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Geospatial distribution of under-five mortality in Alexandria, Egypt: a cross-sectional survey

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Abstract

Background Globally, infectious diseases, including pneumonia, diarrhea, and malaria, along with pre-term birth complications, birth asphyxia and trauma, and congenital anomalies remain the leading causes of death for under-five mortality (U5M). This study aimed to identify the geospatial pattern of U5M in Alexandria and its key determinants.

Methodology We analyzed the geospatial distribution of 3064 deaths registered at 24 health offices reported from January 1, 2018 to June 30, 2019. We adopted two methods of analysis: geospatial analysis and the structural equation model (SEM).

Result Neonates represented 58.7% of U5M, while post-neonates and children were 31.1%, 10.2%respectively. Male deaths were significantly higher compared to females ($P=0.036$). The main leading causes of U5M were prematurity (28.32%), pneumonia (11.01%), cardiac arrest (10.57%), congenital malformation (9.95%), and childhood cardiovascular diseases (9.20%). The spatial distribution of U5M (including the most common three causes) tends to be clustered in western parts of Alexandria (El Hawaria, Bahig, Hamlis, and Ketaa Maryiut). SEM showed the total effects of exogenous and intermediate variables on U5M. The U5M proportionately increased by living in rural areas (8.48), followed by crowding rate (8.35), household size (1.36), population size (0.52), and illiteracy average (0.06). On the contrary, the U5M decreased with increasing access to sanitation (-0.17) and access to drinking water (-4.55).

Conclusion Illiteracy, and poor locality characteristics (household size, population density, and access to water supply and sanitation) were statistically significant predictors of U5M.

Keywords Geospatial distribution, Infant mortality, Under-five mortality, Pneumonia, Environmental risk factors, Infectious diseases, Egypt

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Background

The World Health Organization (WHO) defined under-five mortality (U5M) as the probability that a child born in a specific year or period will die before reaching the age of 5 years, subject to the age-specific mortality rates of that period and expressed in terms of the number of deceased children, out of 1,000 live births [1]. Globally, the U5M rate declined by 61%, from 93 deaths per 1,000 live births in 1990 to 37 in 2020 [2]. Sub-Saharan Africa carried more than half of that burden with 2.8 million under-five deaths (53%), followed by Central and Southern Asia with 1.5 million (28%) [3]. In the Middle East and North Africa, U5M decreased from 66 per 1000 live births in 1990 to 21 per 1,000 live births in 2020 [4]. In Egypt, there was a notable decline in U5M from 87 in 1990 to 19 to 19 per 1,000 live births in 2020 [5].

Globally, infectious diseases, including pneumonia, diarrhea, and malaria, along with pre-term birth complications, birth asphyxia and trauma, and congenital anomalies remain the leading causes of U5M [6]. Other factors includ child characteristics as sex of child [7, 8], birth order [9, 10], birth weight [11], child immunization [12], and breastfeeding [13, 14]; and maternal characteristics as mother's age [15], mother age at first birth [16, 17], mother's education [10], and contraceptive use [18]. In addition, environmental factors such as access to drinking water and sewage disposal [19] together with social factors such as household, social class, household, and employment status [11, 20] have an impact on children's survival. At the national level, economic conditions in terms of household poverty and income per capita are considered among the key predictors of U5M, being associated with access, availability, accessibility, and quality of health services and healthy diet [21, 22].

In 2015, the world began working toward a new global development agenda, seeking to achieve, by 2030, new targets set out in the Sustainable Development Goals (SDGs). The proposed SDG target for child mortality aims to end, by 2030, preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 deaths per 1,000 live births and U5M to at least as low as 25 deaths per 1,000 live births [2]. However, the rate of progress towards these goals significantly varied at the international and national levels, demonstrating an essential need for tracking even more local trends in child mortality [23].

A geographical information system (GIS) is defined as a "computer-based system for gathering, editing, integrating, visualizing, and analyzing spatially-referenced data" [24]. They contain the geographic dimensions of specified geographical areas [25]. This enables the mapping and analysis of spatial data, which may then be employed in business, market research, government, and other fields. Health GIS are integrated systems that include capabilities for maintaining, querying, analyzing, and displaying spatially-referenced health data [26]. GIS databases contain both spatial and non-spatial data, allowing for a better understanding of their interactions through a series of geographical thematic elements. Geographical locations are precisely defined by spatial data. Using GIS, street addresses and coordinates are converted to a specific point on a map [27].

Nation-wide interventions to reduce U5M are costly, especially in developing countries, and hence interventions need to target only essential risk factors in high-risk areas. Despite the decline the U5M in Egypt, certain governorates are still suffering from high U5M, including Cairo (32.11 per 1000 live births), Assiut (28.69 per 1000 live births), and Alexandria (27.65 per 1000 live births) [28]. For that, mapping and geospatial analysis applied to U5M data will the help decision-makers to effectively comprehend the inter-relation interrelation between maternal, child, and household characteristics and how they co-integrate with different underlying factors to influence the survival probability of under-five in different Egyptian governorates. Based on our knowledge, there is only one study done in Egypt to investigate the aggregation of U5M from 1996–2001 using the GIS [29]. We, therefore, aimed to expand the evidence from the previous study, using the geospatial and traditional statistical modeling approach, to specify the hot spots for U5M and identify their associated key risk factors in Alexandria Governorate in Egypt.

Methods

Study setting

We conducted this study in Alexandria Governorate, which is the second-largest urban center in Egypt. It is divided into nine districts, in addition to the new satellite town (New Burg El Arab town). These nine districts are further subdivided into 21 sections, which in turn subdivided into 143 localities. (Supplementary Fig. S1) The total population of Alexandria was estimated to be 5.3 million, accounting for 5.2% of the total population in Egypt in 2019 [30]. Under-five children represented 12.1% of the total population of Alexandria. The urban population represents 98.7% of the total population living in Alexandria [31].

Data source

This study extracted data from the twenty-four health offices that cover different districts in Alexandria Governorate during the period from 01/01/2018 to 30/06/2019. Supplementary Fig. S2 illustrates the different phases of data processing. First, we developed an inventory of U5M based on registration data available at various healthcare offices. Second, a geo-database for the collected data was established and mapped U5M using the children's addresses. Third, we collected data on the hypothetical sociodemographic and economic factors at each locality from the Egyptian population census [32] and integrated them into the developed geo-database. Lastly, the developed geo-database was employed for counting the number of U5M per locality (administrative unit) through spatial join analysis.

Inclusion criteria for deaths

Outcome measure: U5M is defined as any deaths that occurred between birth and the fifth birthday [1]. It is grouped as follows [33]: Neonatal mortality: any deaths within the first 28 days of life, Post-neonatal mortality: the difference between infant and neonatal mortality, Infant mortality: any deaths between birth and the first birthday, Child mortality: any deaths between the exact age of one and five years.

Exclusion criteria

As Alexandria is a referral center for three governorates (Behira, Kafer El-Sheikh, and Marsa Matrouh), we excluded any deaths from these 3 governments, that occurred in Alexandria, while children were receiving medical services. Moreover, any deaths with unspecified housing addresses were excluded.

Predictors of under-five mortality

Characteristics of the child

Age (in days), sex, address, and date of birth, data on causes of death were collected and coded according to the 10th International Classification of Diseases version 10 (ICD 10) [34], and characteristics of the residents in the locality: illiteracy rate, and characteristics of the locality: household size, access to sanitation, access to drinking water, crowding index, and population density.

Statistical analysis

Descriptive analysis

Quantitative variables were summarized as mean ± standard deviation [35] if the data is normally distributed and as median (interquartile range (IQR)) if the data was non-normally distributed. Qualitative variables were presented with percent and frequency.

The spatial and non-spatial statistical methods

The study employed two main statistical techniques (spatial and non-spatial analyses) to explore the risk and protective factors of U5M in Alexandria.

Spatial statistical methods The crude distribution of U5M in Alexandria was first illustrated using the heat map. Then, the spatial pattern of U5M was examined and evaluated through spatial autocorrelation analysis (Moran's I index) which highlights whether the spatial pattern was clustered, dispersed, or random. The analysis involved calculating Moran's I Index value and both a z score and p-value to evaluate the significance of that index. To identify the weighting scheme that was employed in calculating Moran's I index, the inverse distance method was applied, where nearby neighboring features have a larger influence on the computations for a target feature than features that are far away [36]. Hot spot analysis was then performed to delineate those localities with statistically significant hot and cold spots in U5M. For any locality to be a statistically significant hot spot, it should have a high value and be surrounded by other localities with high values as well. Hot spot analysis identified statistically significant hot spots and cold spots through the Getis-Ord (G_i^*) statistic for each feature (locality) in the dataset. Based on this analysis, a z-score for each locality in Alexandria was returned, where significant positive z-scores refer to the more intense clustering of high values (hot spot) and significant negative z-scores indicates more intense the clustering of low values (cold spot) [37].

Non-spatial statistical methods We used the structural equation model (SEM) [38] to identify the different latent variables using one or more observed variables and to impute the relationship between latent variables. Furthermore, SEM was used to test the interaction between the different sociodemographic and environmental determinants (predictors) with the recorded U5M for each locality. We used Normed fit index (NFI > 0.9), Goodness of fit index (GFI > 0.9), Comparative fit index (CFI > 0.9), and Root mean square error of approximation (RMSEA < 0.05) as model fit indicators. We utilized the partial least square-based SEM (PLS-SEM) to solve the multicollinearity between the different predictors. The variables included in the model were distributed as follows: (Supplementary Fig. S3); Exogenous variables: urban/rural, population in thousands, and household size, intermediate variables: crowding rate, illiteracy average, access to sanitation, and access to drinking water, and dependent variable: U5M.

Results

Descriptive statistics

The total recorded deaths of under-five children during the study period (2018–2019) in Alexandria were 3064. During data validation, 140 deaths were excluded as

Table 1 Age and sex distribution of under-five deaths in Alexandria, Egypt

Determinants	Total (*n* = 2924)	Infant mortality (*n* = 2627)		Children mortality (*n* = 297)	Significance
		Neonatal (*n* = 1717)	Post-neonatal (*n* = 910)		
Characteristics of the children					
Mean age at death in days	15 (3–92)	4 (1–10)	90 (51–174)	858 (522–1440)	–
Sex					
Male	1557 (53.2)	937 (54.57)	453 (49.78)	167 (56.23)	0.04
Female	1367 (46.8)	780 (45.43)	457 (50.22)	130 (43.77)	

they were not living in Alexandria, or they had unspecified housing addresses. A total of 2924 deceased children were included in the final analysis. Among those who died, 1717 (58.7%) were neonatal deaths, 910 (31.1%) were post-neonatal deaths, and 297 (10.2%) were children's deaths. More than half (53.2%) were males. The percentage of males who died in the children's age group (1–5 years) was 56.2% and 54.6% died during the neonatal stage. There was a significant association between child sex and U5M ($p = 0.04$) (Table 1).

Table 2 shows the median (IQR) for the characteristics of residents; illiteracy rate [16.90 (8.65–29.02)]; characteristics of locality; household size [3.81 (3.56–4.07)], access to drinking water [99.43 (92–74-99.72)], access to sanitation [99.37 (97.24–99.63)], crowding index [1.14 (1.02–1.26)], and population size [14789 (5009–58228)].

Distribution of U5M in different localities of Alexandria

Figure 1 illustrated that the highest numbers of U5M were reported from the newly developed areas (Western, Southwestern, and Eastern parts) of Alexandria. The lowest number of U5M was observed in the inner old parts of the city.

Further evaluation of the distribution pattern of U5M by spatial autocorrelation revealed that there was a significant clustering of U5M in certain localities. Accordingly, hot spot analysis was done, and we identified two cold spots involving 26 localities in the northeastern and middle parts of Alexandria, while a hot spot was noticed in the western parts of the city including four localities: El Hawaria, Bahig, Hamlis and Ketaa Maryiut (Fig. 2).

Table 2 Distribution of residents and locality criteria in Alexandria

Variable	Median (IQR)
Illiteracy rate	**16.90 (8.65–29.02)**
Household size	3.81 (3.56–4.07)
Access to drinking water	99.43 (92–74–99.72)
Access to sanitation	99.37 (97.24–99.63)
Crowding index	1.14 (1.02–1.26)
Population size	14,789 (5009–58228)

The main causes of death among U5M in Alexandria

Figure 3 showed that prematurity was the most common cause of mortality among under-five children (28.3%), followed by pneumonia (11.01%), cardiac arrest (10.67%), and congenital malformations (9.95%). Table 3 showed that prematurity was the main cause of death among the infant age groups (40.36% and 14.84%, for neonatal and post-neonatal, respectively), while accident/drowning/fall/suffocation was the main cause of death among children age group (20.07%).

Geospatial distribution of the main causes of death among U5M in Alexandria

Figure 4 demonstrated that there was a significant spatial distribution of the three main causes of death among U5M (prematurity, pneumonia, and cardiac arrest) in Alexandria. However, the distribution pattern of cold and hot spots among the three leading causes showed a certain level of similarity, where two cold spots were identified in the northeastern and middle parts of Alexandria, while one hot spot was identified in the western parts of the governorate.

Determinants of the U5M

The final SEM model demonstrated good model-data-fit, i.e., RMSEA = 0.01, GFI = 0.95, NFI = 0.96, and CFI = 0.97. Table 4 shows the total effects of exogenous and intermediate variables on U5M. The U5M increased proportionately by living in rural areas (8.48), followed by crowding rate (8.35), household size (1.36), population size (0.52), and illiteracy average (0.06). In contrast, the U5M decreased by increasing access to sanitation (-0.17) and access to drinking water (-4.55).

Discussion

Since 1990, significant global progress has been made in trimming childhood mortality. The total number of deaths among children under-five worldwide has decreased from 12.8 million in 1990 to 5 million in 2021 [39]. That is owing predominantly to lower

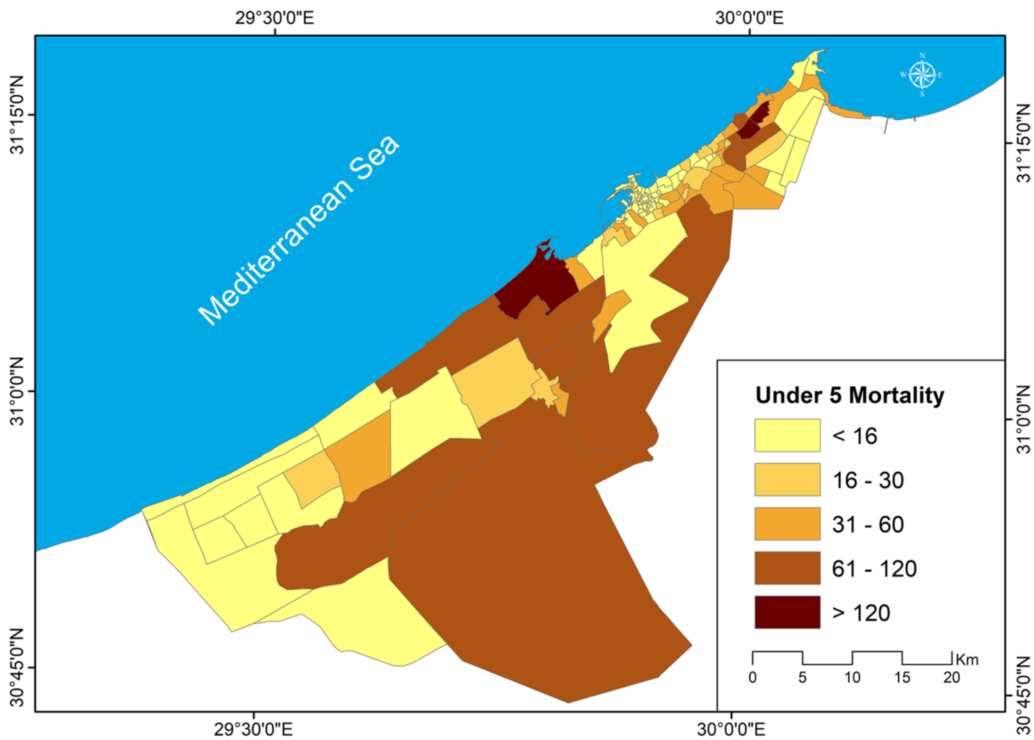

Fig. 1 Distribution of under-five mortality in Alexandria, Egypt

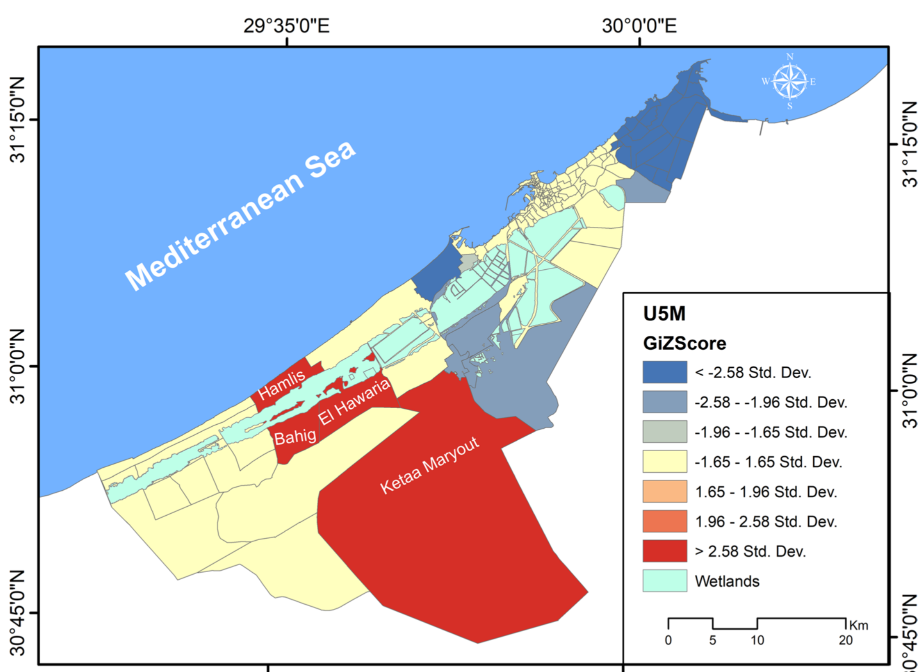

Fig. 2 Identified hot and cold spot areas of under-five mortality, Alexandria, Egypt

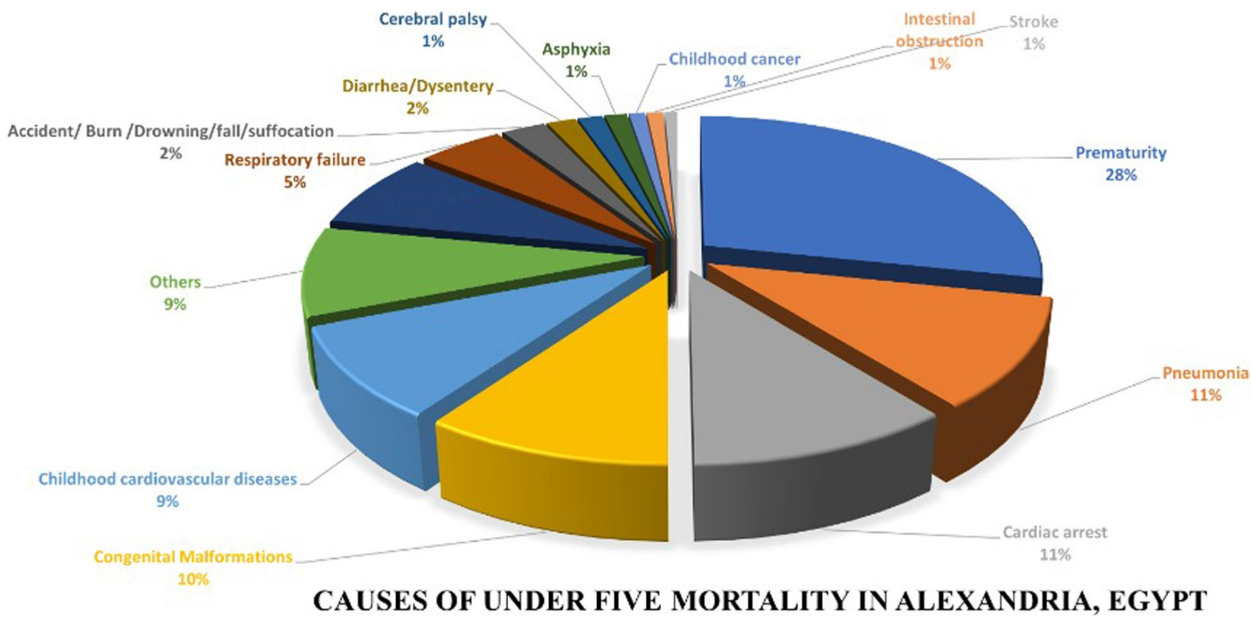

Fig. 3 Causes of under-five mortality, Alexandria, Egypt

Table 3 Different causes of deaths among under-five children according to the different groups

Cause of death	Neonates (< 29 days)		Post-neonates (29 days–< 1 year))		Children (1–4 years)	
	no	%	no	%	no	%
Prematurity	693	40.36	135	14.84	-	-
Pneumonia	143	8.33	135	14.84	44	14.81
Cardiac arrest	164	9.55	122	13.41	23	7.74
Congenital malformations	192	11.18	83	9.12	16	5.39
Childhood cardiovascular diseases	137	7.98	112	12.31	20	6.73
Others	100	5.82	115	12.64	48	16.16
Septic shock	140	8.15	68	7.47	21	7.07
Respiratory failure	83	4.83	51	5.60	6	2.02
Accident/Burn/Drowning/Fall/Suffocation	2	0.12	8	0.88	62	20.88
Diarrhea/Dysentery	4	0.23	33	3.63	11	3.70
Cerebral palsy	9	0.52	9	0.99	23	7.74
Asphyxia	28	1.63	8	0.88	1	0.34
Childhood cancer	2	0.12	11	1.21	14	4.71
Intestinal obstruction	11	0.64	15	1.65	1	0.34
Stroke	9	0.52	5	0.55	7	2.36

incidences of respiratory infections, diarrhea, premature birth problems, intrapartum-related events, malaria, and measles. The extent and trends of cause-specific mortality vary significantly among areas and for different strata of all-cause under-5 mortality [6]. This study investigated the geospatial distribution, the main causes of death, and the underlying risk factors of U5M in Alexandria, Egypt. We found that during the study period, there were 2924 deaths in Alexandria, more than half of them occurred among the neonatal age group. Moreover, there was an uneven pattern of U5M across the different localities of the governorate. The hot spot areas were clustered in the western parts of Alexandria, covering El Hawaria, Bahig, Hamlis, and Ketaa Maryiut localities. Prematurity, pneumonia and cardiac arrest were the main identified causes of U5M

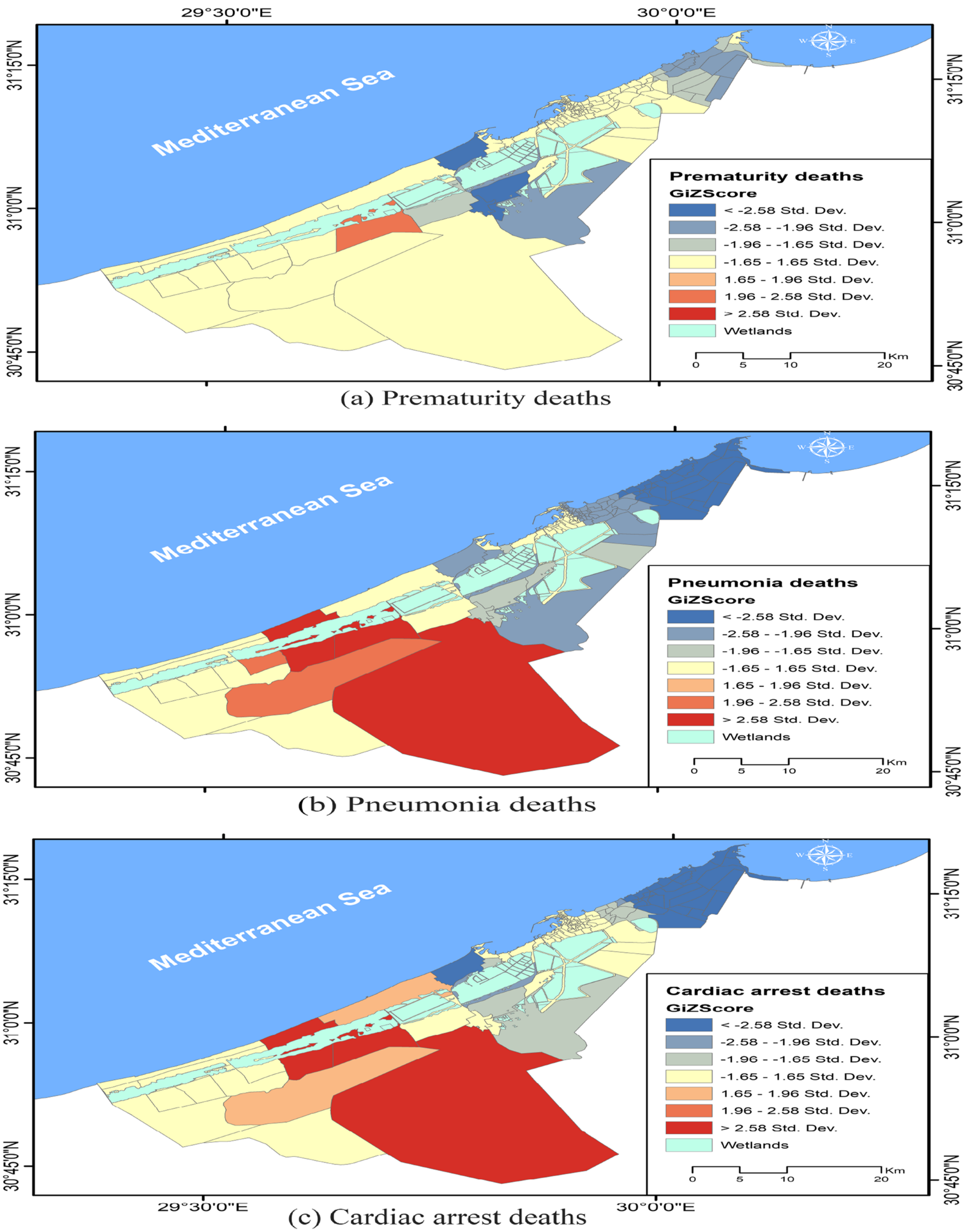

Fig. 4 Geospatial distribution of the main causes of under-five mortality in Alexandria, Egypt

Table 4 The total, direct, and indirect effects of the residents and locality criteria on under-five mortality

Variable	Total effect and direction	Direct effect and direction	Indirect effect and direction
Urban/rural	8.48	0.000	8.48
Population in thousands	0.52	0.514	0.004
Household Size	1.36	0.000	1.364
Crowding Rate	8.35	8.354	0.000
Illiteracy average	0.06	0.02	0.041
Access to sanitation	-0.169	-0.169	0.000
Access to drinking water	-4.552	0.000	-4.552

among the different age groups. The study demonstrated that low socioeconomic factors were clustered in areas with high U5M.

Li et al. [40] in their multicounty analysis of 64 low- and middle-income countries reported that neonatal deaths accounted for 53.1% of the total U5M. The neonatal share of deaths was lower in low-income countries at 44.0%, and higher in lower-middle-income and upper-middle income countries at 57.2% and 54.7%, respectively. This period is the most vulnerable one during child health as it is affected by maternal characteristics, child and birth characteristics, socio-demographic characteristics of the household, and mothers' and other caregivers' health care seeking behaviors.

Identifying the main causes of U5M is very crucial for heath input to determine the appropriate interventions for children's survival. Our study found that the most identified causes of death were prematurity and congenital malformation among the neonatal; prematurity, pneumonia, and cardiac arrest among the post-neonate; and accident/drowning/falling among children. This is consistent with other studies [41–46]. Small gestational ages and sick newborns are usually born prematurely with high risk of death. In addition, preterm birth is usually associated with congenital anomalies. In a study that was based on verbal autopsy to determine the underlying cause of death, Ghazy et al. [46] found that neonatal mortality, post-neonatal mortality, and child mortality accounted for 70.1%, 24.5%, and 5.4% of U5M in Alexandria, respectively. There was no statistically significant difference in cause-specific mortality fraction (CSMF) between males and females. Preterm delivery (57.3%), congenital deformity (17.3%), congenital pneumonia (10.8%), birth asphyxia (8.4%), and stillbirth (3.1%) were the most common underlying causes of death (UCODs) in neonates. Pneumonia (25.9%), childhood cardiovascular illnesses (22.8%), digestive system disorders (11.9%), and diarrhea and dysentery (7.8%) were the most commonly reported UCODs among post-neonates and children. Preterm delivery (40.2%) was the most common UCOD among U5M, followed by congenital deformity (12.1%), pneumonia (7.8%), congenital pneumonia (7.6%), childhood cardiovascular disorders (6.8%), and birth asphyxia (5.9%). Communicable diseases, maternal, neonatal, and nutritional diseases were responsible for 72.0% of U5M, whereas noncommunicable diseases and injuries were responsible for 25.7% and 2.4% of all U5M, respectively. Based on the finding of a systematic review on causes of U5M, there were 530 million deaths (95% CI 492–568) among children under the age of five, primarily due to preterm birth complications (17.7%, 16.1–19.5), lower respiratory infections (13.9%, 12.0–15.1), intrapartum-related events (11.6%, 10.6–12.5), and diarrhea (9.1%, 7.9–9.9), with infectious causes accounting for 49.2% (47.3–51.9). Vaccine-preventable deaths, such as lower respiratory infections, meningitis, and measles, accounted for 21.7% (20.4–25.6) of U5M, and many additional causes, such as diarrhea, may be avoided with low-cost interventions [6].

Findings from the current study demonstrated a relationship between factors reflecting the low socioeconomic class and hot spot areas of U5M. This could be due to difficulty to access the health services in remote areas, shortage of safe and adequate drinking water supply, and low sanitation level. This is in concordance with what was reported previously on the relation between social and environmental factors with children's survival [9, 47–49]. Low sociodemographic conditions at the individual, household, or at the community levels affect the level of maternal education, housing conditions, nutritional status, environmental pollution, family income, and exposure to injuries [30, 50–53].

Strengths and limitations of the study: the cointegration of the locality and population criteria data with the U5M in cross sectional and ecological studies can help the policy makers understand the causal pathways of the risk of U5M. In addition, including all deaths allover Alexandria allows proper assessment of death burden and different determinants. Nonetheless, there are several limitations to the study that are worth noting. First, the census data used for the analysis was a cross-sectional survey, and we cannot infer that the identified risk factors caused the death of the children. The study only showed that these risk factors were just associated with U5M. The true cause of death could only be determined by conducting an extensive death or verbal autopsy on all children under-five. However, the survey data used do not contain these children's autopsy reports, making it difficult to assess the cause, mode, and manner of death. Second, there is the possibility of recall bias as the Egyptian Population Census collects information from respondents about past events, behaviors, and health outcomes. Third, the short study period could affect the evidence rederived from our study. We intended to collect data of 2 years, however, due to the coronavirus 2019 (COVID-19) pandemic, data collectors were not able to visit the health care facility to collect data of the 2nd half of 2019.

Conclusions

In conclusion, this study identified that the western parts of Alexandria, covering El Hawaria, Bahig, Hamlis, and Ketaa Maryiut localities were the hot spots for U5M and the vast majority of those who died were neonates. This is mainly predisposed by factors reflecting low social class like illiteracy, and poor locality characteristics. That's necessitating more attention from the decision makers to pay attention to causes of deaths in hotspots. In addition, they have to makeshift contemporary technology as a step forward for tracking disease epidemiology. Finally, they should implement prevention programs and point out the significance of educational programs for parents and caregivers on the danger signs that impose seeking medical advice. It worth noting that high-quality cause and distribution of death estimates can help Egypt to expedite efforts to stop preventable child deaths and attain SDG 3.2 by 2030 with the continuous effort and investment.

Abbreviations

CFI	Comparative fit index
CSMF	Cause-specific mortality fraction
G_i*	Getis-Ord
GFI	Goodness of fit index
GIS	Geographical information system
ICD10	International Classification of Diseases version 10
IQR	Inter quartile range
NFI	Normed fit index
RMSEA	Root mean square error of approximation
SDGs	Sustainable Development Goals
SEM	Structural equation model
UCODs	Underlying cause of deaths
U5M	Under-five mortality
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43054-023-00221-7.

Additional file 1.

Additional file 2.

Additional file 3.

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Authors' contributions

RMG: conceptualization of research idea, writing and reviewing the manuscript, SA, NY: writing and reviewing the manuscript; EAH: reviewing the manuscript and data collection; AR, AS, MH: statistical analysis; EH, DM, ER, ME, AM, MT, SG; AH, PH, AZ: data collection and curation. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are included in this published article.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee at the High Institute of Public Health, Alexandria University, Egypt. All research activities were in accordance with the International Ethical Guidelines for Epidemiological studies [54].

Consent for publication

Not applicable.

Competing interests

The authors declare no conflict of interest.

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