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COVID-19 reproduction number and non-pharmaceutical interventions in Lithuania

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Abstract. Currently the world is threatened by a global COVID-19 pandemic and it has induced crisis creating a lot of disruptions in the healthcare system, social life and economy. In this article we present the analysis of COVID-19 situation in Lithuania and it's municipalities taking into consideration the effect of non-pharmaceutical interventions on the reproduction number. We have analysed the period from 20/03/2020 to 20/06/2021 covering two quarantines applied in Lithuania. We calculated the reproduction number using the incidence data provided by State Data Governance Information System, while the information for applied non-pharmaceutical interventions was extracted from Oxford COVID-19 Government Response Tracker and the COVID-19 website of Government of the Republic of Lithuania. The positive effect of applied non-pharmaceutical interventions on reproduction number was observed when internal movement ban was applied in 16/12/2020 during the second quarantine in Lithuania.

Keywords: COVID-19 modelling; non-pharmaceutical interventions; reproduction number

AMS Subject Classification: 62P10

Introduction

Since the emergence of the first cases of COVID-19 in Wuhan, China in December 2019, the situation quickly turned into the worldwide pandemics. As of 17th of June

2021, there are over 176 million confirmed COVID-19 cases in the world, and several hundred thousand new cases emerge each day across the globe [1]. In order to be able to control the spread of a virus we need to understand the dynamics of the virus spread and manage it by using the most suitable countermeasures.

In epidemiology, one way to evaluate the temporal variation in the spread of the virus is to calculate the time-varying dimensionless estimate – reproduction number (R). R indicates how many secondary infections might arise from one infected individual. The pandemics develop when $R > 1$; when $R = 1$ the spread is endemic, and the $R < 1$ define the decreasing number of new cases. R estimate is highly dependent on the number of contacts the infected individuals have, probability to infect other healthy individuals and the length of period during which infected individual can infect others [21]. R is often used to determine how the viral transmission changes in regards to changing the policies, adding some restrictions, developing an immunity and other factors [3, 15].

R is calculated using incidence of new infections and serial interval (time between one infection leading to another) data. However, the reproduction number is affected by many factors, including biological, sociobehavioral and environmental which are constantly fluctuating. Moreover, the modelled R values highly depend on the calculation method applied. According to [20] in 2020 there were 21 methods of estimating the reproduction number of infection. These include compartmental, logistic, Bayesian, Monte Carlo, Maximum Likelihood and other methods. In this study we have calculated the R using a Bayesian framework-based method with uncertainty in the distribution of the serial interval presented by Cori *et al.* [10]. The method was implemented in the EpiEstim library of the R programming language [9]. This specific implementation of the method has overcome several drawbacks of other methods: estimates are not right-censored, estimates do not vary much in short periods. The library is plainly documented and user-friendly.

The need of rapid response in this fast evolving COVID-19 pandemics encouraged scientists to apply mathematical approaches to model the dynamics of pandemics and the effect of non-pharmaceutical interventions (NPIs) on the SARS-CoV-2 spread [12]. According to [11] NPIs are public health measures that aim to prevent and/or control SARS-CoV-2 transmission in the community. As prolonged NPIs are causing unwanted social, economic and other disruptions, it is important to use NPIs dynamically and progressively [8, 17].

There have been already a lot of mathematical approaches applied to assess the effectiveness of applied NPIs and public health policies to suppress the spread of SARS-CoV-2. Network-based Susceptible-Exposed-Infectious-Removed (SEIR) compartmental model together with human movement data was used to determine the effectiveness of applied NPIs on the virus transmission [16]. Moreover, Global Epidemic and Mobility Model (GLEAM) was applied to study the impact of applied travel limitations on the spread of the virus internally and outside the country [7]. The analysis of three different models for NPI effectiveness estimation [6] showed that the estimated effect highly depends on the model selected for this purpose.

During the COVID-19 pandemics in Lithuania two quarantines as countermeasures to cope with the spread of the virus were applied: the first one lasted from 20/03/2020 to 20/06/2020, while the second has been applied from 07/11/2020 and lasted till 30/06/2021. During the first quarantine the maximum number of daily new cases was 97, while the maximum daily incidence during the second quarantine was equal to 3,952. In this article we present the analysis of COVID-19 situation in Lithuania and it's municipalities taking into consideration the effective reproduction number and the effect of NPIs on the COVID-19 transmission dynamics during the second quarantine. To our knowledge, this is the first study to analyse NPI effectiveness to control the SARS-CoV-2 transmission in Lithuania and it's municipalities.

1 Materials and methods

1.1 Data

COVID-19 statistics data is being provided by State Data Governance Information System and is publicly available. We retrieved the number of new confirmed COVID-19 cases, number of positive tests, deaths from COVID-19 for each municipality of Lithuania (60 municipalities overall) from "COVID19 statistika dashboards" dataset [22]. We have analysed the period from 20/03/2020 to 20/06/2021 covering two quarantines applied in Lithuania.

In order to evaluate the effect of applied NPIs on the progression of the pandemics, we used following 8 NPIs: school closing, workplace closing, cancel of public events, restrictions on gatherings, closed public transport, stay at home requirements, restrictions on internal movement, international travel controls. We used Oxford COVID-19 Government Response Tracker (OxCGRT) [14] to obtain the NPI data for Lithuania. This dataset consists of 23 government response measures and is being curated by over 200 Oxford University volunteers who are constantly retrieving and updating the data for each country in the world using reliable sources (e.g. governmental websites). NPI information for Lithuania is being updated based on the information provided in the website of Ministry of Health of The Republic of Lithuania [23].

The primary downloaded NPI data was in a form of ordinal variables ranging from 0 to 3 or 4, where the lowest level indicates the least strict intervention and the highest level marks the most strict restrictions (full data description can be found in [14]). We recoded the analysed NPIs into the binary variables as described below:

- 1 if School closing NPI value in original dataset is above 1 and 0 otherwise;
- 1 if Workplace closing NPI value in original dataset is above 1 and 0 otherwise;
- 1 if Cancel public events NPI value in original dataset is above 1 and 0 otherwise;
- 1 if Restrictions on gatherings NPI value in original dataset is above 3 and 0 otherwise;
- 1 if Close public transport NPI value in original dataset is above 1 and 0 otherwise;
- 1 if Stay at home requirements NPI value in original dataset is above 1 and 0 otherwise;
- 1 if Restrictions on internal movement NPI value in original dataset is above 1 and 0 otherwise;
- 1 if International travel controls NPI value in original dataset is above 1 and 0 otherwise.

For reproduction number estimates we used eight NPI binary variables during both quarantine periods. In addition, to describe the situation of second quarantine,

Table 1. Nationwide governmental interventions applied in Lithuania during the second quarantine.

No.	Date	Intervention
1	07/11/2020	start of second quarantine
2	16/12/2020	ban on internal movement
3	02/02/2021	opening of ski centers
4	15/02/2021	opening of non-food shops
5	06/03/2021	partial renewal of sports and leisure services
6	19/04/2021	opening of theaters, shops and permission for events with limitations
7	26/04/2021	opening of sports clubs
8	03/05/2021	graduates returning to schools, hybrid learning
9	10/05/2021	start of hybrid learning for students of 5–11 classes, start of staged vaccination
10	24/05/2021	start of national certificate, opening of pools, allowance of larger public events
11	01/06/2021	allowance of all leisure services

we use detailed information about 11 governmental interventions introduced in second quarantine as well. We retrieved the information about these 11 interventions from the COVID-19 website of Government of the Republic of Lithuania [24]. Dates and descriptions of applied interventions are presented in Table 1. The latter numbering of the governmental interventions we will use later in Fig. 1 and Fig. 2.

1.2 Estimation of reproduction number

We calculated the reproduction number using the method presented by Cori *et al.* [10] where the estimation shows the average number of secondary infections arising after time t if conditions do not change during this time. This method requires only two inputs: the number of new cases and serial interval (time between the start of primary and secondary infections) distribution, and the following equation is used to calculate the estimate:

$$R_t = \frac{I_t}{\sum_{s=1}^{t} I_{t-s} w_s}, \tag{1}$$

where I_t is number of new cases at day t, w_s – current infectivity (probability that secondary infection will appear after s days), s – day when individual was infected. This calculation is implemented in `EpiEstim` R library [9], and is based on main three assumptions:

1. Reproduction number is being estimated using all data from the time period with selected length so it is calculated at the end of this period;
2. In order to achieve sufficient posterior coefficient of variation the accumulated number of new cases in the population or sample should reach minimal number of 11;
3. New cases appear only locally and infection cannot be transmitted to other species.

According to Gostic *et al.* [13], all infections that have occurred during the first specified time period are lost in denominator. Therefore, this method presented by Cori might estimate very large R_t values at the beginning of the time series.

Following the recommendations from Pan American Health Organization [19], serial interval of 4.8 days and standard deviation of 2.3 days with 3 days uncertainty

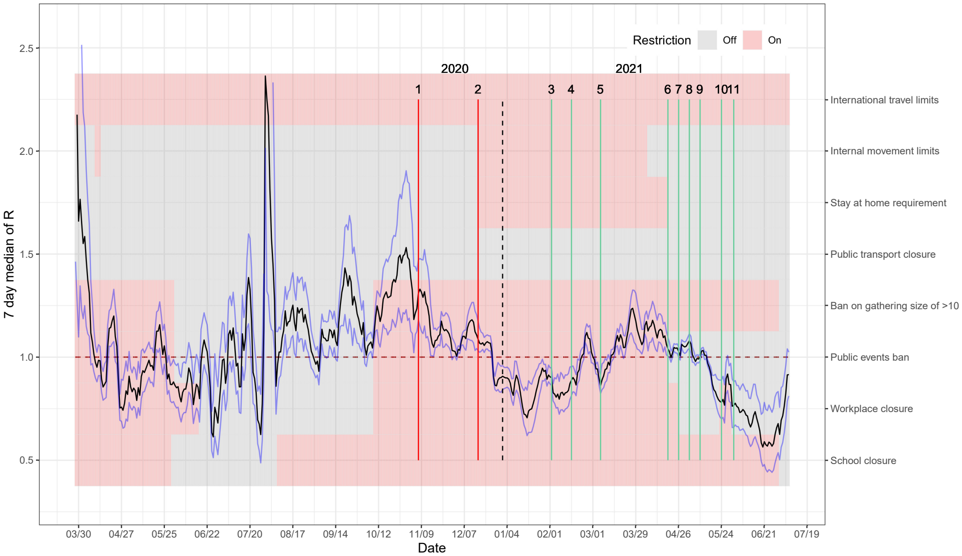

Fig. 1. Reproduction number and the non-pharmaceutical interventions applied at the specific moment in time.

were used for reproduction number estimation. The R_t was estimated only when the accumulated number of new cases reached 11 for each municipality separately. If there was a smaller number of accumulated new cases in the municipality, it was assumed that the reproduction number in that municipality is below 1.

2 Results

2.1 Reproduction number and NPIs in Lithuania

The dynamics of reproduction number and the restrictions applied were analysed from the 20/03/2020 till the 20/06/2021 covering two quarantines applied in Lithuania. The first quarantine was declared in 16/03/2020 and have ended in 16/06/2020. From Fig. 1 one can observe that the estimated R values were very high during the summer season of 2020 but the number of new cases was at low level. This result confirms the feature of selected method that high R values were estimated at the beginning of the pandemics. The effect of specific NPI which is 100% effective can only be observed after some time delay. This is due to the process of clinical infection progression and when the infected individual starts to spread the virus [18]. The number of new cases have started to increase after the summer season, while the applied restrictions were still loosened up. This acceleration of the virus spread evoked the governmental response and resulted in strengthened restrictions with second quarantine in 7/11/2020 (marked with the first vertical red line and number 1 in Fig. 1). After that the reproduction number started to lower, however it has decreased and became lower than 1 only when the additional restrictions of internal movement and requirement to stay at home were applied in 16/12/2020 (marked with the second vertical red line and number 2 in Fig. 1). From February 2021 the reproduction number have started to increase and have exceeded the value of 1. However, the situation

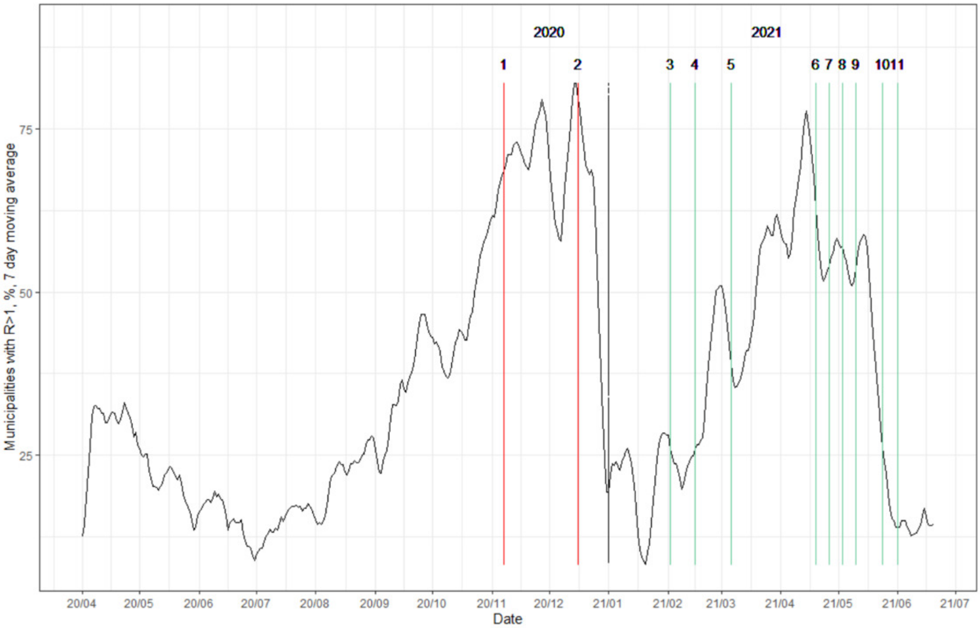

Fig. 2. The dynamics of percentage of Lithuanian municipalities with $R > 1$. Red vertical lines mark the applied governmental restrictions, while green vertical lines show when the restrictions were loosened up. Descriptions of the governmental interventions numbers can be found in Table 1.

in the last several months has improved and together with the steadily decreasing number of new cases governmental restrictions are being lifted (green vertical lines in Fig. 1).

Figure 1 shows the dynamics of 7-day reproduction number median (black curve) with 95% credible interval (blue curves). The red and gray tiles in the background show whether the eight NPIs (listed on the right side of the graph) were applied (On – red background color)/not applied (Off – gray background color) at the specific moment in time. Red vertical lines mark the added governmental restrictions, while green vertical lines show the days when governmental restrictions have been relieved. Red horizontal dashed line marks $R = 1$. The descriptions of nationwide governmental interventions marked with numbers and vertical lines in this figure can be found in Table 1.

2.2 Reproduction number and NPIs in Lithuanian municipalities

Unequal proportions of new cases of COVID-19 in different municipalities of Lithuania suggested estimating the number of reproduction separately for each municipality. Therefore, we have estimated the reproduction number for each municipality separately. As there are 60 municipalities in Lithuania, we cannot present results for each municipality due to limited space. So we calculated the proportion of municipalities with $R > 1$, that is, which part of the country was a source of virus spread. Analysing the reproduction number in separate municipalities of Lithuania we obtained that more than 75% of municipalities had $R > 1$ at the beginning of the second quarantine (it is illustrated in Fig. 2). This number started to decrease only when stricter governmental restrictions were applied in 16/12/2020. Therefore, we performed a more detailed analysis of the situation of municipalities in the second quarantine in two periods – before and after the restriction introduced on 16/12/2021. For both periods, we compared the estimate of R_t at the end of the period compared to the beginning (shown in Fig. 3, where the top panel is for the pre-restriction period and the bottom panel for the post-restriction period).

From the top Fig. 3 we can see that the R_t has lowered in 47 out of 60 municipalities and even decreased below 1 in 5 municipalities (orange arrows) when the second quarantine was applied in 07/11/2020. Indeed, the decrease of R_t was wider spread only when the internal movement ban was applied in 16/12/2020: R_t has diminished in 45 out of 60 municipalities and it has decreased below 1 in 44 out of 60 municipalities (orange arrows at the bottom in Fig. 3). During the period from 16/12/2020 till 02/02/2021 the R_t has decreased for 5 municipalities in which the R_t value was below 1 at the beginning of this period (green arrows at the bottom Fig. 3). In this figure arrows directed to the right and left are showing whether the reproduction number was increasing or decreasing, accordingly, during this period. The green colour shows municipalities that had R_t below 1 at the beginning and have it at the end of the period; orange colour marks municipalities that had R_t above 1 at the beginning and has decreased below 1 at the end of the period; red colour shows where R_t did not decrease below 1 in all periods.

The applied restrictions had a short effect and the situation in municipalities started to deprive till the May of 2021. The possible effect of population's immunity formation and vaccination process itself might be one of the influencing factor for the decrease of viral spread till the end of the analysed period.

3 Conclusions and discussion

In this article we presented the analysis of the SARS-CoV-2 spread in Lithuania and the effect of applied governmental interventions on coping with the pandemics. Non-pharmaceutical interventions were introduced in Lithuania with the first quarantine applied for the whole country. We applied the Cori *et al.* [10] proposed method to calculate the effective reproduction number for viral transmission evaluation. This approach is an improved method to calculate the effective reproduction number overcoming the drawbacks of other methods previously used by other scientists. We estimated reproduction number for Lithuania at country level as well as municipality level. To our knowledge, this is the first study which analysed COVID-19 data with respect to municipalities.

One of the first responses to the increasing spread of the SARS-CoV-2 virus include the non-pharmaceutical interventions which are being applied by the government in each country in the world. The positive effect of applied NPIs was observed when internal movement ban was applied in 16th of December 2020 during the second quarantine in Lithuania. Chang *et al.* [4] found out that the movement ban between cities in the country has an impact on the number of new cases. Moreover, dynamics of the viral spread highly depends on the city's urban characteristics [5].

Current COVID-19 situation in the country is mainly the result of other processes including nation-wide vaccination and formation of population's immunity. However, the causality studies for assessing the effect of other factors, such as environmental

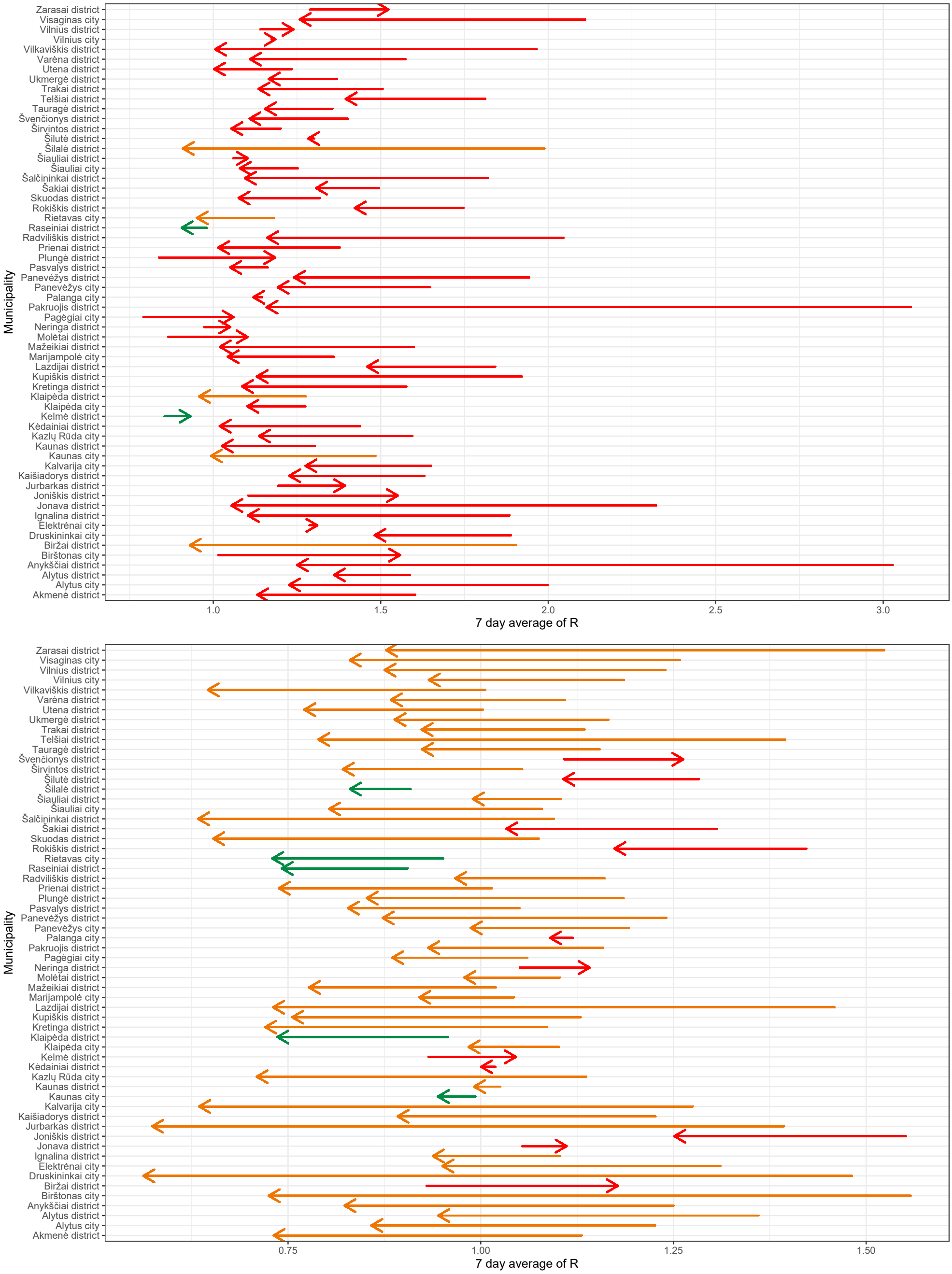

Fig. 3. Change of COVID-19 reproduction number (7 day running average) from 07/11/2020 to 16/12/2020 (top) and from 17/12/2020 to 02/02/2021 (bottom).

factors, could be enrolled.

The uneven number of new COVID-19 cases in Lithuanian municipalities suggested to evaluate the spread for different municipalities separately. Moreover, the effective reproduction number being time-dependent, compared with basic reproduction number, enables to analyse the effect of NPIs, behavioural changes on the viral transmission.

The spread of respiratory infections is highly dependent on the weather conditions and citizens' behaviour [2]. Further analysis of infection's spread including weather conditions and seasonality as variables might be explored when analysing Lithuanian COVID-19 situation.

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REZIUMĖ

COVID-19 reprodukcijos skaičius ir nemedikamentinės intervencijos Lietuvoje

R. Vaišnorė, A. Jakaitienė

Šiuo metu pasaulyje karaliauja COVID-19 pandemija, kuri sukėlė krizę sveikatos apsaugos srityje, taip pat ir socialiniame gyvenime bei ekonomikoje. Šiame straipsnyje pateikiame COVID-19 situacijos Lietuvoje ir atskirose jos savivaldybėse analizę, kurioje analizuojame nemedikamentinių intervencinių priemonių poveikį reprodukcijos skaičiui. Analizuotas laikotarpis nuo 2020-03-20 iki 2021-06-20, kurio metu buvo įvesti du karantino periodai. Reprodukcijos skaičius buvo apskaičiuotas naudojant Valstybės duomenų valdysenos informacinės sistemos pateikiamą naujų COVID-19 atvejų skaičių, tuo tarpu nemedikamentinių priemonių taikymo informacijai naudotas Oxford COVID-19

Government Response Tracker pateikiamas duomenų rinkinys Lietuvai bei Lietuvos Respublikos Vyriausybės COVID-19 tinklalapis. Teigiamas pritaikytų nemedikamentinių intervencijos priemonių efektas pastebėtas pritaikius vidinio judėjimo ribojimą visoje šalyje 2020-12-16 antrojo karantino metu.

Raktiniai žodžiai: COVID-19 modeliavimas; nemedikamentinės intervencijos priemonės; reprodukcijos skaičius