INVESTIGATION OF THE CORRELATION BETWEEN HDI AND MORTALITY RATES DUE TO BREAST CANCER BEFORE AND DURING THE COVID-19

1. Research Question

How does the correlation between incidence and mortality rates due to Breast Cancer (measured in the number of deaths per 100,000 of population) with the Human Development Index (HDI) change before (2015) and during (2019) COVID-19?

2. Background Information

An acquaintance of mine who lives abroad was diagnosed with breast cancer last year. She had a late diagnosis due to fear of contagion and lockdown. Thus, when her treatments started, the cancer had already progressed. Such sad news made me realize how the disease is close to me since I come from a family with a breast cancer history. Therefore, I decided to explore breast cancer trends and understand how it is affected by COVID-19.

Breast cancer grows mostly in the glandular tissue's ducts (in the epithelium). In the first stage, cancerous expansion is only in the duct ("in situ"), where it mostly shows no symptoms and poses a lower rate of metastasis. When tumors begin to disturb the surrounding breast tissue, it is known as “invasive breast cancer.” Then, if it spreads to associating lymph nodes, it is called “regional metastasis.” If it spreads to other organs, it is called “distant metastasis”. Extensive metastasis is the last stage of breast cancer and is fatal for the patient. (Centers for Disease Control and Prevention, 2021)

According to the World Health Organization, “2.3 million new cases of breast cancer and 685 000 deaths” have been reported globally in 2020. From 2015 to 2020, “7.8 million women have been diagnosed with breast cancer”, thus it become the “world's most common” cancer. Patients lose “disability-adjusted life years” because of breast cancer. After puberty, breast cancer may affect any women irrespective of her age, but with increasing diagnosis in later life. From the 1930s until the 1970s, mortality rates due to breast cancer fluctuated little. Treatment rates started to increase in countries which have “early detection programs” with varying types of treatments to fight against the disease in the 1980s.

The Human Development Index (HDI) indicates socioeconomic development in this investigation. HDI data is based on three indices: “a health index (measured by life expectancy at birth), an education index (measured by mean and predicted years of education), and an income index (measured by gross national income per capita).” Indexes have a value between 0 to 1; when the value increases, it implies a greater the socioeconomic status of a country (UNDP Report, 2010).

Studies from Clegg et al., (2009) have revealed that “economic and social situation is directly related to the patients’ stage of diagnosis and survival.” It is known that breast cancer is the second most diagnosed cancer in patients. It thus has a higher rate of treatment, since detecting breast cancer in the early stages is crucial for decreasing the number of mortalities and improving prognosis (Rahimzadeh et al., 2014). However, this picture has changed with the COVID-19 outbreak. Ponkilainen, Ville et al. (2020) showed that patients started to refrain

from going to hospitals, as “admissions decreased by 32% three weeks before the lockdown in March 2020”. The COVID-19 pandemic also affected the patients who receive breast cancer treatment. According to Ozmen, V. et al. (2014), “the total delay time in breast cancer treatment was almost 14 weeks. Thus, nearly one-third of the whole delay time was patient-related delay time. In the COVID-19 pandemic, it can be estimated easily that the patient-related delay time would be longer.”

Understanding the trends in the mortality rates of breast before and during the pandemic is important for developing a public-health strategy in accordance with a country’s current technological advancements and healthcare facilities. This study aims to investigate the mortality rates due to breast cancer and its relationship with HDI and its components by comparing the data from 2015 and 2019. On a large scale, such a study has the potential to reveal the effects of COVID-19 on countries’ healthcare systems.

3. Hypothesis

A correlation is expected between the HDI of a country and the number of breast cancer mortality there both before (2015) and during (2019) COVID-19.

Null hypothesis: HDI does not affect the mortality rate due to breast cancer.

Alternative hypothesis 1: HDI has a negative correlation with the breast cancer mortality rate.

Alternative hypothesis 2: HDI has a positive correlation with the breast cancer mortality rate.

4.Data Sources

- Database of HDI, from the UN Human Development Reports: http://hdr.undp.org/en/data
- Database of WHO on breast cancer mortalities: https://www.who.int/data/gho
- Population database of the World Bank: https://data.worldbank.org/indicator/sp.pop.totl

There are two reasons for choosing abovementioned databases. First, they are reliable since all the sources are presented by the United Nations sub-branches. Second, there is not much database sources concerning breast cancer mortality.

5. Environmental, Ethical and Safety Considerations

Considering the type of this investigation, there are no environmental or ethical considerations can be stated. In terms of physical health however, taking recursive breaks when collecting and analyzing the data is important to reduce screen time and maintain a good posture.

6. Methodology and Trial Investigation

The methodology in this study is demonstrated by a trial investigation with five countries: Austria, Belgium, France, Germany and Ireland.

Selected countries are similar to each other in terms of being European and having a membership in "the Organisation for Economic Co-operation and Development" (OECD). Thus, they are expected to have a similar HDI value. Similar cultural and economic level reduces the effects of irrelevant outside variables, including lifestyle habits or eating patterns. To carry out the trial investigation, the necessary data concerning the population, HDI, and breast cancer mortalities are obtained from the abovementioned data sources for 2015 and 2019.

Table 1. Raw data showing the HDI values, number of deaths due to breast cancer and populations of selected countries in 2015 and 2019

Country	Human Development Index		Estimated deaths due to breast cancer ('000s)		Total Population	
	2015	2019	2015	2019	2015	2019
Austria	0.910	0.919	1.9	1.9	8,642,699	8,879,920
Belgium	0.924	0.936	2.5	2.5	11,274,196	11,488,980
France	0.892	0.905	14.9	15.5	66,548,272	67,248,926
Germany	0.938	0.948	20.5	18.8	81,686,611	83,092,962
Ireland	0.925	0.942	0.7	0.8	4,701,957	4,939,340

7. Sample Calculations

The mortality rate can be calculated by dividing the death counts due to breast cancer to the population of the country in question. Thus, breast cancer mortality rate per person can be found.

$$Mortality\ rate\ (per\ person): \frac{Estimated\ number\ of\ deaths}{Total\ population}$$

If this number is multiplied by 100,000, mortality rate per 100,000 population is obtained.

$$Mortality\ rate\ (per\ 100{,}000\ population) = Mortality\ rate\ per\ person\ x\ 100{,}000$$

Example: Breast cancer mortality rate in Germany per 100,000 population in 2015

$$Mortality\ rate = \frac{20.5}{81{,}686{,}611} = 0{,}000000251\ (per\ person)$$

$$Mortality\ rate = 0{,}000000251\ x\ 100{,}000 = 0{,}025\ (per\ 100{,}000\ population)$$

Table 3.Processed data showing the mortality rates per person and per 100,000 population of selected countries

Country	Mortality rates due to breast cancer per person		Breast cancer mortality rates per 100,000 population	
	2015	2019	2015	2019
Austria	0.000000219838733	0.000000213965892	0.022	0.021
Belgium	0.000000221745302	0.000000217599822	0.022	0.022
France	0.000000223897624	0.000000230486952	0.022	0.023
Germany	0.000000250959120	0.000000226252616	0.025	0.023
Ireland	0.000000148874182	0.000000161964959	0.015	0.016

Table 4. HDI and breast cancer mortality rate in 2015

Country	HDI in 2015	Breast cancer mortality rate per 100,000 population in 2015
Austria	0.910	0.022
Belgium	0.924	0.022
France	0.892	0.022
Germany	0.938	0.025
Ireland	0.925	0.015

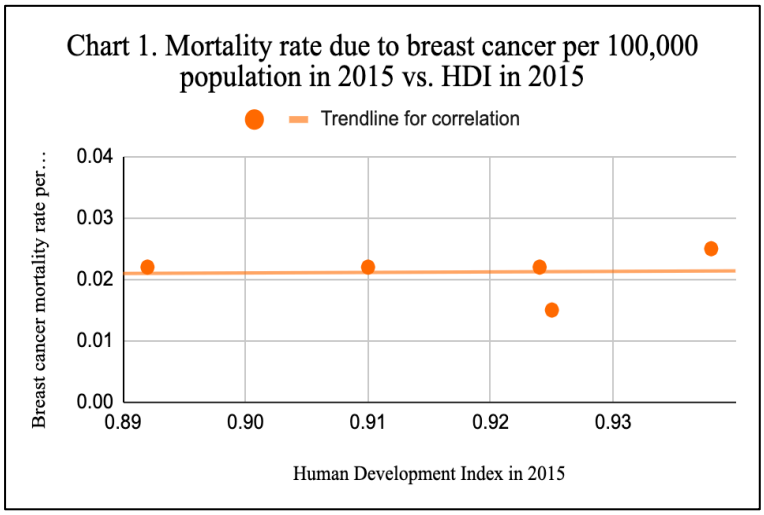
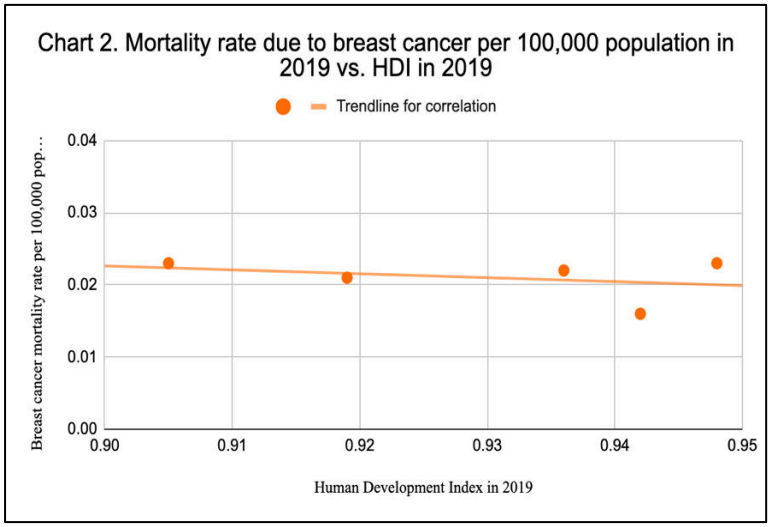


Table 2. HDI and breast cancer mortality rate in 2019

Country	HDI in 2019	Breast cancer mortality rate per 100,000 population in 2019
Austria	0.919	0.021
Belgium	0.936	0.022
France	0.905	0.023
Germany	0.948	0.023
Ireland	0.942	0.016



8. Investigation

According to their HDI values, countries are grouped into 4 categories (UNDP, 2010):

- "very high HDI countries" (HDI > 0.8)
- "high HDI countries" (0.7 - 0.8)
- "medium HDI countries" (0.5 - 0.7)
- "low HDI countries" (HDI < 0.5)

In this investigation, very high and high HDI countries are taken into consideration since only they have sufficient and consistent data.

Table 5. Raw data showing the HDI values, number of deaths due to breast cancer and populations of countries with HDI greater than 0.7 in 2015 and 2019

Countries with HDI > 0.7	**Human Development Index**		**Estimated deaths due to breast cancer ('000s)**		**Total Population**	
	2015	**2019**	**2015**	**2019**	**2015**	**2019**
Bulgaria	0.809	0.810	1.5	1.4	7,177,991	6,975,761
Canada	0.926	0.937	5.7	5.9	35,702,908	37,601,230
Croatia	0.843	0.861	1.1	1.0	4,203,604	4,065,253
Greece	0.880	0.889	2.5	2.5	10,820,883	10,721,582
Italy	0.882	0.897	13.9	13.9	60,730,582	59,729,081
Netherlands	0.932	0.943	3.7	3.5	16,939,923	17,344,874
Norway	0.953	0.961	0.7	0.7	5,188,607	5,347,896
Paraguay	0.723	0.732	0.4	0.5	6,688,746	7,044,639
Poland	0.868	0.881	7.3	8.0	37,986,412	37,965,475
Portugal	0.850	0.867	1.9	2.0	10,358,076	10,286,263
Republic of Korea	0.909	0.923	2.5	2.9	51,014,947	51,764,822
Russian Federation	0.824	0.845	24.3	23.2	144,096,870	144,406,261
Spain	0.889	0.908	7.0	7.1	46,444,832	47,134,837
Sweden	0.937	0.947	1.7	1.6	9,799,186	10,278,887
Switzerland	0.954	0.962	1.6	1.6	8,282,396	8,575,280
Turkiye	0.817	0.842	5.0	5.6	78,529,413	83,429,607
Ukraine	0.774	0.786	8.6	8.1	45,154,036	44,386,203
United Kingdom	0.924	0.935	13.4	12.7	65,116,219	66,836,327
United States of America	0.920	0.930	47.7	48.7	320,738,994	328,329,953

Table 6. Processed data showing the mortality rates per person and per 100,000 population of countries with HDI greater than 0.7 in 2015 and 2019

Countries with HDI > 0.7	**Mortality rates due to breast cancer per person**		**Mortality rates due to breast cancer per 100,000 population**	
	2015	**2019**	**2015**	**2019**
Bulgaria	0.0000002089721205	0.0000002006949493	0.0209	0.0201
Canada	0.0000001596508609	0.0000001569097607	0.0160	0.0157
Croatia	0.0000002616802154	0.0000002459871501	0.0262	0.0246
Greece	0.0000002310347501	0.0000002331745446	0.0232	0.0234
Italy	0.000000228879743	0.0000002327174597	0.0229	0.0233
Netherlands	0.0000002184189385	0.0000002017887244	0.0217	0.0203
Norway	0.0000001349109694	0.0000001308925978	0.0134	0.0130
Paraguay	0.00000005980194195	0.00000007097595775	0.0060	0.0071
Poland	0.0000001921739805	0.000000210717764	0.0192	0.0211
Portugal	0.0000001834317493	0.0000001944340719	0.0183	0.0194
Republic of Korea	0.00000004900524546	0.0000000560226016	0.0049	0.0056
Russian Federation	0.0000001686365568	0.000000160657854	0.0169	0.0161
Spain	0.0000001507164457	0.0000001506316867	0.0151	0.0151
Sweden	0.0000001734837975	0.0000001556588763	0.0173	0.0156
Switzerland	0.0000001931808139	0.0000001865828288	0.0193	0.0187
Turkiye	0.00000006367041098	0.0000000671224545	0.0064	0.0067
Ukraine	0.0000001904591652	0.0000001824891397	0.0190	0.0182
United Kingdom	0.0000002057859041	0.0000001900164262	0.0206	0.0190
United States of America	0.0000001487190547	0.0000001483264002	0.0149	0.0148

Table 7. HDI and breast cancer mortality rate of countries with HDI greater than 0.7 in 2015

Countries with HDI > 0.7	HDI in 2015	Mortality rate due to breast cancer per 100,000 population in 2015
Bulgaria	0.809	0.0209
Canada	0.926	0.016
Croatia	0.843	0.0262
Greece	0.88	0.0231
Italy	0.882	0.0229
Netherlands	0.932	0.0218
Norway	0.953	0.0135
Paraguay	0.723	0.006
Poland	0.868	0.0192
Portugal	0.85	0.0183
Republic of Korea	0.909	0.0049
Russian Federation	0.824	0.0169
Spain	0.889	0.0151
Sweden	0.937	0.0173
Switzerland	0.954	0.0193
Turkiye	0.817	0.0064
Ukraine	0.774	0.019
United Kingdom	0.924	0.0206
United States of America	0.92	0.0149

Chart 3. Mortality rate due to breast cancer per 100,000 population in 2015 vs. HDI in 2015

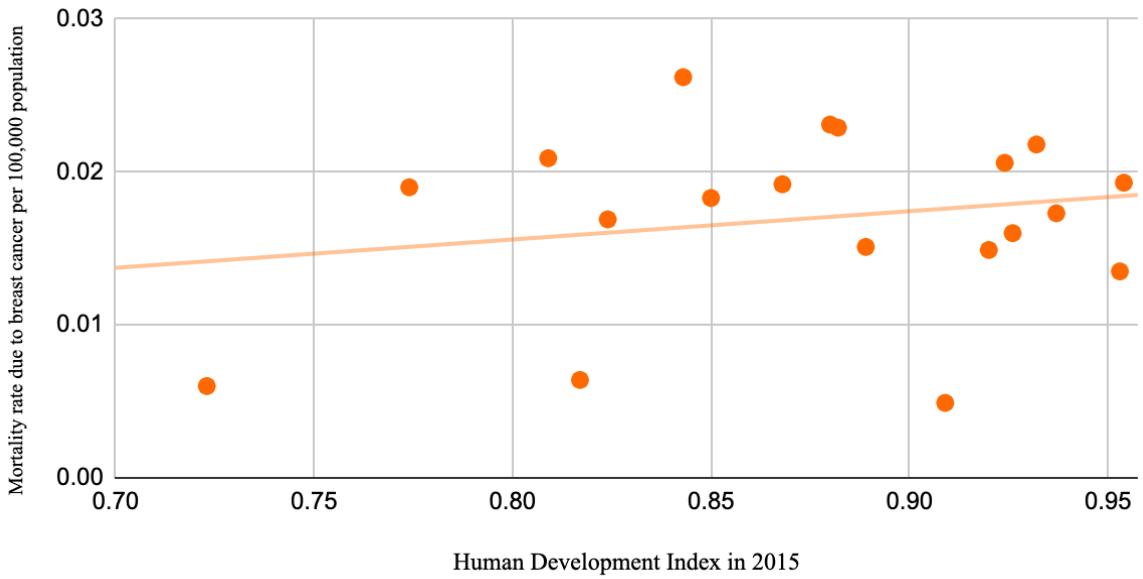
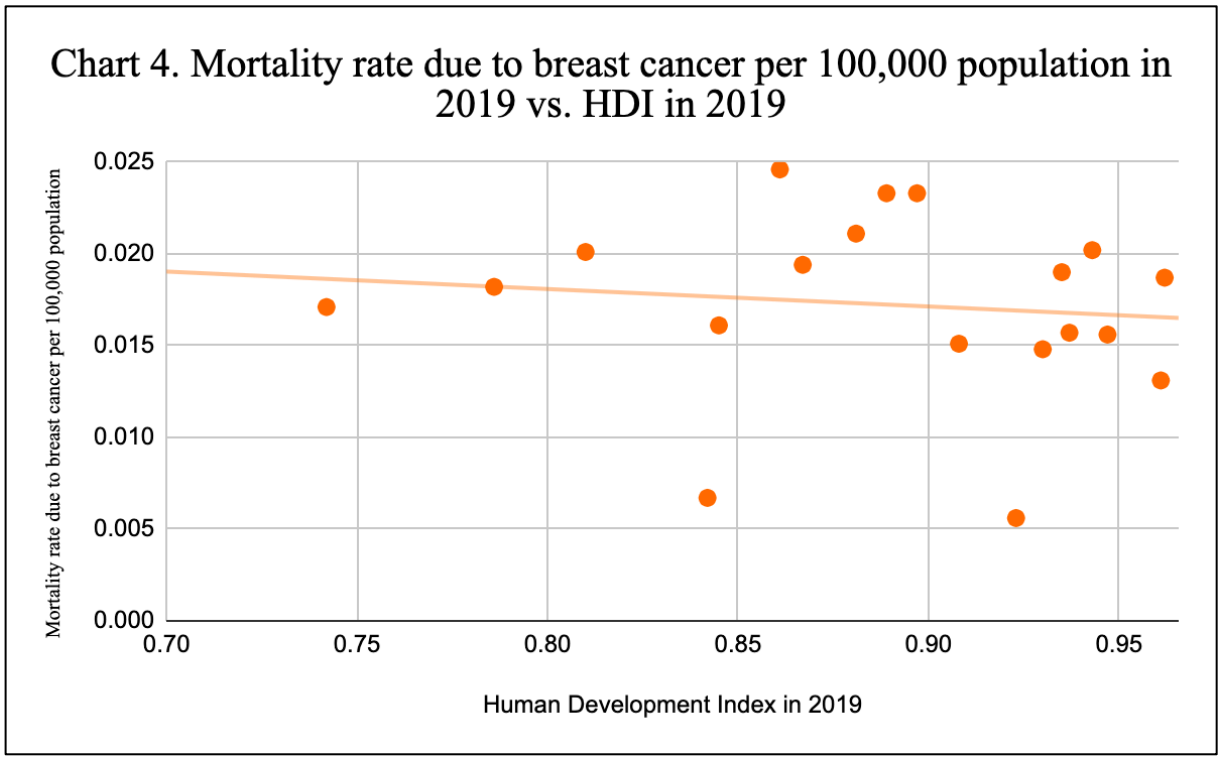


Table 8. HDI and breast cancer mortality rate of countries with HDI greater than 0.7 in 2019

Countries with HDI > 0.7	HDI in 2019	Mortality rate due to breast cancer per 100,000 population in 2019
Bulgaria	0.810	0.0201
Canada	0.937	0.0157
Croatia	0.861	0.0246
Greece	0.889	0.0233
Italy	0.897	0.0233
Netherlands	0.943	0.0202
Norway	0.961	0.0131
Paraguay	0.742	0.0171
Poland	0.881	0.0211
Portugal	0.867	0.0194
Republic of Korea	0.923	0.0056
Russian Federation	0.845	0.0161
Spain	0.908	0.0151
Sweden	0.947	0.0156
Switzerland	0.962	0.0187
Turkiye	0.842	0.0067
Ukraine	0.786	0.0182
United Kingdom	0.935	0.0190
United States of America	0.930	0.0148



9. Statistical Test

When the charts are observed, a linear relationship between the HDI and breast cancer mortality rate. This deduction enables the use of Pearson's Correlation to check the significance of the results. Data from 2019 is used in the calculations.

In Table 9 below, variable X is assigned as the HDI value of the countries, and variable Y is assigned as the breast cancer mortality rate, whereas N represents the total number of countries.

Table 9. Required values for Pearson's Correlation Test

N	X	Y	XY	X^2	Y^2
1	0.81	0.0201	0.016281	0.6561	0.00040401
2	0.937	0.0157	0.0147109	0.877969	0.00024649
3	0.861	0.0246	0.0211806	0.741321	0.00060516
4	0.889	0.0233	0.0207137	0.790321	0.00054289
5	0.897	0.0233	0.0209001	0.804609	0.00054289
6	0.943	0.0202	0.0190486	0.889249	0.00040804
7	0.961	0.0131	0.0125891	0.923521	0.00017161
8	0.742	0.0171	0.0126882	0.550564	0.00029241
9	0.881	0.0211	0.0185891	0.776161	0.00044521
10	0.867	0.0194	0.0168198	0.751689	0.00037636
11	0.923	0.0056	0.0051688	0.851929	0.00003136
12	0.845	0.0161	0.0136045	0.714025	0.00025921
13	0.908	0.0151	0.0137108	0.824464	0.00022801
14	0.947	0.0156	0.0147732	0.896809	0.00024336
15	0.962	0.0187	0.0179894	0.925444	0.00034969
16	0.842	0.0067	0.0056414	0.708964	0.00004489
17	0.786	0.0182	0.0143052	0.617796	0.00033124
18	0.935	0.019	0.017765	0.874225	0.000361
19	0.93	0.0148	0.013764	0.8649	0.00021904
Sum	16.866	0.3277	0.2902434	15.04006	0.00610287

→ Formula of Pearson's Correlation

$$r = \frac{n\,(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

→ Substituting the values

$$r = \frac{19\ x\ 0.2902434 - 16.866\ x\ 0.3277}{\sqrt{[19\ x\ 15.04006\ - 284.461956][19\ x\ 0.3277 - 0.10738729]}}$$

$$r = -0{,}0439$$

$$degree\ of\ freedom = 19 - 1 = 18$$

The *r* value implies a negative correlation between the HDI and breast cancer mortality rate in 2019[1]. Using the critical values for Pearson's correlation test from an academic website[2], the Pearson's correlation coefficient value of $-\ 0{,}0439$ is greater than the critical value of - 1 for the degree of freedom of 18, such that the *null hypothesis* is rejected, and *alternative hypothesis 1* is accepted for 2019 data. Thus, the results of this experiment are statistically significant.

10. Analysis and Conclusion

The results of the investigation have revealed a positive correlation between the HDI of a country and the rate of breast cancer mortality in 2015 (before the COVID-19 pandemic), whereas a negative correlation is detected between variables in 2019 (during COVID-19). The correlations demonstrated in the Charts1 and 2 from the trial investigation were also detected in the Charts 3 and 4 obtained in the final investigation. However, data used in charts investigations have scattered in varying degrees around the trendline, especially with 2015 data. A positive trend implies that countries with a greater HDI value have a greater breast cancer mortality rate in 2015. This can be explained by the greater breast cancer diagnoses rate in developed countries (Francies, Flavia, et al., 2020). However, the lockdowns, restrictions and fear of infection decreased the number of patients diagnosed with breast cancer. This indirectly results in a lower rate of breast cancer mortality. Additionally, countries with a greater HDI value (with few exceptions) dealt with the pandemic better than countries with a lower HDI value (Mirahmadizadeh, Alireza et al.,2022). This leads to a more successful strategy for fighting against non-communicable diseases such as breast cancer. However, cancer (namely breast cancer) has a more challenging treatment process, and hence is harder to compensate with better healthcare strategies.

Previous studies have proved that higher socio-economic status, which is reasonably similar to HDI as a measure of the well-being of a population, is related with increased breast cancer risk (Pudrovska and Anikputa 2012). According to the results of the investigation, such conclusions can be drawn from the 2015 data, therefore, representing the situation before COVID-19. Despite having a relatively low HDI, Ukraine and Turkey are the countries where

[1] A positive value is obtained with 2015 data, signaling a positive correlation. Thus hypothesis 2 is accepted.
[2] Media3.bournemouth.ac.uk, n.d.

mortality rates due to breast cancer are lower before the pandemic and outside the trendline. This can be explained by their geographical advantage, as they are close to Europe, more advance technologies and treatment methods are more accessible. However, data from 2019 implies that there was an overall decrease in breast cancer mortality rates during the peak of pandemic. This can be explained by the increase in the deaths from COVID-19 infection, masking breast cancer deaths. Since the pandemic was an unexpected situation and caused drastic changes in the healthcare system, there might be other factors affecting the results of this investigation. Besides, further research with 2020 and 2021 data is needed for investigating breast cancer cases in a post-pandemic world. The lack of controlled variables should be considered when choosing the countries, and inclusion criteria may be developed for future research.

11. Evaluation

One of the strengths of this study is the accuracy and reliability accuracy of the data sources, as all of them are sub-branches of the United Nations. Besides, since this is a comparative study regarding the effects of COVID-19 on breast cancer, it provides new insight. Additionally, the range and the data are sufficient to come to a conclusion. However, there are some limitations in this study, which are presented in Table 10.

Table 10. Limitations and possible improvements for this investigation

Limitation	Improvement
The year 2015 that the data is collected from (since it was the closest year before the pandemic on WHO data) may not fully represent the "before COVID-19" situation due to the lack of some technological advances in 2015.	The data from a closer year to the pandemic, such as 2018 or 2017, would enable a more accurate comparison between pre-COVID-19 and during COVID-19.
The number of countries selected is rather low (19 countries), which may affect the statistical testing and weakens the results.	Countries with lower HDI values or with smaller populations can be included.
The countries selected had few controlled variables, such as urbanization level, education status, and awareness about breast cancer.	Countries can be selected with a common organization, such as OECD (for European countries) or ASEAN (for Asian countries). Similar climate and GDP per capita can be chosen, though this may limit the number of the countries.

With further research that achieves such improvements, a multipronged strategy regarding the fight against breast cancer can be developed, which prioritizes high human development, increased awareness about breast cancer, and treatment approaches that suit low-resource environments and, lastly a dynamic system that can adapt to extraordinary situations such as a pandemic.

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