Computational Sciences and Engineering 2(2) (2022) 165-179

University of Guilan

Computational Sciences and Engineering

journal homepage: https://cse.guilan.ac.ir/

Analysis of COVID-19 outbreak in Iran by a Suite of Artificial Adaptive System Algorithms

Masoud Asadi-Zeydabadi [a], Massimo Buscema [b, c], Mozhdeh Saffari-Parizi [d], Giulia Massini [b], Mostafa Moradi-Khalaj [e], Weldon Lodwick [c,*]

[a] Department of Physics, University of Colorado Denver, Denver, CO 80217, USA
[b] Semeion, Research Centre of Sciences of communication, via Sersale 117, 00128 Rome, Italy
[c] Department of Mathematical and Statistical Science, University of Colorado Denver, Denver, CO 80217, USA
[d] Auraria Library, University of Colorado Denver, Denver, CO 80217, USA
[e] Department of Civil and Environmental Engineering, 7134851156, Shiraz University, Shiraz, Iran

ARTICLE INFO

Article history:
Received 25 April 2021
Received in revised form 25 May 2021
Accepted 10 June 2021
Available online 20 June 2021

Keywords:
COVID-19 outbreak
Artificial Adaptive System
Topological Weighted Centroid (TWC)
TWC-frequency

ABSTRACT

COVID-19 outbreak in Iran is studied and analyzed using Topological Weighted Centroid (TWC) algorithms. According to this algorithm the origin of the outbreak is mainly in the city of Qom. In addition, it predicts the centers of the epidemic spread in the future as well as pathways of this spread. Since the coordinates of all data were not given, we modify the algorithm based on the frequency (number of cases) and we used TWC-frequency.

1. Introduction

The new COVID-19 virus outbreak started from Wuhan, China. On December 31, the office of World Health Organization (WHO) in China, reported a pneumonia with unknown cause was detected in Wuhan, China [1]. According to the WHO website, on the January 13, 2020, the Ministry of Public Health of Thailand reported the confirmation of the first imported case of COVID-19 from Wuhan [2]. The second confirmed case, on 15 January 2020, was a person who traveled from Wuhan, China to Japan [3, 4]. National IHR Focal Point (NFP) for Republic of Korea reported on

* Corresponding author.
E-mail addresses: Weldon.Lodwick@ucdenver.edu

https://doi.org/10.22124/cse.2021.19484.1012

20 January 2020, the first case in the Republic of Korea, a female, with Chinese nationality from Wuhan [5].

According to the Iranian Student News Agency (ISNA), on 19 February 2020, Iran's Health Ministry confirmed two cases of COVID-19 in Iran [6]. The schools and universities in Qom province Iran were closed as outbreak of COVID-19 on 19 February 2020, according to the ISNA report [7]. On Wednesday March 25, 2020, Iran's Deputy Health Minister said new clues had been found that the origin of COVID-19 in Iran were potentially due to the Chinese workers and students in Qom (see

ISNA [8]). He added, at first we thought it was probably the primary source of the disease from Qom, however now also have the possibility that it originated at two points, in both Qom and Gilan (ISNA [8]).

The analysis in this paper is based on early data, 3 March 2020, as reported in ISNA [9]. According to data that are provided by Johns Hopkins University, Coronavirus Resource Center, the numbers of confirmed cases and deaths in Iran until April 1, 2021 were 1,897,314 and 62,559 respectively [10, 11, 12].

This paper presents the results of the application of a suite of artificial adaptive systems called Topological Weighted Centroid (TWC) to find the origin and pattern of the disease outbreak [13, 14, 15, 16, 17]. The focus is on the early pandemic data.

2. Data

The data used for this study was provided by the ISNA and also from the Johns Hopkins University, Coronavirus Resource Center [9, 10]. ***Table 1*** shows the confirmed cases in Iran on 3 March 2020 [9].

Table 1. Confirmed COVID-19 cases on March 3, 2020

Province	Capital	Latitude	Longitude	Case
Alborz	Karaj	35.807579	50.987419	93
Ardabil	Ardabil	38.2537	48.3	12
East Azerbaijan	Tabriz	38.096237	46.2738	46
West Azerbaijan	Urmia	37.549805	45.078629	5
Bushehr	Bushehr	28.91998	50.83001	0
Chaharmahaal and Bakhtiari	Shar-e-Kord	32.3282	50.8769	0
Fars	Shiraz	29.5926	52.5836	35
Gilan	Rasht	37.2682	49.5891	218
Golestan	Gorgan	36.8456	54.4393	24
Hamedan	Hamedan	34.7989	48.515	10
Hormozgan	Bandar Abbas	27.1832	56.2666	11
Ilam	Ilam	33.635	46.4153	4
Isfahan	Isfahan	32.6539	51.666	120
Kerman	Kerman	30.2839	57.0834	4
Kermanshah	Kermanshah	34.3277	47.0778	7

North Khorasan	Bojnurd	37.4702	57.3143	0
Razavi Khorasan	Mashhad	36.2605	59.6168	29
South Khorasan	Birjand	32.8649	59.2262	5
Khuzestan	Ahvaz	31.3183	48.6706	35
Kohgiluyeh and Boyer-Ahmad	Yasuj	30.6684	51.5875	2
Kurdistan	Sanandaj	35.3219	46.9862	8
Lorestan	Khorramabad	33.4647	48.339	14
Markazi	Arak	34.0954	49.7013	141
Mazandaran	Sari	36.5659	53.0586	62
Qazvin	Qazvin	36.2737	49.9982	55
Qom	Qom	34.6416	50.8746	253
Semnan	Semnan	35.2256	54.4342	30
Sistan and Baluchestan	Zahedan	35.2256	54.4342	6
Tehran	Tehran	35.6892	51.389	1043
Yazd	Yazd	31.8974	54.3569	7
Zanjan	Zanjan	36.683	48.5087	2

The longitude and latitude are given based on the province capitals. We don't have access to data for confirmed cases in each city of Iran. The cases spread out in different cities and villages of each province.

3. Method

3. 1. TWC algorithms

The TWC method is based on statistical thermodynamics and optimizing free energy and entropy. In this method the probability of dispreading the disease to (x_i, y_i) is given in term of energy which is a function of the distance to the infected points. The TWC method is discussed briefly here and for more details about this method see [8]. In statistical thermodynamics for a system of N energy states the probability distribution for ith state is given by

$$p(E_i) = \frac{e^{-E_i/K_BT}}{\sum_{i=1}^{N} e^{-E_i/K_BT}}, \quad (1)$$

where E_i is energy for ith state, k_B is Boltzmann constant, and T is absolute temperature. The free energy is defined as

$$F = -k_BT \ln\left(\sum_{i=1}^{N} e^{-E_i/K_BT}\right). \quad (2)$$

The entropy is given by

$$S = -\frac{\partial F}{\partial T}. \quad (3)$$

In the TWC method the idea of statistical thermodynamics is adapted with some adjustments. Energy is a function of the Euclidean distance between infected points

$$E_i = E\left(\sum_{j=1}^{N} f\left(d_{i,j}\right)\right), \tag{4}$$

where N is the number of the infected points and $f\left(d_{i,j}\right)$ is a function of distance between points i and j. In this method we replaced $\frac{1}{k_B T}$ with an optimization parameter, $C = \frac{1}{k_B T}$.

The optimization parameter C in different TWC models is named as α, β, γ or others. The energy function also would change in different TWC methods. From ***Eq. (1)*** and ***Eq. (4)***, the probability or the weighting factor for point (x_i, y_i) is given by

$$p(x_i, y_i) = \frac{e^{-E\left(\sum_{j=1}^{N} f\left(d_{i,j}\right)\right)C}}{\sum_{i=1}^{N} e^{-E\left(\sum_{j=1}^{N} f\left(d_{i,j}\right)\right)C}}. \tag{5}$$

The coordinates of TWC point or path can be defined by

$$x_{TWC} = \sum_i^N x_i p(x_i, y_i), \tag{6}$$

$$y_{TWC} = \sum_i^N y_i p(x_i, y_i). \tag{7}$$

The TWC method has five main algorithms: $-\alpha, TWC-\beta, TWC-\gamma, TWC-\theta$, and $TWC-i$. The TWC algorithms identify the locations from which the disease dynamics can be thought to diffuse to other places. These locations are computed as past, present, near future, and longer future sites by $TWC-\alpha, TWC-\beta, TWC-\gamma,$ and $TWC-\theta$ respectively. In addition, TWC-θ constructs a graph that models the network through which the diseases is thought to spread.

In this analysis we used different TWC algorithm. Since we don't have data for all points we modify the algorithm based on the frequency (number of cases) and we used TWC-frequency. This algorithm is introduced for the first time in here for geographical data analysis.

3.2 The modified TWC algorithms (TWC-Frequency) and the coordinates

We don't have the exact location for each confirmed case and use outbreak locations as the longitude and latitude of the capital of the provinces. We modify TWC algorithms to adjust the information shortage about the location of other places with confirmed cases. We generate new N coordinates (longitude and latitude) based on the frequency, f, with some random distribution around the province capital.

The number of new points is created as follows

$$N(i) = \text{ceil}(1 + \log f(i)), \text{ if } (f(i) >= 1). \tag{8}$$

The coordinate, (x, y), latitude and longitude are given by

$$\begin{aligned} x_{new}(i) &= x_{PC}(i) + 2(0.05\, random) - 1 \\ y_{new}(i) &= y_{PC}(i) + 2(0.05\, random) - 1 \end{aligned}, \tag{9}$$

where x_{PC} and y_{PC} are the coordinates of the province capital.

In ***Table 1*** there is 28 confirmed points, by using ***Eq. (8)*** and ***Eq. (9)*** increase the number of points up to 99 points. All new points are close to the original points. The distance between points is used in the TWC method. The main reasons we creating the new points, near the original point instead of the repeating the points, are first that the point in TWC needs to be separated from each other with some distances and secondly we need to include cases separated from each other. The new data set that are derived from the original data set in ***Table 1*** by applying ***Eq. (8)*** and ***Eq. (9)*** is given in ***Table 2***.

Table 2. The coordinates (latitude and longitude) of the new points.

Name	Latitude	Longitude	Name	Latitude	Longitude	Name	Latitude	Longitude	Name	Latitude	Longitude
Karaj1	35.83789	50.98461	Gorgan1	36.84066	54.46825	Birjand1	32.82897	59.22377	Qazvin1	36.26757	49.95513
Karaj2	35.79869	50.99788	Gorgan2	36.81112	54.43964	Birjand2	32.8326	59.20324	Qazvin2	36.3166	50.03837
Karaj3	35.76516	51.0279	Gorgan3	36.82985	54.47614	Ahvaz1	31.36424	48.6709	Qazvin3	36.22693	49.95093
Karaj4	35.8362	50.93857	Gorgan4	36.88226	54.42493	Ahvaz2	31.33998	48.67865	Qazvin4	36.30984	50.0283
Karaj5	35.85192	51.01923	Hamedan1	34.76582	48.55783	Ahvaz3	31.32132	48.69085	Qazvin5	36.25887	49.97227
Ardabil1	38.22606	48.34856	Hamedan2	34.77813	48.47615	Ahvaz4	31.29161	48.71713	Qom1	34.64568	50.85838
Ardabil2	38.27596	48.2936	Hamedan3	34.75893	48.50412	Yasuj1	30.69805	51.55773	Qom2	34.6787	50.88638
Ardabil3	38.219	48.30836	Bandar_Abbas1	27.19562	56.27351	Sanandaj1	35.30326	46.97992	Qom3	34.65768	50.87419
Tabriz1	38.09997	46.2872	Bandar_Abbas2	27.19407	56.29113	Sanandaj2	35.32412	46.95779	Qom4	34.60984	50.88168
Tabriz2	38.06381	46.26477	Bandar_Abbas3	27.22433	56.3003	Sanandaj3	35.35717	47.03593	Qom5	34.59619	50.85802
Tabriz3	38.12895	46.32029	Ilam1	33.5984	46.42712	Khorramabad1	33.43866	48.31628	Qom6	34.60818	50.88626
Tabriz4	38.06386	46.31218	Ilam2	33.65031	46.37386	Khorramabad2	33.47039	48.33015	Semnan1	35.26986	54.42852
Urmia1	37.5944	45.0975	Isfahan1	32.70333	51.64565	Khorramabad3	33.45439	48.33768	Semnan2	35.20753	54.46702
Urmia2	37.5998	45.0949	Isfahan2	32.70121	51.63168	Arak1	34.06996	49.69117	Semnan3	35.20692	54.39352
Shiraz1	29.55144	52.54531	Isfahan3	32.60588	51.70822	Arak2	34.05227	49.69149	Semnan4	35.25372	54.39375
Shiraz2	29.62223	52.56402	Isfahan4	32.62555	51.68963	Arak3	34.12685	49.75087	Zahedan1	35.22193	54.43578
Shiraz3	29.57701	52.6156	Isfahan5	32.67631	51.70507	Arak4	34.11193	49.67542	Zahedan2	35.27299	54.44613
Shiraz4	29.57299	52.57638	Kerman1	30.28748	57.08603	Arak5	34.12247	49.71904	Tehran1	35.65108	51.38858
Rasht1	37.24073	49.61094	Kerman2	30.313	57.10049	Sari1	36.56448	53.02438	Tehran2	35.71529	51.3668
Rasht2	37.31524	49.63422	Kermanshah1	34.28065	47.09945	Sari2	36.57295	53.03389	Tehran3	35.72904	51.38272
Rasht3	37.24038	49.54	Kermanshah2	34.31176	47.07581	Sari3	36.58855	53.06013	Tehran4	35.68336	51.37329
Rasht4	37.24038	49.55783	Mashhad1	36.29721	59.60378	Sari4	36.5334	53.08371	Tehran5	35.65869	51.40923
Rasht5	37.30224	49.53942	Mashhad2	36.21327	59.63079	Sari5	36.59982	53.05791	Tehran6	35.7339	51.35756
Rasht6	37.25066	49.60976	Mashhad3	36.28991	59.63295				Tehran7	35.69996	51.38858
			Mashhad4	36.23185	59.57391				Yazd1	31.85532	54.38483
									Yazd2	31.9325	54.31989
									Zanjan1	36.66916	48.51692

4. Analysis and Discussion

4.1. TWC alpha

First, we use $TWC-\alpha$ to identify the origin of the outbreak based on the data in ***Table 1.*** The result was, using longitude/latitude coordinates, Longitude of 50.52 and Latitude of 35.04. This is a location in Markazi province, near the border of the Qom and Tehran provinces. Since we use only longitude and latitude of the capital of the provinces and we don't have the exact location of each outbreak in each province we will modify $TWC-\alpha$ algorithm as described in ***Eq. (8)*** and ***Eq. (9)***. The $TWC-\alpha$ algorithm estimates the origin of the outbreak [13]. ***Figure 1*** shows the source of COVID-19 and the $TWC-\alpha$ point. The $TWC-\alpha$ point is near the Qom. ***Figure 2*** shows the $TWC\alpha$ map. The hot area includes Qom and Tehran.

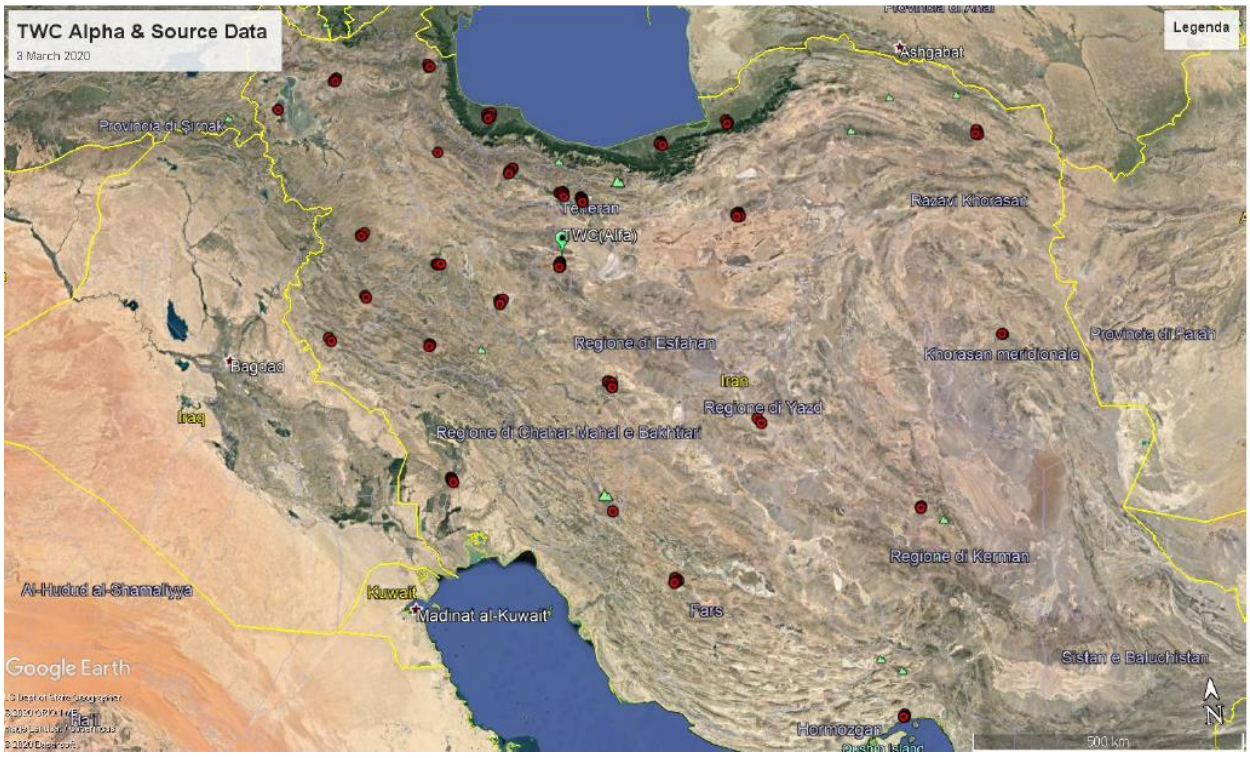

Figure. 1. The source and TWCα points.

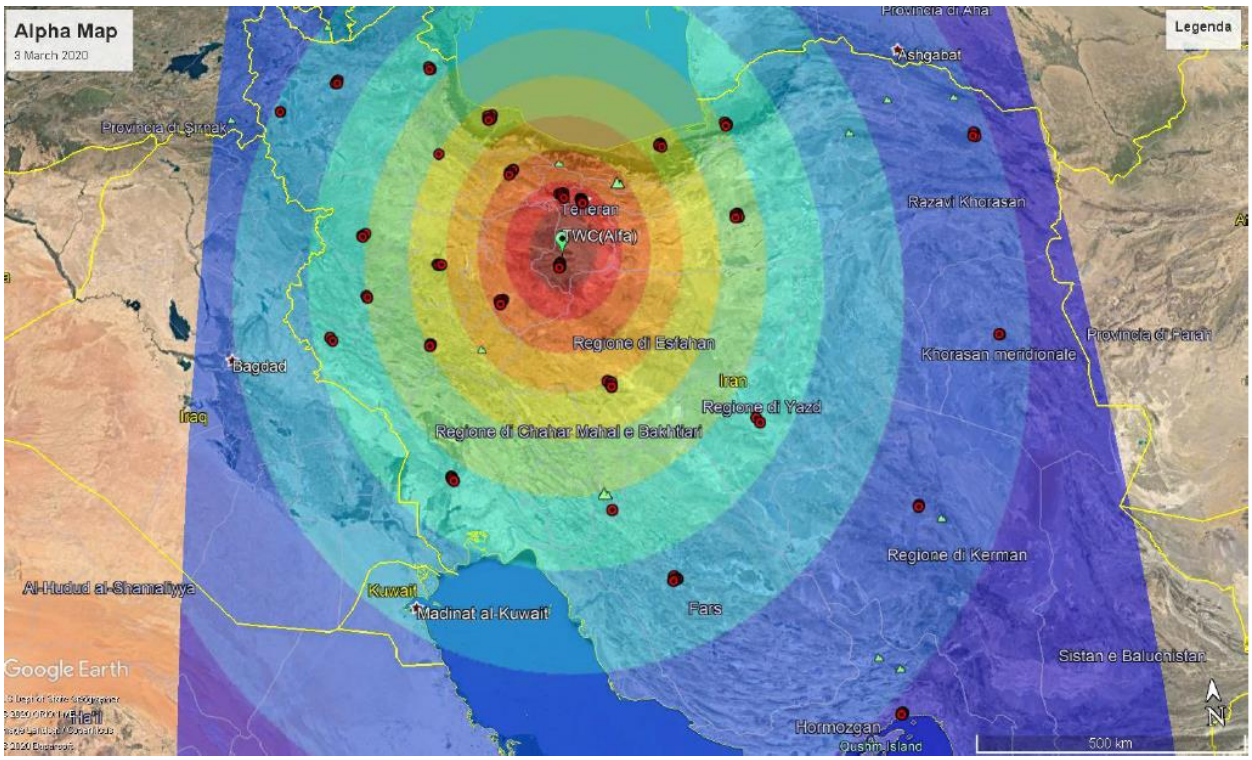

Figure. 2. The TWC − α map.

4.2. TWC beta

The main difference between $TWC-\alpha$ and $TWC-\beta$ algorithms is that in the latter one we include the distance of the point with itself [13]. The $TWC-\beta$ method represents the current condition of the outbreak. ***Figure 3*** shows the $TWC-\beta$ map. The hot area in the $TWC-\beta$ map is expanded compare to $TWC-\alpha$ map and it gets closer to the Caspian Sea in the north of Iran.

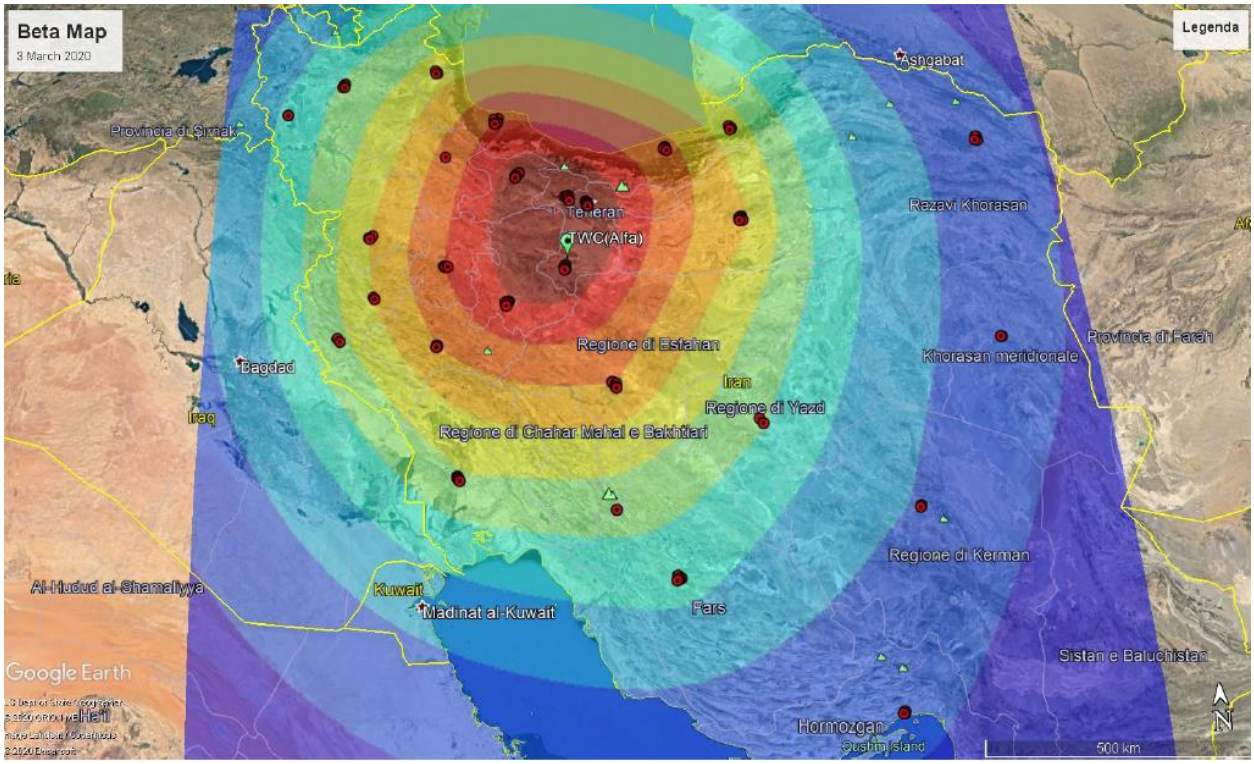

Figure. 3. The $TWC-\beta$ map.

4.3. TWC gamma

The $TWC-\gamma$ is an algorithm that step by step produces a set of new points (trajectory) for each source point [13]. As parameter γ is varying, thus $TWC-\gamma$ creates a trajectory that can be interpreted as the path of the outbreak. The $TWC-\gamma$ represents the evolution of the $TWC-\beta$. ***Figure 4*** shows the $TWC-\gamma$ map. ***Figures 3*** and ***4*** are relatively similar for this data. It suggests that the hotspot of the outbreak stays mainly in the same region. It does not mean the number of infection is not changing. The number can go up or down, however the regions with high disease outbreak do not move significantly to other places. From this perspective, it is statics, even as the number of infection is changing. The dynamics stay internal in each region. It might be as a result of some kind of quarantine isolation or overall the relative change is similar for all regions. There is not a significant difference between ***Figures 3*** and ***4***. However, if we compare ***Figures 3*** and ***4*** carefully, we see the hotspot has small changes particularly toward to north. This is in agree with the reports of more confirmed cases in Gilan and Mazandaran provinces.

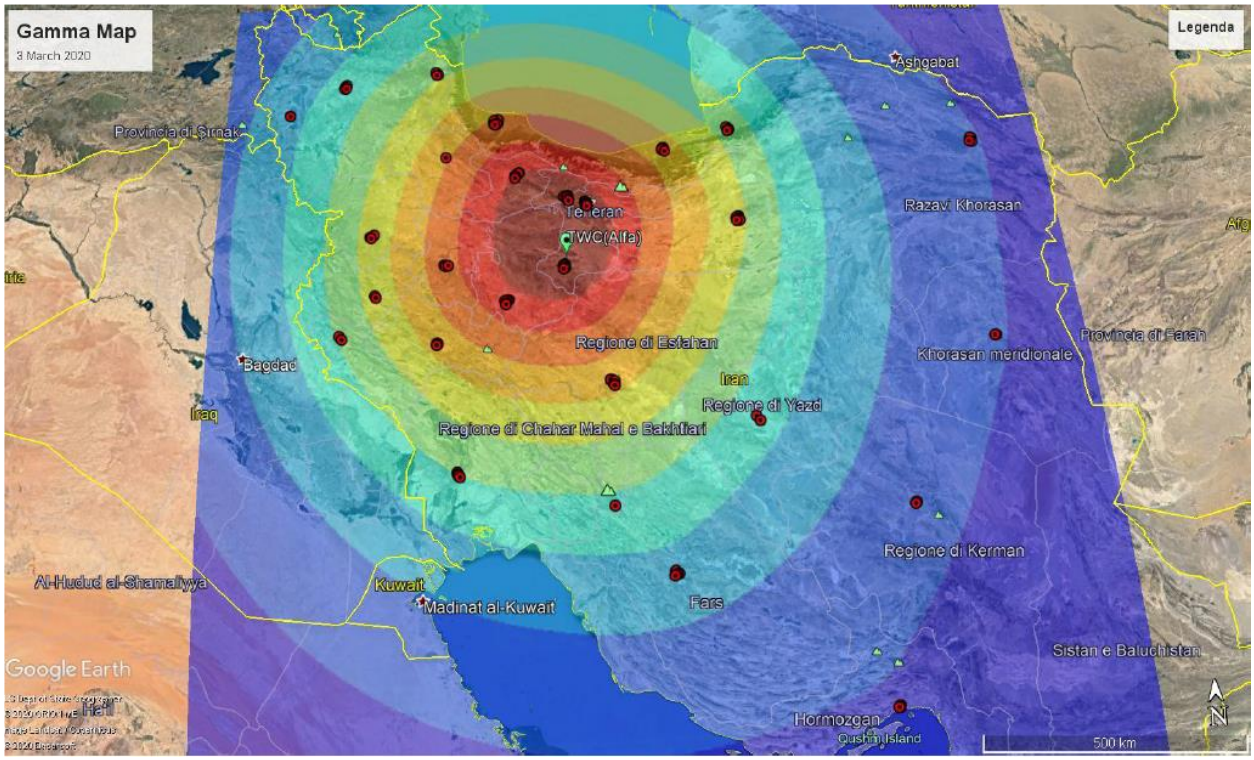

Figure. 4. The TWC $-\gamma$ map.

4.4. TWC theta

The $TWC-\theta$ is an algorithm which is built on the $TWC-\gamma$ trajectories. It represent further evolution beyond and based on $TWC-\gamma$ perdiction. It will provide some idea about the coupling between the points [13]. ***Figure 5*** shows $TWC-\theta$ map. Comparing results of $TWC-\gamma$ and $TWC-\theta$ methods, ***Figures 4*** and ***5***, we predict a small and slow change. The hot spots in ***Figure 5*** are smaller than **Figure 4**, it has a hopeful prediction that the hot space are extinguishing and the disease dynamics is moving toward some recovery state. This result may be interpreted as getting to the end of the first wave of the outbreak. As it is mentioned, the $TWC-\theta$ algorithm provides a network, which can be interpreted as the paths that the pandemic takes. ***Figure 6*** shows TWC paths, that predicts the connection between the sources in the network of disease outbreak. We can see the main hub network of disease is in Qom as it has been reported. This is in agree with results of all TWC algorithm. The center of hot spots in ***Figures 2-5*** is Qom or near this city. The $TWC-\theta$ paths in ***Figurer 6*** show the connection hub to southeast and east is Yazd, Kerman and Shiraz. This seems reasonable according to the highway nets of roads of the region. Mashhad on the northeast is connected to any place in the country since many people will travel to this city. This connection is not predicted by the algorithm. The connection between the provinces on the west and southwest are seems reasonable. Particularly for the provinces on west side of the country that are closed and connected with each other in Zagros Mountains, ***Figure 6*** shows they formed a loop. ***Figurer 7*** shows the map of COVID outbreak on March 3, 2020 [9]. The hot spots from TWC are comparable with this map in ***Figurer 7***. By comparing, the paths in ***Figurer 6*** with the map in ***Figurer 7***, we

find the paths match very well with map, except for Mashhad that is in northeast and it is connected mainly to the outbreak in the north of the country. The people who visit Mashhad from other places in the country mostly come to Mashhad by airlines.

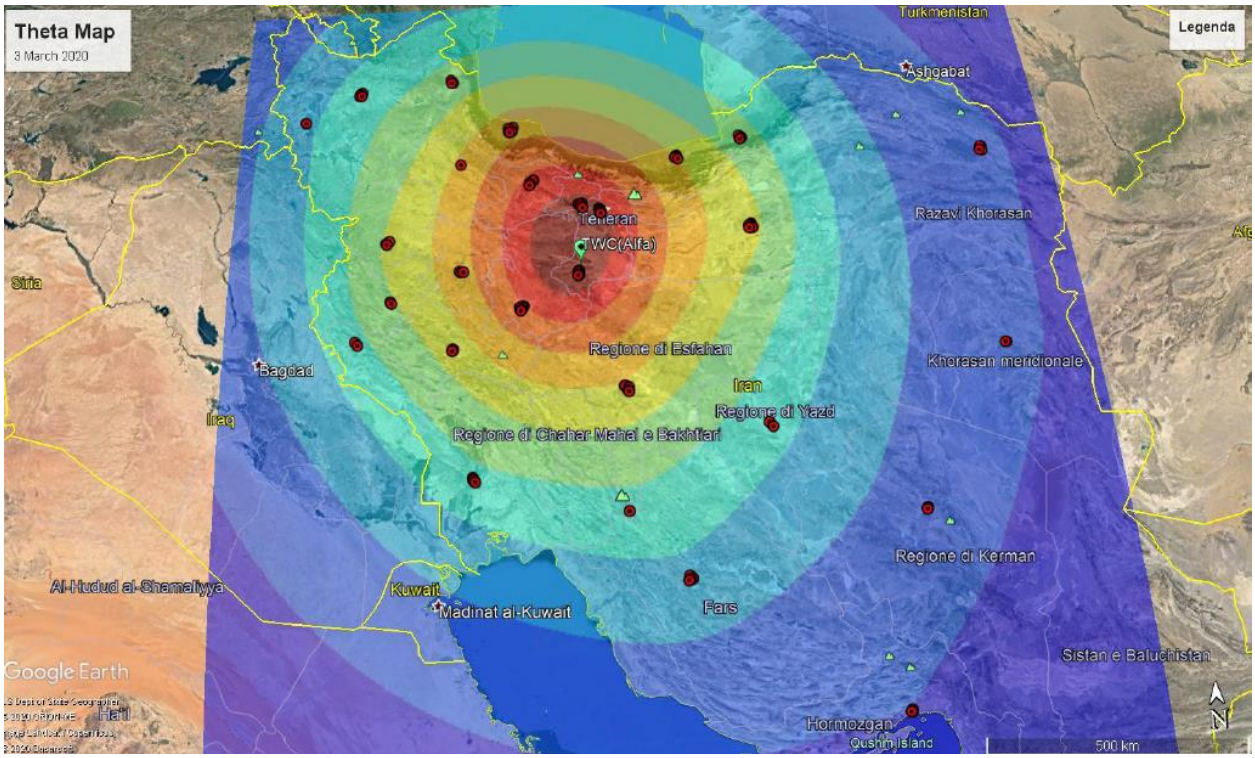

Figure. 5. The $TWC - \theta$ map.

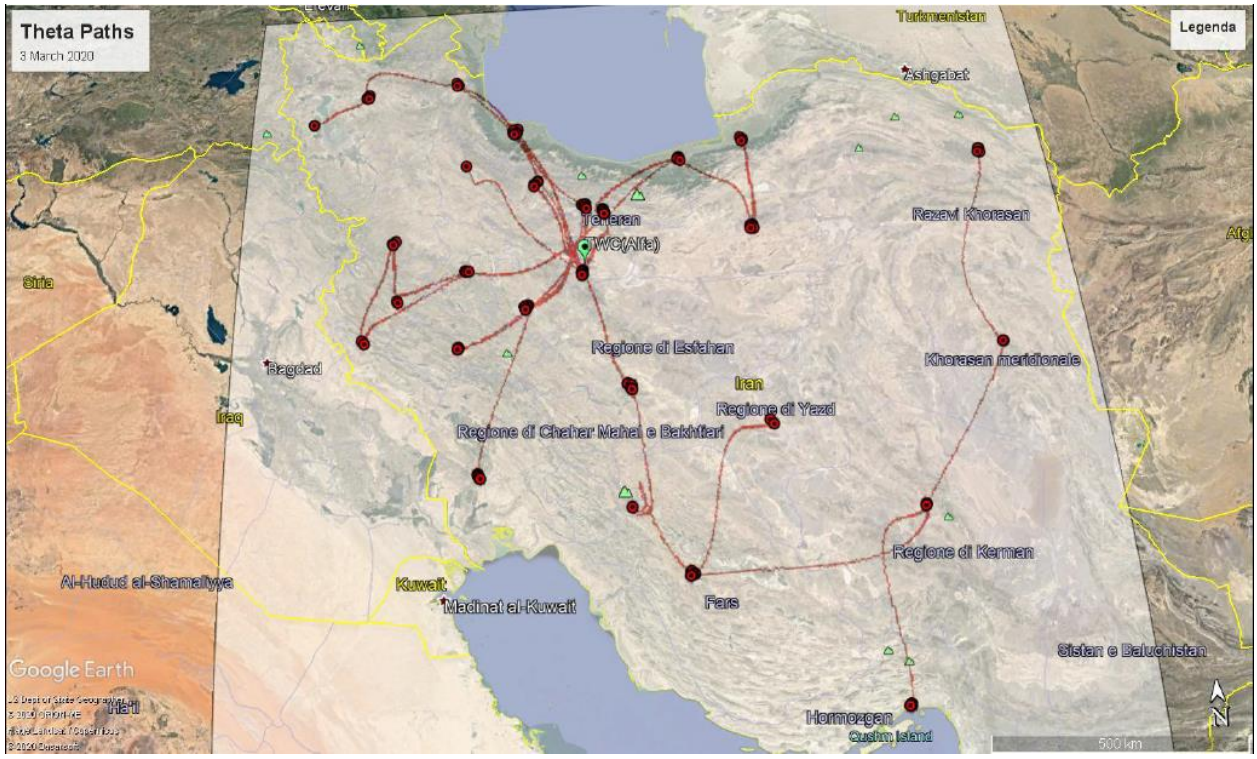

Figure. 6. The $TWC - \theta$ paths.

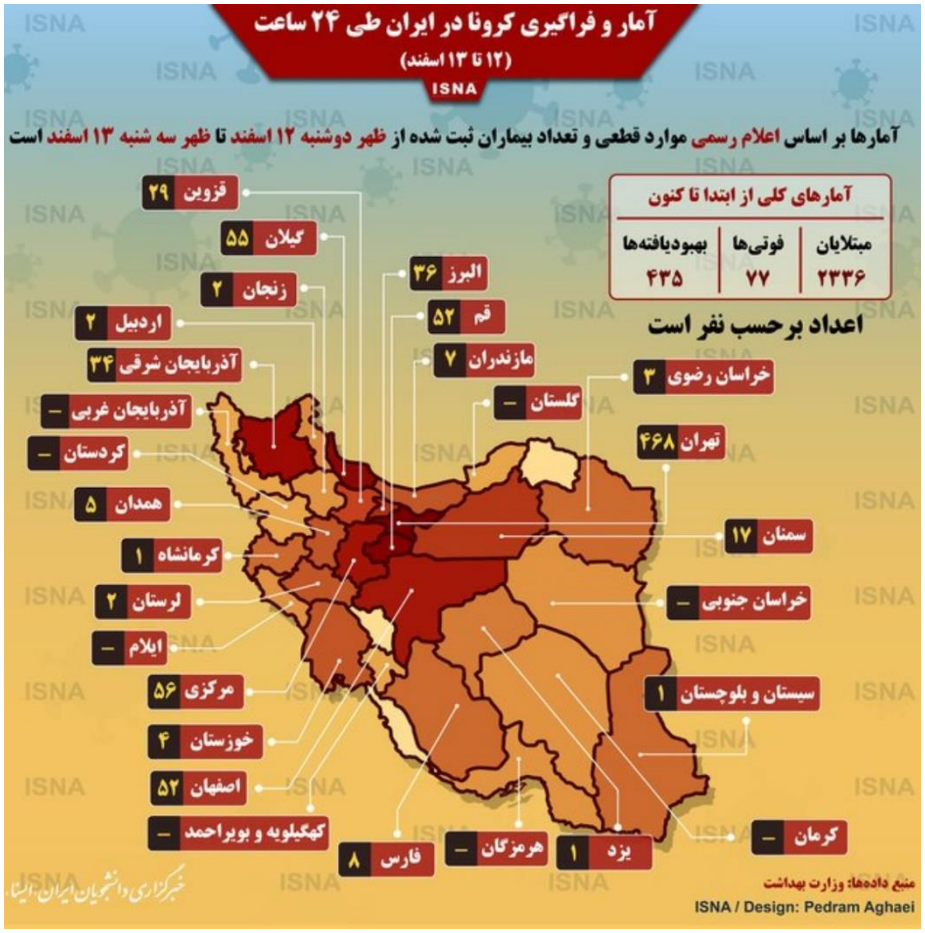

Figure. 7. The map of COVID outbreak on March 3, 2020, Source: https://www.isna.ir/news/98121310808

4.5. TWC iota

The $TWC\iota$ predicts the possible change in dynamics. This method provides cluster of outbreak that can play the role of the source through disease propagation and evolution [13]. Through outbreak evolution we might have recovery in some places and more infection in other places. Due recovery the original sources might disappear or get weaker and new places become the source of outbreak.

In the $TWC\iota$ algorithm we calculate what is called meta distances for N point sources. We use Multi-Dimensional Scaling (MSD) to project the new N point onto a 2-dimensional map. We use the k-mean algorithm for clustering the data. The Davies-Boulding index as fitness criterion [13] was used. The result of $TWC\iota$ algorithm for 3 clusters is given in ***Table 3***. Cluster 3, that includes Qom, Tehran, Gilan and other places, has a largest membership value for Qom. Qom is a city that is reported to be the main source of the outbreak. Health authorities in Iran, mentioned the origin of the outbreak is in Qom. From this analysis, Gilan can also be the source [8]. According to the clusters that are provided by the TWC algorithm, cluster 3 is the main cluster and with no intervention the outbreak might spread out and we might have more clusters. In cluster 3 some other places such as Tehran have large membership values that means they can be a main source for outbreak. Cluster 2 and 3 could be a possible outbreak source in future, if there is no prevention for

disease outbreak. ***Figurer 8*** shows three clusters that are provided from the $TWC\iota$ algorithm on the data. The $TWC\iota$ algorithm predicts outbreak in new places. Cluster 1 has a large membership value is for Yazd. Yazd is the hub connecting to the southeast. The membership values for Kerman, Shiraz and Mashhad are also large. They are main cities that can be the source for the outbreak. The cluster 2 mainly shows the connection for the west side of the country. Hamedan in cluster 3 may be more related to Cluster 2 for the west side of the country. However, Hamedan is close to Arak and Qazvin in cluster 3, therefore, it may be reasonable to show up in cluster 3. ***Figurer 9*** shows the $TWC\iota$ map, according to this map the hot spots of the epidemic outbreak remain the same as the original hot spots in the future. Since Tehran has large population and the people go in and out to Tehran from entire country, Tehran might become a center of the pandemic.

Table 3. Three cluster using $TWC\iota$ algorithm

Cluster 1	
Name	Membership
Bandar_Abbas1	0.7948
Bandar_Abbas2	0.7953
Bandar_Abbas3	0.796
Birjand1	0.8508
Birjand2	0.8509
Gorgan1	0.7456
Gorgan2	0.7332
Gorgan3	0.7429
Gorgan4	0.7412
Kerman1	0.8628
Kerman2	0.8638
Mashhad1	0.8524
Mashhad2	0.8492
Mashhad3	0.8495
Mashhad4	0.8513
Semnan1	0.7439
Semnan2	0.7446
Semnan3	0.7362
Semnan4	0.742
Shiraz1	0.839
Shiraz2	0.8451
Shiraz3	0.8511
Shiraz4	0.8417
Yasuj1	0.7727
Yazd1	0.9088
Yazd2	0.8987
Zahedan1	0.743
Zahedan2	0.7443

Cluster 2	
Name	Membership
Ahvaz1	0.8041
Ahvaz2	0.8148
Ahvaz3	0.8102
Ahvaz4	0.7942
Ardabil1	0.8874
Ardabil2	0.885
Ardabil3	0.8864
Ilam1	0.9635
Ilam2	0.9635
Kermanshah1	0.9437
Kermanshah2	0.9485
Khorramabad1	0.8668
Khorramabad2	0.862
Khorramabad3	0.8564
Sanandaj1	0.9164
Sanandaj2	0.9181
Sanandaj3	0.9137
Tabriz1	0.8962
Tabriz2	0.897
Tabriz3	0.8996
Tabriz4	0.8984
Urmia1	0.8575
Urmia2	0.8565

Cluster 3	
Name	Membership
Arak1	0.9078
Arak2	0.9158
Arak3	0.9256
Arak4	0.9163
Arak5	0.9178
Hamaden1	0.822
Hamaden2	0.8176
Hamaden3	0.8204
Isfahan1	0.7731
Isfahan2	0.7835
Isfahan3	0.7614
Isfahan4	0.7672
Isfahan5	0.7669
Karaj1	0.9303
Karaj2	0.9321
Karaj3	0.9283
Karaj4	0.9317
Karaj5	0.9297
Qazvin1	0.9082
Qazvin2	0.9116
Qazvin3	0.9105
Qazvin4	0.9142
Qazvin5	0.9087
Qom1	0.9596
Qom2	0.954
Qom3	0.9559
Qom4	0.9607
Qom5	0.9611
Qom6	0.9636
Rasht1	0.8615
Rasht2	0.8634
Rasht3	0.8621

Rasht4	0.867
Rasht5	0.8582
Rasht6	0.8612
Sari1	0.8269
Sari2	0.8232
Sari3	0.8189
Sari4	0.8237
Sari5	0.8185
Tehran1	0.918
Tehran2	0.919
Tehran3	0.9175
Tehran4	0.9191
Tehran5	0.9174
Tehran6	0.9198
Tehran7	0.9171
Zanjan1	0.81

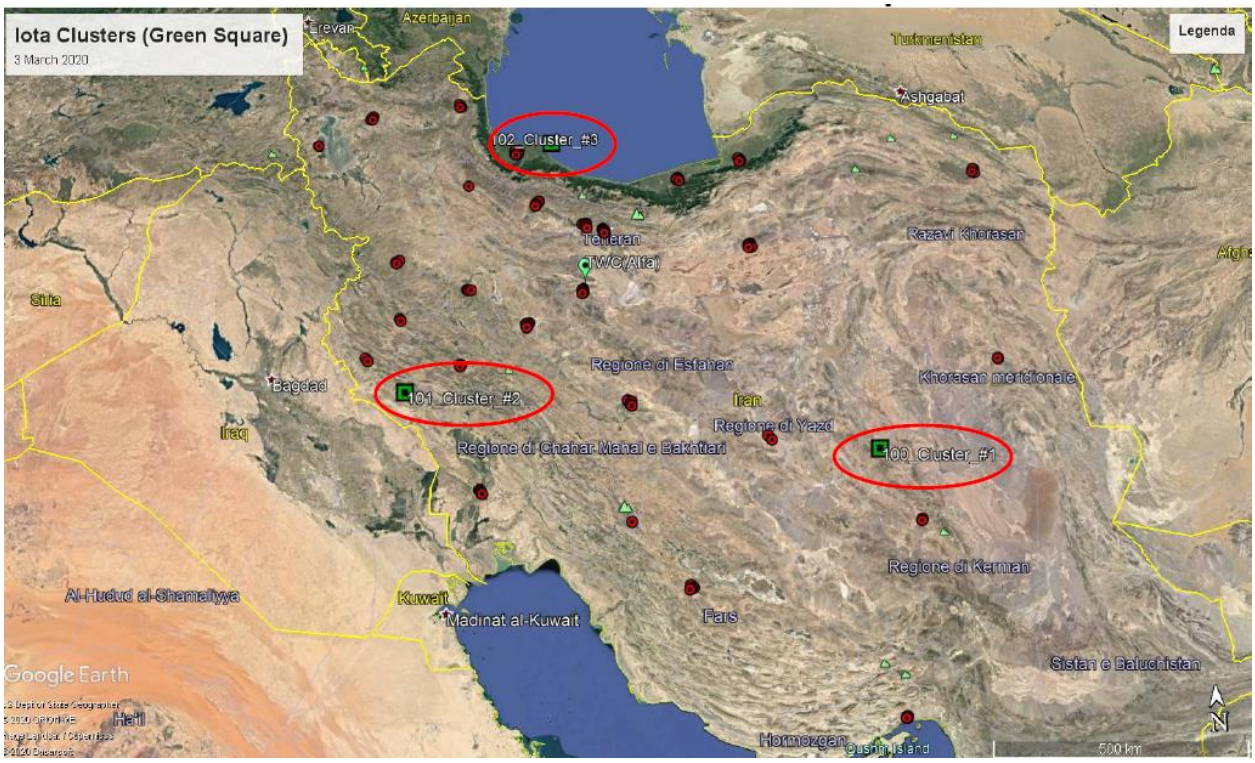

Figure. 8. Three clusters using the $TWC-\iota$ algorithm.

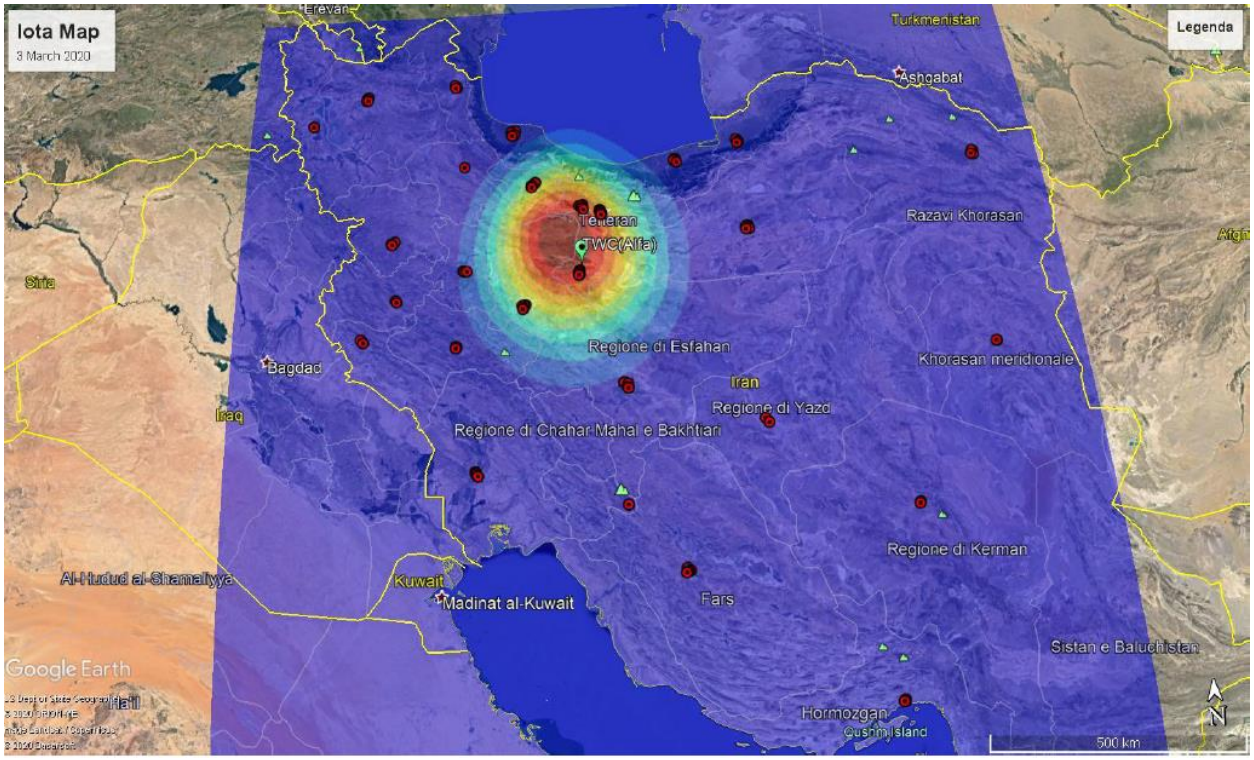

Figure. 9. The $TWC - \iota$ map.

5. Conclusion

We study the COVID-19 outbreak in Iran. In this analysis we used TWC algorithms. The origin of the outbreak identified the city of Qom. The second possible source of the outbreak can be in Gilan. We have used the analysis only on the early COVID-19 confirm cases. The goal to show the efficacy of the results of the predictions identified by the algorithms of TWC. This analyses can be done and compared with actual results given current data. One of the challenge for this analysis is the difficulty of access to the data for all locations including the geographical coordinates. In this manuscript, we used the latitudes and longitudes of the capital of provinces and implemented an algorithm generating new coordinates around the capitals of the province randomly. However, it would be helpful for more accurate TWC analysis, if we have the exact coordinates of the cites.

References

[1] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen

[2] https://www.who.int/csr/don/14-january-2020-novel-coronavirus-thailand/en/

[3] https://www.who.int/csr/don/16-january-2020-novel-coronavirus-japan-ex-china/en/

[4] https://www.who.int/csr/don/17-january-2020-novel-coronavirus-japan-ex-china/en/

[5] https://www.who.int/csr/don/21-january-2020-novel-coronavirus-republic-of-korea-ex-china/en/

[6] http://www.isna.ir/news/98113022537/

[7] http://www.isna.ir/news/98113022952/

[8] https://www.isna.ir/news/99010602656/

[9] http://www.isna.ir/news/98121310808/

[10] https://coronavirus.jhu.edu/map.html

[11]https://github.com/CSSEGISandData/COVID19/blob/master/csse_covid_19_data/csse_covid_19_time_series/time_series_covid19_confirmed_global.csv

[12] https://github.com/CSSEGISandData/COVID-19/blob/master/csse_covid_19_data/csse_covid_19_time_series/time_series_covid19_deaths_global.csv

[13] Buscema M., Massini G. and Sacco P. The Topological Weighted Centroid (TWC): A topological approach to the time-space structure of epidemic and pseudo-epidemic processes, Physica A, (2017).

[14] Buscema, M., Breda, M., Catzola, G. The topological weighted centroid, and the semantic of the physical space – theory in Artificial Adaptive Systems in Medicine, (eds Buscema, M., & Grossi, E.) 69-78 (Bentham, 2009).

[15] Grossi, E., Buscema, M. & Jefferson, T. The topological weighted centroid, and the semantic of the physical space – application, in Artificial Adaptive Systems in Medicine, (eds Buscema, M., & Grossi, E.) 79-89 (Bentham, 2009).

[16] Buscema, M., Grossi, E., Bronstein, A., Lodwick, W., Asadi-Zeydabadi, M., Benzi, R. & Newman, F. A new algorithm for identifying possible epidemic sources with application to the German Escherichia Coli outbreak, ISPRS Int. J. Geo- Inf., 2, 155-200, (2013); DOI:10.3390/ijgi2010155.

[17] Massimo Buscema, Masoud Asadi-Zeydabadi, Weldon Lodwick, Alphonse Nde Nembot, Alvin Bronstein and Francis Newman Ebola paper, Analysis of the Ebola Outbreak in 2014 and 2018 in West Africa and Congo by Using Artificial Adaptive System, Applied Artificial Indigence, 2020.