). This effort of estimating populations is also reinforced by the World Bank in associating population metrics with measures of economy and development (World Bank, 2020). Limited academic research papers conducted in details on population data for Iraq including Al-Khafaji's work on urban growth (Al-Khafaji, 2021) and Rasheed's spatial analysis for the population distributions at a GOV level (Rasheed, 2022). In addition, the UN-Habitat had supplied relevant information on city development and population densities for cities, including the city of Karbala (UN-

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Habitat 2020). General demographic literature, based on the publications of Preston and his co-authors (Preston, C., Heuveline, P., & Guillot, M., 2001) as well as Weeks (2011), provides a theoretical basis for measuring population indicators using mathematical models in contemporary population analysis following a line of research such as Mahmood (2019) and Abdi (2020). The diversity of these sources suggests that the population dynamics of Iraq—at least in this case Karbala—can be studied most effectively by merging official, international, and scholarly data to obtain a fuller picture of demographic change.

3. Fundamental Mathematical Methods

Population data analysis relies at its base on simple statistical methods that allow the researchers to transform raw numbers into measures which can be meaningfully compared and interpreted. (The Population Growth Rate, Statistics South Africa (2005) The population growth rate is essentially the annual increase in size of a population divided by that population's size, and as such has been used for many years in estimates relating to demographic change (Preston et al., 2001). Population density indicators are also used when analyzing the geographical distribution of people – an instrument that is becoming increasingly important in urban planning, particularly in rapidly growing cities such as Karbala city (UN-Habitat, 2020). The third significant dimension of the internal composition of the population is analysed through age and sex distribution. Ratios of age and sex groups are used to identify the differences between sexes or among older/younger portions of the population (Weeks, 2011). Even at an aggregate level, the fertility and mortality rates are two fundamental indicators of demographic change that may help to partially account for a population's natural increase (United Nations 2021). Population tables are widely used in the style of a mortality or life table. as a mathematical tool for calculating all sorts of survival times (e.g., life expectancies). (a) These models are very popular in demography to forecast the future effects of population growth or migration (Mahmood 2019). These straightforward indicators have provided a simple frame for further application of more advanced statistical models in Iraq (CSO, 2022; Al-Khafaji, 2021). So to actually find the human differences Karbala makes, you have to do some real statistical analysis. These are truly the low-hanging fruit of what we ought to be doing before we attempt something like fancier statistical approaches.

4. Statistical Population Models

They provide a sophisticated augmentation to elementary mathematical methods, and may be used for studying the determinants of demographic structure. One particularly suitable method for these analyses is an analysis by life tables at age and sex, as this approach delivers estimates of mortality rates, life expectancy at birth and survival probabilities at specified ages (Preston et al., 2001). This model has been extensively used in the population dynamics literature to project the populations of Iraq (CSO, 2022). Projection models like time series can also be very important to estimate future population size. Figures published by the United Nations (United Nations, 2021) and World Bank (World Bank, 2020), Iraq included Karbala city, which will face dramatic population growth in the future decays; which will demand major challenges to infrastructure and services. Statistical studies in the Iraqi academic literature In the Iraqi academic context, statistical methods were used to estimate linear and multiple regression to demonstrate a correlation between population growth with a set of social or economic factors. For example, Al-Khafaji (2021) connected urban growth levels with internal rates of migration in Karbala and Rasheed (2022) used spatial models to explore the differentiated pattern of population distribution among governorates. Finally, current population models provide better tools for prediction such as use of statistical software to examine fertility and mortality trends (Mahmood, 2019) and the use of remote sensing and machine learning for understanding population dynamics (Abdi, 2020). In this line, population statistical models prove that descriptive and cellular automatisation analysis complement each other, so they do quantitative forecasts. For this reason they become a proper method of studying Karbala as their fast growing Iraqi/pogging representative city.

5. Modern Methods in Data Analysis

In recent years, the study of populations has made great strides in that modern analytical approaches have been adopted which transcend descriptive statistics and deterministic models. Spatial analysis is probably the most important methodology next to spatial identification on studying stratification of people in space and regional disparity. Rasheed (2022) looks at the competition between Iraqi governorates for people. For example, he looked at cities like Karbala, which are either religious or touristy, and found that they have a higher population density than other cities. Geographic Information Systems (GIS) have also become more common in combining population and space maps to help make sense of how people move around and where they live. GIS for sustainable urban planning is an important part of sustainable urban development (UN-Habitat, 2020; Weeks, 2011). Furthermore, the growing popularity of machine learning techniques has made it feasible to use data manipulation with large-scale datasets produced by Big Data to forecast demographic shifts. Classics such as Random Forest Referring back to Abdi's (2020) article, which discusses the similarities and differences between, it begins closely before delving into prediction accuracy. Mahmood (2019) highlighted the importance of mathematical models for improving the accuracy (reliability) of population projections by applying them to forecast fertility and mortality profiles in Arabic nations. Prominent reports from organizations such as the UN (2021) and the World Bank (2020) have further argued for the regular use of these state-of-the-art tools to monitor population dynamics in Iraq, primarily because of the challenges posed by irregularly conducted surveys and the lack of easily accessible data. In the context of complex urban systems like Karbala (based on innovative spatial investigations and astute forecasting), these modern tools and methods are thought to represent a qualitative leap for population studies. On the one hand, they are among the key components that contribute to the creation of an alternative vision by offering perspectives on impending difficulties through rating methods.

6. Case Study of the Holy City of Karbala

The holy city of Karbala is an exceptional population in terms of religious and social features. The capital city receives millions of visitors each year and is a rapidly expanding urban area. Karbala Population growth has been above the national average over the last two decades leading to increasing pressure on infrastructure and public services (CSO, 2022). United Nations (2021) and UN-Habitat (2020) reports confirm that Karbala is challenged by urban expansion as a result of in-country migration movement from the surrounding governorate whose residents migrate to live nearer to religious and economic centers. Some zones have been affected by excessive population density, and unplanned urban expansion. Literature review Conducted empirical studies found that the urbanization process in Karbala is influenced by demographical, and economic factors. Al-Khafaji (2021), showed that internal migration is the main contributor to city's population growing density and Rasheed (2022) through spatial analysis, pointed out that the distribution of population concentration in Karbala shows a high convergence in central portions with unevenness in peripheral neighborhoods. The application of modern techniques which involve the Geographic Information System (GIS) technologies and predictive mathematics and statistics have proven to be of proficiency in predicting growth patterns in the city especially as Karbala grows more significant as a global religious tourist destination (Weeks, 2011; Mahmood, 2019). [8-10] Therefore, it can be said that Karbala is a suitable example of applied case to investigate dimensionality among demographic, social and religious factors which led us to model the role of mathematics to handle the investigating population data in Iraq.

7. Critical Comparison of Methods

Overview of available methods to model several types of population data It is noteworthy that each group of numerical and statistical techniques has its strengths and limitations, which vary with respect to the type of data and the context in which they are used. Simple mathematical models, like crude birth and death rates, are easily calculated but only provide a basic understanding of population dynamics; they are unable to fully capture the intricate structural factors that underlie demographic shifts (Preston et al., 2001; CSO, 2022).

Regression analysis and life tables, two statistical population theories, provide better ways to express the relationships between their variables and future expectations. However, they need consistent and trustworthy data, which may not be available from the Iraqi context (United Nations, 2021; Al-Khafaji,

2021). In a similar vein, time series analysis helps uncover population growth, but it is constrained by incomplete data and temporal discontinuity (World Bank, 2020). The monitoring of settlement distribution and the projection of demographic patterns are qualitatively advanced by this new set of methodological tools, particularly GIS and machine learning tools. Large population datasets from both domestic and foreign studies have been successfully addressed by these techniques (Rasheed, 2022; Abdi, 2020; U.N.-Habitat, 2020). However, due to a lack of technical expertise and training, they are still not widely used in Iraq. This disparity of sources is what prompts me to write that, with the exception of the instance in which you mentioned it on its own location "Hawza" in this special place, such as the holy city of Karbala, we do not have the answer entirely from a single source, but rather it lies in the middle of both things and tools (new and old) to arrive at a partial or full and so forth.

8. Critical Comparison of Methods

According to the literature search related the mathematical and statistical methods for measuring population growth in Iraq mainly in Karbala city, each of these two methods supports the results reached by other method to obtain a real vision on demography. Basic mathematical operations such as growth and density procedures have clarified the magnitude of the populations by modelling whereas modelled data has contributed to explaining inter-relationships between social, economic and demographic variables with expression for numerical description (Preston et al., 2001; CSO, 2022). However, current trends indicate that using these tools alone may not be enough to interpret the growing dynamics of populations. The use of machine learning algorithms in conjunction with spatial analysis has been expanding quickly as a potent tool for spotting hidden patterns in the area and forecasting future patterns (Rasheed, 2022; Abdi, 2020). This fast urbanization and population growth will put a lot of strain on Iraq, especially on religious cities like Karbala (United Nations, 2021; World Bank, 2020). Therefore, it is necessary to investigate new avenues for the development of more integrated national data systems, unlock the potential of modern tools and technology such as GIS and predictive modeling, and develop specialized human capacity to use these effectively (UN-Habitat 2020; Mahmood 2019). Demography can provide valuable and potent analytical tools to support sustainable development policies in this respect.

8. Critical Comparison of Methods

According to the review's conclusion, the main tools for recognizing the shifts in Iraq's population and that of its holy city, Karbala, which is subject to sharp increases in population and pressure on public services, are basic statistical and mathematical tools. Basic mathematical methods such as growth and density periods have been effective for measuring general population patterns (Preston, Heuveline, & Guillot, 2001; CSO, 2022) with statistics models of populations enabling more in-depth analyses on age structure or future outcomes (United Nations, 2021; World Bank, 2020). Recent studies have also verified that developing advanced methodologies (including spatial analysis and machine learning) help discover complex spatial patterns and better predictions in the presence of data limitations in Iraq and a weak research environment (Rasheed, 2022, Abdi 2020). Conclusions and Recommendations In light of the above, some conclusions and recommendations were mentioned by the study.

1. No single technique is able to fully address all aspects of demographic analysis.
2. An integrated traditional and modern approach provides a more comprehensive and secure outcome.
3. The Karbala city is a good case illustrated for the application of these approaches due to its special demographic and social features.

References

[1] Abdi, A. M. (2020). Land cover and land use classification performance of machine learning algorithms in a boreal landscape using Sentinel-2 data. *GIScience & Remote Sensing*, 57(1), 1–20.

- [2] Al-Khafaji, M. (2021). Population growth and urbanization in Iraq: A statistical perspective. *Journal of Social and Economic Studies*, 15(2), 77–95.
- [3] Central Statistical Organization (CSO). (2022). *Iraq Demographic Indicators Report*. Ministry of Planning, Republic of Iraq.
- [4] Mahmood, S. (2019). Mathematical models in demographic analysis: Applications in Middle Eastern contexts. *International Journal of Population Studies*, 5(3), 101–120.
- [5] Preston, S. H., Heuveline, P., & Guillot, M. (2001). *Demography: Measuring and modeling population processes*. Oxford: Blackwell.
- [6] Rasheed, A. (2022). Spatial analysis of population distribution in Iraqi governorates. *Arab Journal of Applied Statistics*, 8(1), 25–44.
- [7] UN-Habitat. (2020). *Urban growth and population density in Iraqi cities: Case of Karbala*. Nairobi: United Nations Human Settlements Programme.
- [8] United Nations. (2021). *Iraq population and development report*. New York: UN Publications.
- [9] Weeks, J. R. (2011). *Population: An introduction to concepts and issues* (11th ed.). Belmont, CA: Wadsworth.
- [10] World Bank. (2020). *Iraq economic monitor: Demographic trends and challenges*. Washington, DC: World Bank.