Comparative Analysis of Testing Strategy for COVID 19 of Countries – Identifying the Key Performers and their Management of COVID-19

By

Parul Aggarwal

Dissertation submitted in partial fulfillment of the requirements of the degree

MBA Hospital and Health Management

Academic year, 2018-2020

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CERTIFICATE BY THE SCHOLAR

This is to certify that the dissertation titled "**Comparative analysis of testing strategy for COVID 19 of countries – identifying the key performers and their management of COVID-19**" is submitted by **Parul Aggarwal**, Enroll No: **0794** under the guidance of **Dr. Alok Kumar Mathur, IIHMR University, Jaipur** for award of **MBA in Hospital and Health Management** of the IIHMR University. I conducted the study at **PricewaterhouseCoopers** during the period from **10th February 2020** to **30th June 2020.**

"The study is my original work and has not formed the basis for the award of any degree, diploma, associateship, fellowship, titles in this or any other institute or other similar institution of higher learning in India."

Parul Aggarwal
MBA-Hospital & Health Management

ABSTRACT

Title: Comparative analysis of testing strategy for COVID 19 of countries – identifying the key performers and their management of COVID-19

Submitted by: Parul Aggarwal

Introduction: COVID-19 which originated from China during Dec 2019 spread across the globe affecting millions of lives. Different countries adopted different strategies to combat the spread of infection, minimize the risk of transmission and experienced different outbreaks.

Many countries imposed strict restrictions, lockdown and social distancing measures to prevent transmission and buy time to manage the resources. However, to prevent new peaks, overwhelming of healthcare facilities suppression of transmission is must for which early diagnosis of cases, tracking and tracing of contacts and isolating them is must. To implement this approach testing in high numbers is required for early identification of cases. Testing serves 4 purposes: diagnosis of cases, breaking the transmission chain, planning and allocation of resources and identifying immune people to understand establishment of herd immunity.

Objectives: This study aims to assess and compare testing strategies adopted by different nations across the world, their effectiveness in containing the spread of virus and comparison with status in India

Methodology: The study is a cross sectional study spanning over 7 countries – USA, UK, New Zealand, South Korea, Taiwan, Japan and India. Cases and tests data were collected from January till mid-June from ourworlddata.org and databases, journals, articles and government sources were referred for literature. Data was analyzed using basic excel functions to calculate correlation coefficient and R^2 for estimation of effectiveness of testing strategies

Findings: Comparing the graphs of tests and cases per million it was observed that South Korea, Taiwan, Japan and New Zealand have implemented effective and timely testing strategies (South Korea, Taiwan, Japan and New Zealand had lower tests required per active case, their R2 numbers are high and correlation coefficient nearing 1) have resulted in containment of outbreak. Whereas, USA and UK have gradually ramped up their testing capacity resulting in increased transmission and ever-growing outbreak.

Countries in the order of highly effective testing strategies to least effective

South Korea > Taiwan > New Zealand > Japan > UK > USA > India

Comparing India, testing capacity was gradually ramped up from March till June However, low testing numbers, focusing only on symptomatic cases resulted in increased transmission and ascending curve of cases despite a prolonged lockdown.

Suggestions: Based on comparing and assessing testing strategies for the countries mentioned above following are the suggestions were concluded for India: Early interventions by Government is required to increase the testing capacity, testing, tracing and isolation of asymptomatic individuals is must to break the chain of transmission, increasing capacity by building drive through and walk in centers, utilizing the power of data for decision making and developing strategies, rolling out surveillance plans and increasing antibody testing, using targeted approach towards testing as per the number of cases in different zones

Key Words: COVID-19, Containment measures, testing, strategies, effectiveness, countries

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Parul Aggarwal

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LIST OF ABBREVIATIONS

SARS	Severe Acute Respiratory Syndrome
WHO	World Health Organization
ALI	Acute Lung Injury
ARDS	Acute Respiratory Distress Syndrome
CDC	Center for Disease Control
EU	European Union
GDP	Gross Domestic Product
RT-PCR	Real Time – Polymerase Chain Reaction
NPI	Non-Pharmaceutical Intervention
USA	United States of America
UK	United Kingdom
OECD	Organization for Economic Cooperation and Development
TTT	Testing, Tracking, Tracing
MERS	Middle East Respiratory Syndrome
RDT	Rapid Diagnostic Test

NAAT	Nucleic Acid Amplification Test
HCP	Healthcare Providers
NHS	National Health Service
ICU	Intensive Care Unit
GPS	Global Positioning System
KCDC	Korea Center for Disease Control and Prevention
NHI	National Health Insurance
ILI	Influenza like illness
ICMR	Indian Council of Medical Research
R&D	Research & Development
ELISA	Enzyme linked Immunosorbent Assay

1. Introduction

Novel coronavirus (SARS-CoV-2) which was first reported to WHO country office in china on 31st December 2019 as the causative agent of an outbreak of pneumonia cases in Wuhan has rapidly spread around the world causing loss of lives, disruption of economies and lockdown of world leading powers.

"Coronaviruses are part of the Coronaviridae family in the Nidovirales order. These viruses cause Acute Lung Injury (ALI) and Acute Respiratory Distress Syndrome (ARDS) which leads to pulmonary failure and ultimately results in fatality" [1]

1.1. Timeline

"The COVID-19 outbreak which emerged in China, initiated in the Hunan seafood Market in Wuhan city and rapidly infected several people.

31st December 2019 – Wuhan Municipal Health Commission reported cluster of 27 pneumonia cases of unknown etiology

9th January 2020 – China CDC reported that a novel coronavirus had been detected as the causative agent of pneumonia cases

12th January 2020 - National Health Commission of China released details about the epidemic suggesting viral pneumonia. Initially the transmission was linked to patients visiting the seafood market but with further investigation it was found that individuals had contracted the virus with no record of visiting the market thus confirming the presence of human to human transmission of virus which was subsequently reported in more than 100 countries

20th January 2020 – Reports of confirmed cases in 3 nations outside China: Japan, Thailand and South Korea

23rd January 2020 – Lockdown of Wuhan city

24th January 2020 – First European case reported in France

30th January 2020 - World Health Organization (WHO) declared this first outbreak of novel coronavirus a 'public health emergency of international concern'" [2]

1.2.Declaration of pandemic and stages

On March 11, WHO declared the COVID-19 outbreak as a global pandemic as the cases outside of China increased 13- fold and number of countries with cases increased threefold[2.] The virus has spread over 4 stages:

1st stage – Cases reported are from people who have travelled from already infected country, there is no local transmission

2nd stage – Local transmission – When people who have brought the virus transmit it to the people, they come in contact with

3rd Stage – Source of infection is untraceable as people who are infected don't have any travel history

4th Stage – Many major clusters on infection across the country resulting in uncontrollable spread[3]

The virus has infected 6,464,330 people across nations claiming 382,717 lives as of 3rd June 2020[4] with many countries in Stage 4

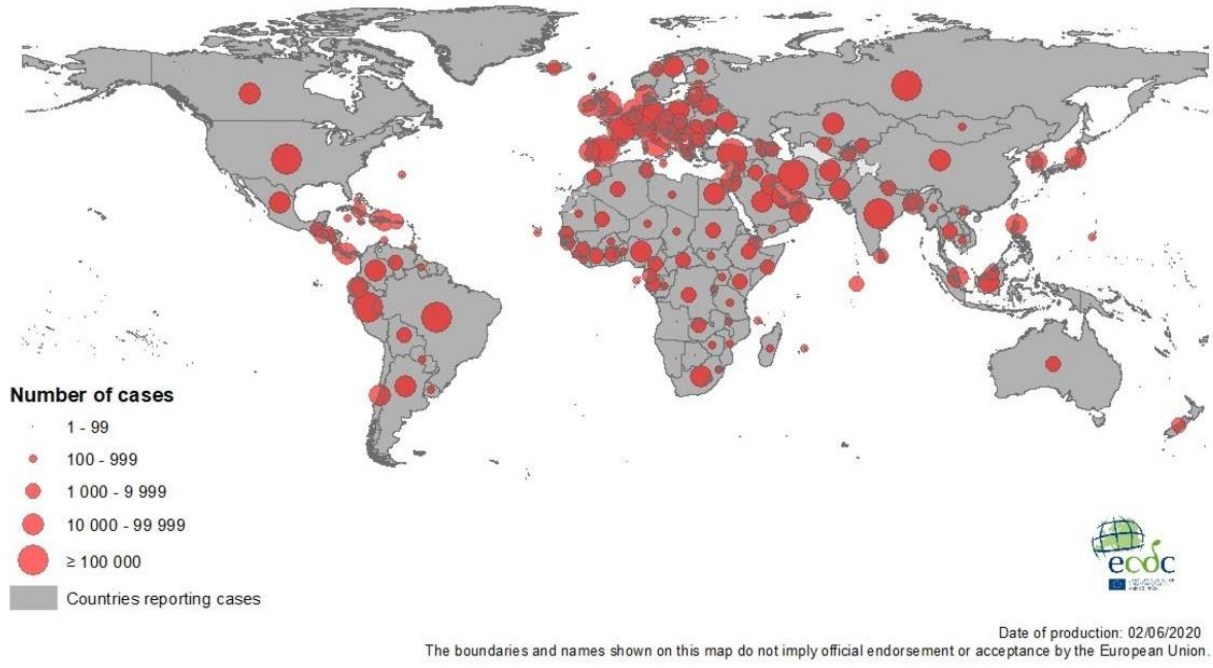


Figure 1: Geographical distribution of COVID-19 cases worldwide[5]

1.3.Indian Scenario

"The first case of COVID-19 in India was reported on 30th January in Kerala's Thrissur district. Crossing the mark of 1,00,000 cases on 19th May 2020, there were a total of 207,615 cases, 100,303 recoveries (including 1 migration) and 5,815 deaths in the country as of 3rd June 2020

India's case fatality rate stands at 3.09%, against the global 6.63% as of 20 May 2020"

Various measures have been undertaken by Government of India to control the pandemic including a nationwide lockdown which started from 24th March 2020, invoking of provisions of the Epidemic Diseases Act, 1897, closure of educational institutions, commercial establishments and public places

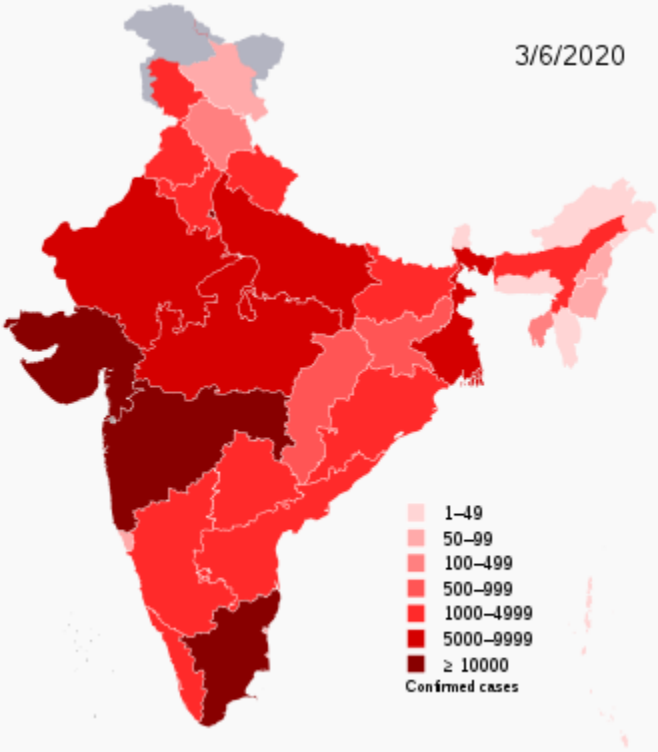


Figure 2: COVID-19 cases in India[6]

1.4.Clinical Features

"Till date, most of the COVID-19 patients develop mild symptoms – dry cough, sore throat and fever while only few develop fatal complications organ failure, septic shock, pulmonary edema,

severe pneumonia, and Acute Respiratory Distress Syndrome (ARDS). Based on the symptoms, disease can be classified into mild, moderate, severe, and critical

Mild Disease: Patients represent symptoms of an upper respiratory tract viral infection which include dry cough, mild fever, nasal congestion, sore throat, headache, muscle pain, and malaise. Majority (81%) of COVID-19 cases fall under mild category.

Moderate Disease: Patients present respiratory symptoms of cough, shortness of breath, and tachypnea

Severe Disease: Patients are present with severe pneumonia, acute respiratory distress syndrome (ARDS), sepsis, or septic shock. Clinical presentations include presence of severe dyspnea, tachypnea (respiratory rate > 30/minute), respiratory distress, $SpO2 \leq 93\%$, $PaO2/FiO2 < 300$, and/or greater than 50% lung infiltrates within 24 to 48 hours. Fever can be absent or moderate

Critical Disease: 5% of patients develop a critical disease having symptoms which includes respiratory failure, RNAaemia, cardiac injury, septic shock, or multiple organ dysfunction. Case fatality rate for critical patients is 49%. Preexisting comorbidities results in higher case fatality rate. These comorbidities include diabetes (7.3%), respiratory disease (6.5%), cardiovascular disease (10.5%), hypertension (6%), and oncological complications (5.6%)" [7]

1.5.Containment Measures

With the virus crossing borders and spreading uncontrollably, countries across the world are prompted to introduce unprecedented measures to contain and control the pandemic. Such measures include[8]:

- Country wide lockdown
- Widespread restriction on travel and mobility
- Strict social distancing measures
- Restrictions on physical attendance at work
- Prohibition of social gatherings
- Closure of schools, universities and public places
- Patient isolation & quarantine
- Contact tracing

- Community Education

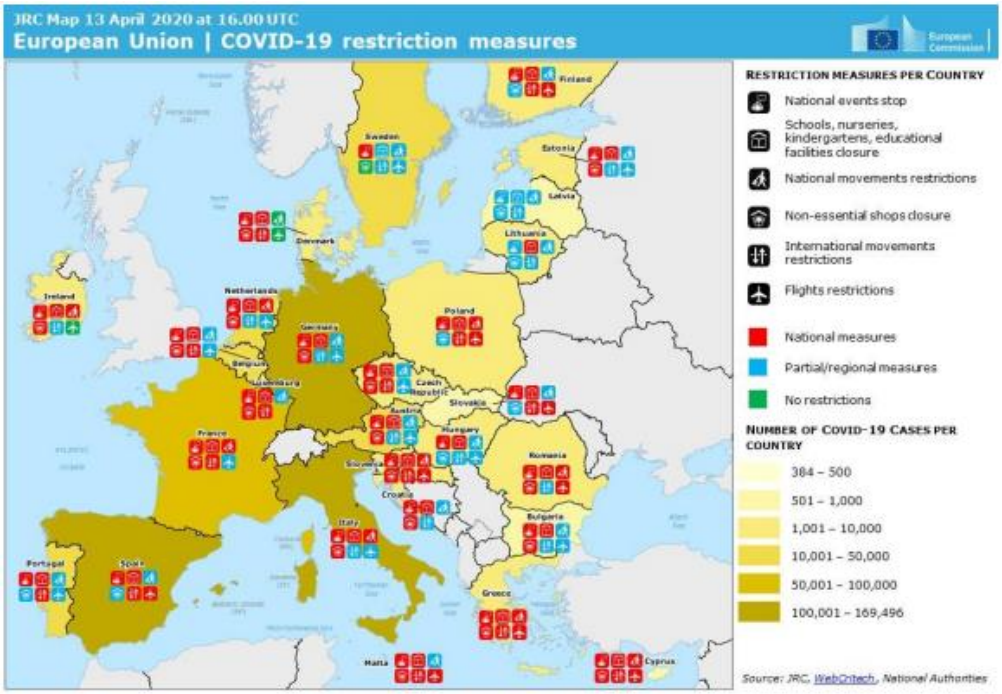


Figure 3: EU – COVID-19 containment measures[9]

Restrictions vary from country to country and nations across the world have adopted different strategies to contain the spread of virus. These measures have been successful to slow down the spread of the virus but at the same time came with a high social and economic cost. These measures had disrupted businesses, affected GDP, increased unemployment resulting in financial market turmoil triggering the need to strategically lifting these measures

To lift confinement restrictions and prevent second wave of infections widespread testing of COVID-19 is extremely crucial. If confinement measures are lifted without a vaccine and effective standardized treatment, infection rate is expected to rebound rapidly. To identify people who are infected, tracking and tracing them to find their close contacts, testing is crucial which will aid in suppression of infection.

Overall testing strategies achieve 3 major goals:

• Suppression of local outbreak resuscitation
• Identification of people who have developed immunity and can safely return to work

• Examine the development of the epidemic, including reaching herd immunity threshold

2. Aim and Objective:

This study aims to assess and compare testing strategies adopted by different nations across the world, their effectiveness in containing the spread of virus and comparison with status in India

3. Literature Review

"COVID-19 which emerged from China has spread its roots all across the world infecting millions. WHO recommends combination of strategies to combat the spread of virus that includes rapid diagnosis, isolation of cases, rigorous tracking and precautionary self-isolation of close contacts" [11]

Testing has been adopted as a core component of combination approach to control COVID-19

COVID-19 epidemic in Switzerland: on the importance of testing, contact tracing and isolation[11] – This study briefly describes importance of testing for successful containment of COVID-19. It described benefits of a liberal testing strategy as:

- To reduce the current Reproduction number from 2-3 to <1 it is necessary to prevent 50-70% of possible transmission which is only possible by effective contact tracing and self-isolation. Following positive results, a person should take self-isolation measures and his/her contacts should be traced and advised to go into precautionary self-isolation to break transmission chains
- "Cases begin with mild symptoms which peak at around 8-10 days. Testing aid to detect infectious individuals and clusters allowing timely isolation. Widespread testing allows accurate estimation of case fatality ratio, finding that the time between disease onset and death is several weeks"
- Accurate data on spread of COVID-19 is required for estimation and preparation of healthcare resources. It helps to identify the proportion of people with mild, severe and critical symptoms allowing management of resources respectively
- Testing helps to assess the effectiveness of control measures to deal with the pandemic

- Antibody testing apart from RT-PCR testing is essential to identify proportion of people infected with the virus. A cohort of people presenting infection can help to determine time of seroconversion, providing crucial information for large scale testing

"Emergence of a Novel Coronavirus Disease (COVID-19) and the Importance of Diagnostic Testing: Why Partnership between Clinical Laboratories, Public Health Agencies, and Industry Is Essential to Control the Outbreak" [12]- This study describes the importance of diagnostic testing in the event of COVID-19 pandemic and necessity for partnership across bodies to strengthen diagnosis infrastructure. It discusses the importance of testing at the front line and provide necessary information to physicians to manage cases effectively. Further it discusses "the opportunity the pandemic has provided for government agencies, industries, public health sector and clinical laboratories to come together and develop a sustainable system for rapid development, production, dissemination and implementation of diagnostic tests"

Covid-19: Over 300 Italian doctors and scientists call for more testing (27 March 2020)[13] – 300 Italian doctors called upon the government to ramp up testing for identification of mild & asymptomatic cases which forms 80% of all cases and help to spread the infection. Article reported that blanket testing in an isolated village of approximately 3,000 people in Northern Italy resulted in decrease in people with symptoms of COVID-19 within 10 days. It was indicated that major proportion of people infected with COVID-19 showed no symptoms but had the ability to infect others, this holds huge implications for testing policy.

Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (February 2020)[14] – The report focuses on planning of steps to control epidemic in infected regions and steps for readiness for geographies not affected. It discusses the steps undertaken in China to contain the infection and their outcomes. Major recommendations involve:

"For countries with outbreaks and/or imported cases" - Extend surveillance to detect COVID-19 transmission chains by testing patients with SARS, screening patients with respiratory illness or COVID exposure, and adding tests to existing surveillance systems

For countries with no infection – Enhance surveillance system for COVID-19, testing of all patients with atypical pneumonia

"Universal weekly testing as UK COVID19 lockdown exit strategy (20April 2020)" [15] – The study discusses the relevance of universal repeated testing as an alternative strategy to exit from lockdown. UK government has imposed alternating periods of lockdown and relaxations as a part of its exit strategy considering the humongous economic and social damage lockdown has caused. An alternative strategy of evaluation of weekly COVID-19 testing of entire population in an entire city as a demonstration site is proposed which is followed by strict home quarantine if tested positive. The feasibility of the test can be tested in one or more cities with 2,00,000 to 3,00,000 people. The rate of infection from the study can be compared with the rest of UK which can help to decide to go for a national roll-out, beginning in high-risk areas

"Testing for COVID-19: A way to lift confinement restrictions (4 May 2020)" [16] **–** This OECD document explains the role of testing to manage COVID-19 when there is no standard cure and vaccine available. It explains three ways by which testing can be used to manage COVID-19:

- Importance of effective testing, tracking and tracing (TTT Approach). TTT has been claimed to be an effective approach for short term to bring epidemic down without resorting to widespread lockdown. This approach is used to block the initial or repeated spread of pathogen with objective of rapid extinction of local outbreaks. TTT has proven to be effective for diseases where with the onset of symptoms infectiousness begins simultaneously for e.g., TTT prove to be effective in outbreaks of the "Severe Acute Respiratory Syndrome (SARS) in 2003, the Middle East respiratory syndrome (MERS) in 2012, and the Ebola virus disease in 2014. Effectiveness of TTT depends on speed and accuracy with which this approach is implemented." TTT not only helps in suppression of outbreak but also to monitor the progress and evolution of epidemic allowing disease spread to be tracked. This helps to effectively manage resources and take decisions about lifting or introducing restrictions.
- Serological testing among targeted population groups of high priority such as frontline workers. Testing health professionals will avoid unnecessary self-isolation and increase capacity of resources. These tests are of particular interest to restart economy.

Serological testing can also be performed taking random samples for estimating prevalence and understand development of herd immunity in the community

- Testing helps to map evolution of epidemic through population surveillance which helps to estimate immunity prevalence in the population. This assessment of immunity also called sero-surveillance helps to determine the level of antibodies required to achieve herd immunity which determines groups of susceptible individuals. Sero-surveillance can also aid in planning vaccination strategies in future avoiding vaccinating those who already have the immunity

Further this study also discusses the implementation feasibility to conduct these tests at widescale level. This includes capacity planning, human resource management, equipment projections.

The study also describes what testing strategies different countries have adopted, their implications, role of technology in enhancing testing and tracking mechanism and privacy issues related with same.

4. Methodology:

4.1. **Study-Design:** Cross sectional study

4.2. **Study-setting and population**: The study spans over 7 countries: USA, UK, NZ, Taiwan, Japan, South Korea, and India.

4.3. **Data collection:** COVID-19 cases and tests data were collected starting from Early January till June middle for the above-mentioned countries from ourworldindata.org. Various journals such as Cambridge University Press, Jama Network, The Lancet, Oxford University Press and SSRN along with pubmed was searched extensively using “COVID-19”, “Country Name”, “Testing strategy” as keywords to identify the relevant literature.

WHO COVID-19 database, CDC COVID-19 database and other Government sources were used as well

4.4. **Analyzing and interpreting the data:** The data collected was analyzed using basic excel functions. XY scatter plot was constructed and correlation coefficient, R^2 was calculated to estimate effectiveness of testing strategies of countries

5. Hypothesis:

1. High testing numbers in early stage of transmission control the pandemic
2. High testing numbers reduce the case numbers of COVID-19 over a period
3. High testing numbers in early stage of transmission flattens the curve of cases

6. Main content:

COVID-19 cases began to appear in countries across the world since the beginning of January 2020, however, they adopted very different approaches to testing experiencing varied outbreaks.

6.1.Types of testing for COVID-19[17]:

Table 1: Types of testing kits

	Molecular test	**Antigen Test**	**Antibody Test**
Names	Diagnostic Test, RT-PCR, Nucleic Acid Amplification Test (NAAT)	Rapid Diagnostic Test (RDT)	Serological Test, Serology blood test
Sample Collection Time taken to get the results	Nasal or throat swab	Nasal or throat swab	Blood draw or finger stick
Results	"Diagnoses active COVID-19 infection"	Diagnoses active COVID-19 infection	Diagnoses previous COVID-19 infection

Each country follows their certain set of guidelines for testing

6.2.Country wise COVID-19 scenario (As of 15th June 2020)[4,18,19]:

6.2.1. United States of America:

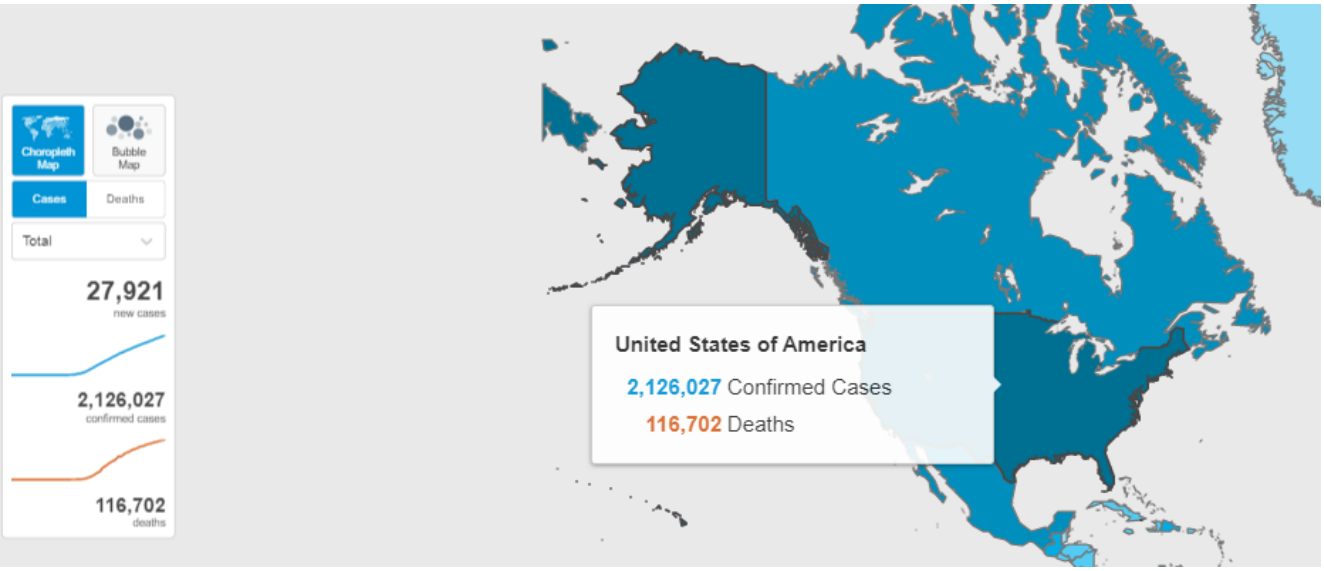


Figure 4: US COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
USA	2,126,027	116,702	23,467,981

	Cases/million	Deaths/million	Tests/million
USA	6458	353	79,302

Testing strategy[20]

US currently allows two types of test: Viral-test (RT-PCR) to test for current infection and Antibody test to test for previous infection

Viral tests are used for diagnosing purposes and can be performed on 5 categories of people as documented by CDC:

1. "Testing individuals with signs or symptoms consistent with COVID-19
2. Testing asymptomatic individuals with recent known or suspected exposure to SARS-CoV-2 to control transmission
3. Testing asymptomatic individuals without known or suspected exposure to SARS-CoV-2 for early identification in special settings

4. Testing to determine resolution of infection (i.e., test-based strategy for Discontinuation of Transmission-based Precautions, HCP Return to Work, and Discontinuation of Home Isolation)
5. Public health surveillance for SARS-CoV-2"

Antibody tests are not recommended for diagnosing purposes but can be used for clinical assessment and to understand the transmission dynamic of virus

6.2.2. United Kingdom:

Figure 5: UK COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
UK	298,140	41,969	1,836,321

	Cases/million	Deaths/million	Tests/million
UK	4,391	618	104,930

Testing Strategy[21]

5 pillars of UK testing strategy were announced on 2nd April and involves 5 key steps:

1. "Scaling up of NHS swab testing for the one with medical needs and where possible

2. Mass swab testing for critical key workers who work in social care, NHS and other sectors
3. Mass antibody testing to assess immunity among people against Coronavirus
4. Surveillance testing to understand the disease and to develop new tests and treatments
5. Diagnostic national effort to build mass testing capacity at a completely new scale"

6.2.3. New Zealand:

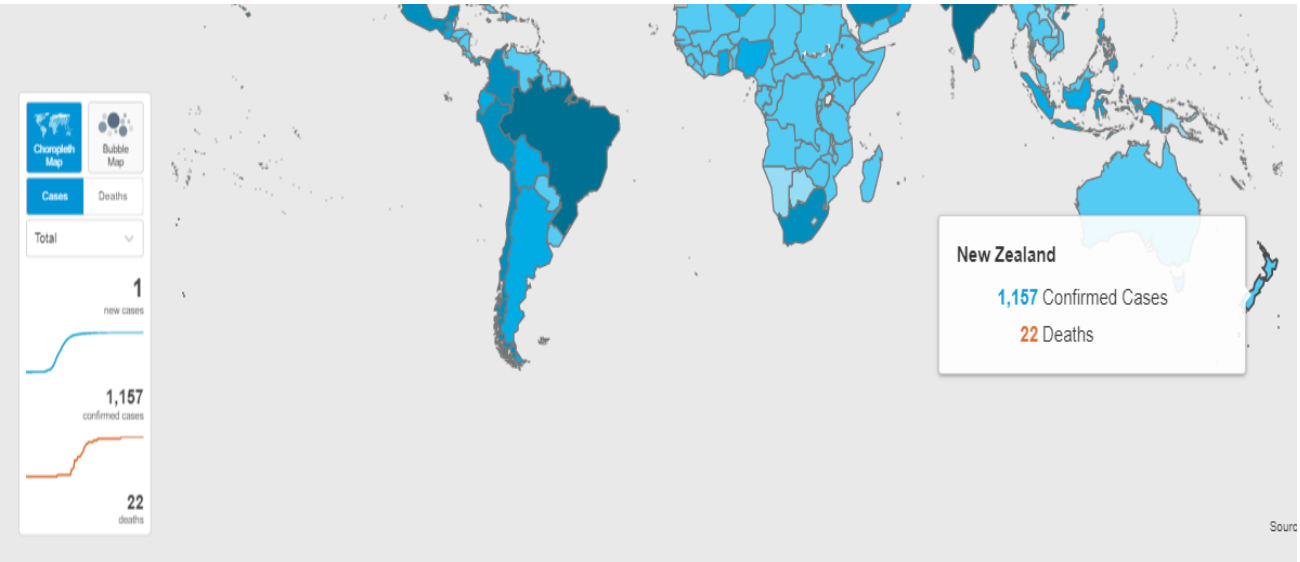


Figure 6: New Zealand COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
New Zealand	1,157	22	312,648

	Cases/million	Deaths/million	Tests/million
New Zealand	239	4.5	64,210

Testing strategy[22]

New Zealand's elimination strategy to combat COVID-19 has testing as one of its crucial steps to identify and isolate COVID-19 cases. Testing strategy involves:

1. “Asymptomatic people, mainly close contacts of cases and isolating them. Regular population testing will help to measure population susceptibility
2. Testing of people who had travelled to or from a country or area of concern, or contact with a suspect, probable or confirmed COVID-19 case in the 14 days before onset of illness
3. Testing of people who have fever ≥38oC OR any acute respiratory infection with symptoms of at least one of: shortness of breath, cough or sore throat with or without fever
4. Healthcare workers with moderate or severe community acquired pneumonia and critically patients in ICU/HDU with severe community acquired pneumonia
5. Testing is also done if clinical judgement warrants the requirement”

6.2.4. South Korea:

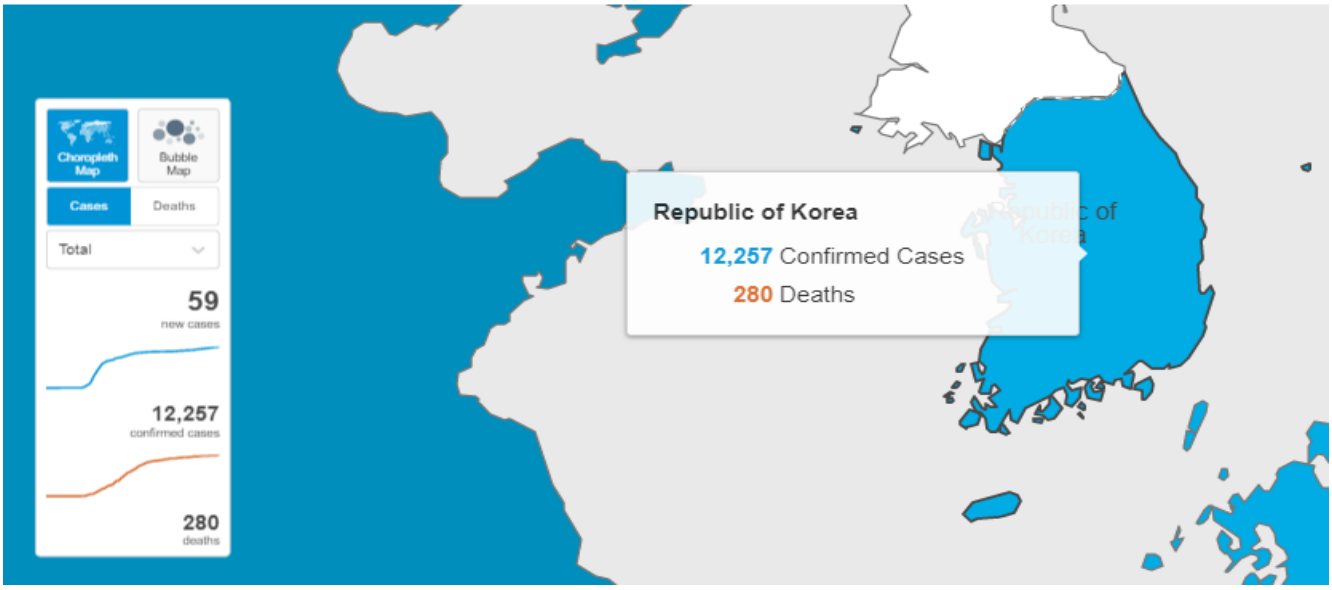


Figure 7: South Korea COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
South Korea	12,257	280	1,105,719

	Cases/Million	Deaths/Million	Tests/Million

South Korea	237	5.44	22,348

Testing strategy[23]

South Korea worked on 3 guiding principle to control COVID-19 outbreak: test, trace and contain. Using this approach South Korea emerged as one of the nations which successfully controlled the spread of infection without imposing any strict lockdown. Some of the key points of its testing strategy includes:

1. It quickly ramped up its testing facilities and tested thousands of people across testing centers. South Korea already tested more than 2,70,000 people by mid-March
2. Approval was granted to private firms developing diagnostic kits (RT-PCR)
3. Extensive use of mobile technology – people tested positive were asked to describe their movements which along with GPS phone tracking, credit card transactions and surveillance camera records helped KCDC to issue real time alerts of movement details of infected people
4. Text alerts – information about newly confirmed patients and their recent trajectories was made available through texts to the population

6.2.5. Taiwan:

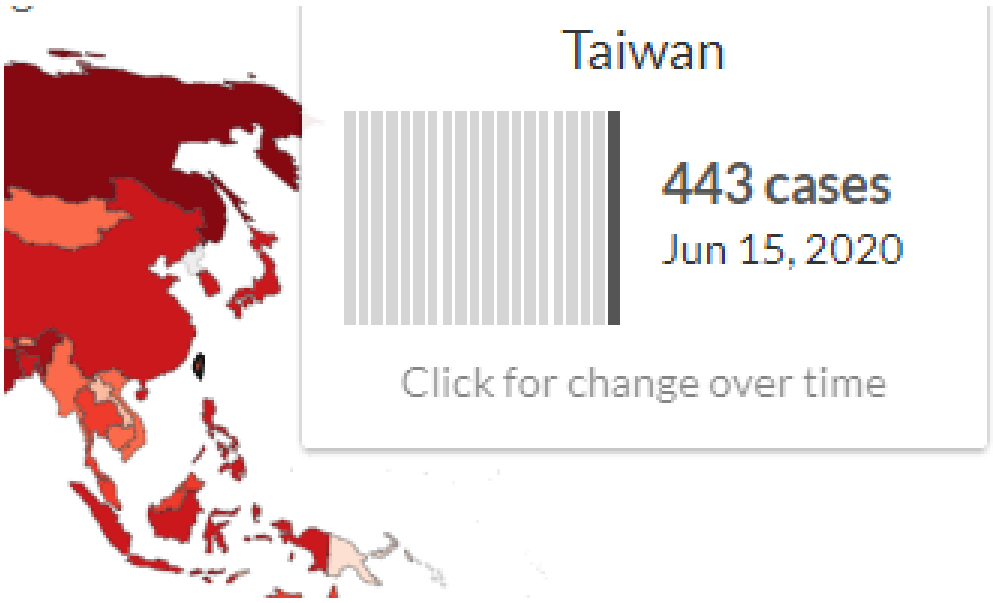


Figure 8: Taiwan COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
Taiwan	443	7	74,699

	Cases/million	Deaths/million	Tests/million
Taiwan	18.6	0.29	3,137

Testing strategy[24,25,26]

1. "Taiwan proactively seek out patients with severe respiratory symptoms (based on information from the National Health Insurance [NHI] database) who had tested negative for influenza and retested them for COVID-19
2. Taiwan aggressively expanded its testing capacity. A national testing network has been established to improve Taiwan's testing capacity which allows the maximum testing capacity per day to reach 3,800 specimen tests and to reduce the wait time for results testing was performed in different areas
3. Prompt response- Taiwan acted swiftly as early as January and began testing in huge numbers"

6.2.6. Japan:

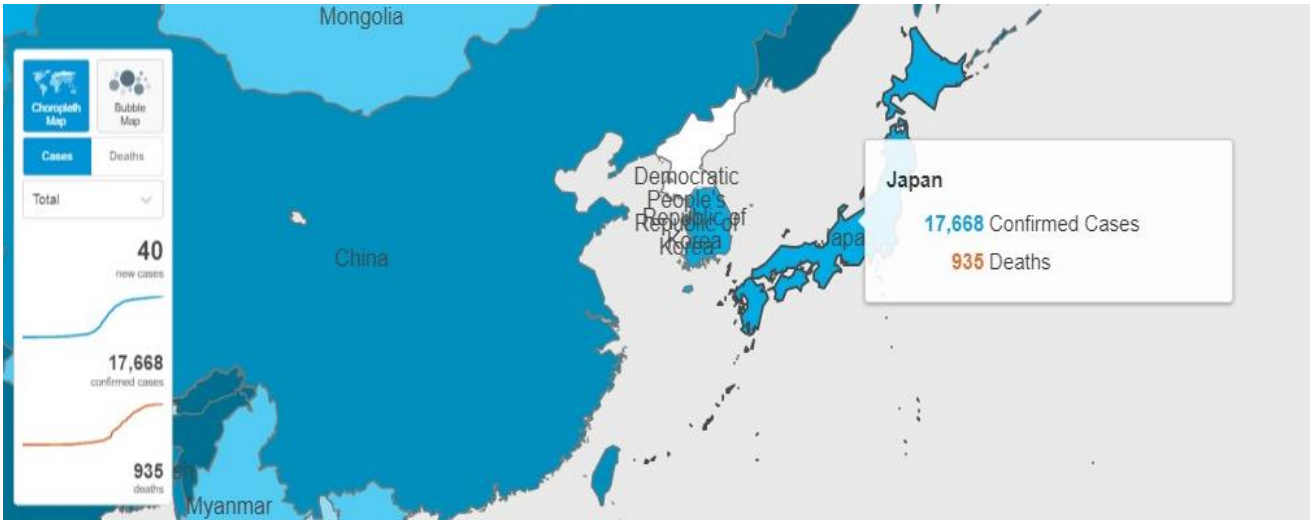


Figure 9: Japan COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
Japan	17,668	935	571,831

	Cases/million	Deaths/million	Tests/million
Japan	139	7	2,752

Testing Strategy[27]

1. Japan adopted a cluster-based approach to deal with spread of infection
2. This approach tracks original infection source and people with high transmissibility are isolated to prevent the virus from spreading. This allows pinpoint testing rather than broad testing
3. This cluster-based approach can only work when there are only a few infected persons and clusters are detectable at an early stage
4. Testing of only symptomatic carriers – limited testing to prevent false negatives and healthcare facilities getting overwhelmed

6.2.7. India:

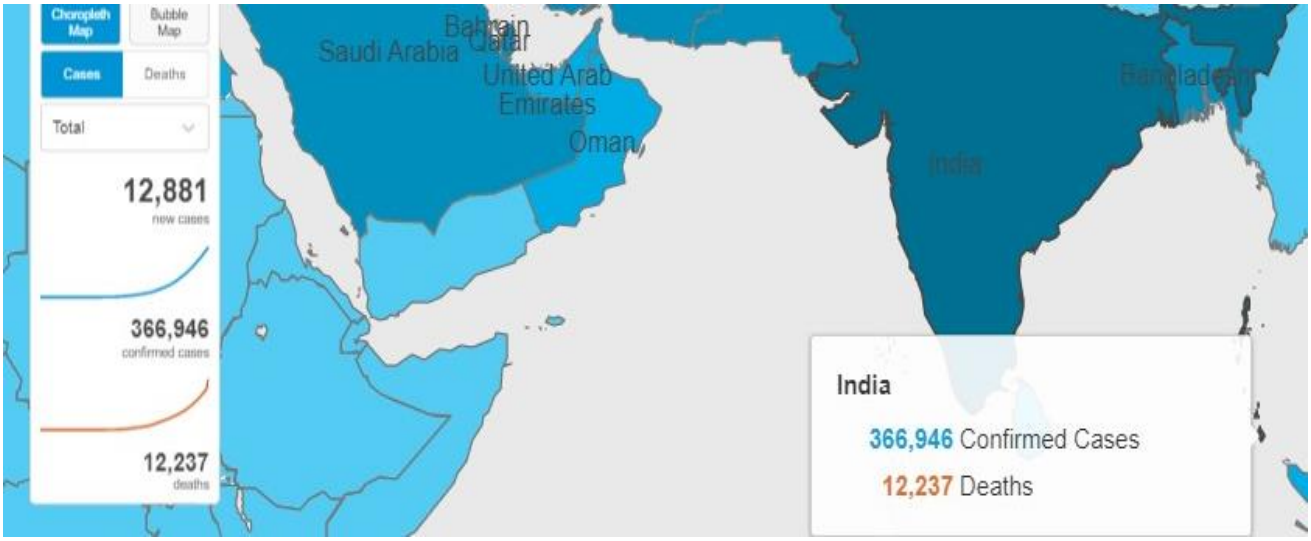


Figure 10: COVID-19 cases and deaths (15th June 2020)

	Cases	Deaths	Tests
India	366,946	12,237	6,249,668

	Cases/Million	Deaths/Million	Tests/Million
India	256	8.6	4,530

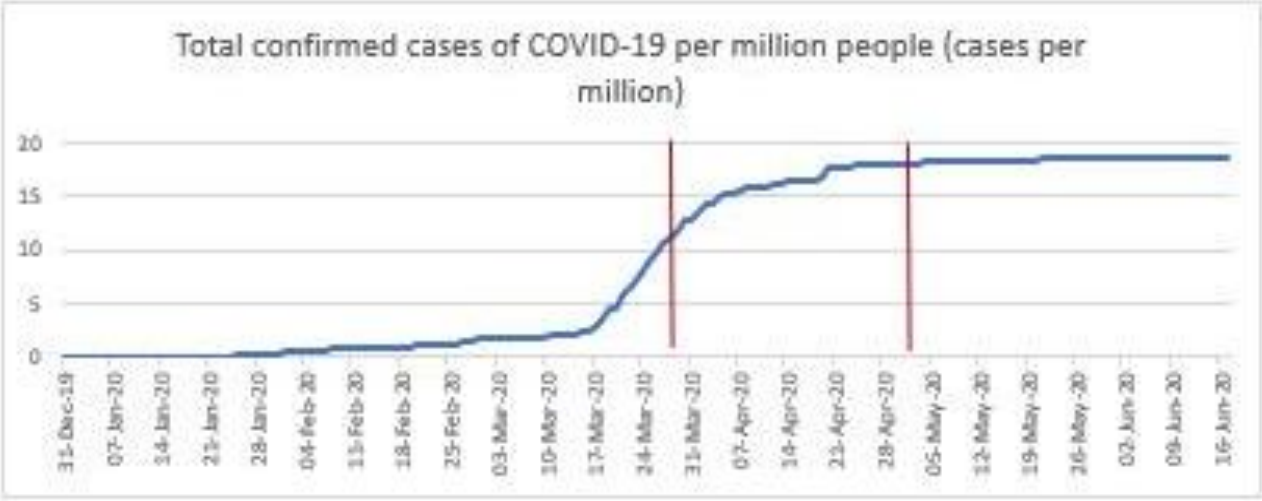
Testing strategy[28,29,30]

1. India's testing strategy evolved over the months since the first case was identified
2. Testing labs for COVID-19 increased from 13 in mid-February to 609 by May – when infection was entering the country from across the world efforts were laid to set up burst of laboratories across cities increasing the number of tests done per day to approximately 1 lakh by end of May
3. TrueNAT machines that are used to detect Tuberculosis virus was approved by ICMR to be used for COVID-19 detection in districts where advanced virological laboratory doesn't exist

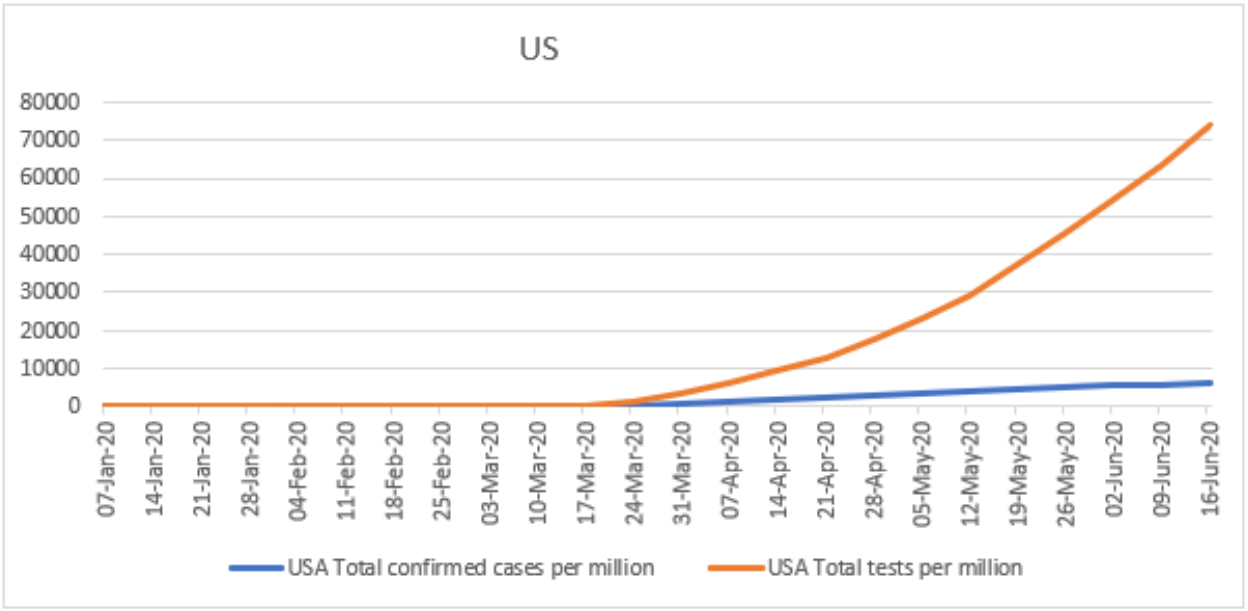
4. All symptomatic ILI cases with history of international travel, those with contacts of laboratory cases, healthcare and frontline workers, within hotspot/containment zones and those among returnees and migrants within 7 days of illness
5. All SARI cases and hospitalized patients who develop ILI are also tested

7. Data and Analysis: *Red lines indicates lockdown period*

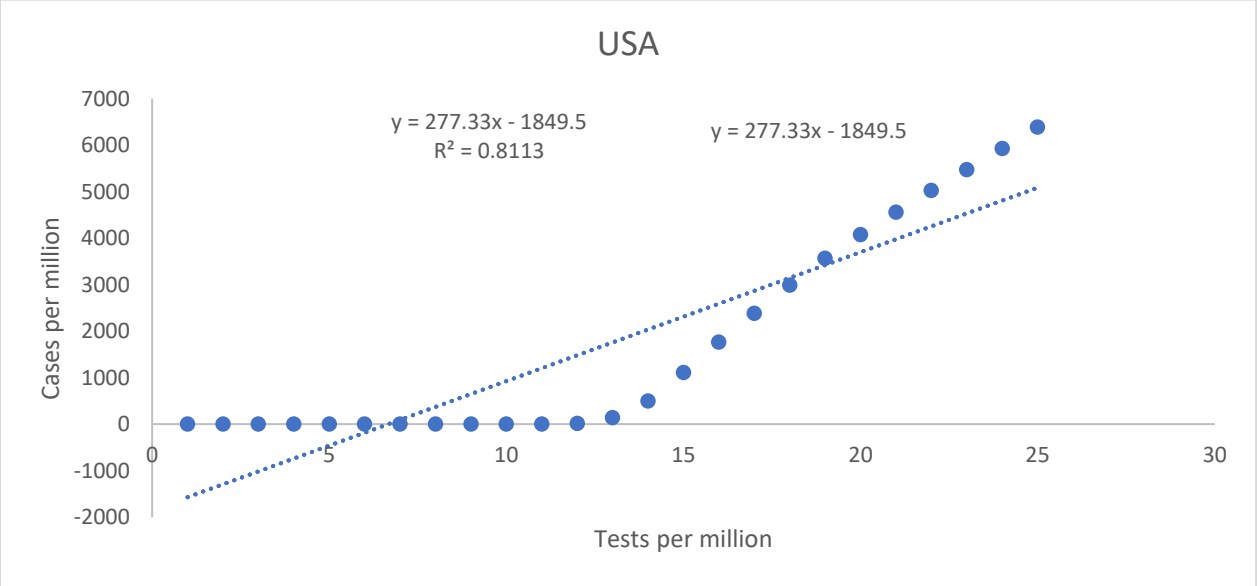
7.1 USA



Graph 1: Total number of COVID19 confirmed cases per 10 lakhs people in USA taken at an interval of 7 days starting from January till mid-June

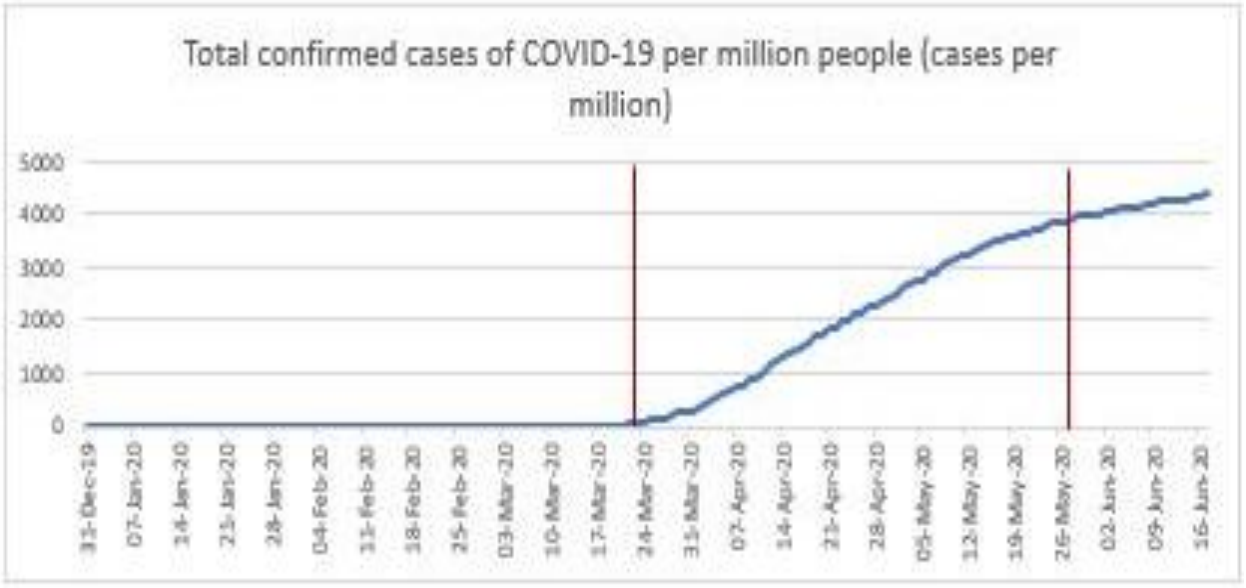


Graph 2: Tests performed per million compared with Total confirmed number of COVID19 confirmed-cases per 10 lakhs people in USA taken at an interval of 7 days starting from January till mid-June

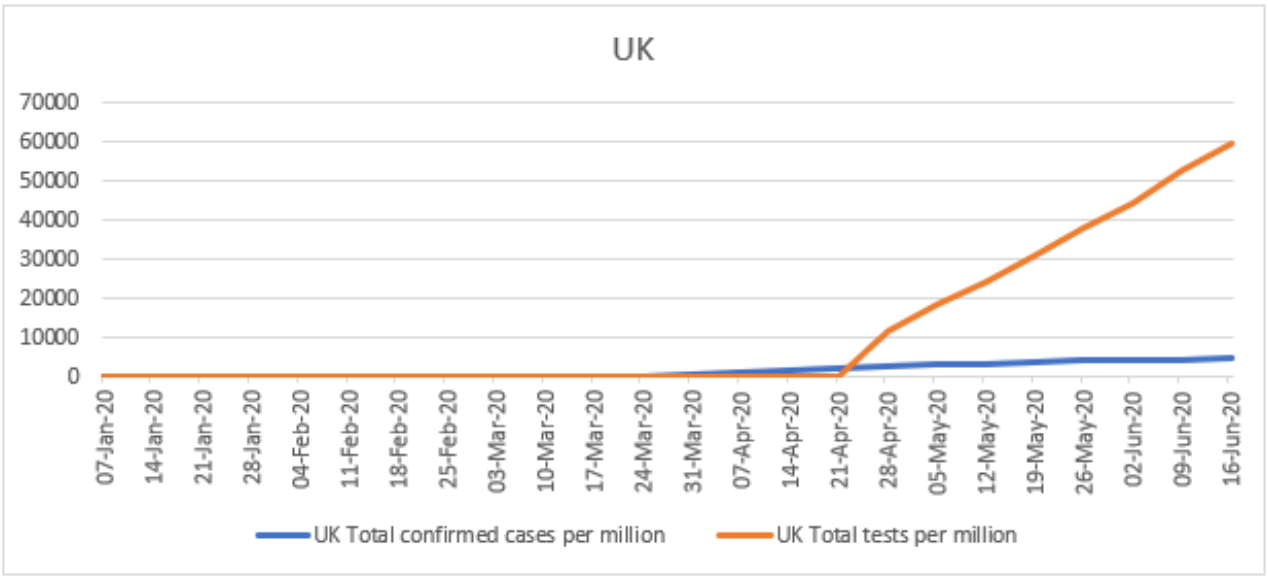


Graph 3: XY Scatter plot– tests and cases per million for USA

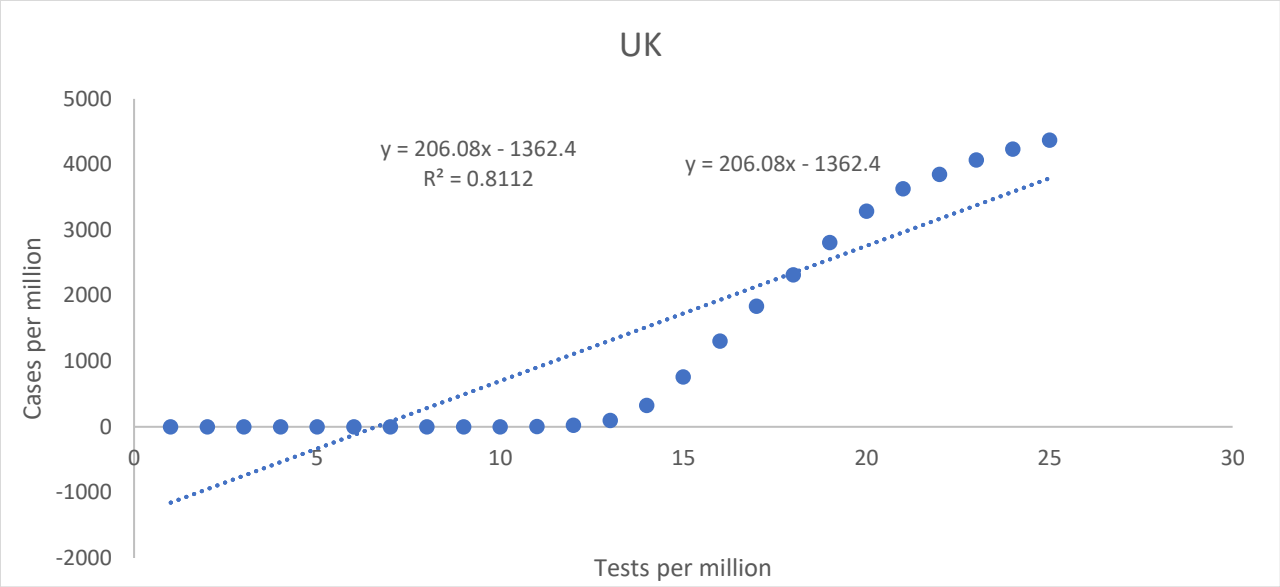
7.2. UK



Graph 4: Total confirmed number of COVID19 cases per 10 lakhs people in UK taken at an interval of 7 days starting from January till mid-June

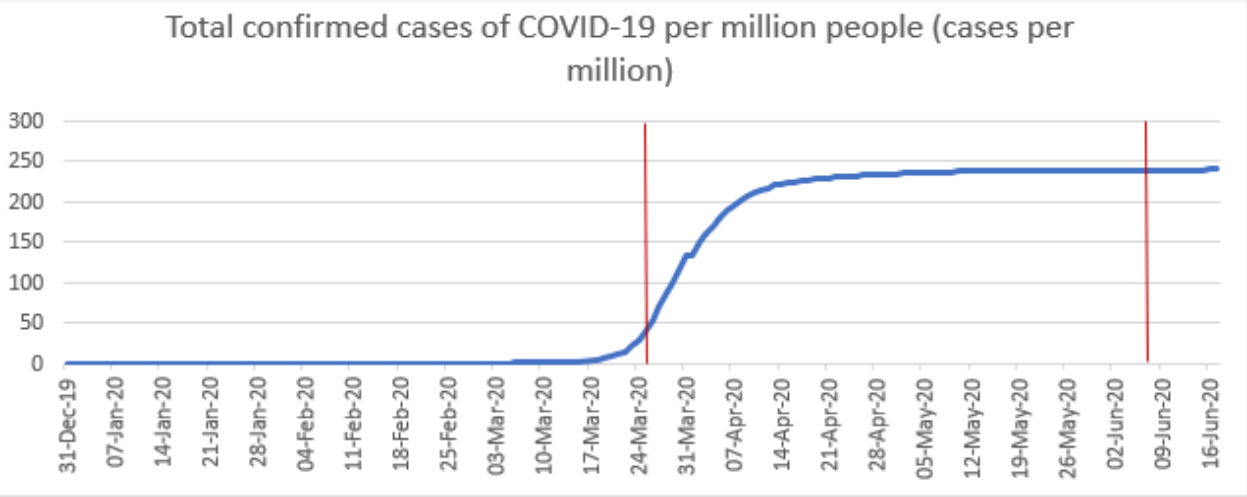


Graph 5: Total tests performed per million compared with total cases per million in UK taken at an interval of 7 days starting from January till mid-June

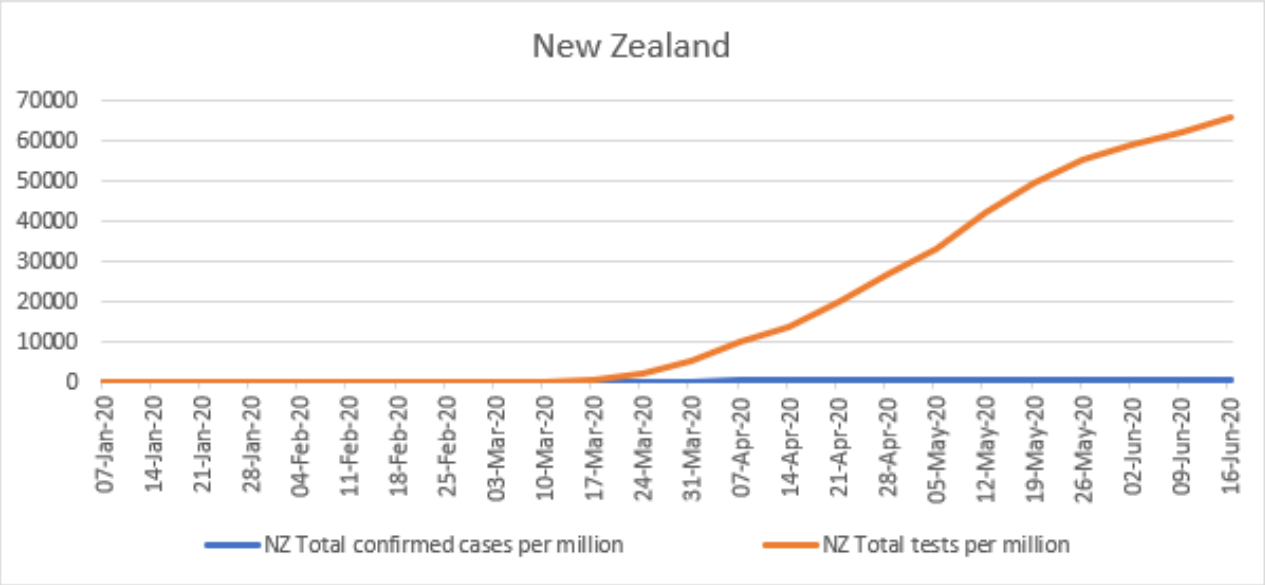


Graph 6: XY Scatter plot– tests and cases per million for UK

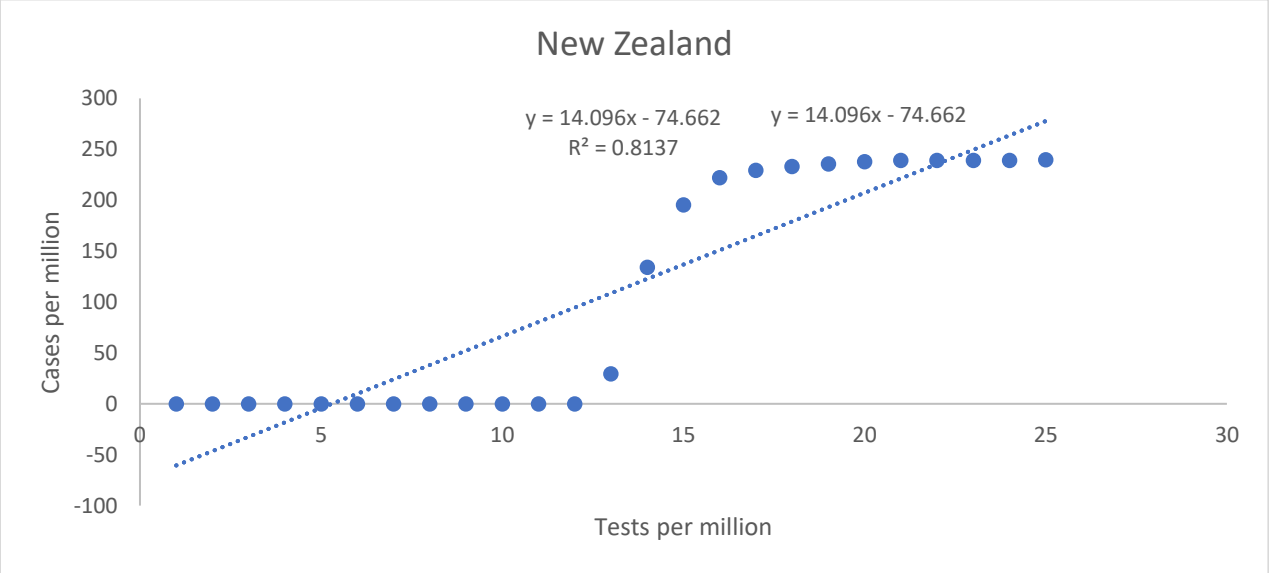
7.3. New Zealand



Graph 7: Total number of COVID19 confirmed-cases per 10 lakhs people people in New Zealand taken at an interval of 7 days starting from January till mid-June

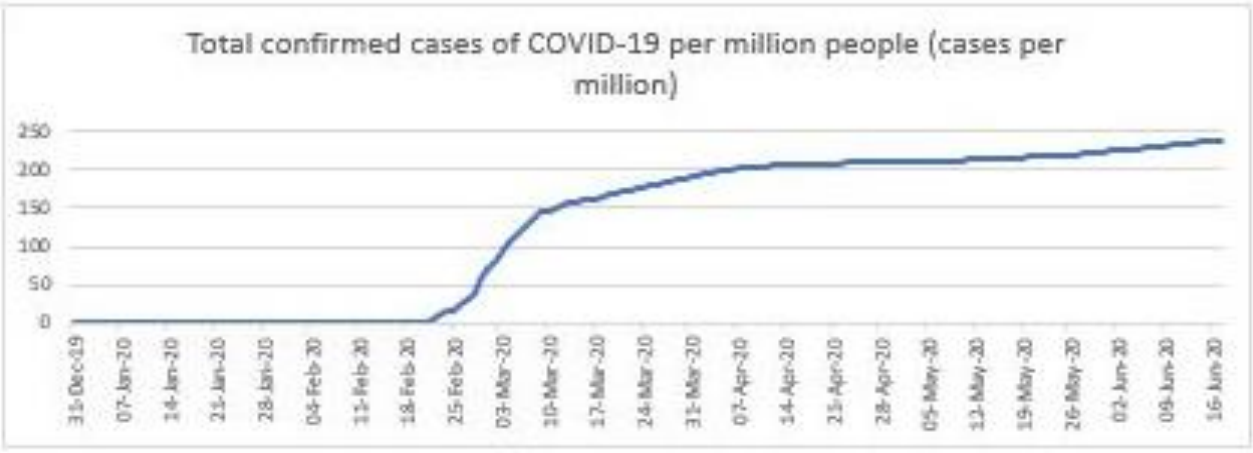


Graph 8: Total tests performed per million compared with Total number of COVID19 confirmed-cases per 10 lakhs people in New Zealand taken at an interval of 7 days starting from January till mid-June

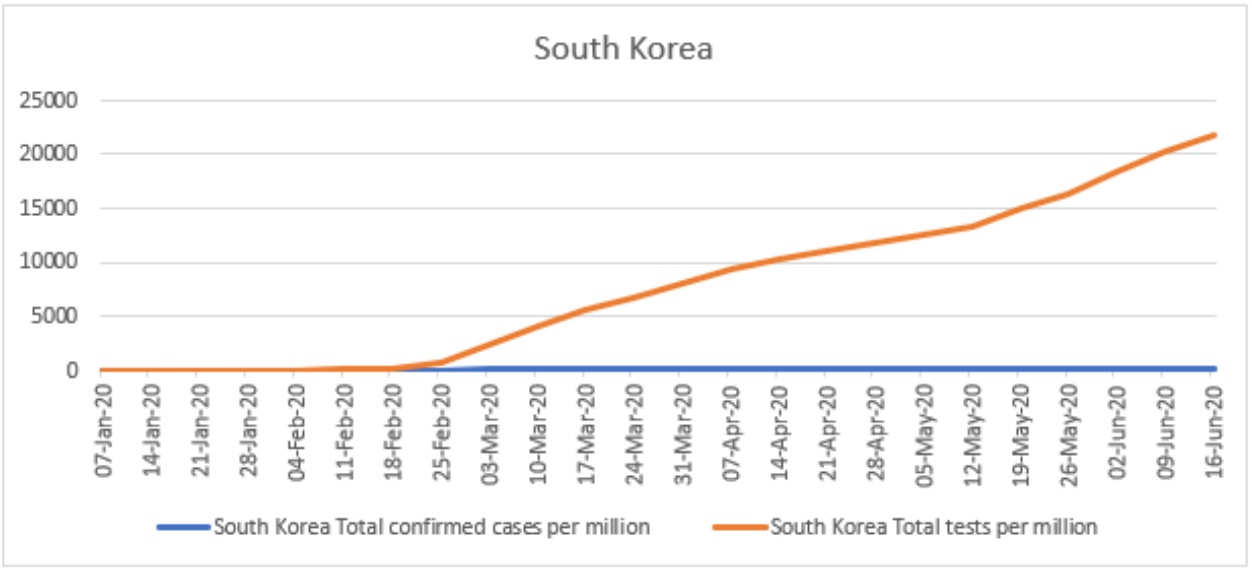


Graph 9: XY Scatter plot– tests and cases per million for New Zealand

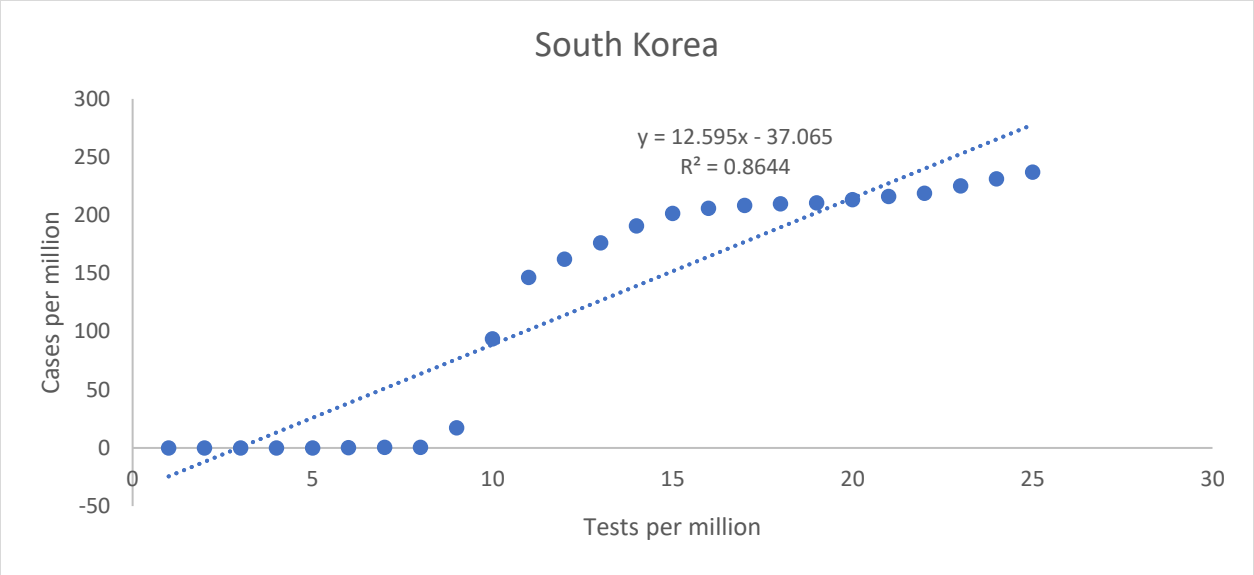
7.4. South Korea



Graph 10: Total number of COVID19 confirmed-cases per 10 lakhs people in South Korea taken at an interval of 7 days starting from January till mid-June

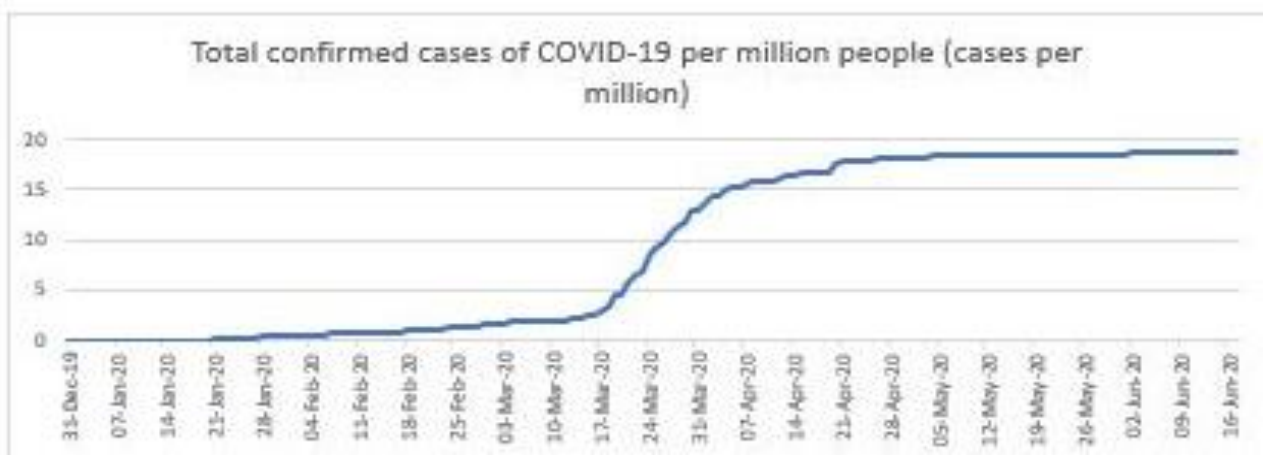


Graph 11: Total tests performed per million compared with Total number of COVID19 confirmed-cases per 10 lakhs people in South Korea taken at an interval of 7 days starting from January till mid-June

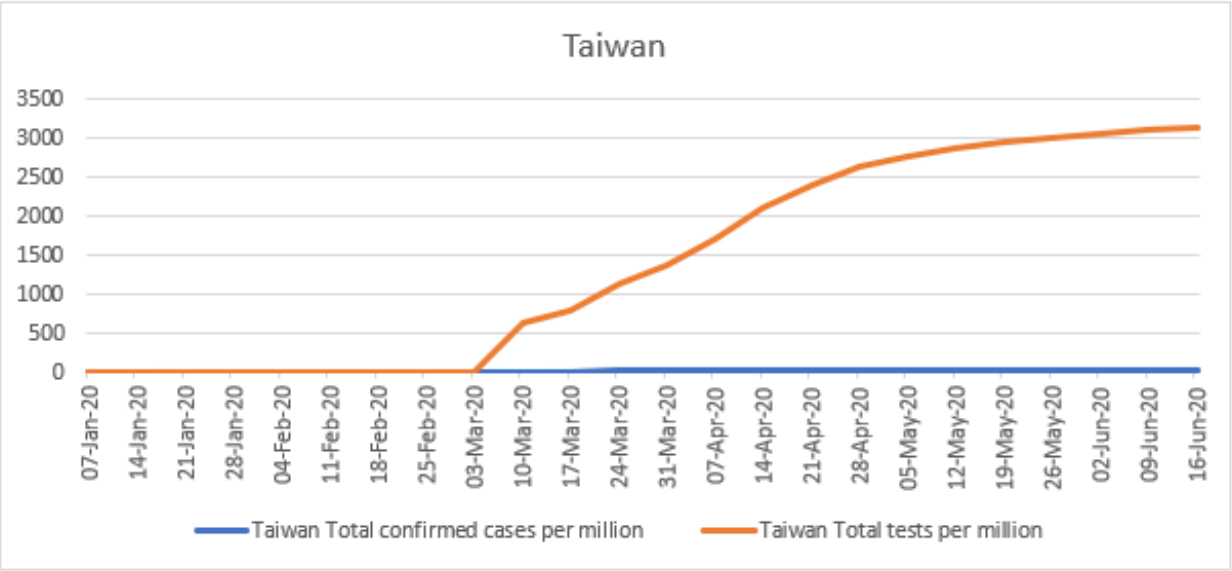


Graph 12: XY Scatter plot– tests and cases per million for South Korea

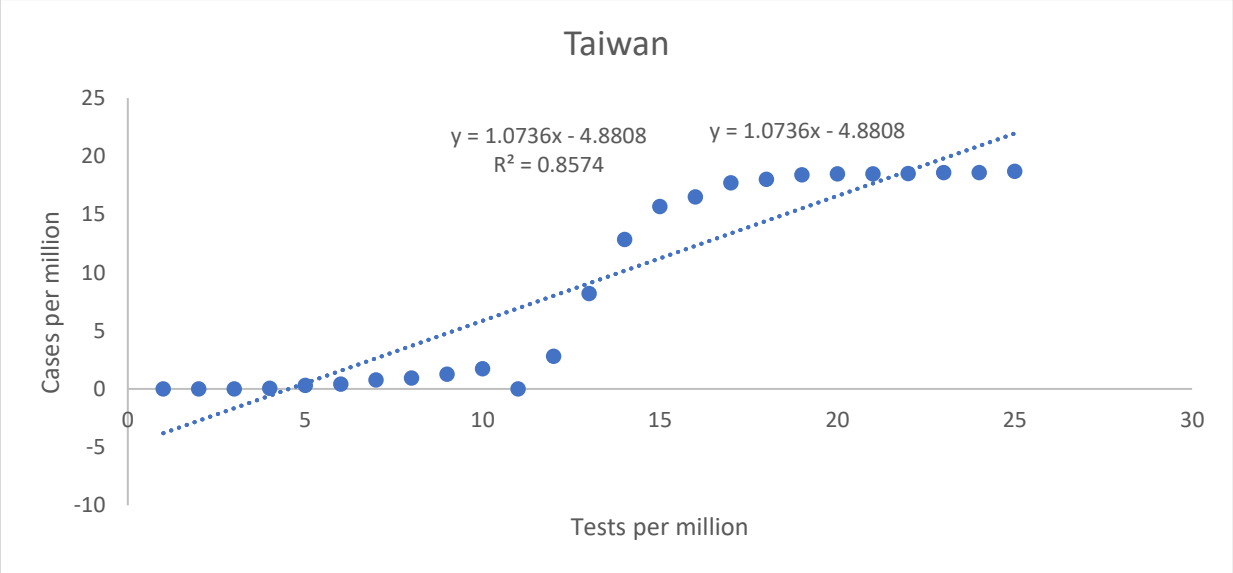
7.5. Taiwan



Graph 13: Total number of COVID19 confirmed-cases per 10 lakhs people in Taiwan taken at an interval of 7 days starting from January till mid-June

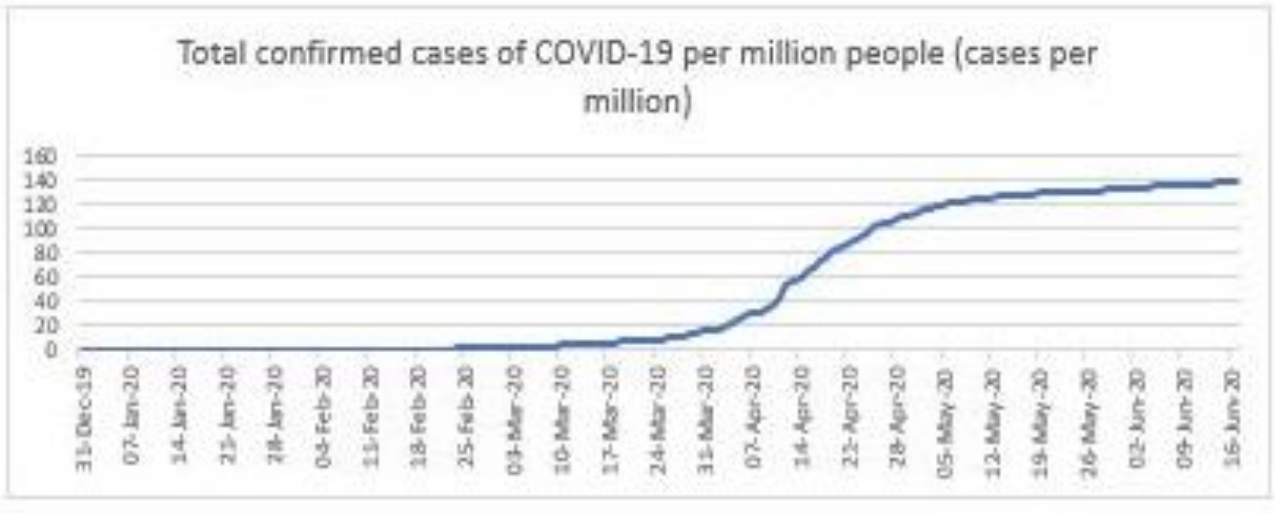


Graph 14: Total tests performed per million compared with Total number of COVID19 confirmed-cases per 10 lakhs people in Taiwan taken at an interval of 7 days starting from January till mid-June

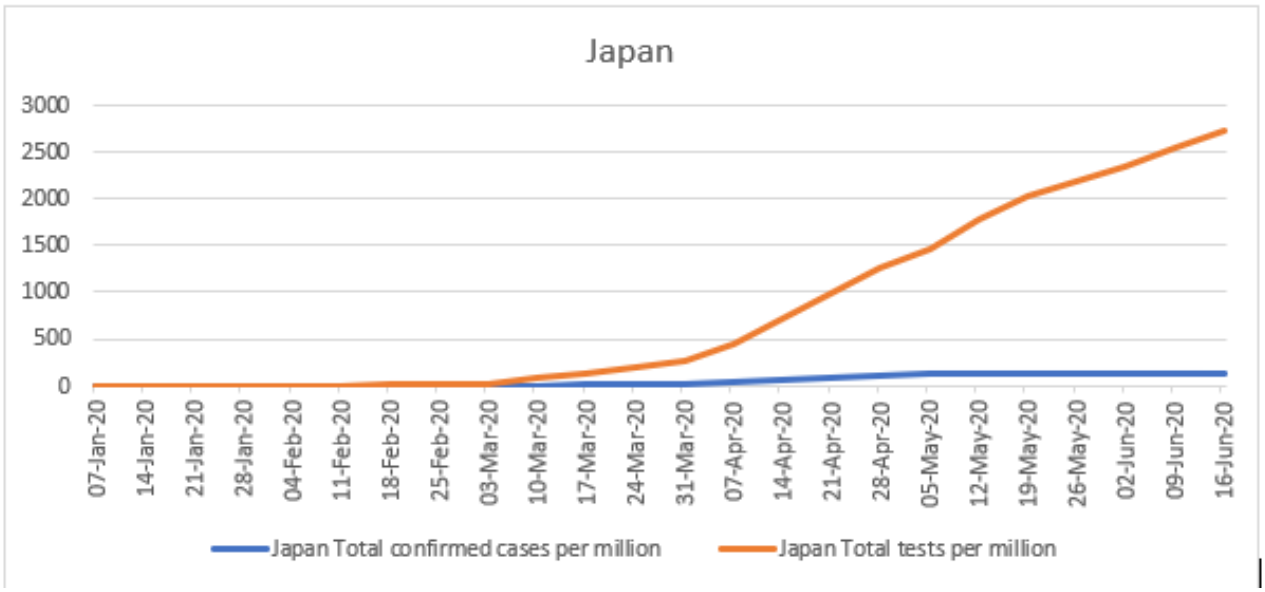


Graph 15: XY Scatter plot– tests and cases per million for Taiwan

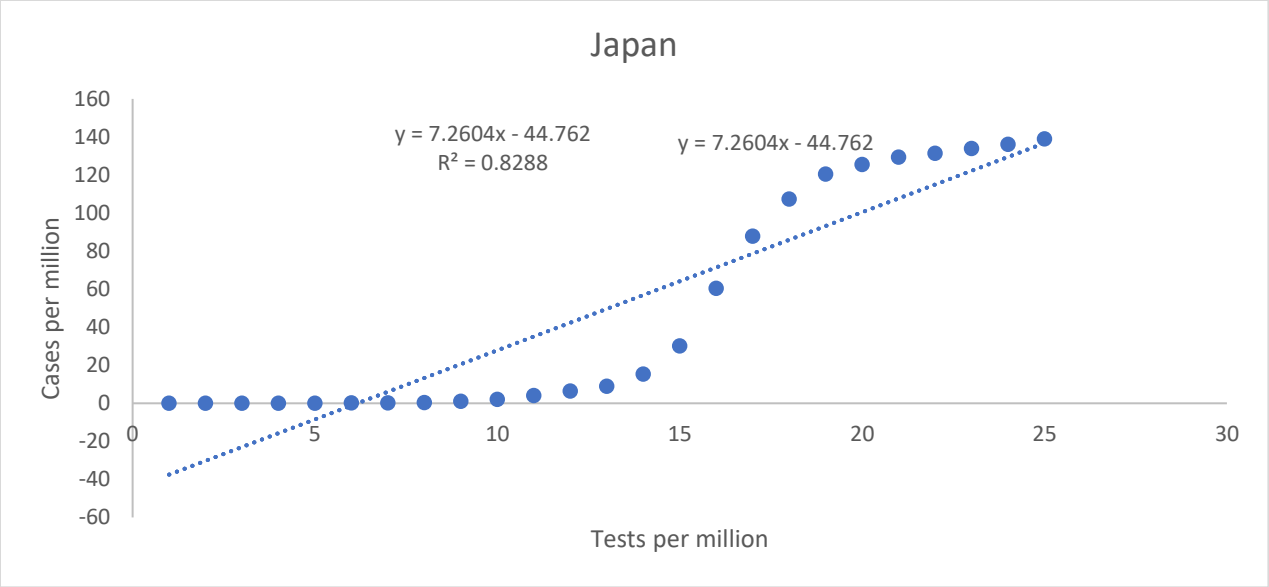
7.6. Japan



Graph 16: Total number of COVID19 confirmed-cases per 10 lakhs people in Japan taken at an interval of 7 days starting from January till mid-June

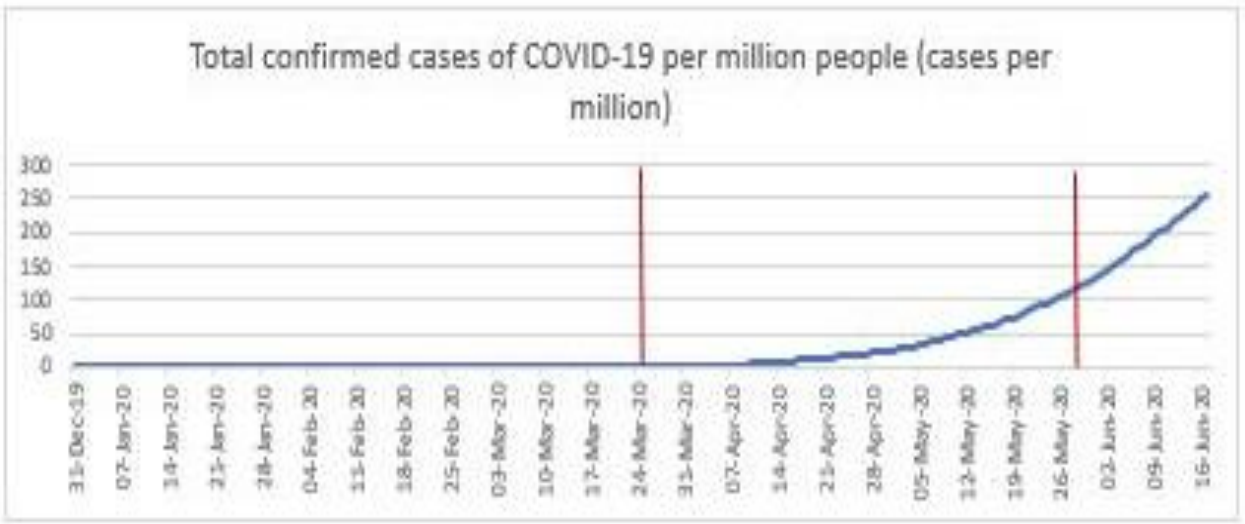


Graph 17: Total tests conducted per 0.001 billion compared with confirmed cases of COVID-19 per million people in Japan taken at an interval of 7 days starting from January till mid-June

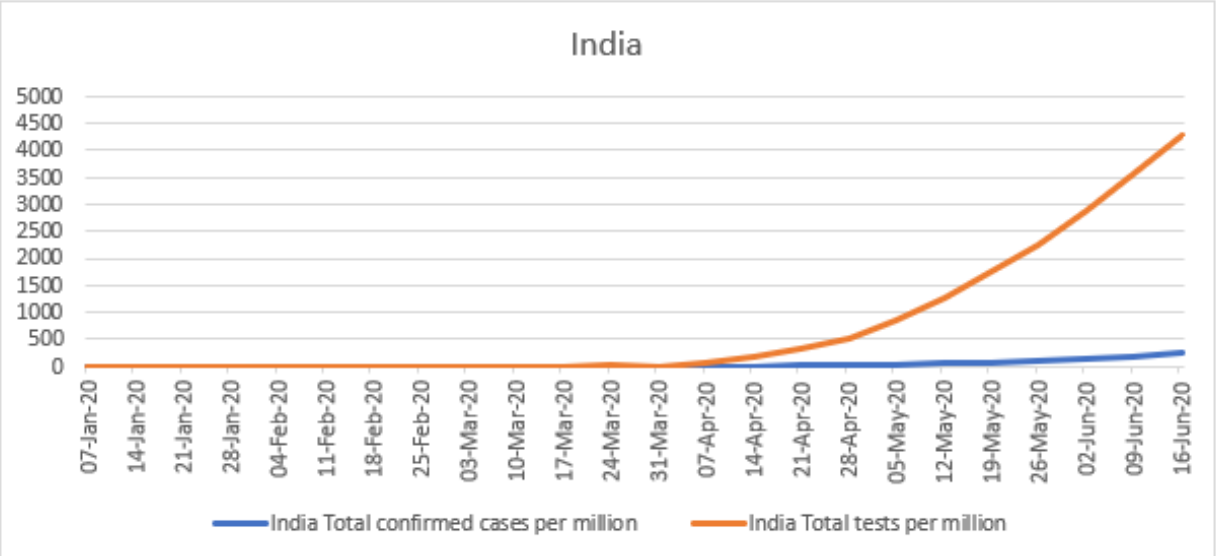


Graph 18: XY Scatter plot– tests and cases per million for Japan

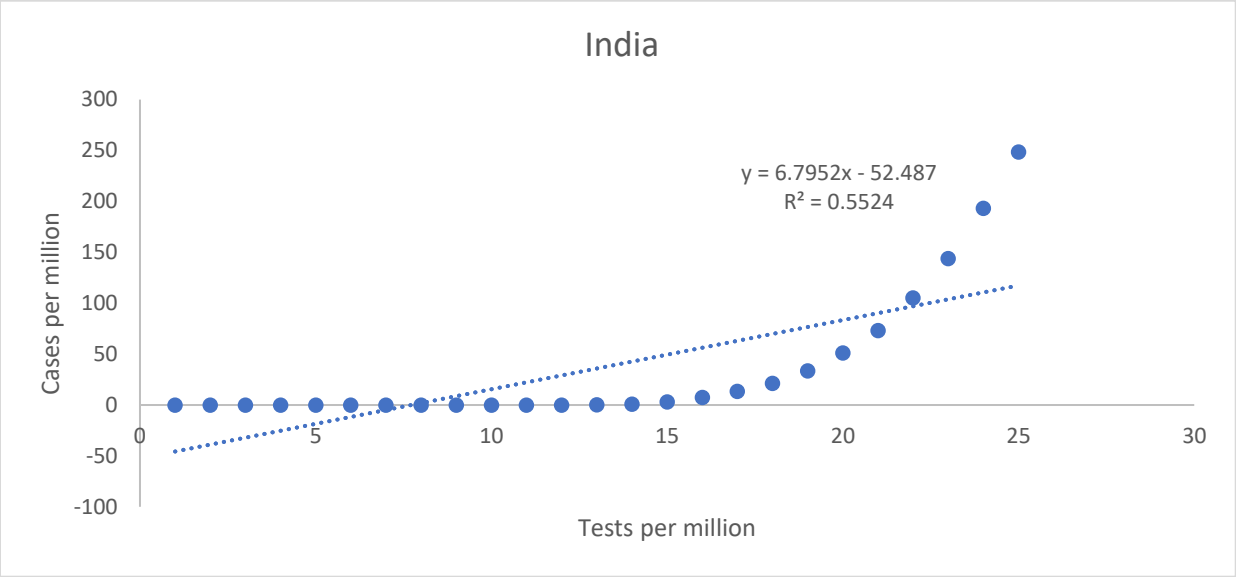
7.7. India



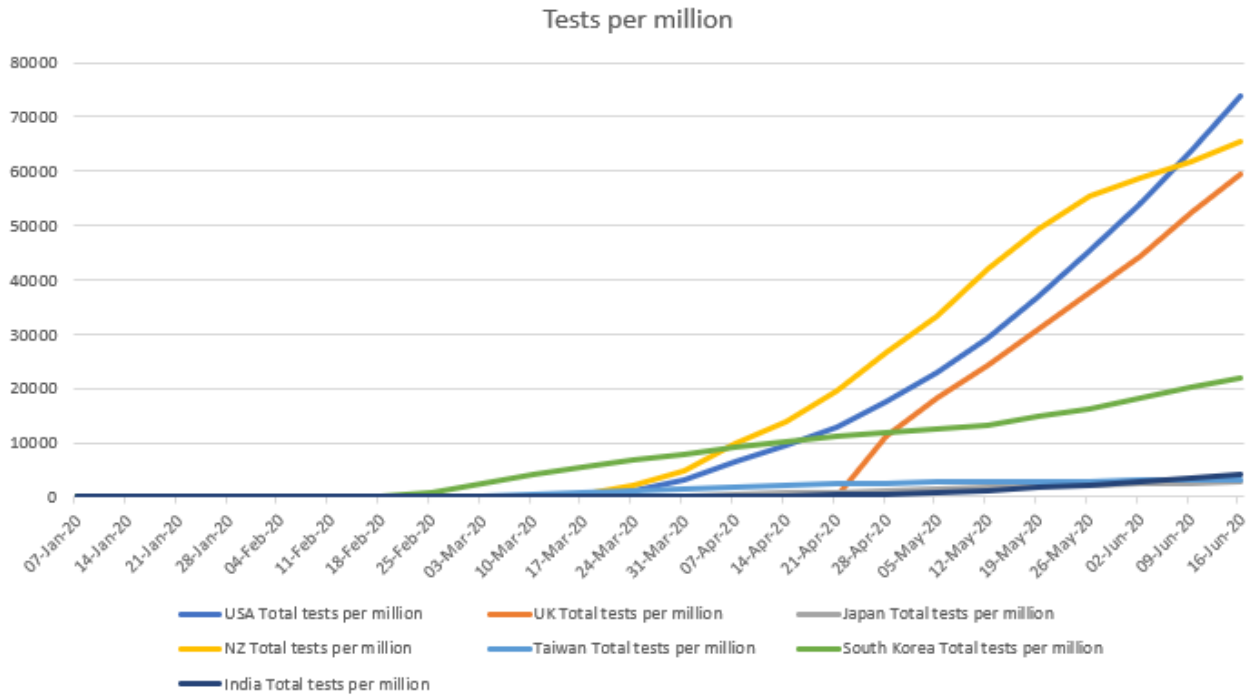
Graph 19: Total number of COVID19 confirmed-cases per 10 lakhs people people in India taken at an interval of 7 days starting from January till mid-June



Graph 20: Total tests performed per million compared with COVID19 confirmed-cases per 0.001 billion people in India taken at an interval of 7 days starting from January till mid-June



Graph 21: X Y Scatter plot– tests and cases per million for India



Graph 22: Inter country comparison of tests per million performed taken over a period of 7 days starting from January till mid-June

8. Calculations:

Table 2: Calculating the number of minimum tests needed for identifying 1 case for the countries using the XY Scatter plots

Country	Best fit equation	Value of X at Y = 1	Tests needed per active case	Value of R^2
USA	y = 277.33x - 1849.5	6.672	6672	0.811
UK	y = 206.08x - 1362.4	6.615	6615	0.811
New Zealand	y = 14.096x - 74.662	5.367	5367	0.813
South Korea	y = 12.595x - 37.065	3.022	3022	0.864
Taiwan	y = 1.0736x - 4.8808	5.477	5477	0.857
Japan	y = 7.2604x - 44.762	6.302	6302	0.828
India	y = 6.7952x - 52.487	7.871	7871	0.552

Table 3: Correlation between cases per million and tests per million

Country	Correlation
USA	0.97
UK	0.92
New Zealand	0.84
South Korea	0.9
Taiwan	0.97
Japan	0.97
India	0.99

9. Interpretation:

Values of X i.e., tests needed for identifying 1 case – Lower the value of X higher is the efficiency of testing strategy of the country which gives us South Korea as the best performing country with the most efficient testing strategy to deal with the pandemic followed by Taiwan, New Zealand, Japan, UK, USA and India

R^2 value is telling us how much of cases is explained by tests i.e., how much of cases are dependent on tests. Higher the value higher the dependency of cases on tests.

South Korea has the highest value of R^2 which shows high dependency of its cases on testing numbers – 86.4% dependency on testing measures, rest 13.6% dependency on other variables

It is followed by Taiwan which has 85.7% dependency of its cases on testing numbers

Country with lowest value of R^2 is India. It shows only 55.2% dependency of its cases on testing numbers

Correlation shows how strongly Cases and tests numbers are dependent on each other**.**

All the countries (except for New Zealand which has a lower correlation number, 0.84) show strong dependency of cases on tests >90%

10. Result

South Korea came out as the country with the best testing strategy compared to the other 6 countries. Its test needed per active case is lowest (3022), R^2 value is highest (86.4%) and correlation coefficient is also high (0.9) which indicates that number of cases are highly and strongly dependent on number of tests performed proving the effectiveness of its testing strategy

On the other hand, India has highest number of tests per active case (7871), R^2 value is lowest (55.2%) and correlation coefficient highest (0.99) which indicates that rate of increase of cases closely follows increase in tests and many other factors other than tests are responsible for increased cases indicating higher number of testing is required.

Countries in the order of highly effective testing strategies to least effective

South Korea > Taiwan > New Zealand > Japan > UK > USA > India

11. Key Observations:

Table 4: Inter country comparison of testing and cases data at an interval of 1 month *(Testing numbers not available for some countries for the month of January and February, hence excluded)*

	Cases /million – 15th March	Tests/million – 15th March	Cases/million – 15th Apr	Tests/ million – 15th Apr	Cases/ million – 15th May	Tests/ million – 15th May	Cases/million – 15th Jun	Tests/million – 15th Jun
USA	8.9	125	1841.42	9930	4238	32557	6458	79302
UK	16.7	593	1382.80	4622	3434	24504	4391	104930
New Zealand	1.65	151	223.54	14549	238	46438	239	64210
South Korea	159	5231	206.57	10426	214	14175	237	22348
Taiwan	2.4	723	16.58	2129	18.4	2897	18.6	3137
Japan	6.1	103	64.04	199	128	1825	139	2752
India	0.06	NA	8.28	745	59.4	1478	256	4530

1) After looking at the cases and tests curve for the countries it can be seen that, South Korea, Taiwan, New Zealand ramped up their testing numbers as early as February end – early March compared to other countries (USA, UK, India) where testing numbers were ramped up by early April

2) Countries which ramped up their testing during early stage of pandemic were able to effectively contain the transmission through tracking, tracing and isolation which led to flattening of curve at later stages – South Korea, Taiwan, New Zealand *(along with effects of other containment measures)*
3) Countries with very few testing numbers during the early stage of pandemic were unable to trace the contacts effectively leading to increased transmission and outburst of cases later, e.g., US reporting as many as 26,000+ cases daily
4) Japan is an exception which kept its testing numbers low but still has been able to control the transmission

12. Data Limitation: Testing data for some countries is not available for the month of January and February

13. Discussion:

Testing for COVID-19 has four uses[34]:

1) Clinical use – for confirmation of diagnosis – this has limited utility to control the pandemic as vast majority of cases have mild symptoms or are asymptomatic, requiring no treatment
2) Breaking the transmission chain – through identification of cases and their isolation. In the scenario of limited resources identification of asymptomatic cases should be prioritized as they not only outnumber the symptomatic cases but also unknowingly keep spreading the infection
3) Planning and allocation of resources – identify epidemiological curve a city/district is. Good quality of data is required to generate reliable estimates of probable and confirmed cases. Emerging hotspots are identified through random sampling of virological tests. This helps in creating targeted policy responses to minimize transmission
4) Estimate development of herd immunity in community – to identify when enough people have developed immunity so that they can't pass on the virus thus breaking the chain of transmission

Most of the countries recorded their first case in January but went on to adopt different approaches to testing strategies leading to varied outbreak. Countries performing high testing numbers during the early stage of pandemic were able to flatten the curve compared to those which didn't.

Technology played a major role in effective implementation of tracking and tracing contacts post testing. Countries have used Bluetooth tracking, GPS tracking, mobile applications, credit card transactions, surveillance records etc. to identify the contacts of positive cases and warn the public about trajectories of positive cases. Although, data privacy concerns were raised in several nations regarding the same.

Comparing the testing strategy adopted by different countries in the table below gives a perspective about what worked for the nations which effectively controlled the pandemic

Table 5: Inter country comparison of testing strategies and its consequences adopted by countries *(Blue – performing)*

	Viral/ Antigen Testing	Antibody Testing	Testing of asymptomatic cases	Early Response	Population sero-surveillance	Use of technology	Lockdown	Cases Curve Flattened
USA								Curve has begun to flatten but cases still reported in large numbers (~26,000+ cases each day)
UK						Mobile apps		
New Zealand		Study among high risk individuals to begin using Ab tests[35]						
South Korea						Mobile apps, credit card tracking, GPS		
Taiwan						Use of GPS, AI labs etc.[36]		
Japan				Japan started early but kept its testing	Started in early June (June 1-June 7)[37]			

				numbers low – focused on pin-point testing				
India		ICMR recently approved some ELISA and RDT kits for surveillance[38]			Maharashtra Government to launch surveillance study among HCWs[39]	Arogya Setu App		

14. **Conclusion:**

Starting in December 2019 from China COVID-19 has spread across the world. Countries have imposed various types of containment measures including lockdown restrictions, social distancing, testing, contact tracing and isolation

Based on the data collected and monitored of number of tests, cases and deaths across the 7 countries for a time period of 5 and a half months we developed some understanding about how early interventions by the government to increase the testing capacity has helped the nations to combat COVID -19 without even imposing strict lockdowns as done by other countries.

South Korea, Taiwan, Japan and New Zealand came out as successful models which implemented different testing strategies to control spread of infection at an early stage without imposing full time lockdown.

South Korea[40] began to ramp up its testing capacity as early as January when COVID -19 cases in countries outside China were reported in single digits. In first days of February South Korea adopted open public testing available to asymptomatic individuals as well and contact tracing of all confirmed cases. This led to early identification of cases and their isolation to prevent the spread of infection. By middle of March South Korea achieved peak of its outbreak far ahead than most of the countries. As the number of cases fell, testing continued at same rates

South Korea was testing more than 22,000 people per day by mid-June. Increased testing numbers along with extensive use of mobile technology to help trace the contacts of positive cases helped South Korea to control the infection without imposing any lockdown

Moreover, Government approved in-house developed testing kits and allowed private and public laboratories to increase their R&D capacity further strengthening the infrastructure required for testing. South Korean government also introduced drive through testing centers and walk in centers across the country that further helped in increasing the tests performed per day. All these steps helped South Korea to flatten their curve at an early as March and kept their total death count as low as 5 per million.

Taiwan is yet another example. A country that shares border with China has proven that with early interventions, use of technology and compliance by the population can help control the pandemic.

Taiwan's cases per million stands at 18 and deaths at 0.29 attributed to its expanded testing capacity and use of technology for contact tracing. Taiwan particularly learned lessons from the MERS outbreak and implemented those to deal with COVID – 19. All this helped Taiwan to achieve peak of its outbreak by early April and flatten its curve without imposing any nationwide restrictions.

Japan- Japan came out as an exception. It kept its testing numbers low and still contained the outbreak achieving peak of the outbreak by April. It focused on clustered approach and pin point testing strategy and identified and tracked original infection source isolating people with high transmissibility. Though initially criticized for low testing numbers Japan showed how targeted approach can help to deal with the pandemic without resorting to Lockdown, disrupting economies. Japan cases and deaths per million stood at 139 and 7 respectively by mid-June.

New Zealand with its elimination strategy has showed how successfully a pandemic can be controlled. By imposing strict lockdown restrictions, banning flights coming from suspected countries, inclusion of widespread tests and isolating them played an effective role in controlling the infection spread. It's cases and death per million as of mid-June stands at 239 and 4.5

New Zealand achieved peak of its outbreak by mid-April.

One of the major differences in these successful countries and other countries like US and UK is the swift action of their government to introduce timely measures. While testing in above mentioned countries was prioritized as early as January UK and US struggled to increase their testing numbers by end of march.

United Kingdom[40] started testing good numbers by February but by early March testing numbers couldn't keep up with the outbreak. By early April UK announced its 5 pillars of testing strategy that focused on ramping up testing capacity, using testing for surveillance and clinical assessment. However, the policy of tracing contacts ceased in March and testing was not extended beyond symptomatic population. As many as 4,000 people were confirmed out of 10,000 people tested daily in April. Outbreak had grown far quicker showing testing numbers were unable to cope up with increased transmission

United States of America[40] - CDC over the past 5 months have evolved testing strategy in USA.

Testing in USA began to ramp up only by mid-March. By end of March 1,00,000 people were tested per day which increased to ~5,00,000 tests per day in June. The number of tests performed in USA outstripped other countries so did its outbreak. In early April daily cases reported in USA was approximately 50 times higher than South Korea. USA has been able to flatten its curve; it achieved the peak of the outbreak in late April when it was reported as many as 48,000 cases per day. However, daily cases reported in US still stands as high as ~26,000 per day indicating extensive transmission of virus in its community.

Population based surveillance studies are undergoing in USA. Data reported can give an evidence of herd immunity established considering the huge population infected in USA.

Comparison with India:

India came a long way with its testing journey. Starting from 13 labs in mid-February Government increased the capacity to 609 by May which have significantly contributed to its increased testing numbers which by mid-June stands at 4,530 per million. But unlike South Korea, Taiwan etc. India was unable to increase its testing numbers in early stage of the pandemic. A strict timely lockdown was imposed towards the end of March and continued till June 1st, but cases began to rise with huge addition in daily numbers as testing numbers increased. Daily cases increased from ~70 in March end to ~11,000 in June. India soon will cross the mark of 4,00,000 cases and will be one of the top 3 most affected country in the world.

India refrained from testing asymptomatic population which have resulted in increased transmission through these unidentified cases.

Government of India imposed timely lockdown to prevent the transmission of infection, but reduced testing capacity prevented timely identification of cases in early stage. Improved infrastructure and accessibility in remote areas is essential for India to increase its testing capacity as well as better use of technology with all the data protection norms in place is essential to successfully follow the approach of test, contact and trace.

15. Suggestions:

Based on findings and assessment of testing strategies of the countries studied above following are suggestions for effective implementation of testing strategies to control a pandemic:

South Korea, Taiwan and New Zealand came out as successful models with respect to their testing strategies.

The 3-guiding principle of South Korea of test, trace and contain helped it to break the transmission chain at an early stage which eventually helped it out to flatten its curve. Government intervened at an early stage, provided approval to the private labs to start testing and gave approvals to their in house developed testing kits. India on the other hand ramped up its capacity gradually. Till date testing is limited to symptomatic individuals leaving out early identification of asymptomatic individuals which bear the major proportion of total cases. India needs to revise its testing strategy to bring in asymptomatic individuals, trace and isolate them to break the chain of transmission. Moreover, learning from the COVID-19 situation, government of India needs to intervene at an early stage to ramp up testing capacity and resources delaying which has resulted in huge surge of cases in the later stages.

Taiwan proactively seek out patients using its National Health Insurance Database, identified them who had tested negative for influenza and retested them for COVID-19. Moreover, like South Korea Taiwan quickly ramped up its testing capacity as early as January. Drive through and walk in centers were established all over the country which allowed testing in huge numbers. Like Taiwan India need to utilize the huge data banks available to aid in decision making and developing strategies. While some states in India implemented the concept of drive through centers such as Kerala and Maharashtra it was not implemented all across. These drive through centers have been successful in ramping up testing numbers in many countries, developing them in India in mass numbers could help the same.

New Zealand's swift actions by its government, testing asymptomatic individuals, testing of people who had travelled to or from a country of area of concern helped it to identify cases during the early months, trace, track and isolate them which eventually broke their chain of transmission. India needs to shift its focus to asymptomatic individuals which forms the major proportion of cases, trace their contacts and isolate them.

Japan came out as exception, while keeping its testing numbers low Japan through its clustered approach and pin-point testing contained the infection. Though not in containment zones/hotspots this approach of Japan can be implemented in green zones in India where cases reported are near zero. This can help detect the clusters of infection and contain them to prevent transmission

USA and UK are in the top tally with highest number of cases. Both the countries started of slow with their testing numbers but ramped up quickly by March end. However, they were unable to keep up with the increasing case numbers. By April end both the countries were testing in lakhs each day. Compared to them India still have huge scope to increase its testing numbers. Both the countries have mapped out their testing plans with focus on increasing testing capacity, rolling out of surveillance programs to estimate immunity against the virus prevalent in the population and antibody testing. India also needs to roll out a strategic plan to increase its numbers, surveillance plans for its different zones.

Compiling the suggestions following are the learnings India can take from the countries studied:

1. Early interventions by Government is required to increase the testing capacity
2. Testing, tracing and isolation of asymptomatic individuals is must to break the chain of transmission
3. Increasing capacity by building drive through and walk in centers
4. Utilizing the power of data for decision making and developing strategies
5. Rolling out surveillance plans and increasing antibody testing
6. Using targeted approach towards testing as per the number of cases in different zones

16. **References**:

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