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Modeling of Coronavirus Spread in Morocco using Statistical Approach: SIR Model

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Abstract

The recently emerged Covid-19 virus has caused more than 65,872,391 infections and 1,523, 656 deaths up to December 8, 2020 worldwide. The disease continues to spread in all countries. The use of mathematical models in public health plays an important role in many aspects, such as rapid visualization of epidemiological information, monitoring, forecasting and estimating the spread of disease, and assisting in decision-making on pandemic prevention and control. The objective of this study is to show the role of SIR model in predicting the evolution of the COVID-19 pandemic in the Moroccan kingdom and to estimate the time necessary for its disappearance. Thus, the results found following the use of the SIR model are almost similar to the results obtained by the Minister of Health in Morocco, so far we notice the rapid spread of this disease and 13 August 2021, the Covid-19 will be 0 confirmed cases. Thus, the calculation of the basic reproduction number R_0 gave a value of 2.003 which shows that the number of infected people does not stop increasing until *a* vaccine for this virus is found. In this case, the respect of the rules of hygiene and containment can lower the value of R_0 and the spread of pandemic.

Keywords: Covid-19, Morocco, SIR model, Basic reproduction number

1 Introduction

Since December 2019, the COVID-19 pandemic has influenced human life and the global economy and has caused major disruptions (1-2). Coronavirus Disease-19 (Covid-19) is a respiratory disease caused by an emerging coronavirus, SARS-CoV-2 (3-4) and Middle East respiratory syndrome (MERS). (5). It is of animal origin (6-7). This disease influences the mental health of the public (8). Post-traumatic stress disorder and depressive disorders constituted the psychological state (9), anxiety and insomnia (10-11). WHO has declared the disease as a public health emergency of international concern (PHEIC) and named it COVID-19. The epidemic began in the Chinese city of Wuhan, Hubei Province, in late December 2019 (12-13). Based on the increasing number of confirmed cases of illness by Covid-19, the outcome will be the largest pandemic of the 21st century to date (14). This virus has spread throughout the world (15), it has infected more than 65 872 391people and 1 523 656 decided cases up to 8 December 2020 (16). Most countries have reported more than 2 000 000 confirmed cases (Americas, Europe, Eastern Mediterranean, South-East Asia), but Africa is 1 547 607cases (about 2 %) and Western Pacific is 914 744 cases (about 1%) (17-18). To model the COVID 19, we choose mathematical methods because they are more precise than the stochastic models (19). In addition, and to predict the spread of endemics, mathematical modelling was used to assist authorities in implementing preventive action plans (20-21). Among the most widely used models is the SIR (22-23-24). Several authors have used the same model in China (25), in Indonesia (26), in Cameroon (27), in Italy (28-29), in Spain (30), in USA (31), in Algeria (32), in Bangladesh (33), in California and Florida (34) and in Africa (35). The first confirmed case of COVID-19 was reported in Morocco on March 2, 2020 (36) through a Moroccan national living in France (37). The COVID-19 pandemic began in the Casablanca-Settat region, which forms a group of more than 5,861,739 million inhabitants along with the surrounding cities (38). The present work consists in showing the importance of SIR model to predict the Covid 19 pandemic in the Kingdom of Morocco

2 Data and methods

2.1 Study area

Morocco is located in theNorth-West Africa. It is bordered to the north by the Mediterranean Sea, to the east and southeast by Algeria, to the south by Mauritania and to the west and southwest by the Atlantic Ocean. It has a population of about 38 million, 52% of which is urban and 48% rural (38). It has a total area of nearly 710,850 km² (Table 1 and Figure 1). The main industries are agriculture, textiles, mining and tourism.

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Table 1: The characteristics of each region of Morocco (38)

Geographic code	Name of the region	Headquarter	Subdivisions		Population 2014		Area	
			Number of provinces and prefectures	Number of communes	Number of inhabitants	%	(en km2)	%
1	Tanger-Tétouan-Al Hoceïma	prefecture of Tanger-Assilah	8	149	3 556 729	9,50	17262	2,30
2	L'Oriental	prefecture of Wejda-Angad	8	147	6 914 346	18,46	90127	11,99
3	Fès-Meknès	prefecture of Fès	9	194	4 236 892	11,31	40075	5,33
4	Rabat-Salé-Kénitra	prefecture of Rabat	7	114	4 580 866	12,23	18194	2,42
5	Béni Mellal-Khénifra	province of Béni-Mellal	5	164	2 520 776	6,73	41033	5,46
6	Casablanca-Settat	prefecture ofCasablanca	9	153	5 861 739	15,65	19448	2,59
7	Marrakech-Safi	prefecture ofMarrakech	8	251	4 520 569	12,07	39167	5,21
8	Drâa-Tafilalet	province of Errachidia	5	109	1 635 008	4,37	115592	15,38
9	Souss-Massa	prefecture of Agadir Ida-Outanane	6	175	2 676 847	7,15	53789	7,16
10	Guelmim-Oued Noun	province of Guelmim	4	53	433 757	1,16	46108	6,13
11	Laâyoune-Sakia El Hamra	province of Laâyoune	4	20	367 758	0,98	140018	18,63
12	Dakhla-Oued Ed-Dahab	province of Oued Ed-Dahab	2	13	142 955	0,38	130898	17,41
	Total		75	1542	37448242	100	710850	100

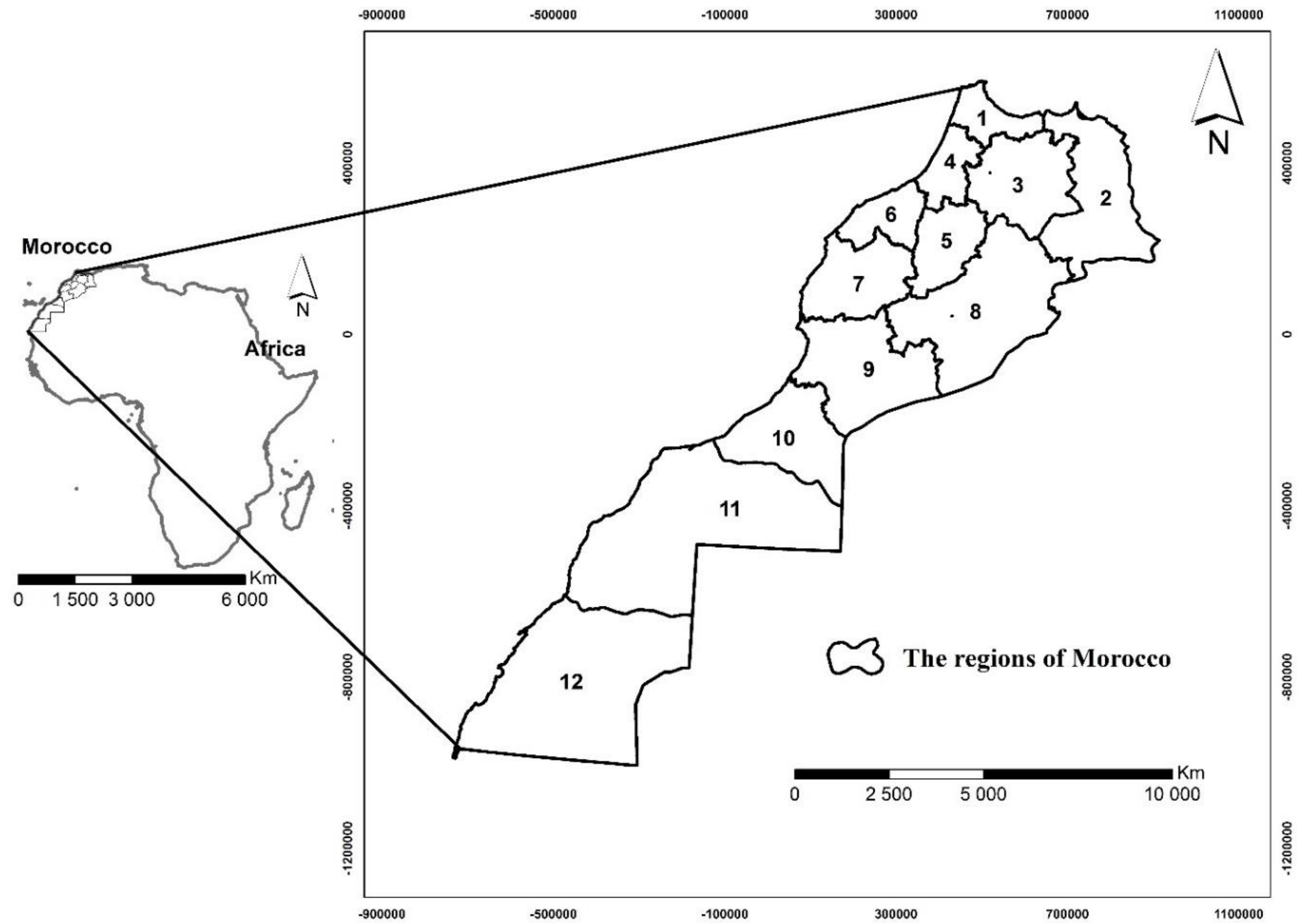

Figure 1: Geographical location of Morocco

2.2 Data

Historical data of people contaminated with COVID-19 from 02 March 2020 until 15 November 2020 were collected and used in this study, from the official website of the Johns Hopkins University (https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html) (39). With the help of a GIS, Data where analyzed using Arc GIS 10.1 and Excel office software

2.3 Modelling of virus spread

The SIR (Susceptible, Invective, and Removed) model was proposed by two researchers W.O Kermak and A. G Mckendrik (40), it has been adopted by authors (23-24-41), the population was subdivided into three compartments as shown in the diagram (Figure 2). We can define these compartments in this way: The Susceptible S or the Healthy (those who have never had the disease, and can contract it), The Infected I (those who are sick, also known as contagious), The Recovered R (those who have already had the disease and are now immune to it. Included in this group those who have died) (40).

To apply this model, the following ordinary differential equations are used:

$$dS/dt=-aSI \quad (1)$$

$$dI/dt=aSI - bI \quad (2)$$

$$dR/dt= bI \quad (3)$$

$$St+It+Rt= N \quad (4)$$

Whose derivatives dS / dt, dI / dt and dR / dt measure the rate of change of quantities S (t), I (t) and R (t). (42), according to Belfin et al. 2020 mean that these parameters *a* and *b*, *a* is the effective transmission rate and *b* is the removal rate (43). For parameters *a* and *b* they were estimated as follows (Table 2), (44-45):

Table 2: The estimation of parameters of the SIR model

Country	Initial number of cases (*I0*)	Contact rate (*a*)	Removal rate (*b*)	Basic Reproduction number (*R0*)
Morocco	1	0.499 (1/day)	0.249 (1/day)	2.003

The SIR model makes several assumptions such as:

- The population is considered homogeneous: each individual has the same probability of meeting another individual (46-47).
- Infection is from individual to individual through contact. Each infectious individual is cured and becomes immune within a unit of time. Immunity is permanent;
- Each infected individual becomes infectious after one unit of time;

The SIR model was used to estimate the spread of the COVID-19 pandemic in the most affected and active region in Morocco.

2.4 The basic reproduction number

The basic reproduction number "R_0": (48-49) is defined as the number of people infected by an individual who contracted the virus before death or recovery. If it is less than 1, I(t) decreases. On the other hand, if it is higher than 1, we are in the presence of an epidemic. To stop the spread of the epidemic, the value of R_0 should be lower by many ways as vaccination ofthe population or by taking other precautions which may reduce "*a*". This parameter has been calculated using the following equation (45-50):

$$R_0= a/b \quad (5)$$

Where; *a* is the infection rate (0.499) and *b* is the recovery rate (0.249)

3 Results and discussion

3.1 COVID-19 disease evolution in Morocco

People can become infected with Coronavirus disease (Covid-19) because of meeting other people infected. The disease may not be spread from person to person. The duration of onset of symptoms varies from one day to 14 days (12-49-51). The Covid-19 pandemic has been developing in Morocco since March 2, 2020. The Ministry of Health in Morocco has announced that there have been 383,323 confirmed cases of coronavirus since the beginning of the pandemic, the number of deaths has reached 6,357 and the number of recoveries has been 257,678 (Figure 3), (37). In recent days, Morocco has seen an increase in confirmed cases especially in regions that have experienced industrial development such as: Region of Casablanca-Settat, Fes-Meknes, Tanger-Tetouan-Al Hoceïma and Marrakech-Safi (Figure 3), (52).

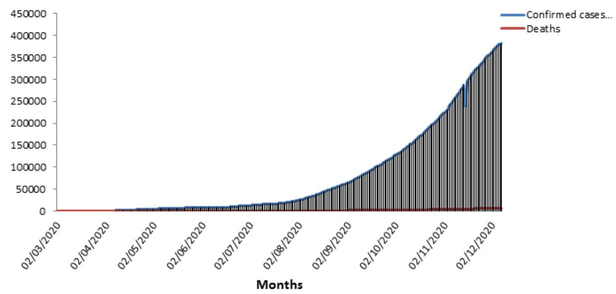

Figure 2: Temporal progress of confirmed cases and deaths from Covid-19 in Morocco (Source: covidmaroc.ma)

3.2 Covid-19 epidemic modeling

The model describes the dynamics of susceptible S(t) who become infected with rate *a*, infected I(t) and withdrawn R(t) over time: The evolution of the state variable were illustrated: I(t) over time for the Morocco (Figure 4).

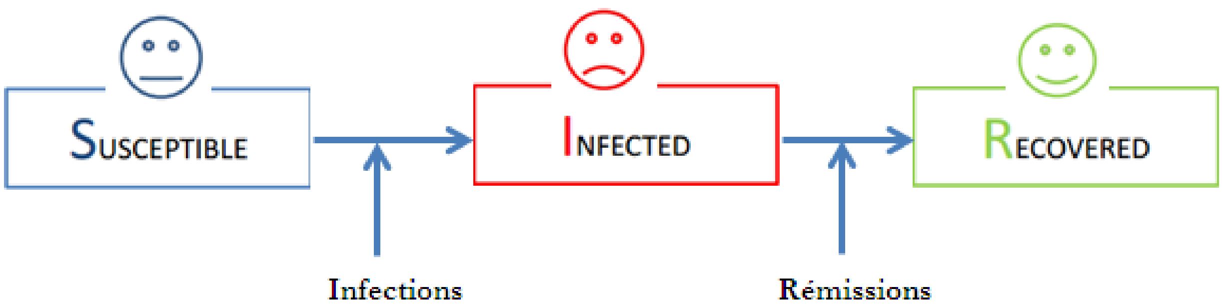

Figure 3: Basic structure of SIR model

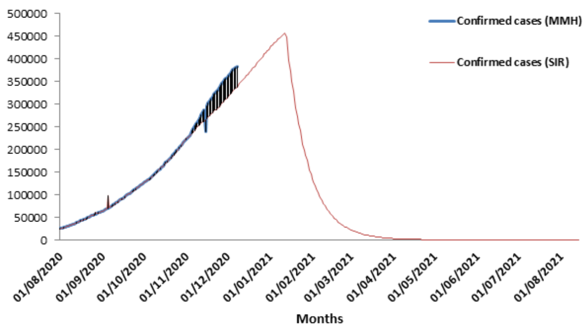

Figure 4: Result of SIR modeling in Morocco for infected people

- S (t): the number of people likely to be infected with: S (0)= 38,000,000
- I(t): the number of persons infected with : I(0)= 1;
- R(t): the number of persons who acquired immunity with : R(0)= 0;
- "a": the infection rate with: a= 0,499;
- "b": the rate of recovery/healing with : b=0.249

The results obtained by this estimate are almost adequate for cases confirmed by the Ministry of Health in Morocco. Details of the estimated spread of the pandemic over the next three months in Morocco are given in Table 3. The disease spreads fairly rapidly to the general population during one month and the number of infected cases increases to a total of 457,970 model-confirmed cases as of January 12, 2021. After one month, the number of infected people may decrease in the country, in which case the end of the coronavirus outbreak will be August 13, 2021. (Table 3 and Table 4).

3.3 The basic reproduction number R0

The results of the calculation of the basic reproductive number is equal (R_0 = 2.003), the value is greater than one, which means an increase in the rate of infection. In order to reduce the number of people likely to be infected, it is essential to follow the rules of hygiene by washing hands with soap, to respect the rules of confinement, to put oneself at a distance of one meter from others and to put masks. These rules can contribute to the decrease of the value of "*a*" and thus the decrease of R_0.Pending the results of the search for a suitable vaccine for this virus.

4 Conclusion

This research was conducted to investigate the benefits of modeling to visualize the COVID-19 pandemic in the short and medium term. The main results of the study. The study showed that statistical analysis and mathematical modeling play a very important role in studying the spread of the COVID-19 disease, which helps authorities to take preventive measures. For example, the estimate predicts that the number of infected people will continue to increase with an R_0 index greater than 1, which is important for compliance with Ministry of Health orders and health and safety regulations.

Table 3: Results obtained from the SIR propagation model of Covid-19 until February 28, 2021

Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*
01/08/2020	24550	01/09/2020	62884	01/10/2020	126355	01/11/2020	223686	01/12/2020	313478	01/01/2021	425115	01/02/2021	135682
02/08/2020	25425	02/09/2020	66001	02/10/2020	128355	02/11/2020	226186	02/12/2020	317055	02/01/2021	427879	02/02/2021	127259
03/08/2020	26000	03/09/2020	66950	03/10/2020	130355	03/11/2020	229046	03/12/2020	321206	03/01/2021	431568	03/02/2021	119352
04/08/2020	26534	04/09/2020	68555	04/10/2020	132154	04/11/2020	231558	04/12/2020	324891	04/01/2021	434344	04/02/2021	111929
05/08/2020	27956	05/09/2020	96688	05/10/2020	133209	05/11/2020	235308	05/12/2020	328936	05/01/2021	437273	05/02/2021	104963
06/08/2020	29345	06/09/2020	71775	06/10/2020	135559	06/11/2020	237386	06/12/2020	331956	06/01/2021	440718	06/02/2021	98425
07/08/2020	29998	07/09/2020	73550	07/10/2020	138359	07/11/2020	241386	07/12/2020	334220	07/01/2021	444161	07/02/2021	92289
08/08/2020	32000	08/09/2020	74000	08/10/2020	140859	08/11/2020	246386	08/12/2020	338208	08/01/2021	446724	08/02/2021	86533
09/08/2020	33105	09/09/2020	77019	09/10/2020	144359	09/11/2020	249898	09/12/2020	342193	09/01/2021	448081	09/02/2021	81132
10/08/2020	33959	10/09/2020	79112	10/10/2020	148359	10/11/2020	251913	10/12/2020	346513	10/01/2021	451266	10/02/2021	76065
11/08/2020	34881	11/09/2020	81918	11/10/2020	150769	11/11/2020	254928	11/12/2020	349769	11/01/2021	454653	11/02/2021	71312
12/08/2020	36004	12/09/2020	83516	12/10/2020	154319	12/11/2020	257878	12/12/2020	353559	12/01/2021	457970	12/02/2021	66854
13/08/2020	37755	13/09/2020	87045	13/10/2020	158074	13/11/2020	260238	13/12/2020	357019	13/01/2021	448891	13/02/2021	62673
14/08/2020	38675	14/09/2020	88111	14/10/2020	160634	14/11/2020	261738	14/12/2020	359799	14/01/2021	422172	14/02/2021	58751
15/08/2020	40009	15/09/2020	89714	15/10/2020	162233	15/11/2020	265003	15/12/2020	362949	15/01/2021	396938	15/02/2021	55073
16/08/2020	41724	16/09/2020	92000	16/10/2020	165221	16/11/2020	267878	16/12/2020	365899	16/01/2021	373122	16/02/2021	51624
17/08/2020	42982	17/09/2020	94022	17/10/2020	169476	17/11/2020	271778	17/12/2020	370050	17/01/2021	350656	17/02/2021	48390
18/08/2020	43942	18/09/2020	96819	18/10/2020	171876	18/11/2020	274178	18/12/2020	373735	18/01/2021	329474	18/02/2021	45358
19/08/2020	46008	19/09/2020	99113	19/10/2020	175376	19/11/2020	277428	19/12/2020	377780	19/01/2021	309513	19/02/2021	42514
20/08/2020	46534	20/09/2020	101642	20/10/2020	177956	20/11/2020	280873	20/12/2020	380800	20/01/2021	290709	20/02/2021	39849
21/08/2020	48563	21/09/2020	102096	21/10/2020	181106	21/11/2020	284316	21/12/2020	383064	21/01/2021	273003	21/02/2021	37349
22/08/2020	50012	22/09/2020	106012	22/10/2020	184586	22/11/2020	286879	22/12/2020	387052	22/01/2021	256337	22/02/2021	35006
23/08/2020	51900	23/09/2020	106219	23/10/2020	187836	23/11/2020	288236	23/12/2020	391037	23/01/2021	240654	23/02/2021	32809
24/08/2020	53111	24/09/2020	109001	24/10/2020	191536	24/11/2020	291421	24/12/2020	395357	24/01/2021	225902	24/02/2021	30750
25/08/2020	54078	25/09/2020	111612	25/10/2020	194516	25/11/2020	294808	25/12/2020	398613	25/01/2021	212028	25/02/2021	28819
26/08/2020	55170	26/09/2020	115112	26/10/2020	199266	26/11/2020	298125	26/12/2020	402403	26/01/2021	198984	26/02/2021	27010
27/08/2020	59906	27/09/2020	116752	27/10/2020	202386	27/11/2020	301623	27/12/2020	405892	27/01/2021	186723	27/02/2021	25313
28/08/2020	58000	28/09/2020	119950	28/10/2020	205986	28/11/2020	305386	28/12/2020	410787	28/01/2021	175200	28/02/2021	23723
29/08/2020	58999	29/09/2020	121730	29/10/2020	210486	29/11/2020	308107	29/12/2020	414435	29/01/2021	164374	*ENC : Estimated	
30/08/2020	61133	30/09/2020	124685	30/10/2020	214986	30/11/2020	310224	30/12/2020	417015	30/01/2021	154204	Number of Cases	
31/08/2020	61817			31/10/2020	218766			31/12/2020	420615	31/01/2021	144652		

Table 4. Results obtained from the SIR propagation model of Covid-19 until August 13, 2021

Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*	Date	ENC*
01/03/2021	22233	01/04/2021	2966	01/05/2021	422	01/06/2021	56	01/07/2021	8	01/08/2021	1
02/03/2021	20836	02/04/2021	2779	02/05/2021	395	02/06/2021	53	02/07/2021	7	02/08/2021	1
03/03/2021	19526	03/04/2021	2604	03/05/2021	370	03/06/2021	49	03/07/2021	7	03/08/2021	1
04/03/2021	18299	04/04/2021	2440	04/05/2021	347	04/06/2021	46	04/07/2021	7	04/08/2021	1
05/03/2021	17149	05/04/2021	2287	05/05/2021	325	05/06/2021	43	05/07/2021	6	05/08/2021	1
06/03/2021	16071	06/04/2021	2143	06/05/2021	304	06/06/2021	41	06/07/2021	6	06/08/2021	1
07/03/2021	15060	07/04/2021	2008	07/05/2021	285	07/06/2021	38	07/07/2021	5	07/08/2021	1
08/03/2021	14113	08/04/2021	1881	08/05/2021	267	08/06/2021	36	08/07/2021	5	08/08/2021	1
09/03/2021	13226	09/04/2021	1763	09/05/2021	251	09/06/2021	33	09/07/2021	5	09/08/2021	1
10/03/2021	12394	10/04/2021	1652	10/05/2021	235	10/06/2021	31	10/07/2021	4	10/08/2021	1
11/03/2021	11614	11/04/2021	1548	11/05/2021	220	11/06/2021	29	11/07/2021	4	11/08/2021	1
12/03/2021	10884	12/04/2021	1450	12/05/2021	206	12/06/2021	27	12/07/2021	4	12/08/2021	1
13/03/2021	10199	13/04/2021	1359	13/05/2021	193	13/06/2021	26	13/07/2021	4	13/08/2021	0
14/03/2021	9557	14/04/2021	1274	14/05/2021	181	14/06/2021	24	14/07/2021	3	14/08/2021	0
15/03/2021	8956	15/04/2021	1193	15/05/2021	170	15/06/2021	23	15/07/2021	3	15/08/2021	0
16/03/2021	8393	16/04/2021	1118	16/05/2021	159	16/06/2021	21	16/07/2021	3	16/08/2021	0
17/03/2021	7865	17/04/2021	1048	17/05/2021	149	17/06/2021	20	17/07/2021	3		
18/03/2021	7370	18/04/2021	982	18/05/2021	140	18/06/2021	19	18/07/2021	3		
19/03/2021	6906	19/04/2021	920	19/05/2021	131	19/06/2021	17	19/07/2021	2		
20/03/2021	6471	20/04/2021	862	20/05/2021	122	20/06/2021	16	20/07/2021	2		
21/03/2021	6064	21/04/2021	808	21/05/2021	115	21/06/2021	15	21/07/2021	2		
22/03/2021	5682	22/04/2021	757	22/05/2021	108	22/06/2021	14	22/07/2021	2		
23/03/2021	5325	23/04/2021	709	23/05/2021	101	23/06/2021	13	23/07/2021	2		
24/03/2021	4990	24/04/2021	665	24/05/2021	94	24/06/2021	13	24/07/2021	2		
25/03/2021	4675	25/04/2021	623	25/05/2021	88	25/06/2021	12	25/07/2021	2		
26/03/2021	4381	26/04/2021	584	26/05/2021	83	26/06/2021	11	26/07/2021	2		
27/03/2021	4105	27/04/2021	547	27/05/2021	78	27/06/2021	10	27/07/2021	1		
28/03/2021	3847	28/04/2021	512	28/05/2021	73	28/06/2021	10	28/07/2021	1		
29/03/2021	3605	29/04/2021	480	29/05/2021	68	29/06/2021	9	29/07/2021	1		
30/03/2021	3378	30/04/2021	450	30/05/2021	64	30/06/2021	9	30/07/2021	1		
31/03/2021	3165			31/05/2021	60			31/07/2021	1		

*ENC : Estimated Number of Cases

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Abbreviations

COVID-19: Coronavirus Disease-2019; **SIR**: Susceptible, Invective, and Removed; **CPH**: Census of Population and Housing; **PHEIC**: Public Health Emergency of International Concern; **MMH**: Moroccan Ministry of Health; **UN**: United Nations; **WHO**: World Health Organization; R_0: The basic reproduction number; **SARS**: Severe Acute Respiratory Syndrome; **MERS**: Middle East Respiratory Syndrome

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language. Also, all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures performed in this studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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