***Dirasat*: Human and Social Sciences, Volume 50, No. 4, 2023**

Deanship of Scientific Research

An Analysis of the Urban System in Daqahlia Governorate, Egypt (1947-2017)

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Received: 25/7/2021
Revised: 12/9/2021
Accepted: 18/4/2022
Published: 30/7/2023

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Citation: Taiema, F. saber . (2023). An Analysis of the Urban System in Daqahlia Governorate, Egypt (1947-2017). Dirasat: Human and Social Sciences, 50(4), 97–120. https://doi.org/10.35516/hum.v50i4.5638

Abstract

Objectives: The present paper deals with the characteristics of the urban system in the Daqahlia Governorate of Egypt across seventy years (1947-2017), through the analysis of the urban growth, the change in cities' sizes, and the hierarchy of the cities and their spatial distribution.

Methods: A set of statistical measures and GIS software were used to perform the analyses. The measures include: The Rank-size rule, The First City Law (Jefferson), the urban primacy index (UPI), an urban concentration index, and the nearest neighbor as performed in GIS.

Results: The results show that, despite a significant change in the size of cities, the urban system does follow a power-law, with an exponent satisfying the rank–size rule. However, Al-Mansurah-Talkha metropolitan area exhibited a highly stable primacy index throughout the 70-years period. The urban concentration index of Mutlu (1989) was steadily declining, meaning more cities and more competition within the urban system.

Conclusions: Overall, the urban system seems to be mature and stable in terms of both rank-size and primacy. However, many research gaps are still to be filled since it is expected that the city sizes in Daqahlia would witness a re-adjustment process to accommodate the migration to the New Mansoura.

Keywords: Urban system, urban hierarchy, urban primacy, rank -size rule, first city law.

تحليل النظام الحضري بمحافظة الدقهلية –مصر(1947-2017)

فاطمة صابر طعيمة

قسم الجغرافيا ونظم المعلومات الجغرافية، كلية الآداب، جامعة بنها، بنها، مصر.

ملخّص

الأهداف: تعالج هذه الدراسة خصائص النظام الحضري في محافظة الدقهلية بمصر عبر سبعين سنة (1947–2017) من خلال تحليل النمو الحضري، تغير أحجام المدن، هيراركية المدن وتوزيعها المكاني.

المنهجية: استخدمت في التحليل بعض المقاييس الإحصائية ونظم المعلومات الجغرافية، وشملت المقاييس:قاعدة المرتبة – الحجم، قانون المدينة الأولى (جيفرسون)، مؤشر الهيمنة الحضرية، مؤشر التركز الحضري.

النتائج: أظهرت النتائج أنه رغم التغير الكبير في أحجام المدن فقد بقي النظام الحضري متبعا قانونا أسيا، قيمة الأس فيه تحقق قاعدة المرتبة – الحجم، كما أن المنطقة المتروبولية المنصورة – طلخا أظهرت ثباتا شديدا في مؤشر الهيمنة عبر فترة السبعين سنة، بينما كان مؤشر التركز الحضري لمولتو (1989) يتدهور بإطراد، ما يعني مزيدا من المدن ومزيدا من التنافس في النظام الحضري..

الخلاصة: على وجه الإجمال يبدو النظام الحضري ناضجا ومستقرا بدلالة كل من المرتبة –الحجم والهيمنة، بيد أن الموضوع مازال يتطلب المزيد من البحث.

الكلمات الدالة: النظام الحضري، الهيراركية الحضرية، الأسبقية الحضرية، قاعدة المرتبة-الحجم، قانون المدينة الأولى.

1. Introduction

For decades, the urban population of the world has been increasing. According to 2018 Revision of the World Urbanization Prospects (UN Population Division, 2019), the world urban population rose from 30% of the total population in 1950 to 55% in 2018, and is projected to be 68% in 2050. The sources of urban growth include natural increase, migration to cities, and reclassification of former rural areas as urban.

Along with the phenomenon of rapid urbanization, continual changes occur in the urban spatial patterns, urban functions, inter-city links, urban layouts, etc. …, with inevitable environmental and socioeconomic impacts. This state-of-affair has made the urban hierarchy system a core concept in the field of urban geography. Moreover, as the urban structure reflects many economic forces, and as urbanization is correlated with economic development, the evolution of city size pattern has attracted interest by economists and social scientists as well (Gabaix & Ioannides, 2004).

1.1 The city size models

Urban geography and urban economics have a long tradition of modeling city sizes. The German geographer Auerbach (1913) was the first to propose the presence of urban regularity in his study on the US and five European states. He showed that the product city size * city rank is roughly constant. This implies that the second largest city is about half the population of the largest city, and that the third largest is about one third, and so on. Statistically, this approximates a Pareto distribution (i.e. a *power law*). Later on, Zipf (1949) restated the relationship, pointing out that not only does the cities' size distribution follow a power law, but that the distribution has a slope parameter close to -1 and a tight fit as indicated by the coefficient of determination. On a log–log scale plot, the relation between the size of cities and their ranks would be a straight downward-sloping line, and if the slope equals -1.0, *Zipf's law* collapses into the *rank-size rule*.

The second model of city size, mostly applicable to the national level, is the *urban primacy*. The model can be traced in many writings from the seventeenth century onward (Meyer, 2019), but it is usually associated with the seminal article by Jefferson (1939) which showed different regularity from that of the rank-size rule. Using data for 51 countries, Jefferson showed that the largest city in terms of population size is often of administrative, commercial and industrial activities that make its population size disproportionately exceeding the country's second largest city. He found that, on the average, if the primate city size is assumed to be 100%, the size of second ranked city is 30%, while the third is 20%. Later on, the original Jeffersonian terminology was slightly altered, and thus the synthesis by Mutlu (1989) came to the conclusion that primacy exists whenever the ratio of the size of the first ranked city to the second exceeds two. The concept of primacy is quite applicable on a world scale, in which case the primate city is a megacity with influence going far beyond its region (Chen and Wang, 2014)

1.2 The empirical evidence

More than seventy years after Zipf, the proposition that city sizes adhere to the rank-size rule is still debatable (Arshad et al. 2018). The *proponents* of the validity of the Zipf law argued that lots of studies showed a surprisingly high coefficient of determination (R^2) when applying Zipf law, and accordingly Krugman (1996a) writes "we are unused to seeing regularities this exact in economics", and he described the regularity as puzzling (Krugman, 1996b), and the rule was even described by Chen (2021) as "superstable". Additionally, the city size distribution following Zipf is fractal, in that the relationship holds at the scale of continents, countries, and districts (Batty 2006). In one of the earliest seminal studies, Rosen and Resnick (1980), using data for 44 countries, found that R^2-values were above 0.95 for 36 of them. Guerin-Pace (1995) found R^2 exceeding 0.99 for the cities of France in the period 1831-1982, and Song and Zhang (2002) gave R^2=0.92 for the cities of China in 1998. The study of Jiang et al. (2015) was unique in two respects: firstly, it was the first to test Zipf's law for all cities worldwide, and, it relied on a definition of "naturally-delineated cities" rather than the census definitions of cities. The findings were that Zipf's law holds for all natural cities worldwide, with deviations for some countries or for some time periods.

The *opponents* of the validity of the Zipf law argued that (1) most of the empirical studies relied on truncated samples, focusing only on large cities (e.g. Giesen et al. 2010, Urzúa, 2000). Indeed, when Nota & Song (2012) altered the truncation point and the sample size, the exponent is shown to be close to -1.0 only for some sub-samples. When Peng (2010) changed the truncation point in his study on the Chinese cities, he found that the exponent was changing. Luckstead & Devadoss (2014b) found that world's largest cities do not follow Zipf's law for all sample sizes. Out of 73 countries, Soo (2005) showed that Zipf's law does not hold for 53 using OLS estimation method, and for 30 using the Hill estimator. Using data from five censuses of Malaysian cities (1957 to 2000), Soo (2007) found that Zipf's law does not hold except for 1957. Using three different datasets of the U.S. cities, Su (2019) found that Zipf's law does not hold. (2) Another pitfall reported by the opponents is that most of studies used the administrative boundaries for defining cities rather than using their (true) economic area, e. g. the analysis of the functional urban areas in Europe conducted by Schmidheiny & Suedekum (2015) showed that the European cities do not follow a power law, and, strangely, that the largest cities are too small to follow Zipf's law. However, such argument is challenged by Berry & Okulicz-Kozaryn (2012) who argued that if urban areas are properly defined, the city size distribution would strictly obey the rank-size (i.e. the slope = -1). (3) Urzúa (2011) claimed that the regression commonly used to test for rank-size rule is erroneous.

Some of the opponents of Zipf propose *alternative statistical distribution* to replace the Zipfian lognormal. For example, Giesen et al. (2010), using city sizes of eight countries, showed that the double Pareto distribution yields a better fit. Reed (2002) showed that, in Spain and the U.S, the lower tail cities exhibit reverse Pareto, while upper tail cities follow Pareto, but Devadoss & Luckstead (2016) found that the rank-size rule is equally applicable for the lower tail cities in the U.S., and Devadoss et al. (2016) came to the same conclusion for India, Moreover, Rozenfeld et al. (2011) found that the rule holds for cities as small as12,000 inhabitants in the US. and 5,000 inhabitants in Britain. Using the 2000 U. S. census and three different definitions of the city, Ioannides & Skouras (2013) showed that their fitted model switched from a lognormal to a Pareto law at population 60,290.

Standing *in between the proponents and opponents* of Zipf, several studies showed that the city size can vary, both in space and time, being Zipfian sometimes and not all the time. Investigating city size of more than 190 countries, Fang et al. (2017b) found differences among countries and regions. In a study dealing with the temporal variations (1950 to 2010) in distribution of the cities in China and India, Luckstead & Devadoss (2014a) found that the city size distribution for China was best fitted using two different models for two periods, and this was attributed to the government's policies regarding internal migration and the one-child policy. Anderson & Ge (2005) showed that the One Child Policy have significantly changed the Chinese urban system. The Indian cities showed also two models that best fit the data for two time periods: before and after the economic reforms in 1990. Luckstead & Devadoss (2014c) found that Zipf's laws holds for largest cities in India after the economic reforms (1991-2011). Using data covering the period 1949-2012, Fang et al. (2017a) found that the year 2000 for China witnessed the shift in urban development strategy, and this is evidenced by different Zipf coefficients. Wan et al. (2020) concluded that the size the Chinese cities did not obey Zipf 's law until very recently as the government policies caused deviations from the law, while market forces reduced them.

No less important than temporal variations, *spatial variations* may also account for the varying degrees of adherence to Zipf 's law. Sun et al. (2021) studied the Chinese case, with Zipf's law more applicable to provinces with industrial activity rather than those of trading activity. For Pakistan, the Zipf 's law does not hold nationally for the period 1951-1998, albeit it holds at a provincial level. Arshad et al. (2019) attributed this to the fact that the urban systems of the provinces are more coherent as compared to the national urban system.

1.3 Attempts at explanation

For a considerable period of time, the primate city and the rank-size rule resulted in a dichotomy, with primacy associated with underdevelopment and the rank-size distribution with economic development and the maturity of the urban system. It was not until 1960s that Berry (1961) showed that city size distribution and the degree of development are not related. Consequently, the new attempts at *the explanation of primacy* was classified by Carroll (1982) into three major classes: economic, political, and the world systems theory. However, the study of Moomaw & Alwosabi (2004) on countries in the Americas and Asia find possible relation between primacy and economic development on one hand, and primacy and dictatorships on the other, while the world systems assumptions have not been supported. In another comprehensive review, Mutlu (1989) presented seven factors argued to be positively associated with primacy: the largest city is the capital city, colonial heritage, centralized administration, agricultural orientation, urbanization ratio, population growth rate, and ethnic heterogeneity. Additionally, five factors were found to be negatively associated with primacy: level of nonagricultural per capita GNP, arable land area, a high degree of interdependence in the urban system, maturity of the urban system, and the ratio of manufacturing employment to service employment.

Contrary of the explanation of primacy, the *explanation of rank-size rule* was mainly based on pure statistical reasoning. Gabaix (1999a, b) cleverly showed that an urban system following Gibrat's law, i. e. the growth of cities is independent of their size, can generate Zipf's law. The same conclusion was reported in Ioannides and Overman (2003) for the U.S. cities, and by Aurélie & Martin (2020) for France. Using Italy and Switzerland as case, Gualandi and Toscani (2019) showed, on statistical basis, that citizen's motivation to immigration and emigration can yield Zipf's law. Benguigui & Blumenfeld-Lieberthal (2007) were the first to introduce time and the rate of creation of new cities in their model, thus the growth of the city size together with the variation of cities' numbers were shown to yield Zipf's law.

Other possible explanations of Zipf's law include the multiple random factors (Lee & Li 2013), including climate, industry, geography, of which each factor alone cannot generate the law.

Alongside the different explanations, some studies cast doubts about city size distribution, the salient example being Sheppard's study (1982), in which he complained that the cities are removed from their context, and that no information is retained about their economic function and their mutual interactions. Gan et al. (2006) argued that Zipf's law is a statistical phenomenon and does not require a theory, while Mansury & Gulyas (2007) argued that the underlying mechanisms remain largely unexplored.

When attempting at explaining Zipf's law, some studies concluded with either refuting the "law" or the use of Gibrat's law to explain Zipf's law. Findeisen & Südekum (2008) showed that the city size distribution of the former West Germany could be better explained using Duranton model. In two contributions, Duranton showed that the outcomes of innovation and local spillovers can yield random growth models (Duranton 2006), and, using of US and French data, that cities slowly grow or decline following net gains or losses of industries. For U. K., Gray (2021) showed that the majority of cities had persistent advantageous or disadvantageous trends, contrary to the concept of randomly distributed shocks adopted by the proponents of Zipf's law. A similar conclusion for Austria was given in Nitsch (2003) who explain Vienna's primacy using the concept of lock-in effects.

To date, the studies concerning the countries of the "periphery" (using the terminology of world systems theory) are still lacking. Of the few ones, Aragón (2014) related the trade policies and the size of cities in Guatemala during the time period1921 to 2002.

1.4 Implications

Urban primacy implies disparities in economic activity across cities. Henderson (2002) showed that primacy strains the urban system, as it absorbs resources to confront the environmental problems in the primate city, thus deteriorating the quality of life in other cities. Indeed, as Multu (1989) showed, many governments implemented policies to check urban primacy to give rise for a more balanced urban system allowing for social equity and economic efficiency. Bo and Cheng (2021) found that the centralization reform in China, initiated in 1983, is an example to counteract the negative effects of primacy, as democratization limits the ability of a national ruling class to concentrate resources in the capital city.

Apart from the topics of urban economics, *zipf's law* can be of wide implications, as exemplified in urban literature. Examples include delineating the administrative boundaries (e. g. Alvioli 2020, using Italy as case), studying the possible impact of economic integration (e. g. Modica 2017, European Union), studying port system (e. g. Xu et al. 2021, Chinese ports), the impact of the diffusion of new innovations on the urban systems (e. g. Tranos & Ioannides 2020, fixed telephony, worldwide), the impact of the diffusion of information on the urban systems (e. g. Peris et al. 2021, Netherlands), making cities resilient and energy efficient (e. g. Salat & Bourdic 2011). Chen and Wang (2014) showed that zipf's law is even applicable in intra-urban cases, in which the urban space is disaggregated through a recursive subdivision process and the ranking of the resulted parts by their size.

Perhaps the most important implication of the city size distribution is the emerging concept of *polycentricity*. A polycentric urban region (PUR) is defined as a city system that has a relatively the same size and is functionally interdependent. A polycentric city system is formed when independent urban centers form more integrated city-system (Liu & Wang 2016). Originally, the concept was intended to promoting regional economic competitiveness while achieving environmental quality (Bailey & Turok 2001, Bartosiewicz & Marcińczak 2020). Developed in Europe, the concept was adopted as a spatial planning tool within the framework of the European Spatial Development Perspective (Rauhut 2017), and later on it was adopted by the Chinese Government (Sun & Lv 2020). Despite of the PUR merits, some of the empirical evidence show that the relation between economic development and polycentricity is not conclusive (Brezzi & Veneri 2015), and that monocentric countries are of lower regional disparities than the polycentric ones, and that the per capita GDP and competitiveness in polycentric countries are not better, compared with that of monocentric countries (Rauhut 2017). Additionally, the term PUR is still described as "fuzzy and stretched" (Burger & Meijers 2012, Taubenböck et al. 2017, Münter & Volgmann 2020). Van Meeteren et al (2016) proposed a re-conceptualization of the concept. Another problem in using the concept in case studies is that the measure of polycentricity is highly sensitive to the choice of a cut-off point and of the number of cities, as exemplified by studies conducted on China (e.g. Zhang & Derudder 2019) and Germany (Möck & Küpper 2020).

1.5 Motives of the study

The urban research concerning Egypt is still lacking studies of this kind. Reviewing the literature reveals only two studies. Abou-Korin (2010) analyzed the urban system of Egypt as a product of political decisions, and Abd El Aal (2007) devised four indices to measure what he termed "the urban hegemony" of the Egyptian cities using the census of 1996.

To fill this research gap, *the aim* of the present study is to highlight the characteristics of the urban system in a governorate representative of Lower Egypt, and to reveal the change in the hierarchical structure of cities during the study period, and the urban distribution and urban primacy of cities and their actual influence. The study has implications to the urban and regional planning, in a possible administrative boundary reform, and a possible electoral re-districting.

2. MATERIALS AND METHODS

2.1 Study area

Located in the northeastern part of Egypt’s Nile Delta, Daqahlia is the third largest governorate (3,459 km^2) in the Egyptian ecumene, following Sharqia and Beheira. It extends from the mid-delta (south) to the Mediterranean (north), and thus spans over fertile lands with abundant water resources throughout the year (south), to the salt-affected and sandy soils (north). This physical setting gave rise to variations in population densities, and consequently variations in urbanization (Fig. 1). The present administrative boundaries of Daqahlia are delineated in the course of a nation-wide administrative re-adjustments, including the incorporation in 1955 of three districts formerly belonging to Gharbia (Bilqas, Shirbin and Talkha), and the ceding of Faraskur district to Damietta, and Diarb Nigm district to Sharqia.

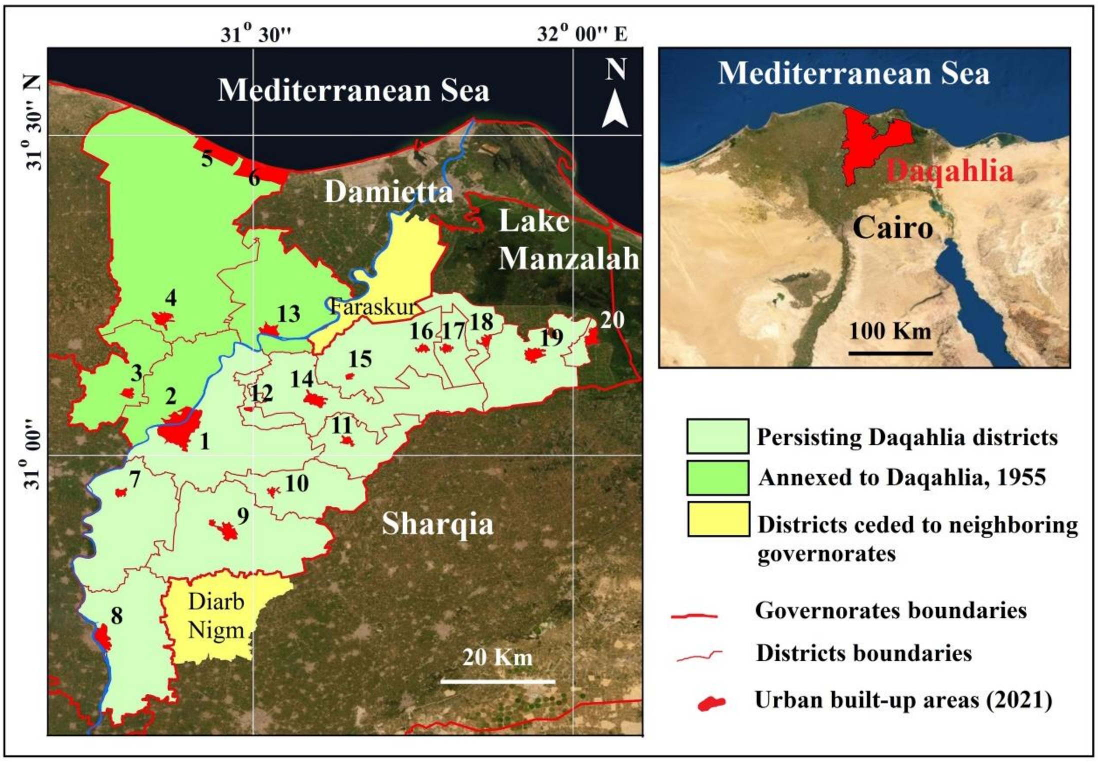


Fig. 1. Location of the study area and its administrative subdivisions. Numbers refer to cities: (1) Al- Mansurah; (2) Talkha; (3) Nabaruh; (4) Bilqas; (5) New Al- Mansurah (under development); (6) Jamasah; (7) Aja; (8) Mit-Ghamr; (9) As-Sinbillawayn; (10) Timmay al-Imdid; (11) Bani Ibayd; (12) Mahallat Damanah; (13) Shirbin; (14) Dikirnis; (15) Minyat An-Nasr; (16) Al-Kurdi; (17) Mit Salsil; (18) Al-Jammaliyya; (19) Al-Manzalah; (20) Al-Matariyyah. Built-up areas were delineated in Google earth pro from imageries dated May 2021.

Al-Mansurah, the seat of the governorate, is continually expanding, with an *annual* expansion rate of the built-up area amounting to 8.5% during the two decades of 1995-2015 (Hegazy and Helmi, 2020). Together with its twin city Talkha, Al-Mansurah was anticipated to be "a magnet city in Delta region" according to the master plan of both cities (General Organization for Physical Planning, 1994). This plan was criticized on the ground that it exacerbated the problems of urban environment (e. g. El-Dardiry and El-Ghonaimy 2009).

2.2 Census data

Egypt has long tradition in taking population censuses. The returns of the first two censuses in modern Egypt, which have been achieved in 1826 and 1846, are still kept in *Dar al Wathaiq* (the National archive) and have never been published. The first published census is that of 1882. Except for special cases, as was the case of the Sinai Campaign in 1956, the censuses were taken on a regular decennial basis. However, in the present study, the census of 1947 was chosen as a point of departure for the fact that the urban phenomenon in Daqahlia was not so pronounced until World War II. Indeed, the war conditions have brought about deep changes in both the Egyptian economy and demographics.

Accordingly, the analysis will be based on the data provided in eight censuses (1947, 1960, 1966, 1976, 1986, 1996, 2006 and 2017). Unfortunately, all of them do not provide the researcher the resolution necessary for a study in urban geography. The concept of the *census tract* has never been adopted in Egypt, and the published data are usually aggregated in one figure for each city, except for the seats of governorates for which the data show the population by *shiakha*, i.e. the smallest administrative unit of a major city. Today, the *shiakha* is only of historical significance, as the duties of the former *sheikhs* (i. e. local chiefs) have been transferred to the respective authorities.

More important is the definition of the urban boundaries, and hence the calculation the urban population, based on the concept of the "natural city". This is not an easy task to achieve, as the urban-rural transition is fuzzy. This research issue is of global recognition. Fang and Yu (2017) presented a review of more than 32,000 research on urban agglomerations, and the methods to delineate an agglomeration using open-source data have recently been suggested (e.g. Cao et al. 2020, Ch et al. 2021).

2.3 Statistical measures

2.3.1 The Rank- size relationship

Zipf's law can be represented mathematically by one-parameter, two-parameter, or three-parameter form. Of the two-parameter form two models are possible (see for details: Chen 2016). If the city sizes data cannot be well fitted using the one-parameter form, one the two models of the two-parameter form may be used, otherwise, the three-parameter form would be the last resort.

The general form of the rank-size relationship is P_k = P1k − q, in which k is the city rank (by its population size), P_k is the size of the kth city, P1 is the size of the largest city, and q is the scaling exponent of the distribution (Chen 2012). If q is close to 1, then the Zipf's law collapses into the rank–size rule.

An alternative expression of the relation is the logarithmic form lnRk = ln P1 − α lnPk. where α is the estimated coefficient. The standard test for Zif's law is drawing a graph showing the log of the ranks of cities versus the log of their population (size). If the law holds, very high coefficient of determination (R^2) is obtained, and the result will be a straight line with α close to 1.

2.3.2 Urban primacy and urban concentration

The original (Jeffersonian) definition of primacy was that it is a *quality* of a particular distribution of cities in which the largest one is abnormally large. To express this concept quantitatively, various indexes have been devised, in which the size of the largest city was related to that of the second largest, the three largest (Jefferson), even the four largest, or all cities within the system (El-Shakhs 1972). The latter concept is unique in that it combines the primacy and Zif's law, both being special cases corresponding to certain values on the continuum of primacy values as defined by the El-Shakhs' equation (the higher the value the higher the primacy).

$$P_i = \frac{1}{(n-i)}\left[\frac{C_i - C_{(i-1)}}{C_i} + \frac{C_i - C_{(i-2)}}{C_i} + \cdots + \frac{C_i - C_n}{C_i}\right]$$

Where C is the city size, n the number of cities, i the rank of the city (by its size, the largest city is ranked 1 and the smallest ranked n), P_i primacy of city with rank i over all the cities with ranks less than i

Recognizing the deficiencies of the urban primacy indexes, Mutlu (1989) devised the H index that measures the *urban concentration*, H is defined as follows:

$$H = \sum_{i=1}^{n} \left(\frac{p_i}{p}\right)^2$$

where P_i is the population of ith city, P the total urban population, and n the number of cities.

The merit of the H index is that it considers the sizes of all cities within a system, and that it measures the degree of competition among the cities. If H equals one, then one city monopolizes the space. Smaller values of H mean more equal-sized cities and more competition. However, the H index and urban primacy, though related, are not the same thing. Urban concentration can exist without having primacy, and primacy can exist without having high urban concentration, as found in the empirical study of Multu (1989).

For the special case of the *biprimate* countries, i. e. the two largest cities are of about the same population, Moomaw and Alwosabi (2004) devised the so-called PRIMACY1-4 and PRIMACY2-2. The former is the ratio: size of the largest city/sum of the sizes of the second, third and fourth largest cities. The latter is the ratio: sum of the sizes of the two largest cities/sum of the sizes of the third and fourth largest.

2.2.3 The nearest neighbor analysis

First developed by Clark and Evans (1954) for studying ecology, and later used in studying the settlements pattern, the nearest neighbor analysis is a method that focuses on the distances between points rather than on the settlement size or the density of points in a study region. The aim is to determine whether the observed point pattern is clustered, dispersed or random.

In this method, the distance between each pair of points (cities) is measured and the closest neighboring point (city) is determined. The average of these *observed* nearest neighbor distance is calculated. This average is then compared with the *expected* distance between nearest neighbors assuming the point pattern is random. The nearest neighbor index, R, is the ratio between the observed and expected values:

$$R = \frac{R_o}{R_e} = \frac{\bar{x}}{1 / (2\sqrt{n / A})}$$

where $\bar{x}$ is the average distances between points and their nearest neighbors, n is the number of points and A is the area of the study region. By convention, A is the smallest rectangle that encloses all the points, and this is the default setting adopted for ArcGIS software. Optionally, the area of the study region can be supplied, and in such case a slightly different value of R would result.

The R values vary from 0 to a maximum of about 2.15. A value of R close to zero indicates a clustered point pattern, R =l indicates a random pattern, and a value of R close to 2.15 indicates a dispersed pattern (Burt et al. 2009). Fortunately, the shape of study area is not of the narrow rectangular type, which requires cautions in the interpretation of R value, as demonstrated by Rogerson (2001).

3. RESULTS AND DISCUSSION

3.1 Defining an urban center

A major problem in studying city size distribution is the delineation of the city boundaries and the lack of a universally accepted definition of a city (Gabaix & Ioannides 2004, Jiang & Jia 2011). In most studies, the administrative borders adopted in population censuses have resulted in measurement errors, with a likely bias of results (Roberts et al. 2016).

For more than a century, the designation of a certain settlement in Egypt as "urban" has been a matter of an official declaration by the respective authority. Officially, any settlement in Egypt is classified as either "urban" or "rural" irrespective of its major economic base. The default for any settlement is the rural status, and the change of status to acquire urban qualifications is possible only through an official decision. Thus, the Aluminum City (26.00 N, 32.32 E), which is the residential area of a huge industrial aluminum complex, is still classified as rural by default. Contrarily, Siwa (29.20 N, 25.52 E), which has a majority of agricultural manpower, is considered urban by official designation. This state-of-affair has resulted in inaccuracies and misinterpretations when dealing with Egypt's urban geography.

If urbanization is to be judged by the morphology, then the settlements in the study area would exhibit a wide spectrum of morphologies, between the two extremes of purely urban and purely rural, and in most cases clear-cuts are difficult to be drawn. Alternatively, if urbanization is to be judged based on the proportion of non-agricultural manpower, then most of the villages would be considered as cities. Using the third criterion of the population size of a settlement would not be helpful, as a threshold for urban is not applicable for Egypt, and, more importantly, as the population size is misleading so long as it represents an administrative unit rather than an agglomeration.

For the very case of Daqahlia, the dichotomy of urban/rural in the oldest dataset used, i.e. the census of 1947, may be investigated through the detailed tabulation of *'ezbas* (hamlets) versus the residents within the *cordon* (i e the municipal boundaries). **Table 1** shows to what extent the data on the urban size may be refined by subtracting the populations of the hamlets (practically purely rural, but officially urban) from the populations of the cities as statistical entities.

Table 1. Refining the populations sizes ('000 inhabitants) of the urban centers of Daqahlia, using the detailed data of the census of 1947

cities	Population within the municipal boundaries	Population of *'ezbas*	Total population of the city
Al- Mansurah	102	*	102
Mit-Ghamr	29	*	29
As-Sinbillawayn	24	2	26
Al-Manzalah	21	1	22
Bilqas	19	16	35
Shirbin	13	3	16
Talkha	13	*	13
Dikirnis	11	1	12
Aja	7	*	7

Unfortunately, the census of 1947 was the last one to differentiate the urban population into residents within the municipal boundaries and residents outside them in the *'ezbas*. However, in view of the figures of table 1, it can be concluded that, except for the case of Bilqas, the population size within the statistical boundaries do not deviate significantly from the true size of the urban population, and thus the "total population" column will be used in tracing the growth of urbanization, except for Bilqas, of which its true urban population of about 19000 is used in further tables. Indeed, the *'ezbas* once belonging to Bilqas in 1947 are promoted later to full-fledged rural entities.

3.2 Development of urbanization

Egypt has long tradition of urbanization. As far as we know from the documentary materials, the cities of the ancient Egyptian civilization are mostly linked to the administrative and religious functions, as the temples were exclusively located in the seats of the *spt*(s) (the administrative unit). This urban tradition was preserved during the Greco-Roman and Islamic eras. The only novelty was the establishment of a handful of industrial cities on islands of Lake Manzalah or near its shore. In these full-fledged cities, the world-class *Qabati* (=Coptic) textiles were made and exported. The fate of all these cities was a result of both the encroachment of the lake and the Crusader threats to the coasts of Egypt. Consequently, the urbanization was declined and practically was confined to two towns (judged by the writings of the Muslim geographers): Daqahla, the seat of *Kawra* (province) of Daqahlia; and Nawasa the seat of Al-Mirtahia (Tousson 1926). The unification in 1315 of these two *Kawra* into the [Greater] Daqahlia was accompanied by the transfer of the seat to Ashmoun Ar-Rumman, which developed into a veritable city as described in Ibn Doukmak (1893).

However, the urbanization in Daqahlia was not a monopoly of Ashmoun, as Al- Mansurah gained importance and momentum. Established in 1219 during the confrontations with the crusaders in the North Delta, Al- Mansurah (literally: the victorious) was originally a walled city, with palaces and hotels (Ibn Doukmak 1893). Among the Ottoman administrative reforms in 1527 was the transfer of the seat of Daqahlia to Al- Mansurah, which caused the immediate decline of Ashmoun. This development provides an additional evidence of the role of the administrative function in the rise and fall of the Egyptian urban centers. The growth of Al- Mansurah was further enhanced by the incorporation, in 1903, of the two villages Mit Hadar and Mit Talkha.

The advent of second-order administrative divisions (*qism*(s)) in modern Egypt was initiated in 1826, and thus opening a new era for urbanization. The choice of the new seats of administration was almost based on their favorable location of a settlement on a navigable waterway, whatever its population size was. Accordingly, Daqahlia was divided into four *qism*(s) in 1826: Al- Mansurah, Mit-Ghamr, As-Sinbillawayn and Mahallat Damanah, in addition to Shirbin (then part of Gharbia). This development did not last for long, as the introduction of railways was accompanied by the transfer of the seats to settlements with railway stations, or the creation of new *qism*(s) (renamed *markaz* as of 1870) on the railway. Daqahlia was linked to the national railway network in 1860s onwards: Talkha (1863), Al- Mansurah and As-Sinbillawayn (1865), Shirbin (1869), Bilqas (1888). In a second phase, light railways were constructed to function as collectors of the agricultural products for export, and thus linking into the network Dikirnis (1898), Al-Manzalah and Al-Matariyyah (1908), and later Mit-Ghamr and Aja (Wiener 1932) (**Fig. 2**). This explains why Talkha was chosen to be seat of a newly created *markaz* (1871), and again explains the choice as seat of the modest settlement of Aja, which was ranked fifth in size (4,507 inhabitants) among the settlements of its *markaz* in the census of 1907 (Statistical Department, 1909). This is depicted in Fig. 2, and could explain the reason of the transfer of the seat from Minyat Samannud to Aja in 1907. The two settlements are 4 kms apart, and Minyat Samannud was of better location in 1863 when it was chosen to be seat of a new *qism*. It is lying on the (navigable) Damietta Branch of the Nile, opposite Samannud (in Mid-Delta) which was linked to the national railway network in 1858. However, in 1907 Aja became a railway hub and, immediately, it was promoted to an urban status while Minyat Samannud was reverted to a rural status.

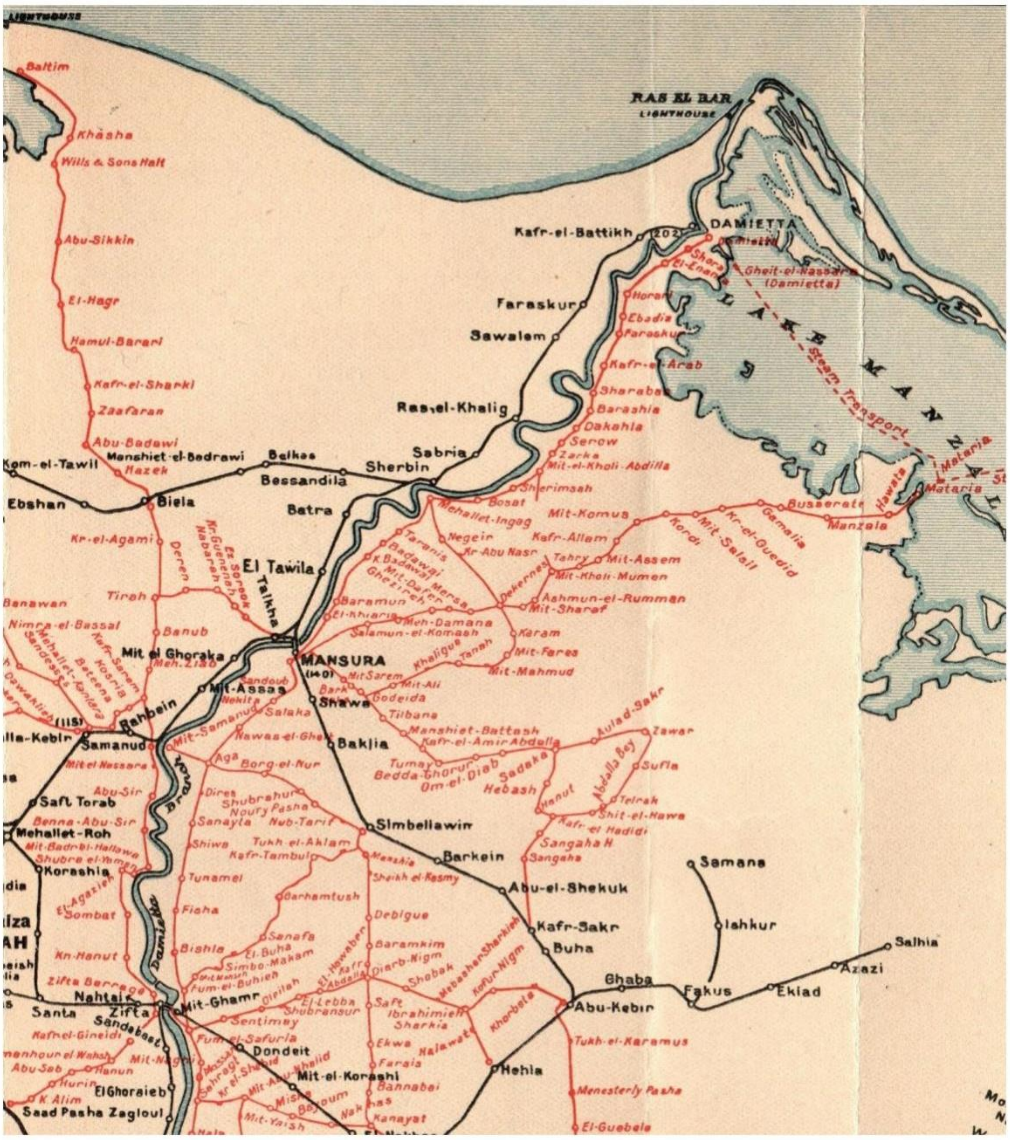


Fig. 2 The railway network that shaped the urban system of Daqahlia. Black lines denote State Railways (standard gauge), red lines denote light railways (narrow gauge). Source: adapted from Wiener (1932).

For the time span adopted for this study**, Table 2.** is a synthesis of the census data, and **Fig. 3** shows three snapshots representing the start date, end date and a midpoint date. Interestingly, the urban status of about half of the 19 cities was acquired as late as the 1970s onwards. These newly transformed cities are still preserve the original rural morphology and layout, which are characterized by the narrow lanes and the traditional *Dayer en-Nahiah* (literally: the ring [street enclosing] the village's [built-up area]) (**Fig. 4**). This is in direct contrast with the layout of the older generation of cities, in which all aspects of rural morphology were obliterated thanks to the efforts of the *Service du Tanzim*, which was active since 1880s. **Fig. 5** shows how this generation of cities was well-planned already by 1940s.

Table 2. Development of the cities' sizes ('000) (1947 to 2017) lying within the present-day boundaries of Daqahlia

Cities	City status as of	1947	1960	1966	1976	1986	1996	2006	2017
Al- Mansurah	1527	102	165	191	259	333	369	438	544
Mit-Ghamr	1826	29	40	43	72	92	102	117	134
As-Sinbillawayn	1826	26	37	41	49	60	72	87	108
Talkha	1871	13	20	24	37	55	66	78	99
Dikirnis	1871	12	16	19	38	49	59	68	88
Shirbin	1897	16	23	25	32	40	46	55	66
Aja	1907	7	9	11	13	14	16	18	41
Al-Manzalah	1929	22	29	33	44	55	60	75	111
Bilqas	1943	19	33	41	50	73	88	95	120
Al-Matariyyah	1960	*	36	41	61	73	88	100	142
Al-Jammaliyya	1979	*	*	*	*	45	59	64	87
Minyat An-Nasr	1979	*	*	*	*	29	49	57	72
Nabaruh	1991	*	*	*	*	*	31	39	52
Mit Salsil	1991	*	*	*	*	*	30	31	42
Bani Ibayd	1991	*	*	*	*	*	27	30	40
Timmay al-Imdid	1992	*	*	*	*	*	12	14	18
Al-Kurdi	2000	*	*	*	*	*	*	26	39
Jamasah	2000	*	*	*	*	*	*	2	4
Mahallat Damanah	2008	*	*	*	*	*	*	*	28
Total		246	413	469	655	918	1174	1394	1835

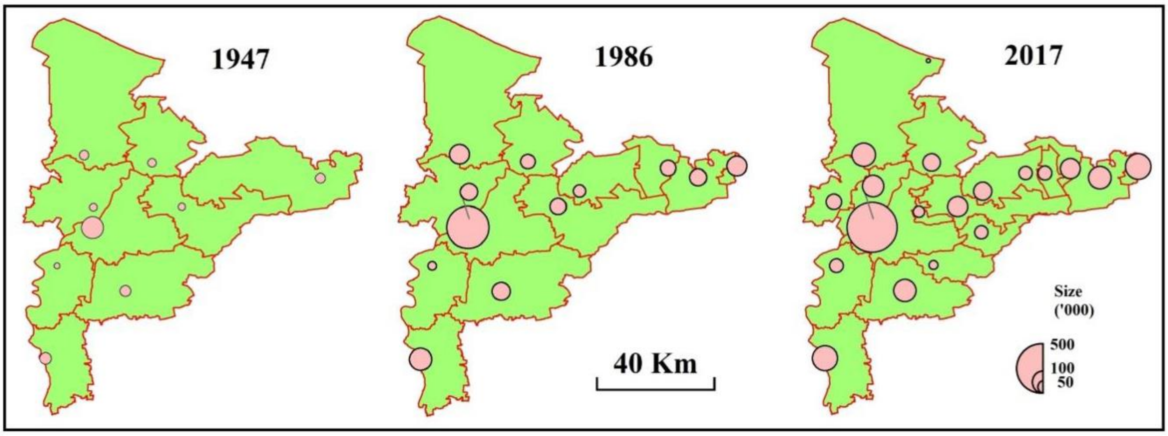


Fig. 3 Evolution of the cities' sizes within the present-day boundaries of Daqahlia**.**

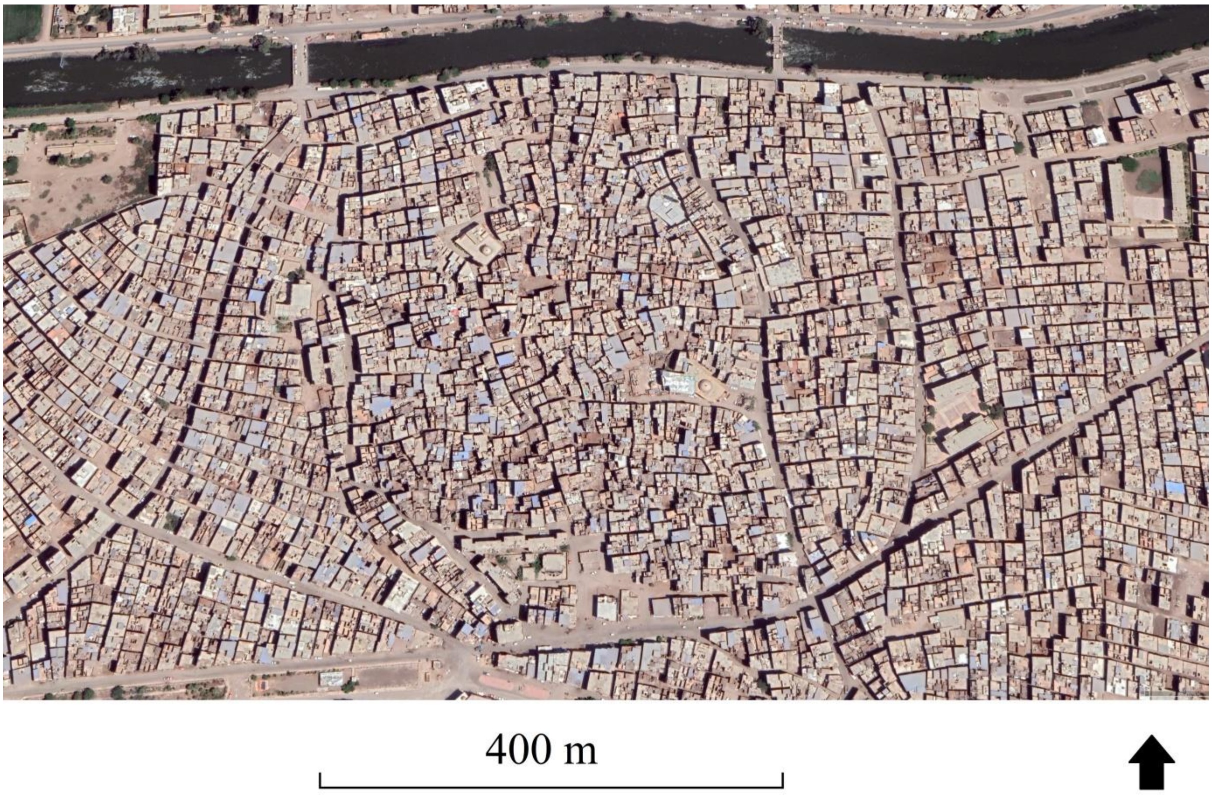


Fig. 4 An example of the layout of the new generation of cities: Mahallat Damanah (2020). Note the ring street which is characteristic of the Nile Delta villages.

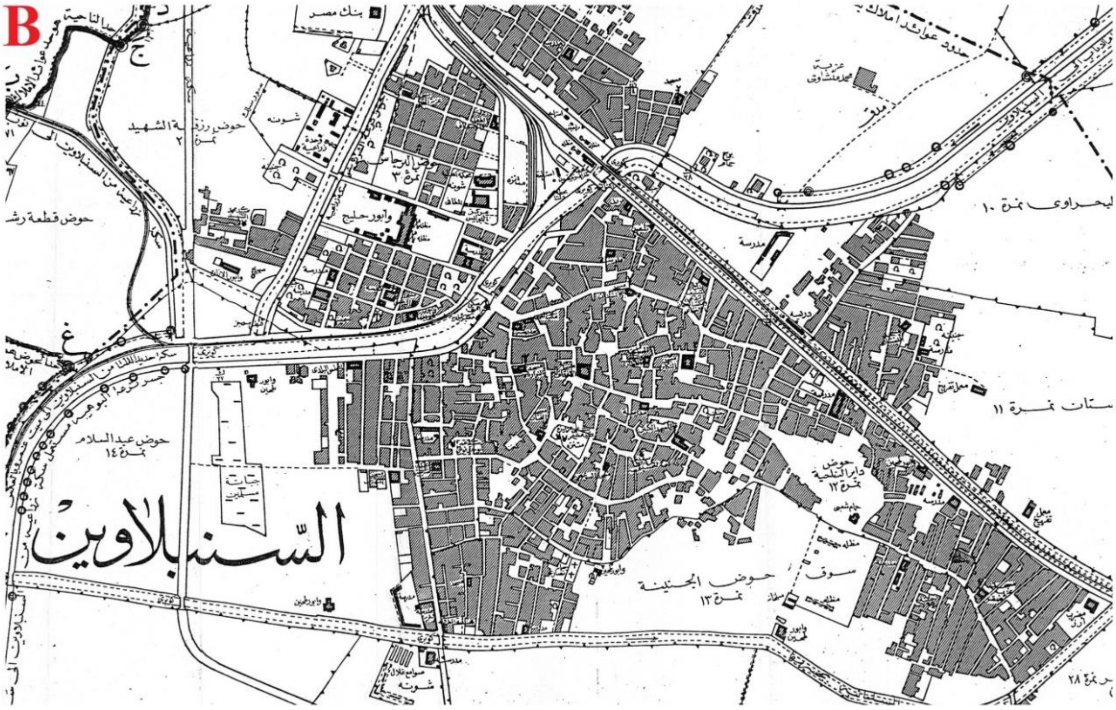


Fig. 5 Two examples of the layout of the older generation of cities: (A) Al- Mansurah as surveyed in 1926-1928; (B) As-Sinbillawayn. Source: Survey of Egypt (1935, 1951).

An additional evidence about the non-urban character of the new generation of cities is that the livelihood of their population is still resemble that of the rural areas. The census of 2017 showed that 31.9% of the rural manpower in Daqahlia are involved in the primary sectors (agriculture and fishing). It is striking that some of the new cities have higher percentages than that of the rural areas (**Table 3**).

Table 3. The proportion (%) of the manpower in the primary sectors according to the census of 2017

Al-Matariyyah	50.8
Al-Jammaliyya	44.5
Minyat An-Nasr	23.0
Nabaruh	6.1
Mit Salsil	26.0
Bani Ibayd	41.5
Timmay al-Imdid	25.2
Al-Kurdi	28.9
Jamasah	5.7
Mahallat Damanah	17.0

The case of Al-Matariyyah city is unique, as its two original constituent villages (El 'Oqbiyin and El Ghasna) were totally destructed in a conflagration in April 1907. In the aftermath, the decision was to rebuild the two villages as one settlement that appears a well-planned city in the cadastral survey achieved in 1911 (**Fig. 6**). However, the settlement remained officially rural albeit its urban layout, and its size which was comparable to, and even far larger than, that of most of the first generation cities (see Table 2). The reason was that fishing was, and is still, the main livelihood for the people and that Al-Matariyyah were overshadowed by the influence of Al-Manzalah, which is lying only 7 kms to the west. The decision to give Al-Matariyyah to a city status was guided mainly by security reasons, as it is the most appropriate location to control the illegal activities in the vast Lake Al-Manzalah.

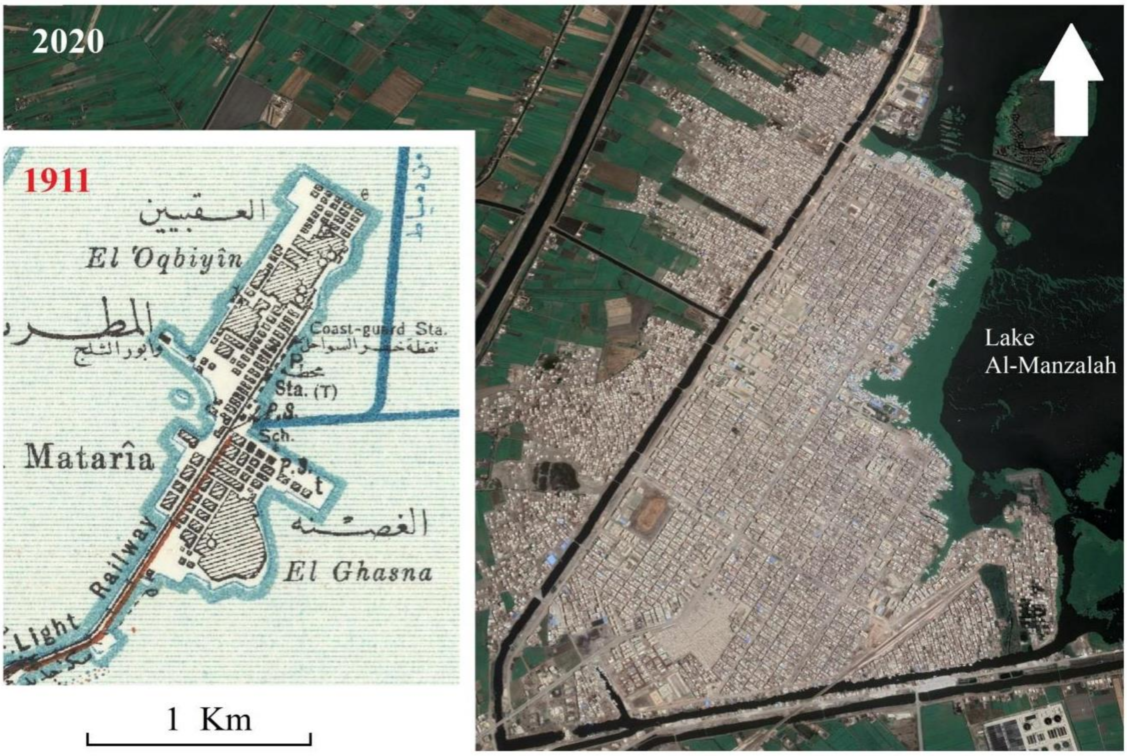


Fig. 6 Al-Matariyyah in the cadaster of 1911 (in reduced scale, as shown in the topographical map series), and in 2020.

Why then the newer generation of cities were promoted to a city status though their lack of the urban character? As the authorities has never stated the reason for the decisions, one may seek the answers through three possible reasons: (1) the need for creating second-order administrative units (districts, =*markaz*) to accommodate the population growth; (2) the need for creating second-order administrative units to reduce the distance (and thus the cost) to obtain the many administrative services; and (3) serving the interests of the ruling elite, especially through creating new electoral constituencies. Referring to the census 2017 (**Table 4**), the first possible reason cannot be supported in seven of the ten new cities. The table shows that the nine older cities provide services for 82% of the rural population while 18% are being served by eight new cities, and that two new cities are not assigned to districts. A similar argument can be made for the distance (reason #2), based on the multiple buffers shown in **Fig. 7**, in which the warmer the color the longer the distance. Indeed, several personal communications with the residents of the newer generation of cities revealed that the political reasons were the main driving force behind the decisions of urbanizing such settlements.

Table 4. The rural population ('000) served by seats of districts, according to the census of 2017

Older generation of cities	Pop.	Newer generation	Pop.
Al- Mansurah	620	Al-Matariyyah	36
Mit-Ghamr	662	Al-Jammaliyya	50
As-Sinbillawayn	457	Minyat An-Nasr	194
Talkha	292	Nabaruh	230
Dikirnis	264	Mit Salsil	31
Shirbin	360	Bani Ibayd	91
Aja	496	Timmay al-Imdid	179
Al-Manzalah	248	Al-Kurdi	0
Bilqas	410	Jamasah	0
		Mahallat Damanah	34
Total	3809	Total	845

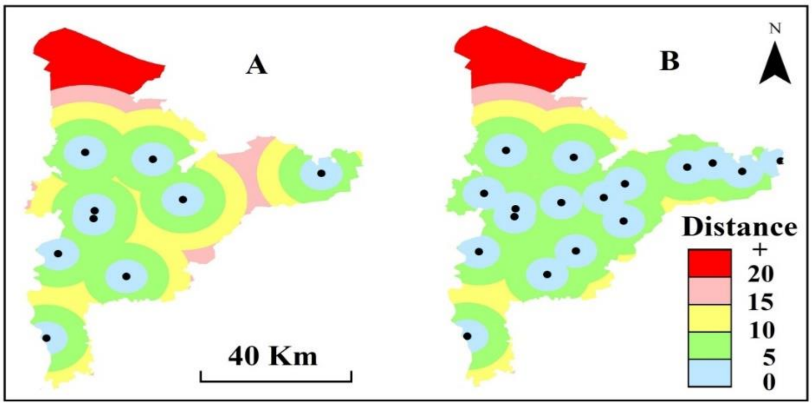


Fig. 7 Multiple buffers for the distances from the seats of districts: (A) Older generation of cities; (B) All cities.

To explore the growth of urbanization and its constituents, a good time series can be calculated only for the first generation cities (**Table 5**). For Al- Mansurah, The higher rates for the episodes1947-1960 and 1966-1976 were due to mere administrative decisions (the incorporation in 1960 of the two rural settlements of Jedilah and Sandub, and the additional incorporation in 1970 of Qolonjil village), and in the other episodes the rates were generally comparable to the national (rural + urban) rates, as there were no significant differences in fertility between the rural and urban population in Egypt.

The exceptional growth of Bilqas and Talkha could be explained by their new additional functions, with Bilqas as the base of the extensive land reclamation projects in the former *Barari* (i. e. the wasteland) of the Northern Delta, and Talkha as one of the emerging industrial cities of the Nile Delta with two power plants (236 and 420 MW) and a fertilizers complex.

The proportion of growth due to the rural-urban migration cannot be calculated, as the required data on internal migration is not available in the censuses of Egypt.

Table 5. Annual growth rates (%) of the cities of Daqahlia (1947 to 2017) using the exponential equation (void cells denote rural status)

Cities	1947-1960	1960 - 1966	1966 - 1976	1976 - 1986	1986 - 1996	1996 - 2006	2006 - 2017
Al- Mansurah	3.7	2.4	3.0	2.5	1.0	1.7	2.1
Mit-Ghamr	2.5	1.2	5.2	2.5	1.0	1.4	1.3
As-Sinbillawayn	2.7	1.7	1.8	2.0	1.8	1.9	2.1
Talkha	3.3	3.0	4.3	4.0	1.8	1.7	2.3
Dikirnis	2.2	2.9	6.9	2.5	1.9	1.4	2.5
Shirbin	2.8	1.4	2.5	2.2	1.4	1.8	1.7
Aja	1.9	3.3	1.7	0.7	1.3	1.2	7.8
Al-Manzalah	2.1	2.2	2.9	2.2	0.9	2.2	3.7
Bilqas	4.2	3.6	2.0	3.8	1.9	0.8	2.2
Al-Matariyyah		2.2	4.0	1.8	1.9	1.3	3.3
Al-Jammaliyya					2.7	0.8	2.9
Minyat An-Nasr					5.2	1.5	2.2
Nabaruh						2.3	2.7
Mit Salsil						0.3	2.9
Bani Ibayd						1.1	2.7
Timmay al-Imdid						1.5	2.4
Al-Kurdi							3.9
Jamasah							6.6
Mahallat Damanah							
All cities of Daqahlia	4.0	2.1	3.3	3.4	2.5	1.7	2.6
All Egypt (rural and urban)	2.4	2.4	2.0	2.8	2.0	2.1	2.3

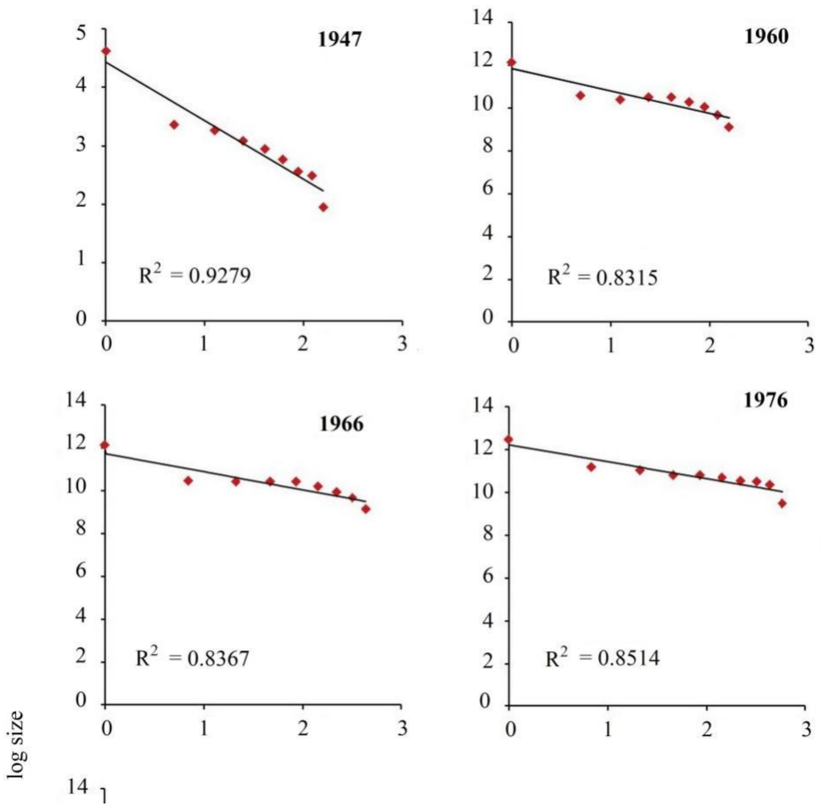
Table 6. shows that the annual growth rates are not strongly related, either negatively or positively, to the cities' sizes. In other words, the urban system of Daqahlia throughout the period 1947-2017 strongly adhered to Gibrat's law, which can, statistically, generate Zipf's law.

Table 6. Pearson's coefficient for the cities size and their annual growth rates

1947- 1960	1960 - 1966	1966 - 1976	1976 - 1986	1986 - 1996	1996 - 2006	2006 - 2017
0.48	-0.07	0.00	0.14	-0.27	0.17	-0.30

3.3 The Rank- size rule

Lumping together the data of the twin cities Al- Mansurah and Talkha as one metropolitan area, and omitting Jamasah as it is a resort, full of visitors in summer and hardly inhabited in winter, the data from eight censuses (1947 to 2017) (see Table 1) were used to construct the log rank *vs* log size plots, to test whether Zipf's law holds for the study area. The results are shown in **Fig. 8** and **Table 7.**



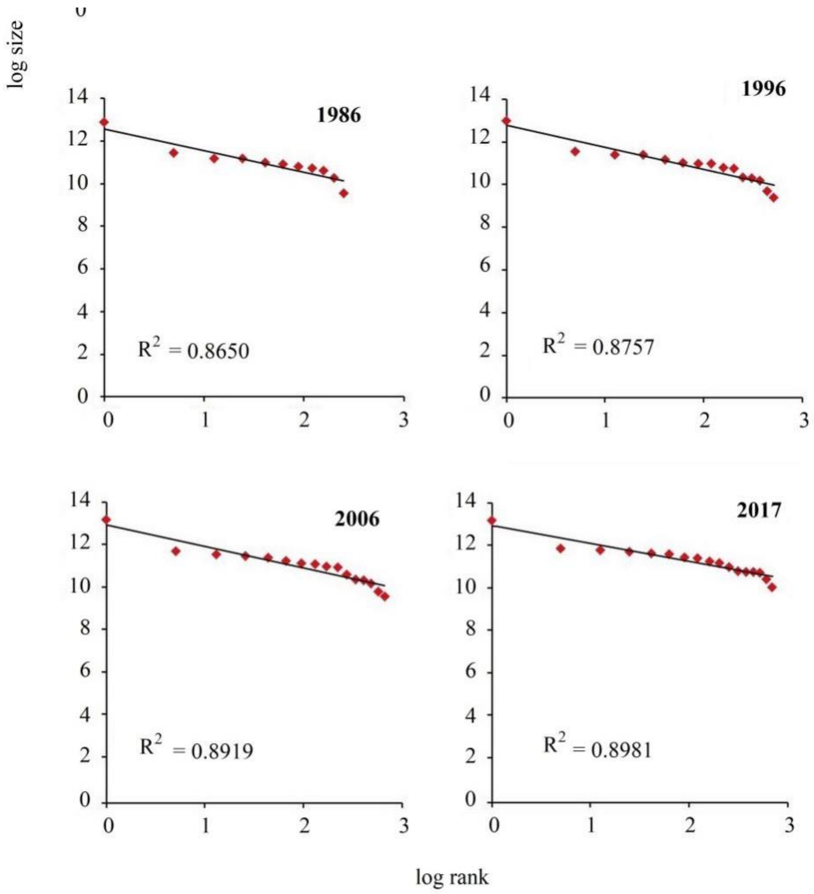


Fig. 8 log rank *vs* log size distributions of the cities of Daqahlia in eight censuses.

Table 7 the R^2 and the slope values of the log rank-log size plots

Census year	1947	1960	1966	1976	1986	1996	2006	2017
R^2	0.93	0.83	0.84	0.85	0.87	0.88	0.89	0.90
Zipf's exponent	- 0.93	- 1.00	- 1.00	- 0.94	- 0.85	- 0.86	- 1.03	- 0.97

The linear fit gives fair values of R^2 and exponent values equal to, or close to, 1. These results show that the cities of Daqahlia do follow a power-law, with an exponent satisfying the rank–size rule. Compared with the global Zipf's exponent of 0.66 (Fang et al. 2017b), or with exponents significantly larger than 1 documented in 29 studies (Nitsch 2005), or close to 2 for both India and China (Gangopadhyay & Basu 2009), and more than 2 for Brazil (Moura & Ribeiro 2006), the urban system under study seems to adhere well to the rank–size rule. However, Al- Mansurah-Talkha metropolitan area is always above the fitted line, and the lower tail cities are lying below the line. This state-of-affair suggests the testing of primacy as an alternative model. A comparable case of primacy is that of New York among the US cities (Chen & Zhou 2004), though the US city-size distribution strongly follows the rank-size rule over a long period of time.

3.4 Urban primacy and urban concentration

Using El-Shakhs (1972) formula (*vide supra*), the urban primacy index was calculated for five of the census years (**Table 8**). Recalling that the higher the value the higher the primacy, some conclusions can be drawn: (1) Al- Mansurah-Talkha exhibited a highly stable primacy index throughout the 70-years period, with a pronounced gap between it and all other urban centers; (2) the calculated index for each of the other cities (over all the cities with lower ranks) cannot be related to the classification of the city as belonging to the old or the new generation. Indeed, the case of Aja (see above) is an example of an old generation city of very limited primacy. The sole asset of Aja was its location as hub on the light railway network, dismantled in 1954. After that Aja became renowned for its small-scale canning industry; (3) the index for the cities of the highest rank (bottom of the columns) is not applicable using the formula.

Table 8 the urban primacy index using El-Shakhs (1972) formula

2017		1996		1976		1960		1947	
Al- Mansurah	0.88	Al- Mansurah	0.88	Al- Mansurah	0.85	Al- Mansurah	0.85	Al- Mansurah	0.84
Al-Matariyyah	0.51	Mit-Ghamr	0.52	Mit-Ghamr	0.43	Mit-Ghamr	0.33	Mit-Ghamr	0.41
Mit-Ghamr	0.51	Al-Matariyyah	0.48	Al-Matariyyah	0.38	Bilqas	0.34	As-Sinbillawayn	0.42
Bilqas	0.49	Bilqas	0.52	Bilqas	0.30	As-Sinbillawayn	0.39	Al-Manzalah	0.39
Al-Manzalah	0.49	As-Sinbillawayn	0.46	As-Sinbillawayn	0.35	Al-Matariyyah	0.47	Bilqas	0.39
As-Sinbillawayn	0.52	Al-Manzalah	0.39	Al-Manzalah	0.37	Al-Manzalah	0.45	Shirbin	0.41
Dikirnis	0.45	Dikirnis	0.43	Dikirnis	0.41	Shirbin	0.46	Dikirnis	0.42
Al-Jammaliyya	0.49	Al-Jammaliyya	0.49	Shirbin	0.59	Dikirnis	0.44	Aja	n a
Minyat An-Nasr	0.46	Minyat An-Nasr	0.48	Aja	n a	Aja	n a		
Shirbin	0.49	Shirbin	0.50						
Nabaruh	0.33	Nabaruh	0.31						
Mit Salsil	0.21	Mit Salsil	0.39						
Aja	0.24	Bani Ibayd	0.48						
Bani Ibayd	0.29	Aja	0.25						
Al-Kurdi	0.41	Timmay al-Imdid	n a						
Mahallat Damanah	0.36								
Timmay al-Imdid	n a								

An alternative model to the primacy is the urban concentration in the sense of Mutlu (1989). **Table 9** shows that the quantitative measure of concentration, the H-index, was steadily declining, meaning more cities and more competition within the urban system.

Table 9 the H-index of Mutlu (1989) applied to the study area

Census year	1947	1960	1966	1976	1986	1996	2006	2017
Number of cities	8	9	9	9	11	15	16	17
H-index	0.26	0.24	0.25	0.25	0.22	0.17	0.17	0.16

The two results about primacy and concentration should be considered as complementary rather than contradictory. Al-Mansurah-Talkha is still primate by its size, its high-quality health services, its educational institutions including two universities, the many factories, and the administrative bodies of the governorate level. However, competition with the smaller cities does exist in many aspects of services.

3.5 Nearest neighbor

The use of two options to calculate the nearest neighbor coefficient in ArcGIS 10.3 software yields a dispersed urban pattern, with p-value less than 0.01 (**Fig. 9**) in case of supplying the software with the area (the more accurate option), and p-value of about 0.03 using the default in which the program assigns a hypothetical rectangle as area boundary. This result is logical in view of the lack of the land cover types that may disrupt the settlement continuity. A consequence of this result is that the urban system seems to be balanced, and, with the urban primacy index results the system seems to be well mature.

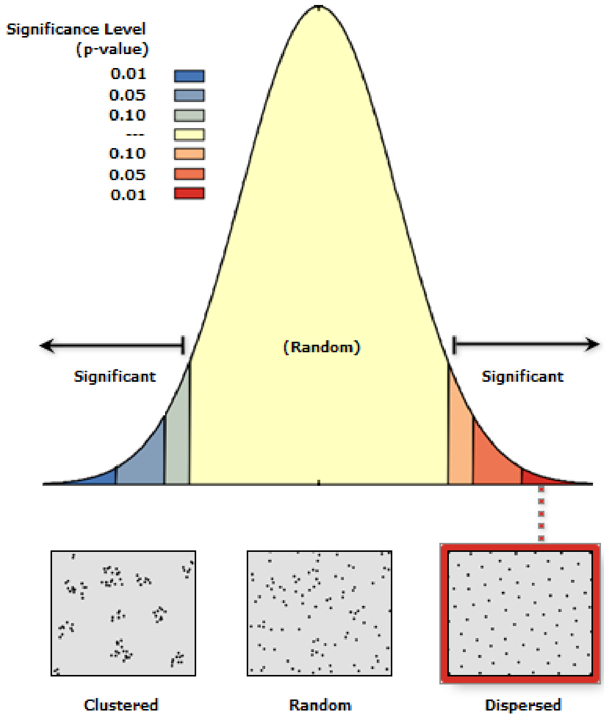


Fig. 9 Result of the calculation the nearest neighbor coefficient in ArcGIS 10.3.

3.6 Implications for further research

A major obstacle that hinders the research on urban geography of Egypt is the lack of reliable quantitative data on the interactions among the urban centers, the per capita GDP, the environmental quality, …etc. Studying the urban system of Daqahlia in terms of the concept of PURs is still almost an impossible task, as polycentricity should not be limited to its morphological component, i.e. the balanced size of cities, but equally important is the functional polycentricity, i.e. the balanced functional interactions within the system (Bartosiewicz & Marcińczak 2020). As noted by Burger et al. (2014), the empirical studies on PURs tend to examine only one type of functional relations among cities, and therefore, a cities system can appear to be polycentric if analyzed using one type of functional relations but monocentric using another type of relations. Indeed, the lack of data necessary for PURs analysis seems to be of global dimensions. With the exception of China (Liu et al. 2016, Wang 2021), the majority of empirical research on polycentricity has dealt with cases from Europe. Similarly, using Zipf's law to explore relations, as the relation between carbon emissions and the city development (e.g. Wei et al. 2021) is still hindered by the lack of data. For the researchers in urban geography of Egypt, there is still a lot of tasks to be done, foremost of which is the devise of suitable and parsimonious means of acquisition of data on the interactions within the urban system.

4. CONCLUSION

The use of the historical and the statistical data to study the urban system of Daqahlia reveals that, despite the increase in the city sizes and numbers throughout seventy years, the urban system seems to be mature and stable in terms of both rank-size and primacy. However, many research gaps are still to be filled, and this would depend on how creative the future researchers will be in gathering the required data. This paper may be the last to document the present-day urban system of Daqahlia, as the establishment of the New Mansoura City in 2017 will revolutionize the whole urban system. With two universities and world class hospitals, the city will alter most of the present day urban interactions. Additionally, the peoples native to Daqahlia were given priority to inhabit the new city, and thus, it is expected that the city sizes in Daqahlia would witness a re-adjustment process to accommodate the migration to the New Mansoura. However, the pace of these changes cannot be anticipated, as the city is still in its first stage of development.

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