Asian Journal of Research in Infectious Diseases

5(2): 25-36, 2020; Article no.AJRID.61513
ISSN: 2582-3221

Evaluation of EWMA Control Charts for Monitoring Spread of Transformed Observations of COVID-19 in India

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BPS and MJV designed the study and performed statistical analysis. Authors AKT and SS wrote the study protocol and wrote first draft of the manuscript. Author UDD managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRID/2020/v5i230165
Editor(s):
(1) Dr. Giuseppe Murdaca, University of Genoa, Italy.
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Complete Peer review History: http://www.sdiarticle4.com/review-history/61513

Original Research Article

Received 12 September 2020
Accepted 04 October 2020
Published 08 October 2020

ABSTRACT

COVID-19 a pandemic due to novel corona virus emerged from Wuhan, China in December 2019 and now the whole world facing its threat. This is a disaster pandemic for almost every nation on the earth. Such novel corona virus impacts on every country in the world irrespective of race, ethnicity, environment and economic status. In this study, an attempt has been made to use statistical process control technique to understand spread of COVID-19 in some major states of India as well as India. Warning limits and control limits has been estimated and discussed for average weekly growth index

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of COVID-19 pandemic. Study indicates that there is no hope for controlling the pandemic in near future because the average weekly growth index of COVID-19 pandemic is far from zero.

Keywords: COVID-19; growth index; control chart; EWMA.

1. INTRODUCTION

COVID-19 is the most significant global crisis of modern world these days. Expanding across the globe, this pandemic has exceeded pace and size of almost all modern time diseases. The health consequence due to this pandemic is distressing. Wuhan, China is the origin of this pandemic and it spread all over the world because of the lack of awareness and its severity timely. The pandemic has triggered unexpected global economic crisis along with social confusion, and also changed our habits, method of trade, social and economic relations, forms of work, and political organizations (WHO, [1]).

It has exposed global unpreparedness to tackle this pandemic and raised many important questions about size of infected case, growth rate and its terminal point, etc. It has also produced challenge to develop competent models for explaining the nature and dynamics of the epidemic which will be the base to implement various prevention programs. There is also a need of monitoring the effectiveness of the preventing programs and policies. The effective monitoring and needful changes can make a significant difference between spread of COVID-19 and fatality caused. During a pandemic, timely and reliable indications about pandemic status i.e. it is increasing, stabilizing or vanishing, may plays a vital role. Every government is spending its resources to check the pandemic and to protect its citizens.

India is the second most populated country in the world with highly dense population. India has become the third worst affected country in the world in terms of the number of COVID-19 cases after USA and Brazil. Since India has highly dense population and it has also increased the testing capacity, the number of confirmed cases has been increased. As of now (Aug 20, 2020) a total of 2904340 confirmed cases and 54975 deaths in India (covid19india.org). The number of the confirmed cases and deaths are growing day by day in all most all states of country and as a whole. Social factors and some preventive measures like lockdown, social distancing population density, hand washing habits etc vary from state to state. So, the growth of cases is different in different state. The major cities such as Mumbai, New Delhi, Chennai, Ahmadabad, Pune etc are particularly badly affected. The mortality in India is expected to be lower because of the low average age of India's population. The Central and State Governments are taking several measures and formulating several protocols to control over the spread of COVID-19. The Ministry of Health and Family Welfare has taken actions to control the spread of this virus. Still, multiple plans and strategies are necessary to handle the current outbreak. There is a need of monitoring the effectiveness of the preventing programs and policies started by the Government.

If there is no effective monitoring of disease then despite of all effort there will not a desirable outcome. Since, in usual conditions, there is always need of monitoring then during the pandemic, role of monitoring the efficacy of the program is much needed so that adverse events can be minimized. It is difficult to apply the pandemic data directly to mathematical models and check the effect of efforts and preventive measures on the pandemic because total number of cases is unknown. The problem, to make sure how effective the emergency response has been and also how to invest resources more scientifically and efficiently in the future is to be addressed. This purpose can be served by dealing with monitoring the process. Statistical process control (SPC) techniques can help in monitoring the process of pandemic spread. Control chart is a graph in which data are plotted over time and used to study the stability of process.

Basically, the origin of control charts lies in graphical and statistical analysis of process data with the rationale of understanding, monitoring and improving process performance. The main advantage of these charts over other analysis methods is that they provide a simple graphical method with backing of proper statistical theory. These charts enable to display process performance, results and also examine the data chronologically as a time series with valid statistical assumptions. They are easy to construct, use and remain relatively easy to interpret.

W. Shewhart developed control charts for monitoring and controlling manufacturing processes (Shewhart, [2]). Control Charts are usually used to study the stability of a process. In the study of health services the SPC techniques are useful to monitor the stability of performance and also to evaluate their variability caused by external factors. Control charts can help us two manners, first whether the process is in control or not and second, which type of variation is affecting the efficiency of the process. The charts distinguish the source of variations: common cause (or chance cause) which is out of human control and is inherent to any process and special cause (or assignable cause) which is preventable and is caused by outer factor (Mohammed et al.,[3]). Different course of actions are required to tackle these variation for common cause some alteration and for special cause an action on extrinsic factor is required (Tennant et al., [4]). Basically the control charts have three lines; central line (the mean), upper and lower lines as control limits. These limits are usually taken at three times standard deviations from mean (Wheeler, 1995).

The aim of this paper is to show the way of implementing control charts in healthcare during this pandemic. Using the control charts in health care setting is advocated in late 1980's (Berwick, [5]). There are various existing studies of application of control charts in several fields. Many studies suggests, the technique of Statistical process control performed efficiently in various fields such as monitoring the performance of hospital, pre and post operative complications, no. of infections etc. (Finison et al., [6] Finison & Finison, [7], Benneyan, [8]; Maccarthy & Wasusri,[9]; Clemente et al., [10]; Suman et al., [11]; Wiemken, [12]) and are increasingly being adopted for public health surveillance (Woodall, [13]; Morton et al.,[14]; Benneyan, [8]). It is suggested that understanding, monitoring and controlling variation in clinical variables is an important part of clinical practice Glasziou et al. [15]. Recently, Perla et al., [16], using hybrid Shewhart chart i.e. *C-chart* and *I-chart*, to detect the start and end of exponential growth in reported deaths within a geographic area, illustrates the various growth phases in the process of reported deaths. Further, Liu et al. [17], using (a completely non-parametric) Exponentially Weighted Moving Average (*EWMA) control* chart based on rank methods for a multivariate process demonstrate the performance of the method on real Japanese influenza data.

2. DATA AND METHODOLOGY

Control charts are the most commonly used quality control tools and committed to monitoring and detecting shifts in the process parameters over time. Control charts are based on the assumption that data are normally distributed and the monitored characteristic is independently distributed (there is no autocorrelation in the production process).

Control charts are designed to detect instability of the monitored processes. In the control chart central line is located at a level equal to the average of the monitored characteristic. In addition to this, there are two control limits (upper and lower) and two warning lines (upper and lower). There are several sets of rules that can be used in monitoring processes and help to detect trends in the time series (Montgomery, [18]).

Let $P_1, P_2, ...P_t$ are the consecutive time series observations on confirm daily cases of COVID-19 cases. Now we define a growth index G_t for the construction of control chart. The growth index for period *t* can by written using the formula

$$G_t = \left[\frac{P_t}{P_{t-1}}\right], \text{ for } t = 2, 3, 4....$$

If G_t >1 means number of COVID-19 cases are increasing and if G_t <1 means number of COVID-19 cases are decreasing over the time. When G_t =1 means number of COVID-19 cases are remain same over the time. It is expected that in presence of effective preventive measures such as lockdown, masking and distancing, G_t will become zero mean no COVID-19 cases further. If it is not so then we can say preventive measures taken by the government are not effective due to defiant behavior of peoples. Pawłowski [19] suggests that the warning lines equal to the average of the process characteristics $\pm\sigma$ and the upper and the lower control limits respectively at the following levels, the average $\pm 2\sigma$. Since the monitored characteristic is an index (the ratio of two successive time series values) the level of the control and warning lines has to be estimated. The standard deviation σ is estimated as

$$\sigma = \frac{\overline{R}}{d_2\sqrt{n}}$$, here we taken 16 weekly data

thus n =7 and d_2 =2.704 for n =7.

It can be made on the basis of a large sample taken from a stable process. Location of successive points on the control chart determines the prediction method for the next period. Pawłowski [19] suggested the following possible options of the forecasts for the *t*+1 period construction:

a) If successive points corresponding to the last *r* measurements are between the warning lines then it should be concluded that the process is stable and the forecast could be stated at the level of the average of the last *r* measurements (*r* is the number of recent points between the control lines), that is for r ≥ 1

$$P_{t+1} = \frac{1}{r}\sum_{i=0}^{r-1} P_{t-i}$$

b) Two successive points that are above the upper (lower) warning line indicate a tendency of an increase (or decrease) and the forecast should be described in the following form

$$P_{t+1} > \frac{1}{r}\sum_{i=2}^{r+1} P_{t-i} \quad for\ r \geq 1$$

c) A single point above the upper (lower) control limit determines the forecasts in the following form

$$P_{t+1} > \frac{1}{r}\sum_{i=1}^{r} P_{t-i} \quad for\ r \geq 1$$

The data of cumulative corona virus positive cases from May 2, 2020 to July 24, 2020 are taken from the website www.covid19india.org [20] for India as well as some major states.

3. RESULTS AND CONCLUSION

Table 1 presents, weekly growth index (*G*) for major states of India as well as whole country. Also range and standard deviation of the *G* are estimated and given in the table. As above mentioned, the *G* explains growth status of COVID-19 cases in different weeks. If the value of *G* is more than one means, cases are growing from preceding day to next day, if it less than one, it indicates cases are decreasing. For COVID-19 free, the estimate of *G* should be tends to zero. Most of the Indian states are quite different in culture and population density, so analysing COVID-19 cases, considering India as a whole may not provide us the right picture, thus there is a need of state wise analysis of COVID-19 growth status.

Table 1a. Estimated values of $\overline{G}_t$ and R for India and northern states

Date Segment		India		Uttar Pradesh		Madhya Pradesh		Rajasthan		Bihar	
From	To	$\overline{G}_t$	R	$\overline{G}_t$	R	$\overline{G}_t$	R	$\overline{G}_t$	R	$\overline{G}_t$	R
02-May-20	08-May-20	1.0588	0.4258	1.0962	1.3403	1.0768	1.4716	1.1672	1.0849	1.3537	3.3194
09-May-20	15-May-20	1.0293	0.5246	1.0472	0.9407	1.1247	0.6855	1.0889	0.8484	1.3666	2.6577
16-May-20	22-May-20	1.0894	0.4131	1.1530	1.6295	1.0344	0.6167	1.0734	0.7574	1.6068	3.5394
23-May-20	29-May-20	1.0370	0.3247	1.0655	0.8659	1.0404	0.8028	1.0244	0.3196	1.1485	1.8968
30-May-20	05-Jun-20	1.0252	0.2627	1.2544	2.2197	1.0541	0.6386	0.9712	0.5043	1.0361	0.9754
06-Jun-20	12-Jun-20	1.0328	0.3850	1.0516	1.0294	0.9939	0.6243	1.0234	0.6617	1.0466	1.0039
13-Jun-20	19-Jun-20	1.0429	0.3016	1.0699	0.3886	0.9725	0.3173	1.0612	0.6290	1.1732	1.7308
20-Jun-20	26-Jun-20	1.0344	0.2596	1.0040	0.5105	1.0547	0.5949	1.0527	0.5566	0.9967	0.7318
27-Jun-20	03-Jul-20	1.0338	0.1944	1.0551	0.5555	1.0123	0.5438	1.0221	0.4094	1.2342	1.6292
04-Jul-20	10-Jul-20	1.0303	0.1646	1.0797	0.7443	1.0997	0.8616	1.0920	0.6077	1.0613	1.4455
11-Jul-20	17-Jul-20	1.0340	0.1218	1.0445	0.4038	1.1636	0.9292	1.0175	0.5293	1.3133	1.1327
18-Jul-20	24-Jul-20	1.0521	0.2494	1.0686	0.3152	1.0161	0.3830	1.0718	0.3917	1.0218	0.5923

Table 1b. Estimated values of $\bar{G}_t$ and R for some major states (Contd.)

Date Segment		Maharashtra		Gujarat		Delhi		Haryana		West Bengal		Odisha	
From	To	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R
02-May-20	08-May-20	1.1023	1.6833	1.0301	0.3112	1.1601	1.4874	1.2781	3.0604	1.5389	3.2114	1.8806	3.3095
09-May-20	15-May-20	1.1025	1.0348	0.9829	0.1775	1.0838	1.0382	1.2446	1.6631	0.9597	0.6731	1.4878	4.2860
16-May-20	22-May-20	1.1071	0.6071	1.2017	2.7389	1.0954	0.9637	1.0682	1.3030	1.1099	0.7935	0.9589	2.1250
23-May-20	29-May-20	0.9969	0.3852	1.0052	0.1996	1.1355	1.2735	1.4980	2.6252	1.1748	1.1634	0.9784	0.7479
30-May-20	05-Jun-20	0.9937	0.3152	1.0482	0.2029	1.0406	0.5466	1.0752	0.7457	1.0868	0.7308	1.1527	0.8944
06-Jun-20	12-Jun-20	1.0677	0.5917	0.9965	0.1213	1.0848	0.5710	1.0354	0.5786	1.0228	0.4096	1.0679	1.4065
13-Jun-20	19-Jun-20	1.0201	0.4025	1.0129	0.0781	1.0701	0.5580	1.0710	0.6708	0.9639	0.2964	1.1319	1.2692
20-Jun-20	26-Jun-20	1.0470	0.3813	1.0108	0.1054	1.0265	0.5304	0.9760	0.4109	1.0694	0.3464	1.1275	1.2279
27-Jun-20	03-Jul-20	1.0427	0.4049	1.0250	0.0983	0.9647	0.3891	1.0490	0.7050	1.0322	0.1608	1.2403	1.6700
04-Jul-20	10-Jul-20	1.0406	0.4672	1.0356	0.0932	1.0006	0.8416	1.0347	0.5574	1.0899	0.2426	1.0544	0.4261
11-Jul-20	17-Jul-20	1.0132	0.3530	1.0118	0.0391	0.9615	0.4968	1.0504	0.1723	1.0712	0.2408	1.0152	0.6985
18-Jul-20	24-Jul-20	1.0283	0.4030	1.0173	0.0661	0.9678	0.6263	1.0055	0.3760	1.0251	0.2508	1.1491	0.8430

Table 1c. Estimated values of $\bar{G}_t$ and R for southern states (Contd.)

Date Segment		Andhra Pradesh		Karnataka		Kerala		Tamil Nadu		Telangana	
From	To	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R	$\bar{G}_t$	R
02-May-20	08-May-20	0.9882	0.2597	1.5047	3.5000	0.0000	0.0000	1.2199	1.2289	1.5584	3.5238
09-May-20	15-May-20	1.1686	1.1924	1.5369	4.2407	1.7757	2.8846	0.9712	0.5610	1.4293	2.4544
16-May-20	22-May-20	1.0607	1.6094	1.2719	1.6847	1.3136	1.6576	1.0998	0.5008	1.1173	0.9887
23-May-20	29-May-20	1.0977	0.9420	1.1876	1.5547	1.1535	1.5280	1.0232	0.4622	1.2039	0.9085
30-May-20	05-Jun-20	1.1083	0.7819	1.2920	1.5520	1.1016	0.5743	1.0775	0.2860	1.1523	2.2513
06-Jun-20	12-Jun-20	1.5167	4.8418	0.9931	1.1773	0.9636	0.5626	1.0481	0.1706	1.0960	1.3374
13-Jun-20	19-Jun-20	1.1334	0.4611	1.0977	1.0333	1.0952	0.8832	1.0228	0.6130	1.1950	0.6186
20-Jun-20	26-Jun-20	1.0402	0.1840	1.0742	0.7435	1.0414	0.4103	1.0844	0.2964	1.1072	0.3290
27-Jun-20	03-Jul-20	1.0586	0.4279	1.2606	1.2059	1.0777	0.7136	1.0258	0.1342	1.1139	0.6554
04-Jul-20	10-Jul-20	1.1192	0.5731	1.0568	0.5637	1.1146	0.5515	0.9800	0.2567	0.9540	0.4187
11-Jul-20	17-Jul-20	1.0748	0.2791	1.0819	0.4268	1.1043	0.4627	1.0309	0.0841	1.0261	0.3396
18-Jul-20	24-Jul-20	1.1973	0.7149	1.0542	0.4201	1.0442	0.6920	1.0607	0.1821	1.0197	0.3249

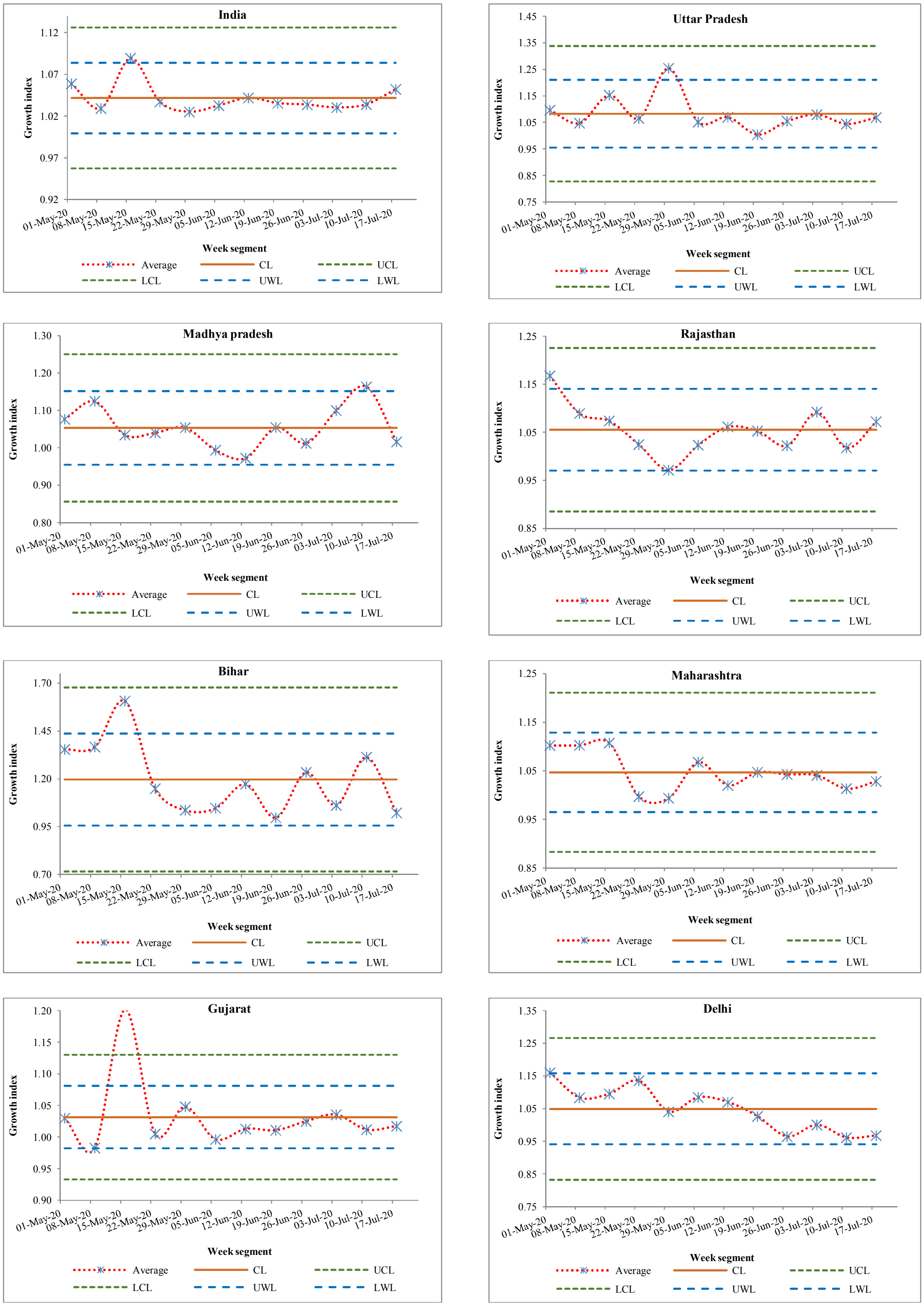

Fig. 1a. Average control chart of growth index for India and different states

Fig. 1b. Average control chart of growth index for India and different states (contd.)

The growth index of COVID-19 for India in first time segment (02 May-08 May, 2020) was 1.0588 and results also show that the growth index is observed different for different states. In the beginning growth of COVID-19 cases for Kerala was minimum and it was maximum for Odisha. Irregular pattern of growth index is observed in all segments for each and every states as well as India. The growth index has been decreased in the beginning weeks for Odisha, West Bengal, Haryana, Delhi, Rajasthan etc. and then further increased. However it has been increased from first segment to last segment for Andhra Pradesh and Kerala. The range of growth index is also observed irregular for all states and for India.

It have been also estimated the average growth index of whole duration for all major states of India as well as whole country and it is given in Table 2. Table indicates that Karnataka has highest growth index followed by Bihar and Odisha for the study period. It has been observed that growth index of Gujarat is minimum. Table 2, shows that Madhya Pradesh, Rajasthan, Maharashtra, Delhi and Tamil Nadu have same level of growth index. The fifth column of the Table 2 shows the standard deviation of growth index for all selected states. The maximum variation in growth index was found in Bihar followed by Odisha and Karnataka and the minimum variation was found in Gujarat followed by Tamil Nadu and Rajasthan.

Here we plot *X-bar* chart and *EWMA-chart* of COVID-19 cases for India as well as some of the states. The *X-bar* chart for India shows that the average growth index is found below to the central line from mid June to the mid July but unfortunately it crosses the central line after that means preventive measures are not effective. The average growth is still more than one indicates, in the near future the burden of pandemic will increasing. The upward movement shows a warning to the authorities for the growing number of COVID-19 cases. Perhaps it may be the effect of loosening the lockdown and insensitive behavior and wrong attitude of people towards severity of this pandemic. For better control the average growth index should be below to the central line and for COVID-19 free condition the average growth index must be close to zero. According to the *X-bar* chart, India and almost every state show more fluctuation in the beginning of the process but stabilize at the end perhaps because the variation in reporting of the data in the beginning, but the situation is almost same in all the states of India. Some states such as Maharashtra, Andhra Pradesh, Kerala shows the average growth index is still more than the national level. It is noteworthy that state of community spread of COVID-19 which is said to be the most distressing form of corona virus spread among the society but there is no clue of occurrence of community spread in India. Although, index values are within the control limits but one cannot say that India or any state are in desired condition. It will come when the index for some week touches zero-*axis* after crossing the lower control limit.

It has been already established that *EWMA* chart is superior to the usual *range* chart or s^2 chart on the account of its ability to promptly detection of small percent change in the process standard deviation (Crowder & Hamilton, [21]). According to the given *EWMA* charts, India along with many states does not have six sequential points

Table 2. Estimated values of $\bar{\bar{G}}_t$, $\bar{R}$ and σ for India and some major states

Sl. No.	States	$\bar{\bar{G}}_t$	$\bar{R}$	σ
1	India	1.0417	0.3023	0.0423
2	Uttar Pradesh	1.0825	0.9120	0.1275
3	Madhya Pradesh	1.0536	0.7058	0.0987
4	Rajasthan	1.0555	0.6083	0.0850
5	Bihar	1.1966	1.7212	0.2406
6	Maharashtra	1.0468	0.5858	0.0819
7	Gujarat	1.0315	0.3526	0.0493
8	Delhi	1.0493	0.7769	0.1086
9	Haryana	1.1155	1.0724	0.1499
10	West Bengal	1.0954	0.7100	0.0992
11	Odisha	1.1871	1.5753	0.2202
12	Andhra Pradesh	1.1303	1.0223	0.1429
13	Karnataka	1.2010	1.5086	0.2109
14	Kerala	1.0654	0.9101	0.1272
15	Tamil Nadu	1.0537	0.3980	0.0556
16	Telangana	1.1644	1.1792	0.1648

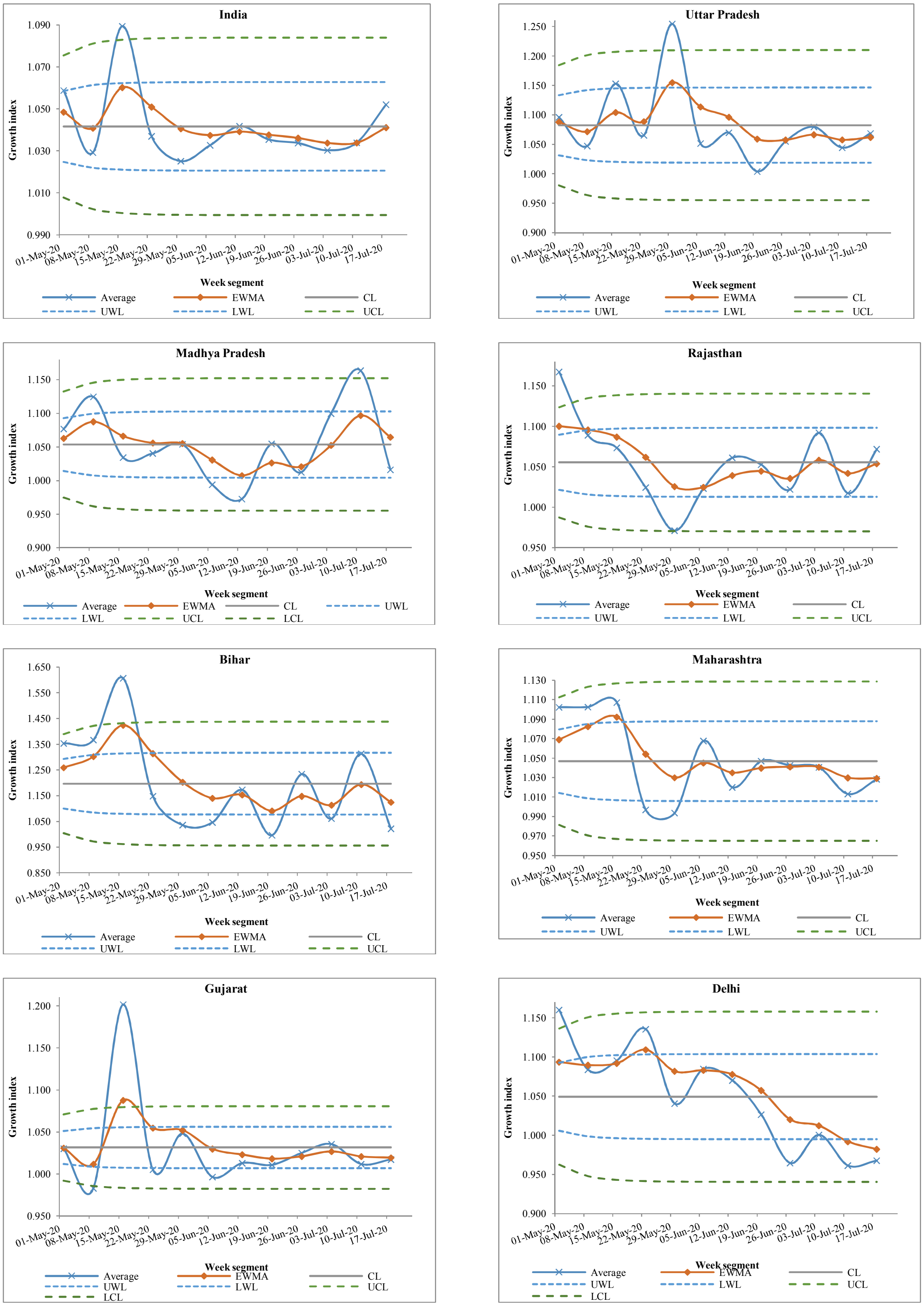

Fig. 2a. EWMA chart of growth index for India and different states

Fig. 2b. EWMA chart of growth index for India and different states (Contd.)

descending or eight sequential points that are below the centre line so the data indicates system is unstable. Some states Maharashtra, Gujarat, Haryana, West Bengal, Odisha, and Karnataka having six sequential points below the central line. Eleven out of fifteen states are below the central line whereas Rajasthan, Madhya Pradesh, Andhra Pradesh and Kerala are above the central line. India and few states (Rajasthan, Andhra Pradesh, Odisha and Tamil Nadu) are moving upward which is unfavorable to preventing spread of COVID-19 whereas Madhya Pradesh, Bihar, Delhi, Haryana, West Bengal, Karnataka, Kerala and Telangana are moving downward in the study period. This study demonstrates a significant role for Statistical Process Control techniques to understanding the important point of time.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

ACKNOWLEDGEMENT

Authors are extremely thankful to the referees for valuable suggestion to improve the manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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