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Under the Patronage and Honoring of HRH Prince Saud bin Nayef bin Abdulaziz, Governor of the Eastern Province: Saudi Cancer Foundation Successfully Launches "AlSharqia Wardiyah 18"

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Original Article

Modeling Cancer Incidence and Mortality in Yemen Using GLOBOCAN 2020 Estimates: An Empirical and Rank–Based Analysis

Gamal Abdul Hamid [1, 2], Amen Bawazir [3,4], Safa A. Shukry[2], Taher Bin Sumiat [5], Noureddine Ouerfelli [6]

[1] Hematology and Laboratory Department. Faculty of Medicine and Health Sciences, University of Aden, Aden, Yemen
[2] National Oncology Center, Aden, Yemen.
[3] College of Medicine. AlMaarefa University. Riyadh, Saudi Arabia.
[4] Community Medicine Department. Faculty of Medicine and Health Sciences, University of Aden, Aden, Yemen
[5] Seiyun University. College of Medicine. Hadhramout. Yemen
[6] Institut Supérieur des Technologies Médicales de Tunis, LR13SE07, Laboratoire de Biophysique et Technologies Médicales, Université de Tunis El Manar, Tunis, Tunisia.

Abstract

Background: Cancer is a growing public health concern in Yemen, yet comprehensive quantitative analyses of its epidemiology remain limited. This study provides an empirical, rank–based model of cancer incidence and mortality in Yemen using GLOBOCAN 2020 estimates, aiming to characterize the relationship between new cases and deaths and to evaluate the applicability of linear, logarithmic, and power–law models.

Methods: We analyzed GLOBOCAN 2020 data for Yemen, including 16,476 new cancer cases and 12,103 cancer–related deaths. Linear regression (forced through origin), logarithmic transformation, and power–law models were applied to model the relationship between the number of new cases (Nc) and deaths (Nd). A severity index (σ) derived from rank order was introduced, and cumulative risks were modeled. Comparisons with global and regional data were performed.

Results: Breast cancer was the most frequent malignancy (17.6% of cases), followed by colorectal cancer, leukaemia, stomach cancer, and non–Hodgkin lymphoma. The linear model yielded a mortality–to–incidence ratio of 67.74% ($Nd = 0.6774 \times Nc$). The logarithmic model provided an improved fit ($\ln Nd = 1.04565 \times \ln Nc - 0.62732$; $R \approx 0.986$), indicating a near–unity behavioral index ($\alpha = 1.04565$). A power–law model ($Nd = 0.53402 \times Nc^{1.04565}$) further confirmed this robust dependency. High–lethality cancers (oesophagus, liver, pancreas, and lung) showed mortality rates approaching 95%, whereas breast and thyroid cancers had lower ratios (56.6% and 26.3%, respectively). Rank–based analyses revealed exponential decay patterns, and a novel severity metric (σ) effectively stratified cancer burden.

Conclusions: The strong correlation between incidence and mortality in Yemen underscores a high overall cancer lethality, likely due to late–stage diagnosis and limited treatment access. Mathematical modeling, including power–law and severity indices, provides actionable insights for resource allocation and early detection priorities. Strengthening cancer registries and expanding screening programs are critical.

Keywords: GLOBOCAN Yemen 2020, cancer epidemiology, incidence and mortality, empirical modeling, rank–based analysis, severity metric, cumulative risk, age–standardized rates, power–law model.

1. Introduction

Globally, cancer remains a leading cause of morbidity and mortality, with an estimated 19.3 million new cases and nearly 10 million deaths in 2020 [1, 2]. Population aging, lifestyle factors, and environmental exposures drive this burden. Within this global context, Yemen

Corresponding author: Amen A. Bawazir, Faculty of Medicine and Health Sciences, University of Aden, Aden, Yemen, bawazir56@gmail.com, ORCID 0000–0002–6308–3136, Mail: P.O. Box 71666, Riyadh 11597, Office Phone: +966–112532828

presents a distinct epidemiological profile shaped by its young population, socioeconomic constraints, and a fragile healthcare system [3–5].

According to GLOBOCAN 2022 data, Yemen reported 16,476 new cancer cases that year, with projections indicating a substantial rise to 44,200 cases by 2050, alongside an age–standardized incidence rate of 97.0 per 100,000. During the same period, there were an estimated 11,900 cancer–related deaths in 2022, reflecting an age–standardized mortality rate of 76.5 per 100,000, which is anticipated to climb to around 33,300 deaths by 2050 [6].

Breast cancer is the most common malignancy overall, while colorectal and stomach cancers are prominent among males. These patterns reflect both global trends and region–specific determinants, including Tobacco use, infectious agents, Khat Chewing Practice, and dietary habits [3, 7, 8].

The Yemeni healthcare system faces severe limitations: shortages of diagnostic tools, uneven distribution of oncology services, and ongoing humanitarian pressures often result in late–stage diagnosis and poor survival [3, 9]. Despite descriptive data, there is a lack of comprehensive quantitative approaches to analyze the interplay between incidence, mortality, and cancer severity.

This study applies a rigorous modeling framework, including linear, logarithmic, and power–law regressions, rank–order analysis, and severity indices, to GLOBOCAN 2020 data for Yemen. Our objectives are to: (1) quantify the relationship between cancer incidence and mortality; (2) identify high–lethality cancers; (3) introduce a severity metric for comparative analysis; and (4) provide evidence–based recommendations for cancer control.

2. Materials and Methods

2.1 Data Source

Cancer incidence and mortality data for Yemen in 2020 were obtained from GLOBOCAN 2020 database, compiled by the World Health Organization's International Agency for Research on Cancer (IARC–Lyon) and presented in the Global Cancer Observatory (GCO) database (https://gco.iarc.who.int). This source provides standardized estimates of cancer burden worldwide, including the number of new cases (Nc), the number of deaths (Nd), and age–standardized rates.

Due to the absence of a comprehensive national cancer registry in Yemen, the GLOBOCAN estimates are partly based on modeling approaches using data from regional sources and incidence–to–mortality ratios derived from comparable populations. While these estimates represent the best available data, they may be subject to uncertainty and should be interpreted with caution.

Estimates are available in the GCO for 33 cancer types based on the International Classification of Diseases, Tenth Edition (ICD–10). The numbers of new cancer cases and cancer deaths were extracted for all cancers combined (ICD–10 codes C00–97/C44) and for 33 cancer types: Lip, oral cavity (C00–06), Salivary glands (C07–08), Oropharynx (C09–10), Nasopharynx (C11), Hypopharynx (C12–13), Oesophagus (C15), Stomach (C16), Colorectum (C18–C21), Liver (Including intrahepatic bile ducts) (C22), Gallbladder (C23), Pancreas (C25), Larynx (C32), Lung (including Trachea and bronchus) (C33–34), Melanoma (C43), Mesothelioma (C45), Kaposi sarcoma (C46), Breast (C50), Vulva (C51), Vagina (C52), Cervix uteri (C53), Corpus uteri (C54), Ovary (C56), Penis (C60), Prostate (C61), Testis (C62), Kidney (C64), Bladder (C67), Brain, central nervous system (C70–72), Thyroid (C73), Hodgkin lymphoma (C81), non–Hodgkin lymphoma (C82–86+C88), Multiple myeloma (C90), and Leukaemia (C91–95).

This study identified the five most prevalent cancers and their associated mortality rates in Yemen. In addition to the number of new cases and deaths, two measures of direct standardization are employed to facilitate comparisons between populations, adjusted for differences in age structures: age–standardized rates (ASRs) per 100,000 person–years and the cumulative risk of developing or dying from cancer before the age of 75 years.

The data were stratified by cancer type, sex, and age. This study utilized publicly available data from GLOBOCAN 2022; therefore, ethical approval was not needed. However, the study adhered to the Declaration of Helsinki and ethical guidelines for secondary data analysis.

2.2 Variables and Definitions

The analysis is based on the following key variables:

- **Number of new cases (Nc):** total incident cancer cases for each cancer type.
- **Number of deaths (Nd):** total cancer–related deaths for each cancer type.
- **Mortality–to–incidence ratio (Nd/Nc):** used as an indicator of cancer severity and lethality.

This ratio provides a simplified measure of survival patterns at the population level, where values approaching unity indicate high lethality and poor prognosis.

2.3 Statistical and Modeling Approach

To investigate the relationship between cancer incidence and mortality, several empirical modeling approaches were applied:

Linear regression model:

A linear model was used to evaluate the global relationship between Nc and Nd across cancer types[10]. The slope of the regression line represents the average mortality–to–incidence ratio.

Logarithmic transformation model:

A logarithmic model was applied to assess scaling behavior between incidence and mortality. This approach allows the estimation of a behavioral index (α), reflecting the degree of proportionality between Nc and Nd.

Power–law model:

The relationship between incidence and mortality was further analyzed using a power–law formulation, which enabled characterization of nonlinear dependencies and reinforced the interpretation of the logarithmic model.

The goodness of fit of the models was evaluated using the correlation coefficient (R), with higher values indicating stronger relationships between variables.

2.4 Analytical Framework

The analysis was conducted across major cancer types reported in GLOBOCAN 2020 for Yemen. Cancers were ranked according to incidence and mortality, and their respective mortality–to–incidence ratios were computed.

Based on the mortality–to–incidence ratio (MIR), cancers were classified into high–, moderate–, and low–lethality categories [11], a method commonly used to provide a comparative framework for assessing cancer severity and identifying priority areas for public health intervention across populations and cancer sites (See Table 3S).

3. Results

3.1 Descriptive Overview

In 2020, Yemen recorded 16,476 new cancer cases and 12,103 cancer–related deaths according to GLOBOCAN estimates (See Table 1S). Breast cancer was the most frequently diagnosed malignancy, followed by colorectal cancer, leukaemia, stomach cancer, and non–Hodgkin lymphoma. Together, these cancers account for a substantial proportion of the national cancer burden (See Table 2S).

Several cancers exhibited high mortality relative to incidence, particularly oesophagus, liver, lung, and pancreas cancers, suggesting advanced–stage diagnosis and limited therapeutic effectiveness.

3.2 Incidence–Mortality Relationship

Firstly, a strong linear relationship was observed between the number of new cases (Nc) and the number of deaths (Nd) across cancer types. The linear regression model indicates a global mortality–to–incidence ratio of approximately 67.74%, reflecting relatively high overall cancer lethality (Fig. 1).

$$N_d = \mu_r \cdot N_c \approx 0.6774 \cdot Nc \qquad (1)$$

Where the μ_r (=0. 6774) represents the national mortality–to–incidence ratio. It indicates that the community's cancer burden appears to be reduced (or adjusted) to about 67.74% of the core/reference value. This relationship suggests that, at the population level, mortality increases proportionally with incidence, with limited deviation across major cancer types.

Secondly, the suggested power–law model (Eq. 2) also confirms this dependency, indicating that variations in cancer incidence are closely mirrored by changes in mortality. This behavior reflects a relatively uniform structural relationship between disease occurrence and fatal outcomes across cancer types.

$$N_d = k \cdot N_c^{\alpha} \qquad (2)$$

Where α (=1.04565) is equivalent to a behavioral index of the mortality rate, which indicates the tendency of a cancer to generate deaths and it is dimensionless, and k (=0.53402) is equivalent to a consistency coefficient. The value of (k) less than unit inspires as that the number of deaths (N_d) is always less than the number of new cases (N_c), while the value of (α) lightly greater than unity indicates that the number of deaths (N_d) practically cannot exceed the number of new cases (N_c)

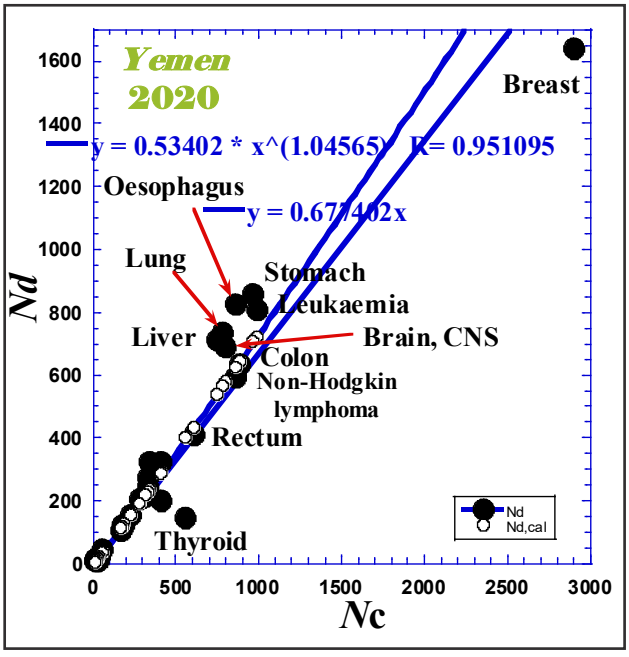


Figure 1. Dependence, linear and in power law, between the number of new cases (N_c) and the number of deaths (N_d) for Yemen 2020. Solid line: the first is the linear fit using Eq. 1, and the second is the fit in power law using Eq. 3.

3.3 Logarithmic and Power–Law Modeling

Logarithmic transformation of the Nc–Nd relationship (Eq. 3) resulted in a high correlation coefficient (R ≈ 0.986), indicating an excellent fit of the model (See Figure 3S). The estimated behavioral index (α ≈ 1.04565) is close to unity, suggesting a near–proportional scaling between incidence and mortality.

$$lnN_d = \alpha \cdot lnN_c - \beta \quad (3)$$

Where the two adjustable positive parameters have the following optimal parameters (α=1.04565) and (β=0.62732).

3.4 Cancer Severity Patterns

Firstly, the correlation between the ranks of the number of new cases (N_c) and the number of deaths (N_d), shows a sharp decrease with approximately an exponential behavior (Fig. 2).

Secondly, to observe this behavior in another manner, we suggest a new property (σ) derived from the rank (R_k), which can be named as severity, seriousness, or gravity, and expressed as follows:

$$\sigma = \frac{R_k}{R_k - 1} \quad (4)$$

We note that the severity (σ) becomes infinity when (R_k) tends towards the unit and (σ) becomes zero when (R_k) tends to infinity (Fig. 3).

The presence of a horizontal asymptote in Fig. 3 leads us to suggest the following expressions with only one adjustable parameter (γ_i), which respect the boundary conditions:

$$N_c = (N_{cmax} - N_{cmin}) \cdot (1 - e^{-\gamma_c(\sigma_c - \sigma_{min})}) + N_{cmin} \quad (5)$$

$$N_d = (N_{dmax} - N_{dmin}) \cdot (1 - e^{-\gamma_d(\sigma_d - \sigma_{min})}) + N_{dmin} \quad (6)$$

Where (σ_{min}) is the minimal severity corresponding to the maximum of the Rank ($R_{k,max}$ = 35 for Penis), ($N_{i,max} - N_{i,min}$) is the jump magnitude of variation of N_i (N_c or N_d) and (γ_i) is an adjustable parameter characterizing the rapidity to reach the maximum in Fig. 3 or how quickly the values of the number of new cases (N_c) or the number of deaths (N_d) fall with rank (R_k) in Fig. 1. This factor (γ_i) will be an excellent indicator for comparison between countries or an evolution index of one country from one year to another. Table 1 summarizes the optimal values of different parameters of (Eqs. 5 and 6).

Numerical application of (Eqs. 5 and 6) gives the following practical formulae (Eqs. 7 and 8, respectively) for Yemen 2020 data:

$$N_{c1} = 2894 \times [1 - \exp(-3.1 \times (\sigma_c - 1.029411765))] + 0 \quad (7)$$

$$N_{d1} = 1638 \times [1 - \exp(-3.7 \times (\sigma_d - 1.029411765))] + 0 \quad (8)$$

The mortality–to–incidence ratio (Nd/Nc) revealed substantial heterogeneity in cancer severity. Cancers such as the oesophagus, liver, pancreas, and lung exhibited ratios approaching unity, indicating very high lethality and poor survival outcomes (See Table 2S, Figs. 1S and 2S). In contrast, cancers such as breast and thyroid showed lower ratios, reflecting comparatively better prognosis. Intermediate levels of lethality were observed for colorectal cancer and non–Hodgkin lymphoma, suggesting potential benefits from improved early detection and treatment.

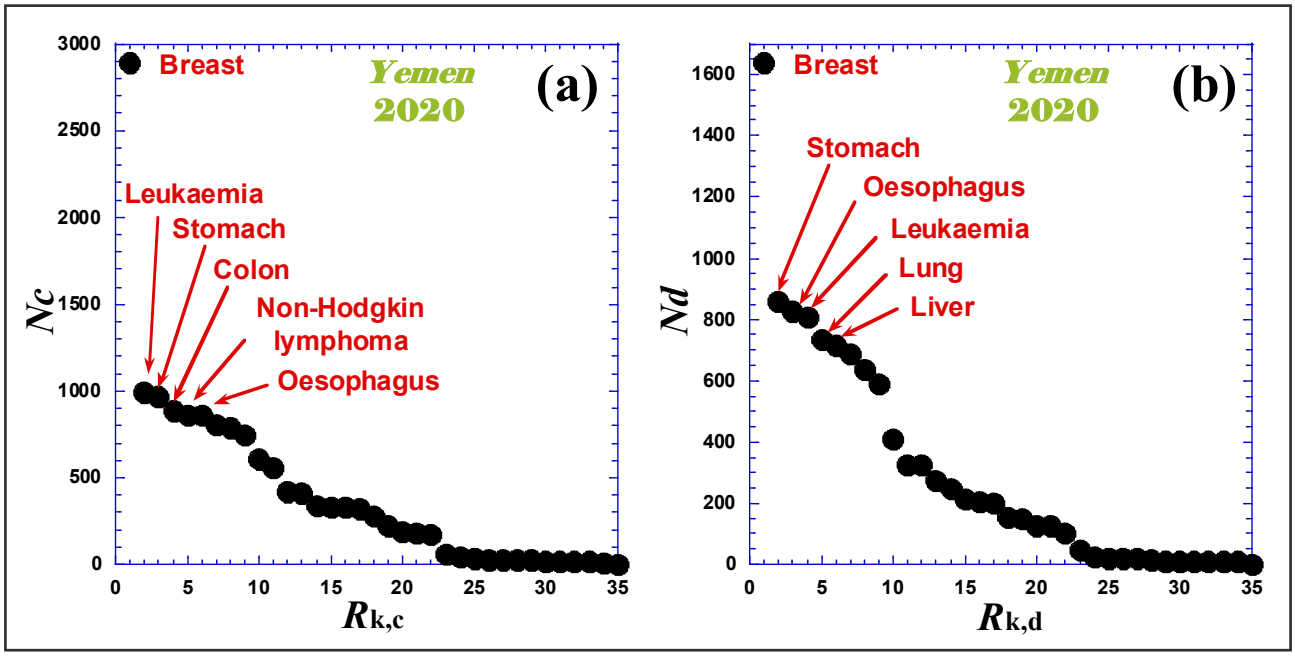


Figure 2. Correlation of the corresponding rank with (**a**): number of new cases (N_c) and (**b**): the number of deaths (N_d) for Yemen 2020.

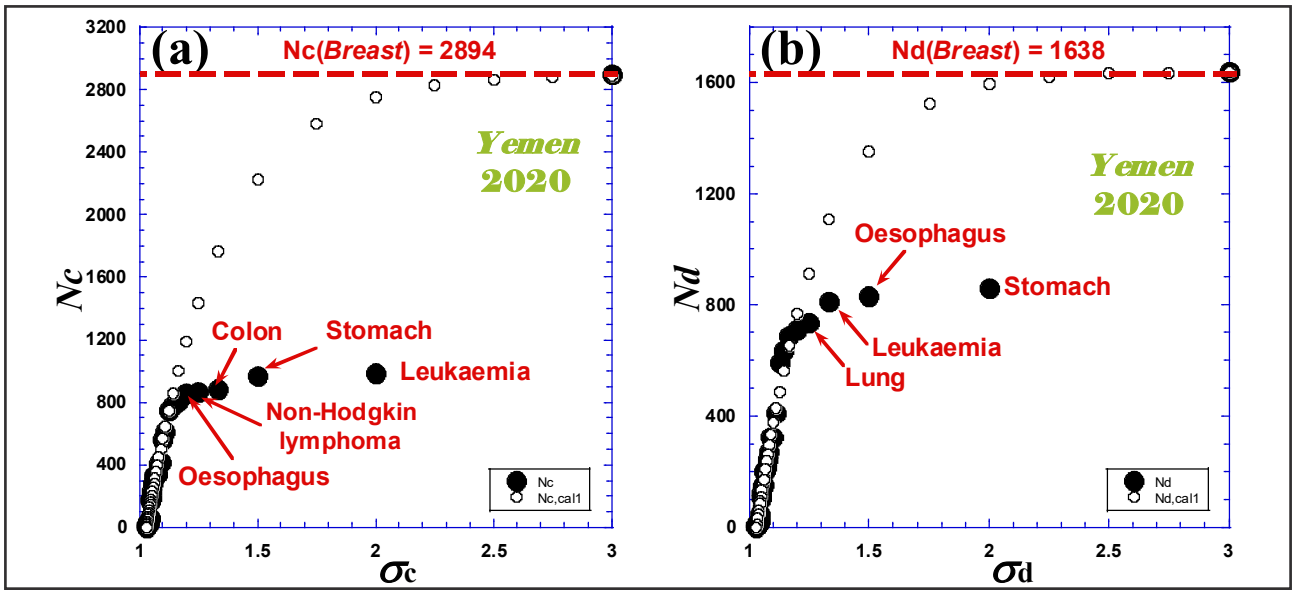


Figure 3. Variation with respect of the corresponding severity (σ) of; (**a**): the number of new cases (N_c); (●): effective values and (○): calculated ($N_{c,cal1}$) values by (Eq. 5); and, (**b**): the number of deaths (N_d); (●): effective values, (○): calculated ($N_{d,cal1}$) values by (Eq. 6) for Yemen 2020.

i	$N_{i,min}$	$\sigma_{i,min}$	γ_i	$N_{i,max}$	$\sigma_{i,\infty}$	$R_{ki,0}$
New cases (Eq. 5)	0	1.029411765	3.1	2894	3.0	1.500
Correspondence	Penis			Breast – Leukaemia		
Deaths (Eq. 6)	0	1.029411765	3.7	1638	3.0	1.500
Correspondence	Penis			Breast – Stomach		

Table 1. Optimal adjustable parameter values of (Eqs. 5 and 8) for Yemen 2020.

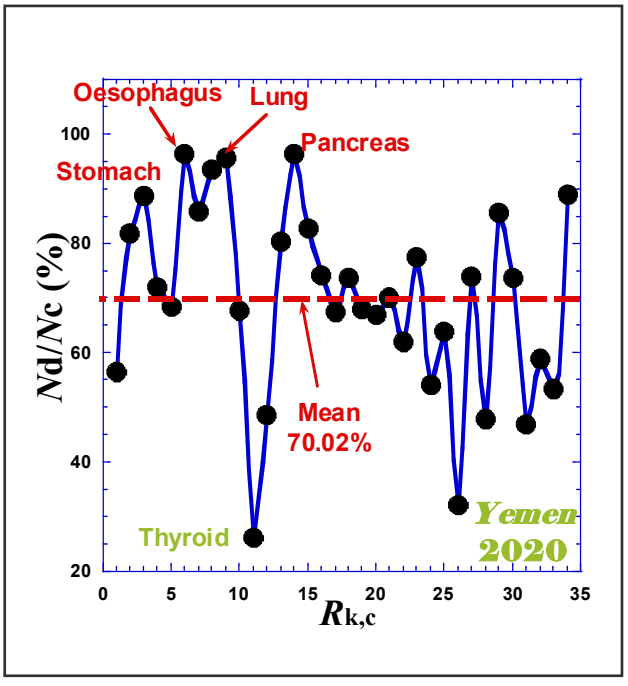


Figure 4. Variation of the ratio: number of deaths–number of new cases (N_d/N_c), with respect of the rank of new cases ($R_{k,c}$) for Yemen 2020.

Overall, these findings highlight distinct severity profiles across cancer types and emphasize the importance of targeted public health interventions based on disease–specific lethality. Globally, we can conclude that ($N_d \leq N_c$) and N_d/N_c = (70.02±3.01) %, indicating that, on average, approximately 60 % of new cases result in deaths (Fig. 4) .

In the other hand, the graphical representation (Fig. 5) of the cumulative risk with the corresponding number of new cases (N_c) and the number of deaths (N_d) shows that the trend of data points cannot be fitted in linear regression, and the dependency nature is mathematically quite complicated. However, the proposed linear equation written in (Fig. 5) and expressed by (Eqs. 9 and 10) is just a rough approximation to be used as a simple application, which can be interesting in practice for estimation or prediction in the case of the absence of other more efficient empirical models. Moreover, the suggested multiplicity coefficient (a_i) in (Eqs. 9 and 10) can also play an interesting role in comparison between countries or an index of evolution through time.

$$Cum.Risk(c) = a_c \times N_c \qquad (9)$$

$$Cum.Risk(d) = a_d \times N_d \qquad (10)$$

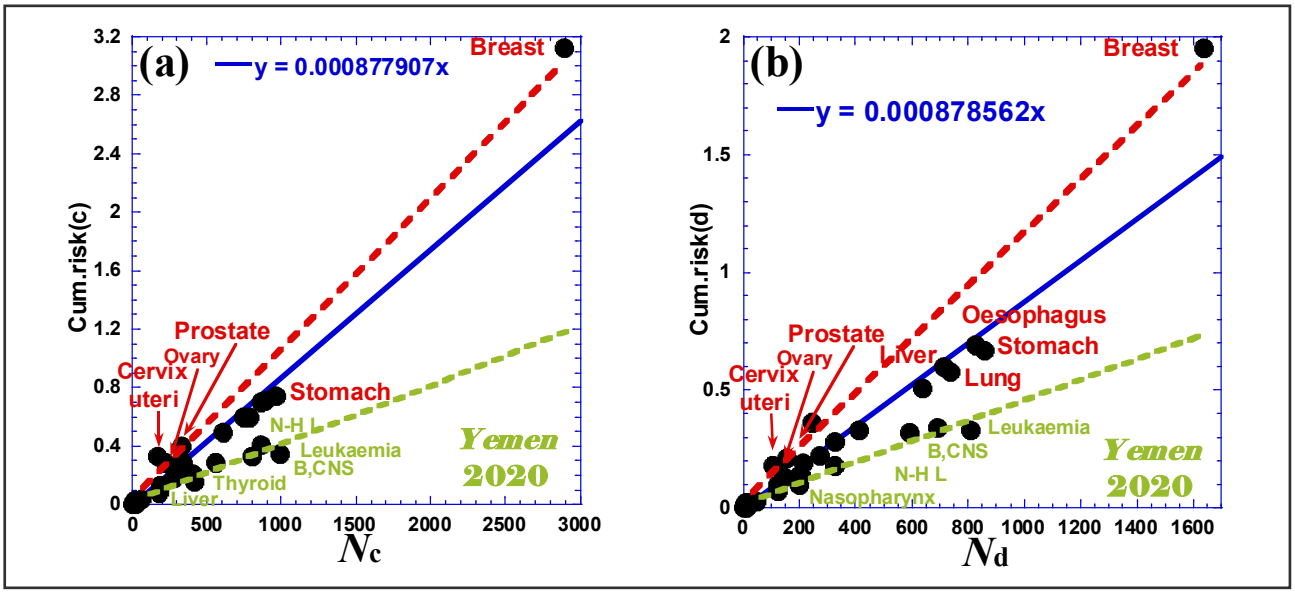


Figure 5. Correlation of the cumulative risk with the corresponding: (**a**) the number of new cases (N_c) and (**b**) the number of deaths (N_d) for Yemen 2020.

We note that the values of (a_c =8.779×10^{-4}) and (a_d =8.786×10^{-4}) represent the slope of the linear regression related to the global set of data (Fig. 5). Nevertheless, a deeper analysis shows that we can approximately classify by sub–group of cancers with similar or common features [see the two dashed (red and green) lines in Fig. 5]. Nevertheless, it needs future deep analyses by Oncology experts to uncover the nature or the classification of these sub–groups, for example, the red sub–group contains principally male and female organ cancers, while the green sub–group contains principally digestive and respiratory organs cancers. For example, cancers predominantly affecting reproductive organs tend to cluster in one subgroup, while cancers affecting digestive and respiratory organs, form another distinct cluster.

4. Comparative Analysis of Incidence and Mortality (Yemen *vs.* World)

In 2020, Yemen exhibited a distinctive cancer profile compared to global averages. While the world average mortality–to–incidence ratio often reflects a high proportion of late–stage diagnoses in developing regions, Yemen's specific ratio of 67.74% highlights a significant burden, particularly in high–lethality cancers like lung and colorectal malignancies.

The data reveal that the Age–Standardized Incidence Rate (ASR) for Yemen (97.0 per 100,000) is slightly lower than the global average, yet the risk of developing cancer before age 75 remains significant at 9.8%. Comparative modeling shows that while Breast cancer incidence in Yemen (17.6% of female cases) aligns with Arabic trends, the mortality rates for Colorectum cancer in males (ranking 1st in deaths) are disproportionately high compared to global male averages, largely driven by local tobacco consumption patterns.

4.1. Comparative Tables (Yemen *vs.* World 2020)

We present below three Comparative Tables, which can be interesting for comparison and inspiration, and see where the Yemen 2020 Situation is relative to the Worldwide 2020 average data (Table 2, & Fig. 6).

Summary–statistic 2020	Yemen/ World	Males	Females	Both sexes	Females/Males Ratio
Population (%)	**Yemen**	**50.376**	**49.624**	**100**	**0.98507**
	World	50.417	49.581	100	0.98342
Number of new cancer cases for 100,000 of the population	**Yemen**	**24.003**	**31.238**	**55.240**	**1.30142**
	World	129.125	118.377	247.502	0.91676
Number of deaths and cancer cases for 100,000 of the population	**Yemen**	**19.000**	**21.579**	**40.579**	**1.13574**
	World	70.928	56.823	127.751	0.80114

Table 2. Summary–Statistics of the top–most frequent cancers for (**Yemen &World 2020**) from https://gco.iarc.fr/today/home [1]

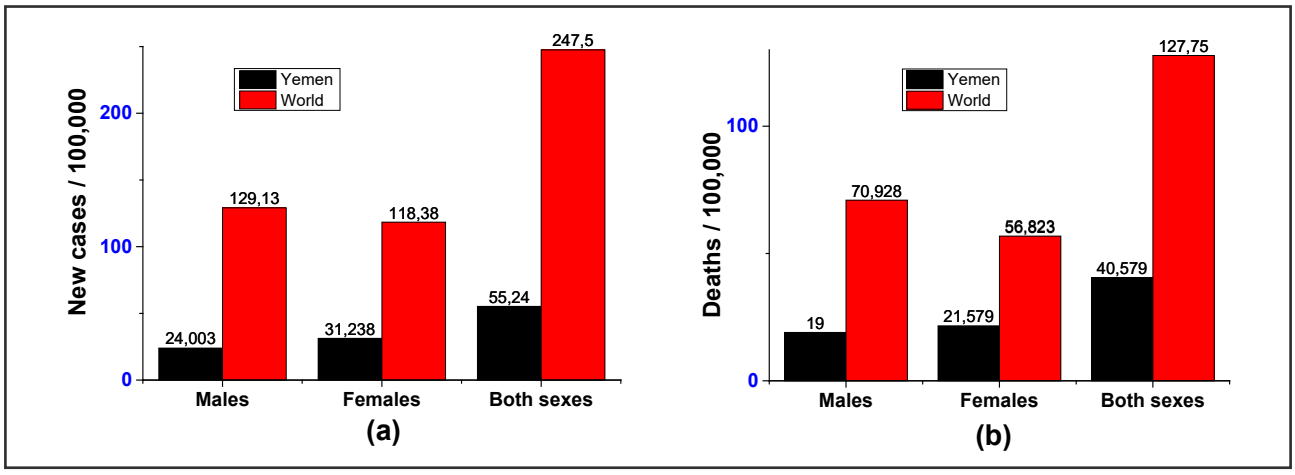


Figure 6. Summary–Statistics of the top–most frequent cancers for (**Yemen &World 2020**). (**a**): for new cases (N_c) and (**b**): for deaths (N_d), per 100,000 of population.

The 2020 IARC data reveals distinct variations in cancer profiles between Yemen and global trends, driven heavily by sex–specific differences. While breast and colorectal cancers rank as the top two most frequent malignancies for both sexes globally and in Yemen, the distribution diverges significantly among males and lower–ranked cancers (Table 3). Globally, male–dominated or tobacco–related malignancies like lung, prostate, and liver cancers lead among men and the combined population; in contrast, Yemen exhibits a high burden of hematological and gastrointestinal malignancies, with colorectal, stomach, and non–Hodgkin lymphoma (Non–HL) leading in males, and leukemia and stomach cancers ranking highly across both sexes.

Table 4 compares the ten leading cancer types by incidence and mortality in Yemen and globally in 2020. Breast cancer was the most common cancer and the leading cause of cancer–related deaths in Yemen, accounting for 17.6% of new cases and 13.5% of deaths, compared with 11.7% and 6.9%, respectively, worldwide. Several cancers, including leukemia, stomach cancer, esophageal cancer, non–Hodgkin lymphoma, and brain/CNS tumors, ranked higher in Yemen than globally in both incidence and mortality. In contrast, lung and colorectal cancers, which are among the most common cancers worldwide, contributed a smaller proportion of new cases and deaths in Yemen. These findings highlight a distinct cancer profile in Yemen, characterized by a relatively higher burden of hematological and gastrointestinal malignancies compared with global patterns.

We note that this method of comparison allows us to highlight the disparity between Yemen and the World average for the most frequent new cases of cancers when the ranks in Yemen is less than in the World (Figures 6Sa and 6Sb); likewise, for the most dangerous cancers to alerts which of the top cancers are more deadly, and this when the percentages in Yemen is greater than in the World (Figures 7Sa and 7Sb).

5.2. Model Parameter Comparisons

Table 5 display the comparison of parameter values of proposed models for the top new cases and deaths cancers site between Yemen &World 2020) from https://gco.iarc.fr/today/home.[1]

We conclude that in all cases and situations, the diagram shows promising results, both for new cancer cases and deaths. This is explained by the mortality–to–

Males		Females		Both sexes	
Yemen	World	**Yemen**	World	**Yemen**	World
Colorectum	Lung	**Breast**	Breast	**Breast**	Breast
Stomach	Prostate	**Colorectum**	Colorectum	**Colorectum**	Lung
Non–HL	Colorectum	**Oesophagus**	Lung	**Leukaemia**	Colorectum
Leukaemia	Stomach	**Leukaemia**	Cervix uteri	**Stomach**	Prostate
Brain, CNS	Liver	**Stomach**	Thyroid	**Non–HL**	Stomach

Table 3. Comparison between **Yemen &World 2020** for the top 5 most frequent cancers excluding non–melanoma skin cancer (*Ranked by cases*) from https://gco.iarc.fr/today/home.[1]

New cases					Deaths				
Cancer	Yemen		World		Cancer	Yemen		World	
	Rank	(%)	Rank	(%)		Rank	(%)	Rank	(%)
Breast	1	17.6	1	11.7	**Breast**	1	13.5	4	6.9
Leukaemia	2	6.0	14	2.5	**Stomach**	2	7.1	10	3.2
Stomach	3	5.9	12	2.4	**Oesophagus**	3	6.8	6	5.5
Colon	4	5.4	4	6.0	**Leukaemia**	4	6.7	11	3.1
Non–HL	5	5.2	12	2.8	**Lung**	5	6.1	1	18.0
Oesophagus	6	5.2	9	3.1	**Liver**	6	5.9	2	8.3
Brain, CNS	7	4.9	20	1.6	**Brain, CNS**	7	5.7	13	2.5
Lung	8	4.8	2	11.4	**Colon**	8	5.3	5	5.8
Liver	9	4.5	8	3.3	**Non–HL**	9	4.9	12	3.1
Rectum	10	3.7	7	3.8	**Rectum**	10	3.4	10	**3.4**

Table 4. Summary of top 10 new cases and deaths by cancer site (**Yemen &World 2020**) from https://gco.iarc.fr/today/home.[1]

incidence ratio in Yemen (67.74%), which is higher than the global average (~53.6%), indicating poorer survival outcomes.

5.3. Comparative Tables (Yemen *vs.* other Countries) in Globocan 2020

Table 6, compares statistical and mathematical modeling parameters across 21 countries against a global baseline [12–30]. The relative percentage ratios, core coefficients, and scaled adjustment factors show marked regional variation, with values ranging from very low levels in European cohorts to pronounced peaks in countries such as Mauritania and Vietnam, indicating strong local differences in the modeled phenomena.

4. Discussion

The present study provides a quantitative assessment of cancer epidemiology in Yemen by modeling the relationship between incidence and mortality using GLOBOCAN 2020 estimates. The results demonstrate a strong and consistent dependency between the number of new cases (Nc) and the number of deaths (Nd), as evidenced by both linear and nonlinear modeling approaches.

The linear relationship observed between Nc and Nd, with a global mortality–to–incidence ratio of approximately 67.74%, indicates a relatively high level of cancer lethality at the population level. This finding suggests that a substantial proportion of diagnosed cancer cases result in death, reflecting potential delays in diagnosis, limited access to treatment, and constraints within the healthcare system [31, 32]. Although Yemen's healthcare system was already fragile, the war has significantly exacerbated conditions, pushing the system into a severe state of collapse [33–35]. Such a pattern is consistent with settings where early detection programs and specialized oncology services are limited [3].

Eq. #	Yemen	World
1	$Nd \approx 0.67740 \cdot Nc$	$Nd \approx 0.53645 \cdot Nc$
3	$N_d = 0.53402 \cdot N_c^{\,1.04565}$	$N_d = 0.30874 \cdot N_c^{\,1.03067}$
7	$N_c = \Delta N_c\,(1 - e^{-3.1(\sigma_c - \sigma_{min})}) + N_{cmin}$	$N_c = \Delta N_c\,(1 - e^{-2.9(\sigma_c - \sigma_{min})}) + N_{cmin}$
8	$N_d = \Delta N_d\,(1 - e^{-3.7(\sigma_d - \sigma_{min})}) + N_{dmin}$	$N_d = \Delta N_d\,(1 - e^{-2.5(\sigma_d - \sigma_{min})}) + N_{dmin}$
…	$(ASR_i) = \mathbf{0.51842} \times (ASR_m) + \mathbf{1.780}$	$(ASR_i) = \mathbf{0.3824} \times (ASR_m) + \mathbf{2.6138}$
…	$ASR_m = 28.5 \cdot (1 - e^{-0.035 \cdot ASR_i})$	$ASR_m = 19.5 \cdot (1 - e^{-0.032 \cdot ASR_i})$

Table 5. Comparison of parameter values of proposed models for the top new cases and deaths cancers site between **Yemen &World 2020**) from https://gco.iarc.fr/today/home.[1]

Country	Ref.	μ_r (%)	N_d/N_c (%)	α	k	$a_c \times 10^5$	$a_d \times 10^5$
		Eq. 1		Eq. 6		Eq. 15	Eq. 16
World	17**	53.645	51.17	1.03067	0.30874	257.5	235
Yemen	*	**67.74**	**70.02**	**1.04565**	**0.53402**	**87.791**	**87.856**
Mauritania	29	69.41	72.79	0.96353	0.79502	674.9	636.2
Zimbabwe	22	63.2	67.34	0.9955	0.65936	227.08	225.06
Libya	15	57.222	60.6	1.0303	0.48698	102.74	77.229
Tunisia	26	58.968	56.11	1.06319	0.36423	102.74	77.229
Ghana	11,12	62.29	65.9	1.02212	0.55296	85.789	77.205
Sudan	24	53.405	63.37	1.01065	0.58152	62.112	59.764
Saudi Arabia	20	37.92	52.13	0.98109	0.51065	52.772	51.49
Algeria	32	44.85	56.25	1.02593	0.43696	39.86	34.73
Morocco	25	49.78	60.43	0.98402	0.61949	48.216	32.882
Romania	30	55.65	53.74	1.01291	0.4372	48.216	32.882
Poland	14	61.22	58.06	1.00105	0.51972	21.511	15.716
Egypt	13,23	72.23	57.07	1.08387	0.28968	17.026	14.833
Iran	27	60.29	62.3	1.04701	0. 36951	16.108	12.884
Turkey	28	62.88	48.78	1.06659	0.24672	14.587	12.134
Vietnam	31	81.02	60.11	1.0369	0.42413	11.688	10.696
Mexico	19	36.12	50.84	0.98299	0.50745	14.139	10.069
Bangladesh	18	76.04	63.36	1.05022	0.41077	9.188	8.773
Russia	21	51.75	52.76	1.00946	0.43347	6.7648	5.0597
Eastern Europe	31	52.99	53.45	1.00679	0.44701	3.1858	2.3575
India	30	64.29	68.62	1.01811	0.55509	1.2872	1.2296
Europe–27	16	42.17	46.35	1.03658	0.26352	1.8634	1.1143

Table 6. Comparative Tables (Yemen vs. other Countries) in Globocan 2020

* Present work. ** From Globocan 2020 data.

The logarithmic and power–law analyses further reinforce the robustness of this relationship. The behavioral index ($\alpha \approx 1.04565$), close to unity, indicates near–proportional scaling between incidence and mortality across cancer types. This suggests that increases in cancer incidence are closely mirrored by increases in mortality, with limited variability in survival outcomes between different cancers. From an epidemiological perspective, this behavior may reflect systemic factors affecting cancer management rather than cancer–specific biological differences alone [36].

Despite this overall proportionality, the analysis reveals marked heterogeneity in cancer severity. Malignancies of the oesophagus, liver, pancreas, and lung have mortality–to–incidence ratios close to 1.0, reflecting poor survival due to late diagnosis and limited treatment options. In Yemen, this burden is especially severe, with an age–standardized oesophageal cancer incidence rate of 6.4 per 100,000 (GLOBOCAN 2020) and mortality rates that nearly match incidence, highlighting major gaps in cancer care [4, 37]. In contrast, cancers such as breast and thyroid demonstrate lower mortality ratios, suggesting relatively better outcomes, potentially due to earlier detection or more effective treatment modalities.

Comparison to global pattern

While Yemen's incidence–mortality relationship mirrors the global pattern structurally, its overall lethality runs

higher, pointing to systemic gaps in early diagnosis and treatment and, consequently, weaker survival outcomes than the global norm. From a modeling perspective, Yemen's behavioral index ($\alpha \approx 1$) aligns with global trends, reflecting proportional scaling between incidence and mortality. However, the somewhat elevated mortality levels indicate a tilt toward greater lethality within this broadly universal relationship. This combination of near–proportional global behavior alongside cancer–specific variability reflects the dual character of Yemen's cancer burden. The strong overall incidence–mortality relationship reflects health–system limitations affecting cancers broadly, while variation in mortality ratios across cancer types points to disease–specific opportunities for intervention, particularly where earlier detection and treatment could meaningfully improve survival.

From a public health perspective, these findings underscore the importance of strengthening cancer control strategies in Yemen [3, 37, 38]. Efforts should prioritize the development of early detection programs, particularly for high–incidence cancers such as breast and colorectal cancer, as well as improved diagnostic and treatment capacity for highly lethal cancers. In addition, enhancing cancer surveillance systems and establishing robust national registries would improve data accuracy and support more effective policy planning.

Severity contrast

Unlike the global cancer landscape, which shows a roughly even mix of high– and low–lethality cancers [39], Yemen's profile is weighted more heavily toward highly lethal types, especially oesophageal, liver, and lung cancers. This difference points to gaps in early detection, healthcare access, and treatment availability. These contrasts illustrate how constraints within the healthcare system influence cancer outcomes [40]. As survival rates for many cancers continue to improve globally, Yemen's persistently high mortality highlights the urgent need for stronger cancer control efforts.

In summary, the integration of empirical modeling into cancer epidemiology provides valuable insights into the structure and severity of the cancer burden in Yemen. The strong dependence between incidence and mortality highlights systemic challenges, while the observed heterogeneity across cancer types points to targeted opportunities for improving cancer outcomes.

4.1 Limitations

The present study has several limitations. The analysis is based on GLOBOCAN 2020 estimates for Yemen, which are partly modeled due to the absence of complete national cancer registry data, with mortality estimates derived from incidence–to–mortality ratios of neighboring countries, thereby introducing notable uncertainty in the reported figures. Furthermore, the modeling approach operates at the population level and focuses on aggregate relationships, which carries the risk of ecological fallacy and prevents direct application to individual risk prediction; it also does not account for age–specific patterns, stage at diagnosis, or treatment variability. Additional constraints include the exclusion of competing risks in cumulative risk calculations, a simplification that overestimates cancer risk in older populations, as well as the use of cross–sectional data, which cannot distinguish between cohort effects, period effects, or temporal changes in healthcare access. Finally, the severity index and swiftness factors are specific to Yemen's 2020 distribution and may not generalize to other countries without recalibration, limiting the external validity of the findings.

6. Conclusion

The present study demonstrates that cancer incidence and mortality in Yemen exhibit a strong and consistent relationship that can be effectively captured using empirical modeling approaches. The high global mortality–to–incidence ratio (≈67.74%) reflects a substantial level of cancer lethality, likely associated with late–stage diagnosis and limited access to specialized care.

The near–proportional scaling between incidence and mortality, as indicated by a behavioral index close to unity ($\alpha \approx 1.04565$), suggests that increases in cancer burden are closely mirrored by mortality outcomes across cancer types. At the same time, marked heterogeneity in mortality–to–incidence ratios highlights important differences in cancer severity, with certain malignancies such as oesophagus, liver, lung, and pancreas exhibiting extremely poor prognosis.

These findings underscore the need to strengthen cancer control strategies in Yemen, particularly through improved early detection, enhanced diagnostic capacity, and expanded access to treatment. In addition, the development of robust cancer surveillance systems remains essential for improving data quality and supporting evidence–based decision–making.

Overall, the present work illustrates the value of integrating quantitative modeling into cancer epidemiology to better understand disease dynamics and inform public health priorities in resource–limited settings.

Declarations

Data Sources: The data supporting the present study are publicly available and can be accessed at the Globocan 2020 platform of the Global Cancer Observatory:

https://gco.iarc.fr/today/home. This database provides comprehensive cancer statistics, including incidence, mortality, and prevalence estimates for various countries, including Yemen.

Ethics Statement: The present study utilized publicly available data from the Globocan 2020 database of the Global Cancer Observatory (https://gco.iarc.fr/today/home). As the data are deidentified and aggregated at the population level, no ethical approval was needed. The study adheres to all ethical guidelines for the use of publicly accessible data and ensures that the information is used solely for academic and research purposes to inform public health strategies.

Conflicts of Interest: The authors declare that they have no conflicts of interest in the present work.

Data Availability Statement: All necessary data are included in the present work; extra data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Modeling suggestions NO, AB, Parameters optimization AB, NO, writing original draft GA, NO, AB, Supervision GA, Conceptualization AB, TB, SA S Methodology AB, NO, Software NO, Validation AB, NO, Formal analysis GA, NO, Investigation AB, TB, Data curation SA S, TS, Writing–review & editing AB, GA, NO, Visualization SA S, TB, Resources investigation AB, T B.

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