Journal of
Babol University of Medical Sciences
JBUMS
e-ISSN: 2251-7170 p-ISSN: 1561-4107

The Role of GIS Mapping Program in Evaluating the Geographical Distribution of Patients with COVID-19 during the First Wave of the Epidemic in Babol

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Article Type
Research Paper

ABSTRACT

Background and Objective: One of the first cities that announced the outbreak of COVID-19 in Iran was Babol, in the north of Iran. Geographic Information System (GIS) is an important tool in tracking and dealing with the spread of diseases. The aim of this study is to investigate the effect of the weekly GIS reports on the spread of the disease in controlling COVID-19.

Methods: This cross-sectional study was conducted for two months, from the third week of the beginning of the epidemic till the end of the first wave of COVID-19. The geographic address of hospitalized patients was extracted and pinned on the map of Babol. Coding was done in the Python program (python 3.7.6) and the information was placed in an online map that can be enlarged and separated to show the alleys and houses. Moreover, the information was entered into the GIS software and the weekly output was obtained in HTML and PNG formats. The output results of the maps were used as the basis for follow-up in the deputy health department, and after the creation of operational teams, the follow-up of points with high prevalence was done on a weekly basis until the end of the first peak of the COVID-19 epidemics.

Findings: The number of hospitalized patients in hospitals of Babol had an upward trend from the beginning of the disease until March 12, 2020. After that, according to the measures taken (including the preparation of patient distribution maps), at first a steady trend and after ten days, a downward trend was observed. A total of 174 pollution points were found in Babol city and Babol county, of which 60 pollution points were related to Babol city.

Conclusion: Based on the results of this study, the preparation of distribution maps of COVID-19 patients in Babol and targeted follow-ups helped to control the first peak of this outbreak within 10 days.

Keywords: *The New Coronavirus, COVID-19, GIS, Mapping*.

Received: May 31st 2021
Revised: Aug 30th 2021
Accepted: Oct 27th 2021

Cite this article: Shirafkan H, Bijani A, Mozaffarpur SA. The Role of GIS Mapping Program in Evaluating the Geographical Distribution of Patients with COVID-19 during the First Wave of the Epidemic in Babol. *Journal of Babol University of Medical Sciences*. 2022; 24(1): 254-64.

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[DOR: 20.1001.1.15614107.1401.24.1.32.8]
[DOI: 10.22088/jbums.24.1.254]

Introduction

Since its first detection in China in late 2019, the effects of the new coronavirus (COVID-19) have shaped global patterns of morbidity and mortality, and revealed the strengths and limitations of health care systems and social safety networks (1). Due to the widespread outbreak of COVID-19 in the world, almost all countries were involved in dealing with it, and various epidemiological assessments have been carried out and published in different parts of the world. The first official case in Iran was also announced in March and plans were made to control the disease (2). One of the first Iranian cities that officially announced the outbreak of COVID-19 and started protective measures was the city of Babol (3). Of course, based on a retrospective review, it seems that there were suspected cases of COVID-19 in the previous months in the affiliated hospitals of Babol University of Medical Sciences. However, after the hospitalization of four patients suspected of COVID-19 in March 2020, the presence of this disease was officially announced (3).

Babol is the most populous city of Mazandaran province in the north of Iran. Considering the history of Babol in the field of health and treatment, the existence of an independent university of medical sciences and the trust of many people in nearby cities, visits to Babol hospitals increased dramatically in March. The lack of public quarantine in March and the arrival of critically ill patients caused a crisis in the second week of March 2020 in the affiliated hospitals of Babol University of Medical Sciences (3). It caused exhaustion of health care personnel and increased death among critically ill patients.

Geographic Information System (GIS) is an important tool in tracking and fighting the spread of diseases. The first map was used to check the geographical location of patients in 1694 in Italy to control the plague (4). After that, mapping was used in various infectious diseases, including yellow fever, cholera, and the influenza epidemic in 1918. Since the 1960s, after the formation of electronic mapping systems, the possibility of analyzing, visualizing and finding geographical patterns of disease spread increased (4). In a review article which was conducted on studies related to mapping in health, out of 865 reviewed studies, it was seen that 248 studies (28.7% of the studies) focused on the mapping of infectious diseases (5). In recent years, we have witnessed a revolution in the use of geographic information systems in health systems in the world (6, 7). Therefore, by entering the information related to the geographic locations of the patients in the program, it is possible to have the geographic distribution of the disease online or at certain periodic times (such as weekly or daily) and plan protective measures.

One of the activities that was carried out in the first wave at Babol University of Medical Sciences was determining the high incidence of COVID-19 in Babol. Knowing about the extent of distribution, areas with more and less pollution and even clean areas, facilitates planning for disease control in the health care system (8). Although these maps serve as an effective political and social tool in relation with the disease, their greatest impact and benefit can be seen in tracking the progress of the disease and infected points at the community level (9). In several studies, different methods of mapping during the pandemic of COVID-19 have been investigated and all of them have emphasized the necessity and importance of using one of the available methods (1, 8, 9).

The main goal of this research is to periodically investigate the spread of the disease in the areas covered by the health department of Babol University of Medical Sciences, Babol, northern Iran.

Methods

After being approved by the Ethics Committee of Babol University of Medical Sciences with the code IR.MUBABOL.REC.1399.042, this cross-sectional study was conducted from March 12, 2020 (the third week of the beginning of the epidemic) until the end of the first wave of COVID-19 (April 24, 2020).

To implement this program, a team consisting of a biostatistician, an epidemiologist, an urban geography expert and five computer and programming experts was formed. Regular daily meetings were held for planning.

The inclusion criteria were hospitalization with suspected or probable diagnosis of COVID-19 in hospitals affiliated to Babol University of Medical Sciences and the availability of patients' geographic information. The information about the exact geographic address of the patients was obtained from the HIS and MCMC systems. In order to check the quality and clean the data (data cleansing), all the data of the two systems (including hospitalization, discharge, and death) were merged, duplicate items were individually checked and removed. In cases where there was a discrepancy, if a patient's name was mentioned in only one of the systems, that patient's name was entered in the information list of the patient. If the discrepancy was related to the status of discharge, hospitalization or death, the relevant expert in the hospital where the patient was hospitalized was contacted to ensure the condition of the person. MATLAB software was used for data modeling. The model with the highest R^2 value was selected and interpreted as the appropriate model. In order to find the time and point at which the number of patients per day reaches zero, a differentiation was taken from the obtained model and solved based on x (time/day). The obtained answer was reported and interpreted.

In order to map the patients in Babol, the obtained geographical information was pinned on the map of Babol. After determining the approximate addresses of all possible locations, the number of patients in each area was counted. To present the report, coding was done in Python program (Python 3.7.6) and the information was placed on an online map that can be enlarged to show the alleys and houses. In addition, the information was entered into the Arc-GIS 10.7.1 software and finally the output was taken from the GIS software.

Babol county has 6 districts, 7 cities and 673 villages. The capital of this county is the city of Babol. In the information from output images, the distribution of patients in Babol county is determined based on the number of infected cases. Due to the aggregation of more cases of infection in the city of Babol, in order to be more accurate, the map is presented in two forms in all cases: the map of Babol county and Babol city. The maps are presented in both HTML and PNG formats based on a weekly report as well as an aggregate report (from the beginning of the disease). Furthermore, according to the available data, an analysis of this spread and indication of areas with high infection cases were done every week. Using these analyses, an estimate of the future possibilities of dealing with COVID-19 in Babol county was presented on a weekly basis.

Results

From the onset of the pandemic (February 20, 2020) to April 2020, 1264 suspected COVID-19 patients were admitted and treated in the hospitals of Babol University of Medical Sciences. The geographic information of 879 cases (69.54%) was available and entered into the mapping study. The information on the number of hospitalized patients suspected of COVID-19 based on day in the period of January 2020 to April 2020 is presented in Figure 1.

[DOR: 20.1001.1.15614107.1401.24.1.32.8]
[DOI: 10.22088/jbums.24.1.254]

Figure 1. Hospitalization process of suspected COVID-19 patients in Babol hospitals

As it can be seen, the number of patients hospitalized in Babol hospitals had an upward trend from the beginning of the disease until March 12, 2020. After that, due to the measures taken, it found a steady course (Plato) at first and finally, after about ten days, a downward course was observed. In addition, cumulative data were used to fit a statistical model to investigate the course of the disease. Based on this, a simple and univariate model was designed. In this model, Babol county was considered completely closed, that is, it had no entry and exit. The considered parameters of this model are the number of hospitalized patients. The fitting equation on this graph is a quadratic function.

$P(t) = -0.0012\, t^4 + 0.0518\, t^3 - 32.803\, t + 88.593$
$R^2 = 0.9975$

By solving the derivative function of the relation obtained from the period of March 21 to 26, the value of t (time parameter) was found to be 45.63. A simple analysis of this equation is that if the behavior model of the people is similar to March 21 to 26, the disease will be controlled until 45 days later, that is, until May 22. But if we fit the model on the data obtained from the beginning of the pandemic (the behavior model of the people is similar to February 20 until March 5), then the behavior of the function will move towards the exponential function.

$P(t) = 1.3006\, e^{0.2571t}$
$R^2 = 0.9871$

This means that the disease will have an upward trend again. It means that it is practically impossible to break the disease chain. Of course, this model is a simple model in which only one independent variable and an incubation period of 10 days are considered.

In the results obtained from the output of the Python software, a zoomable map was created. These maps were produced weekly and cumulatively. In this map, the areas involved in each level are created as clusters. By selecting each cluster or zooming the map, each cluster is divided into sub-clusters. An example of this

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map can be seen in Figure 2. For example, in the central part of Babol county, a cluster with the number 100 can be seen. By clicking on this cluster, it will be broken into smaller clusters.

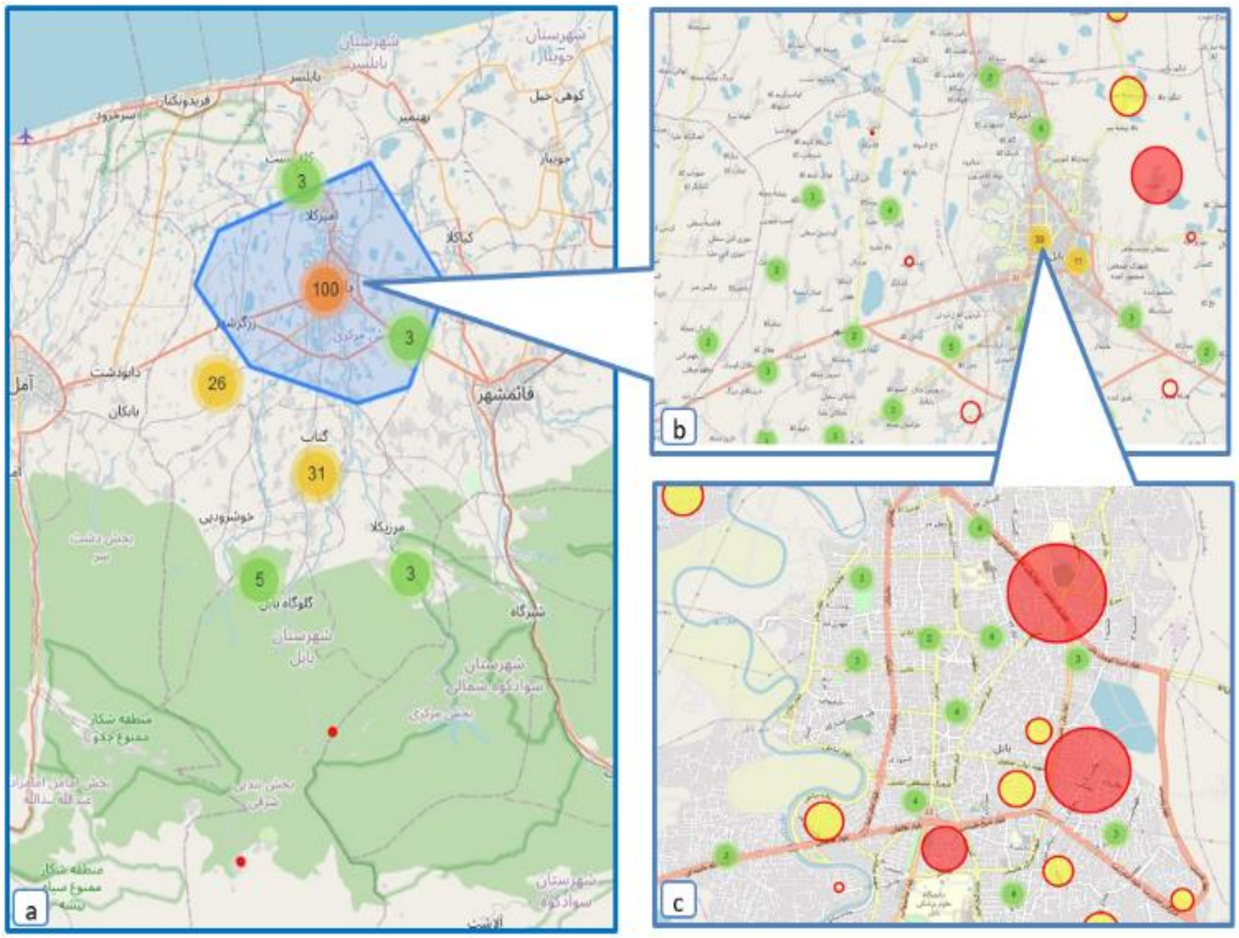

Figure 2. Geographic map of the distribution of patients with COVID-19 in Babol. a) In the part specified in the map, 100 clusters of pollution points have been found, and each of these clusters includes other clusters that are geographically closer to each other. b) By clicking on it, it is divided into smaller points, which can also be seen by enlarging the map. c) By zooming in more or by clicking on the point with a frequency of 39, the contamination points can be divided into smaller areas. With the continuation of this process, contamination points can be seen at the level of different neighborhoods. At the level of neighborhoods, the level of contamination is distinguished by different colors. Contamination of one or two people with a small and yellow circle, up to 10 people with yellow circles that are drawn according to the number, and being small or large. In addition, the pollution of more than 10 people is marked with red circles, and the area of the circle is proportional to the level of contamination in that neighborhood.

A total of 174 contamination points were found in Babol county and Babol city, of which 60 contamination points were related to Babol city. In order to investigate and find the distribution of hospitalized cases by different districts and regions in Babol county during the first wave of the pandemic, GIS maps of the distribution of patients were drawn on a weekly basis for Babol city as well as the entire county (Figure 3). In addition, in order to examine the development process in different regions, maps were also drawn in cumulative form (Figure 4). An example of these maps can be seen in Figures 3 to 6.

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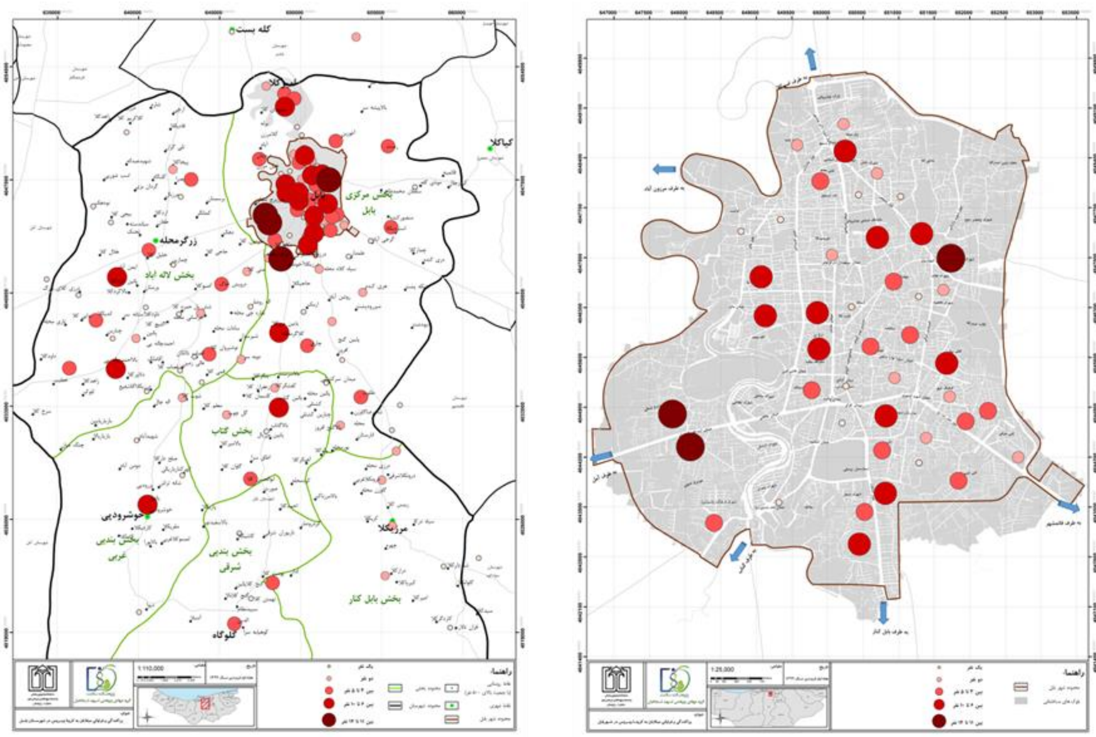

Figure 3. Distribution of suspected COVID-19 patients in a) Babol city and b) Babol county from March 20, 2020 to March 27, 2020

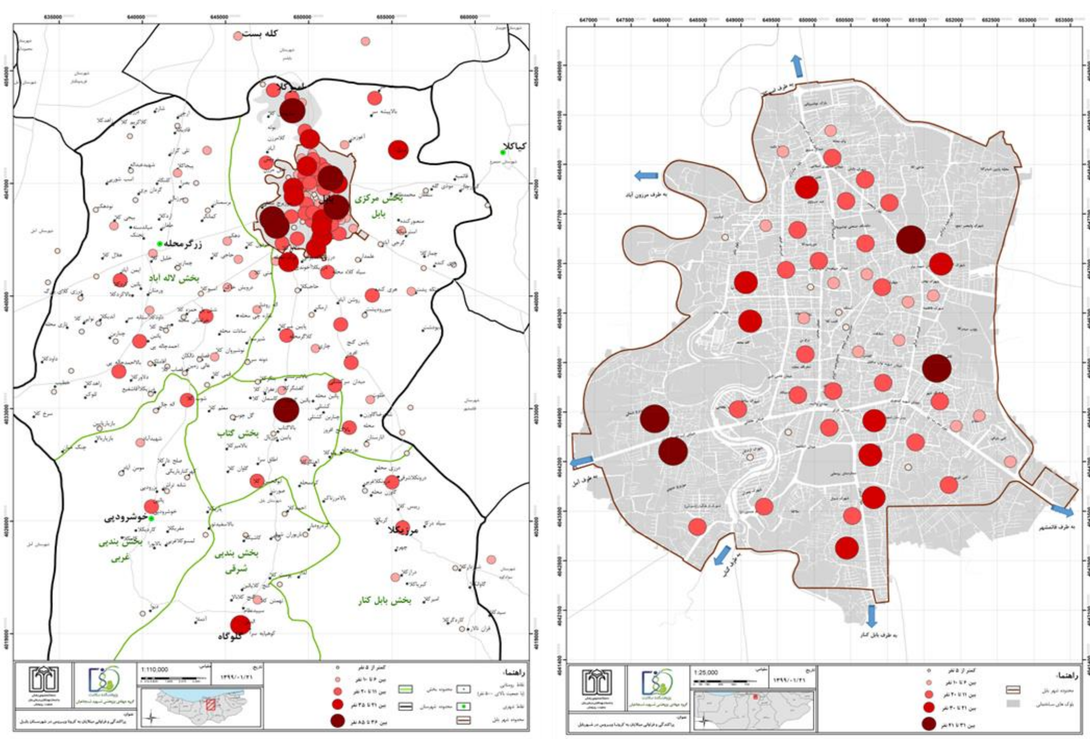

Figure 4. Cumulative results of a) Babol city and b) Babol county from the beginning of the epidemic until April 24, 2020

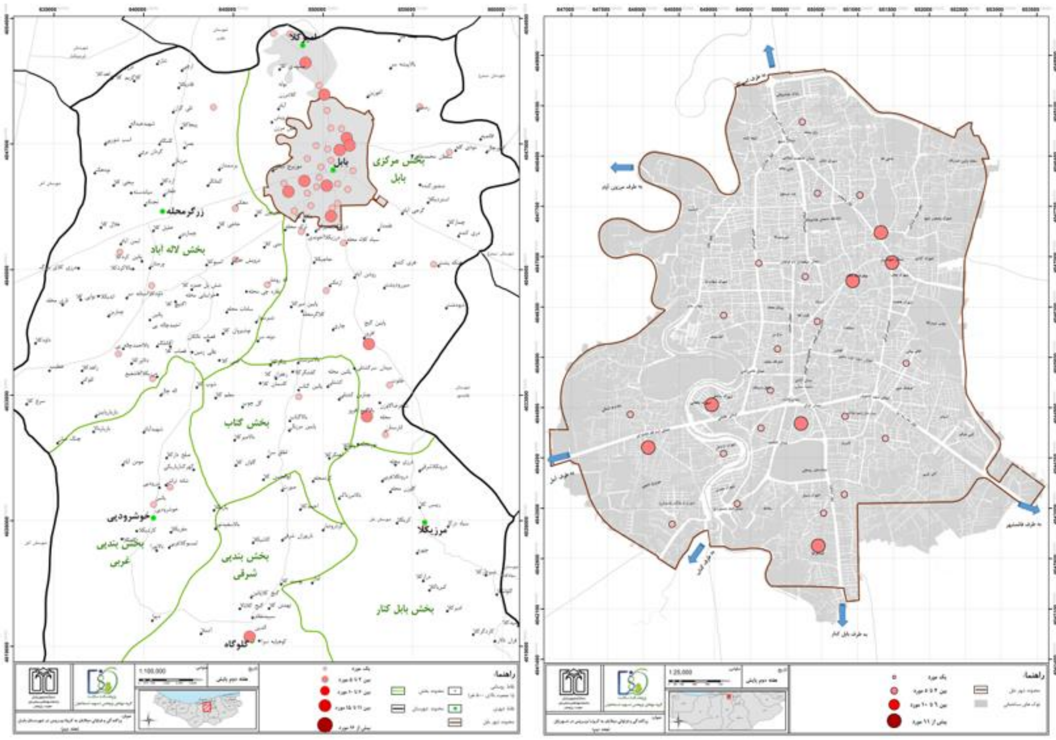

Figure 5. Cumulative distribution of suspected COVID-19 patients in a) Babol city and b) Babol county until February 28, 2020

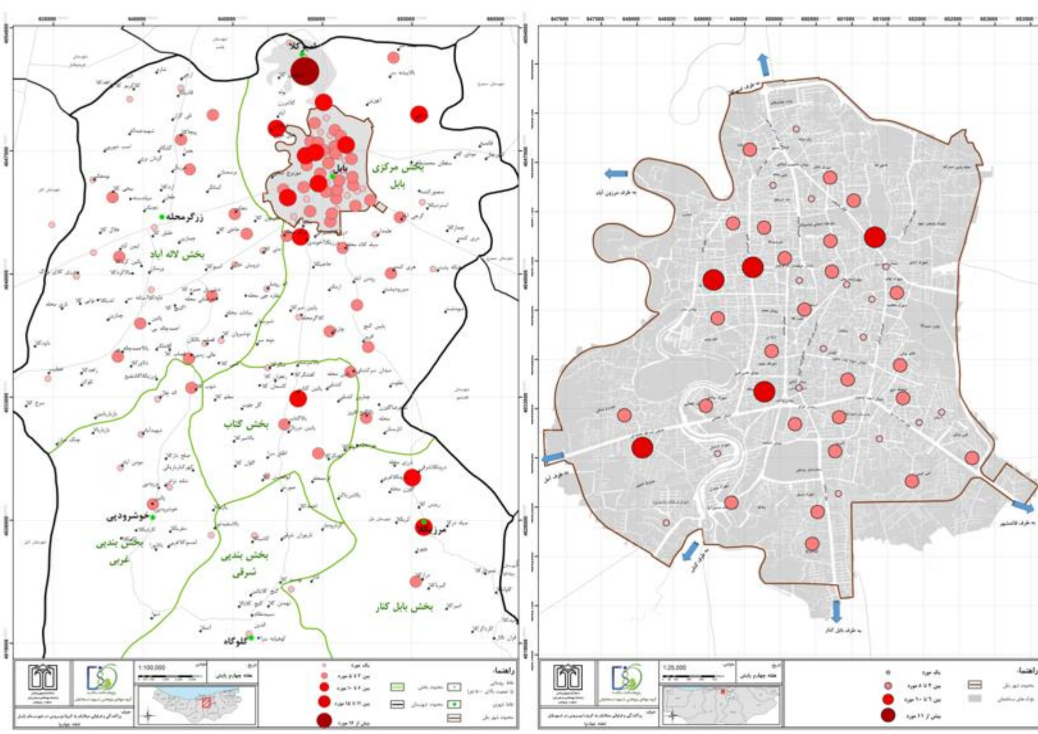

Figure 6. Cumulative distribution of suspected COVID-19 patients in a) Babol city and b) Babol county until March 12, 2020

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As can be seen in Figures 3 to 6, the number of cases (hospitalization of patients) has increased from February 26 until March 12, 2020. From March 12, 2020, the rate of hospitalization decreased gradually.

The reports of this team, which identified high-risk areas on a weekly basis, were sent regularly and weekly to the president of the university, vice president of health and vice president of medical treatment. Based on these weekly reports of the Vice Chancellor for Health of Babol University of Medical Sciences, teams for intervention (disinfection, training and quarantine) were formed and sent to the infected areas. The possible results of these interventions can be seen in the lack of growth and even the reduction of the incidence of the disease in the following week. From March 2020, based on the reports of this team and the decision of the city supply council, and according to the distribution maps in Babol county (especially in the areas with weekly markets), the markets and gathering places identified in the high-incidence areas were closed and home quarantine was implemented in those areas with more care (Figure 7). As can be seen in Figures 4 and 7, the distribution of infection in places with high frequency in the first week of the program which led to interventions, clearly shows a lower infection. It should be noted that all these maps were prepared separately for inpatients, outpatients, inpatients and outpatients together, and cases with positive COVID-19 lab test (RT-PCR) according to the requests and needs of the authorities and were provided to them.

During the two months of implementation of this program, the decreasing course of infection has been quite clear in all weeks. This plan was stopped after about two months of implementation and after success in helping to control the first wave of the epidemic.

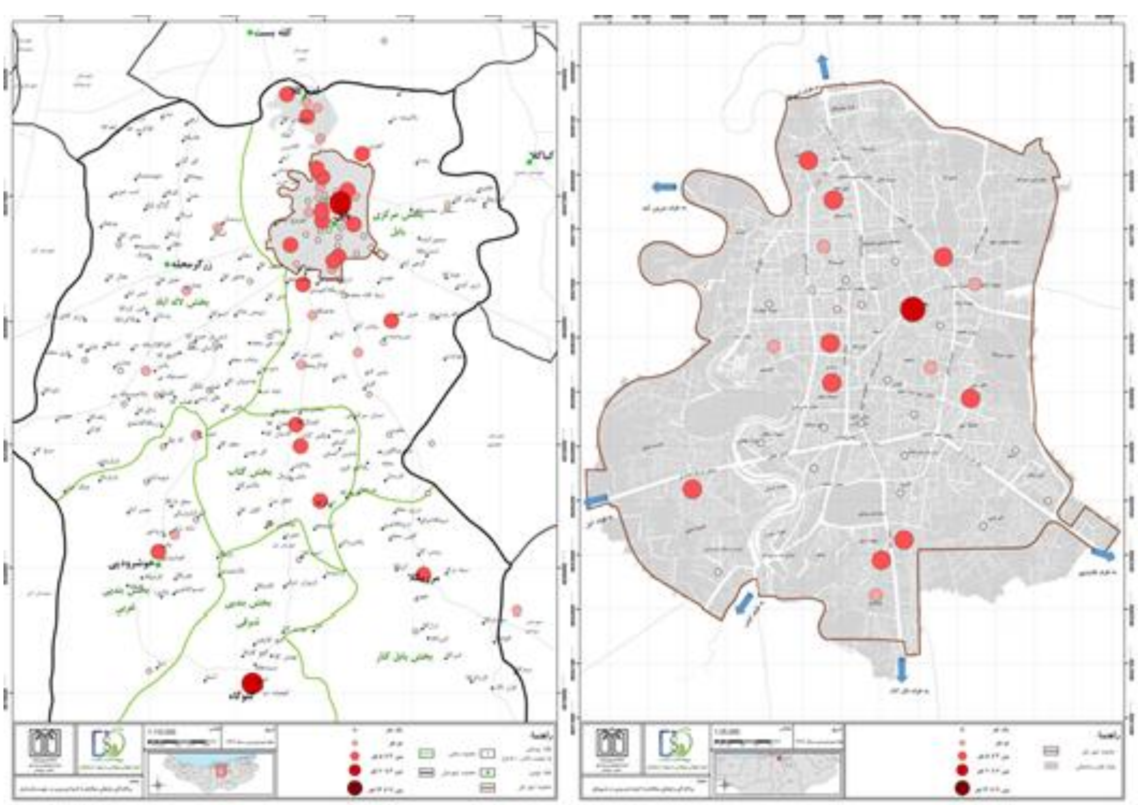

Figure 7. Distribution of suspected COVID-19 patients in a) Babol city and b) Babol county from March 28, 2020 until April 6, 2020

Discussion

In this study, the decreasing trend of COVID-19 in the first phase of the epidemic in Babol county was observed after preparing weekly reports of the spread of the disease in Babol county using the GIS model. According to the results obtained from this study, after a week of reporting the areas with high incidence and focusing on those areas by the health staff, the incidence of the disease has decreased in all cases in those areas. A general decrease in incidence has also been observed in about two weeks after the intervention. Of course, paying attention to the results of these reports by closing weekly markets, closing high-risk trades and starting partial quarantine in the city has been effective in achieving results in reducing infections and deaths. The results of this applied research are consistent with the existing theory in this field, which states that focusing and paying more attention to contaminated areas can be effective in reducing the incidence of the disease in these areas (10).

The implementation of government interventions such as observing social distance, quarantine of patients and follow-up of people around them based on the epidemic management protocol in Iran is of great importance (11). Therefore, the observance of these interventions by the people and the government has an effect in predicting the modeling. In addition, according to an authoritative scientific report, identification and isolation of infected cases and contact tracing can play an important role in controlling the epidemic (12).

The trend of the COVID-19 pandemic and the estimation of the number of patients and their distribution mapping in Babol were conducted and reported on a weekly basis according to mathematical and statistical models. Although this prediction may be accompanied by random errors, it has been made with assumptions about the trend of the COVID-19 epidemic in Iran, as well as people's behavior and government interventions (sampling of severe cases and hospitalization), and this is consistent with other studies conducted in this area (8, 9). The positive point of this research is the applicability and practical use of its results in practice (control of COVID-19 in Babol county). The weekly research results are sent to the Vice Chancellor for Health and Communicable Diseases Unit, causing more focus and coordination with urban and rural health centers and sending the center's doctor, disease control officials and other experts of medical centers for further disinfection of contaminated passages and more accurate control of infected areas for 15 days.

Considering the anxiety and stress in the society at the beginning of the epidemic of COVID-19 (13-15), in order to prevent these reports from creating psychological and security consequences (caused by the fear of highly contaminated areas, fleeing from contaminated areas and making disease control harder, etc.), the weekly results of this survey and the presented maps were presented only to the president of the university and his two related assistants.

In this study, instead of presenting the "incidence" of the disease, the "frequency" of cases in different regions of Babol county was reported. The reason for this is because in the case of infectious diseases, given the increase in the possibility of contagion in areas with more population, if population indices (such as prevalence, incidence, etc.) are used for reporting, in areas with more population, these indices show smaller numbers and may draw less attention to these high-risk areas (2, 16). However, a geographical area with a large population, given the possibility of high contagion, creates more importance for preventive measures even with low incidence (but with a high frequency of infection).

In this research, in addition to the aforementioned GIS map, dedicated coding was done in Python software for presentation. The result of this coding is the preparation of a clustered map in HTML format. This map is online and has the ability to focus on different points and is more accurate. It seems that by spending more time, this software coding can be used in the future even in a normal situation to determine the distribution of diseases that need care in the health care system.

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One of the problems and limitations of this study was the difficult access to basic information. Information systems, which in many cases did not match each other well enough, made it difficult to extract basic data. It is necessary for the information systems of the Ministry of Health to be designed in such a way that they can be combined together for future use.

It also seemed that due to the insufficient preparation of the information registration system, part of the information was not completed accurately in the first weeks of the epidemic, which requires more detailed planning for more accurate information recording to be used in planning for the outbreak of infectious diseases.

Another limitation of the work was the lack of accurate geographical maps suitable for the health care system of the country. This means that despite an orderly health care system in Iran, the geographic accessibility of each health home and health center was not clear, which made it difficult to do follow up on the areas with high contamination. Therefore, it seems that preparing accurate aerial maps to determine the geographic accessibility of health care centers is one of the necessary tasks to face such conditions.

Adopting the GIS-Science approach and especially the use of location-based information tools can improve the shortcomings of other reports in this field and help control diseases (17). It seems that this mapping system has the ability to be extended to other diseases (even non-communicable) in the country and it can be used to facilitate the control of diseases.

It is suggested that in future studies on infectious diseases, indices of prevalence, incidence, age- and gender - specific rates, and mortality rates should also be calculated and reported in addition to distribution.

According to the results of this research, the preparation of maps of the distribution of COVID-19 patients in Babol county and targeted follow-up of the operational teams of the deputy health department of Babol University of Medical Sciences, was able to help control the first peak of the COVID-19 outbreaks within 10 days.

Acknowledgment

Hereby, we would like to thank the students active in the operational team, Mohammad Javad Hasan Nataj, Jaber Shokri, Danyal Ansa, Sadeq Abbaspour, Sina Satari, Saber Kazemi, Irfan Hatami, Mustafa Mirsolhdar, Fatemeh Hashemi and Azar Hasanpour who helped in the implementation of this project. We also appreciate the staff of School of Persian Medicine in Babol who supported the operational team during the first wave of the COVID-19 epidemics.

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