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# Spatio-temporal trends in COVID-19 morbidity and mortality due to elderly: a global perspective

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**COVID-19 spread worldwide after emerging at the end of 2020 with a higher spread and death among the elderly and varies across the continent and country. This study aimed to investigate the spatio-temporal trends in COVID-19 morbidity and mortality due to the elderly. COVID-19 infected cases and death data were converted into morbidity and mortality rates per 1,000 population. Thematic maps were used for spatial illustration over time. Linear and Theil-Sen regression models were used to estimate the rate of change in COVID-19 morbidity and mortality due to the elderly. The results revealed a significant relation and change in the global COVID-19 morbidity and mortality rates due to the elderly population (p-value < 0.05). Europe experienced the highest rate of change in COVID-19 morbidity due to the elderly population, followed by Oceania and North America. Moreover, the elderly proportion had the greatest rate of change in COVID-19 mortality in North America, followed by Europe and Africa. The results of this study will enable researchers and experts for data-driven decisions that are more resilient. Moreover, it enables healthcare experts and policymakers to develop guidelines to improve preparedness for future pandemics.**

**Keywords** COVID-19, Morbidity, Mortality, Elderly, Spatial and temporal trend, Theil-Sen regression

During the COVID-19 pandemic from January 2020 to May 2024, there have been over 704 million COVID-19 infections and more than 7 million COVID-19-attributable deaths worldwide[1]. The morbidity and mortality trends of COVID-19 differ among countries based on their healthcare systems, public health measures, and demographic characteristics. The pandemic largely affects the elderly, with more than 80% of global COVID-19 deaths occurring among people aged 65 years or older (Mueller et al., 2020). The elderly are at high risk of morbidity and mortality from COVID-19 as they tend to decline in bodily functions and a weakened immune system, leading to poorer health outcomes, which increases COVID-19 severity[2–5].

The global population is steadily aging. In 2022, the world population aged 65 and older was 771 million accounting for 10% with the highest percentage in Europe and North America (18.7%) followed by Oceania (16.6%) and Eastern and South-Eastern Asia (12.7%)[6]. The Asia-Pacific region has the most rapid increase in the older population[7]. Several studies reported that high morbidity and mortality rates were predominantly observed in European countries and America. Numerous studies indicate that the risk of mortality from COVID-19 increases with age.

Previous studies have focused on morbidity and mortality rates across countries[8]– [9]. Still, there is a gap in research for examining the effect of the elderly proportion on the morbidity and mortality rates of COVID-19 at the global scale. The data on COVID-19 morbidity and mortality rates vary across countries and thus there is a need to be investigated. Therefore, this study aimed to analyze the spatio-temporal trends of COVID-19 morbidity, mortality, and the elderly population worldwide. Moreover, exploring the COVID-19 morbidity and mortality due to the elderly population is crucial because pathogens continue to mutate, and new emerging pandemics may affect global mortality rates, which is crucial for developing more effective responses to current and future health crises. This study aims to describe global variation in COVID-19 morbidity and mortality and the elderly population. Moreover, quantify the rate of change in morbidity and mortality due to the elderly population continent and year-wise. Finally, provide a comparison of linear and Theil-Sen regression slopes for the robustness.

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## Methods

### Data source and management

The global data on COVID-19 from 2020 to 2022 were acquired from the website of 'Our World in Data(OWID)' (https://ourworldindata.org/). This dataset contains information on 218 countries, including country names, the number of COVID-19 cases, and the number of deaths. The data on the population and the proportion of the population aged 65 and above from 2020 to 2022 for 265 countries were downloaded from the website of the World Bank. For COVID-19 data, we excluded countries having missing data in any year and merged these data with the population and the percentage of the elderly. After merging the data, we excluded 39 countries that had missing COVID-19 data in any year. Finally, the data of 179 countries were used for further analysis.

### Data Pre-processing and analysis

The number of COVID-19 cases and deaths was divided by the number of population in that country and converted into morbidity and mortality rates per 1,000 population. Percent of elderly, morbidity, and mortality rates were classified using quartiles as: less than lower quartile ($Q_1$), between Q1 and less than median ($Q_2$), between Q2 and less than upper quartile ($Q_3$), and upper quartile and higher ($Q_4$) in order to illustrate on the thematic maps. Countries were classified according to continent-wise: Asia (AS), Oceania (OC), Africa (AF), Europe (EU), North America (NA), and South America (SA). Continent and year were combined to form a new variable called "continent-year". The flowchart of the study is shown in Fig. 1.

### Statistical methods

Morbidity and mortality rates per 1,000 are the two outcomes of this study. Linear regression was employed to investigate the impact of the elderly on COVID-19 morbidity and mortality by continent-wise (Eq. 1), year-wise (Eq. 2), continent-year-wise (Eq. 3) and overall, and reported coefficients were used to understand the trend. The linear regression model assumes the form as follows:

$$Y_i = \alpha_i + \beta_i X_i + \epsilon_i \tag{1}$$

where $\alpha_i$ and $\beta_i$ are the intercept and slope for $i$-th continent ($i = 1, 2, \ldots, 6$). $X_i$ is the proportion of the elderly, $Y_i$ is morbidity or mortality rates. $\epsilon_i$ is the independently and identically distributed error term.

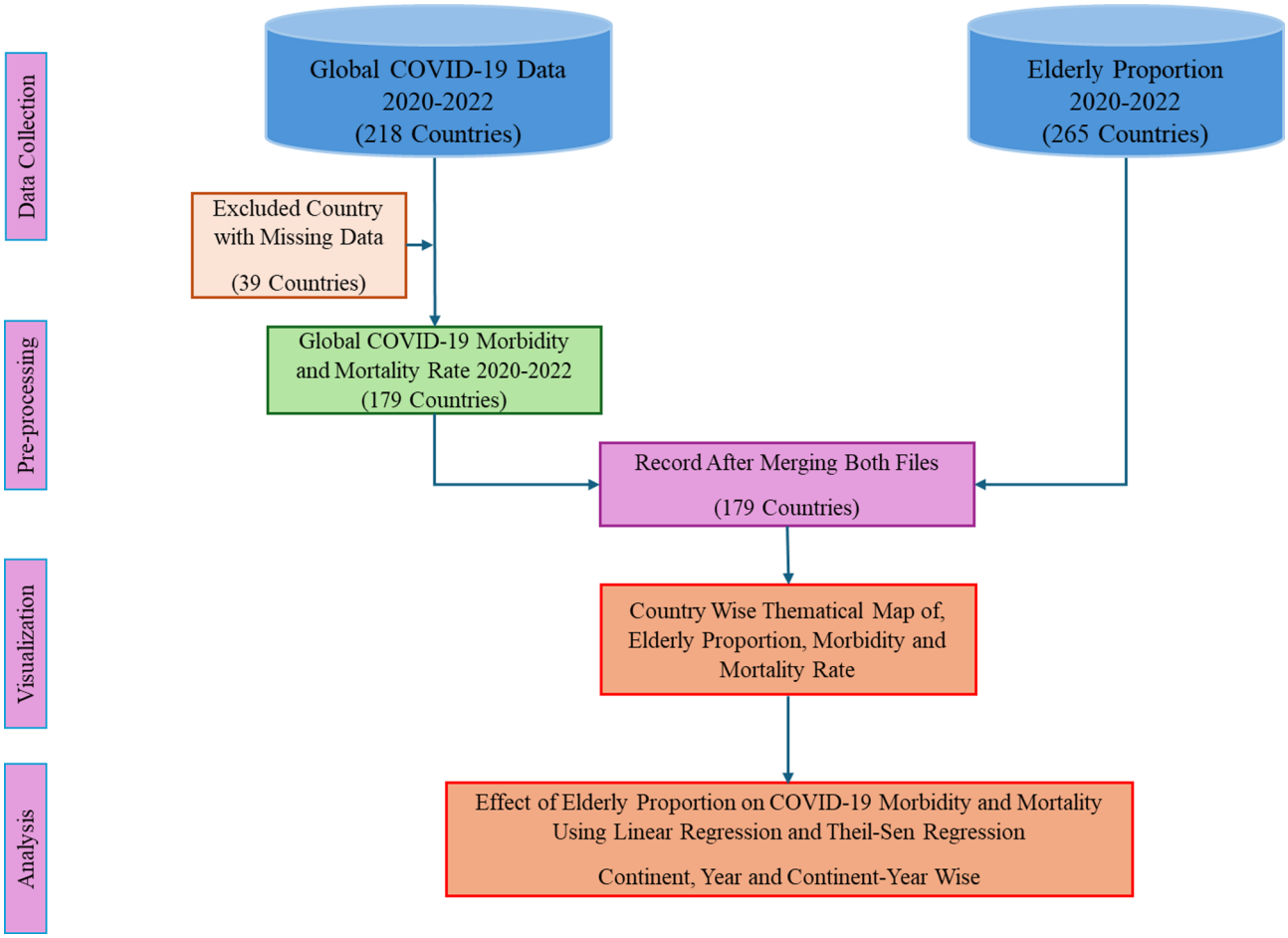


**Fig. 1**. Flowchart of the Study.

$$Y_j = \alpha_j + \beta_j X_j + \epsilon_j \quad (2)$$

where $\alpha_j$ and $\beta_j$ are the intercept and slope for *j*-th year ($j = 2000,\ 2021,\ 2022$). $X_j$ is the proportion of the elderly, $Y_j$ is morbidity or mortality rates. $\epsilon_j$ is the independently and identically distributed error term.

$$Y_{ij} = \alpha_{ij} + \beta_{ij} X_{ij} + \epsilon_{ij} \quad (3)$$

where $\alpha_k$ and $\beta_k$ are the intercept and slope for the *i*-th continent and *j*-th year. $X_{ij}$ is the proportion of the elderly, $Y_{ij}$ is morbidity or mortality rates. $\epsilon_{ij}$ is the independently and identically distributed error term. For overall we combine all the data and create a pool data to evaluate the overall global effect of morbidity and mortality due to COVID-19 for the proportion of the elderly. This model was considered by relaxing the yearly and continental dependence assumption as a robust analysis of individual models. Linear regression models were widely used to quantify the rate of change for the assessment of trend. This rate of change in COVID-19 due to the unit change in elderly was quantified from the estimated slope $\beta$ and its significance. The assumptions and goodness-of-fit of regression models were checked using Q-Q plots. However, the results of linear regression models are significantly influenced by outliers due to volatile data across the continents. COVID-19 morbidity and mortality have variation and outliers, so the Theil–Sen regression model was used to estimate the rate of change and compare the results with linear regression as a more robust method. The Theil-Sen regression was introduced by[10]–[11] as a robust method based on the median instead of the mean. Theil-Sen is determined by the median of all pairwise slopes. Thus, the slopes using Theil–Sen regression are calculated as follows:

$$Slope_{ij} = Median(y_k - y_l)/(x_k - x_l) \quad (4)$$

where $y_k$ and $y_l$ are the morbidity (or mortality) and $x_k$ and $x_l$ are the proportion of the elderly population. Six slope coefficients were obtained from continent-based models, three from the year-based models, and 24 from the continent-year models by using linear regression and Theil-Sen regression model. These slops coefficients from each regression model for morbidity and mortality were used to construct comparative forest plots for different slopes. The plots illustrate the spatial and temporal trend as a rate of change in morbidity and mortality in each continent, year, and continent-year-wise, along with 95% confidence intervals. All statistical analyses and visualizations were generated in R language[12]. The base layer of the maps was created using the *rnaturalearth* library of R.

## Ethical considerations

The study was approved by the Human Research Ethics Committee of the Faculty of Nursing, Pattani Campus, Prince of Songkla University (REC: NUR.PN005/2023). We declared that all methods were in accordance with the relevant guidelines and regulations.

## Results

The results presented in Table 1 indicate a steady increase in the proportion of elderly individuals over the study period. The highest average COVID-19 morbidity rate was observed in 2022, while the highest mortality rate occurred in 2021. Among regions, Europe had the largest proportion of elderly individuals, followed by North America and Oceania. Similarly, Europe recorded the highest average COVID-19 morbidity, followed by North America and Oceania. In terms of mortality, Europe also ranked highest, followed by South America and North America.

The Thematic plots illustrated in Fig. 2 show the COVID-19 morbidity and mortality rates per 1,000 population and the elderly population proportion for the year 2020–2022. The morbidity, mortality, and elderly rates were divided into lower, lower-middle, middle-upper, and upper quartiles. The very severe situations are in those countries where the rate is higher than the upper quartile of the countries. Most countries in the European

| | Proportion of the elderly | | Morbidity rate/1,000 | | Mortality rate/1,000 | |
|---|---|---|---|---|---|---|
| | Mean (SD) | Median | Mean (SD) | Median | Mean (SD) | Median |
| Year | | | | | | |
| 2020 | 9.95 (7.02) | 7.84 | 24.62 (86.03) | 09.45 | 0.33 (0.44) | 0.11 |
| 2021 | 10.14 (7.12) | 7.95 | 172.82 (1413.80) | 41.32 | 0.76 (0.80) | 0.53 |
| 2022 | 10.32 (7.22) | 8.16 | 175.62 (707.44) | 36.31 | 0.29 (0.33) | 0.16 |
| Continent | | | | | | |
| Asia | 8.57 (6.17) | 6.75 | 51.92 (94.21) | 16.44 | 0.28 (0.41) | 0.14 |
| Oceania | 9.51 (5.29) | 7.66 | 57.66 (98.98) | 15.92 | 0.26 (0.43) | 0.06 |
| Africa | 3.67 (1.84) | 3.14 | 46.13 (279.99) | 01.62 | 0.09 (0.23) | 0.02 |
| Europe | 18.79 (4.44) | 19.26 | 309.68 (1750.29) | 66.23 | 0.90 (0.69) | 0.73 |
| North America | 10.26 (4.60) | 8.90 | 111.08 (371.01) | 32.40 | 0.52 (0.47) | 0.39 |
| South America | 8.93 (2.96) | 8.33 | 46.78 (39.54) | 37.21 | 0.88 (0.80) | 0.78 |

**Table 1**. Summary statistics of the percentage of the elderly, morbidity, and mortality rate due to COVID-19.

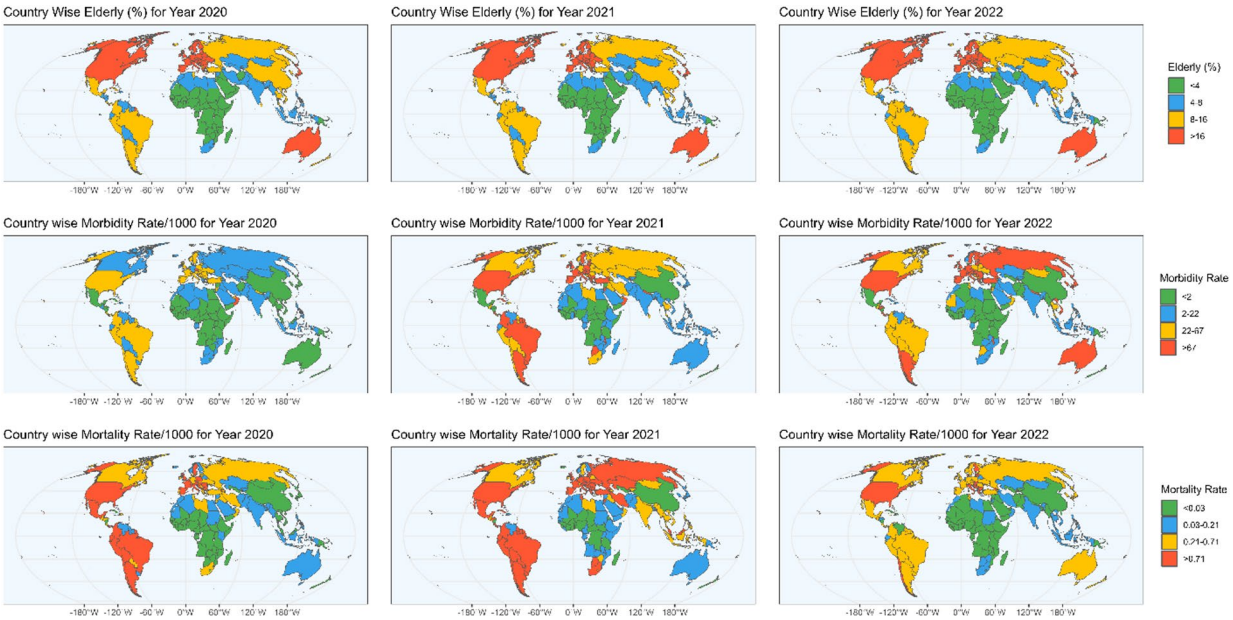


**Fig. 2**. Proportion of elderly population, morbidity and mortality rate per 1,000 population in each country, and years.

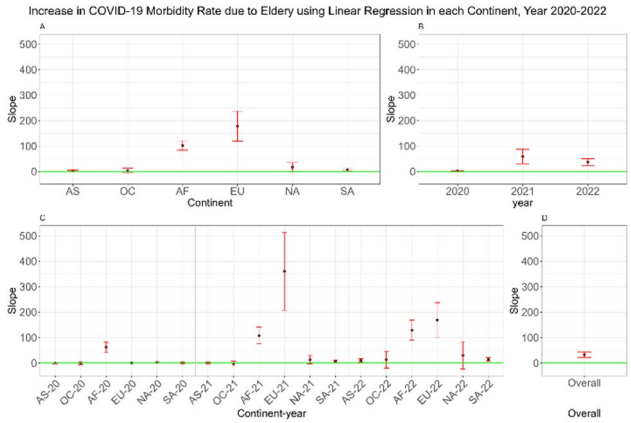


**Fig. 3**. Trends of Rate of Change in COVID-19 Morbidity Rate per 1,000 Due to Change in Elderly Population using Linear Regression from 2020–2022.

continent had a high percentage of elderly and morbidity rates but mortality rates were high in some countries. Russia has a relatively high elderly population, with a high morbidity rate and a relatively high mortality rate. Australia's continent showed a high percentage of elderly, COVID-19 morbidity, and mortality rates. North America's continent had a high percentage of elderly, morbidity, and mortality rates, especially in the United States. Most countries in the Asia continent had relatively low percentages of elderly, morbidity, and mortality rates. However, in Japan, there was a high percentage of elderly and morbidity rate, but the mortality rate was relatively low. Thailand and Vietnam had relatively high percentages of elderly and morbidity rates, but had low mortality rates. China had a relatively high percentage of elderly, but had low morbidity and mortality rates. All countries in Africa had lower percentages of elderly, morbidity, and mortality rates. In the South American continent, most countries had relatively high percentages of elderly, morbidity, and mortality rates.

Figure 3 presents the rate of change in COVID-19 morbidity rate due to the change in the percentage of elderly for each continent, year, content-year, and overall using the linear regression model. The results from the continent-wise linear regression model revealed that Europe experienced a notable and significant rise in the COVID-19 morbidity rate due to the proportion of the elderly. While the African continent experienced a moderately significant rise in the COVID-19 average morbidity rate, due to the elderly population. The results from the year-wise model showed a notable and significant increase in the morbidity rate of COVID-19 in 2021 and 2022, with average rates of 70 and 40 per 1,000, respectively, coinciding with a 1% rise in the proportion of elderly individuals. The overall morbidity rate increase is 25 per 1,000 on average, with a 1% increase in the


**Fig. 4**. Trends of Rate of Change in COVID-19 Morbidity Rate per 1,000 Due to Change in Elderly Population using Theil Sen Regression from 2020–2022.

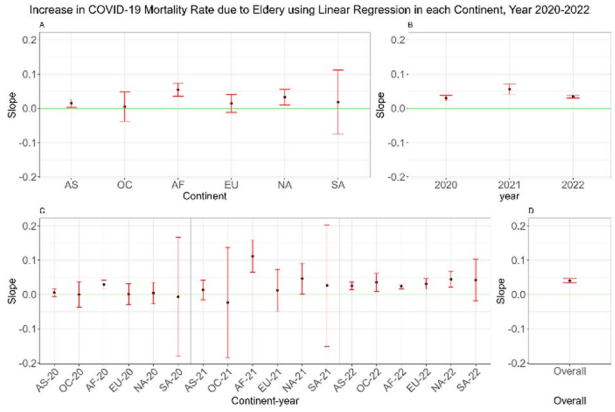


**Fig. 5**. Trends of Rate of Change in COVID-19 Mortality Rate per 1,000 Due to Change in Elderly Population using Linear Regression from 2020–2022.

elderly population. The rate of change is very high due to the outliers and variation in each continent. To adjust this, we present the Theil-Sen estimate as a robust method.

Figure 4 presents the rate of change in COVID-19 morbidity rate due to the unit change in the percentage of elderly for each continent, year, continent-year, and overall using the Theil-Sen model. The results from the continent-wise Theil-Sen model indicated that Oceania experienced a significant rise in the COVID-19 morbidity rate of 9 per 1,000 with each 1% increase in the proportion of the elderly. With a 1% increase in the elderly population, Europe can experience a significant rise in the COVID-19 morbidity rate of 6 per 1,000. The results from the year-wise model indicated that a 1% increase in the elderly population was significantly associated with an increase in the morbidity rate of COVID-19 from 2020 to 2022, with rates of 1, 5, and 6 per 1,000, respectively. The results from the continent-year-wise model revealed that in 2022, Europe experienced a significant increase in morbidity rate, 30 per 1,000, with a 1% increase in the elderly population. In 2021 and 2022, North America had a significant rise, while Oceania also observed a significant rise in 2022, with a morbidity rate ranging from 5 to 18 due to a 1% increase in the elderly population. The overall morbidity rate increase is 4 per 1,000 with a 1% increase in the elderly population.

Figure 5 displays the rate of change in COVID-19 mortality rate due to the change in the percentage of the elderly population using the linear regression model. There was a significant relationship between the rate of change in COVID-19 mortality due to change in the elderly proportion. The results from the country-wise linear regression model indicated that Africa experienced a notable higher rate of change in the COVID-19 mortality rate of 0.05 per 1,000 with each 1% increase in the proportion of elderly individuals. While the North American continent experienced a higher rate of change COVID-19 mortality rate of 0.03 per 1,000 when 1% increase in the elderly population. The results from the year-wise model indicated a notable increase in the mortality rate of COVID-19 in 2021 and 2022, with rates of 0.05 and 0.03 per 1,000, respectively, coinciding with a 1% rise in the proportion of elderly individuals. In 2021, Africa experienced a significant increase in mortality rate, with a rise of 0.11 per 1,000, with a 1% increase in the elderly population. In 2021 and 2022, North America witnessed a substantial rise, while South America also observed a significant higher in 2022, with a mortality rate ranging from 0.03 to 0.04 due to a 1% increase in the elderly population. The overall mortality rate was 0.04 per 1,000.

Figure 6 displays the rate of change in COVID-19 mortality rate due to the change in the percentage of the elderly population using the Theil-Sen regression model. The results from the continent-wise Theil-Sen model showed that South America experienced higher rate of change in the COVID-19 mortality rate, 0.05 per 1,000, with a 1% increase in the proportion of elderly individuals. While the North American continent experienced a higher rate of change in the COVID-19 mortality rate, 0.04 per 1,000, with a 1% increase in the elderly population. The results from the year-wise model indicate a higher rate of change in the mortality rate of COVID-19 in 2020 to 2022, with rates of 0.025, 0.07, and 0.02 per 1,000, respectively, with a 1% rise in the proportion of elderly individuals. In 2021, Europe experienced a significantly higher mortality rate, with a rise of 0.07 per 1,000, with a 1% increase in the elderly population. In 2021 and 2022, North America witnessed a substantial rise, while Oceania and South America also observed a significant rise in 2022, with a mortality rate ranging from − 0.025 to 0.025 and − 0.01 to 0.02 due to a 1% increase in the elderly population. The overall slope of the mortality rate was 0.03 per 1,000.

The rate of change in COVID-19 morbidity and mortality rates due to the change in the percentage of the elderly is illustrated in Fig. 7 through the slope coefficient. Europe experienced a significant higher rate of change in COVID-19 morbidity rates, which accounted for a substantial 30%. On the other hand, Africa experienced the lowest COVID-19 morbidity rate. North America experienced a significant increase in the rate of change in COVID-19 mortality due to elderly population. Africa experienced the lowest rate of change in COVID-19 mortality when the percentage of the elderly population increased by 1%.

## Discussion

This study employed linear regression and Theil-Sen regression to explore the global COVID-19 morbidity and mortality trend due to the change in the proportion of the elderly population in 2020–2021. The Theil-Sen regression model provides robust findings for global situations when high variations and outliers are there. The change in the elderly proportion in Europe affects the slope of COVID-19 morbidity rates, followed by Oceania and North America, whereas the change in the elderly proportion in North America had a notable rate of change in COVID-19 mortality, followed by Europe and Africa. The rise in the elderly population also indicated a higher rate of change in morbidity and mortality during the years 2020–2021. The increase in the elderly population was associated with an increase in morbidity and mortality across nearly all regions during the years 2021 and 2022.

The increase in the elderly population was significantly associated with the increase in morbidity across Europe, North and South America, and Oceania, while the same demographic change was associated with a significant increase in mortality in Europe, North America, Africa, Asia, and Oceania. Europe, North America, and Oceania are already experiencing aging societies, whereas Asia and Africa have a lower elderly proportion. The findings are consistent with prior studies[5,8,13]– [14], suggesting that an increase in the elderly population played a role in the rise of COVID-19 cases and deaths. The elderly often experience a decline in immune function, which, coupled with chronic conditions such as hypertension, diabetes, and cardiovascular diseases, makes them more vulnerable to severe illness[15]. This may reflect the region's demographic structure and the prevalence of healthcare disparities, as suggested by prior studies[16].

In our study, the United States exhibited high morbidity and mortality rates, which may be partly attributed to its large elderly population. However, countries such as Japan and Australia, despite having similarly high proportions of older adults, reported considerably lower COVID-19 morbidity and mortality. This contrast suggests that factors beyond population age structure, particularly the effectiveness of containment strategies, played a crucial role in mitigating the impact of the pandemic[17]– [18]. Cheng et al. reported that countries implementing stringent containment measures achieved significant reductions in excess mortality by 5.7% in 2020 and 12.9% in 2021 compared with countries exhibiting weaker responses. Similarly, nations with moderately effective strategies experienced reductions of 6.7% in 2020 and 10.6% in 2021. However, by 2022, these differences across performance groups were no longer statistically significant, likely due to the rapid spread of the Omicron variant and the widespread development of herd immunity within populations[17].

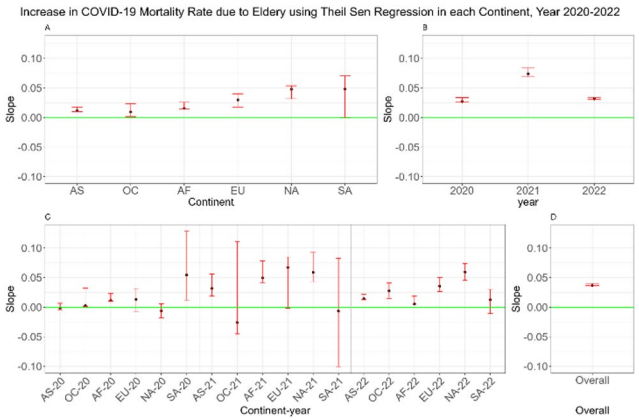


**Fig. 6**. Trends of Rate of Change in COVID-19 Mortality Rate per 1,000 Due to Change in Elderly Population using Theil Sen Regression from 2020–2022.

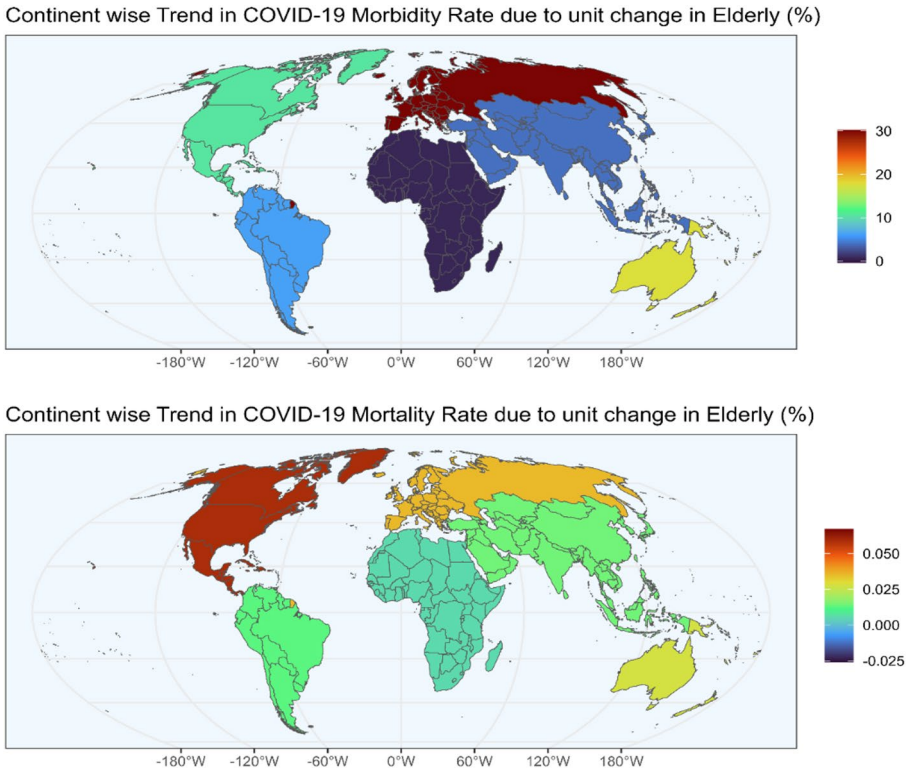


**Fig. 7**. Trend of COVID-19 Morbidity and Mortality Due Elderly Percentage in Each Continent.

The year-wise results also indicated a significant association between the rise in the elderly population and the increasing rates of COVID-19 morbidity and mortality. However, results from continent-year-wise showed the significant association of percent change in the elderly in the years 2021 and 2022 in North America, Europe, Africa, and Asia on COVID-19 morbidity and mortality, whereas the significant association was observed in 2020 in Africa and South America.

This study has a few limitations. COVID-19 data may be gathered and reported in different ways by each country. The data were categorized based on continents by assuming the homogeneity of the environmental and regional situation due to neighboring countries. However, the effect of the change in the aging population on morbidity and mortality may be limited due to the ecological study. In addition, the proportion of vaccinated individuals was not included in the analysis. Since COVID-19 mortality is influenced not only by the proportion of elderly individuals but also by vaccination coverage, this omission may affect the results.

## Conclusion

The global COVID-19 morbidity and mortality rates are associated with elderly data across countries. The outliers significantly affect the results from the linear regression model, but this problem can be mitigated by employing Theil-Sen regression. Regions with high proportions of elderly as Europe, North America, and Africa, suffered with higher COVID-19 morbidity and mortality rates. The experience with the COVID-19 pandemic has enabled us to make data-driven decisions that are resilient to future outbreaks of new diseases with similar transmission characteristics, to reduce morbidity and mortality rates, especially in elderly populations.

## Data availability

The data used in this study is free and available online. The data related to COVID-19 morbidity and mortality is available on the website Our World in Data (OWID) (https://ourworldindata.org/). The data on the elderly population is available from the website of the World Bank (https://data.worldbank.org/).

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## References

1. World Health Organization. *COVID-19 Dashboard*, retrieve at 10 Jan 2025. https://data.who.int/dashboards/covid19/cases (2024).
2. Bartleson, J. M. et al. SARS-CoV-2, COVID-19 and the aging immune system. *Nat. Aging.* **1** (9), 769–782 (2021).
3. Castelo-Branco, C. & Soveral, I. The immune system and aging: a review. *Gynecol. Endocrinol.* **30** (1), 16–22 (2014).
4. Chen, Y. et al. Aging in COVID-19: Vulnerability, immunity and intervention. *Ageing Res. Rev.* **65**, 101205 (2021).
5. de Almeida, R. S. C. et al. dos,& Factors associated with mortality in critically ill patients with COVID-19. *Revista de Epidemiologia e Controle de Infecção*, *12*(4), 135–142. (2022).

6. United Nations Department of Economic and Social & Affairs, P. D. *World Population Prospects 2022 Summary of Results* (Vol. UN DESA/POP/2022/TR/NO. 3.). (2022).
7. ESCAP, U. Asia-Pacific report on population ageing 2022: trends, policies and good practices regarding older persons and population ageing. (2022).
8. Chang, D., Chang, X., He, Y. & Tan, K. J. K. The determinants of COVID-19 morbidity and mortality across countries. *Sci. Rep.* **12** (1), 5888 (2022).
9. Tazerji, S. S. et al. Global data analysis and risk factors associated with morbidity and mortality of COVID-19. *Gene Rep.* **26**, 101505 (2022).
10. Sen, P. K. Estimates of the regression coefficient based on kendall's Tau. *J. Am. Stat. Assoc.* **63** (324), 1379–1389 (1968).
11. Theil, H. A rank-invariant method of linear and polynomial regression analysis. In Henri Theil's Contributions To Economics and Econometrics: Econometric Theory and Methodology (345–381). Dordrecht: Springer Netherlands. (1992).
12. R Core Team. *R: A language and environment for statistical computing*. In R Foundation for Statistical Computing. (2024).
13. Bonanad, C. et al. The effect of age on mortality in patients with COVID-19: a meta-analysis with 611,583 subjects. *J. Am. Med. Dir. Assoc.* **21** (7), 915–918 (2020).
14. Rana, R. Impact of Covid-19 on Older Population: Review of the Initial Phase. *Handbook on COVID-19 Pandemic and Older Persons: Narratives and Issues from India and Beyond*, 13–19. (2023).
15. Blagosklonny, M. V. From causes of aging to death from COVID-19. *Aging (Albany NY).* **12** (11), 10004 (2020).
16. Sytdykova, K. A. et al. Age-related risk factors affecting the population morbidity. *Cardiometry* **27**, 221–228 (2023).
17. Cheng, C. et al. Excess mortality and containment performance during the COVID-19 pandemic: evidence from 34 countries. *Am J. Public. Health.* **115** (9), 1518–1528 (2025).
18. Hatami, H. et al. COVID-19: National pandemic management strategies and their efficacies and impacts on the number of secondary cases and prognosis: A systematic review. *Int. J. Prev. Med.* **13** (100), 1–10 (2022).


## Author contributions

JJ, AL, and HK contributed to the conceptualization and design of the study. JJ, AL, and HK organized and pre-processed the data. AL and HK analyzed the data. JJ and RJ wrote the initial draft. JJ, AL, RJ, and HK revised the initial draft. AL and HK finalized the data. All the authors read and approved the final draft.

## Declarations

## Competing interests

The authors declare no competing interests.

## Ethical considerations

The study was approved by the Human Research Ethics Committee of the Faculty of Nursing, Pattani Campus, Prince of Songkla University (REC: NUR.PN005/2023). We declared that all methods were in accordance with the relevant guidelines and regulations.

## Additional information

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