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# High Risk Areas of Covid-19 Pandemic in UK: An Epidemiological and Spatiotemporal Analysis

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**Abstract:**

Since the outbreak of Covid-19 the humanity has faced great global health crisis. Covid-19 have affected all countries of the world, causing thousands of deaths and economic hardships. In United Kingdom as well as other regions of the world, the virus is infectious to people of all aspects of life, social, political, economic as well as moral. The objectives of this study was to ) to understand the epidemiological characteristics of COVID-19 pandemic in UK; 2) to understand the spatiotemporal characteristics of COVID-19 pandemic in UK, and 3) to map out the high risk areas/regions of COVID-19 pandemic in UK. To achieve these objectives, a quantitative study was conducted using secondary data collected from various sources. The data collected included Covid-19 statistics of tests, confirmed cases, and deaths in UK. The data analysis techniques applied comparative analysis, descriptive statistics and spatial autocorrelation using Moran's I index (Local Indicators of Spatial Association). The findings of the study indicated that that England has the highest rates of confirmed Covid-19 case, deaths and conducted tests while Northern Ireland has the lowest rates of confirmed Covid-19 case, deaths and conducted tests. There were no correlation or relationship between the regions under study, in terms of Covid-19 reported cases, tests or deaths. For both year 2020 and 2021, the Covid-19 confirmed cases, tests and deaths among the four neighboring regions were significantly different from each other. The research recommends that each nation should bear its responsibility of adopting and implementing measures geared towards addressing and controlling the spread of Covid-19 pandemic. As well, individuals should take personal preventive measures to avoid being infected with Covid-19 virus, especially in the high risky areas.

**Keywords:** epidemiological, spatiotemporal, coronavirus, pandemic, high risk areas,

## 1.0 Introduction:

Throughout the development of human society, infectious diseases have been considered life-threatening due to their contagious characteristic. A handful of these disease claim millions of lives of people worldwide every year, posing great threat to human existence and development. Corona Virus (COVID-19) is a new infectious disease that was identified and reported on December 8 2019 by the Wuhan Municipal Health Committee in China (Mo, Tan, Mai, Bei, Qin, Pang & Zhang, 2020). Since the outbreak of the COVID-19, humanity has faced a great global health crisis. The quick spread of the virus from China to other countries such as Italy, Germany, Thailand, Japan, Vietnam, United States of America led to the World Health Organization to declare its outbreak

as a Public Health Emergency of International Concerns (PHEIC) on January 30th 2020. By 16th March 2020, there were more than 180,000 confirmed cases of corona virus worldwide, with more 7,000 deaths caused by the virus (World Health Organization, 2021). The virus has continued to spread worldwide, with all the countries worldwide having reported infection and death cases. By 30th January 2021, one year after the WHO declared COVID-19 a PHEIC, the world had recorded 101,581,407 cases and 2,197,209 total deaths. However, the global health sector had made significant interventions through vaccinations, where by that date, 10,318,313 people had been fully vaccinated, with 57,259,251 received at least one dose of vaccination (World Health Organization, 2021).

Currently, the corona virus disease pandemic has affected every country in the world, and no individual could be considered safe. The virus is infectious to people of all aspects of life, social, political, economic as well as moral. As compared to other infectious disease that have occurred in the past, such as severe acute respiratory syndrome (SARS), COVID-19 has proved more rapidly spread and deadly (Wu & McGoogan, 2020). Comparing the estimated basic reproductive number (ROS), COVID-19 was approximately 3.1 (Imai, et al., 2020) while that of SARS was lower at 2.7 (Riley, et al., 2003). The transmission mechanism of COVID-19 have not been perfectly well understood, though the virus has been considered as the most destructive and widespread disease worldwide. This gap in evaluating and understanding the spread, diagnostics and treatment of COVID-19 calls for an integrated investigation towards an international and effective response to the outbreak.

In United Kingdom, measures to address the COVID-19 pandemic was adopted and implemented as early as March 2020, when the Prime Minister Boris Johnson declared: “From this evening I must give the British people a very simple instruction—you must stay at home” (Johnson, 2020a). Some of the measures announced then included behavioral regulations, public health support by the police department, closure of schools among others. Though these measures have been considered necessary, scientists and scholars have a different observation, that there is dire need to gather evidence in term of epidemiology and spatiotemporal analytics, so as to effectively model the different aspects of the epidemic, identify and define key points of interventions. These interventions could be appropriate towards reduction of the population illness peak, as well as effective management of illness in the long-run (Sky News, 2020).

The Covid-19 pandemic, both in UK and globally is surrounded by many unknowns, ranging from the spatio dimension which helps in understanding the phenomena geographically and potential mapping, to the epidemiological, which helps to understand the incidences, distribution control mechanism of the disease. A few studies have been conducted to address the epidemiological aspects of the virus, but only focus on the disease characteristic, indicators and distribution. The studies on spatial and temporal distribution has analyzed the two aspects separately. However, the studies have not considered the possible interaction of spatiotemporal aspects, hence their ability to accurately predict its spatial and temporal evolution is limited. From a health science perspective, to accurately understand and interpret the COVID-19 Pandemic, the declared global pandemic requires intensive spatiotemporal dimension and epidemiological analysis with statistical tools.

The aim of this study is to conduct an epidemiological and spatiotemporal analysis to identify high risk areas of coronavirus. This aim is two-fold. The first part is to conduct the epidemiological analysis of Covid-19 in UK, by identifying the trend of the virus over times, in various aspects such as tests conducted, confirmed cases and deaths. The analysis is also conducted to understand the epidemiological parameters of the virus such as characteristic and symptoms; and the spatiotemporal aspects such as locations and distribution patterns of COVID-19 pandemic. The second aspect is the spatiotemporal analysis. This

compares the prevalence of Covid-19 in UK nations, and whether there is any correlation between these regions, in terms of tests conducted, confirmed cases and deaths.

## 2.0 Literature Review:

### 2.1 Assessing Infectious Diseases:

Whenever a new infectious disease epidemic emerges, there are two pieces of information that are critical, (1) how infectious it is, and (2) the modes of its transmissions (Nicastri, et al., 2020). An infectious disease may emerge, and re-emerge in a particular place, and potentially spread widely making every human being susceptible to the diseases. This is the case that has happened with COVID-19. In United Kingdom, and globally, the new corona virus is a major challenge to human existence, posing great health concern and declared as a national health emergency (WHO, 2020). The challenge in this situation is that policy makers are expected to make effective and informed decisions, in the presence of uncertainties and incomplete information.

In the transmission of an infectious disease like the current COVID-19 epidemic, the intensity of its spreading is influenced by factors such as the number of people already infected, the number of individuals who are susceptible to be infected, human contact patterns facilitating transmission, and the demographic of the concerned population (Rotejanaprasert, Lawpoolsri, Pan-ngum & Maude, 2020). The application of different available transmissibility measures is dependent on the data availability and type and could be calculated using various techniques. The metric of transmissibility that could be computed and easily applied is the growth rate (Farrington, Andrews, Beale & Catchpole, 1996), which could modelled in the case the disease is exponentially increasing. Another metric measure that could be applied is the reproduction number (R) which measures the expected quantity of subsequent infections occurring over the course of the infectious period. Inferring to Hébert-Dufresne, Althouse, Scarpino & Allard (2020), is the most effective to use among the reproduction numbers, in the context of a large population, where every individual is susceptible to be infected without any control measures.

### 2.2 COVID-19 in UK:

Like any other nations in the world, United Kingdom has faced its own challenges of addressing the COVID-19 pandemic. As of 18th April 2021, UK was in its second wave of COVID-19, like many other world nations, with approximately 4,393,311 confirmed cases, and 127,307 confirmed deaths as reported by WHO. However, it is critical to highlight the intervention undertaken in the UK, where 43,084,487 vaccines have been administered (World Health Organization (WHO), 2021).

UK has a population of 67.8 million people, ranking as the third largest country in Europe and the population projected to surpass 70 million by 2029 (Office for National Statistics, 2019). Its population growth is majorly contributed by migration and aged people. It's among the most densely populated country in Europe with about 281 people per square kilometer. This density levels raises concerns, as long as the highly infectious COVID-19 pandemic is concerned (Worldometer. U.K. population, 2020). Life expectancy for females is 83.3 years and 80.2 years for male and 18% of the population are aged 60 years and above. Considering that mortality rate is high for the aged population (Daw, El-Bouzedi & Ahmed, 2020; Flynn et al., 2020) the country faces a great challenge of implementing effective measures to address the pandemic.

According to the health indicators highlighted by the WHO for the UK, the non-communicable diseases were considered as a high risk factor for poor prognosis after contracting Acovid-19 (World Health Organisation, 2020). Obesity, which is majorly contributed by poor health behaviors and socio-demographic factors and its associated long-term risky conditions have been considered as the major risk factors of high morbidity from COVID-19 (Intensive Care National Audit and Research Centre, 2020). Other risky conditions quite prevalent in UK include type 2 diabetes with an approximate prevalent of 3.9 million people

(Diabetes UK. Diabetes Facts and Stats: 2015); heart and circulatory diseases with a prevalence of 7.2 million people (NHS Digital, , 2017); hypertension with a prevalence of 12.5 million people (Bhaskaran et al., 2014); and cancer as well as other mental health conditions. The high prevalence of these medical conditions calls for effective and well informed COVID-19 intervention measures.

### 2.3 Empirical Literature:

There are several studies that has been conducted to evaluate the COVID-19 pandemic, applying either the concept of epidemiological, spatiotemporal or both analysis. A review of these studies guides the current study in the developing the debt methodology and analytical techniques to adopt, based on the study environment. Giuliani, Dickson, Espa & Santi (2020) carried out a study on modeling and predicting the spatio-temporal spread of COVID-19 in Italy. The study applied the endemic-epidemic time-series mixed-effects generalized linear model to analyse predict and understand the spatio-temporal diffusion of the pandemic. The methodology borrows from the data-science by presenting the regional visualization of the COVID-19 cases. The notable findings of this study is that there were evidence that the provinces that imposed urgent strict measures managed to break the spread of the disease, as well as limit the spread of the pandemic to the nearby areas. Another study worth evaluating was conducted by Rotejanaprasert, Lawpoolsri, Pan-ngum, Maude (2020), to preliminary estimate the temporal and spatio-temporal dynamics measures of COVID-19 transmission in Thailand. From the data science point of view, the study applied the concept of transmissibility and preliminary estimation of reproduction numbers over time and space. The study found out that the basic reproduction numbers were between 2.23 and 5.90, with an average of 3.75.

Daw, El-Bouzedi & Ahmed (2020) investigated the epidemiological and spatiotemporal characteristics of 2019 COVID-19 in Libya. The study applied the logistic regression analysis and data visualization technique to map the highly COVID-19 risky regions in Libya. From critical perspective, some interesting findings were reported such as a male-to-female ratio of 2.1:1 with aged parents reporting higher severity and mortality rates. The study also indicated an increase in the spread of the disease in the middle and southern regions as compared to other regions. Li et al., (2021) investigated the epidemiology of COVID-19 using a systematic review and meta-analysis of clinical characteristics, risk factors and outcomes. The study applied a pooled estimates of the clinical characteristics, COVID-19 patient's disease severity subgroups and country/region. Some interesting epidemiological findings were that the average age was 46.7 years, 51.8% were male, and severity was 22.9% resulting to 5.6% mortality (Li et al., 2021). The results also indicated that Underlying immunosuppression, diabetes, and malignancy were the three conditions that were associated with severe cases of COVID-19.

## 3.0 Methodology:

### 3.1 Research Philosophy and Method:

The research philosophy and strategy adopted in a study depends on the type of the data used to carry out the study. In consideration of philosophies, the researcher opted to use the interpretive philosophy. This was due to the nature of research, whereby the views of the people were the central determinant of the findings of the research. Among the three applicable research methods (quantitative, qualitative and mixed method), this study adopted the quantitative study method. The reason was because the data used was quantitative and quantitative data analysis techniques was applied for the study.

### 3.2 Sources of Data:

This study used publicly available data of COVID-19 in United Kingdom. The sources of the data used were majorly two, The World Health Organization Data and the Coronavirus (COVID-19) in the UK. The two sources maintained daily updates of the COVID-19 data from the time the pandemic started in the UK to the date of carrying out this research. The data was collected in metrics of number of: tests conducted, confirmed cases,

deaths reported, vaccinations administered, and healthcare statistics which included patients admitted, patients in hospital, and patients on ventilation. Additional data for COVID-19 in terms of Age, Gender and Sex was derived from Office of National Statistics London Data Store and National Health Service.

The time span of the analysis was from 1st February 2020 to 30th April 2021, covering a period of one year and three months. The starting data was considered suitable as it covered the onset of the COVID-19 Pandemic in UK where the first case was reported on 31st January 2020. The span also covers other significant announcement and measures regarding the COVID-19 pandemic such as on 23rd March 2020 when the first lockdown was announced in UK. The study areas covered in the study is the United Kingdom, consisting of Scotland, England, Wales and Northern Ireland nations. The study region map is presented in the figure below.


**Figure 1: Research Study Area of United Kingdom**

### 3.3 Statistical Analysis:

#### *3.3.1 Epidemiology Analysis:*

A comprehensive descriptive epidemiological analysis was conducted to from the four regions of study in the United Kingdom. The descriptive epidemiological analysis was evaluated on the basis of the data variables, including the deaths, infection cases, and vaccinations, hospital characteristics (patients in hospital, admitted and on ventilation). An extensive epidemiology analysis was conducted to investigate how these variables (cases, deaths, vaccination and hospital characteristics) varied among Age, Gender as well

as the ethnic group of the patients. This analysis adopted a time-series data for the study period of 1st February 2020 to 30th April 2021. This means that the epidemiological study explored the distribution aspect of COVID-19 in terms of frequency and patterns, as well as the associated demographic characteristics. However, it is important to acknowledge that due to the unavailability of data, this study was unable to explore the determinants epidemiological aspects of COVID-19 such as the cause and risky factors or health related states due to lack of data over the specified period. The epidemiology of specified population was analyzed from the region perspective in the study area.

### *3.3.2 Spatiotemporal Analysis*

To measure the spatiotemporal correlation between the four nations in United Kingdom, the Moran's autocorrelation coefficient also referred to as Moran index (Moran's I) in its application in health science. The statistic was first suggested by Moran (1948) and later popularized through the classic work of Cliff and Ord (1973). The Moran Index (Moran I) is the measure of the spatiotemporal autocorrelation which is majorly applied in identifying the spatial hotspots or clusters in a spatiotemporal study.

From a critical review of literature, there are few studies that have been carried out on this topic applying the Moran's index, and none was found to have been carried out in United Kingdom. Moran I is an extension of the Peason's product-moment correlation coefficient with the capabilities of spatial pattern correlation (Cliff & Ord, 1973). In the formulation of the Morans I for the purpose of this study, the attribution of the adjacent region is characterized by the Moran index. We assume that the variable x is the attribute value of the region. Then the Moram index "I" is expressed as:

$$I = \frac{n\sum_{i=1}^{n}\sum_{i=1}^{n} w_{ij}\,(x_i - x)(x_j - \bar{x})}{\sum_{i=1}^{n}\sum_{i=1}^{n} w_{ij}\,\sum_{k=1}^{n}(x_k - \bar{x})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This is translated in to

$$I = \frac{\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}\,(x_i - x)(x_j - \bar{x})}{S^2\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}} \ldots\ldots\ldots\ldots\ldots (2)$$

Where: $S^2 = \frac{1}{n}\sum_i (x_i - \bar{x})^2$ and $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

$W_{ij}$ implies the matrix of the spatial dependence which describes the correlation between the explained variables of section $i$ and section $j$. The Moran Index ranges from [-1, 1] and the value of 0 implies that the two parts does not have correlation. The spatial weight matrix could be described using two parts: (1) on the basis of geographical distance, where $W_{ij}$ implies the physical distance between two regions $i$ and $j$; (2) the simple binary adjacent whose elements could be expressed in rows $i$ and columns $j$. This can be expressed as follows:

$$W_{ij} = \begin{cases} 1\ region\ i\ and\ j\ are\ connected \\ 0\ thers \end{cases} \ldots\ldots (3)$$

The Moran's I inference is based on the null hypothesis of spatial randomness. Under null hypothesis, the distribution of the statistic is obtained through normality assumption (independent normal random variates) or what is referred to as the randomization. In other words, it implies that each observation or value is equally likely to occur at any region. The statistic is also presented using the Moran's scatter plot, which was proposed by Anselin (1966). The plot consists of a spatially lagged variable on the y-axis and the original variable on the x-axis. The slope of the linear fit to the scatter plot indicated the Moran's I statistic (Anselin, 1996). The various statistical calculations for this study, the diagrammatic representation of the findings and the mapping of the regions was conducted with the help of Excel and GeoDa Statistical software.

## 4.0 Research Results:

### 4.1 Epidemiology Analysis

The first epidemiological analysis done was to evaluate the covid-19 test conducted among the four countries of United Kingdom (Scotland, England, Wales and Northern Ireland). The comparison of tests were done between end of year 2020 and by May 2021, to evaluate the efforts of each country in carrying out the tests. The results are presented below.

**Table 1: Covid-19 tests results**

| Area Name | Year of Date | No. of Virus Tests | % Change |
|---|---|---|---|
| England | 2020 | 2,872,124,913 | |
| England | 2021 | 13,282,343,406 | 362.457 |
| Northern Ireland | 2020 | 84,729,672 | |
| Northern Ireland | 2021 | 252,311,133 | 197.7837 |
| Scotland | 2020 | 248,360,739 | |
| Scotland | 2021 | 692,000,095 | 178.627 |
| Wales | 2020 | 134,307,437 | |
| Wales | 2021 | 406,284,313 | 202.5032 |

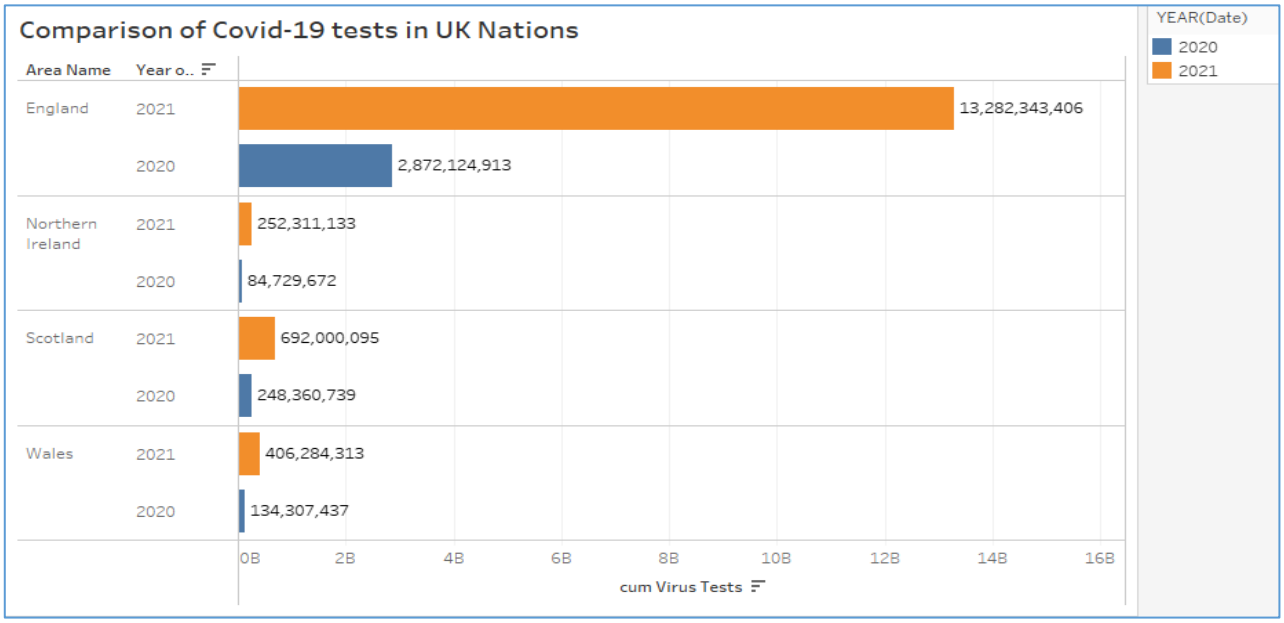



**Figure 2: Covid-19 tests results**

The % change column shows the efforts of the countries in conducting tests. Since the population is different, the percentage change displayed actual effort. The results indicates that England has the highest % change in number of virus tests (362.5%) followed by Wales (202.5%), then Northern Ireland (197.8%) and finally Scotland (178.6%).

Another analysis was the number of hospital admissions of patients suffering from COVID-19. The analysis was conducted to evaluate the cumulative trends of the total people admitted to hospitals. The figure below shows the trend among the four countries. From the results, England was found to have the highest number of COVID-19 hospital admissions. Between October 2020 and February 2021, the England is found to experience a sharp rise in the number of hospital admissions. However, England is observed to have significantly managed the growth in hospital admission. The other three nations (Wales, Northern Island and Scotland) have experience quite low increase levels of hospital admissions. To have a complete evaluation of their performance, the three countries were compared alone, where Wales reported the highest amount of hospital admissions. North Ireland had the lowest hospital admissions. Overall, the trend is that there has been an increase in the total number of hospital admissions since the COVID-19 was reported in United Kingdom.

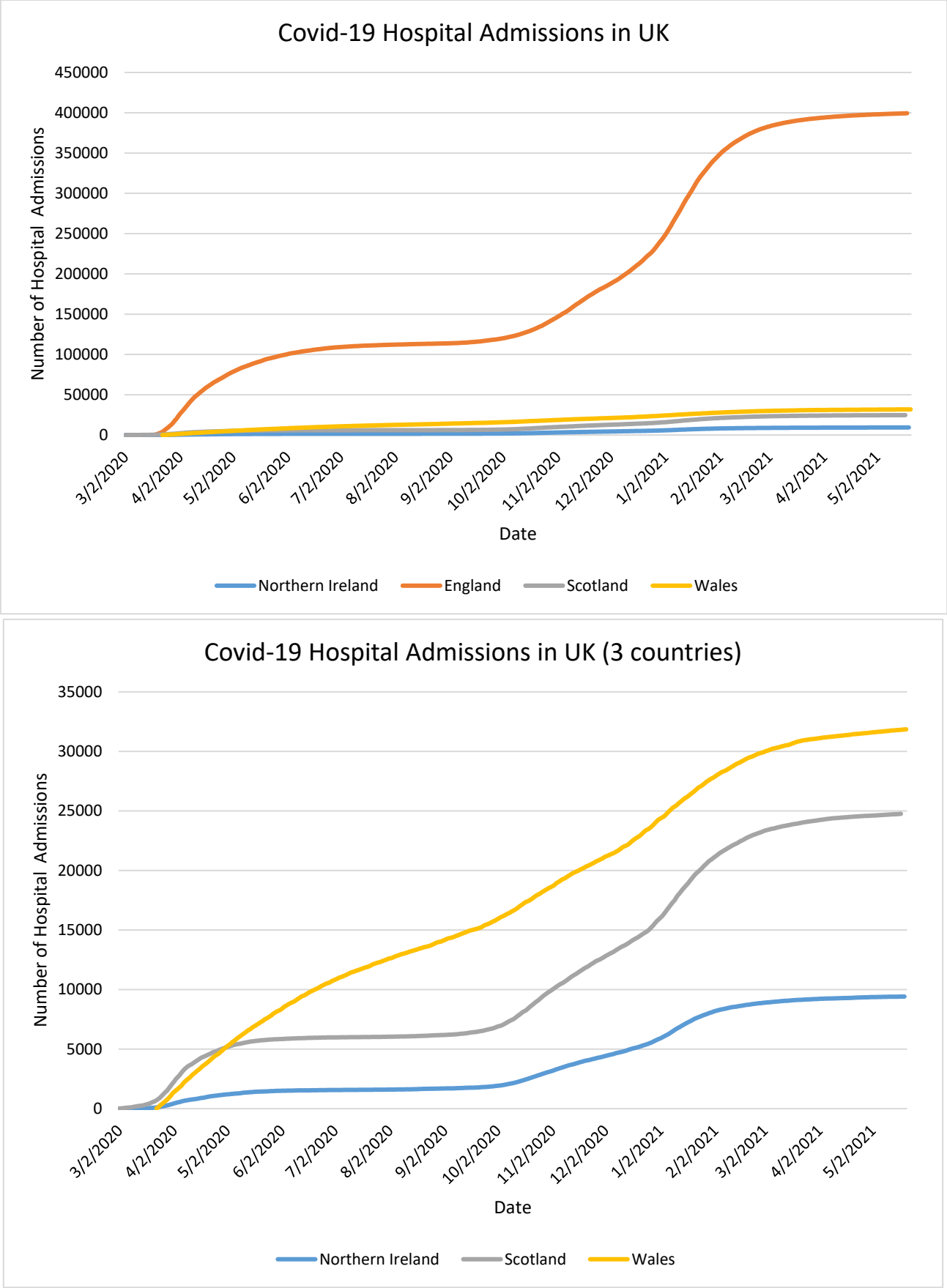
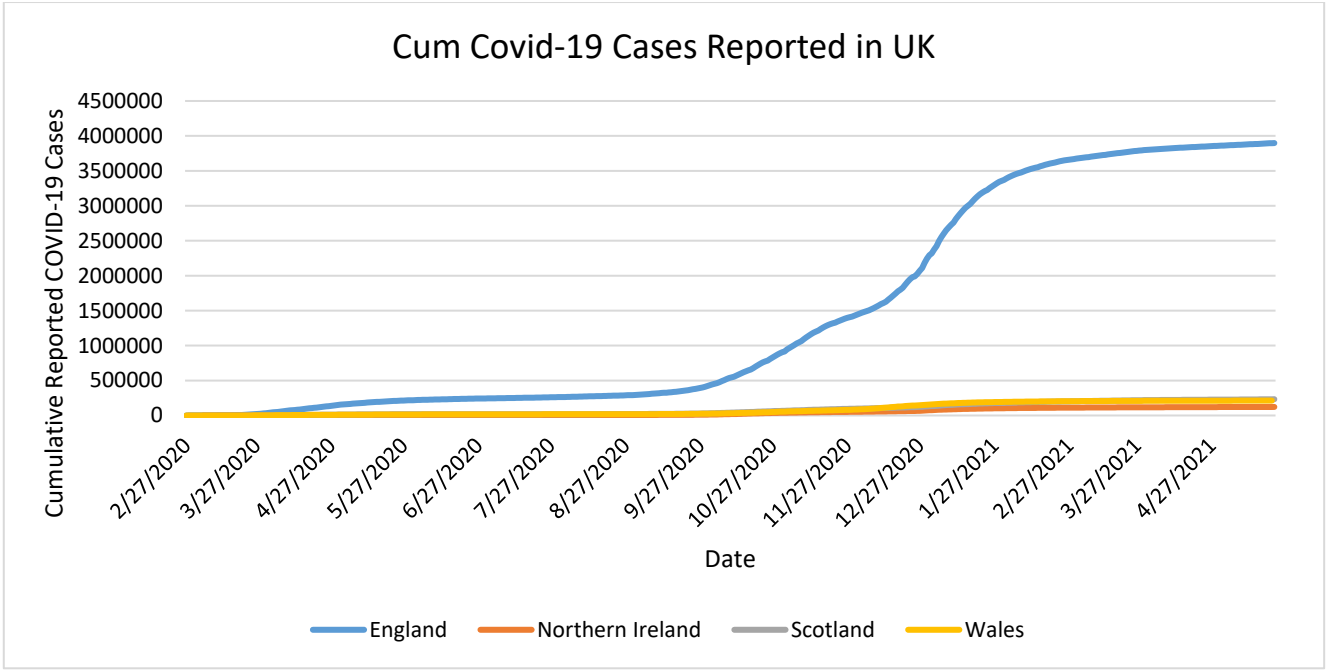



**Figure 3: Covid-19 Hospital Admissions in UK**

Another epidemiological analysis conducted was that of the COVID-19 cases reported in UK. The comparison of the four nations were conducted and in terms of the total cumulative reported cases, over the period of study. The results of the study is presented in the figure below.



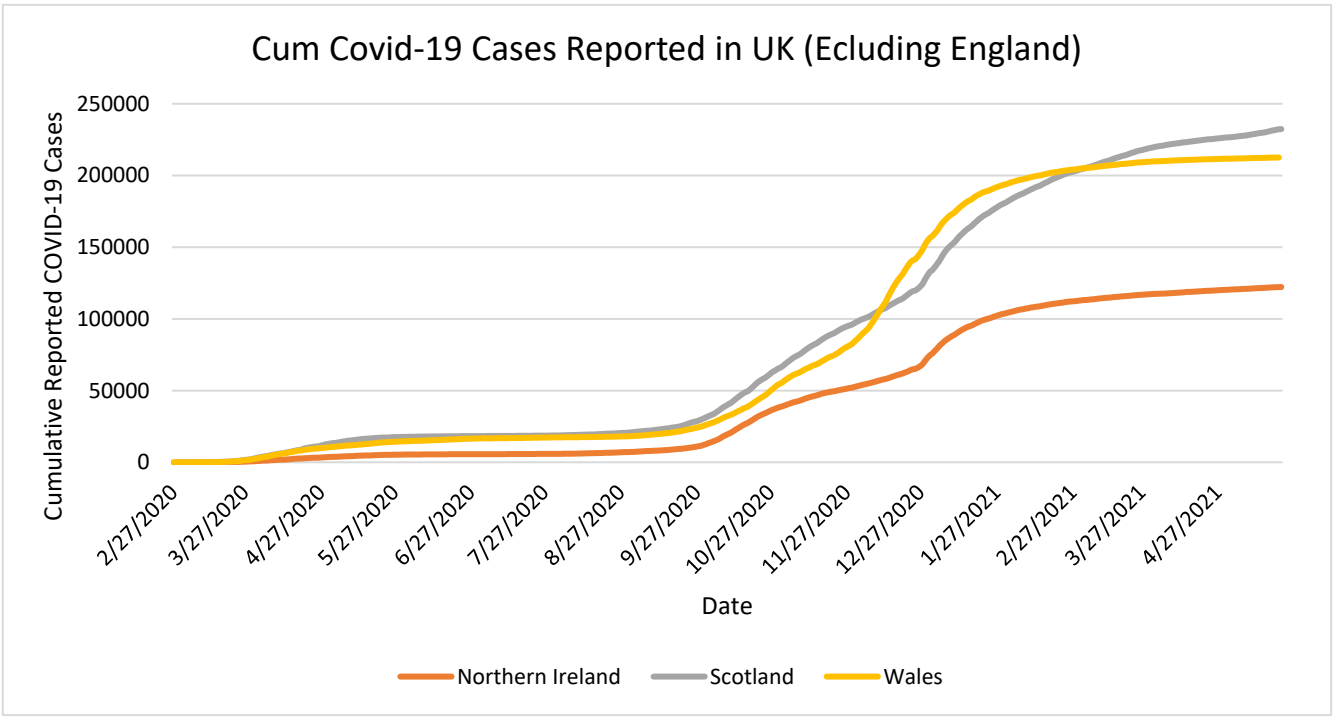




**Figure 4: Cum Covid-19 Cases Reported in UK**

From the first line graph comparing the four nations, England was reported to have the highest number of reported cases as shown in the graph. The COVID-19 cases are seen to significantly increase between October 2020 and February 2021. After that, the cases are seen to slightly increase over a period of time. To effectively see the trends of other three nations, England was eliminated and the graph of three countries (Wales, Northern Island and Scotland) was drawn, as presented above. Overall, Northern Ireland was reported to have the least number of COVID-19 cases since it was first reported in UK. Scotland and Wales have experienced fluctuating trends. Wales was has reported lower cases than Scotland but between Mid-December 2020 and early March 2021, Wales had a higher reported number of COVID-19 cases. By March 2021, the UK countries proves to have contained the spread of the virus as indicated by the flattening trend, except for the case of Scotland, whose cases are still rising significantly. It is important to note that over the period, all UK countries has been experiencing increasing trends in reported cases of COVID-19.

This research also analyzed the Covid-19 cases in England, based on their Age-groups. It it important to note that the epidemiological analysis of age-group was only conducted in England due to data availability. The graph below shows the cumulative confirmed cases from the date Covid-19 was reported in England, up to 30th April 2021 (the study period of this research).

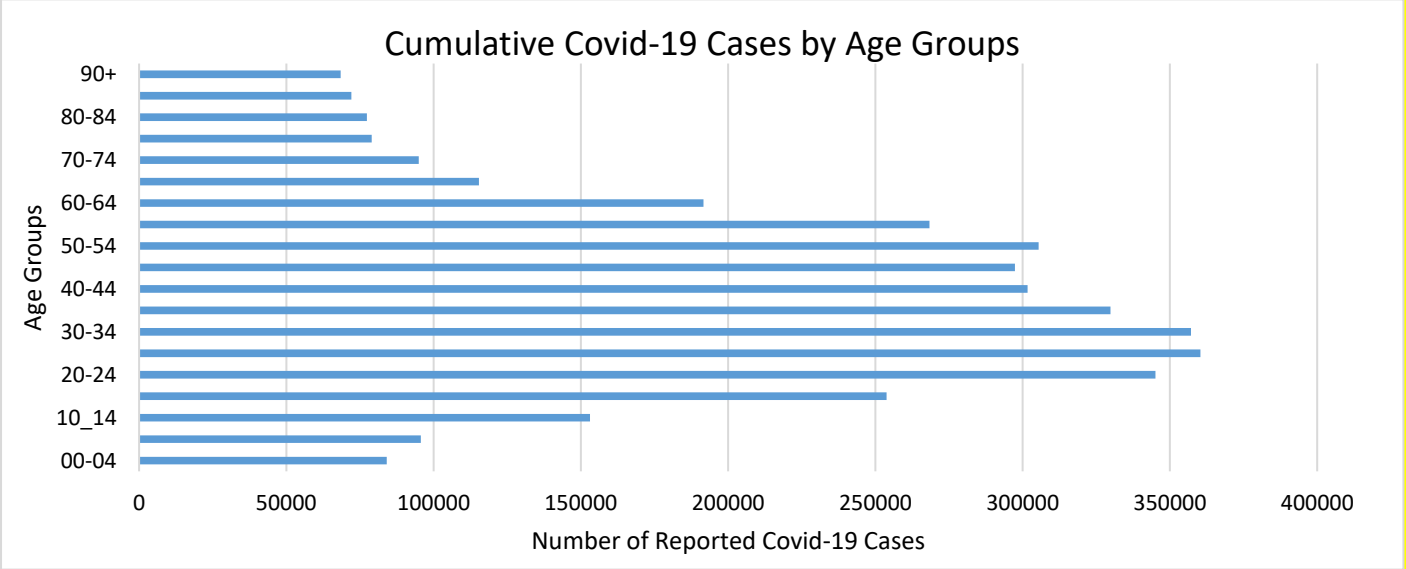
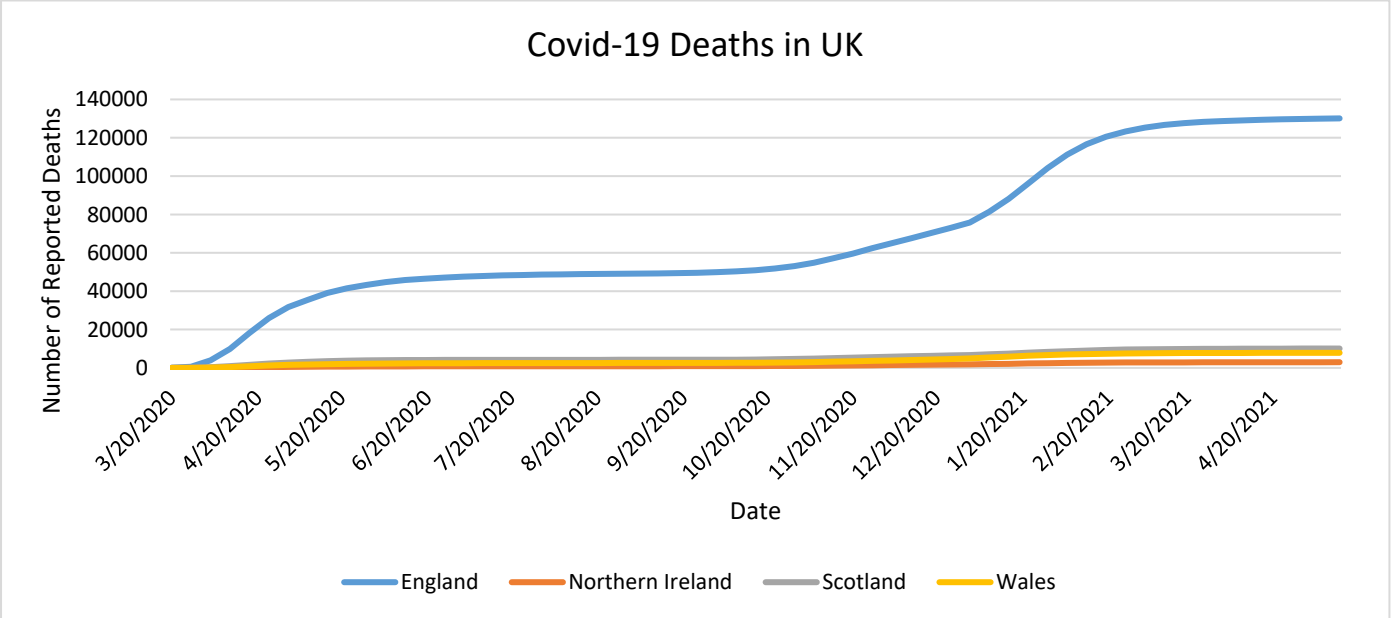



**Figure 5: Cumulative Covid-19 Cases by Age Groups**

The graph above shows that the age group with the highest cumulative cases was 25-29 years followed by those aged between 30-34 years. Most of the infection cases seemed to concentrate between the ages between 15 – 59 years, which represents the most productive ages of a human being. It is also notable that the infants that were infected with Covid-19 were also many in England, accounting for more than 84,000 cases.

The research also investigated the COVID-19 deaths in United Kingdom and compared the four countries trends for the period covered in this research. The comparison of the four countries shows that England has the highest number of COVID-19 deaths. The trends of COVID-19 cases among the four countries is shown in the figure below.

The graph above shows that England experienced several phases of increase and decrease in number of COVID-19 deaths. The first phase with high rate of deaths was between February 2020 and May 2020, where there were a sharp increase in the total number of COVID-19 reported deaths, the period which was referred to as the 'first wave'.



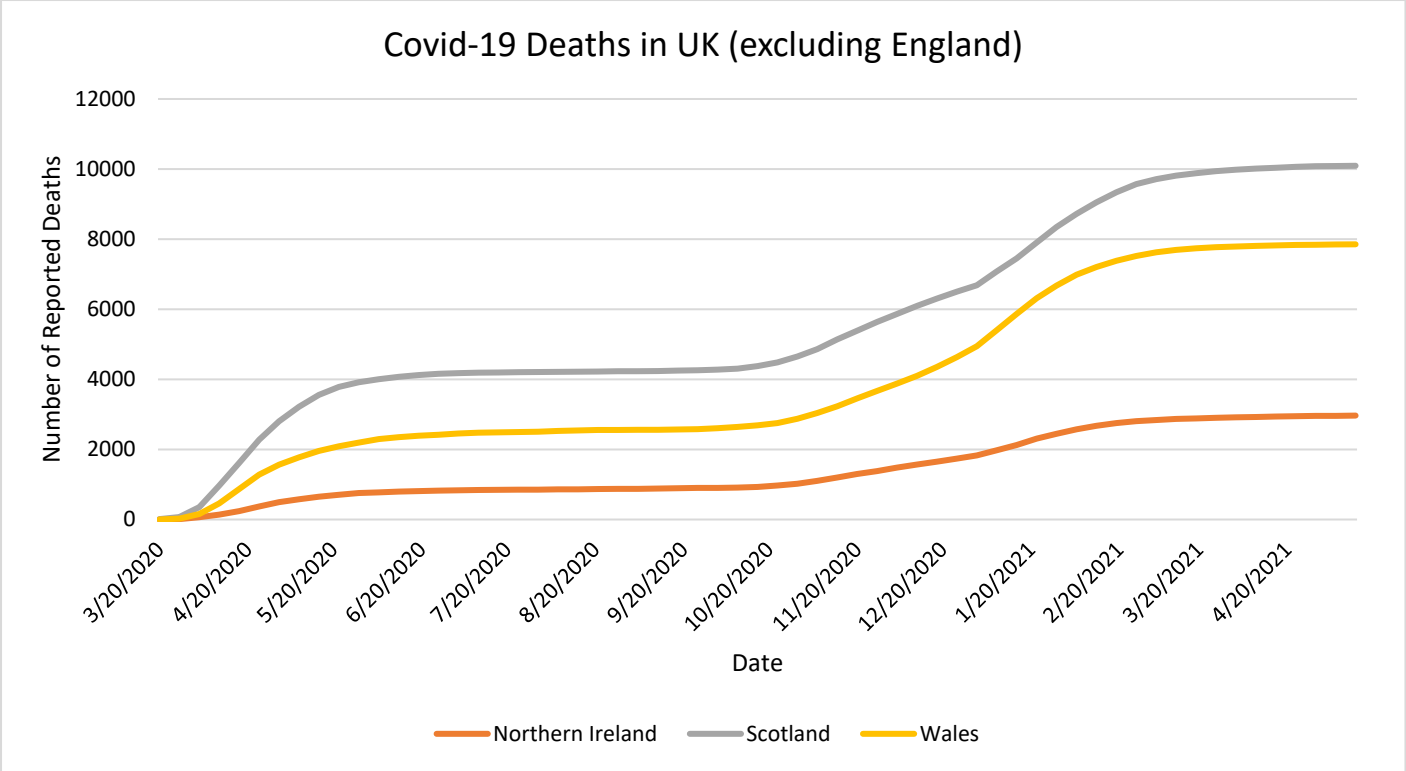



**Figure 6: Covid-19 Deaths in UK**

From May 2020 to November 2020, the number of deaths increased at a low rate. However, from mid-November 2020 to the end of February 2021, England experienced high rates of COVID-19 deaths, the period which was pronounced as the "second wave". After that, the country seemed to have contained the increase in COVID-19 deaths, as there were slight increase in the total number of deaths. The comparison with three other countries was conducted by eliminating England and comparing the trend of the other three countries. The graph shows that from the inception of the COVID-19 pandemic, Northern Ireland experience the lowest number of COVID-19 deaths as compared to other nations in UK, and the next in rank was Wales and then Scotland. A critical evaluation of the trend of the deaths experience in the region shows that all the countries experienced the same phases of increase and decrease in number of COVID-19 deaths. For instance, the first wave between February 2020 and May 2020, where there were a sharp increase in the total number of COVID-19 reported deaths, and the second wave between mid-November 2020 to the end of February 2021, where as well, there were a sharp increase in the total number of COVID-19 reported deaths.

**Spatiotemporal Results**

For comprehensiveness in data comparison, the considered period was divided in to two categories, the year 2020 period and year 2021 period. The spatiotemporal results for the two periods were compared to depict the changes various aspects such as Covid-19 confirmed cases, deaths, tests conducted and vaccines administered. The spatial effects of the whole Covid-19 pandemic period considered is represented by LISA map and the Moran's I scatter plots and Moran's I statistics. The results are presented in the figures below.

***4.3.1 Spatiotemporal Analysis of Covid-19 Deaths in UK***

This section was a spatiotemporal analysis of the Covid-19 deaths in UK. The purpose was to find out which regions in UK had the highest deaths and whether there were any spatial-correlation between regions in terms of death occurrence. The analysis was conducted using Quantile maps, Local Indicators Spatial Association (LISA) maps and Moran's I index at 0.05 significance level. The results are presented in the figures below.

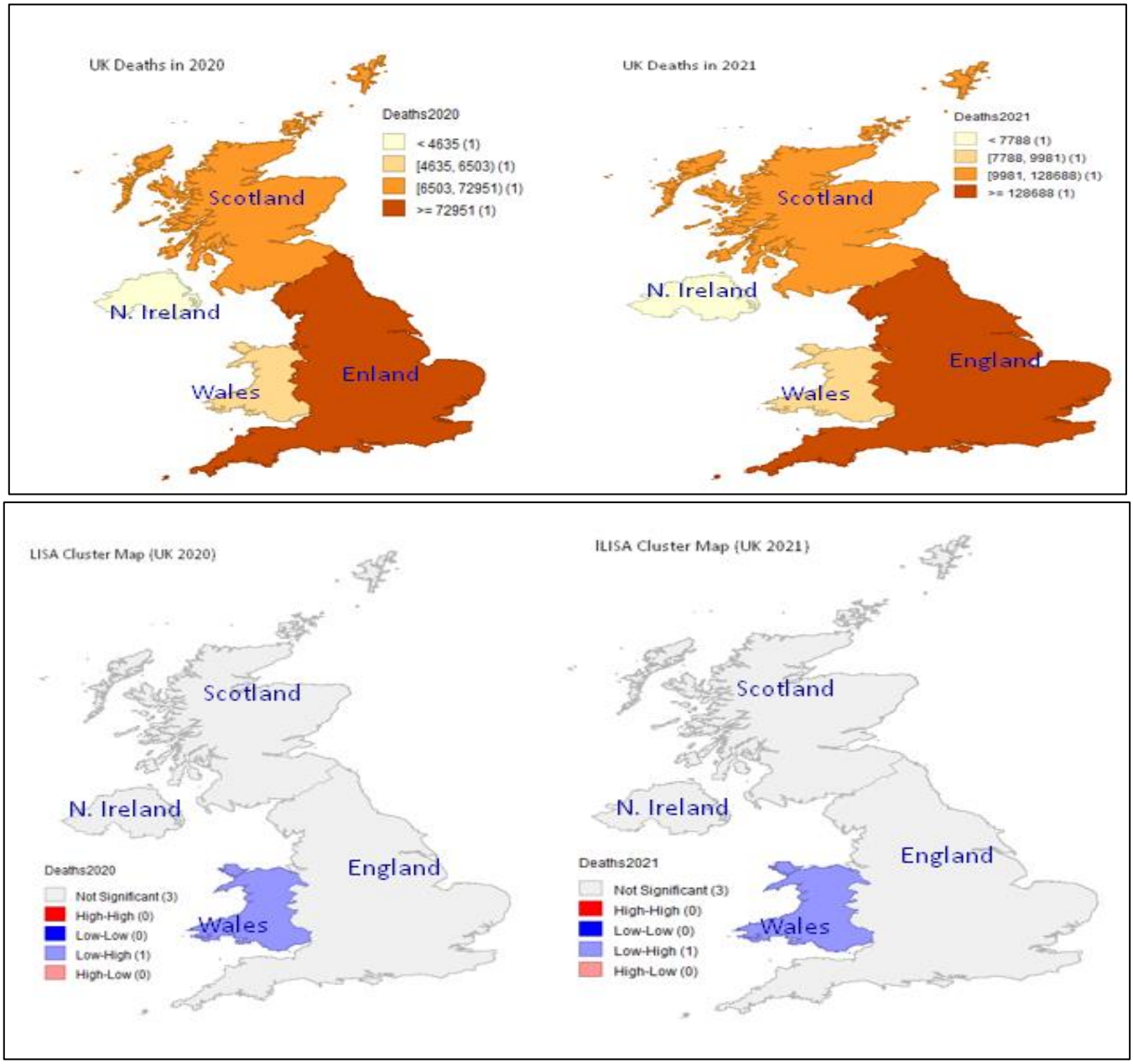
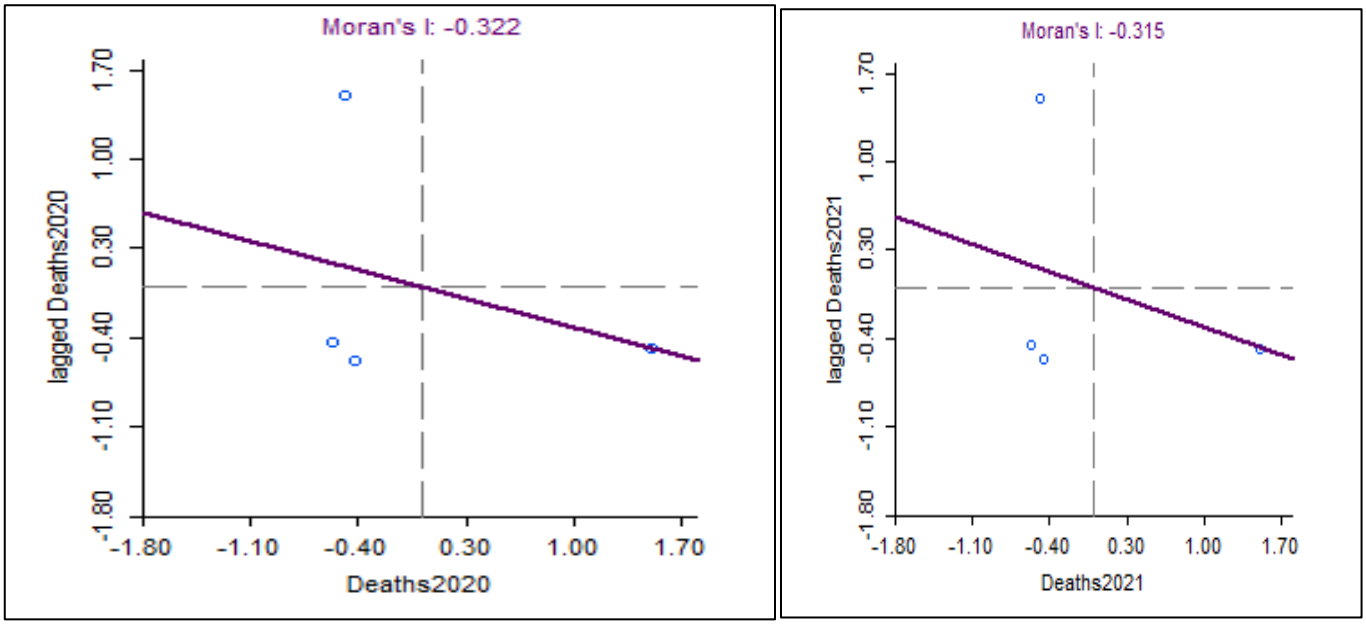



**Figure 7: Spatiotemporal Analysis of Covid-19 Deaths in UK**



From the analysis of the quantiles maps, both 2020 and 2021 deaths statistics are similar, where England has the highest number of deaths, clustered above 72951 by end of 2020 and above 128,688 by end of April 2021. Scotland ranked second in terms of number of deaths, followed by Wales and lastly Northern Ireland. The LISA cluster maps shows the location having significant local spatial autocorrelation by the type of association. Considering the LISA cluster maps, it is observed for both the two phases (2020 and 2021) three regions (England, Scotland and Northern Ireland) displayed non-significant spatial autocorrelation (no spatial clusters or outliers). However, for Wales, the results indicated Low-High implying cluster outliers. Considering the Moran's I index, it was -0.322 (for year 2020) and -0.315 (for year 2021) with a significance of 0.001. This indicates there is no association of the number of deaths between adjustment or neighboring regions in UK.

### *4.3.2 Spatiotemporal Analysis of Covid-19 Confirmed Cases in UK*

This section was a spatiotemporal analysis of the Covid-19 confirmed cases in UK. The purpose was to find out which regions in UK had the highest confirmed cases and whether there were any spatial-correlation between regions in terms of Covid-19 confirmed cases occurrence. The analysis was conducted using Quantile maps, Local Indicators Spatial Association (LISA) maps and Moran's I index at 0.05 and 0.001 significance level. The results are presented in the figures below.

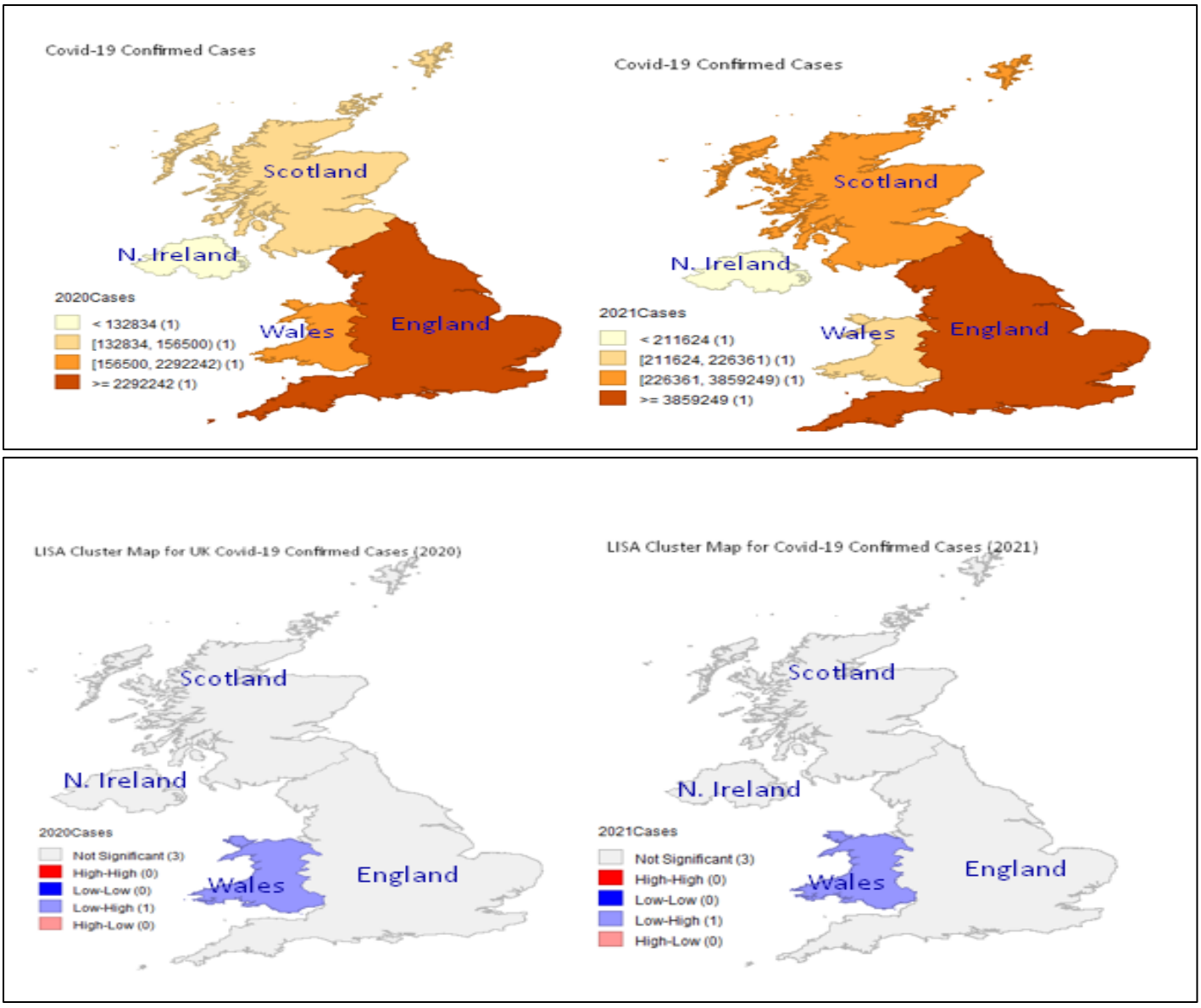
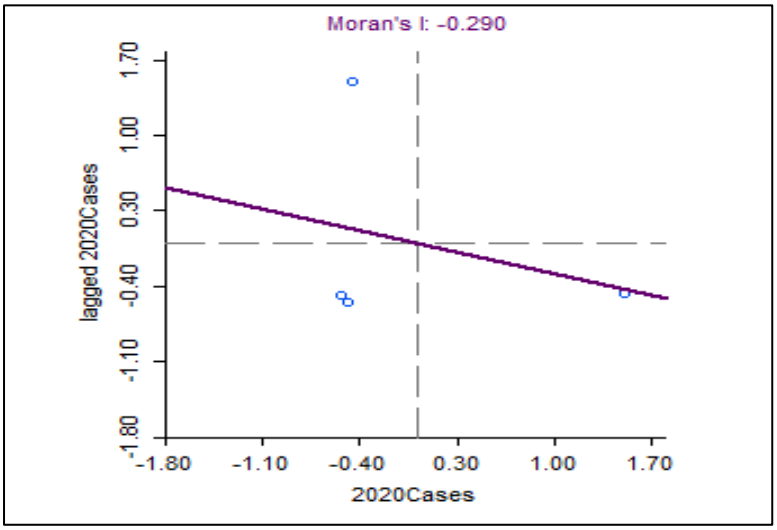
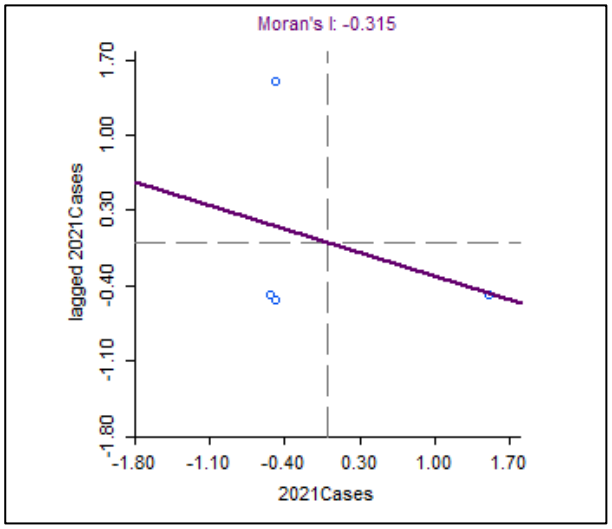



**Figure 8: Spatiotemporal Analysis of Covid-19 Confirmed Cases in UK**




The first results presented in the graphs above were those of the quantile maps, which depicted the density of confirmed cases in each of the considered region in UK. From the analysis of the quantiles maps, similar results are observed for both phases (year 2020 and year 2021). Among the four regions, England had the highest number of Covid-19 confirmed cases, for both end of year 2020 and by end of April 2021. The number of cumulative confirmed Covid-19 cases were clustered above 2292242 by end of 2020 and above 3859249 by end of April 2021. However, a significant change is observed between Wales and Scotland in terms of number of cases confirmed. By the end of year 2020, Wales was the second country with largest Covid-19 confirmed cases, after England. The results were clustered between 156,600 people and 2292242 people. The third nation was Scotland. However, by the end of April 2021 (the period of conducting this study), Scotland had surpassed Wales to be the second nation in UK with the largest number of Covid-19 reported cases. However, it is notable that Northern Ireland has maintained its status as the country with the least cases of Covid-19 confirmed cases for both year 2020 and year 2021.

The second analysis was to evaluate whether among the four regions, there are any neighboring regions which depicted similar confirmed cases as their neighboring regions. This was evaluated using the LISA Cluster maps. The LISA cluster maps shows the location having significant local spatial autocorrelation by the type of association. Considering the LISA cluster maps, it is observed for both the two phases (2020 and 2021) three regions (England, Scotland and Northern Ireland) displayed non-significant spatial autocorrelation (no spatial clusters or outliers). However, for Wales, the results indicated Low-High implying cluster outliers.

The last set of graphs showed the Moran's I index graph and the associated statistics. For the year 2020, Moran's I index graph, the line occupied the Low-High quadrats and Low-High quadrants of the graph. The Low-High quadrants indicated that a region with low Covid-19 confirmed cases were neighbored by a region with high Covid-19 confirmed cases, while the High-Low quadrants indicated that a region with high Covid-19 confirmed cases were neighbored by a region with low Covid-19 confirmed cases. Considering the Moran's I index, it was -0.290 (for year 2020) and -0.315 (for year 2021) with a significance of 0.001. Since the Moran's I index was negative, and significantly close to 0, it implied that negative spatial autocorrelation or dissimilarity (values are different from the surrounding or neighboring values). In other words, the number of confirmed Covid-19 cases among the four neighboring regions were significantly different from each other.

### *4.3.3 Spatiotemporal Analysis of Covid-19 Tests in UK*

The purpose of this section was to evaluate the effort made by nations in United Kingdom to test

its citizens against the Covid-19 virus, and compare the results. The section also evaluated if there is any association between the neighboring regions, in terms of the number of tests conducted, which in turn shows their effort in conducting the tests. The analysis was conducted using Quantile maps, Local Indicators Spatial Association (LISA) maps and Moran's I index at 0.05 and 0.001 significance level. The results are presented in the figures below.

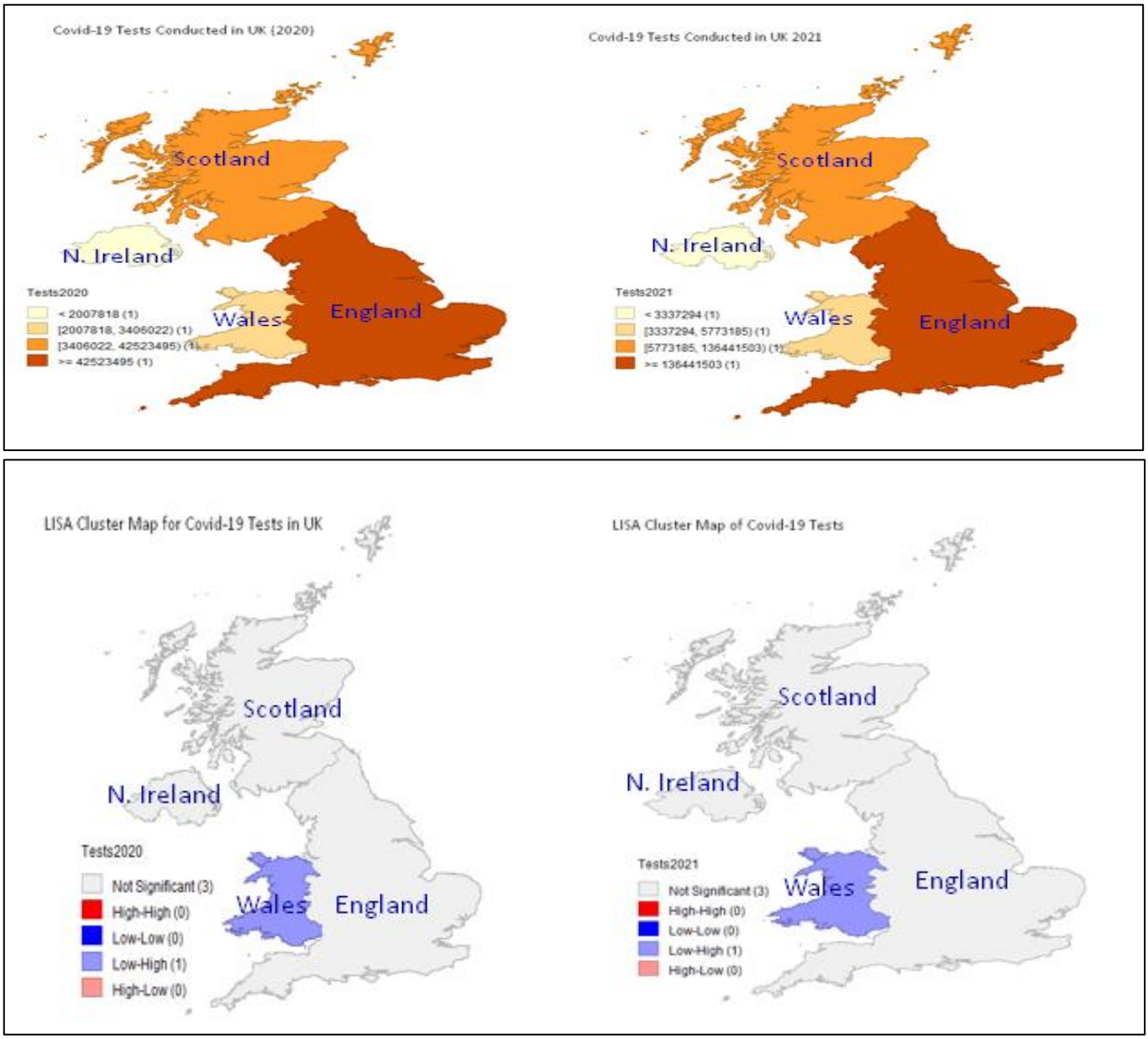
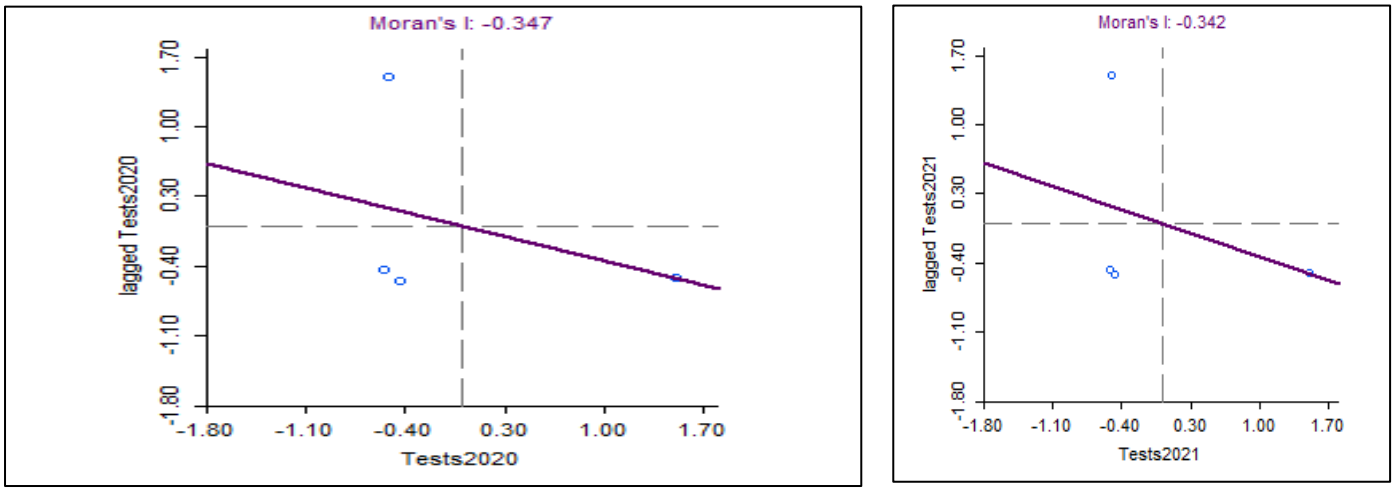



**Figure 9: Spatiotemporal Analysis of Covid-19 Tests in UK**



The graphs above were first for those of the quantile maps, which depicted the number of tests for Covid-19 conducted in each region in UK. From the analysis of the quantiles maps, similar results are observed for both phases (year 2020 and year 2021). Among the four regions, England had the highest number of Covid-19 tests conducted, for both end of year 2020 and by end of April 2021. The number of cumulative tests conducted were clustered above 42523495 by end of 2020 and above 136441503 by end of April 2021. For both phases, Scotland was the second in number of Covid-19 tests conducted in UK followed by Wales and lastly the Northern Ireland. It is notable that Northern Ireland has maintained its status as the country with the least cases of Covid-19 confirmed cases for both year 2020 and year 2021. The second analysis was to evaluate whether among the four regions, there are any neighboring regions which depicted similar confirmed cases as their neighboring regions. This was evaluated using the LISA Cluster maps. The LISA cluster maps shows the location having significant local spatial autocorrelation by the type of association. Considering the LISA cluster maps, it is observed for both the two phases (2020 and 2021) three regions (England, Scotland and Northern Ireland) displayed non-significant spatial autocorrelation (no spatial clusters or outliers). However, for Wales, the results indicated Low-High implying cluster outliers. The other section of analysis was a set of graphs that showed the Moran's I index graph and the associated statistics. For both phases, Moran's I index graph, the line occupied the Low-High quadrats and Low-High quadrants of the graph. The Low-High quadrants indicated that a region with low Covid-19 confirmed cases were neighbored by a region with high Covid-19 confirmed cases, while the High-Low quadrants indicated that a region with high Covid-19 confirmed cases were neighbored by a region with low Covid-19 confirmed cases. Considering the Moran's 1 index, it was -0.347 (for year 2020) and -0.342 (for year 2021) with a significance of 0.001. Since the Moran's I index was negative, and significantly close to 0, it implied that negative spatial autocorrelation or dissimilarity (values are different from the surrounding or neighboring values). In other words, the number of confirmed Covid-19 cases among the four neighboring regions were significantly different from each other.

**Discussions:**

This chapter discusses the findings of this study, based and comparison with the objectives of the study, and with reference to other literature review and theoretical concepts adopted. The first objective of this research was to investigate the epidemiological characteristics of the Covid-19 pandemic in United Kingdom. This objective was achieved by addressing sub-objectives of comparing the changes in Covid-19 tests efforts, confirmed cases, and deaths, in the UK region nations, which are England, Scotland, Wales and Northern Ireland. The comparison of these metrics were conducted using line graphs to show the trends of the Covid-19 statistics over a period of time (from the time Covid-19 started to the time when this study was being conducted). Varying trends of Covid-19 conducted tests, confirmed cases, deaths and other epidemiological characteristics**.**

The first findings discussed in this section is in reference to research question one "**epidemiological characteristics of COVID-19 pandemic in UK"** which evaluated the characteristics and trends of Covid-19 pandemic in UK in terms of confirmed cases, tests conducted and deaths confirmed. The first discussion is based on objective **1-A (To compare the changes in COVID-19 test efforts over time among UK nations).** Considering the efforts made towards conducting Covid-19 tests among the people, significant improvement in efforts is observed between year 2020 and year 2021. For instance, England reported the highest percentage change in tests conducted (363% increase) followed by Wales 202% increase. This is a confirmation that wide range of tests were being conducted as a means of identifying the people suffering from Covid-19 to pave way for medication and treatment. Comparing the four countries, England was found to have done the highest Covid-19

number of tests for both year 2020 and 2021, which, to a significant extent, could be attributed to be largest population in the region. However, the statistics depict significant effort in all countries to conduct the Covid-19 test. This is confirmed by the findings of Sartorius, Lawson & Pullan (2021) who indicated that daily Covid-19 in UK ranged between 10,000 – 20,000 daily in early April 2020 and steadily increased over time. This was enabled by the effort of commercial partners conducting mass-swab testing as well as additional government workers such as the NHS workers.

Hospital admission was a critical aspect evaluated in this study. From the findings of this study, three important observation were evident. The first observation is that England reported the highest number of Covid-19 hospital admissions, followed by Wales, then Scotland and Northern Ireland had the lowest Covid-19 hospital admissions. However, it is important to note that Scotland had higher Covid-19 hospital admissions than Wales from the first time Covid-19 was reported in UK until June 2020, when the hospital admissions on Covid-19 in Wales surpassed that of Scotland and remained higher for the rest of the period. The second observation made is that there are 4 phases experienced by all the countries in UK in terms of Covid-19 hospital admission trends. The first phase the "first peak" which occurred between March 2020 and around June 2020. This phase is characterized by a sharp rise in number of Covid-19 hospital admissions. The second phase is "first stagnation" between June 2020 to November 2020. This was marked by a slow growth in the number of Covid-19 hospital admissions. The third phases was the "second peak" which between November 2020 to March 2021, characterized by a sharp rise in the number of the Covid-19 hospital admissions. These phases are observed in all the nations, in more or less the same pattern. This is an indication that in the UK, Covid-19 displayed similar trends. The third observation is that since Covid-19 was reported in UK, there has been a rising trend or increasing number of Covid-19 hospital admissions. This is an indication that there still need adoption and implementation of enough measures to address the spread of the Covid-19 virus.

The second presentation is in reference to research objective 1-B, **(To compare the changes in COVID-19 confirmed cases over time in UK).** The study did a graphical representation of the Covid-19 confirmed cases in UK, comparing the nations of England, Wales, Scotland and Northern Ireland. From the results, England was the leading county in terms of the number of Covid-19 confirmed cases as compared to other countries in UK. Northern Ireland was the country with the least Covid-19 confirmed cases over the period covered by the study. The second and third place in terms of the Covid-19 confirmed cases was alternately taken by Scotland and Wales. Similar findings were also highlighted by Steel & Donnarumma (2021) who indicated that England topped in terms of the number of Covid-19 confirmed cases in UK. Another important observation is the trend of the Covid-19 confirmed cases. As presented in the graph above, the region experienced a sharp increase in the number of Covid-19 confirmed cases between October 2020 and February 2021 in all the countries. This marked the period of the second wave of Covid-19 virus, which, according to Coccia (2020) occurred between October 2020 to the first quarter of 2021. This second wave is characterized increase Covid-19 infections and admission to hospitals and ICUs.

The third presentation is in reference to research objective 1-C, **(To compare the changes in COVID-19 deaths over time in UK).** When comparing the Covid-19 deaths in UK, interesting observations are made. First, among the four countries, England is observed to have the highest cumulative confirmed Covid-19 deaths since the period the pandemic started in UK covered in the study period. Though England has a higher population as compared to other countries, the intensity of the virus could be considered to be higher as compared to other countries in UK (Goyal, Chaturvedi & Arora, 2021). A critical evaluation of the trend of Covid-19 deaths in UK reveals interesting facts regarding the prevalence and effects of Covid-19 in UK. Two waves of the

pandemic are evident. The first wave is represented by a great rise in number of deaths which occur immediately after the outbreak of the pandemic - between February 2020 and May 2020, where there were a sharp increase in the total number of COVID-19 reported deaths. The second wave was reported between mid-November 2020 to the end of February 2021, which also indicated a sharp rise in Covid-19 deaths. The second wave had serious effects in terms of number of deaths as compared to the first wave (Moss, 2021). As found in the number of confirmed cases, England reported the highest deaths while Northern Ireland had the least number of deaths in the region.

The other analysis carried out in this research was a spatiotemporal analysis of the Covid-19 pandemic in UK, in terms of the tests, confirmed cases and deaths. This was made in reference to the second research questions and associated objectives which evaluated **the spatiotemporal characteristics of COVID-19 pandemic in UK.** Under the second research question, the first objective discussed is **to model the spatial-temporal patterns of COVID-19 tests, confirmed cases and deaths in UK.** The first analysis was the death reported from Covid-19 in UK. The comparison of the Covid-19 deaths incidences depicted that England had the highest incidence followed by Scotland with Northern Ireland ranking as the last one a situation which was maintained for both 2020 and 2021 study periods. Regarding the spatial autocorrelation of the study regions, the statistics shows that there was insignificant spatial association between three regions – England, Scotland and Northern Ireland. The insignificant association is an indication that there were no spatial clusters or outliers in the region. However, for the two periods (2020 and 2021) Wales shows a Low-High cluster which implies presence of cluster outliers. An interesting results were presented by the position of the Moran's I Low-High and High-Low in the LISA cluster maps. It implies that regions in UK and among the regions of study, areas that reported low covid-19 deaths were neighbored by areas that reported high covid-19 deaths, while areas that reported high covid-19 deaths were neighbored by areas that reported low covid-19 deaths. These findings were confirmed by the Moran's I index which was -0.322 (for year 2020) and -0.315 (for year 2021) with a significance of 0.001. The negative value of the Moran's I index implies that there is no association of the number of deaths between adjustment and neighboring regions in UK. It is therefore evident, as displayed in the covid-19 deaths trends, each country reported significantly different figures with a major difference from one region or country to another.

The analysis of the Covid-19 confirmed cases showed a variation between the two periods considered (year 2020, and year 2021). For the period of 2020, England was reported to have the highest proportion of reported Covid-19 cases, followed by Wales, Scotland and lastly Northern Ireland. However, for the results shows that the confirmed cases increased at a greater rate in Scotland in the year 2021, in a way that it became the second country with the highest number of Covid-19 confirmed cases after England. Two possibilities could explain these fluctuations. Either, Wales had adopted and implemented stringent measures to control the spread of the virus, or Scotland had relaxed in controlling the spread of the virus. The shift in the prevalence of Covid-19 confirmed cases in an indication that Scotland was more affected by the 'second wave' of Covid-19 as compared to Wales. The objective of this subsection was evaluated using Moran's I graph and Moran's I Index. The graph showed that the occupied quadrants were Low-High and High-Low, which applied that there were no areas with high Covid-19 reported cases, or low Covid-19 reported cases were adjacent or neighboring each other. In other words, there were no correlation between the four regions considered in the study (England, Scotland, Wales and Northern Ireland) in terms of the reported Covid-19 cases. These results were confirmed by the negative and significant Moran's I index (-0.290 for year 2020, and -0.315 for year 2021). The overall observation is that the Covid-19 confirmed cases in each of the regions were not related to those of other region.

The evaluation of the Covid-19 tests reported the effort of the concerned governments and authorities to conduct Covid-19 tests of its people. From the statistics, the data revealed that for the study period of this research, England conducted the highest number of tests, then Scotland, Wales and lastly Northern Ireland. From the evaluation of the Moran's I graph and index, the results showed that there were non-significant spatial autocorrelation (no spatial clusters or outliers) for three regions, England, Scotland and Northern Ireland. However, Wales showed presence of cluster outliers. The occupation of the Low-High and High-Low quadrants in the Moran's I index implied lack of association or relationship between the tests observations conducted in different regions. Following this discussions, the objective "**to compare spatial-temporal patterns of COVID-19 over time in UK" was met from the fact that for all the regions, and as confirmed by Moran's I graph and statistics,** there is no association of the number of deaths, tests and confirmed cases between neighboring regions in UK.

The last objective of this research was to identify **which are the high-risk areas/regions of COVID-19 pandemic in UK.** From the findings of this study, the most risky region could be mapped out. The riskiness was based on the probability of contracting Covid-19 virus, or dying from the virus, which was in turn based on the number of confirmed cases and deaths reported in each region. Comparing the four regions – England, Scotland, Wales and Northern Ireland – England reported the highest cumulative number of reported cases and deaths for both the two study periods, 2020 and 2021. Similarly, Northern Ireland reported the lowest cumulative number of reported cases and deaths for both the two study periods, 2020 and 2021. This study therefore marked England as the riskiest region in UK for possibility of contracting Covid-19 virus and possible death.

From the findings of this study, several implications could be stated. First, Covid-19 statistics (infections, cases and deaths) has been increasing since it was first discovered in UK. Therefore, this paper recommends that each person should take appropriate measures to protect himself/herself from the virus. Second, the government should enhance its measures and strategies geared towards fighting the spread of Covid-19. Since the cases and deaths of Covid-19 in each UK country is not related to the neighboring country, this research recommends that each nation should bear its responsibility of adopting and implementing measures geared towards addressing and controlling the spread of Covid-19 pandemic.

**Conclusions:**

The purpose of this study was three-fold: first to understand the epidemiological characteristics of COVID-19 pandemic in UK; second to understand the spatiotemporal characteristics of COVID-19 pandemic in UK, and third to map out the high risk areas/regions of COVID-19 pandemic in UK. A quantitative study was conducted using secondary data collected from various sources regarding Covid-19 statistics of tests, confirmed cases, and deaths in UK. The data analysis techniques applied comparative analysis, descriptive statistics and spatial autocorrelation using Moran's I index. From the findings and conclusions presented in the previous sections, several conclusions could be made, as well as the implications of the study. The first conclusion is in relation to the first objective of the study, that England has the highest rates of confirmed Covid-19 case, deaths as well as conducted tests. Northern Ireland has the lowest rates of confirmed Covid-19 case, deaths as well as conducted tests. While Scotland and Wales were alternating in terms of the highest in terms of confirmed cases, it was found that Scotland has the highest number of Covid-19 deaths as compared to Wales. The second conclusion is in relation to the second objectives of the study. From the findings of the study, it is conclusive that there were no correlation or relationship between the regions under study, in terms of Covid-19 reported cases, tests or deaths. The study concludes that regions with low Covid-19 confirmed cases, tests and deaths were neighbored by a region with high Covid-19 confirmed cases, tests and deaths; while regions with high Covid-19 c confirmed cases, tests

and deaths cases were neighbored by a region with low Covid-19 confirmed cases, tests and deaths. For both year 2020 and 2021, the Covid-19 confirmed cases, tests and deaths among the four neighboring regions were significantly different from each other. England was found as the region with the highest risk of Covid-19 followed by Scotland, and the least risky nation was found to be Northern Irelands. The implications of these conclusions is that since there is no relationship between the regions, each nation should bear its responsibility of adopting and implementing measures geared towards addressing and controlling the spread of Covid-19 pandemic. Additionally, individuals should take personal preventive measures to avoid being infected with Covid-19 virus, especially in the high risky areas. This research is considered as significant contribution to the Covid-19 research in UK, by the findings that the Covid-19 cases and situation observed in different UK regions are independent of each other. The study also contributes to the existing literature regarding Covid-19 epidemiological and spatiotemporal analysis. The study recommends that the future studies should consider conducting the spatial-temporal analysis of smaller geographical areas, such as states or counties in England.

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