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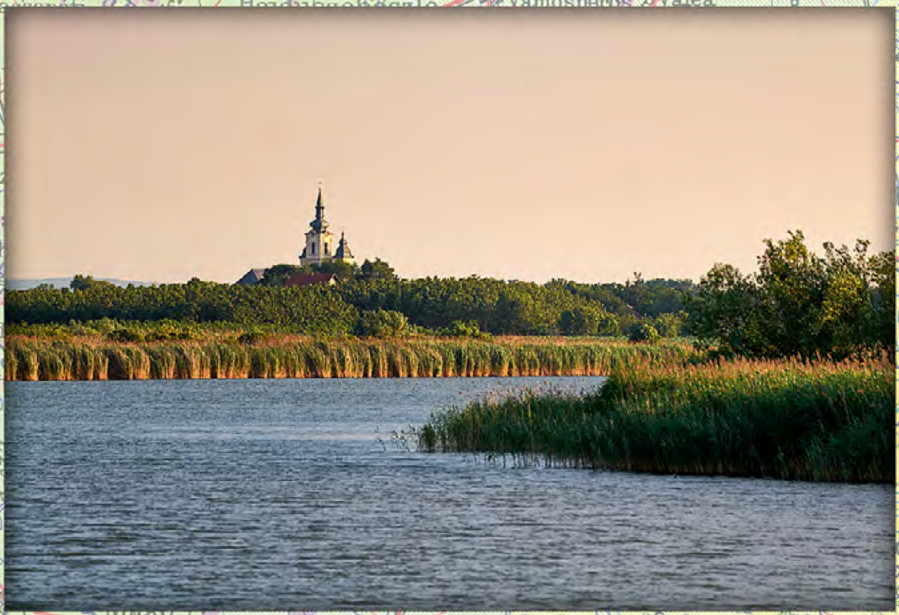

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GIS Based Methodology to Analyse the Public Transport Supply – Hungarian Case Studies

Martin Bárta[A]

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Abstract

The paper aims to introduce a new way of comparing the efficiency of public transport operations based on publicly available data. It draws on four main sources, the Hungarian Central Statistical Office, public transport provider data, GTFS and OSM map layers. Methodologically, it combines the use of the GTFS format and corresponding static timetable component files, Thiessen polygons and empirical selection of relative indicators. As places of research, three comparable Hungarian cities have been selected by their population size; Pécs, Szeged and Miskolc. The comparison consists of 8 quantitative indicators that cover six major geographical aspects of transport operation (accessibility in terms of proximity, capacity, connectivity, density, frequency and velocity of vehicles). The analysis does not consider the mode of public transport, thus opening up the possibility of an independent comparison of efficiency regardless of various infrastructure characteristics. The results show that Miskolc and Pécs achieved the best values in four indicators. On the contrary, the city of Szeged, despite its diverse structure of transport modes, does not have an advantage in any aspect. The relatively loosely anchored methodology leaves room for an extension to include economic, environmental, and other specific factors.

Keywords: public transport; GTFS; Thiessen polygons; indicators; accessibility; GIS

Introduction

The analysis of the efficiency of public transport operations in a selected city can be approached from the perspective of many different disciplines. Within the exact disciplines, economic, environmental and geographical (spatial) factors are essential. In terms of the possibilities for inter-city comparison and visualisation of specific differences, the most appropriate tools for analysis appear to be geographical ones, which include not only the basic aspect of the distribution of the selected characteristic in space but also significant interconnectedness with downstream factors. Examples include the issue of transport accessibility, the quality of which depends, among other things, on the stop distance from the origin or destination, the capacity and condition of the vehicles used for transport, or the cost of the transport itself. This fundamental ability of geography to link several otherwise independent sectors makes it possible to create a relatively comprehensive analysis from purely geographical indicators. For the reasons mentioned above, this study thus works with a selection of rather geographic indicators only, leaving open the possibility of a possible extension to other more advanced tools from economics or environmental science.

Geographical factors can be further subdivided into individual spatial aspects of transport infrastructure related to the accessibility of the selected area in general. These include the connectivity of stops by lines of connections, the density of the transport network concerning the area and population of the territorial unit, the frequency of connections at stops, the capacity of transport vehicles, the average oper-

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ation time (velocity) of vehicles and, of course, the proximity (distance) of stops to the origin or destination. Public transport accessibility in the broader sense of the word permeates across many methodologies as an overarching goal of interest. Many studies focus on detailed research on one selected aspect and seek new methods to further refine and subdivide the aspect into more precise sub-categories. The connectivity function and the continuities between transport modes are addressed in studies by (Bryniarska & Zakovska, 2017) and (Ceder et al., 2009). The specific source of Google Transit and its use in connectivity is found in the works of (Chowdhurry et al., 2014) or (Hadas, 2013). As the relatively least telling aspect of accessibility, transportation network density is most often studied in graph theory and is used more in larger regional units. The issue of connection frequency is mostly found in more comprehensive studies involving a wider range of accessibility factors. Capacity and, more generally, the quantitative characteristics of vehicle usage is an object of interest in, for example, the paper of (Medvid et al., 2020). Vehicle speed, expressed in the time taken to cover the distance between two stops, similarly to frequency, appears more frequently in multi-criteria analyses.

The detailed structure of operation time of vehicles deals (Matulin et al., 2011). (Birr et al., 2014) extends the topic to predictive models of vehicle arrival time at a stop. Accessibility in the sense of proximity is primarily addressed by GIS-oriented methodologies using network analyses in (Háznagy et al., 2015) and (Luo et al., 2019). (Mavoa et al., 2012) uses both proximity and frequency aspects to assess accessibility. A comprehensive geographical view of a transport system‘s efficiency, quality, and accessibility and its sub-elements always represent a specific selection of the indicators or functions used. By its very subjective nature, the nature of the area of interest does not have the ambition to include everything that interferes with the system‘s functioning.

Nevertheless, more and more works deal with the complex synthetic concepts of the efficiency of urban public transport. Their approach to processing differs in many respects. Typical examples are quantitative vs qualitative studies, hard or soft data methodologies, comparative or case studies, etc. Another critical factor is the purpose of the study, which determines whether it will be more theoretical or practical. (Bajčetić et al., 2018) and (Ušpalytė-Vitkūnienė et al., 2020) work in their methodology with the perception of the user and the direct participant of the traffic, while (Zhou et al., 2021) links transport quality assessment with educational activities. The theoretical framework and the complexity of defining adequate indicators are described by (Išoraite, 2005). The strategic use of comprehensive urban transport assessment for the potential development of an area is found in the works of (Gaal et al., 2015) and (Hawas et al., 2016). More and more studies can be found concerning large urban municipal or even regional units and their comprehensive comparisons with the GIS application.

In the case of this paper, we can talk rather about a new combination, though belonging closest to the last type. The objectives of this thesis can be summarised in several basic points, conditions and the resulting research questions:

1. to develop a comparable system for assessing the geographical efficiency of public transport operations based on selected indicators
2. applying only publicly available data sources to maximise the transferability of the methodology to any city
3. comparison of three case studies, Hungarian cities (Szeged, Miskolc and Pécs) according to the resulting values of the indicators

The research questions are then mainly related to the comparison itself. According to geographical factors, which of the three examined cities shows the highest vs lowest public transport efficiency? Which geographical factors most significantly influence the resulting overall efficiency rating? Based on an essentially arbitrary selection of indicators, can relevant results be obtained to reveal strengths and weaknesses and possible optimisation?

Study area

Regarding the availability of public transport data within Hungary and comparable population size, three cities, Szeged, Miskolc and Pécs, have been selected for comparison. According to the Hungarian Statistical Office, their population on 1 January 2021 was 159 074 (Szeged), 150 695 (Miskolc) and 140 237 in the case of Pécs (KSH, 2021). They occupy the third, fourth and fifth positions in the ranking of the largest cities in Hungary. The relative position within Hungary is shown in Figure 1.

In terms of public transport, cities vary considerably in transport modes and main types of transport. In Pécs, only the bus network is currently in operation. In Miskolc, there is the bus network and, to a small extent, the tram network, and finally, in Szeged, buses, trolleybuses and trams are used. The choice of these three cit-

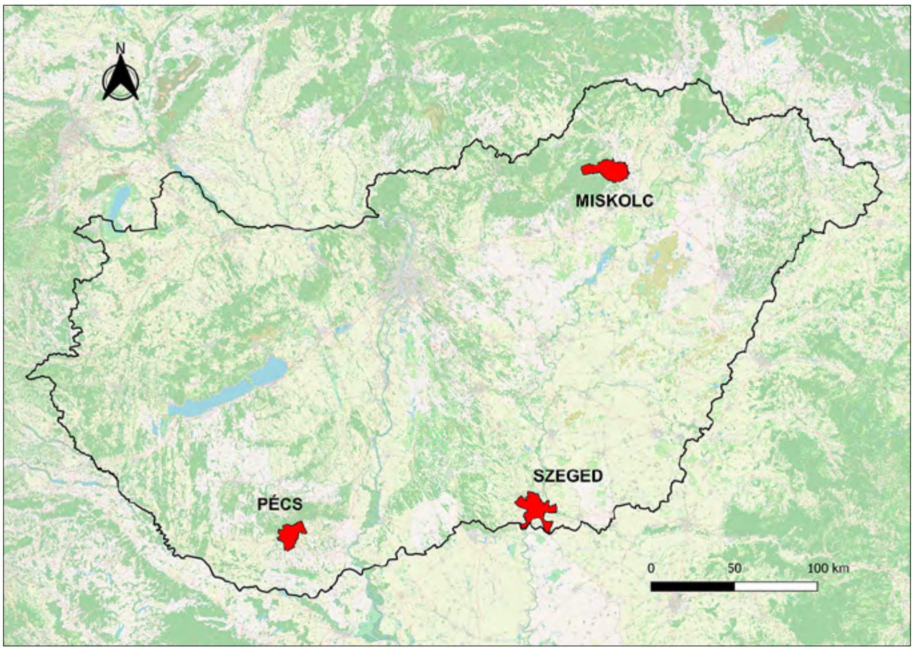

Figure 1. Location of the analysed cities within Hungary
Source: own elaboration from (OSM, 2021)

Table 1. Basic characteristics of public transport in Szeged, Miskolc and Pécs by 2021

City	Population	Area (km^2)	Length of transport network (km)	Number of stops	Number of routes (lines)
Szeged	159 074	281,00	132,2	290	48
Miskolc	150 695	236,67	164,7	263	46
Pécs	140 237	162,78	153,4	265	75

Source: own elaboration of data from (KSH, 2021), (Transitfeeds, 2021)

ies for the analysis thus reflects the three most common combinations of public transport modes. An overview of the basic attributes of the selected cities and their public transport is given in Table 1. All of these characteristics are included in more detail in the final analysis.

In addition to knowledge of population, area and transport network, it is also necessary to describe the character of cities in terms of the distribution of the major land cover classes. Looking at Figure 2, it is clear that the diverse composition of the landscape significantly differentiates the conditions for the functioning and accessibility of transport infrastructure. While agricultural areas dominate Szeged, Pécs and Miskolc are mainly forests and semi-natural areas. Urban artificial surfaces then form the main population centres and thus the densest concentration of the transport network. Of course, the need for transport links is not only associated with urban development but occurs in almost any land cover class where there is some form of housing, employment offer or tourist sites. Thus, in Miskolc, for example, urban transport extends relatively far beyond the boundaries of the typical urban areas into the centre of Bükk National Park, or in Pécs, a network of lines connects the peripheral sites of industrial extraction and settlement there with the city centre. In Szeged, on the other hand,there is virtually no area outside the main centre with adjacent neighbourhoods where either accommodation, work, or tourist functions meet. That may consequently lead to a large area without transport services, although it administratively falls within the city borders.

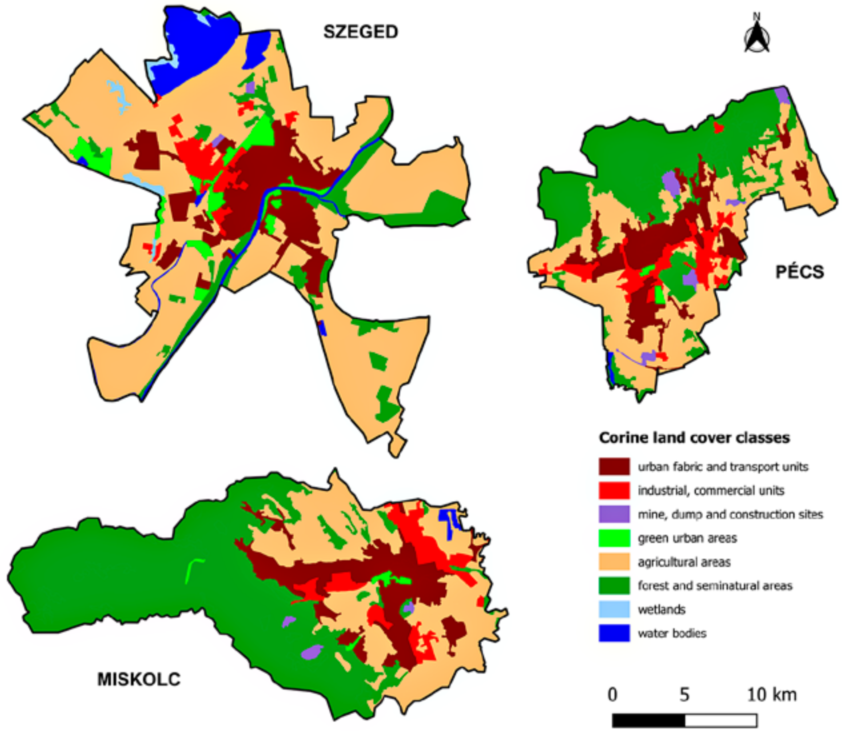

Figure 2. Distribution of main land cover classes within examined cities
Source: own elaboration from (OSM, 2021), (Land-Copernicus, 2018)

Methods of analysis and GTFS

The methodology is based on four broad types of publicly available sources. The basic one is the statistical office, which provides input data for analysing the actual population and the area of the administratively defined units. The core part of the data for most aspects of accessibility is obtained from the GTFS database of files on Hungarian cities (Transitfeeds, 2021). Each city contains data from a different provider, Szeged (DAKK, 2021), Miskolc (MVKZRT, 2021), Pécs (Biokom, 2021).

A GTFS timetable is a set of text (CSV) files packaged in a ZIP archive. It is a format for timetables and related geographical information. In addition to static information, it also supports the feeding of real-time data from public transport operations. The files must be encoded in UTF-8. The static component consists of five required files defining agency, stops, routes, trips and stop times. Two filenames describing calendar and calendar dates are conditionally required. The other ten optional files may provide, e.g. information on frequencies, continuity or fares (GTFS, 2021). The GTFS format significantly facilitates the processing of detailed timetable information. Due to regular updates and archiving of old data, extensive analyses and comparisons of urban transport operations can be performed. It is thus the cornerstone of many studies, such as (Bok & Kwan, 2016), (Prommaharaj et al., 2020). However, the nature of static timetables may not always correspond to actual travel times, as the creation of the timetable cannot consider all relevant factors that randomly or even regularly influence (ex. congestion) the performance of the transport operation. (Wessel et al., 2017) examines the differences between scheduled and observed services. A balanced critique and detailed explanation of the individual components of GTFS is further presented by (Kujala et al., 2018).

The primary data from the transport companies themselves are then used as a source for vehicle capacities aspect and potential extension of the limited source of GTFS files. The transport providers in these cases always manage the entire public transport network, Szeged (SZKT, 2021), Miskolc (MVKZRT, 2021), Pécs (Tüke Busz, 2021). Compared to the previous types, this is relatively the least reliable source because of the different approaches to managing and operating the published data. Map visualisation and spatial distribution of the population and traffic data collected are essential parts of the analysis. For this purpose, the universal map source OSM (OpenStreetMap) is used. All data used are based on the period before the end of July 2021.

A system of 8 indicators was then compiled that shows both the absolute and relative values of 6 major geographical aspects by using these four primary sources. It covers accessibility in the meaning of proximity, connectivity, density, frequency, occupancy (capacity) and velocity (speed). The complete list of examined indicators shows in Table 2. The indicator formulas have been empirically designed and arithmetically adjusted to range their values from 0 to 200. Further attenuation of the incommensurability of different results is achieved by standardising the modified Bennet method. It is the sum of the relative deviations (percentage distances) from mean values per indicator. Except for indicators 3 and 5, all others are based on a combination of GTFS and public transport companies‘ data. The critical aspect of accessibility (proximity) is represented by indicator 5, which attempts to measure differences in the size of un-served

Table 2. List of 8 main indicators used for the analysis

Num.	Indicator	Min value	Max value	Type
1	Average number of connections at a stop during one working day per number of inhabitants multiplied by 100 000	0	–	A, F
2	Average number of connections at a stop during one Sat., Sun., or public holiday per number of inhabitants multiplied by 100 000	0	–	A, F
3	Density of public transport network by number of inhabitants and area of the municipality	0	–	A, D
4	Weighted mean of total capacity (occupancy) of one vehicle	0	–	A, O
5	Percentage difference of the 10th percentil of the largest Thiessen polygone areas by total area of the city	0	100	A
6	Number of lines per number of stops multiplied by 100	0	–	A, C
7	Average number of connections (WD + HOL) per lines	0	–	A, C, F
8	Average velocity of public transport according to operated lines (km/h)	0	–	A, V

(A = accessibility, C = connectivity, D = density, F = frequency, O = occupancy (capacity), V = velocity)

Figure 3. Cities partitioning using Thiessen polygons for set of stops
Source: own elaboration of data from (OSM, 2021), (Transitfeeds, 2021)

areas with the Thiessen polygon method. Its range of values is governed by the percentage difference, i.e. from 0 to 100.

The method of Thiessen polygons (also Voronoi diagram) works on the principle of partitioning the space according to the distances between a set of given points so that each point falls into a polygon whose boundaries are always formed by half the distance between each point. The design of this method is discussed in detail and practically used for transport analysis (Wang et al., 2014). It has also been applied for multicriteria analysis of bus and tram stops (Bárta & Masopust, 2020). An illustration of what such partitioning looks like in the example of all examined cities is shown in Figure 2. Here, two basic factors come into play: the density of stops and their distribution within the city limits. More regularly located stops mean fewer above-average polygons, with the optimal state of accessibility corresponding to the same area per polygon. However, it is important to note that another equally important aspect is the degree of arbitrariness in the delimitation of the city borders concerning the nature of the settlement and the need of citizens.

Results

The calculations of the individual indicators provided a clear picture of the distribution of values for the three selected cities. A concise statistic of this distribution of values gives Table 3. The capacity aspect of the average vehicle most closely describes the difference in using different combinations of transport modes. The relatively most significant deviation from the average is associated with synthetic indicator number 7. The explanation lies in its dual meaning. The higher the connectivity in the form of more lines, the fewer connections per line, which means it is impossible to have above-average connection frequency and connectivity for a better relative result. The aspect of an average speed of service between two stops included in the last indicator deviates only minimally from the average due to the similar attributes of the transport infrastructure and the size of the cities in question. The map visualizations of the absolute values of the number of connections at stops within Figure 3 extend the first two frequency indicators and the third network density indicator with a more detailed spatial distribution and associated localization of the disparities between the core and peripheral parts of the cities. The intervals for the number of connections have been kept the same except for the upper limit of the highest. The busiest stops occur in the centre of Pécs, although, unlike the other two cities, they are served only by bus lines. The urban design and its effect on the layout of the transport network and the arbitrariness of the administrative demarcation and density also significantly influence the Thiesson polygon method results. The city of Szeged, which is designed compactly with a radial street network, a smaller distance of peripheries from the centre and a large area, suffers from this effect to a considerable negative extent. That also corresponds to the lowest population density compared to Miskolc and Pécs.

Specific differences in absolute values by indicator can be seen in Figure 4, which also refines the range of values from Table 3. A more convenient idea of comparing indicators between cities is given by the relative format in Figure 5. working with a modified Bennet method based on percentage distances from the mean value. According to this method, it is apparent to see which cities perform below or above average, considering the range of a given indicator. The city of Pécs,

Table 3. Results of 8 indicators with min, mean and max values

Num.	Indicator	Min value	Mean value	Max value
1	Average num. of connec. at a stop during one working day per number of inhab. multipl.by 100 000	120,15	139,12	150,29
2	Average num. of connec. at a stop during one Sat., Sun., or public holiday per num. of inhab. multipl. by 100 000	81,39	88,25	99,50
3	Density of public transport network by number of inhabitants and area of the municipality	19,78	26,49	32,11
4	Weighted mean of total capacity (occupancy) of one vehicle	102,82	121,18	146,11
5	Percentage difference of the 10th percentil of the largest Thiessen polygone areas by total area of the city	26,61	41,66	53,46
6	Number of lines per number of stops multiplied by 100	16,55	20,78	28,30
7	Average number of connections (WD + HOL) per lines	18,91	45,91	66,91
8	Average velocity of public transport according to operated lines (km/h)	23,34	23,79	24,59

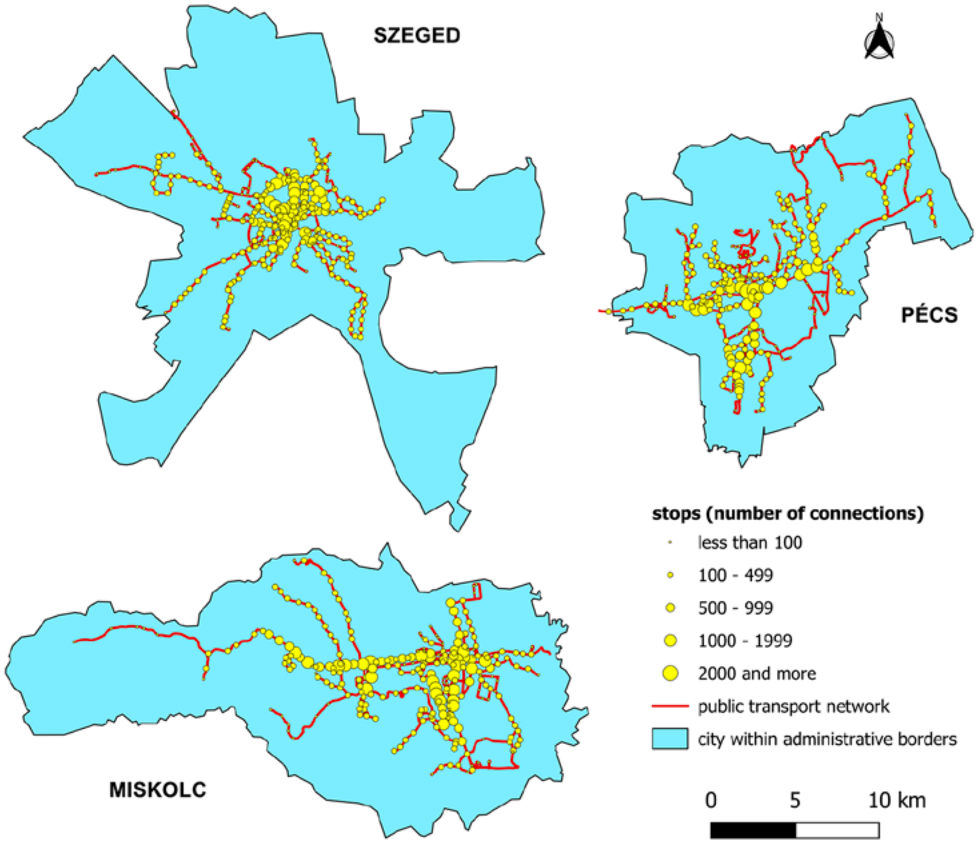

Figure 4. Number of connections (trips) by public transport within examined cities in 2021
Source: own elaboration of data from (OSM, 2021), (Transitfeeds, 2021)

in this comparison, achieved the absolute most significant negative deviation within the aspect of connectivity and frequency. See the explanation above. Nevertheless, overall it significantly outperforms Szeged. Finally, for Miskolc, the sum of the difference between positive and negative deviations results in the highest values on average and the position of the most efficient public transport operation.

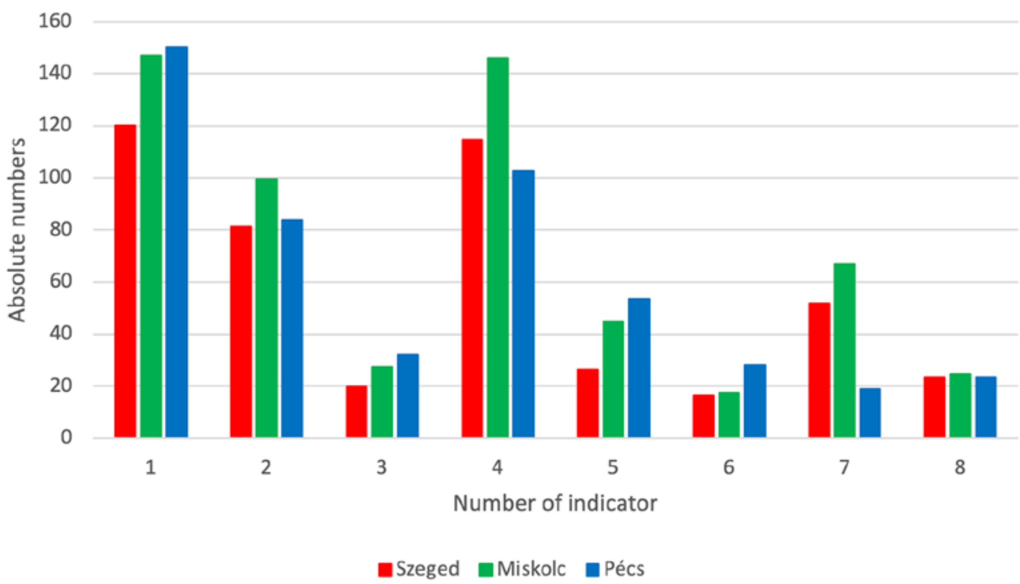

Figure 5. Results of 8 indicators in absolute values

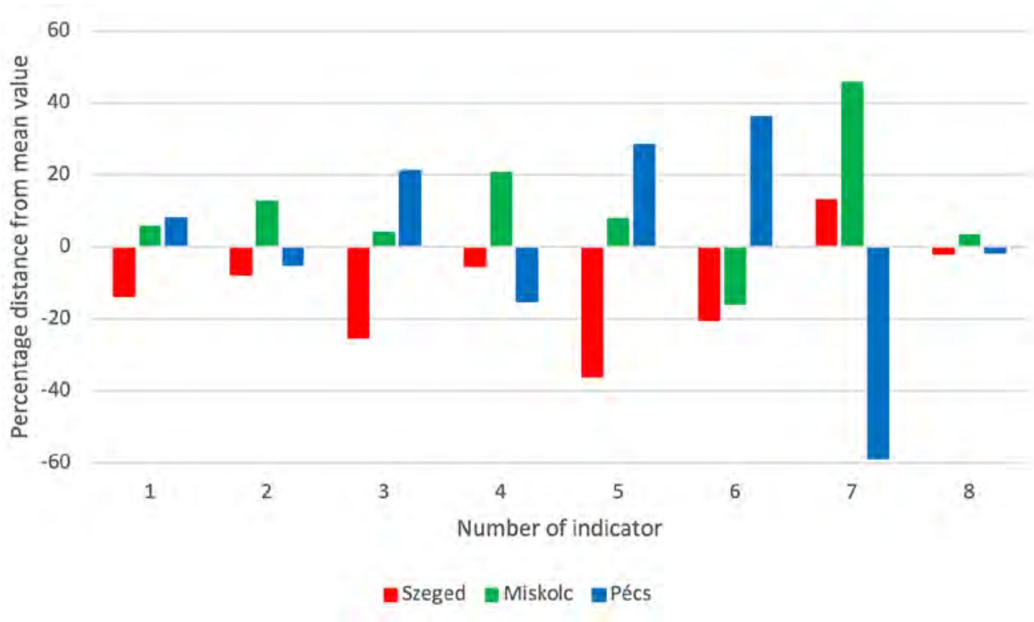

Figure 6. Results of 8 indicators in relat. values based on percent. distan. from mean value

Discussion and conclusion

Evaluating the efficiency of traffic draws on a selection of quantitative relative indicators means making an inevitable compromise between the availability of reliable data, including as many influencing factors as possible and the objective setting of weights for individual indicators. This study is based on a combination of only hard, verifiable data, a relatively small number of indicators using only geographical aspects, and a relatively objective level of assessment of the importance of each indicator for inter-comparison. The incomplete listing of significant factors and their very general inclusion in the formulas can be considered a significant shortcoming in the choice of indicators. A certain simplification of an otherwise complex issue has been applied for several quite different reasons. For any comparison, it is necessary to obtain sufficient data to allow two or more selected examples to be evaluated in the same way. In the context of transport analysis, the data source issue is complicated by the dependence on publicly available materials or the need to collect data from own observations. However, far from all necessary aspects can be obtained from public databases or own field research. Therefore, a certain narrowing of perspective was inevitable. The reason for the overall triviality of the formulas can be explained by the desire for a more accessible methodology to be extended to include economic or environmental factors, which could be loosely linked to an interdisciplinary geographical angle. The objective assessment of the weight of a given indicator and the subsequent results was partly guaranteed by using the modified Bennet method, a form of standardisation that accounts for the percentage distance from the mean value. Of course, the chosen method does not, even so, provide absolute independence from the inherently subjective selection of indicators.

The methodology is, to some extent, intertwined with (Bárta, 2020) and (Bárta & Masopust, 2020). However, unlike the previous ones, it attempts intercity comparisons while incorporating more precisely defined geographical aspects. The GTFS format as a systematic way of accessing traffic data appears in an increasing number of studies. More advanced command formation and the most efficient use of static component files have been inspired by (Bok & Kwan, 2016) and (Kujala et al., 2018) in particular.

In terms of methodology and results, three main points have been met in line with the objectives, so we can answer the research questions. The analysis shows that Miskolc has the most efficient public transport operation in absolute and relative data. Due to the higher diversity of transport modes, Szeged surprisingly comes out worst in almost all indicators. However, the difference in efficiency between the cities is not significant enough to draw critical conclusions. The more complex question of the relevance of specific factors for the analysis results can be viewed from several angles. Because of the arbitrariness of the chosen indicators, it is necessary to choose the most unbiased guide. For this purpose, the modified Bennet method of percentage distances from the mean value of each indicator was used. According to this method, the combination of accessibility and connectivity in the form of the average number of connections per number of lines clearly stands out, the extent of which most influences the final result of the evaluation. Beyond purely numerical differences, however, the significance of some indicators, particularly the accessibility derived from Thiesson polygons, is closely tied to the nature of the administrative delimitation. Therefore, cities whose borders do not correspond to the settlement pattern with the population distribution may exhibit significantly lower efficiency, even though they do not stand out in other areas. The answer to the key question of the relevance and applicability of the arbitrary indicator methodology to specific disparities and optimisation options is broadly positive, given the possibility of focusing on the most detailed urban districts and consistent comparability with the corresponding average for the higher unit. Although this paper does not directly examine the detailed structure of the selected cities, its methodology based on a detailed GTFS timetable format, combined with possible network analysis, offers the possibility of an accurate analysis of gaps in spatial and time accessibility that is crucial for any optimization. Yet, it is essential to note that the selection of geographical factors alone without economic, environmental and other factors does not provide a comprehensive view of the issue of evaluating a complex public transport system.

In conclusion, this paper can be classified as another attempt at a geographical comparative evaluation of selected factors interacting with the daily operation of urban public transport. Despite a specific generalisation and simplification of a complicated issue, it can serve as a tool for future analysis of strengths and weaknesses and possible extension for economic and environmental factors of public transport operations.

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Precipitation Patterns in the Gambia from 1981 to 2020

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Abstract

The present study used composite analysis and rainy season definition to investigate rainfall patterns in The Gambia from 1981 to 2020. Rainfall dataset as observed by 10 meteorological stations scattered across The Gambia was used. Results showed that the highest single month rainfall ever recorded in The Gambia during the study period was observed in Sapu, in the eastern sector of the country. The station recorded a total rainfall amount of 767 mm in August, 1999, while the lowest single month rainfall ever recorded was 463 mm in September 2012. It was observed in Jenoi, a station situated in the western sector of the country. Climatological results showed that the study area experienced monomodal rainfall regime during the West African Monsoon, and that the southern part of the western sector region such as Sibanor tend to receive more rainfall compared to other regions of the study area. Part of the central region receives the least annual rainfall. The eastern sector of The Gambia received much of its rain from May to October with July - September as the peak of the rain season. During May - October, Sapu received the heaviest rainfall while Fatoto received the least amount. Results also show that July - September is the period when significant amounts of rainfall are received over the eastern sector of the study area. While May and October are both transitional months, the eastern sector of the study area receives more rains in October than in May. The western sector of the study area, on the other hand, received much of its rain from June to October with July - September as the peak of the rain season. During June - October, Sibanor received the heaviest rainfall while Jenoi received the least amount. The results also show that July - September is the period when significant amounts of rainfall are received over the western sector of the study area. Although June and October are both transitional months, the western sector receives more or less the same rain amounts in June and October. Results further found that, to avert losses associated with excess or deficit in crop water requirement, in the eastern sector, crops with high water requirement should be grown before August as maximum rainfall is observed in August, whereas crops with minimum water requirement should be grown in May or October, that is when minimum rainfall is experienced. In the western sector, on the other hand, crops requiring high water amount should be grown before August or September when maximum rainfall is recorded in the sector, whereas crops with minimum water requirement should be grown in June or October. This study will help create awareness on the erratic rain seasons due to Climate Change, and to provide farmers with information on rainfall distribution in The Gambia to avert losses and impacts associated with water deficit or excess on society, agriculture, and the environment.

Keywords: rainfall; composite analysis; rainy season; monsoon; monomodal; The Gambia

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Introduction

Precipitation is one of the most important meteorological variables in West Africa where economies mainly depend on rain-fed agriculture (Nangombe et al., 2018). This is due to the fact that precipitation deficit or excess usually have huge impacts on agriculture, society, and the environment. Thus, calling for the need to study precipitation concentration in West African countries. In West Africa, the summer monsoon accounts for more than 75 percent of the total annual rainfall (Akinsanola & Zhou, 2018a). The West African Summer Monsoon (WASM) is a highly determining factor of socio-economic development activities over the region (Janicot et al., 2011). Researchers have linked the inter-annual rainfall timescales in West Africa to El Niño-Southern Oscillation (ENSO) (beyond the scope of this study), by stating that ENSO is the most important sea surface temperature pattern influencing the West African Monsoon dynamics (Joly and Voldoire, 2009). It has been found that the precipitation patterns over West Africa are experienced in the location of the monsoon trough (Nicholson, 2008, 2009). Based on findings from several studies over West Africa, the variation in the WASM rainfall is controlled by various and complicated processes, and is also sensitive to Global Warming (Akinsanola & Zhou, 2018a; Akinsanola et al., 2015; Sylla et al., 2013; Nicholson, 2013; Sultan & Janicot, 2003). Precipitation in West Africa is characterized by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ), also referred to as Inter Tropical Discontinuity (ITD) over West Africa. During boreal summer, the ITCZ propagates northward reaching about 20oN at the peak of the rainfall season, that is in August, whereas during winter the ITCZ is located along the Gulf of Guinea Coast. Over West Africa, during boreal summer, surface airflow is peaked by two jets, namely: the Tropical Easterly Jet (TEJ) and African Easterly Jet (AEJ).

It has been established that rainfall variability in the Sahel region of West Africa is very high and the region had experienced severe droughts in most of the 1980s. The current debate is some studies, for example (Sanogo et al. 2015; Giannini, 2015) have stated that rainfall in the Sahel has increased after the severe droughts of the 1980s. On the other hand, some researchers have stated that the droughts continued to be experienced in the Sahel region through the 1990s (L'Hote et al., 2003; Nicholson et al., 2000). Thus, the need to study rainfall distribution over individual Sahel countries in order to have a clear picture of rainfall patterns. In West Africa and in this study, precipitation and rainfall are used interchangeably.

Located in the Western Africa region, The Gambia is a small country, and particularly highly vulnerable to Climate Change impacts. The Gambia's vulnerability to climate change impacts stems from: a high reliance on climate-sensitive economic activities such as farming, livestock rearing, fisheries and forestry; the presence of large population clusters, the low capacity of the country's social and ecological systems to cope with climatic extremes (Gizaw & Gan, 2017). Of great concern is the projection that during the rainy season in West Africa, the central Sahel is going to get wetter, while the western Sahel is projected to get dry (IPCC, 2007a). Although with medium confidence, it has also been projected that with global warming of 2o C, West Africa is to experience arid, drier, and more drought-prone climate, and with 3o C global warming, meteorological drought frequency will increase, and their length will double from about 2 – 4 months in the western Sahel (Adelekan et al., 2022). Situated in the western Sahel region, The Gambia is one of the countries expected to be affected by these projections. Given the fact that the small West African country's economy is dominated by extensive rain-fed agriculture, therefore, analysis of long historical rainfall data is imperative in order to: (1) provide robust information on the distribution of precipitation; (2) better prepare farmers on extreme events mitigation to avert agricultural losses. Social-economic sectors such as water management, agriculture and infrastructure development are affected by the average amount and the temporal distribution of precipitation, as excessive precipitation and lack of precipitation both have adverse effects on society (Sadiq & Qureshi, 2014). Therefore, understanding the distributions of precipitation makes it possible to estimate the likelihood of rainfall being within a specified range. In order to better prepare for future extreme events, the amount and seasonal distribution of rainfall are the most important factors to consider when looking at rainfall across The Gambia. The goal of this paper, therefore, is to focus on The Gambia and examine precipitation distribution for the period 1981 - 2020.

The remainder of this paper is designed as follows; section 2 covers description of the study area, the data, and the methodology in the study, section 3 discusses the findings of the study, and section 4 gives the conclusion and recommendations.

Study area, data and methodology

Study area

The Gambia is the smallest country on mainland Africa. It is bounded by latitudes of 13° to 14° N and longitudes of 17° to 14° W (figure 1), and situated on both sides of the lower reaches of the river Gambia. The river Gambia flows through the center of the country, thereby dividing the country into the north and south banks, and empties into the Atlantic Ocean. The Gambia is characterized by low land features, and is surrounded by Senegal on three sides, except to the west where about 80km of coastline on the Atlantic Ocean marks the western border of the country. The Gambia's climate is characterized by one short rainfall regime, that is monomodal, due to the north-south migration of the Inter-Tropical Convergence Zone. The West African monsoon brings rain to The Gambia. Rain is observed between June and October (Gu & Adler, 2004; Gianini et al., 2003). No part of the country is desert.

Data

In this paper, monthly rainfall data from 1981 to 2020 over The Gambia as observed and archived by 10 meteorological stations (figure 1c) spread across The Gambia, and overseen by The Gambia Meteorological Department was studied. The Gambia Meteorological Department is a government technical department in charge of weather and climate monitoring in The Gambia. At the time of this research, it runs a network of 10 meteorological stations widely spread across The Gambia. 10 meteorological stations with quality-controlled data have been used in this study. These stations have complete and continuous data records and are distributed widely across the country.

Recently, several gridded data sets of daily/monthly precipitation based on satellite products have become available for the entire African continent. In most of these data sets the satellite products have actually been merged with information based on rain gauge data. These gridded data sets, however, provide quite different representations of daily/monthly precipitation behavior (Sylla et al., 2013), hence, giving rise to a certain degree of uncertainty. Therefore, the value of such data sets for the quantitative evaluation of various characteristics of rainfall beyond the basic ones is limited. Due to these reasons, we have used rain-gauge measurement data in this study. The network of rain-gauges shown in figure (1c), are sufficient to study the synoptic meteorological conditions of The Gambia. In the present study, we divided the study area into two sectors (western and eastern) (figure 1c).

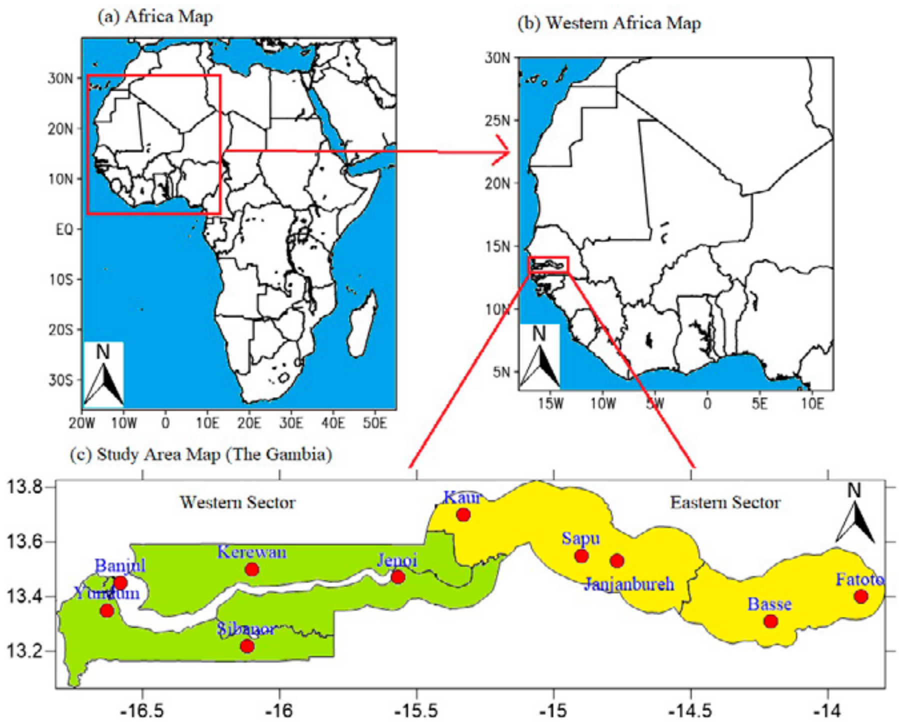

Figure 1. The Geographical location of (a) Western Africa on the map of Africa (red rectangle), (b) The Gambia in Western Africa (red rectangle), (c) the study area showing meteorological stations (red dot), eastern sector (yellow shade), and western sector (green shade)

Methodology

Composite Analysis

In this study, in order to establish the spatial rainfall distribution, composite analysis was used. Composite analysis is defined as the identification and averaging one or more categories of fields of a variable which are selected based on their association with main conditions. And then use the results of the composites to generate hypotheses for the distribution of rainfall geographically, temporally, and seasonally which may be associated with the individual scenarios (Folland et al., 2009). A number of authors, including Libanda et al. (2015); Koumare, I. (2014); Ogwang et al. (2012); Ininda (1995); Okoola (1999) have used composite methods in their analyses over Southern, Western, and Eastern Africa, respectively.

Rainy Season Definition

In the present study, we defined the rainy season at each synoptic station on the basis of monthly precipitation following the method suggested by Liebmann and Marengo (Liebmann and Marengo, 2001). As a method to view precipitation season they defined the rainfall accumulation quantity A for a given calendar day of the year as:

$$A(month) = \sum_{n=1}^{month} R(n) - \overline{R} \cdot month \tag{1}$$

Where *R(n)* is the climatological monthly precipitation as a function of the month of the year and is the climatological annual mean monthly precipitation.

Should the rainy season at a given station be considered as the period during which climatological monthly precipitation exceeds its annual average, then an upward slope of the total quantity indicates the onset of the rainy season, while a downward slope indicates the end. It is worth noting that the definition of the rainy season used here is local, as it is based on the climatology of monthly precipitation at a given station.

Results and discussion

In this chapter the results obtained from the methods used to address the aims of the present study are presented and discussed.

Table 1 presents the latitudes and longitudes of the meteorological stations used to gather rainfall data from 1981 – 2020.

Table 1. Location of the Meteorological Stations used

Name	Latitude (°N)	Longitude (°W)
Banjul	13.45	16.58
Basse	13.31	14.21
Fatoto	13.40	13.88
Janjangbureh	13.53	14.77
Jenoi	13.47	15.57
Kaur	13.70	15.33
Kerewan	13.50	16.10
Sapu	13.55	14.90
Sibanor	13.22	16.12
Yundum	13.35	16.63

Spatial characteristics of 1981 – 2020 rainfall

Figure 2 displays the average seasonal rainfall over The Gambia. From the figure, it can be seen that the southern part of the western sector region such as Sibanor tend to receive more rainfall compared to other regions. This is likely because Sibanor is located in a thick vegetation cover zone in The Gambia. Part of the central region receives the least annual rainfall in the study area.

The eastern sector of The Gambia receives much of its rain from May to October with July - September as the peak of the rain season. This means that the findings of Gu and Adler (2004), and Gianini et al. (2003) that rain is observed between June and October did not capture the rain season in the eastern sector of The Gambia where most farming activities are carried out. As can be seen from the composite of the eastern sector of the country below (figure 3a), during May - October, Sapu received the heaviest rainfall while Fatoto received the least amount. The observed high rainfall amount recorded in Sapu compared to other stations in the eastern sector is due to its close proximity to the river Gambia, whilst the low rainfall amount observed in Fatoto is because it is the farthest station inland, therefore it has the farthest proximity from a water body. The results also show that July - September is the period when significant amounts of rainfall are received over the eastern sector of the study area. From 1981 – 2020, all areas received less than 50 mm of rainfall during the month of May. While May and October are both transitional months, the eastern sector of the study area receives more rains in October than in May.

The western sector of the study area, on the other hand, receives much of its rain from June to October with July - September as the peak of the rain season. This supports the findings of Gu and Adler (2004), and Gianini et al. (2003). Also, as can be seen from the composite of the western sector of the study area below (figure 3b), during June - October, Sibanor

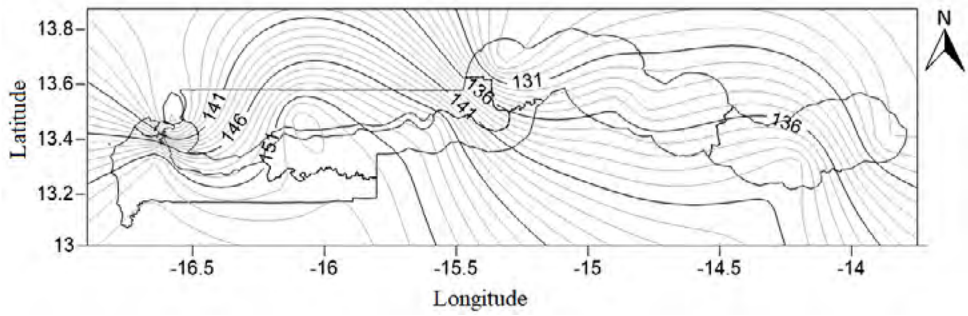

Figure 2. Mean seasonal rainfall (mm) distribution over The Gambia

received the heaviest rainfall while Jenoi received the least amount. These findings support those of Nicholson (2013), which stated that rainfall in the Sahel reduces towards the Sahara Desert. The results also show that July - September is the period when significant amounts of rainfall are received over the western sector of the study area. From 1981 – 2020, all areas received less than 100 mm of rainfall during the month of June. While June and October are both transitional months, the western sector of the study area receives more or less the same rain amounts in June and October.

During 1981 – 2020, as can be seen from Table 2, all stations recorded high amounts of rainfall between July - September and a decline in October. This trend confirms the life cycle of the Inter Tropical Convergence Zone (ITCZ). The ITCZ is an east-west oriented low-pressure region near the equator where surface North-easterly and Southeasterly trade winds meet (Premaratne et al, 2021). It is known as the Inter Tropical Discontinuity (ITD) in West Africa by some scientists; it is the northern edge of the Western African Monsoon (Janicot, 1992). Its movement north and south of the equator is a consequence of the earth's rotation around the sun (Nicholson, 1981). The ITCZ is the dominant rain producing mechanism over Western Africa. Over The Gambia it remains inactive until early or mid-May, reaching its peak in August giving the Gambia its main rains before it propagates southwards.

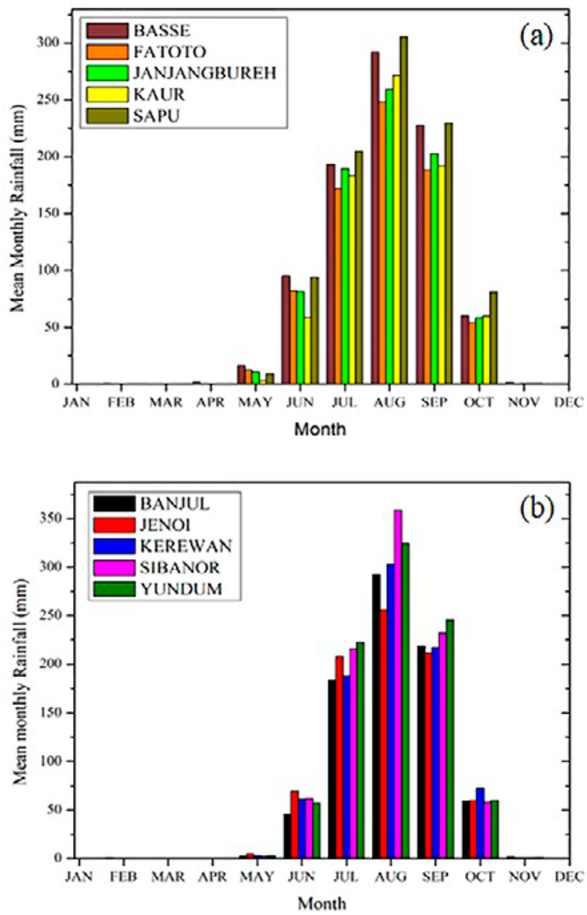

Figure 3. Mean monthly rainfall over the (a) eastern sector, (b) western sector of The Gambia

Table 2. Mean monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Banjul	0.5	0.7	0.0	0.0	2.5	45.7	182.9	292.0	218.9	59.3	1.4	0.2
Basse	0.2	0.3	0.1	1.6	16.3	95.3	193.5	291.8	227.4	60.0	1.4	0.2
Fatoto	0.1	0.2	0.1	0.2	12.3	82.3	172.1	248.0	188.4	54.6	0.3	0.2
Janjangbureh	0.2	0.0	0.1	0.0	10.4	81.3	189.5	259.3	202.7	58.3	0.5	0.0
Jenoi	0.0	0.0	0.0	0.0	4.5	69.1	207.3	255.7	211.5	60.1	0.9	0.2
Kaur	0.1	0.1	0.0	0.0	3.4	58.6	183.3	271.7	191.8	60.0	0.5	0.0
Kerewan	0.4	0.6	0.0	0.0	2.8	61.1	188.1	302.8	217.0	72.4	0.8	0.1
Sapu	0.0	0.1	0.0	0.0	8.7	94.1	204.4	305.1	229.6	81.0	0.6	0.1
Sibanor	0.1	0.2	0.0	0.0	2.4	61.8	215.7	358.6	232.1	58.0	0.8	0.3
Yundum	0.3	0.5	0.0	0.0	2.7	57.4	222.3	324.2	245.9	60.2	1.2	0.3

Maximum and Lowest Rainfall, and Standard Deviation

In order to observe guidelines of the United Nations' Food and Agricultural Organization (FAO) that different crops have different water requirement, and different growing period (number of days from sowing to maturity) in The Gambia, analysis of maximum and lowest rainfall, and standard deviation is done for individual stations across the study area to: (1) understand rainfall climatology at individual stations, and (2) provide farmers with robust information on the type of crops to grow and when to grow them in different regions across The Gambia based on the maximum and minimum, and standard deviation of rainfall in that area. This will go a long way in reducing losses associated with above (below) required water by different crops.

Individual station rainfall climatology during the period of study for the eastern and western sectors is shown in figures 5 (a – e) and figures 6 (a – e), respectively. The figures show the maximum rainfall record-

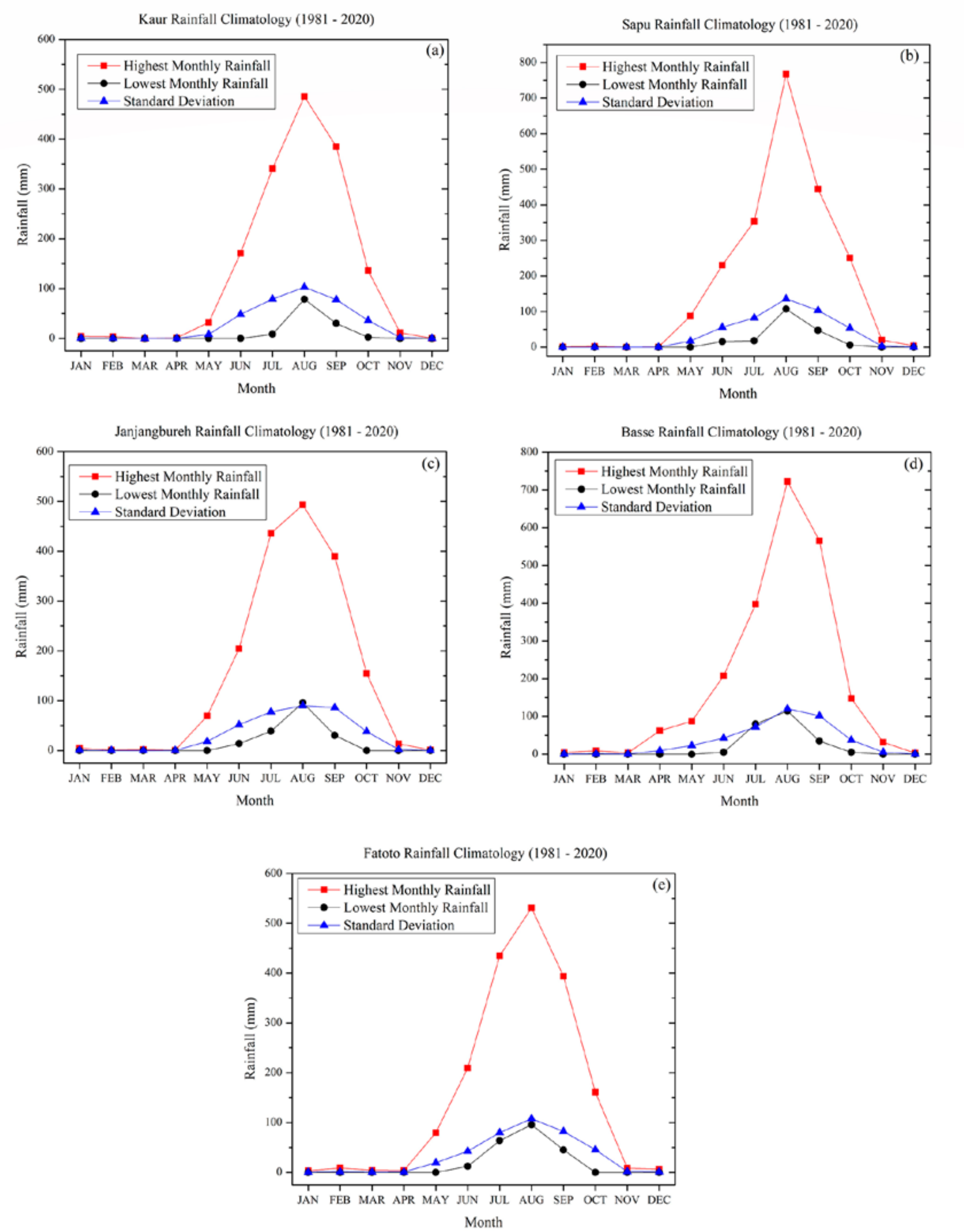

Figure 4. Rainfall variability at individual stations (Eastern Sector)

ed, standard deviation, and lowest rainfall recorded. The highest monthly rainfall received on record for Banjul during the study period was 662 mm in 2010 in the month of September (Table 3). Kerewan recorded its highest monthly rainfall in August 1988 which amounted to 680 mm. The highest monthly rainfall reported in Kaur was 486 mm in the month of August, 1982. 493 mm is the highest monthly rainfall received during the 1981 – 2020 period in Janjangbureh, in August 1999. Basse received its maximum monthly rainfall in August 1999 which amounted to 723 mm. Fatoto reported 531 mm in August, 1999 during the period of study. In August, 1999, Sapu received 767 mm as its maximum monthly rainfall during the study period. Jenoi recorded its highest monthly rainfall in September 2012 which amounted to 463 mm. The highest monthly rainfall reported in Sibanor was 632 mm in the month of August, 1988. 654 mm is the highest

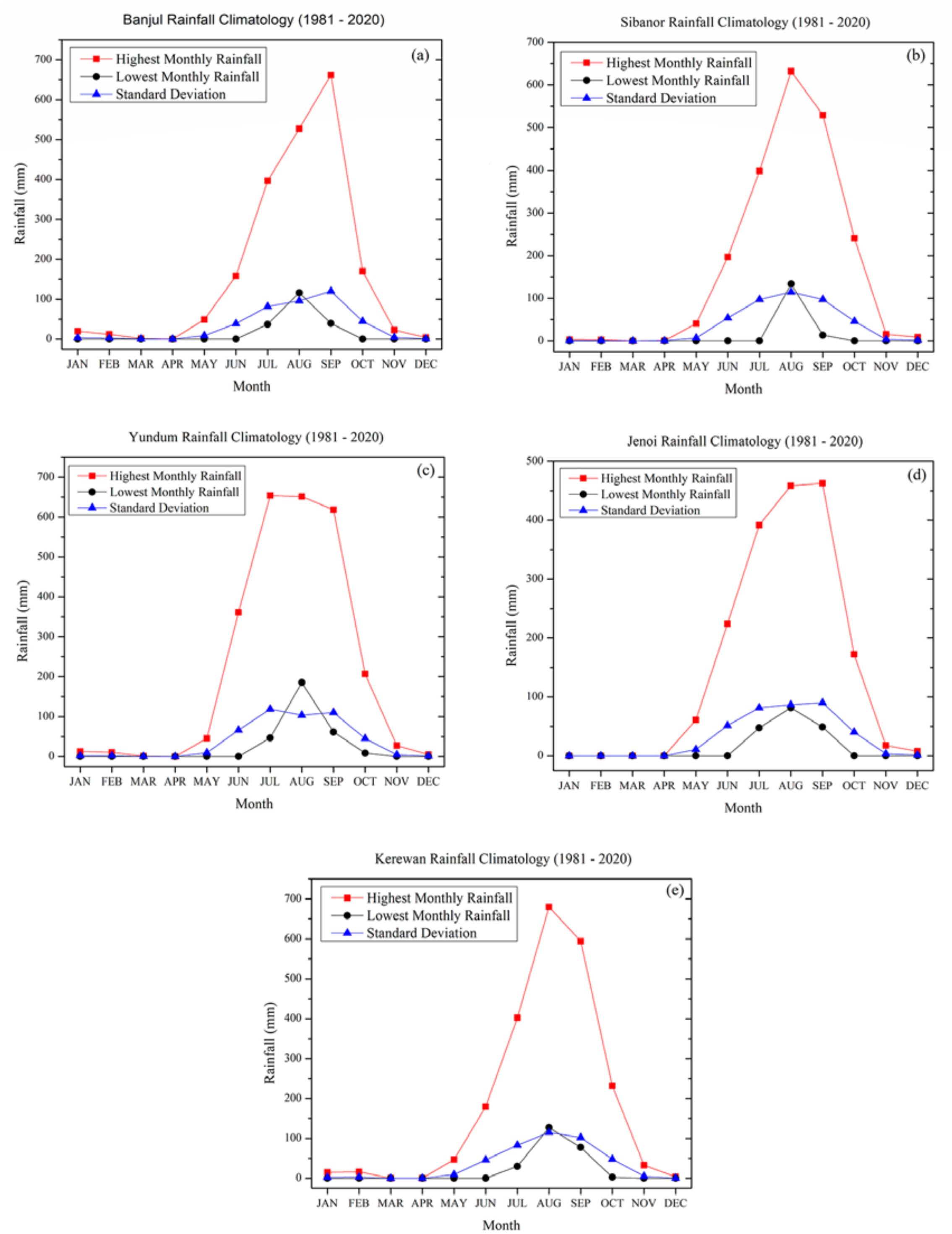

Figure 5. Rainfall variability at individual stations (Western Sector)

monthly rainfall received during the 1981 – 2020 period in Yundum in July, 2009.

In the eastern sector, to avert losses associated with excess (deficit) water requirement, crops with high water requirement should be grown before August, because maximum rainfall is experienced in August; whereas crops with minimum water requirement should be grown in May or October as that is when minimum rainfall is experienced. On the other hand, in the western sector, to avert losses associated with excess (deficit) water requirement, crops with high water requirement should also be grown before August or September is when maximum rainfall is recorded, whereas crops with minimum water requirement should be grown in June or October because that is when minimum rainfall is observed.

Table 3. Highest station rainfall received during the study period

Station	Rainfall (mm)	Year	Month
Banjul	662	2010	September
Basse	723	1999	August
Fatoto	531	1999	August
Janjangbureh	493	1999	August
Jenoi	463	2012	September
Kaur	486	1982	August
Kerewan	680	1988	August
Sapu	767	1999	August
Sibanor	632	1988	August
Yundum	654	2009	July

Conclusion

This study investigates rainfall patterns in The Gambia by considering periodic interval of 40 years (1981-2020). The study domain experiences monomodal rainfall regime during the West African Monsoon season. Climatologically, the eastern sector of The Gambia receives much of its rain from May to October with July - September as the peak of the rain season. The western sector of the study area, on the other hand, receives much of its rain from June to October with July - September as the peak of the rain season. Hence, rainfall onsets earlier in the eastern sector than in the western sector. The southern part of the western sector region such as Sibanor tend to receive more rainfall compared to other regions of the study area. Part of the central region receives the least annual rainfall in the study area during the study period. The Gambia is particularly affected by the movement of the ITCZ which brings rains when it enters the Gambia from the South in May as it traverses to the North of West Africa, reaching its most northern peak in August.

The result from maximum and minimum, and standard deviation of rainfall both in the eastern and western sector of the study area show that stations across the country record different amount of rainfall in different months. In the eastern sector, crops with high water requirement should be grown before August, this is when maximum rainfall is experienced, whereas crops that require minimum water should be grown in May or October. On the other hand, in the western sector, crops that require high water amount should be grown before August or September as this is when maximum rainfall is recorded, whereas crops with minimum water requirement should be grown in June or October.

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Spatially Differentiated Impacts of Covid-19 on Selected Indicators of Mortality in Slovakia in 2020

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Abstract

Slovakia is a country with a specific development of the Covid-19 pandemic. While it was among the countries with the lowest number of cases and lowest mortality during the first wave, during the second and third waves Slovakia gradually became one of the countries with the worst development of the pandemic. The aim of this contribution is to summarise the situation in Slovakia during the first year of the pandemic and investigate its influence on selected indicators of mortality. An attempt was also made at determining its influence on the lethality rate of Covid-19, changes in mortality, and excess deaths. The research considered regionally differentiated levels and identification of risk districts from the aspect of the abovementioned phenomena.

Keywords: Covid-19; spatial analysis; mortality; lethality; excess deaths

Introduction

The influence of the Covid-19 pandemic on the population of given country is usually evaluated based on the number of cases and the number of deaths. These two statistics create a daily updated international panel of data which are managed by the World Health Organisation (WHO) and the John Hopkins University. Both metrics are distinctively influenced by the availability of testing and by various definitions of Covid-19-related deaths in individual countries (Riffe et al., 2021; in Karlinsky & Kobak, 2021). The influence of the pandemic among countries or over time is also conditioned by different levels of coverage and the reliability of data. An interregional comparison can be more demanding because the reported numbers of cases and deaths are distinctively influenced by the specific conditions of the regions. To analyse the influences and impacts of infection for longer, "closed" time periods is the best solution for monitoring and comparing infection rates at the regional level. This removes shortages in the statistics of regions and it also considers "running-down" data whose processing required a determined amount of time. In Slovakia, but also in the majority of advanced countries worldwide, the annual data are available on mortality, specific deaths according to basic structures of population, or death causes. These data, together with data on the course of infection on behalf of regions (of positivity of tests, prevalence, incidence, daily mortality growths) create a suitable basis for regional analyses. Further indicators and important information can be gained for monitoring the regionally differentiated impacts of Covid-19 on the population and selected demographic processes.

This contribution utilises the indicated databases to analyse the development of research into the pandemic in Slovakia and its regions. It is focused on the influence of one of the most important impact of the pandemic – increased mortality. By means of considering more indicators it follows the development, level, and alterations in mortality during the

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pandemic. The contribution also examines whether and to what extent the generally confirmed spatial concentration of coronavirus in Slovakia determines different levels of mortality in different regions. The aim of this contribution is to assess the state and development of the pandemic at a national level and to determine the differentiated mortality rate (of selected indicators) in different districts of Slovakia during the first year of the pandemic (2020). The direct effects of Covid-19 on three significant indicators of mortality are quantified, namely: lethality, specific, and excessive mortality. The results of the spatial analyses presented here identify implicitly the most affected regions from an aspect of selected indicators of mortality during the first and second waves of the pandemic in Slovakia.

Problems in evaluating lethality in times of a pandemic

The relatively broad and different definitions of lethality adopted by countries lead to various, often unsuitable or confusing interpretations. This ambiguity and common misunderstandings can result in an underestimation of the pandemic which is, according to a considerable part population, comparable to ordinary infection with low mortality. However, the high numbers of deceased persons evidence the relatively high risks and lethality associated with the infection.

Countries worldwide, however, have different definitions of cases of Covid-19 lethality. As a consequence, the numerator and denominator of each formula used for calculating lethality differ according to how it is defined. The WHO recommends the use of definitions of the cases of monitoring which are at a disposal in the temporary instructions of the WHO on the global monitoring for Covid-19 (WHO, 2020b). Lethality is defined for the purpose of monitoring deaths caused by clinically compatible illnesses in probable or confirmed cases of Covid-19. No period of full recovery should exist between the onset of the disease and the time of death (WHO, 2020c). The ratio of lethal cases is the quotient of the individuals with a diagnosed disease who will die of this disease. This ratio expresses the rate of gravity among found-out cases. Reliable data, which can be used for evaluating lethality, will usually be obtained at the end of a period after solving all cases (the affected persons have either died or they have recovered). During ongoing epidemics, the calculation of lethality provides only a conditioned estimation influenced by delays in the data of cases and deaths. This leads to great differences in estimations of lethality during the course of the epidemic. Restricting the analysis on solved cases is a simple solution for moderating distortion as a consequence of delays during the period in progress. However, this method does not fully eliminate all the problems connected with delayed reporting. Distortions and final estimations can be, for example, also influenced by differences in the time needed to solve cases. If people that are afflicted coronavirus are expected to die more rapidly than they would recover, the lethality can be overvalued; it can also be undervalued under the opposite circumstances. Therefore, statistical methods should be applied to forecast future results based on the probability of past results. For example, the modified version of Kaplan-Meier's analysis of surviving (Lipsitch et al., 2015) appears to be a very suitable method. It is generally stated that the lethality of Covid-19 is influenced by age, gender, ethnic membership (Pan et al., 2020), and by corresponding co-morbidities (Gold et al., 2020). Any attempt to assess only the rate of lethality in a population does not take into consideration the basic heterogenities among various risk groups. On the contrary, it leads to relevant distortions in the consequences of their different distributions in populations and among them (Angelopoulos et al., 2020). Therefore, estimations of death risk on individual risk groups should be focused on in order to better describe the real formulae of lethality occurring in populations. Potential distortions and inaccuracies are an accompanying sign of lethality estimation. These distortions can differ among various foci during the pandemic. At the beginning of infection, there is a greater probability of finding serious cases with a greater lethality. The patients with heavy illnesses will probably reach health service establishments and their illnesses will be confirmed by laboratory tests. However, the delays in producing death reports can lead to an underestimation of lethality. Cases of and deaths related to Covid-19, which occur in communities, often remain undetected or are reported late because they have been improperly ascribed to other causes. It is improbable that all deaths would be reported and properly assigned although death surveys can be the subject of smaller prejudices than cases survey.

The Covid-19 pandemic came accompanied by wide variations in the estimations of lethality, which can be, and often are, also misleading. It is hard to compare countries number of cases as they use various definitions of the word "case". They differ in their probabilities of revealing and registering all deaths related to Covid-19. Deviations in lethality can also be explained partially by time delays. The different quality of care or therapy during the various stages of illness can also play a part in these discrepancies. Finally, the different profiles of patients (age, gender, ethnic membership, and basic co-morbidities) in particular countries, especially in the case of big differences, influence the differentiated rates of lethality to a considerable degree.

The lethality of the Covid-19 illness was originally determined by the WHO as 3.4% (WHO 2020a, d). However, the values of lethality according to countries are considerably different. The lethality of Covid-19 has at times been reaching around 20% in countries with an explosive development of the epidemic and with insufficient testing of citizens. In contrast, statistics below 1% have also been reported in countries where the pandemic was under control and testing was extensive. Deaths were mainly recorded in older and attenuated patients, and persons suffering of other serious illnesses, chiefly of the heart and respiratory passages. Children are considered to be less threatened (Cennimo 2019). More epidemiological and regional studies exist in the present day which indicate different levels of lethality. Ioannidis (2020) stated the lowest lethality of Covid-19, indicating a value of 0.23%. This estimation, however, is distinctively lower than that established by other researchers until now. The majority of works, including the ones published by the WHO, have indicated a several-fold higher lethality, and the lethality rates in October 2020, for example, were at a level of 2.2% worldwide (ECDC, 2020). The study by Piroth et al. (2020) showed that in March and April 2020 approximately 16.9% of patients with Covid-19 had died in French hospitals, recording a three times greater lethality than the one registered for persons hospitalised with the flu. High lethality rates have also been recorded in the United Kingdom, where the values sometimes reached around 15%. Calculations of lethality were only made based on closed cases (the healed persons plus the dead persons) because the health outcomes of infected persons were unknown (Our World in Data, 2020)[1]. This means that in spite of the high values of lethality in France and the United Kingdom, the lethality rates had been undervalued in both countries.

Significance of monitoring and evaluation of excessive mortality during Covid-19

Excessive mortality is a term used in epidemiology and demography to designate the number of deaths from all causes beyond that which would be expected under "normal" conditions. Indeed, excessive mortality is a more complex criterion of the total influence of the pandemic on deaths than the confirmed number of deaths itself (lethality) related to Covid-19. In addition to the confirmed deaths, excessive mortality also includes deaths which have been incorrectly diagnosed and reported. The concept also encompasses deaths due to other causes which can be ascribed to total crisis conditions (Giattino et al., 2020). The excessive mortality can be measured several ways in times of a pandemic. The simplest way involves subtracting from the number of found-out des in given period during the pandemic the average number of deceases in the same period in previous years. Karlinsky and Kobak (2021) performed a linear extrapolation of the trend in the years 2015-2019 to calculate the excessive mortality during the pandemic in 2020. Chan et al. (2021) quantified the influence of the coronavirus on excessive mortality by estimating the number of deaths that would have occurred under "normal" conditions then if the pandemic had not taken place. Subsequently, they subtracted the gained value from the reported, total death number for all age groups and both genders. Llod-Sherlock et al. (2021) used quasi-Poisson models to estimate excessive mortality during the first wave of the Covid-19 pandemic. Equally, Woolf et al. (2020) estimated the expected deaths using a hierarchic Poisson regression model modified on the weekly numbers of deaths. Other authors (CDC, 2020) have used Farrington surveillance algorithms in analyses of excess deaths connected with Covid-19-related illnesses and compared these with historical trends of mortality. The P-score provides a useful means of estimating excessive mortality; it is a percentage difference between the number of deaths in a week in given year (e.g., in 2020) and the average number of deaths in equal weeks for determined years (most often over five-year periods). However, the P-score has some limitations. For example, the five-year average number of deaths can be perceived as a relative gross rate of "normal" deaths because it does not consider the trends in the size of populations or mortality. It is important to note that countries with older populations, which have a higher risk of mortality (including from illness related to Covid-19), will have as a standard a higher P-score in all age groups. The number of confirmed deaths caused by the coronavirus can differ from the total impact of the pandemic on deaths for several reasons. More countries have reported only Covid-19-related deaths which occurred in hospitals, omitting those people who died of Covid-19 complications at home. Other countries have, in turn, only reported deaths for which testing had confirmed that the patient had been infected by the virus. This registration, however, does not include the Covid-19-related deaths of untested individuals. Discrepancies in the numbers of deaths can also be caused by disunited systems of death reports which are not sufficiently precise (being valid especially for poorer countries). In fact, a pandemic can lead to an enhanced number of deaths

[1] The number of found-out cases depends on testing to a certain degree, but also on deaths and possibly on whether or not persons consider themselves victims of Covid-19. Since it is more tested, lethality is also decreasing in various countries worldwide (Our World in Data, 2020).

for other reasons also, including: attenuated systems of health care; a smaller number of people seeking therapy for other health risks; or less available financing and therapy for other diseases (e.g., AIDS, tuberculosis, and others). More deaths from other causes can thus be an implicit result of the pandemic. Secondary deaths do not result directly from infection with the virus[2], but rather from the lack of necessary healthcare during the epidemic. Indeed, states have had to eliminate health care or directed it in the first place to the therapy of patients with the coronavirus. On the other hand, mobility restrictions can lead to a smaller number of deaths resulting from traffic accidents during the pandemic. The interventions and measures put in place to stop the spread of Covid-19 can in turn reduce the number of deaths associated with the flu. The indicated realities show that the confirmed deaths related to Covid-19 often do not count on the total impact of the pandemic on the deaths, but in contrast to excessive mortality, they contain information on the cause of death. In turn, the advantage of monitoring excessive mortality is that it includes not only those who died of Covid-19-related complications but also those who died from all other causes. Both metrics are necessary for understanding the total influence of the pandemic on deaths.

In addition, Beaney et al. (2020) pointed out the irreplaceable role and meaning of monitoring excess deaths, consider the excessive mortality as a "gold standard" for measuring the impact of Covid-19 on mortality. They called to attention that the data monitored during the pandemic (cases and deaths), which quantify the total extent of illness in countries, have comparative restrictions according to the different sizes of populations as well as other differentiated demographic characteristics. The authors stated that age is strongly connected with mortality du to Covid-19 and the different age structure of populations has a distinctive influence on lethality as well as on total mortality. Even if these factors can be adapted or standardised, the comparisons of the mortality of Covid-19 remain restricted unless we understand how the definitions of mortality differ[3]. For example, the Russian definition of death cases of Covid-19, in contrast to the majority of European countries, relies only on the results of an autopsy. The recorded death had to be caused directly by Covid-19 meaning that it would not be counted if it was found-out that the patient had Covid-19 but it had not caused their death. This leads to insufficient reporting especially since Russia had one of highest numbers of Covid-19 cases in the world, and in spite of this, Russia reported very low rates of mortality due to the virus (only 1.7%) until July 31, 2020. In this context, Beaney et al. (2020) stated that with the proceeding development of the pandemic, the experts are focusing on excessive mortality as a more reliable metric for comparing countries more and more. Excessive mortality provides an estimation of the additional number of deaths over a given time period in comparison with the expected number of deaths. By the including all the causes, excessive mortality overcomes the differences among countries for reporting and testing for Covid-19, but also regarding incorrect classifications of the cause of death in death certificates. Given that the occurrence of further diseases will remain stable in the course of time, the excess deaths in cases which are directly or indirectly caused by Covid-19 can also be considered. Excessive mortality can also be standardised according to the age or size of a population, enabling mutual comparisons among countries. The excessive mortality is then a meaningful indicator which includes all causes of death and at the same time it is a metric of the overall influence of Covid-19 on mortality. Therefore, the timely and complex systems for collecting and reporting data on excessive mortality together with mortality caused by concrete causes (lethality) can be useful for monitoring trends within countries and among them.

Methods and data sources

The study utilises a relatively broad spectrum of data from relevant sources, especially from the WHO, Our World in Data, the European Centre for Disease Prevention and Control (ECDC), John Hopkins University, The Human Mortality Database, Statistical Office of the Slovak Republic (ŠÚ SR), Ministry of Health of SR, National Centre of Health Service Information (NCZI), the data of portal mapa.Covid.chat, and further sourc-

[2] Persons are considered for secondary victims of coronavirus who were not infected by virus but they died or yet will die because they did not get necessary health care in time of the epidemic.

[3] The World Health Organization (WHO) defines the decease of Covid-19 like a decease at which the Covid-19 is main cause of death, and it includes the confirmed also suspect cases. If Covid-19 is a factor which contributes to this but it is not the cause leading directly to death then it is not counted. Directing of the World Health Organization, however, has been introduced in April 2020 within which the countries could already introduce their own directing. In consequence of this considerable differences in the report of deceases of Covid-19 exist among countries.

es. An analysis focused on rating the level and development of prevalence[4] and incidence[5] is a starting point for evaluating situation in Slovakia during the first year of the pandemic and determining its position in the international context. The conceptual frame for rating the state and development of the pandemic situation in Slovakia was based on a range of relevant indicators. Selected indicators and characteristics such as cumulative calculi, rate of confirmed cases, sliding median, trend characteristics, and others, were monitored from the view of the infection level, development, changes, trends, but also from a spatial aspect. Their values for Slovakia were compared with those of selected countries, especially with the nearby Czech Republic. Research on the regionally differentiated impacts of the pandemic on lethality, mortality, and excessive mortality in districts was used to determine a coefficient of the spatial concentration and comparison of values of relative data. The P-score was utilised for comparing the rates of excessive mortality. Correlative analysis (concretely Spearman's correlative coefficient) was used to analyse the relationships between the monitored phenomena (share of old population and lethality of Covid-19). The information presented here provides a brief description of the situation in Slovakia in 2020 as well as in the context of its comparison with situations in other countries in Europe. The analyses proceed from certified data sources and from information from various relevant and reliable sources.

Evaluation of the development of the pandemic in Slovakia

The analysis focused on rating the level and development of Covid-19 prevalence and incidence is a conceptual starting point for evaluating the situation in Slovakia and determining its global position during the first year of the pandemic. The analysed data incorporate the most significant aspects of the pandemic – the level, seriousness, risks, and trends of its development and spreading. A detailed overview of the state and development of prevalence and incidence is a precursor for subsequent analyses focused on monitoring the influence and impacts of the pandemic at the level of lethality, mortality, and excessive mortality[6] in Slovakia in 2020 (Table 1). Data and indicators, which represent a necessary basis of information for important decisions, were also analysed. The cumulative number of confirmed positive cases and deaths includes daily increments and follows long-term developments. Changes in the rate of confirmed cases indicate continuous or turning trends of development. A seven-day sliding median is a basic criterion for regulations and the strictness of measures. Daily confirmed new cases demonstrate the ongoing development of the pandemic. Fourteen-day specific incidences reveal in detail the development of infections according to various structures and categories of the population.

Table 1. Descriptive statistics of basic data on Covid-19 in Slovakia (as of 31 December 2020)

The population	5,459,781
Number of tests performed	1,445,486
Rate of confirmed cases	184,508
Rate of confirmed deaths	225
Prevalence (seven-day sliding median)	2,095
Lethality of Covid-19	4,404
Excess deaths	402
Excess deaths (in %)	28.5
The share of lethality of Covid-19 in all deaths (in %)	6.8
The share of lethality of Covid-19 in excess deaths (in %)	72.0
The share of the old population (65 and over) on total lethality of Covid-19 (in %)	85.2

Source: mapa.Covid.chat (2021), Štatistický úrad SR (2021), Our World in Data (2021)

Evaluation of the lethality of Covid-19 in Slovakia

A precise understanding of the term lethality must be achieved to obtain the real picture on lethality during the Covid-19 pandemic. This work proceeds from the definition of lethality according to Maxdorf (2020). Lethality is a demographic indicator which is expressed as a rule in percentages as a quotient of the number of persons having died of a specific disease to the number of persons affected by this illness. The following formula can be used to express the formal record for calculating the such defined lethality:

$$m_t^c = \frac{M_t^c}{\bar{S}_t^c}$$

- m = lethality,
- c = cause,
- t = time (period),
- M = mortality,
- S = medium state of population

To evaluate the lethality of Covid-19 in Slovakia, one should bear in mind that it is impossible to gain a fully precise number of victims (deaths) of the vi-

[4] Prevalence is a statistical concept referring to the number of cases of a disease that are present in a particular population at a given time.
[5] Occurrence of new cases of disease over a specified time period.
[6] Excessive mortality designates the number of deaths relating to all causes beyond those that would be expected under „normal“ conditions.

rus. Deviations in values of lethality in both directions (higher or lower) have been influenced by more factors. An overvaluation or undervaluation of lethality has been in part conditioned by testing, especially with a lack of registering positive cases. These have been connected either with "dual" registration or, on the contrary, by the non-recording of part of the tested persons and then by their non-inclusion in a registration system. Certain inaccuracies in the lethality values could also be caused by problems associated with ascribing the cause of death and by differences between the reported deaths and the total number of deaths.

Level of lethality differentiated by regions and age

Specific indicators of lethality have been used to obtain information regarding the various levels of lethality of Covid-19 in different regions as well as according to age. The regional indicator expresses the level of lethality in each district; the numerator expresses the mortality of Covid-19 in the district and the denominator expresses the medium state of the district's population. The level of lethality differentiated by age is expressed by a specific indicator of mortality according to age. The numerator expresses the mortality of Covid-19 of a monitored age category and the denominator expresses the medium state of the population of the monitored age category. This contribution analyses concretely seniors that are 65 in age and over.

Correlative analysis

The information revealing high rates of lethality of Covid-19 in seniors evokes questions regarding the extent to which values of lethality level are determined by age. In other words, it is unknown whether age represents a significant (predictive) factor of high mortality (lethality) due to Covid-19 in the senior population (a high share of the population in Slovakia has a post-productive age). The indicated relation was determined based on an examination of the dependence between the share of the old population (65 and older) and lethality. The relationships among the monitored phenomena were analysed using regional data on behalf of the districts. The data of the Statistical Office of the SR – "Balance of population according to age" and "The deceased persons according to cause of death, age, and gender" were utilised for the analysis. In the first step of the examination of dependence two assumptions were made regarding the relationships, namely: direct (1) and differentiated (2) effects of the influence of a high share of the senior population on lethality. The correlative analysis and the Spearman´s correlative coefficient values (below Skk) pointed to a medium-strong direct dependence (Skk = 0.387) and spatially relatively differentiated influence of the old population on the level of their lethality.

Changes in mortality and excessive mortality in districts during Covid-19

The analysis of the differentiated levels of the development of Covid-19-related deaths (their increase/decrease) in the districts proceeded from a standardised rate of mortality. Its average values for the last five years (2015-2019) were subtracted from the values for the year 2020. The results obtained for mortality were counted-over with regard to relatively low increments to 100 thousand inhabitants of mid-year population. The following procedure was chosen to measure excess deaths at the regional level during the Covid-19 pandemic. The number of expected deceases was estimated from the mortality data from the last five years (2015-2019). The indicated data on mortality were double-checked prior to this to eliminate "mortality shocks" which may distort long-term trends of mortality. Subsequently, the expected (estimated) deaths for the same year were subtracted from the registered deaths for the year 2020. Values of excess deaths were thus obtained for each district. A 95-percentage confidence interval was used due to the small size of the population and small number of deaths in most districts (the number of deaths is significantly influenced by processes of accidental nature).

Results

State and development of prevalence and incidence

Figure 1 shows a distinctive growth of the number of infected persons from October 2020. At the end of September, the number of infected was under the limit of 11,000, but at the end of October it had reached almost 60,000. On the last day of November, this number already exceeded 107,000, and at the end of the year, up to 184,508 persons had been infected.

Figure 2 also confirms the growing trend of the number of infected persons which includes changes in the rate of confirmed cases. The curve of positivity turned red over time, representing an unfavourable development with the rate of confirmed cases exceeding 10%.

The unfavourable development of prevalence is also displayed in Figure 3, which reveals the growth of values of the seven-day sliding median. It concerns a significant indicator on the basis of which the criteria for

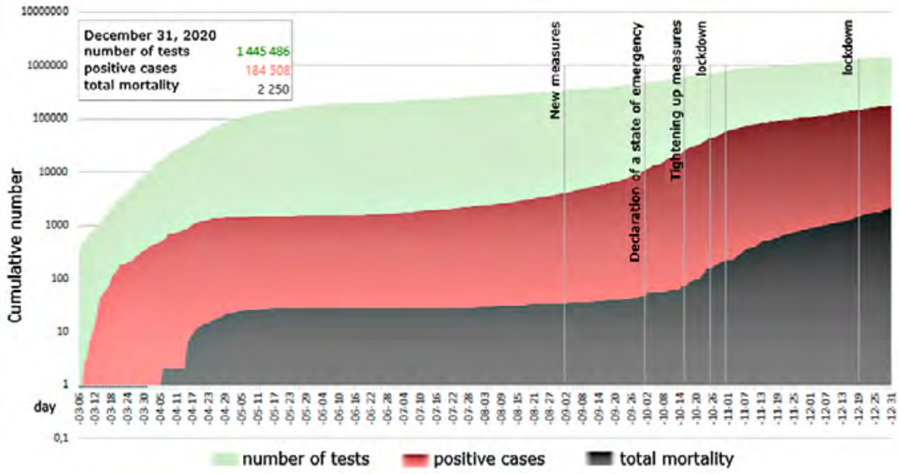

Figure 1. Cumulative number of tests, confirmed positive cases, and deaths up to 31/12/2020
Source: mapa.Covid.chat (2021), Our World in Data (2021)

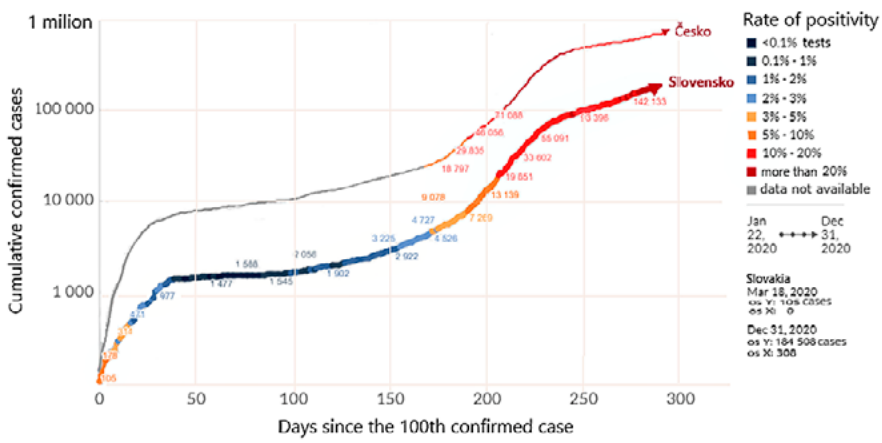

Figure 2. Changes in the rate of confirmed cases of Covid-19
Source: Johns Hopkins University (2021), Our World in Data (2021)

making stricter or looser measures are determined[7]. The limit for Slovakia was set to a value of 500 which was exceeded for the first time on 1/10/2020. Development in the following days, however, with relatively high values has never decreased under the indicated limit. On the contrary, shortly before Christmas, it reached maximum value of 3 045 cases.

Research on the specific incidence of lethality according to age groups (Figure 4) showed that while at the beginning of December most infected persons were in the age category of over 80-year-olds, the number of infected persons at the end of the month belonging to lower age categories (50-64; 25-49; 15-24) had distinctively increased. The steep growth of the curve of infected persons in the stated age categories indicates an insufficiency of adopted measures but also their non-observance by a considerable part of the population. It was manifested by the increased number of patients with a heavy course of illness, by the occupancy and exploitability of hospitals, as well as by the enhanced mortality of older persons.

Development and changes of lethality at a national level

In 2020 the Covid-19 pandemic caused the deaths of over four thousand people (4 404) in Slovakia and thereby became the third most frequent cause of death in the country (~6.8% of all recorded deaths). However, it became a massive cause of death only during the second wave of the pandemic. Over 97% of deaths ascribed to Covid-19-related illnesses happened in the last quarter of 2020 (ŠÚ SR, 2021). During December of that year, more than half (54%) of the annual deaths were related to Covid-19. According to the

[7] One of decisive criteria for release of measures is so-called sliding median of number of infected persons during the last seven days which is daily evaluated. Approximately after 2 weeks in one phase it will be decided whether it passes to further phase. At the release of measures accepted in fight against the pandemic in Slovakia it is calculated the sliding median from daily number of new infected persons during the past week which is cleared from new infected persons in quarantine centres.

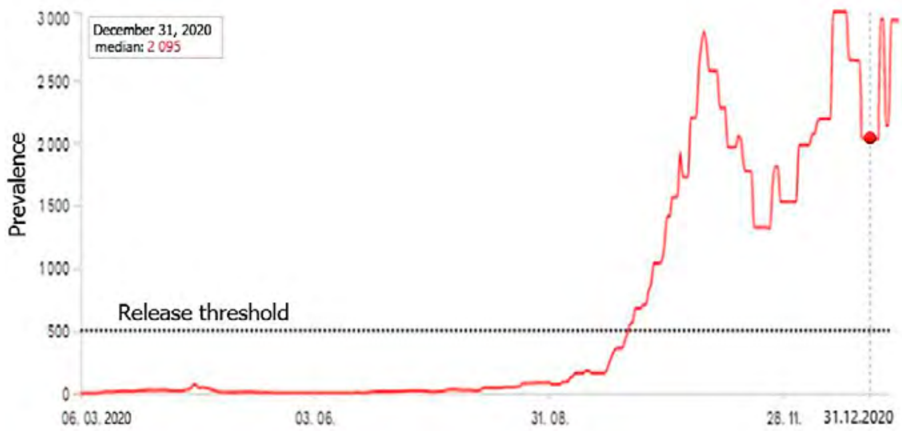

Figure 3. Seven-day sliding median
Source: mapa.Covid.chat

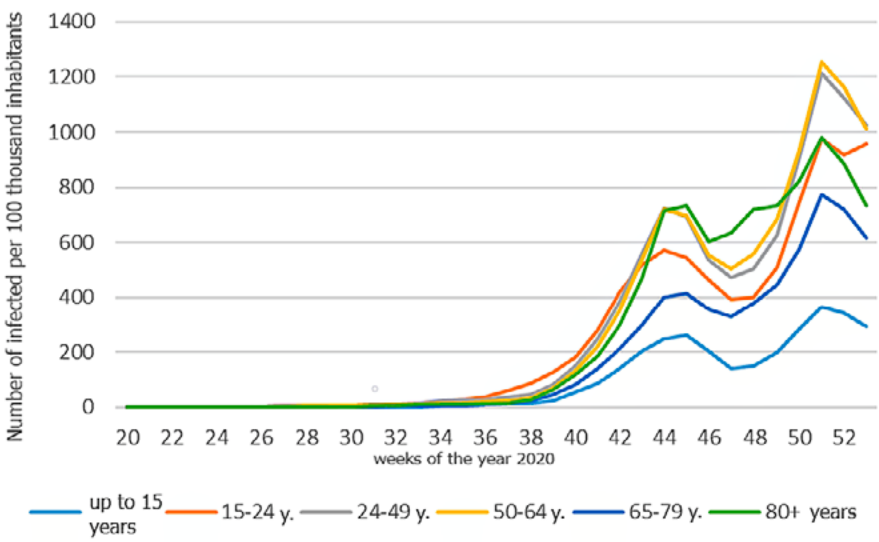

Figure 4. Fourteen-day specific incidence according to age groups
Source: ECDC (2021)

development of daily and average seven-day lethality in Slovakia (Figure 5), lethality values were low until the middle of December. However, in last days of the year the curve of new deaths was distinctively growing, as confirmed by the sliding average of new confirmed daily deaths from Covid-19 during seven days[8]. Until October 31st, Slovakia had recorded a total of 219 deaths related to Covid-19; a month later (30/11) 868 deaths had been registered and up to 2,250 at the end of the year (31/12) (mapa.Covid.chat 2021)[9]. The lethality values in Slovakia for the monitored period were considerably time differentiated. The highest value of 1.9% was recorded during the first wave, and on May 16th, it decreased distinctively before reaching a minimum value of 0.3% on October 16th. Following this date, the values began to grow again before reaching a value of 1.2% on December 31st. During the whole monitored period it had an average value of 1.19%. In comparison, Bulgaria experienced a lethality of 4%, Italy 3.5%, Hungary 3.2%, and Belgium 3% over the same period. Yemen had the highest lethality (29%) in the world (by 31/12/2020).

Figure 6 outlines the unfavourable development of the Covid-19 situation comparing the cumulative confirmed deaths in selected countries. The figure clearly shows that in in the last days of 2020 the cu-

[8] At all sources of data on the pandemic the daily data have not to relate indispensably to the deceases just in that day but to the deceases reported in that day. Because the reporting can distinctively differ from day to day regardless to any real changes of deceases, therefore it is useful to display seven-day sliding average of the daily data.

[9] The indicated numbers forced the government to accept a stricter lockdown which, however, began to be valid from the New Year (2021) and according to the majority it came late.

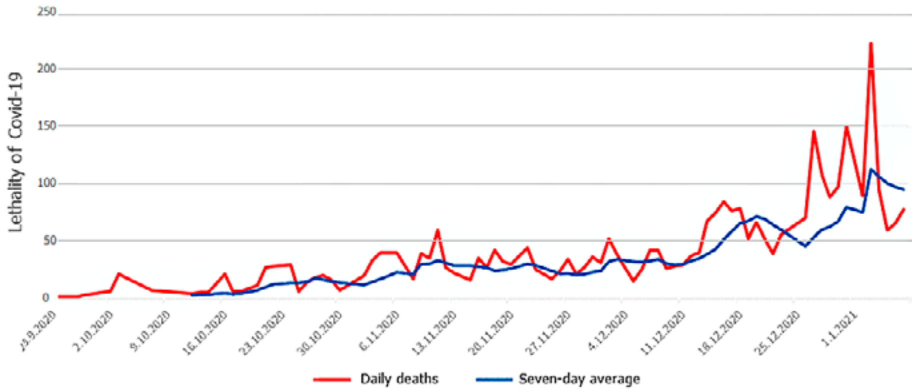

Figure 5. Development of the mortality of Covid-19
Source: Ministry of Health of the SR (2021a)

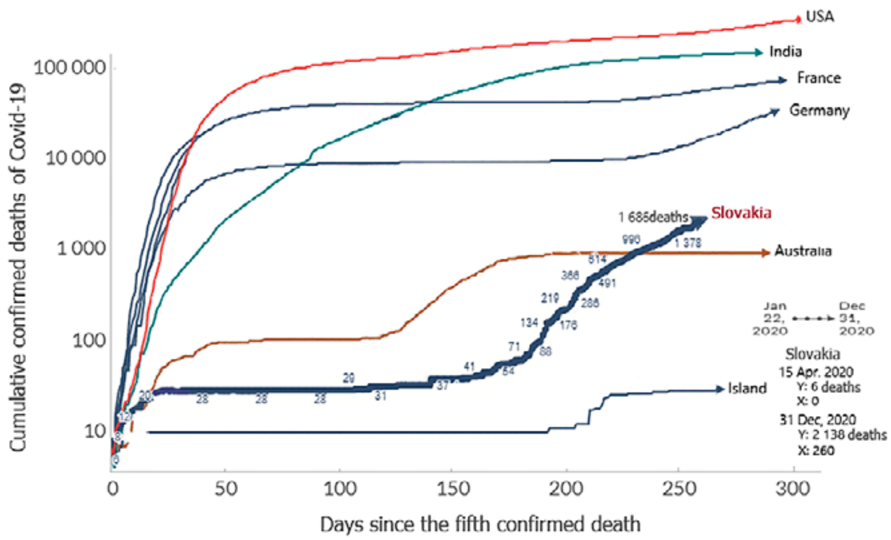

Figure 6. Cumulative confirmed deaths related to Covid-19 in selected countries
Source: Johns Hopkins University (2021), Our World in Data (2021)

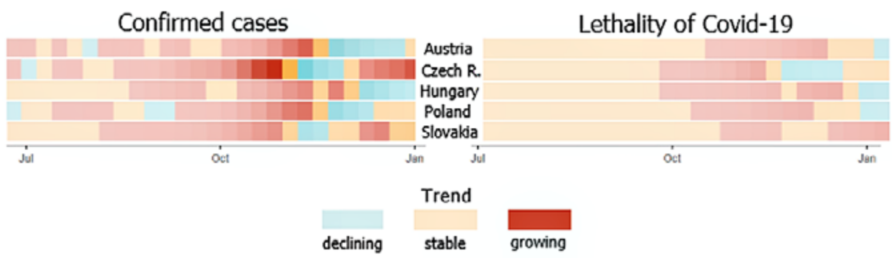

Figure 7. Developmental trends of 14-day confirmed cases and of lethality
Source: ECDC (2021)

mulative curve of deaths in Slovakia was disproportionately steep relative to that of other countries.

A worsened situation from the aspect of lethality (also of confirmed positive cases) can also be seen in Figure 7 which displays the developmental trends of 14-day confirmed cases and of lethality from July 2020. This visually dissimilar graphical representation enables not only a monitoring of different developmental trends but also a comparison of differentiated development and states in neighbouring countries at a certain time.

Regionally differentiated levels of lethality

The lethality in Slovakia was different from a time aspect as well as being distinctively differentiated spatially. The regional interval of confirmed deaths (lethality) from Covid-19 in the districts moved in intervals from 0.29% (Krupina district) up to 5.27%

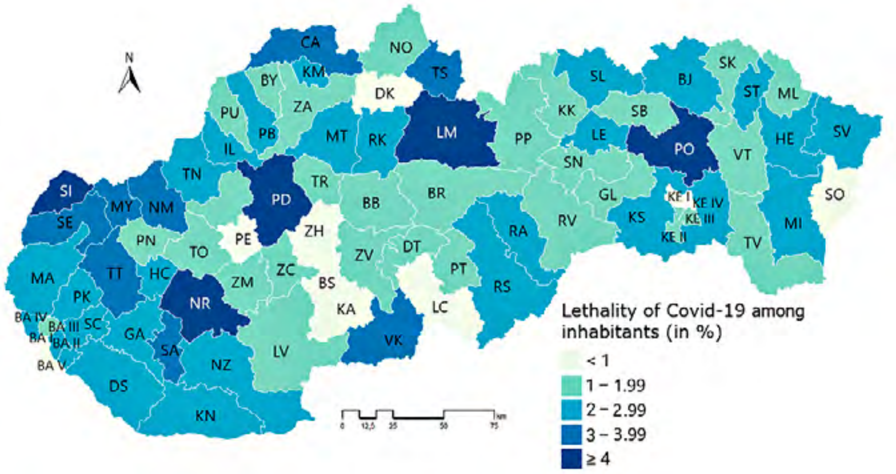

Figure 8. Lethality of Covid-19 among inhabitants in districts of Slovakia in 2020
Source: ŠÚ SR (2021), Institute of Health Analyses IZA (2021a, 2021b)

The abbreviations of districts: BB - Banská Bystrica, BS - Banská Štiavnica, BJ - Bardejov, BN - Bánovce nad Bebravou, BR - Brezno, BA - Bratislava, BY - Bytča, CA - Čadca, DT - Detva, DK - Dolný Kubín, DS - Dunajská Streda, GA - Galanta, GL - Gelnica, HC - Hlohovec, HE - Humenné, IL - Ilava, KK - Kežmarok, KN - Komárno, KE - Košice, KS - Košice-okolie, KA - Krupina, KM - Kysucké Nové Mesto, LV - Levice, LE - Levoča, LM - Liptovský Mikuláš, LC - Lučenec, MA - Malacky, MT - Martin, ML - Medzilaborce, MI - Michalovce, MY - Myjava, NO - Námestovo, NR - Nitra, NM - Nové Mesto nad Váhom, NZ - Nové Zámky, PE - Partizánske, PK - Pezinok, PN - Piešťany, PT - Poltár, PP - Poprad, PB - Považská Bystrica, PO - Prešov, PD - Prievidza, PU - Púchov, RA - Revúca, RS - Rimavská Sobota, RV - Rožňava, RK - Ružomberok, SB - Sabinov, SC - Senec, SE - Senica, SI - Skalica, SV - Snina, SO -Sobrance, SN - Spišská Nová Ves, SL - Stará Ľubovňa, ST - Stropkov, SK - Svidník, SA - Šaľa, TO - Topoľčany, TV - Trebišov, TN - Trenčín, TT - Trnava, TR - Turčianske Teplice, TS - Tvrdošín, VK - Veľký Krtíš, VT - Vranov nad Topľou, ZM - Zlaté Moravce, ZV - Zvolen, ZC - Žarnovica, ZH - Žiar nad Hronom, ZA - Žilina

(Presov district) of deaths. Thirteen districts had relatively high lethality values (more than 3%). A low lethality rate was exhibited by seven districts in which the values of lethality were under 1%.

The differentiated values of lethality of Covid-19 (Figure 8) indicate a considerable heterogeneity between the considered districts. Simultaneously, they show that the districts with very high lethality, but also with very low lethality, are situated evidently as isolated regions all over the country. Clusters (macroregions) are created only by the districts with middle and lower levels of lethality (the values of lethality lie in intervals from 2-3% or from 1-2 %) and with lower levels of lethality.

Regionally differentiated levels of the lethality of seniors

The different demographic characteristics of the districts must also be considered to postulate the considerable regional differentiability of lethality. The districts of Slovakia are differing considerably in the number of their populations, demographic compositions, levels of mobility of the population, and so on. To a large extent, the values of lethality are determined especially by the age structure of a region's inhabitants. The statistics show that the people over 65 years of age are most threatened by a heavy course of illness or by death relating to Covid-19 during the monitored year. This reality is connected with known facts and findings. Firstly, an older age diminishes the ability of the organism to produce immune reactions. An older age thus contributes to a higher occurrence of infections and virus illnesses. Secondly, older persons have a greater likelihood of having comorbidities (heart disease, diabetes, pulmonary illnesses, chronic illnesses with a decreased immunity…) which distinctively enhance the risk of mortality associated with the coronavirus. Indeed, the majority of the victims of Covid-19 (deaths) belonged to the senior age category (over 65 years). This population formed up to 85% of the total number of all persons deceased due to Covid-19. In Slovakia, this age category had a higher share of lethality in up to 45 districts (Figure 9). Moreover, the values of lethality of over 65-year-olds formed 100% of deaths in four Slovakian districts (Lucenec, Turcianske Teplice, Zarnovica, and Poltar). The share of Covid-19-related deaths of the indicated age group was under 80% in only ten districts, and the minimum value of 51.9% was registered in the Kezmarok district.

The detected correlation between an older age and lethality can be viewed as a straight line passing through measured points with a moderately ascending character (Figure 10). The graph in Figure 10 characterises the position of some districts as "buckling points". Their position points either to an "extremely" high share of lethality in some regions (red points) or to a very low share of lethality in the monitored age

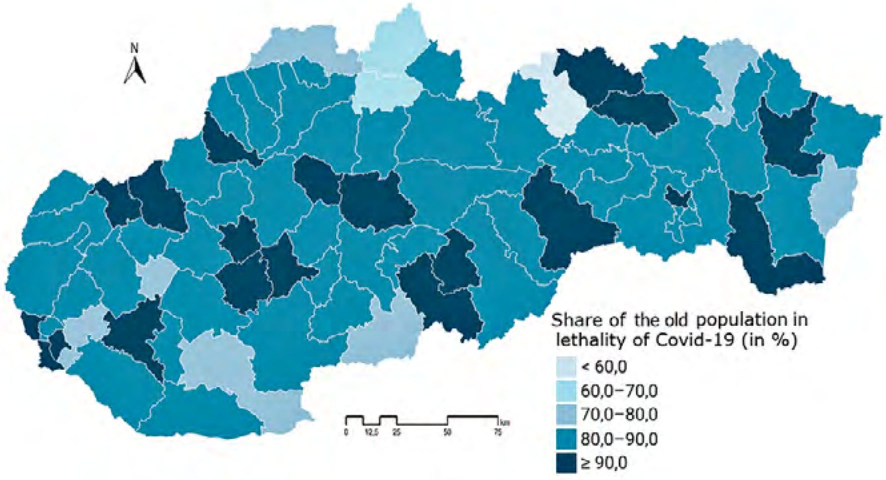

Figure 9. Lethality of Covid-19 of the population in the old (65 and over) age group in districts of Slovakia in 2020
Source: ŠÚ SR (2021)

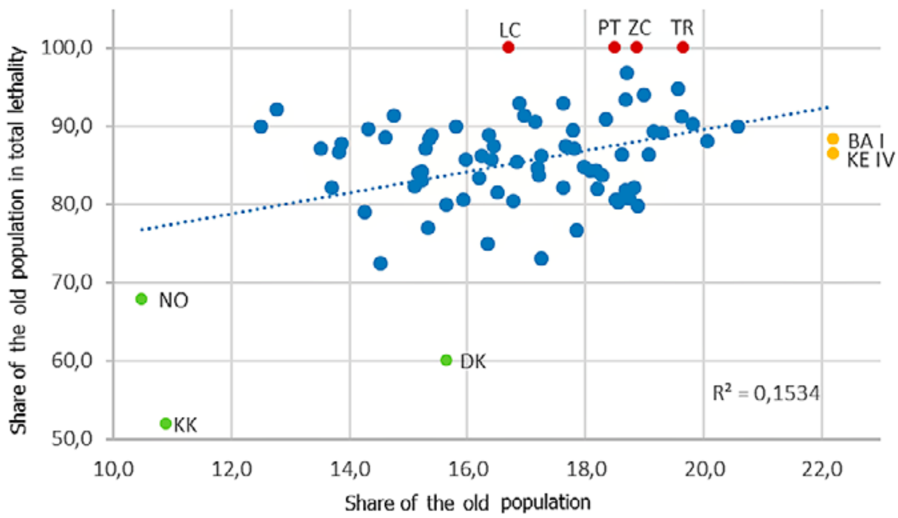

Figure 10. Share of the old population (65 and over) and lethality of Covid-19 in districts of Slovakia in 2020
Source: ŠÚ SR (2021)

group (green points). Other factors play a more intensive role than the virus itself in districts with a low lethality or mortality of seniors.

Changes in mortality

The coronavirus contributed to the number of deaths reaching more than 59,000 in Slovakia in 2020, representing a 10% growth in comparison with the average of the previous five years (2015-2019). The rate of mortality grew approximately by a hundred deaths to 100,000 inhabitants. Last year, the gross rate of mortality reached a value of 10.82 per mil in Slovakia. Out of 100,000 inhabitants, 1,082 people died during the year. The previous five-year average was lower by roughly a hundred persons (984) during 2015-2019. In 2020, the gross rate of mortality was the highest it has been over the last 70 years. Overall, Covid-19 caused 73 deaths per 100,000 inhabitants. Thus, the mortality represented a growth by 5,565 persons against the previous five years.

The results of regional mortality development showed that mortality grew in 71 districts (Figure 11). A total of 34 districts also showed a steep growth of mortality, representing areas with unfavourable and very unfavourable mortality ratios of men[10].

But at the same time only two of these districts registered a high share of deaths related to Covid-19. A relatively smaller growth of mortality was observed in

[10] At men only three from these districts and at women four districts from view of mortality intensity are distinguished by average mortality ratios expressed by life span at birth. In other words, life span at birth in none from identified districts with high growth of deceases does not exceed the average values.

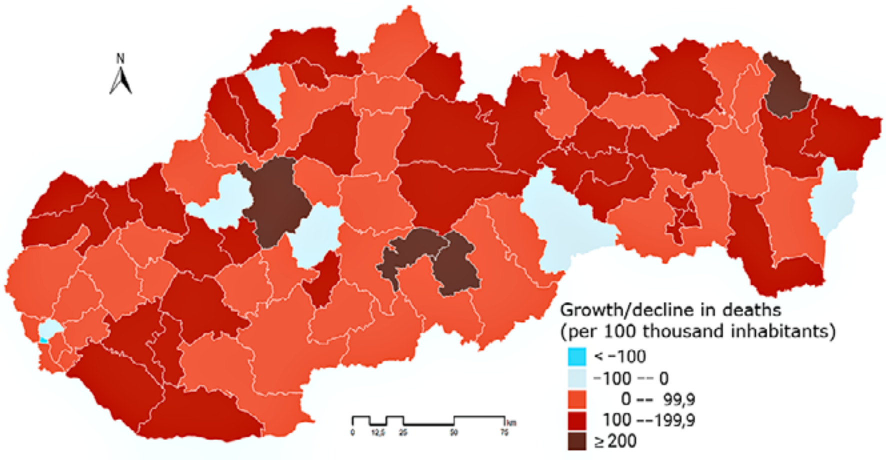

Figure 11. Growth (decline) of deaths in districts of Slovakia in 2020
Source: ŠÚ SR (2021)

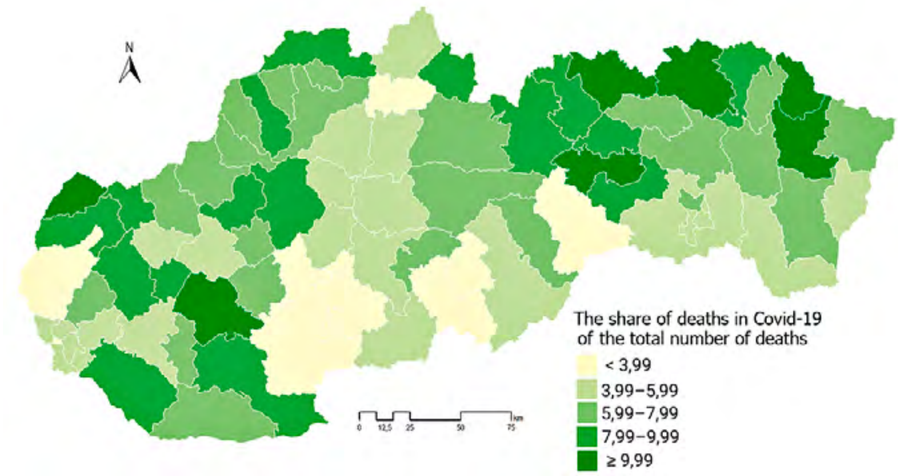

Figure 12. Share of deaths attributed to Covid-19 in districts of Slovakia in 2020
Source: ŠÚ SR (2021)

33 districts and eight districts even exhibited negative values of mortality (decline). This means that in 2020 they had a lower mortality than the average of the previous five monitored years. Two out of five districts of the capital and metropolis of Slovakia, i.e., of Bratislava, registered the highest decline.

Figure 12 shows the districts with the highest and lowest shares of “Covid-19 deaths”. Shares exceeding 10% were found in seven districts, and up to five of these were found in the east of the republic. These districts (with a high share of Covid-19 mortality) had all been a regional focus of infection in the course of the year. Some of the indicated districts were foci several times, which caused their increased rates of mortality due to Covid-19. On the contrary, ten districts registered a very low share of Covid-19-related deaths (less than 4%).

Development and level of excess deaths

Altogether the deaths of which the coronavirus was the main cause covered 72% of excessive deceases. Deaths due to other causes accounted for the rest. Covid-19 became a new category of its own in the classification of death causes, which played a dominantly part in the growth of the number of deaths. Figure 13 present the excessive mortality visualised as the gross (raw) number of deaths. The number of raw deaths provides a gross overview of its range. Up to 1,409 deaths had been recorded in Slovakia by November 8th, 2020, or 402 more than recorded by the five-year average (2015-2019).

The values of excess deaths on behalf of individual districts are presented in Figure 14. Increased levels of overdeaths can be seen in the districts of southwestern and southeastern Slovakia and in the districts of the regional towns of Nitra, Zilina, and Presov. The majority of these districts were identified as regional and some even overregional foci of infection in 2020.

The calculated coefficient of spatial concentration showed that half of the registered excess deaths were concentrated in 21 districts; Covid-19 had a main share of excess deaths in thirteen of these. The wide

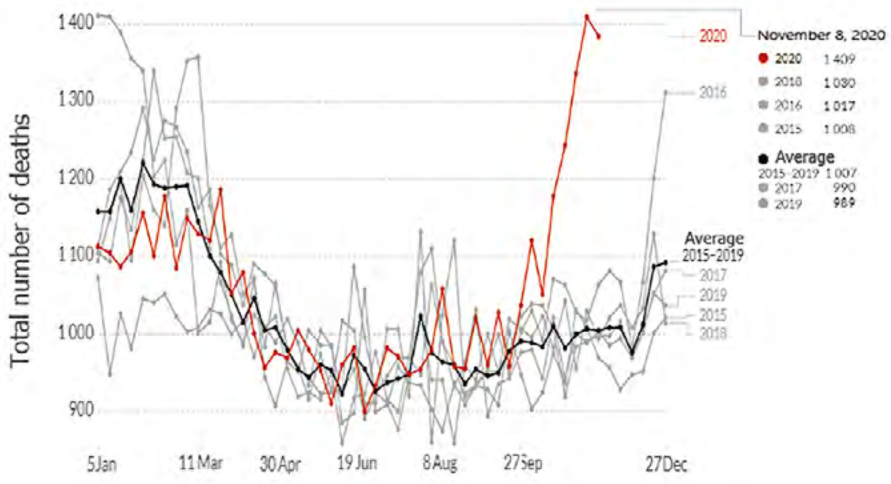

Figure 13. Excessive mortality in Slovakia during the Covid-19 pandemic ("raw" number of deaths)
Source: The Human Mortality Database (2021), Our World in Data (2021)

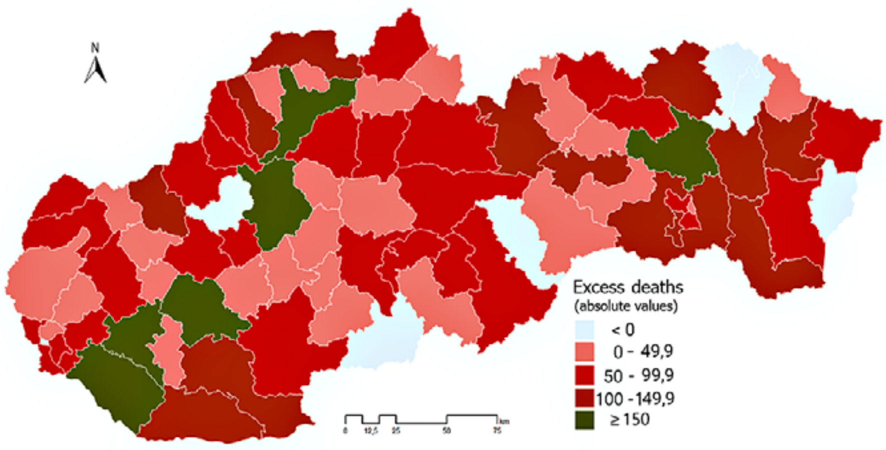

Figure 14. Excess deaths in districts of Slovakia in 2020
Source: ŠÚ SR (2021)

interval between the "district" values of overmortality due to Covid-19 (from 12% up to 77%) and the total number of overdeaths evidences the distinctively differentiated influence of infection in monitored spatial units.

Discussion and conclusion

The evaluation of the pandemic situation in Slovakia and its influence on selected indicators of mortality is complex. These were connected in the first place by definitions and by a relatively wide comprehension of monitored indicators. In case of lethality it is even connected with its different definition. Lethality is defined one way in some countries of Central Europe and in another in countries of Western Europe. A further problem was related to the registration of data from testing, especially of positivity cases. This factor was manifested mostly in lethality evaluation. The positivity rate is a factor (denominator) directly influencing the level of lethality. Overvalued lethality values of Covid-19 could partly be a consequence of antigen (Ag) testing, particularly related to a lack of registering positive cases. In fact, issues were associated with more persons testing positively at home (pensioners, economically active population, people without symptoms, and so on) and not reporting the result of the testing. Inaccuracies in the registration of positively tested persons could cause also an opposite effect, i.e., the undervaluation of lethality. Several cases have been registered when persons that had tested positive through Ag testing had subsequently undergone polymerase chain reaction (PCR) testing. In the case of positive results, the registration issues concerned double positivity and dual inclusion. Even if this error (duplicate registration) was relatively quickly removed, it influenced the accuracy of the results. Deviations of the lethality values in one or in the other direction (its overvaluation or undervaluation) could also be caused by problems in ascribing a cause of death, differences among the number of reported and overall deaths, and the way Covid-19 deaths are recorded (Ministry of Health of the SR, 2021a). In this context, it would be necessary and useful to determine whether or not the obtained results on the lethality of Covid-19 in Slovakia were deviated, and in which direction and to what extent. This, however, requires new and relatively complicated analyses, and detailed revaluations and arrangements (correction of indicated errors) for the registration of positively tested persons.

The evaluation of the pandemic in Slovakia was partly also influenced by the fact that the obtained data had been various and sometimes incorrectly explained or confusedly interpreted. In large measures, the correctness of the results depended on understanding the mechanisms by means of which Covid-19 influences various aspects of mortality. The dynamics of the development of the pandemic during the analysed period also had an influence on the evaluation. The whole first wave and the beginning of the intensive second wave belong to this period. During the first wave, Slovakia was among the countries with the lowest number of cases and the lowest associated mortality. The low values of cases and of monitored indicators of deaths during the first wave represented "isolated islands" in spatial terms. The low level of infected persons and of mortality did not enable a detailed evaluation, deeper interpretation, or more significant generalisation of mortality. The second wave (its beginning) was marked by distinctive increases of the "level" of cases but the monitored period only caught its initial phase. Comparative analyses at a national and regional level revealed the suitability of these reasons as a concept for interpreting the development of the pandemic and its impacts on mortality. The results allowed a comparison between the differences and differentiated impacts of the two waves on selected indicators of mortality. The closed annual time period enabled the analysis of the influences and differentiated impacts of the pandemic at a regional level. It was shown that the monitored indicators of mortality had been influenced not only by the pandemic (by the number of cases) but also by the different characteristics and specific conditions of the districts. The distinctive growth of the number of cases enhanced the level of infection and the values of monitored indicators in almost all districts. This area-wide increase was considerably spatially differentiated, and besides the levels of infection, the increase was conditioned particularly by the different demographic characteristics of the individual spatial units examined. The different profiles of the population (age, gender, ethnic membership, and basic comorbidities) in individual districts, especially in cases of great differences, had a significant influence on lethality determination and, to a large extent, they determined the levels of monitored indicators of mortality. However, until new mortality tables are made available, complex results can be achieved on the intensity of the influence and impacts of Covid-19 on further indicators of mortality in Slovakia. The comparison of mortality tables before and during the pandemic shows not only the growth of the total values of the probability of death among the population, but also mortality growth in various categories. The numbers of living persons will be diminished more quickly with age. Also, the medium life span, especially in age categories over 65 years, can be temporally and more distinctively reduced in risk regions affected intensively by the infection.

This study also confirmed that analyses focused on broader social and demographic indicators should be incorporated in future research to acquire a better understanding of the mechanisms through which Covid-19 influences various aspects of mortality. For example, Kim et al. (2021) tested the geographical differences of social and demographical indicators, mobility, and environmental factors in connection with the number of cases and with mortality related to Covid-19 in New York. Research has also focused on producing tools to identify superspreading places (SSP) which disproportionately spread the Covid-19 virus, i.e., foci, compounds, localities, and regions with a high intensity of cases. These are places with a high cumulation of the population or with a frequency of contacts distinguishing themselves by many further common social and demographical features. Huang et al. (2021) attempted to identify such SSP during four pandemic waves. Studies focusing on social and economic conditions, connections, and contexts of infected persons will provide a significant research direction for understanding the influence and impacts of the pandemic on mortality. Poor people, for whom the highest mortality rates have been recorded, have always bearded the greatest burden of large health crises and of the pandemic. Indeed, it is already evident that people with low social and economic statuses are much more exposed to Covid-19. From the point of view of mortality, older age categories associated comorbidities, which in the case of infection complicate the therapy of the virus itself, are the most affected. The excessive mortality rates connected with the coronavirus are also obvious among poor people in marginalised and socially dependent communities. The repeated phrase that "the Covid-19 does not discriminate" is a dangerous myth which excludes the greater vulnerability of those who are most socially and economically dependent (Patel et al., 2020).

The real contribution of this study lies in its relatively precise and detailed representation of the spatio-temporal aspects of the pandemic in Slovakia in 2020. Empirically, the study presented new information regarding mortality indicators and their differentiated levels in regions of Slovakia during the Covid-19 pandemic. The study provided a valuable research input, particularly in terms of the methodology used for understanding the relatively complicated problems associated with estimating and interpreting monitored indicators in times of an ongoing pandemic. The procedures and methods used here can also be applied to examine the impacts of the pandemic on the monitored demographic processes of other countries or their regions. This study can also serve in the comparative analyses of various aspects and indicators of mortality, and the examination of the spatially differentiated impacts of the pandemic in various spatial units and over distinctive periods (phases or waves) of the pandemic.

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Using Correlation Analysis to Examine the Impact of Covid-19 Pandemics on Various Socioeconomic Aspects: Case study of Indonesia

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Abstract

This paper diagnoses the determination of Covid-19 on economic and social aspects in Indonesia. Panel data collected from 34 provinces in Indonesia for the 2020-2023 period supports the quantitative method. Three analyzes (Spearman, Kendall, and Pearson) were used to measuring the relationship and its partial effect. Research findings indicate that Covid-19 cases have a negative impact on labor productivity, migration, domestic violence, and sexual harassment. From other results, per capita spending, well-being, unemployment, and poverty actually increased when there was a surge in Covid-19. For the Spearman rho correlation, with a degree of 1 percent ($p < 0.01$), there is a significant effect between capita spending on well-being, per capita spending and well-being on migration, and poverty on labor productivity. Tested by Kendall's tau and Pearson, the Covid-19 tragedy positively affected per capita spending, well-being, unemployment, poverty, and mortality, but labor productivity, migration, domestic violence, and sexual harassment were negatively affected by Covid-19. The partial probability level ($p < 0.05$ and $p < 0.01$) reveals a significant effect of per capita spending on well-being, migration on per capita spending and well-being, and poverty on labor productivity. Although per capita spending has a significant impact on well-being (5 percent confidence level), there is a slight difference from the Pearson test, where with a tolerance limit of 1 percent, poverty affects sexual harassment significantly. Covid-19 has taught many things, so that humanity does not disappear with conditions that seek peace. Policy makers need to schedule a more inclusive national and regional resilience system.

Keywords: Social; economy; Covid-19; Correlation; panel data

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Introduction

Although in some countries declared the status of Coronavirus disease 2019 (Covid-19) from 'pandemic' to 'endemic', it will always be known as a global disease in the 21st century (e.g. Melimopoulos, 2022; Katzourakis, 2022; The Lancet Infectious Diseases, 2022). This transition of status does not guarantee a brief holistic recovery (Rahmawati et al., 2022). The domino effect is that humans are threatened with extinction because they spend a lot of energy to fight this virus, continuity across generations, it tested the phase of caring in navigating the existence of the ecosystem. Recently, Donthu (2020) and van Barneveld et al. (2020) find that the peak of the fall in prosperity and a crisis of confidence also hit the wealthy, or those who were previously considered upper class, to make it through difficult times.

After going through two periods, since its emergence was detected in China in 2019, local, domestic, and cross-border governments have again focused on thinking about and perfecting regulations that prioritize economic and social resilience (Rahman et al., 2021). For example in Indonesia, for the long term, the government maneuvered through large-scale social restrictions (PSBB) and claimed that this policy was more stringent which was channeled to limit routines such as tightening transportation modes, restricting cultural attractions, reducing activities in public facilities, school holidays, stop religious celebrations and activities in places of worship, and insulate offices (Anugerah et al., 2021). In the short term or after easing, it is now turning to imposing restrictions on community activities (PPKM). The second regulation emphasizes more on the microscale, where the Java-Bali PPKM is focused on the islands of Bali and Java as the 'epicenters' in Indonesia (Khoirunurrofik et al., 2021). In practice, the government centralizes offices and educational networks (Maria et al., 2021). Without compromising the health aspect, only 75 percent of implementing work from home (WFH) and teaching processes, while 25 percent direct these activities in offices (WFO), school buildings, and universities through epidemiology.

The government's success in driving the spread of Covid-19 has actually broken economic and social mobility (Ibn-Mohammed et al., 2021). The high control of operating hours in all fields is contrary to the desire of business people, communities, media, and scholars to immediately escape from the bondage of welfare. Considering the population size in Indonesia is classified as densely after China, India, and the USA, it is difficult to imagine getting out of suffering (Irwansyah et al., 2022). Uniquely, of the 4 countries, only two countries are classified as economic market forces, referring to an inclusive economic growth rate (GDP). The large demographic bonus from Indonesia and India does not reflect an even proportion of prosperity. The portrait of the 'middle income trap' only rests on the dilemma of a decline in happiness (Kurniawan et al., 2021).

Towards economic stability is relatively long, but there are certain clauses that are met. Its vital condition relates to political courage in decision-making that maintains the framework of national independence. With managing social visits, work spaces, gatherings, and even restoring community psychology, Panneer et al. (2022), Popkova et al. (2021), Muhyiddin and Nugroho (2022), and Mustari et al. (2022) emphasized that the response of stakeholders in integrating a complex economic empowerment system is the most ideal thing. In an instant, developments that allow full awareness of being devoted to organizations, households, and social groups at least give birth to closeness and moral commitment. Covid-19 is not only the responsibility of the government, but all components. Sustainable development embodies mechanisms that automatically facilitate the achievement of international goals (Shulla et al., 2021).

Not always disasters in the world like the Covid-19 outbreak are gradual. In this period, humans must survive and confine themselves for a moment in the fight to prevent transmission. Referring to the pattern of dependence on humanity from the cycle of empirical, theoretical, and recent phenomena, the urgency of the paper is to identify the effects of Covid-19 growth on socioeconomic in Indonesia. The agenda for the paper is composed of five points. The first phase is the introduction. Followed by data and methods in the second phase. Results are in the third phase. Furthermore, the fourth and fifth phases include discussion and conclusion sessions. The essence of the study maps the effects of the Covid-19 pandemic that hinders or improves social and economic structures based on seven pillars (per capita spending, well-being, unemployment, poverty, labor productivity, migration, mortality, domestic violence, and sexual harassment).

Publications highlighting the relevance of Covid-19 to social and economic factors support research motivation. Examining the decline in household consumption due to Covid-19, it is traced in the capacity of families who tend to spend their spending on medicines, increasing internet quota while children are studying at home, and preparing food supplies whose intensity is higher than the normal situation (Amalia et al., 2020). Not enough, it predicted economic uncertainty to reduce well-being (Thygesen et al., 2021; Bathina et al., 2021). Suryahadi et al. (2021), Haldar and Sethi (2022), and Ohrnberger et al. (2021) linked the government's anticipation through intensive lockdowns, so that various industries reformed the system and rejuvenated with more modern technology. Companies quickly adapt and adopt production tools dynamically, but labor productivity fluctuations trigger employees to lose their jobs, mass unemployment, and encourage poverty. For the sake of locking at the regional level and domestic borders, the government will prohibit job seekers from abroad from entering and leaving the country for a while. Tightening regulations also stop urbanites from migrating to minimize physical contact.

In essence, human habitats cannot lock themselves away for too long, be it at home, in certain locations, and for an uncertain of time. People find it hard to shine like they used to because of the pleasures of continuing to grow isolated. This has prompted the UK government to allocate a portion of public spending into Covid-19 disaster mitigation (Minister for Patient Safety, Suicide Prevention and Mental Health of the UK, 2021). At an enormous cost, the government is trying to offer special assistance to patients with mental disorders and feelings of out-of-bounds anxiety to re-motivate the population (Li et al., 2019). Volunteers, doctors, psychiatrists, and medical personnel are mobilized so that sufferers stimulate an inspiring unity of life (Shroff et al., 2022). Planning combined with careful tracking, control, and mentoring becomes a synchronized health insurance. In other places, for example, poor countries and developing countries, they are still rethinking whether to try this crucial regulation or are they are still fighting with physical safety. The distribution of vaccines is only limited to a program to reduce the death rate, but concrete steps to trace the traces of sexual harassment and domestic violence are still constant. In fact, if you follow the counseling transformation that is intended for the public, it makes sense rather than only targeting the body's immune system to reduce the risk of exposure. It is known that the world mortality ratio because of being positive for Covid-19 is not much compared to people who have experienced domestic violence and sexual harassment. (Kotlar et al., 2021; Mittal & Singh, 2020; Usta et al., 2021). Traits (2020), Kaukinen (2020), Evans et al. (2020), Campbell (2020), and Sacco et al. (2020) suspect that wives and children are more often victims while staying at home during the pandemic.

Data and methods

Data set

In the context of sources of information, data is collected from official government publications. National scale data are simulated over four periods (2020 to 2023). Specifically, for data in 2022-2023, it is a linear prediction that implies future developments and is still temporary. The research output limits only nine parameters. Economic factors comprise five elements (per capita spending, well-being, unemployment, poverty, and labor productivity) and four social factors (migration, mortality, domestic violence, and sexual harassment).

Each indicator refers to concepts and definitions by the discoveries of professionals, scholars, and scholars who are competent in their field. The functions and terms of all variables are summarized in Fig. 1.

Data processing

It presented the data interpretation instrument through a quantitative approach. The investigative technique uses the panel regression method based on associations between 34 provinces in Indonesia, so that the cross-section and time-series data are 1,360 samples. Social and business studies with Covid-19 issues tied to panel regression analysis are still ongoing (e.g. Khalid et al., 2021; Tinungki et al., 2022; Barría-Sandoval et al., 2022; Çivak et al., 2021; Abdelkafi et al., 2022; Pan, 2022; Haldar and Sethi, 2021; Junaidi et al., 2020; Ong and Marheni, 2021). There are two formulations in the panel regression, including models that only consider individual effects (αi) and include the effects of time or time variables as follows:

One way model:

$$Y_{it} = \alpha + \alpha_i + X'_{it}\beta + \varepsilon_{it}$$

Two way model:

$$Y_{it} = \alpha + \alpha_i + \delta_t + X'_{it}\beta + \varepsilon_{it}$$

As shown in Fig. 1, the two functions of the above equation are played by Covid-19 as independent variables and eight dependent variables positioned by per capita spending, well-being, unemployment, poverty, labor productivity, migration, mortality, domestic violence, and sexual harassment. Constants (α) represent terms in algebraic operations in the form numbers and do not contain variables. Then, is the vector or parameter of the estimation result, it is the observation, and it defines the regression error term. This equation also shows where there is an additional time effect denoted by delta, which is fixed or random between periods.

Correlation analysis examines trends in the impact of Covid-19 on economic and social factors. In

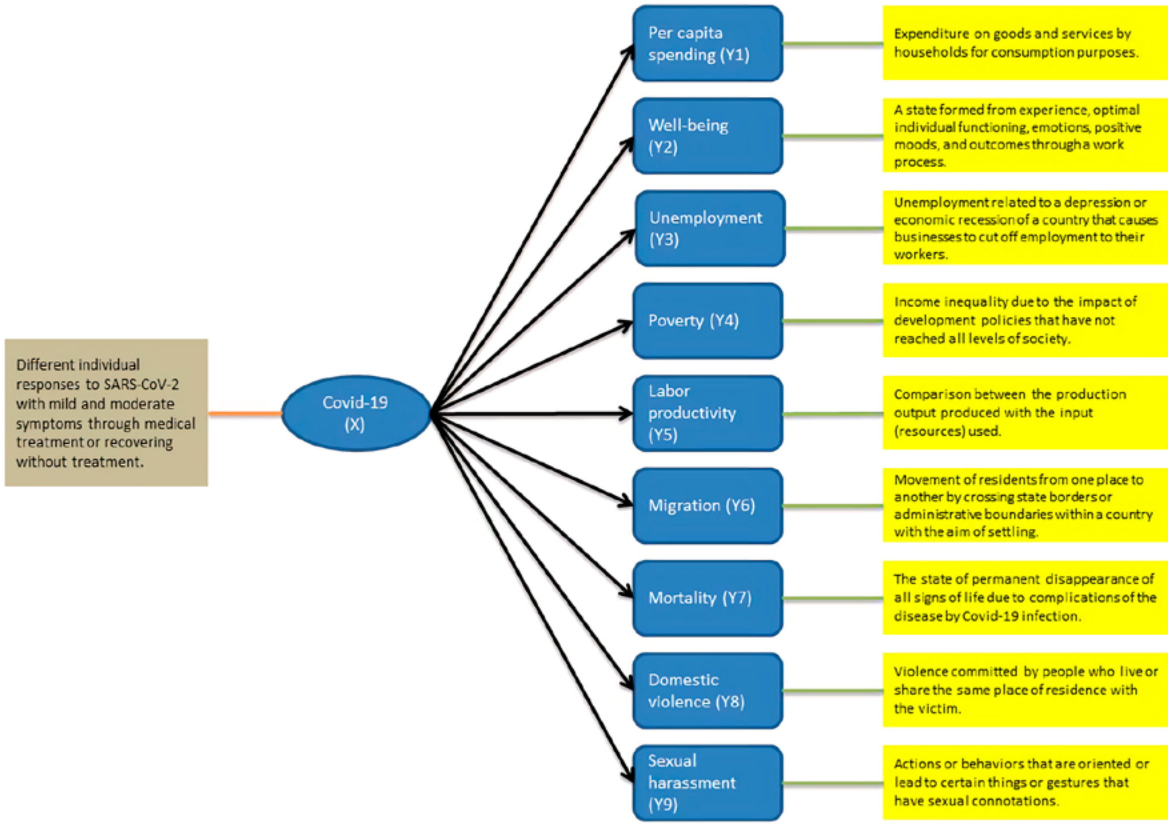

Figure 1. Conceptual framework
(Source: compiled from Varlamovaa dan Larionova , 2015; Tapsin dan Hepsag, 2014; Gaucher et al., 2022; Musikanski et al., 2017; Soylu et al., 2018; Streeten, 1994; Yulia dan Irina, 2020; Salehi et al., 2012; Muñoz-Mora et al., 2022; Melde, 2012; Akin dan Banfi, 2019; Choi et al., 2019; Bhaskaran et al., 2021; Walby et al., 2017; Robinson, 2003; Rakovec-Felser, 2014; Merkin, 2012; Bondestam dan Lundqvist, 2020; Focacci et al., 2022; Patel et al., 2020).

Table 1. Interpretation of correlation coefficient and significance type

Coefficient interval	Relationship	Level of confidence	Specification
> 0.9	Very high correlation	p < 0.001 (99.9 percent)	Highly significant
< 0.9	High correlation	p < 0.01 (99 percent)	Very significant
< 0.7	Medium correlation	p < 0.05 (95 percent)	Significant
< 0.5	Low correlation	p > 0.05 (95 percent)	Not significant
< 0.2	Very low correlation	p < 0.1 (90 percent)	Considerable

Source: modified from Schmidt and Osebold, 2017; Singh, 2013

standard statistical rules, there are three correlation assumptions, namely Spearman, Kendall, and Pearson (Chok, 2008; Bolboacă and Jäntschi, 2006; Bishara and Hittner, 2012; May and Looney, 2022). After the data was tabulated, the statistical software was programmed via IBM-SPSS v.25. The sophistication of this tool not only concludes positive (+) and negative (-) coefficients, but also combines probabilities. The absolute values of the correlations and their associated p-values are described in Table 1.

Wonu et al. (2021), Kozak (2008), and Schober et al. (2018) claim that correlation analysis can solve the hypothesis. In the proof, the correlation tests the partial effect between variables with tolerances above or below the tolerance limit. It is worth testing other hypotheses. If the probability is less than alpha, then H_1 is accepted and H_0 is rejected and vice versa.

$H_1: r \neq 0$
There is a significant correlation between x and y.

$H_0: r = 0$
There is no significant correlation between x and y.

Hypothesis development

Research design to set detailed parameters in variables (see Table 2). Collectively, the hypothesis offering frames the connections between variables whose outcome is the hypothesis accepted or otherwise.

Table 2. Variable specifications and range of hypotheses

Variables and symbols	Scope	Unit	Hypotheses and expected markers
Covid-19 (X)	Annual positive cases	Incidence	
Per capita spending (Y1)	Household consumption	Rp (IDR)	H_1: The higher the Covid-19 case, the lower the per capita spending.
Well-being (Y2)	Human happiness	Index	H_2: The higher the Covid-19 case, the lower the well-being.
Unemployment (Y3)	Conjuncture unemployment	Percent	H_3: The higher the Covid-19 case, the stronger the unemployment.
Poverty (Y4)	Relative poverty	Percent	H_4: The higher the Covid-19 case, the stronger poverty.
Labor productivity (Y5)	Value added workforce	$ (USD) per hour	H_5: The higher the Covid-19 case, the lower the labor productivity.
Migration (Y6)	Groups that move abroad looking for formal and informal jobs	Person	H_6: The higher the Covid-19 case, the lower the migration.
Mortality (Y7)	Died due to Covid-19	Person	H_7: The higher the Covid-19 case, the stronger the mortality.
Domestic violence (Y8)	Psychological and physical violence in the household	Case	H_8: The higher the Covid-19 cases, the stronger the domestic violence.
Sexual harassment (Y9)	Sexual acts that can happen and not wanted by anyone and anywhere	Case	H_9: The higher the Covid-19 case, the stronger the sexual harassment.

Source: compiled from Databoks, 2022; Central Bureau of Statistics, 2022

The operationalization of the above variables decorates nine hypothetical targets based on the premise. There is a similarity in size among the six variables. The first is unemployment and poverty (percentage). Second, between migration and mortality (person). Third, domestic violence and sexual harassment (cases). However, Covid-19, per capita spending, well-being, and labor productivity have diverged.

Results

Descriptive statistics

Table 3 accommodates the recapitulation of national data from 34 provinces. Descriptive statistical data informs that there is a different slope of the ten variables. The gap in per capita spending with unemployment referring to the minimum, maximum, mean, and standard deviation (SD) scores looks fantastic. Regarding the acquisition of the largest value from the minimum, it reached 4,170,994.71, while the smallest was 4.94. From the maximum version, the dominant one is 4,822,910.12 and 6.26 is the smallest. Looking at the mean, the highest is up to 4,529,290.74, then the lowest is at 5.56. During 2020-2023, SD scores were striking, with the largest being 273,542.79, but 0.59 being the lowest.

Table 3. Descriptive statistical unit

Var.	Min.	Max.	Mean	SD	N
x	743,198	6,057,142	3,049,478.50	2,549,687	1,360
y1	4,170,994.71	4,822,910.12	4,529,290.74	273,542.79	1,360
y2	68.28	73.98	71.11	2.35	1,360
y3	4.94	6.26	5.56	.59	1,360
y4	8.50	10.19	9.67	.79	1,360
y5	12.10	15.04	13.75	1.40	1,360
y6	234,451	512,168	363,056.75	130,208.54	1,360
y7	22,138	156,553	118,303.75	64,311.97	1,360
y8	299,911	431,471	358,360	55,326.73	1,360
y9	5,237	6,872	5,720	778.18	1,360

Source: compiled from Databoks, 2022; Central Bureau of Statistics, 2022

Correlation analysis

Starting from the Spearman's rho correlation, the use of this statistical method is to test allegations about the existence of a relationship between variables in an ordinal database (ranking) or on a ratio scale without meeting the assumption of normality (Hauke and Kossowski, 2011; Bobera et al., 2016). Within four periods, Table 4 depicts the negative and positive correlations or in very low to very high items. At this moment, it is clear that the relationship from Covid-19 to labor productivity, migration, domestic violence, and sexual harassment is negative ($C = -0.600$, $C = -0.400$, $C = -0.800$, and $C = -0.800$). The rest, if Covid-19 cases increase, per capita spending, well-being, unemployment, and poverty will actually increase. The partial coefficients of the five ($C = 0.400$, $C = 0.400$, $C = 0.400$, $C = 0.600$, and $C = 0.800$), are positive correlations. Five hypotheses are accepted and the remaining four are rejected. The probability level refers to 1 percent, so there is a two-way significance of per capita spending on well-being ($p = 0.000$), then per capita spending and well-being on migration ($p = 0.000$), and poverty on labor productivity ($p = 0.000$). Interestingly, the correlation from Covid-19 to mortality and vice versa as the highest coefficient is up to 80 percent.

The next session examines the correlation of Kendall's tau (τ). This correlation is the group of non-parametric statistical tests (Puka, 2011). In the presentation process, there are no assumptions that require observations or samples to be normally distributed. In addition, there is also no provision in which a construct formed from a variable must be linear (Dehling et al., 2017). Ho et al. (2021) argue that the use of research data is not normal (not linear). This is, of course, quite different from parametric statistical tests because there are special provisions regarding data that have a linear and normal distribution.

Curiosity on partial and two-way effects in Kendall's test is presented in Table 5. For the correlation coefficient, the correlation of the independent variable's relationship to the dependent variable seems too far away. There is a mix of negative to positive coefficient points. The biggest one is the correlation between Covid-19 and mortality with the acquisition of 0.667 (66.7 percent), so it is classified as a medium correlation. The rest, more to the very low correlation, where there is reaching -0.667. Practically, the correction level starts from < 0.2 – < 0.7 or in the very low to medium classification. Here, it explains that the increase in Covid-19 so far has increased per capita spending, well-being, unemployment, poverty, and mortality. Then, the Covid-19 tragedy in Indonesia has actually reduced labor productivity, migration, domestic violence, and sexual harassment. In other words, hypotheses 1, 2, 8, and 9 are rejected. However, there are no significant obstacles for hypotheses 3, 4, 5, 6, and 7.

In both partial probabilities ($p < 0.05$ and $p < 0.01$), there is a significant effect of per capita spending on

Table 4. Spearman's Test

Var.	x	y1	y2	y3	y4	y5	y6	y7	y8	y9
x	1	.400 (.600)	.400 (.600)	.400 (.600)	.600 (.400)	-.600 (.400)	-.400 (.600)	.800 (.200)	-.800 (.200)	-.800 (.200)
y1	.400 (.600)	1	1** (.000)	.600 (.400)	-.400 (.600)	.400 (.600)	-1** (.000)	.800 (.200)	-.200 (.800)	.200 (.800)
y2	.400 (.600)	1** (.000)	1	.600 (.400)	-.400 (.600)	.400 (.600)	-1** (.000)	.800 (.200)	-.200 (.800)	.200 (.800)
y3	.400 (.600)	.600 (.400)	.600 (.400)	1	-.400 (.600)	.400 (.600)	-.600 (.400)	.800 (.200)	.200 (.800)	-.200 (.800)
y4	.600 (.400)	-.400 (.600)	-.400 (.600)	-.400 (.600)	1	-1** (.000)	.400 (.600)	.000 (1.000)	-.800 (.200)	-.800 (.200)
y5	-.600 (.400)	.400 (.600)	.400 (.600)	.400 (.600)	-1** (.000)	1	-.400 (.600)	.000 (1.000)	.800 (.200)	.800 (.200)
y6	-.400 (.600)	-1** (.000)	-1** (.000)	-.600 (.400)	.400 (.600)	-.400 (.600)	1	-.800 (.200)	.200 (.800)	-.200 (.800)
y7	.800 (.200)	.800 (.200)	.800 (.200)	.800 (.200)	.000 (1.000)	.000 (1.000)	1 (.000)	1	-.400 (.600)	-.400 (.600)
y8	-.800 (.200)	-.200 (.800)	-.200 (.800)	.200 (.800)	-.800 (.200)	.800 (.200)	-.400 (.600)	-.400 (.600)	1	.600 (.400)
y9	-.800 (.200)	.200 (.800)	.200 (.800)	-.200 (.800)	-.800 (.200)	.800 (.200)	-.400 (.600)	-.400 (.600)	.600 (.400)	1
Obs.	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360

Source: SPSS v.25
*Notation: **p < 0.01*

Table 5. Kendall's Test

Var.	x	y1	y2	y3	y4	y5	y6	y7	y8	y9
x	1	.333 (.497)	.333 (.497)	.333 (.497)	.333 (.497)	-.333 (.497)	-.333 (.497)	.667 (.174)	-.667 (.174)	-.667 (.174)
y1	.333 (.497)	1	1* (.000)	.333 (.497)	-.333 (.497)	.333 (.497)	-1** (.000)	.667 (.174)	.000 (1.000)	.000 (1.000)
y2	.333 (.497)	1** (.000)	1	.333 (.497)	-.333 (.497)	.333 (.497)	-1** (.000)	.667 (.174)	.000 (1.000)	.000 (1.000)
y3	.333 (.497)	.333 (.497)	.333 (.497)	1	-.333 (.497)	.333 (.497)	-.333 (.497)	.667 (.174)	.000 (1.000)	.000 (1.000)
y4	.333 (.497)	-.333 (.497)	-.333 (.497)	-.333 (.497)	1	-1** (.000)	.333 (.497)	.000 (1.000)	-.667 (.174)	-.667 (.174)
y5	-.333 (.497)	.333 (.497)	.333 (.497)	.333 (.497)	-1** (.000)	1	-.333 (.497)	.000 (1.000)	.667 (.174)	.667 (.174)
y6	-.333 (.497)	-1** (.000)	-1** (.000)	-.333 (.497)	.333 (.497)	-.333 (.497)	1	-.667 (.174)	.000 (1.000)	.000 (1.000)
y7	.667 (.174)	.667 (.174)	.667 (.174)	.667 (.174)	.000 (1.000)	.000 (1.000)	-.667 (.174)	1	-.333 (.497)	-.333 (.497)
y8	-.667 (.174)	.000 (1.000)	.000 (1.000)	.000 (1.000)	-.667 (.174)	.667 (.174)	.000 (1.000)	-.333 (.497)	1	.333 (.497)
y9	-.667 (.174)	.000 (.1000)	.000 (1.000)	.000 (1.000)	-.667 (.174)	.667 (.174)	.000 (1.000)	-.333 (.497)	.333 (.497)	1
Obs.	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360

Source: SPSS v.25
*Notation: *p < 0.05, **p < 0.01*

well-being (*p = 0.000*). On the other hand, migration also affects per capita spending and well-being (*p = 0.000*), and poverty with labor productivity (*p = 0.000*).

According to Sinnema and Robinson (2012), the Pearson correlation is addressed to the strength of the direction and calculates the linearity of the two variable relationships. The Pearson correlation measure examines the change from one predictor variable to another, with the main aim being in the same direction or in the opposite direction.

Table 6. Pearson Test

Var.	x	y1	y2	y3	y4	y5	y6	y7	y8	y9
x	1	.245 (.755)	.093 (.907)	.352 (.648)	.646 (.354)	-.822 (.178)	-.280 (.720)	.623 (.377)	-.731 (.269)	-.629 (.371)
y1	.245 (.755)	1	.988* (.012)	.580 (.420)	-.572 (.428)	.001 (.999)	-.950 (.050)	.886 (.144)	-.546 (.454)	.596 (.404)
y2	.093 (.907)	.988* (.012)	1	.534 (.466)	-.689 (.311)	.128 (.872)	-.929 (.071)	.812 (.188)	-.449 (.551)	.711 (.289)
y3	.352 (.648)	.580 (.420)	.534 (.466)	1	-.257 (.743)	.233 (.767)	-.805 (.195)	.447 (.553)	-.004 (.996)	.237 (.763)
y4	.646 (.354)	-.572 (.428)	-.689 (.311)	-.257 (.743)	1	-.756 (.244)	.543 (.457)	-.141 (.859)	-.259 (.741)	-.999** (.001)
y5	-.822 (.178)	.001 (.999)	.128 (.872)	.233 (.767)	-.756 (.244)	1	-.123 (.877)	-.460 (.540)	.823 (.177)	.721 (.279)
y6	-.280 (.720)	-.950 (.050)	-.929 (.071)	-.805 (.195)	.543 (.457)	-.123 (.877)	1	-.800 (.200)	.373 (.627)	-.522 (.448)
y7	.623 (.377)	.886 (.114)	.812 (.188)	.447 (.553)	-.141 (.859)	-.460 (.540)	-.800 (.200)	1	-.855 (.145)	.177 (.823)
y8	-.731 (.269)	-.546 (.454)	-.449 (.551)	-.004 (.996)	-.259 (.741)	.823 (.177)	.373 (.627)	-.855 (.145)	1	.213 (.787)
y9	-.629 (.371)	.596 (.404)	.711 (.289)	.237 (.763)	-.999** (.001)	.721 (.279)	-.552 (.448)	.177 (.823)	.213 (.787)	1
Obs.	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360

Source: SPSS v.25
*Notation: *p < 0.05, **p < 0.01*

Broadly speaking, Table 6 captures the opposite frequencies of the four relationships and the five relationships that are in line with the proposed hypothesis. Between 2020-2023, the level of causality proves that when Covid-19 rises, it will strengthen per capita spending ($C = 0.245$), well-being ($C = 0.093$), unemployment ($C = 0.352$), poverty ($C = 0.646$), and mortality ($C = 0.623$). The increase in Covid-19 cases reduces labor productivity ($C = -0.822$), migration ($C = -0.280$), domestic violence ($C = -0.731$), and sexual harassment ($C = -0.629$). The highest determination when compared to other relationships is Covid-19 to poverty at 64.6 percent. At the level of p-values (5 percent), two-way significance occurs between per capita spending and well-being ($p = 0.012 < 0.05$) and a level of 1 percent or not exceeding the 0.01 limit is poverty against sexual harassment ($p = 0.001 < 0.01$).

Discussion

The soaring number of Covid-19 infections in Indonesia during the last three periods was because of incomplete vaccination doses, lack of population interest in vaccine programs, government socialization that was not balanced with background knowledge, uneven infrastructure, homecoming flows during religious celebrations, and ideological heritage that clashes with the benefits of vaccines with individual beliefs. The government is waiting for the right time to campaign for a 'new normal' if that point of view is slowly eliminated. In turn, the struggle and holding on for a while is 'hibernation' it is not impossible that it will shine like other countries. This is not the end of everything. Moreover, Indonesia hopes that the Covid-19 chain will end or be broken by 2023. Closing access with a top line is not a logical solution to stopping the Covid-19 cluster as it was in early 2020, but an adaptive distribution that combines coordination and protection on all fronts, in harmony with restoring healthy living traditions.

The plurality of historical backgrounds, traditions, cultures, ethnicities, and races of the population in Indonesia in each region unites to fight Covid-19. Even though they live and are scattered on separate islands due to the sizeable area of Indonesia, this is not an excuse and instead becomes a geographical advantage that blocks the transmission route of the pandemic (Susanto et al., 2020). Here, the Indonesian government is not too bothered about limiting the mobility of the population. This position clearly benefits Indonesia. However, the vital problem is the level of density that accumulates in 2-3 areas, which are indeed the concentration of infection prevention. The predicate of Indonesia as one nation that failed to close access to the transmission of Covid-19 is an antithesis that hurts the field of epidemiology (Roziqin et al., 2021). Compared to neighboring areas such as Singapore in Southeast Asia, which have a minor population, they have made achievements because they make quick and responsive decisions. Therefore, Indonesia's superior climate and geographical composition have been wasted and have not hampered this virus. At the world level, performing the Indonesian government's policies is the 4th worst in solving the Covid-19 problem. Unfortunately, the government's

Figure 2. Blocking zone
Source: The Harian Jogja, 2020

ambiguous steps to comprehensively track Covid-19 do not represent a transparent framework (Ayuningtyas et al., 2021).

Recent studies that highlight geographical opportunities and weaknesses from demographic pressures in the face of the Covid-19 pandemic emergency support the scientific facts above. Covid-19 threatens to lose from this crisis, undermining the long-term social health insurance system, accumulating in social financing (Sparrow et al., 2020). Economic motives to dampen structural changes that are oriented it oriented to the strength of solidarity from the layers of society to contemporary ideas (Abdi et al., 2021). A transferable approach to an island-based country. Social responsibility makes people aware of prioritizing social actions (Sundawa et al., 2021). This truth became a 'topic of conversation' around the world because Indonesia changed the mode, which was originally a large-scale lockdown with full control of the central government, now returned to local governments (city – district – province).

However, the hard work of the Indonesian government needs to be appreciated. They have operated lockdown policies that represent a wider audience to various points. Fifty border gates are temporarily closed. The inflow and access to outside the area from the end of March 2020 to the end of August 2020, especially land transportation, is closed with a movable concrete barrier (MBC). To suppress the rate of development of new variants such as Beta, Delta, and Alpha, the government made an anatomy and locked the distribution of transmission starting from the center of the capital (Jakarta). The mapping of coherence to cover and limit the movement of the population extended not only to big cities but also to villages or villages (see Fig. 2). The special areas 'circled in red' are zones, the 'little red circles' are buffer zones or boundaries, and the 'non-red' ones are designated as separate zones.

The seriousness of the government in risking the way forward cannot be immediately felt. For a short period, pathology and social intervention were implemented through quarantine and psychotherapy courses. Responding to economic difficulties, the government willingly set policies on food subsidies, social help, discounts on primary needs, and online pre-employment training to control hunger.

Following the example of China, which made brilliant improvements to emerge from the Covid-19 invasion. Launching from The Worldometer (2022), the country that accounts for 18.47 percent of the global population and the largest in the world, takes preventive initiatives by neutralizing bad news in the media about the origins of the Covid-19 disease which is thought to be deadly, intentionally created and created as a weapon biological mass killers, the existence of a global conspiracy, smoothing the third world war, deciding international trade competition, and other misinformation (Zhao et al., 2021; AlTakarli, 2020; Keni et al., 2020). If public trust is hampered, it will disrupt psychology and trigger simultaneous anger (Yu et al., 2021).

Conclusions

The aim of this paper is to study the socio-economic impact of the brutality of Covid-19 in Indonesia. The analysis determined by the three approaches concludes that a pandemic that is developing positively affects per capita spending, well-being, unemployment, poverty, and mortality. Other results also confirm that the growth of Covid-19 has negatively affected labor productivity, migration, domestic violence, and sexual harassment.

Learning from Indonesia, recommendations to the government to be careful and reconsider a fair middle ground in combining economic networks and health protocols. Must prioritize one of the two in lightening the multi-layered burden of all parties. The options chosen are expected to make it easier for elements of society. Innovative and creative programs are worth fighting for. Without ignoring humanity, partnering outside government institutions is effective. There is no reason to abandon public demands only for the sake of the economic aspect, but government competence must also support the social aspect.

Because it limited the target data for 2020-2023, other researchers can absorb the shortcomings of the methodology by adding more mature instruments, such as variables related to complex social events and economic phenomena. Further work has implications for academic development. Practical contributions are concerned with improving welfare levels and taking the initiative toward incidental vulnerabilities.

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An Example of the Adverse Impacts of Various Anthropogenic Activities on Aquatic Bodies: Water Quality Assessment of the Provadiyska River (Northeastern Bulgaria)

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Abstract

Anthropogenic activities deteriorate the quality of water resources, which reduces their socio-economic suitability, endangers public health, and affects aquatic life. This work presents the results of physicochemical monitoring of the Provadiyska River (Northeastern Bulgaria) and aims to assess water quality status according to the guidelines pointed out in the National regulatory standard – Regulation H-4/2012 for characterization of the surface waters. The selected river has become one of the most seriously polluted streams in the territory of the country due to the effect of various human practices occurring in the drainage basin, such as agriculture, industry, and urban development. Data about the values of ten physicochemical variables (pH, EC, DO_2, N-NH_4, N-NO_3, N-NO_2, N-tot, P-PO_4, P-tot, and BOD_5), recorded at four measuring points during the period 2015–2020 have been used. Results obtained indicate that almost all of the parameters considered do not meet the reference norm for “Good status”, thus water quality could be assessed as “Moderate”. Failed variables appear to be EC, N-NH_4, N-NO_3, N-NO_2, N-tot, P-PO_4, P-tot, and BOD_5 whose highest observed content remains from two up to nine times above the maximum permissible limits of Regulation H-4/2012. Water contamination arises from different sources and activities, including the excessive fertilization of croplands, the unregulated release of animal manure from livestock farms, the uncontrolled discharge of municipal and industrial effluents into the river, etc. The expansion of sewerage systems in the settlements, the construction of wastewater treatment facilities, as well as the adoption of codes for best farming practices are among the most important actions that should be taken to reduce the deleterious effects of various anthropogenic activities on water quality.

Keywords: water quality; water pollution; human impact; Bulgaria

Introduction

Water, a prime natural resource and precious social asset, forms habitats for aquatic species, serves vital human needs, and at the same time plays an increasingly important role in various sectors of the global and national economy. As a result of this multipurpose use, water quality suffers from a range of anthropogenic activities like agriculture, urban development, industry, etc. Agriculture provides employment to millions of people and is responsible for feeding the growing world’s population (Kernebeek et al., 2016). However, some farming practices, such as the excessive usage of fertilizers and pesticides, enrich surface water bodies with nitrogen and phosphorus, which causes structural changes in the freshwater ecosystems and

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provokes eutrophication (Chislock et al., 2013, Withers et al., 2014, Dodds & Smith, 2016, Romanelli et al., 2020). The expansion of urban regions due to the rapidly rising population also brings environmental issues. The untreated or inadequately treated municipal effluents contain fecal coliforms and so import pathogenic bacteria into the waters. Such microbial organisms pose a serious threat to public health (Mills et al., 2018, Nazemi et al., 2018). Industrial wastewaters inflict no less harmful effects. Two examples include the chemical factories emitting synthetic materials and the mining enterprises releasing heavy metals into the rivers. Those substances often engender intoxication and hide carcinogenic risks, so their presence in the aquatic bodies is an issue of great concern (Mohammadi et al., 2019, Ravindra & Mor, 2019, Sall et al., 2020).

The implementation of the Water Framework Directive (WFD) 2000/60/EC of the European Parliament and the Council of 23 October 2000 requires all EU member states to protect and improve the quality of their surface and sub-surface water resources, so that all streams, lakes, and aquifers achieve “Good status” at the latest by 2027. Currently, five years before the stated deadline, the implementation of the mentioned objective seems to be a difficult task. Although a set of rules, measures, and action programs in this field were prepared by decision-makers and stakeholders during the last two decades, about 40% of the EU waters still do not meet the requirements. One of the main obstacles hindering the European states to achieve the WFD’s target remains the anthropogenic influence on the aquatic streams (Vilmin et al., 2018).

Bulgaria is among the European countries with most dramatically declining population and shrinking economy during the last decades. As a result of those socio-economic processes, the human impact on the environment gradually weakens and a lot of water bodies tend to improve their quality (Varbanov & Gartsiyanova, 2015, Seymenov, 2019). However, some regions in the territory of the country continue to be pressured by various anthropogenic activities and so critically contaminated rivers can still be established (Radeva & Seymenov, 2021). One such example includes the Provadiyska River, which has been classified as “an ecological hot-point with seriously polluted sections” due to the discharge of wastewater products from farmlands, settlements, and industrial enterprises. Gartsiyanova (2016) reported elevated concentrations of ammonia ions, nitrates and nitrites in the river waters for the period 1993–2014. The annual bulletins published by the Executive environment agency between 2000 and 2018 concerning the ecological status of the rivers in the Black Sea drainage area showed severe contamination with increased values of suspended solids, nitrates, phosphates, and organic matter as a result of the direct discharge of untreated municipal and industrial effluents into the stream channel.

Thus, this work aims to assess the water quality status of the Provadiyska River in compliance with the reference norms pointed in Regulation H-4/2012 for characterization of the surface waters. The realization of the stated objective is expected to update the existing knowledge from previous investigations with new data for a more contemporary period.

Study area

The Provadiyska River is a watercourse in the northeastern section of Bulgaria, which flows in a length of 119 km and has a drainage basin of 2132 km^2. The investigated stream originates from the eastern slopes of the Samuil hills in the Eastern Danube Plain at an altitude of 441 m above sea level, later runs southeast and northeast, and empties into the Beloslav Lake, which is connected with the Varna Lake, which in turn drains into the Black Sea (Figure 1).

The hydrological features of the Provadiyska River at the gauging station near Sindel include a mean annual flow 2.33 m^3/s. The high runoff phase occurs from February to April, while the low discharge period is most typical between August and October (Hristova, 2012).

Data and methods

Statistical information about the values of ten physicochemical variables has been used. Data concern the measured content of the following parameters: pH, electrical conductivity (EC), dissolved oxygen (DO_2), ammonium nitrogen ($N\text{-}NH_4$), nitrate nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total nitrogen (N-tot), orthophosphates ($P\text{-}PO_4$), total phosphorus (P-tot), and five-day biochemical oxygen demand (BOD_5), in-situ collected and then processed in an accredited laboratory following a standardized procedure. The measurements were carried out by the Executive environment agency at four sampling points during the period 2015–2020 with a frequency of the observations four times per year. The monitoring sites,

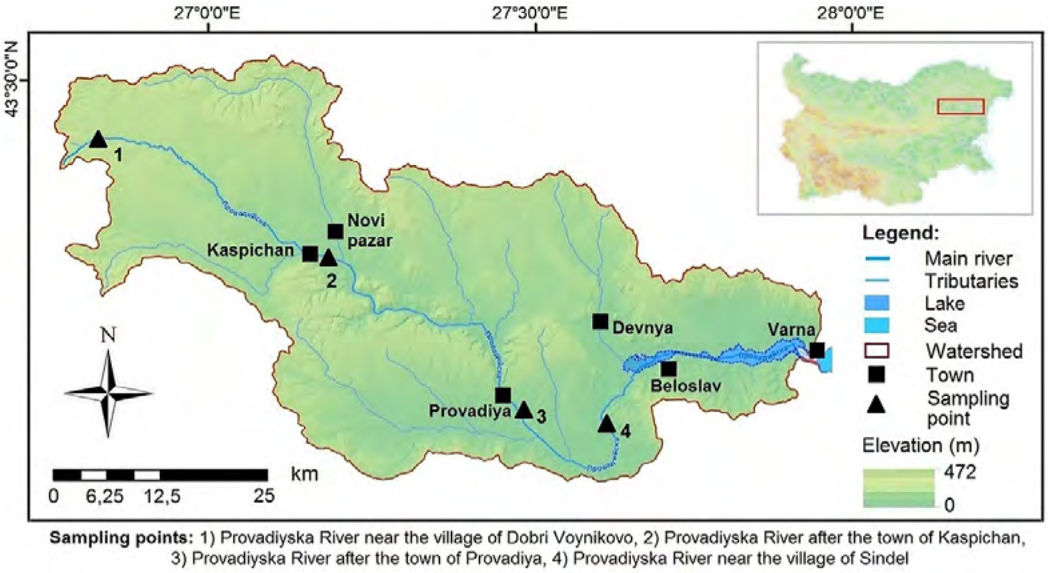

Figure 1. Map of the relief and drainage network showing the location of sampling points

falling within surface water bodies of type R4: Semi-mountain rivers in a Pontic province (a measuring point near the village of Dobri Voynikovo) and R11: Small and medium Black Sea tributaries (monitoring sites after the towns of Kaspichan and Provadiya, and near the village of Sindel), have been selected so that cover parts of upstream, midstream, and downstream reaches of the Provadiyska River (Figure 1). Water quality status has been analyzed following the guidelines of the National regulatory standard – Regulation H-4/2012 for characterization of the surface waters (Table 1). The term "water pollution" will be used in this paper when the value of a given physicochemical parameter does not meet the reference norms for "good" and "excellent" status, recommended in Regulation H-4/2012.

Descriptive statistics, i.e. minima, maxima and means, calculated for each variable have been presented in the first stage of the work. Water quality has been related to the land use/land cover structure. For this purpose, a map of the CORINE land cover in the Provadiyska River basin has been made using the database of COPERNICUS Land Monitoring Services (2018).

Table 1. Reference values of physicochemical parameters at different water body types as pointed out in Regulation H-4/2012 for characterization of the surface waters

Water body types	Water quality status	Water quality parameters									
		pH	EC, µS/cm	DO_2, mg/l	$N\text{-}NH_4$, mg/l	$N\text{-}NO_3$, mg/l	$N\text{-}NO_2$, mg/l	N-tot, mg/l	$P\text{-}PO_4$, mg/l	P-tot, mg/l	BOD_5, mg/l
R4	Excellent	–	<700	>8.0	<0.04	<0.5	<0.01	<0.5	<0.02	<0.025	<1.2
	Good	6.5–8.5	700–750	8.0–6.0	0.04–0.4	0.5–1.5	0.01–0.03	0.5–1.5	0.02–0.04	0.025–0.075	1.2–3.0
	Moderate	–	>750	<6.0	>0.4	>1.5	>0.03	>1.5	>0.04	>0.075	>3.0
R11	Excellent	–	<850	>6.0	<0.3	<1.0	<0.03	<1.0	<0.07	<0.15	<2.0
	Good	6.5–8.5	850–900	6.0–5.0	0.3–0.65	1.0–2.5	0.03–0.06	1.0–2.5	0.07–0.15	0.15–0.3	2.0–5.0
	Moderate	–	>900	<5.0	>0.65	>2.5	>0.06	>2.5	>0.15	>0.3	>5.0

Results

The physicochemical parameter ***pH*** is a measure informing about the active reaction of water (acidic, neutral, or alkaline). The possible numerical range varies from 0 up to 14. Generally, values less than 7 mean an acidic reaction; numbers equal to 7 indicate a neutral reaction, and ratings greater than 7 reveal an alkaline reaction. The value of this variable depends on some natural conditions. For instance, river waters flowing over karst terrains with limestone rocks are more often alkaline, unlike those running through volcanic and metamorphic formations that are chiefly acidic. In addition, the wastewaters from mines and metallurgical enterprises usually decrease the values of pH. Neutral to weakly alkaline water is considered to be most suitable for aquatic life and human use (Omer, 2019). Results obtained show that the waters of the Provadiyska River are characterized by neutral to slightly alkaline reaction (Table 2). A possible explanation of this result gives the significant share of sedimentary rocks, as well as the lack of ore mines in the drainage basin. Frequency analysis indicates that from 90.9% (the Provadiyska River after Kaspichan) to 100.0% (the Provadiyska River near Dobri Voynikovo and after Provadiya) of the collected samples fall within the numerical range for "Good status" recommended in Regulation 4/2012 (Figure 2).

Table 2. Descriptive statistics of the values of physicochemical variables in the surface waters

River – water sampling point	Values	pH	EC, µS/cm	DO_2, mg/l	N-NH_4, mg/l	N-NO_3, mg/l	N-NO_2, mg/l	N-tot, mg/l	P-PO_4, mg/l	P-tot, mg/l	BOD_5, mg/l
Provadiyska – Dobri Voynikovo	Minimum	8.03	578	7.00	0.22	3.50	0.02	3.50	0.05	0.08	1.58
	Average	8.25	638	9.14	0.53	8.24	0.06	9.18	0.06	0.13	4.50
	Maximum	8.48	810	10.60	1.10	11.70	0.15	12.10	0.08	0.19	8.40
Provadiyska – after Kaspichan	Minimum	7.26	458	3.00	0.05	1.13	0.04	1.60	0.03	0.10	1.32
	Average	8.14	709	8.55	0.62	5.98	0.11	7.62	0.10	0.25	4.65
	Maximum	8.66	990	14.20	2.50	13.20	0.50	15.10	0.50	0.90	12.00
Provadiyska – after Provadiya	Minimum	7.72	760	5.52	0.08	2.21	0.03	2.68	0.04	0.09	1.51
	Average	8.04	1163	7.93	0.46	5.64	0.07	6.49	0.20	0.28	2.87
	Maximum	8.32	1590	10.20	1.91	9.69	0.12	9.81	0.53	0.66	6.30
Provadiyska – Sindel	Minimum	7.47	723	3.57	0.03	3.16	0.02	3.20	0.03	0.06	0.70
	Average	8.18	1252	7.84	0.23	6.34	0.11	6.72	0.21	0.27	2.48
	Maximum	8.67	2606	11.89	1.11	11.40	0.46	11.80	0.55	0.78	7.30

Electrical conductivity (EC) is a physicochemical parameter showing the ability of water to conduct electricity. Waters are among the natural resources that are electrical conductors, but this property is influenced by multiple factors like turbidity, mineralization, lithology, and land use. The increased values of EC usually do not cause great concerns because they are often a reflection of natural conditions, such as the presence of calcium ions, which seems to be closely linked to lithology. However, some unsustainable anthropogenic practices like the unregulated disposal of solid or chemical wastes can also provoke increased electrical conductivity (Omer, 2019). The measurements show that the waters of the Provadiyska River are characterized by an elevated ability to conduct electricity (Table 2). The lowest values are established at the sampling sites near Dobri Voynikovo and after Kaspichan. On the other hand, the highest levels are recorded at the measuring sites after Provadiya and near Sindel. Frequency analysis gives the following information: from 7.7% (the Provadiyska River after Provadiya) to 87.5% (the Provadiyska River near Dobri Voynikovo) of the collected samples achieve "Excellent status". Excluding the sampling points near Dobri Voynikovo and after Provadiya, where no values within the numerical range for "Good status", in the rest measuring sites between 4.3% (the Provadiyska River at Sindel) and 4.5% (the Provadiyska River after Kaspichan) of all tests fall into "Good status". Increased values of EC are established at all measuring sites, so between 9.1% (the Provadiyska River after Kaspichan) and 92.3% (the Provadiyska River after Provadiya) of the samples could be assessed into "Moderate status" following the norms of Regulation 4/2012 (Figure 2).

Dissolved oxygen (DO_2) is a measure showing the amount of oxygen that is present in water. Surface water bodies absorb and dissolve a part of the available oxygen in the lowest layer of the atmosphere. The presence of sufficient oxygen in water maintains aquatic life and protects natural habitats. However, unfavorable hydro-ecological conditions, such as eutrophication, can critically reduce the dissolved oxygen levels (Omer, 2019). The lower oxygen saturation usually leads to suffocation and death of aquatic species, which is closely related to the loss of biodiversity in the aquatic ecosystems. The resulting information reveals that the waters of the Provadiyska River almost do not suffer from oxygen deficit (Table 2). Two exceptions are the monitoring sites after Kaspichan and near Sindel, where 13.9% and 4.3% of all samples remain under the reference range for "Good status". Regarding

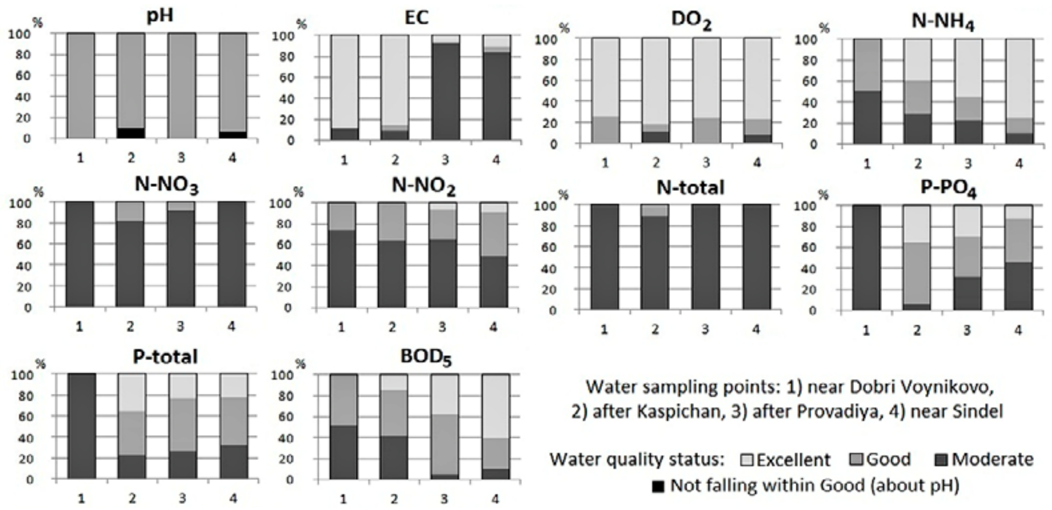

Figure 2. Frequency (% of all samples) of water quality variables in a certain status according to the reference values stated in Regulation H-4/2012 for characterization of the surface waters

all analyzed water measuring points, from 4.3% (after Kaspichan) up to 25.0% (near Dobri Voynikovo) of the collected tests fall in "Good status", while between 75.0% (near Dobri Voynikovo) and 81.8% (after Kaspichan) of the recorded samples achieve "Excellent status" according to Regulation 4/2012 (Figure 2).

Ammonium nitrogen (N-NH_4) is a chemical compound of ammonia – a colorless gas with a pungent smell and one of the three inorganic nitrogen forms (the other two include nitrates and nitrites). Ammonia and its compounds are released as a result of the decomposition of organic matter by aerobic bacteria during the microbiological process of ammonification. The elevated concentrations of ammonium nitrogen in water bodies usually indicate an inflow of sewerage wastewaters or livestock farming effluents containing excrements, urine, and liquid manure. Ammonia and its compounds are able to inflict toxic effects on freshwater ecosystems (Omer, 2019). Results show the waters of the Provadiyska River suffer from ammonia pollution (Table 2). Excluding the monitoring point near Dobri Voynikovo, where no values in the numerical range for "Excellent status", frequency analysis reveals that in the rest measuring sites from 40.9% (after Kaspichan) to 73.9% (near Sindel) of the collected tests achieve the best status. Between 17.4% (near Sindel) and 50.0% (near Dobri Voynikovo) of the samples fall in "Good status", and from 8.7% (near Sindel) to 50.0% (near Dobri Voynikovo) of the recorded tests could be assessed into "Moderate status" in accordance with Regulation 4/2012 (Figure 2).

Nitrate nitrogen (N-NO_3) is a chemical compound of the nitrate – a water-soluble salt of the nitric acid and one of the three inorganic nitrogen forms (the other two include ammonia and nitrites). Nitrates are formed as a result of the oxidation of ammonia ions by aerobic bacteria during the microbiological process of nitrification. Nitrates are not toxic substances, but under certain conditions, it is possible to transform into carcinogenic nitrosamines (nitrites). Nitrate pollution almost always indicates an inflow of soil runoff saturated with chemical agents like artificial fertilizers, pesticides, and plant protection products, which continue to be widely used for agricultural purposes. Those products are applied onto arable lands in order to be achieved an accelerated yield of crops or the same crops to be protected from pests, but their excessive dispersal causes unfavorable effects on water quality (Withers et al., 2014). Results obtained show the waters of the Provadiyska River suffer from significant nitrate pollution (Table 2). The measured maximum content of this variable exceeds the reference norm for "Good status" at all monitoring points. Most severe is the contamination at the water sampling site after Kaspichan, where the highest observed value is almost six times above the maximum permissible limit. Frequency analysis indicates that samples falling in the numerical range for "Excellent status" are not recorded. Between 81.8% (after Kaspichan) and 100.0% (near Dobri Voynikovo and near Sindel) of the tests could be assessed in "Moderate status", which reveals permanent nitrate contamination (Regulation 4/2012) (Figure 2).

Nitrite nitrogen (N-NO_2) is a chemical compound of the nitrite – a water-soluble salt of the nitrous acid and one of the three inorganic nitrogen forms (the other two include ammonia and nitrates). Nitrites originate from nitrates that have been transformed under certain conditions like acidic pH or increased temperature. A further chemical reaction of the nitrite with amines forms nitrosamines – carcinogenic substances, which can inflict toxic or mutagenic effects on aquatic ecosystems and human health (Omer, 2019). Consequently, the presence of nitrites in waters is an issue of great concern. The sources of nitrite nitrogen in the watercourses include discharges of domestic, industrial, and agricultural effluents, which have been nitrate polluted. Later, under some conditions, a part of those nitrates have been transformed into nitrites. The resulting data reveals that the waters of the Provadiyska River are polluted with nitrite nitrogen (Table 2). The measured maximum levels of this variable exceed the highest permissible limit for "Good status" at all sampling points. Therefore, from 52.2% (near Sindel) to 75.0% (near Dobri Voynikovo) of the collected tests could be assessed into "Moderate status". Frequency analysis also shows that from 23.1% (after Provadiya) up to 39.1% (near Sindel) of all tests fall within the numerical range for "Good status" following Regulation 4/2012 (Figure 2).

Total nitrogen (N-tot) is a physicochemical parameter showing the overall content of nitrogen in the waters – both in the form of inorganic compounds (ammonia, nitrates, and nitrites) and as an organic substance as well. Nitrogen is an essential nutrient for aquatic ecosystems, but its increased content causes adverse hydro-ecological effects (Omer, 2019). Although nitrogen is naturally occurring in environment, water pollution is often provoked by human activities. The untreated municipal wastewaters, as well as the chemicals, which are often dispersed onto arable lands, appear to be among the leading causes of nitrogen contamination (Withers et al., 2014). The conducted measurements indicate that the waters of the Provadiyska River seem to be seriously loaded with respect to nitrogen (Table 2). The maximum values of this parameter exceed the highest permissible limit for "Good status" at all monitoring sites. Most polluted are the waters of the river after Kaspichan, where the highest content is about seven times higher than the reference norms. Frequency analysis shows that 9.1% of the measured concentrations at the Provadiyska River after Provadiya achieve "Good status", while values falling within this numerical range in the rest of the monitoring points are not established. Between 90.9% (after Provadiya) and 100.0% (near Dobri Voynikovo, after Kaspichan, and near Sindel) of the tests could be categorized into "Moderate status" according to Regulation 4/2012 (Figure 2).

Orthophosphates ($P\text{-}PO_4$) are water-soluble salts of orthophosphoric acid. Orthophosphates are nutrient components naturally presenting at low levels in waters, soils, and plants. However, increased values of orthophosphates in the rivers can cause an overgrowth of algae, resulting in algal blooms and eutrophication. The process of eutrophication blocks sunlight, decreases oxygen amounts, and so affects aquatic life (Withers et al., 2014). The pollution sources could be both natural (like soil erosion) and human-induced (as uncontrolled disposal of agricultural and domestic effluents containing phosphorus-rich fertilizers and laundry detergents). Results show the waters of the Provadiyska River are contaminated with orthophosphates (Table 2). The highest observed values seem to be higher than the maximum permissible limit for "Good status" at all monitoring sites. Frequency analysis confirms this statement and reveals between 4.5% (after Kaspichan) and 100.0% (near Dobri Voynikovo) of all tests could be assessed into "Moderate status". Excluding the sampling site near Dobri Voynikovo, where no values in the numerical range for "Good status" and "Excellent status", in the rest measuring points: from 38.5% (after Provadiya) up to 59.1% (after Kaspichan) of the collected tests achieve "Good status", and between 7.7% (after Provadiya) and 36.4% (after Kaspichan) of all samples fall within "Excellent status" in accordance with the guidelines of Regulation 4/2012 (Figure 2).

Total phosphorus (P-tot) is a physicochemical parameter informing about the overall content of phosphorus and its compounds in the waters – both as inorganic salts (like phosphates and orthophosphates) and as an organic substance. Phosphorus is a nutrient with an essential role for plant and animal growth. However, elevated values of this parameter cause an overgrowth of algae, which provokes structural changes in aquatic ecosystems and leads to eutrophication (Withers et al., 2014). Water pollution with phosphorus comes from some natural processes occurring in the drainage basin (such as soil erosion or weathering of phosphorus-containing rocks) and anthropogenic activities as well (like unregulated disposal of untreated agricultural and household wastewaters). The conducted measurements show the waters of the Provadiyska River appear to be polluted with regard to phosphorus. The highest observed content remains above the maximum permissible limit for "Good status". Frequency analysis confirms this result and informs: from 22.7% (after Kaspichan) up to 100.0% (the near Dobri Voynikovo) of all tests fall into "Moderate status". Excluding the monitoring site near Dobri Voynikovo, where no values falling in the numerical range for "Good status" and "Excellent status", in the rest measuring points between 40.9% (after Kaspichan) and 53.8% (after Provadiya) of the samples achieve "Good status", and from 21.7% (near Sindel) up to 36.4% (after Kaspichan) of all tests could be categorized into "Excellent status" following Regulation 4/2012 (Figure 2).

Biochemical oxygen demand (BOD_5) is a measure showing the amount of dissolved oxygen consumed by aerobic bacteria and microorganisms while they decompose organic matter over a specific time period (five days). Microorganisms living in surface water bodies use oxygen to support their vital and metabolic processes, but under some circumstances, such as nutrient enrichment and eutrophication, microbial metabolism consumes dissolved oxygen in a larger amount than normal (Omer, 2019). The problem arises from the fact that aquatic species may die if oxygen is depleted by microbial metabolism. The lack of sufficient oxygen in water due to its excessive consumption by aerobic bacteria results in long-term hypoxia, which causes a loss of biodiversity and degradation of the aquatic ecosystem. Therefore, biochemical oxygen demand is often used as an indicator of the overall degree of water contamination with organic matter (Omer, 2019). Results show the waters of the Provadiyska River are characterized by increased biochemical oxygen demand (Table 2). The highest values of this variable exceed up to three times the reference norms for "Good status", meaning the river waters suffer from significant organic pollution. Frequency analysis shows that from 7.7% (after Provadiya) up to 50.0% (near Dobri Voynikovo) of all tests could be assessed into "Moderate status", between 26.1% (near Sindel) and 53.8% (after Provadiya) of the recorded samples fall in the numerical range for "Good status", while from 13.6% (after Kaspichan) up to 60.9% (near Sindel) of the collected tests achieve "Excellent status" according to Regulation 4/2012 (Figure 2).

Discussion

Compared to a previous research article, the results obtained in the current work demonstrate a lot of similarities, but highlight some differences as well. Gartsiyanova (2016) explored water quality of the rivers in the Black Sea drainage basin in Bulgaria during the period 1993–2014. The cited author reported that the Provadiyska River is the most contaminated watercourse in the investigated territory. The leading pollutants before its mouth include nitrate nitrogen and nitrite nitrogen – the average values of those parameters are 5.08 mg/l and 0.21 mg/l, while the maximum levels reach 16.50 mg/l and 0.45 mg/l, respectively (Gartsiyanova, 2016). The resulting data in this work establishes a slightly lower maximum content of nitrate nitrogen, but higher average values. Respecting nitrite nitrogen, the mean concentrations calculated in the present paper appear to be lower than those in the cited study, but the highest observed values remain approximately the same (Table 2). In addition, in the annual bulletins of the Black Sea basin directorate concerning the ecological conditions of the surface waters in the period from 2000 to 2018, the Provadiyska River was defined as "an ecological hot-point with increased values of various chemical parameters". The obtained results in the current research reveal an analogous situation. All this suggests the waters of the Provadiyska River do not significantly improve their quality and continue to be seriously polluted during the period 2015–2020. The failed variables at all sampling points are ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total nitrogen, orthophosphates, phosphorus, and biochemical oxygen demand whose highest content exceeds from two up to nine times the maximum permissible limits for "Good status", recommended in Regulation 4/2012 for characterization of the surface waters. In contrast, the pH-value and the dissolved oxygen level remain mostly within the reference norm (Table 2). The analysis of the territorial distribution in the content of the physicochemical variables does not find any spatial changes along the length of the river. Most of the parameters considered maintain relatively similar concentrations or demonstrate unsustainable increase/decrease of the values from one sampling site to another without a clearly expressed direction of change. An exception is an electrical conductivity whose values obviously increase from upstream to downstream part.

Water quality is a reflection of natural processes and anthropogenic activities occurring in the river basin. A detailed picture of spatial distribution of both primary and human-transformed landscapes in a given catchment area gives the land use/land cover structure. The predominant land cover class in the study region is "Non-irrigated arable lands", which occupies 72.4% of the total area. Some of the rest most character lands include "Forest" (14.3%), "Urban areas" (3.6%), "Shrub and/or herbaceous vegetation" (3.2%), "Industrial units" (2.3%), "Permanent crops" (1.9%), while the other classes have a smaller relative share (Figure 3). In short, there is a significant predominance of human-transformed landscapes. The drainage basin of the Provadiyska River is traditionally pressured by anthropogenic activities, such as agriculture, industry, and urban development. The Eastern Danube Plain is occupied by farmlands with cereal and technical crops, while the foothills of the Provadiya Plateau and the Frangen Plateau are covered by vineyards and orchards. In addition, a lot of livestock farms exist in the vicinity – e.g. the swine-breeding complex near the village of Avren, the poultry farm near the town of Devnya, etc. The Provadiyska River basin concentrates a total of 113 settlements, including the third most populated town in Bulgaria – Varna with a population of about 330 000 people,

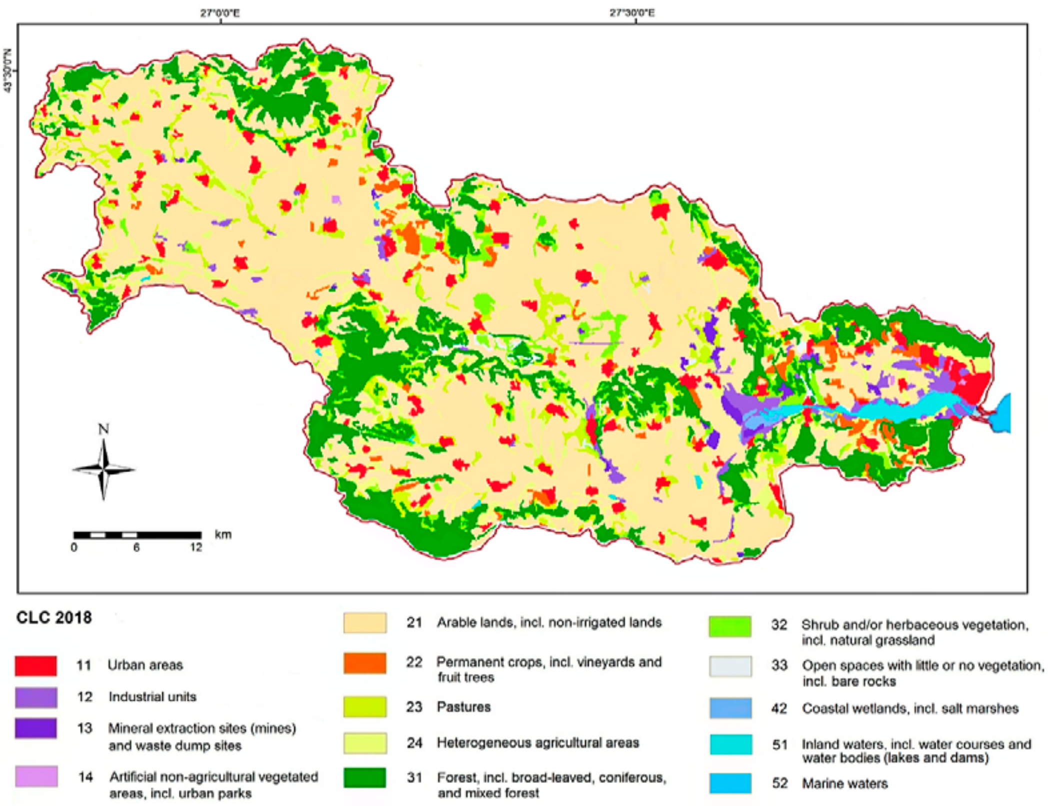

Figure 3. CORINE Land Cover (2018) of the Provadiyska River basin

smaller cities like Kaspichan, Novi pazar, Provadiya, Devnya, and Beloslav, as well as over 100 villages (Figure 1). The agglomeration of Varna, which attracts almost 25–30 km from the surrounding territories, is a highly industrialized zone with some of the largest enterprises in the Balkan Peninsula. In this region operate cement, glass, porcelain, and faience production factories (near Kaspichan and Novi pazar), a synthetic soda ash production site and an artificial fertilizer enterprise ("Solvay sodi" and "Agropolychim" near Devnya), a salt mine ("Provadsol" near Provadiya), a coal-fired thermal power plant ("Varna Power Plant") (Figure 3). Moreover, three agglomerations (Kaspichan, Novi pazar, and Beloslav) with a population equivalent of greater than 2000 people still are not connected to sewage systems and thus they do not meet the requirement of Directive 91/271/EEC concerning the collection, treatment, and discharge of wastewaters released from urban areas and certain industrial sectors. Consequently, water pollution originates from many sources. The leading polluting activities include the excessive fertilization of the arable lands, the unregulated disposal of animal manure from the livestock farms, the uncontrolled deposition of solid wastes into illegal rubbish dumps, as well as the widespread discharges of household and industrial effluents from the settlements with a lack of public sewerage network and wastewater treatment facilities.

Conclusion

The conducted analysis, based on the recorded values of ten physicochemical variables at four sampling points in the period 2015–2020, shows that almost all of the parameters considered do not meet the reference norms for "Good status", recommended in the National regulatory standard – Regulation 4/2012 for characterization of the surface waters. The failed variables at all monitoring sites include ammonium nitrogen ($N\text{-}NH_4$), nitrate nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total nitrogen (N-tot), orthophosphates ($P\text{-}PO_4$), total phosphorus (P-tot), and biochemical oxygen demand (BOD_5) whose maximum concentrations remain from two up to nine times above the highest permissible limits stated in Regulation 4/2012. Thus, water quality could be assessed as "Moderate" regarding those parameters. Compared to a previous study, the resulting information in this work shows a partly similar situation and suggests that the Provadiyska River is one of the most seriously and permanently polluted watercourses in the territory of Bulgaria during the last three decades. Water contamination is due to the effect of various anthropogenic activities occurring in the catchment area, especially agriculture, urban development, and industry. The unregulated disposal of untreated effluents from arable lands, livestock farms, urban and rural settlements, and industrial units is a major issue. Construction of public sewage network and wastewater treatment infrastructure in the agglomerations with a population equivalent of greater than 2000 people to remove the release of raw municipal and industrial wastes is strongly recommended. In order to abate the agricultural pollution, it is necessary to reduce the excessive dispersal of fertilizers and pesticides onto croplands through the promotion of sustainable farming practices. The implementation of the listed advices could improve water quality, which would protect human health and aquatic life. The results obtained supplement previous research articles and provide valuable information for a recent period. In future, this study could be extended by calculating water quality indices.

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The Future Climatic Variabilities in the Mano River Union, its Implications on Socio-Economic Development

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Abstract

Knowledge of climatic variability of any country or region is essential to socio-economic development. This is particularly important as most sectors of national development can be altered if the climatic conditions are unsuitable. A hypothetical case lies in the fact that agriculture largely depends on apposite climate for fruitful production. The Mano River Region consists of some of the world's poorest and least developed nations (Guinea, Sierra Leone, Liberia, Cote D'Ivoire). The primary means of sustenance in this region is rain-fed agriculture. Knowledge of current and future climatic conditions in the region will be of significant benefit to the economy of the region. This work investigates the current and future state of climate in the region using six climatic parameters (Maximum and minimum temperature, Precipitation, Relative Humidity, Wind Speed and Solar Radiation) spanning 1975—2018. To model the impact/relationship, Kalman Filter was used. These variables were grouped into state transition and control variables. Transfer functions which depict relationships between every two variables at a time with one being input and the other considered as output were used to determine state transition and control variable matrices. Control variables (population and land use) were introduced to control the dynamism of the model in MATLAB environment. Results show that there is a drastic variation in climate in the region within the period of the data. This work establishes that there are rapid variabilities in these parameters which can be attributed to increase in population and loss of vegetation.

Keywords: Kalman Filter; Transfer Function; Climatic Variability

Introduction

The world over is faced with the increasing devastating effects of climate change. Developed countries have a better understanding of the nature of their climate, hence, there are mitigation strategies in place to ameliorate the adverse effect of climate change and other environmental issues on its citizens and economy (Butler, 2018). On the contrary, although Africa is most likely to experience extreme negative consequence of climate change, there is particularly low level of understanding of climate change variability within the region. Additionally, lack of institutional framework, high climate variability and high dependence on rainfed agriculture (Sultan et al., 2016; Abrams, 2018) and inconsistencies in model prediction (Sorland et al., 2018) could worsen the consequences. Countries of this region which are predominant-

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ly least developed nations have low adaptive capacity for climate change, hence, the need for immediate and urgent study to enhance climate change monitoring. It has been indicated in previous works that the highest concentration of vulnerability is located along coastal zones of West Africa. Political instability in the West African sub region has made development of institutional framework impossible (Seiyefa, 2019). In an effort to institute mitigation strategies in countries of this nature, knowledge of the climate dynamics in the region is highly essential.

Climatic variabilities can be attributed to both natural and anthropogenic causes. While solutions to the natural causes are somehow beyond the capacity of humans, those of anthropogenic causes can be reduced when the right mechanisms are instituted. Dominating the list of anthropogenic causes is the drastic increase in population which subsequently breeds urbanization. As urbanization occurs, land no longer remains the same. As a result, loss of vegetation in the region has assumed a threatening dimension.

The impact of climatic variabilities on man and the environment can be of serious consequence since it touches on factors that are fundamental to human existence such as agriculture/vegetation, soil/land, water, air, and temperature among others all at local and global scales (Maviza & Ahmed, 2021). Bearing in mind the fact that West African sub-region and particularly the MANO River Union (MRU) survives predominantly on Agriculture (Asare-Nuamah & Botchway, 2019), bearing also in mind that climatic variabilities can exert grave consequence on agriculture, it is therefore important to undertake a research on climatic variabilities in the region. Results of the research will provide the required information for mitigating any foreseeable negative consequences on agriculture in particular and the environment in general.

There exist few literatures on climatic variability in the MRU region, therefore information about variabilities was scanty. Soro et al. (2017) showed that temperature in Cote D'Ivoire will increase by 1.2°C to 3°C by the year 2060 whereas rainfall will increase by 5% to 23% during this period. These findings are in agreement with Kouakou et al. (2012) for average temperature (3°C to 4.1°C) with slight disagreement in rainfall prediction (31.40% to 55.4%). It is predicted that these variations might have adverse effects on future cocoa production which will subsequently affect the national economy given the fact that cocoa contributes significantly to the national revenue of that MRU nation (Coulibaly et al., 2017).

Although Liberia is highly vulnerable to the impacts emanating from climatic variabilities, not much has been done in addressing climate change. According to the United States Agency for International Development (USAID) 2014 published report, an average increase in annual temperatures in Liberia is expected by the 2050s to vary anywhere between 1.4°C – 4.7°C from 2008 (Stanturf et al., 2013). Available climate model suggests that an overall increase in average annual rainfall as well as in the number of heavy rainfall events will occur in Liberia in the coming years (USAID, 2012). A country with agriculture supporting approximately 75% of rural dwellers, any change in the climate system will gravely affect food security and floods especially when 58% of the country's population reside in coastline areas (Stanturf et al., 2013).

The climate of Sierra Leone has some differences as compared to other parts of the MRU. This is due to the sharp topographic and ecological gradients of the country (Jalloh et al., 2011). Sierra Leone lacks adequate climatic information required for decision making. Therefore, researchers used global models of the Sierra Leone climate system to make local derivation (Trzaska et al., 2017). Global models have made long term predictions of Sierra Leone with an increasing value of average annual temperature between 1.5°C to 4°C from 2016.

The Republic of Guinea is expected to experience high variabilities with average temperature ranging between 0.3°C to 4.8°C by the year 2050 from year 2000, precipitation is expected to drop by 36.4% (Distefano, 2012). Loua et al. (2017) analyze meteorological parameters (1931-2014) trends with some agro-climatic risks in Guinea. The study ascertained that there is a variation in rainfall with September of each year being the highest recorded month. It was also found that the current average temperature in the study area ranges between minimum 15°C – 21°C and maximum 26°C – 33°C.

These studies are however limited in that they did not consider other factors of climatic varaibility namely: Relative Humidity, Wind Speed, Solar Radiation, Atmospheric Pressure, etc. These parameters play specific roles in the dynamism of any climatic system. Therefore, this study employs additional parameters along with Temperature and Precipitation to explain the climate system in the region.

A climate system can be approximated to any dynamic system in which changes in constituent members alter the dynamics of the overall system (state). Knowledge of the past and current conditions of a state is central to determining the future of the state. Kalman Filter as a state estimator can be used in climatic studies since it is capable of providing information of a state (climate) at any point in time (past, present and future) in the presence of external disturbance given the rightful input parameters (Soubdhan et al., 2016). Various studies have been conducted to examine the effect of various filtering methods on ability to predict climatic vraibilities, the Kalman filter is considered to be most preferred method for these methods based on the accuracy of the results obtained (Neslihanoglu et al., 2021). It must however be noted that Kalman filter may not be the best method for a non-linear situations. The linear system demonstrated in some literatures as being able to accurately predict climate (Sreehari & Pradeep-Ghantasala, 2019) is assumed in this study.

It is against this background that this study uses Kalman Filter to model climatic variabilities in the MRU region using historical climatic data and control variables of population and land use. Kalman Filter as a state estimator, is used to approximate the dynamic nature of the climate in the region and making accurate predictions for future purposes.

Study area

The Mano River Union (MRU) was originally established between Liberia and Sierra Leone on October 3, 1971. Guinea and Cote D'Ivoire later joined on October 25, 1980 and May 15, 2008 respectively. The core objective of the union is to accelerate economic growth, social progress and cultural advancement amongst members by active collaboration and mutual assistance in matters of common interest in economic, social, technical scientific and administrative fields (MRU, 1974). The union faced series of challenges in meeting its objective due to political instability which engulfed the region between 1989 and 2003 (USAID, 2003). The region remains one of the poorest parts of the world with majority of the citizens of these nations living below the poverty line (World Bank, 2018).

The Mano River Union consists of four West African countries as shown in Figure 1. The name of the Union was derived from the Mano River which begins in the Guinea highlands and forms a border between Liberia and Sierra Leone. The region lies between latitude 4oN and 13oN and longitudes 3oW and 15oW with the southern part of the region covered by the Atlantic Ocean. The Northern part of the region is predomantly occupied by the Sahel region. The current population in the region is approximately 47 Million (UNDP, 2017).

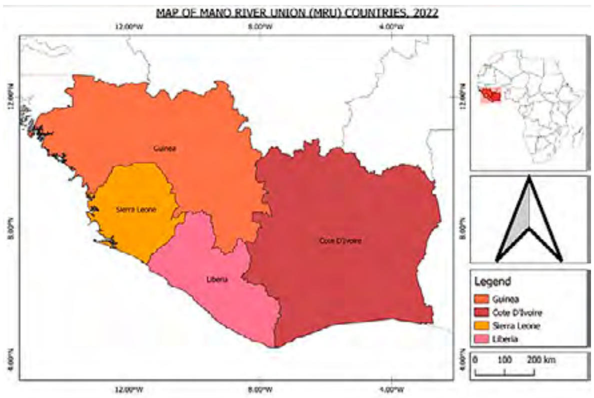

Figure 1. The study area (MRU Countries)
Source: Author, 2022

Materials and methods

Data

As indicated in Table 1, the data used for this study were obtained from different sources and reconciled for all years between 1975 and 2018. Average temperature was computed from maximum and minimum temperature values. The data was recorded on a daily basis and loaded in Microsoft Excel in a pivot table with yearly average computed.

Kalman Filter

Linear Quadratic Estimation (LQE) or otherwise known as Kalman filtering is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone (Welch and Bishop, 2001). The Kalman

Table 1. Data and Sources

No.	Data	Source	Period
1	Longitude, latitude, elevation (m), maximum temperature1(°C), minimum temperature (°C), precipitation (inch), wind speed (m/s), relative humidity (%), solar radiation (mj/m²)	National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) https://globalweather.tamu.edu	1901-2018
2	Land Use (km²)	West Africa: Land Use and Land Cover Dynamics (30m resolution) https://eros.usgs.gov/westafrica/land-cover/land-use-and-land-cover-trends-west-africa	Epochs 1975, 2000, 2013
3	Population	United Nations World Population Prospects 2017 https://esa.un.org/unpd/wpp/	1950 – 2018

Filter can be divided into two stages, **prediction** and **update** as indicated in Figure 2. Details of the Kalman Filter equations are in Table 2.

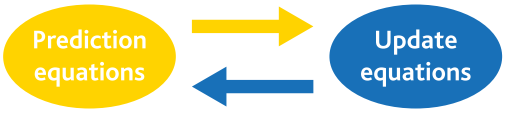

Figure 2. Fundamental of Kalman Filter
Source: Author, 2022

Data Gaps

The period of the data vary with respect to the dataset. Therefore, the data were reconciled with 1975 – 2018 being the common period for all data. Most of the data obtained are daily records. They were averaged to determined monthly values. The linear interpolation formula in equation (7) was used to account for data gaps.

$$(y-y_1)=\left(\frac{y_2-y_1}{x_2-x_1}\right)(x_2-x_1) \quad (1)$$

- Where y= the value to be interpolated, y_1 = the previous climatic data at time x_1, y_2 = the next climatic data at time x_2. Table 3 is a list of all working variables used in this study with symbolic representation.

State Transition Matrix

The State Transition Matrix of Kalman Filter is the matrix that relates the input of the system to the model. Six parameters (Maximum Temperature, Minimum Temperature, daily Precipitation, Relative Humidity, Wind Speed and Solar Radiation) made up the input parameters.

Table 3. Definition of Working Variables

No	Parameter	Representation
1	Maximum Temperature	Mx
2	Minimum Temperature	Mn
3	Precipitation	Pr
4	Wind Speed	Ws
5	Relative Humidity	Rh
6	Solar Radiation	Sr
7	Population	Po
8	Land Use	Lu

Control Variables

These are variables responsible to control the dynamism of the system. The control variables relate the model to the climatic variables. In this case, land use and population were selected as Control Variables. The control variables were chosen as indicated in previous literature (Galanis et al., 2006).

Table 2. Kalman Filter Equations

Prediction Equations		
Name and Equation	**Definition of terms**	**Equation No.**
Predicted State $X_{k_p}=Ax_{k-1}+B\mu_k+w_k$	X_{kp} is the Current State A is the State Transitional Matrix x_{k-1} is the previous state B is a transition Matrix μ_k Control Variable Matrix w_k Error	(2)
Process Covariance $P_{k_p}=AP_{k-1}+A^T+Q_k$	P_{kp} is the Process Covariance Matrix P_{k-1} Previous Covariance Matrix Q_k Process Covariance Error	(3)
Update Equations		
Kalman Gain $K=\frac{P_{k_p}H}{HP_{k_p}H^T+R}$	K is the Kalman Gain H is an identity matrix the same dimension as A R is the error. Note 0<K<1	(4)
Measurement update $Y_k=CY_k+Z_k$	Y_k the New Measurement C is a vector which is the same as the Identity matrix Y_k Measurement from sensor (data) Z_k Error related to the sensor	(5)
State Update $X_k=X_{kp}+K\left[Y_k-HX_{k_p}\right]$	X_k Updated measurement X_{kp} is the predicted state Y_k measured value	(6)
Process Covariance $P_k=(I-KH)P_{k_p}$	P_{kp} predicted previous process covariance matrix	(7)

Transfer Functions

These are functions that relate input to output of a system. For a continuous system, it is the Laplace Transform of output to input. To determine the transfer functions which will be used for the State Transition and Control Variable matrices, the data was converted to polynomial using Lagrange Interpolation for unequal interval. The Laplace Transform of the resulting equation taken, and using least square, the unknowns were determined. These were now aggregated into the State Transition and Control Variables Matrices.

The state transition matrix (A) for the Kalman Filter process becomes all transfer function determined as given in Equation 8.

$$A = \begin{bmatrix} MxMx & MxMn & MxPr & MxWs & MxRh & MxSr \\ MnMx & MnMn & MnPr & MnWs & MnRh & MnSr \\ PrMx & PrMn & PrPr & PrWs & PrRh & PrSr \\ WsMx & WsMn & WsPr & WsWs & WsRh & WsSr \\ RhMx & RhMn & RhPr & RhWs & RhRh & RhSr \\ SrMx & SrMn & SrPr & SrWs & SrRh & SrSr \end{bmatrix} \quad (8)$$

Similarly, the control variable matrix becomes:

$$B = \begin{bmatrix} LuMx & PoMx \\ LuMn & PoMn \\ LuPr & PoPr \\ LuWs & PoWs \\ LuRh & PoRh \\ LuSr & PoSr \end{bmatrix} \quad (9)$$

Equation (10) is the final model determined throughout the process for all six climatic variables in the region.

$$\begin{pmatrix} Mx \\ Mn \\ Pr \\ Ws \\ Rh \\ Sr \end{pmatrix} = \begin{pmatrix} MxMx & MxMn & MxPr & MxWs & MxRh & MxSr \\ MnMx & MnMn & MnPr & MnWs & MnRh & MnSr \\ PrMx & PrMn & PrPr & PrWs & PrRh & PrSr \\ WsMx & WsMn & WsPr & WsWs & WsRh & WsSr \\ RhMx & RhMn & RhPr & RhWs & RhRh & RhSr \\ SrMx & SrMn & SrPr & SrWs & SrRh & SrSr \end{pmatrix} \begin{pmatrix} Mx_{k-1} \\ Mn_{k-1} \\ Pr_{k-1} \\ Ws_{k-1} \\ Rh_{k-1} \\ Sr_{k-1} \end{pmatrix} + \begin{pmatrix} LuMx & PoMx \\ LuMn & PoMn \\ LuPr & PoPr \\ LuWs & PoWs \\ LuRh & PoRh \\ LuSr & PoSr \end{pmatrix} \begin{pmatrix} Po \\ Lu \end{pmatrix} + \begin{pmatrix} w_{Mx} \\ w_{Mn} \\ w_{Pr} \\ w_{Ws} \\ w_{Rh} \\ w_{Sr} \end{pmatrix} \quad (10)$$

Where

$\begin{pmatrix} Mx \\ Mn \\ Pr \\ Ws \\ Rh \\ Sr \end{pmatrix}$ = Current State , $\begin{pmatrix} MxMx & MxMn & MxPr & MxWs & MxRh & MxSr \\ MnMx & MnMn & MnPr & MnWs & MnRh & MnSr \\ PrMx & PrMn & PrPr & PrWs & PrRh & PrSr \\ WsMx & WsMn & WsPr & WsWs & WsRh & WsSr \\ RhMx & RhMn & RhPr & RhWs & RhRh & RhSr \\ SrMx & SrMn & SrPr & SrWs & SrRh & SrSr \end{pmatrix}$ = State Transition Matrix, $\begin{pmatrix} Mx_{k-1} \\ Mn_{k-1} \\ Pr_{k-1} \\ Ws_{k-1} \\ Rh_{k-1} \\ Sr_{k-1} \end{pmatrix}$ = Previous State

$\begin{pmatrix} LuMx & PoMx \\ LuMn & PoMn \\ LuPr & PoPr \\ LuWs & PoWs \\ LuRh & PoRh \\ LuSr & PoSr \end{pmatrix}$ = Control Variable Matrix, $\begin{pmatrix} Po \\ Lu \end{pmatrix}$= Control Variables, $\begin{pmatrix} w_{Mx} \\ w_{Mn} \\ w_{Pr} \\ w_{Ws} \\ w_{Rh} \\ w_{Sr} \end{pmatrix}$ = Error

The model is generalized below:

$$x_{(1:m,\,1)} = \boldsymbol{A}_{m \times m} x_{[(1:m,\,1)-1]} + \boldsymbol{B}_{(1:m,1:l)}\, u_{l \times 1} + w_{m \times 1} \quad (11)$$

- Where,
  m, m = size of $\boldsymbol{A}$
  l = Number of columns in $\boldsymbol{B}$

Equation (10) is the Kalman Filter prediction equation for the entire process. The current state which is the state of interest and is based on the previous state, the initial process covariance matrix and the control variable matrix. At each stage of the process, the state of the climate in the region can be approximated.

Spatial Interpolation

The data was spatially interpolated to create a spatial distribution over the region for each climatic variable in ArcGIS 10.4 using the Kriging algorithm.

Rate of Change

After the computation of the state (status of the climatic system) at each year of interest, it is compared with the previous year of the initial year of the entire dataset. Due to this, the dataset was divided into decades commencing from 1980 to the year of interest. The model is now capable of computing the change in the climate system after every ten years for each country for the entire West African Region. Equation (12) was used to determine the change in each parameter.

$$Y = \frac{x_2 - x_1}{x_1} \cdot 100\% \tag{12}$$

- Where Y is the percent change, x_2 is the value at the previous year and x_1 is the value at the current year.

Results and discussion

The results from this study was categorized into decadal values beginning with the year 2020 and ending 2050. The rate of change equation in Equation (12) was used to compute the decadal change for each country. The second part of this section deals with visualization, model validation and performance. To begin with, Table 4 shows results from the model represented in decadal form for all countries in the region.

Table 4 shows the summarized result of the parameters for the four countries in the Mano River Union after the implementation of the model with target year being 2050. Overall, Cote D'Ivoire is expected to have the highest recorded values of Average Temperature followed by Guinea. Solar radiation and wind speed are also expected to increase for the projected years. The least recordings of Average Temperature is expected to occur in Liberia followed by Sierra Leone. On the contrary, Liberia will experience the highest recording of precipitation for the projected years, followed by Sierra Leone while Guinea is expected to receive the least projected precipitation. Liberia is also expected to receive the highest values of relative humidity which subsequently supports the findings that increase in precipitation positively affects relative humidity. From the table, it is evident that densely populated countries have the highest increase in average temperature.

Considering these results in Table 4, Table 5 shows the rate of change for each country in the study area. From Table 5, the Mano River Union is expected to experience increase in annual average temperature by approximately 8%, annual precipitation of 3%, a change of 0.7% in wind speed, relative humidity of -14% and Solar Radiation of 5%. While percentage temperature obtained from a Celsius scale are generally considered unreliable, the results in this study

Table 4. Summary of Results

Country	Year	Ave. Temp (°C)	Precipitation (inch)	Wind Speed (m/s)	Relative Humidity (%)	Solar Radiation (mj/m²)	Land Use (km²)	Population
COTE D'IVOIRE	2020	27.07367	5.023181	1.806645	0.86425	18.30604	63,872	27,509,794
	2030	27.87305	4.696118	2.190408	0.784826	18.78541	60,841	37,261,376
	2040	28.75358	4.706665	2.238524	0.751066	19.65938	57,954	50,469,668
	2050	28.92612	4.719031	2.069686	0.761901	19.31016	55,204	68,359,991
GUINEA	2020	26.72547	5.257016	2.430891	0.700531	19.36799	16,209	13,842,319
	2030	27.36835	5.312469	2.417552	0.63562	20.12407	15,933	17,379,246
	2040	28.32824	5.72602	2.59795	0.577374	20.75238	15,663	21,819,913
	2050	28.35551	5.188646	2.303221	0.615088	20.21015	15,397	27,395,238
LIBERIA	2020	25.9289	8.413921	1.273107	0.973969	16.34489	65,787	5,133,237
	2030	26.40276	7.950083	1.506757	0.918969	16.64167	65,435	6,393,896
	2040	26.82904	8.961138	1.357428	0.914135	16.67668	65,085	7,964,156
	2050	27.11463	7.895248	1.437664	0.913442	16.4801	64,736	9,920,053
SIERRA LEONE	2020	26.58135	8.267902	1.691439	0.893027	17.66483	9,927	8,064,060
	2030	26.84456	7.924362	2.023584	0.854139	17.66575	9,581	9,623,757
	2040	27.28321	8.148898	2.053618	0.83009	18.07016	9,248	11,485,120
	2050	27.60995	7.489075	1.766792	0.829621	17.75088	8,926	13,706,496

nevertheless supports the idea that increase in atmospheric temperature results to decrease in relative humidity (Coffel et al., 2017). The projected value of annual temperature for 2050 is in agreement with the Intercontinental Panel of Climate Change value of 0.5 to +4oC and those of Sylla et. al (2016) for the West African Subregion (IPCC, 2013).

Table 6 shows the covariance between climatic parameter for each country in the region. As shown, there are numerous relationship that can be deduce from the table above. Notably among them is the covariance between parameters in Liberia and Cote D'Ivoire. These values are relatively similar with the only difference occurring in precipitation and solar radiation. In Liberia, Solar Radiation has a positive

Table 5. Rate of Change of Parameters

Country	Year	Average Temperature (%)	Precipitation (%)	Wind Speed (%)	Relative Humidity (%)	Solar Radiation (%)
COTE D'IVOIRE	2030	0.00295	-0.00651	0.02124	-0.00919	0.00262
	2040	0.00316	0.00022	0.00220	-0.00430	0.00465
	2050	0.00060	0.00026	-0.00754	0.00144	-0.00178
GUINEA	2030	0.02405	0.01055	-0.00549	-0.09266	0.03904
	2040	0.03507	0.07785	0.07462	-0.09164	0.03122
	2050	0.00096	-0.09385	-0.11345	0.06532	-0.02613
LIBERIA	2030	0.00183	-0.00551	0.01835	-0.00565	0.00182
	2040	0.00161	0.01272	-0.00991	-0.00053	0.00021
	2050	0.00106	-0.01189	0.00591	-0.00008	-0.00118
SIERRA LEONE	2030	0.00099	-0.00416	0.01964	-0.00435	0.00001
	2040	0.00163	0.00283	0.00148	-0.00282	0.00229
	2050	0.00120	-0.00810	-0.01397	-0.00006	-0.00177
Total		0.07511	-0.02559	-0.00692	-0.14452	0.05100

Table 6. Covariance Matrix for parameters in the region

COUNTRY	PARAMETERS	Average Temperature	Precipitation	Wind Speed	Relative Humidity	Solar Radiation
COTE D'IVOIRE	Ave. Temperature	0.734	-2.796	0.117	-0.041	0.482
	Precipitation	-2.796	16.153	-0.734	0.195	-1.849
	Wind Speed	0.117	-0.734	0.037	-0.009	0.089
	Relative Humidity	-0.041	0.195	-0.009	0.003	-0.028
	Solar Radiation	0.482	-1.849	0.089	-0.028	0.353
GUINEA	Ave. Temp	0.628	1.981	0.009	-0.038	0.396
	Precipitation	1.981	37.787	0.706	-0.206	2.485
	Wind Speed	0.009	0.706	0.015	-0.002	0.031
	Relative Humidity	-0.038	-0.206	-0.002	0.003	-0.029
	Solar Radiation	0.396	2.485	0.031	-0.029	0.324
LIBERIA	Ave. Temp	0.268	-0.539	0.024	-0.013	0.037
	Precipitation	-0.539	158.332	-0.805	0.043	0.482
	Wind Speed	0.024	-0.805	0.01	-0.002	0.009
	Relative Humidity	-0.013	0.043	-0.002	0.001	-0.004
	Solar Radiation	0.037	0.482	0.009	-0.004	0.024
SIERRA LEONE	Ave. Temp	0.209	-3.017	0.012	-0.012	0.043
	Precipitation	-3.017	76.022	0.194	0.16	0.315
	Wind Speed	0.012	0.194	0.033	-0.003	0.02
	Relative Humidity	-0.012	0.16	-0.003	0.001	-0.004
	Solar Radiation	0.043	0.315	0.02	-0.004	0.037

covariance with Precipitation but this value is negative in Cote D'Ivoire. For all countries, there is an inverse relationship between Average Temperature and Relative Humidity. There is also inverse relationship between relative humidity and wind speed in the region whereas a positive correlation exists between average temperature and solar radiation. With the exception of Cote D'Ivoire, solar radiation in the region has a positive covariance with relative humidity. The values in red are the respective variance in each country. It shows how each value deviates from the mean. It can be seen that precipitation has the highest variance in each case. This is because, there are some months of the year where precipitation recordings can be as low as 0 and for some months, precipitation recordings can reach values about 200mm.

MRU Future Climate and Impacts

The variabilities in any climate system have the ability to alter agriculture, water resources and biodiversity to a greater extent. According to the Intercontinental Panel on Climate Change (IPCC), warming above 2°C may counteract the positive effects of more rain on millet, cocoa, sorghum and other agriculture produce. Similarly, these variabilities could have an adverse effect on livestock production across the region.

As shown in Figure 3, coastal areas in the region will continue to experience regulated temperature. This is however due to the proximity of the area to the Atlantic Ocean. The increase in temperature varies as one moves from coastal areas to inland areas. For year 2050 (D), it can be seen that the spatial distribution of average temperature is gradually moving to the south east of the region. The northern parts of Cote D'Ivoire and Guinea shall experience the highest increase in temperature for the predicted years with annual average temperature reaching up to 31°C. These variabilities could have negative impacts on agricultural activities which serve as a means of livelihood for the population. In addition, loss of vegetation could stress cattle rearing and as such farmers and herdsmen could move further south to continue their activities. It is known that the movement of herdsmen has associated security implications.

In Figure 4, the decadal spatial distribution of precipitation over the MRU region is shown. The figure clearly show variability across the four decades. The intensity of precipitation in the region will be higher around coastal areas especially Liberia and Sierra Leone. From the central region to the north which is largely Guinea and Cote D'Ivoire, precipitation is expected to be lower than the coastal areas especially during the second half of the century. Increase in precipitation in the coastal region could indicate a possibility of flooding which is already being experienced in these countries (Nka et al., 2015; EM-DAT, 2018). The central and Northern regions are expected to experience drought at those areas are prone to drought (Climat Environnement Societe, 2012). The decrease in rainfall can lead to human and cattle migration to-

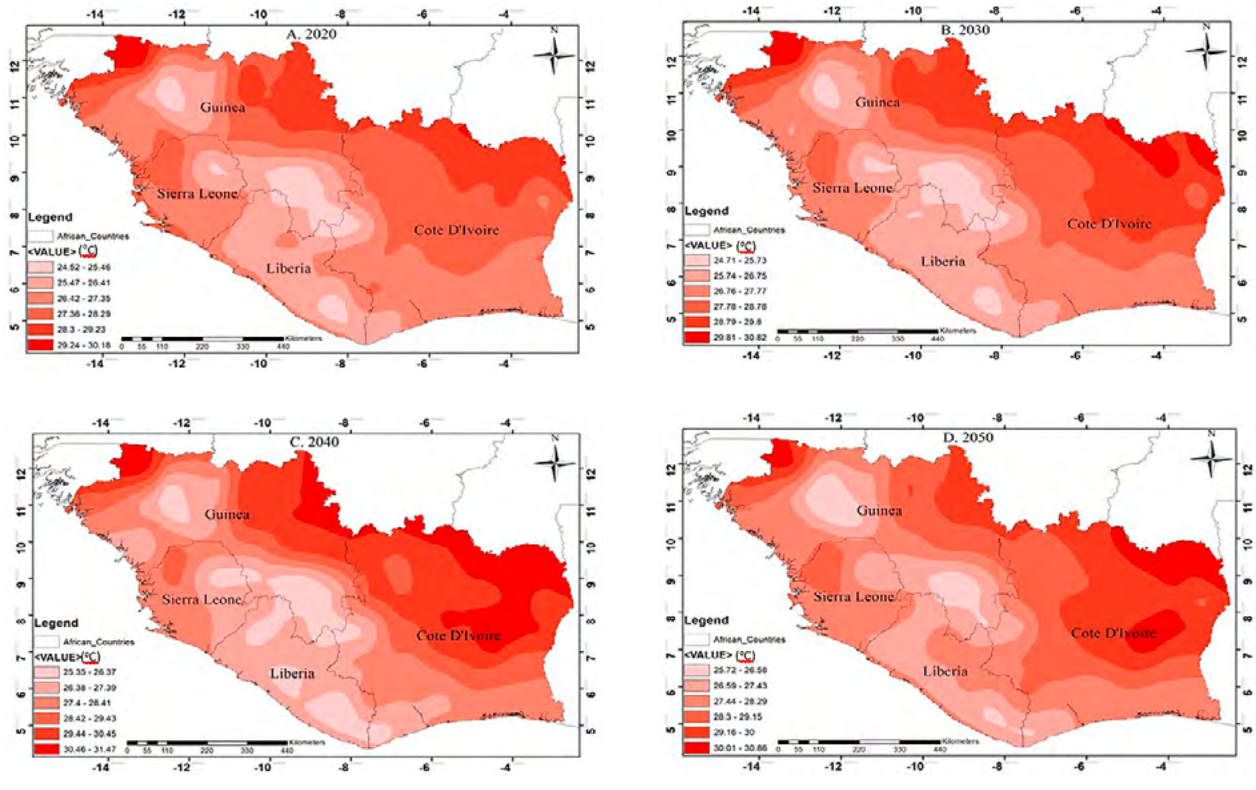

Figure 3. Decadal Spatial Distribution of Average Temperature (°C) in the MRU region for the period (2020-2050)

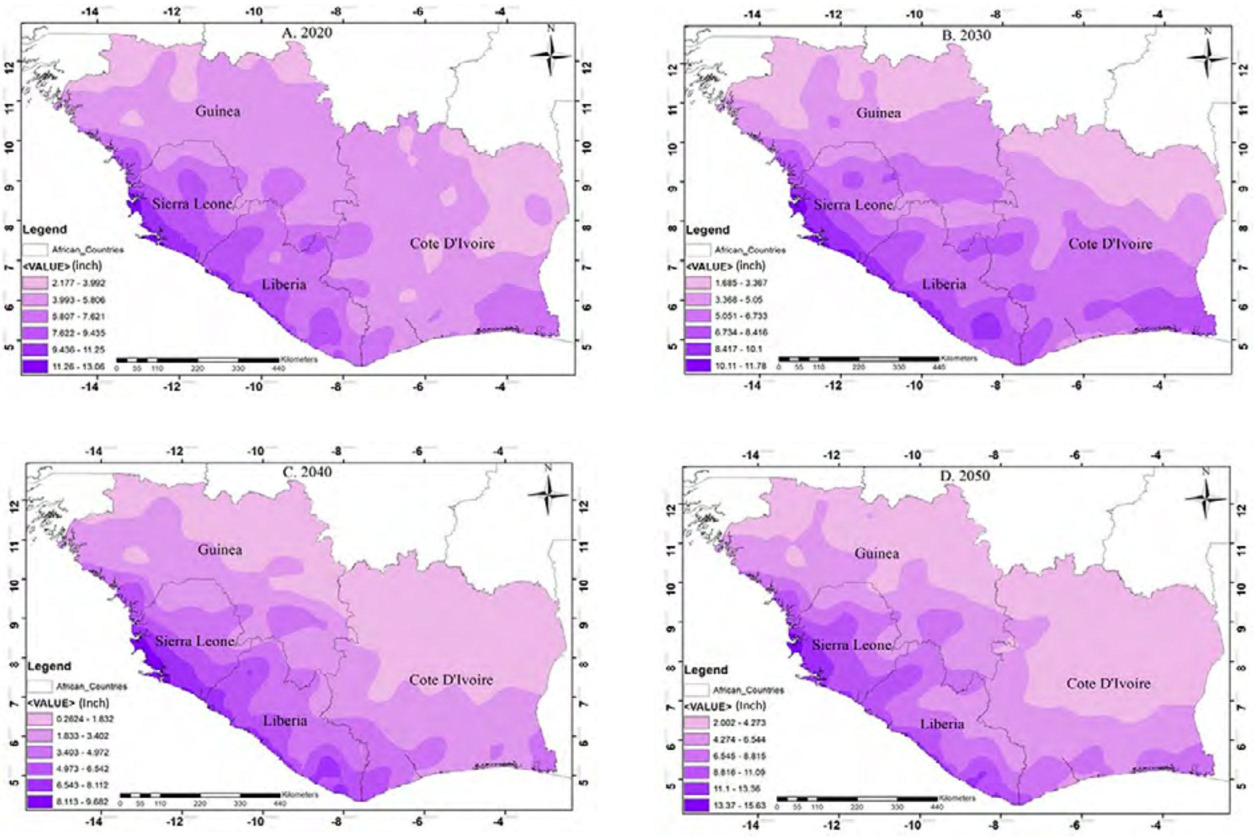

Figure 4. Decadal Spatial Distribution of Precipitation (inch) in the MRU region for the period (2020-2050)

wards areas where fodder crops are available (ECOWAS-SWAC, 2008). Cases have been seen in other West African nations where these migrations brought issues of security concern.

Figure 5 appears to be the opposite of Figure 3 which supports the finding that increase in atmospheric temperature results to decrease in relative humidity (Coffel et al., 2017). The density of relative humidity is gradually decreasing in the southern part of the region. Relative humidity indicates the likelihood of precipitation, dew, or fog which suggests that there is a direct relationship between relative humidity and rainfall. Coastal areas particularly Liberia and Sierra Leone will have the highest predicted values of relative humidity. The northern part, particularly Cote D'Ivoire and Guinea shall receive the lowest predicted values of relative humidity. The region is set to experience heat stress because of rapidly growing population, severe threat to human health and energy infrastructure. Changes in Relative Humidity have the propensity to obstruct radio signals which can also affect GPS signals and other wireless networks (Luomala & Hakal, 2015).

Figure 6 shows the spatial distribution of Wind Speed across the study area for the period 2020 – 2050. As shown, the intensity of wind speed increases from coastal areas to northern parts. It is also shown that there is a positive correlation between the average temperature and wind speed in the region. The northern part which includes parts of Guinea and Cote D'Ivoire will receive the highest of wind speed as those areas are closer to the Sahel region. Areas with high wind speed have the potential for the utilization of wind energy. These are some of the few climatic parameters that have positive effects due to their variation.

As shown in Figure 7, solar radiation in the study area is lowest in the southern parts especially for Liberia, Sierra Leone and the middle belt of Cote D'Ivoire. The northern parts of the region shall experience high solar radiation as opposed to the south. This study agrees with Bazyomo et. al., (2016) that solar radiation in Liberia and Sierra Leone is on a downward trend but disagrees with the values obtained for Guinea and Cote D'Ivoire as solar radiation values are on the increase in these two countries (Guinea and Cote D'Ivoire). Solar radiation in some instances may exert significant negative impact on humans. Some of these effects include sunburns, skin cancer and cataract (Maria et al., 2013). Those areas in the region of high solar radiation can benefit for the utilization of solar potential for photovoltaic applications. This is one of the positive effects of climatic variabilities.

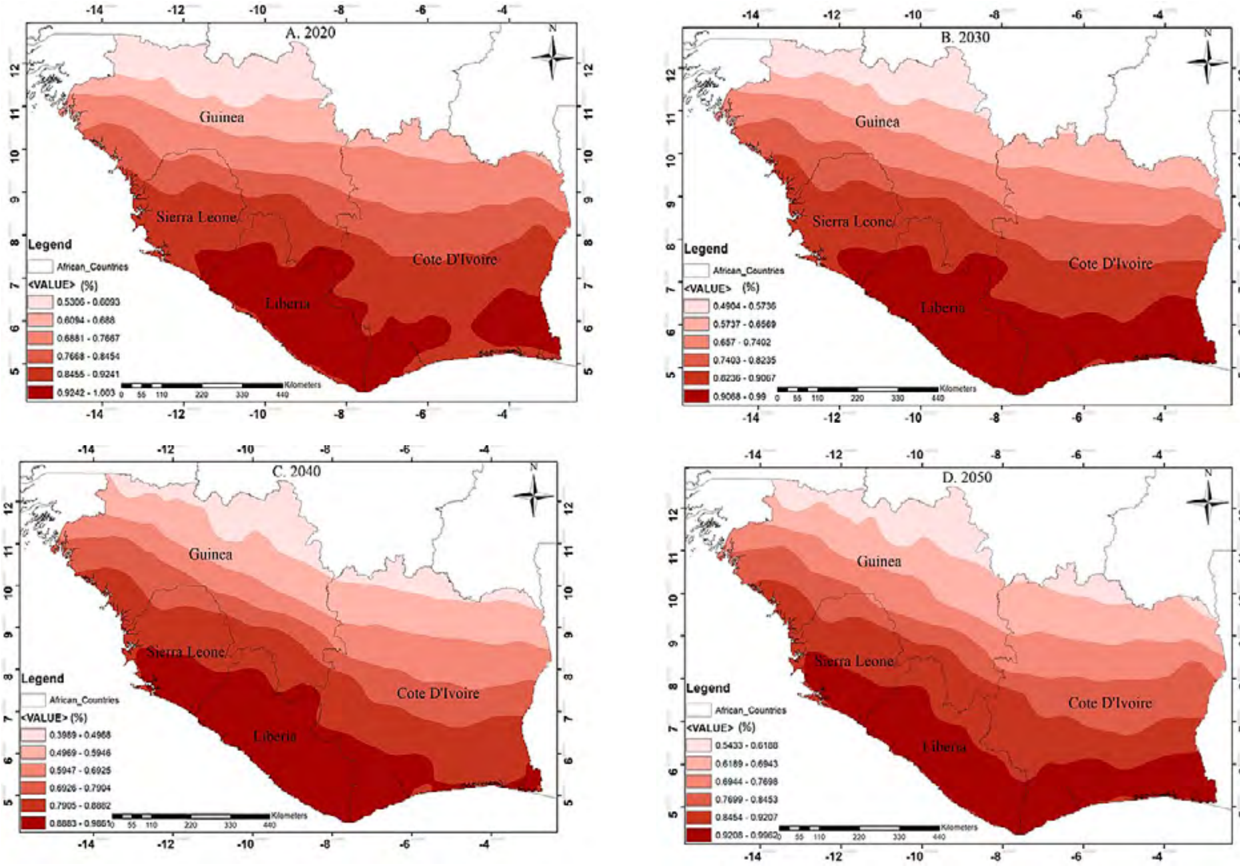

Figure 5. Decadal Spatial Distribution of Relative Humidity (%) in the MRU region for the period (2020-2050)

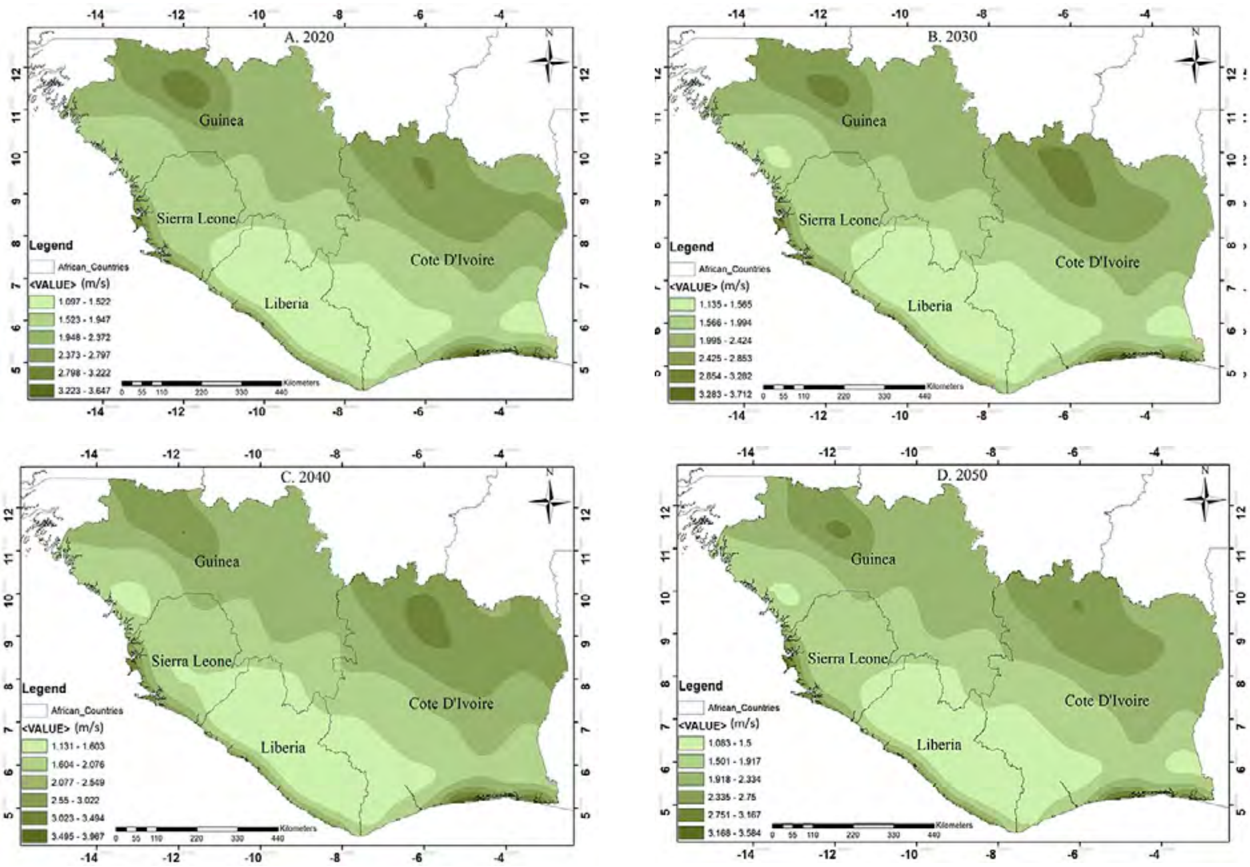

Figure 6. Decadal Spatial Distribution of Wind Speed (m/s) in the MRU region for the period (2020-2050)

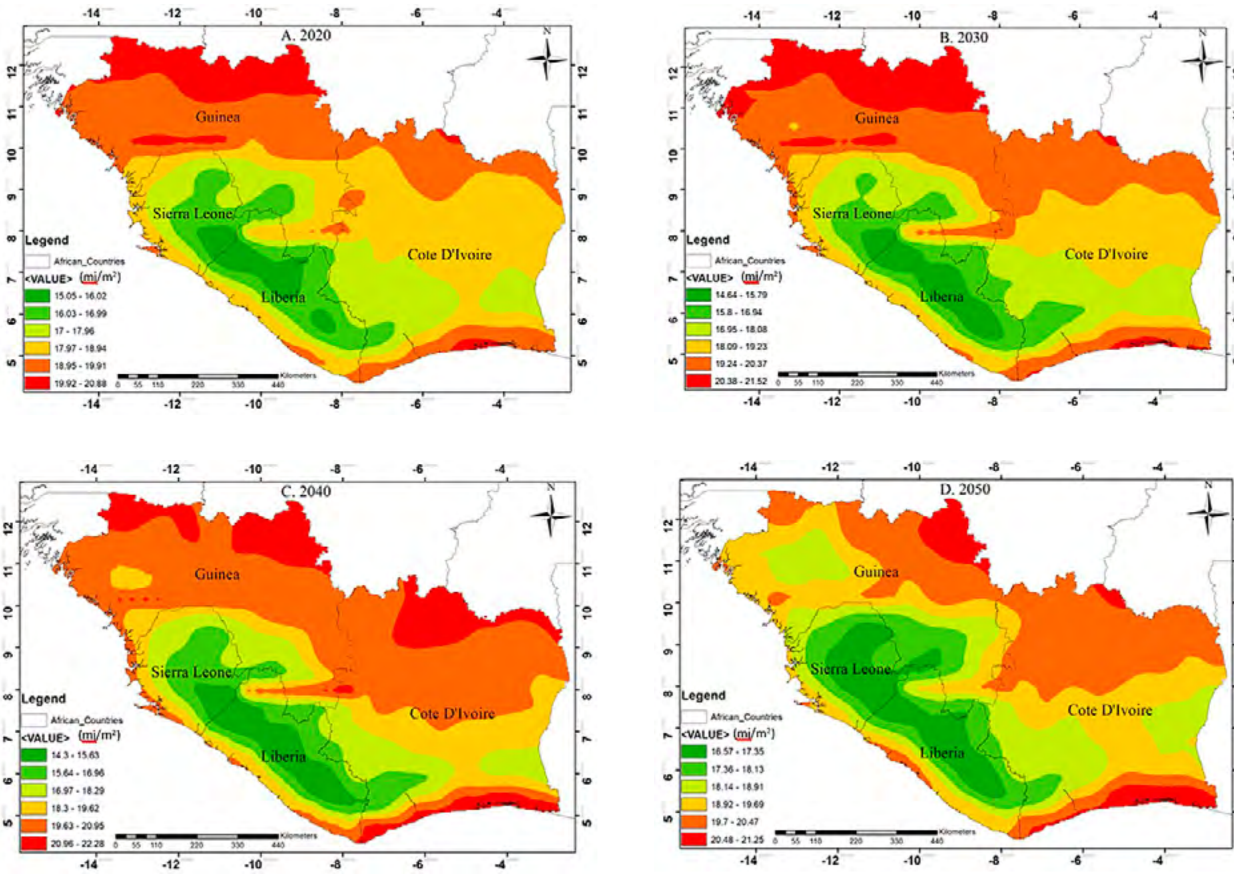

Figure 7. Decadal Spatial Distribution of Solar Radiation (mj/m²) in the MRU region for the period (2020-2050)

Conclusion and recommendation

This work presented a novel approach for modeling the climatic variability in countries making up the Mano River Union. The work has analytically showed that the control variables used in this study (population and land use) have serious impact on climate change variations in the study area. Noting the fact that population and land use both depend on human factors, it can be deduced that this study established a relationship between climatic variabilities and anthropogenic activities in the region.

This study shows that temperature is generally moderate at the coastal region but increases towards the middle and the northern region. However from the 2050 prediction, it can be seen that increase in average temperature is gradually moving to the south east of the region (Figure 3D). The intensity of precipitation is observed to be growing higher at the coastal region and much less in the northern region (Figure 4). Depending on various factors, this could be warning signal to flooding in the southern part. Results also show that density of relative humidity is gradually decreasing in the southern part of the region. A decreasing relative humidity, increasing temperature and rapidly growing population could set a possibility for heat stress in the region. The intensity of wind speed from the results is observed to increase from coastal areas to northern parts. (Figure 6). Increased intensity of wind speed is predicted to be moving southwards as seen in Figure 6 (D). Solar radiation as predicted in the study area is lowest in the southern parts and stretch to the middle belt of the region. The northern part is predicted to experience higher solar radiation as opposed to the south.

The results of this study suggest that predicted climate variabilities can trigger negative outcome on man and the environment. It was noted earlier that Agriculture is the majour occupation of people living in the MRU region. Agriculture could be seriously affected by the predicted results of variations in temperature, precipitation, relative humidity, wind speed and solar radiation, either individually or collectively. This could threaten food security in the region and could have spillover effect on neighbouring countries.

Cognizant of the results obtained, the study recommends the following:

1. Countries in the region formulate policies for the protection of forest since the region has the largest forest cover available in the West African Sub Region;
2. The establishment of institutional framework for public awareness on climate resilient and collaboration among countries in this region;
3. Countries in the MRU region need to consider appropriate policy that can reduce population growth rate since increased population can trigger majour land use changes;
4. Adoption of a common strategy for land use sustainability across West Africa is important to forestall possible spillover effects from neighbouring countries to MRU region;
5. Stakeholders should consider the establishment of centers that will be responsible to gather meteorological data;
6. MRU nations should ensure that the implementation of UNFCCC is fully adhered to;
7. Additional work be done to include atmospheric pressure, moisture and aerosol and also to quantify these variabilities.

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