Spatiotemporal Modeling in Wireless Communication Networks

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Abstract:

This study aims to analyze the flow migration of individuals between Iraqi governorates using real anonymized data from Korek Telecom company in Iraq. The purpose of this analysis is to understand the connection structure and the attractiveness of these governorates through examining the flow migration and population densities. Hence, they are classified based on the human migration at a particular period. The mobile phone data of type Call Detailed Records (CDRs) have been observed, which fall in a 6-month period during COVID-19 in the year 2020-2021. So, according to the CDRs nature, the well-known spatiotemporal algorithms: the radiation model and the gravity model were applied to analyze these data, and they are turned out to be complementary to each other. However, the results explore the flows of each governorate at two levels of abstraction: The Macroscopic and Mesoscopic. These results found that the spatiotemporal interaction models are complementary to the other, as the determined flows based on the radiation model have been used in the gravitational model. Furthermore, flows summary among all the governorates as well as for each of them has been obtained separately. Thus, based on the total number of flows, the highest attraction rate was between Nineveh and Dhi Qar governorates which reached 64%, while the lowest attraction was between Wasit and Karbala governorates which reached 7%. In addition, the extracted geographical maps showed each governorate ratio. Regarding the color of each governorate that degraded from light to dark, which indicated the low to high attraction respectively. In the future, it is possible to obtain more detailed data, and to use complex network algorithms for analyzing this data.

Keywords: Call detail records, COVID-19, Flow Migration, Gravity model, Iraqi CDRs, Radiation model.

Introduction

In general, a network consists of a number of nodes connected by a number of connections. Furthermore, communication networks may be utilized by managers to regulate and track various communication flows. As a result, in recent decades, wireless networks have become an essential component of communication, as well as a really revolutionary paradigm change, enabling multi-media conversations between persons and devices from everywhere. As society shifts toward an information-centered approach, having access to information at all times and from any location becomes increasingly crucial [1]. Trip generation is one of the transportation models that aims to predict the number of incoming and outgoing trips, for example O_i and D_j for the expulsion and attraction area. The total number of trips depends on personal trips such as going to school, family size and car ownership, as well as attractions such as staff numbers and business areas as a total [2]. Human migration is one of the types of human mobility, which is summarized by the movement of an individual or individuals from one place to another by changing the locations of their home. At the present time, it is very important to forecast human migration when urban planning, trade and the spread of infectious diseases [3]. Additionally, migration flows must be seen as a global front because they announce or because their growth accompanies the globalization process. This is obviously a theme, an approach in the study of migration among many studies. Indeed, the development of globalization leads and has already caused migration to increase, but these are "not free" migrations, caused by necessity and need. So, at the present time, migration flows are seen as a real geographical, social, and even economic

resettlement and reorganization of areas subject to seasonal or permanent migration for certain reasons imposed by certain conditions [4]. Thus, the migration can include several aspects, including individuals, groups, and even families. It may be categorized at several levels to understand it more clearly, as individual migration is within the micro level, while total or mass migration is within the macro level [5]. Migration includes long trips such as work and treatment outside the country, as well as pleasure trips, especially trips that require flight, train, or any highway[6].

As well as, the most popular models used for this type of study are gravity, radiation and log-linear models. So, as the migration of the population is first classified into two categories, international and internal, and is often analyzed separately, in addition to that, the motives behind the perpetuation and initiation of both of migration types, such as economic, cultural, and political migration, often differ in their importance. Respectively, the gravity model is one of the important models in spatial interaction models. Based on the attractiveness of the thing in a place or time such as space-time (spatiotemporal), presence of students in the University at times of the Day, the momentum is high, and it is the opposite at night, or farmers are directed between governorates and regions according to the season to work in farms and agricultural places. This means gravity depends on two regions: production and attraction [7]. Thus, based on the mobile phone data, which is the main factor for the distribution calculation in this model. Spatial interaction modeling involves the analysis of flows from an origin to a destination, either over physical space (migration) or through abstraction space (telecommunication) [8]. Besides, it could be said that gravity is a formula which predicts or calculates the amount of trade between two countries or two cities inside one country, in other words, it predicts the people's migration between two regions. As well as, the mileage between source and destination could be said from point to point [9].

In addition, the proposed radiation model may not depend precisely on distance, but on the radial population distributions of the original location. Given the parameter-free nature of the model, the predictive accuracy of many phenomena affected by mobility and transportation processes can be substantially improved in areas without previous mobility measurements[10]. The radiation model is inspired by the gravitational model, but it is considered a stochastic process that requires a population and no parameters. In the original gravitational model the Euclidean distance equation is usually used to calculate the distance while the radiation model does not depend on the distance while on the population and the total population in a circle of radius r_{ij} centered in i, this means that a person travels to the nearest location where an improvement in working conditions is likely. Therefore, the radiation model depends on the origin and destination of the population, as well as the total population within the originally centered circle. In physics, the radiation model represents the transmission of energetic particles or waves through a vacuum, while in social science it shows the flows of people through different locations. Therefore, the radiation model predicts the average migratory flow between two sites as well as the flux variance. The model depends on the possibility of moving between regions and the number of opportunities between them, and the most likely to use it is as an alternative to employment [11]. The emission and absorption process of electromagnetic beam is influenced by the radiation models, as these atoms emit in all directions, from the first region and are absorbed in each direction in the locations or the second area, depending on the energy from which they are produced (individuals within the same distance at the site of the origin). In radiation model equations, distance is not explicitly used [12].

The spread of the Coronavirus epidemic has led to great challenges, including activating e-learning, reducing travel between cities, closing all shops and other challenges, and this affected several aspects, the most important of which is financial. Therefore, many national governments have implemented restrictions measures to limit the spread of the epidemic and reduce infection rates. So, new coronavirus outbreaks (COVID-19) continue to increase globally, causing many losses and global economic crises. The outbreak has led to an emergency response phase among many countries [13]. As well as, Facebook has provided huge data for Italian mobility in almost the same time in order to analyze and investigate how to work on the actual closure system in light of these conditions and how it affects the municipal economy. Whereas, areas with high financial capacity were subjected to a stronger closure while those with limited income were subjected to resistance to closure. Moreover, Iraq is one of these countries that was subjected to the lockdown at certain times, as this closure affected the owners of daily income, as the epidemic was spreading very quickly until preventive and awareness measures were taken and the spread of vaccines and control its spread [14]. In recent years and periods, mobile phones have become the most important sources for data transmission and geographical mobility.

Where, it constitutes 77% as a prevalence rate in the world and 68% in industrialized countries. So, the Call Detailed Records (CDRs) have proved useful in shedding light on mobility trends. While some information may be lost while the user privacy anonymization is in progress, it remains useful when mobile calls and text are being made as well as the location of the cell tower associated with a call or text [15]. The CDRs include all the data of the caller and called such as the free tower from which the call was made, the tower for the call recipient, the source and recipient points of the calls, the amount according to the bill for each call with its time, the amount charged for each call, the total bill time, the total remaining free time, as well as cell towers are provided for each caller. In the case of locating each person in a particular case, the mobile phone data will be used to be used for this purpose [16]. In addition, sudden change in people's lives by moving to safer areas or following government instructions can be caused by natural disasters such as floods, fires and snowstorms. This type of human mobility can be captured using mobile data and other Location Based Social Networks (LBSN) such as geo-referenced Twitter data[17]. Furthermore, certain applications can also help collect data for users after their consent and by using a certain technology that depends on the stability and movement of the mobile phone by people, such as the disaster alert application from Yahoo Japan Corporation in Tokyo, Japan, which helps in sending notifications and notifications to users in the event of disasters natural[18].

The rest of this paper is organized as follows: Section 2 explains the related work; Section 3 describes the datasets used. While, Section 4 represents method and materials with the standard formulas, structures and tables. Then, Section five displays the result discussion. Finally, the conclusion section represents the summary of the article content.

Related Work

This section will present several researches that investigated such a case study with applying various methodologies. Thus, the trip distribution model in[2] was developed using the doubly-constrained gravity model for the city of Alexandria using the 2002 census data. The trips were distributed within several points in the region, as well as the trip intersections in order to verify the validity of the model. As [19] explained, the use of two methods to test the impact of a new transport facility, and the results were a comparison between two models of spatial inactivity, the gravitational

model and the radiation model, as they were applied to real data containing 5000 trips distributed to more than 100 families, and also containing many students and owners of simple businesses and total residents. The aim of these comparisons was to measure the accuracy of the models between the origin and destination; however, the models were not compared. For several reasons, these models are used to analyze the impact of a specific network, such as the bus rapid transit network in Brazil, and this was done by measuring the variance between the distributions of trips and formulating the accessibility index to the new point. In addition,[12] human mobility patterns influence the spread of epidemics, and mobile data is one of the rich sources of mobility data. Where, different methods are presented to fit the micro-motion, radiation model and gravity model to work on the spatially collected motion data. Where population data was used to derive the population census at different scales and models were implemented on each scale. The results concluded that the radiographic models use less parameters than the gravity model and are more accurate in predicting trips between sites in specific countries, and that the estimates of some parameters change between countries, with different accuracy, and highlight the incomplete spatial data in proportion to the model.

However, the research[11] described spatial interaction models to be used for human mobility based on physical laws and also in the different aspects behind the spread of disease. Where gravity and radiation models were proposed as media to describe the ways infectious diseases are transmitted by population movement, mobile phone data on millions of Kenyan people was used to analyze their movement and movement. The results led to the failure of the gravity and radiation model in certain ways to capture the movement of people, each of them failed in a different way as both of them overestimated the diffusion of travel, in addition to that the performance of each of them was poor in rural areas. In addition,the study of [20] examined one of the factors affecting human migration is sea level rise as millions of people living in coastal areas are threatened or exposed to migration. A modeling framework has been proposed to predict the effect of sea level rise (SLR) on migration patterns from the demographic and geographic data that can be obtained. The approach evolves the radiation model to detect resident's unwillingness or failure to migrate and re-immigrant and cascading effects in migratory patterns. Where, the application of the model was used mathematically to clarify internal migration in Bangladesh. The results expect that in 2050 there

will be a decrease in the population due to this type of migration. Gravity models considered as the first modeling approaches have been used in trade for the first time. Also, the study of [21] has analyzed the connection between trades, geography and technology renovation under academic qualifications. Then, tested how technology and geography affected the trades. Meanwhile, in [22] it has been used in the Twitter dataset in NY city as the place of study indicates too many trips available easily. Also, focuses on the commute trip, because it is stable temporally and represents the largest amount among populations. Meanwhile, the main key in this method is accomplished in threefold, discovering the chances of social media at different levels in trip distribution, using machine learning technique to predict the distribution at census level, lastly a comparison among three models gravity, random forest, and neural network models to detect the best model for trip distribution at census field levels. According to [6] a gravitational distribution model was applied to CDRs, the data was collected from 1.819.928 users phone in Portugal for 18 months for the period $2006 \ and \ 2007$, and many models were obtained by computing the regression line between real migration flows within a specified time and between two specific regions. However,[23] analyzed the CDRs data for an urban area that investigates how people move, given that this data is based on the messaging, calling and internet activities of nearly one million mobile phone users in the city of Milan. Since the population represents the real mass of the small people living in the city, and the spread of the towers is consistent over a known area, for example, 200 meters or less. The purpose of this research is to re-describe the movements of people in the city and to describe the places in full as a result of the high accuracy of the spatial data. This was done by checking how human mobility in a given urban area is through the notion of the spatial importance that Point of Interest (PoI) plays in mobility. As well as, this procedure can be worked with GPS and Wi-Fi datasets.

Furthermore, [17] analyzed and also used anonymous mobile phone data to model the migration that occurred in La Guajira, Colombia in 2014 due to the severe drought that occurred at that time. Whereas, the results indicated a decrease in the population by up to 10% in the 6 months that the work was carried out. In addition, the migration prediction achieved a success rate of 60% for the total number of people who migrate. The radiation model was also modified to capture weather as one of the factors that drive mobility, showing a decrease in RSS and RMSE measures by 4.5% compared to the other standard models. Moreover,

the use of mobile phone data in [24], had been implemented at the four-year level in Namibia from an anonymous source helped to derive estimates of internal migration and how to model it from telephone records at the sub-annual and national levels. As well as the accuracy of these estimates compared to the population census data. In addition, how the spatial gravity model works with CDRs data so that it can capture the flows accurately. The results shed light on the migration estimates made using mobile phone data, which is a promising way to complete national immigration statistics. As well as in [25], the best route between two locations can be determined by GIS and artificial intelligence algorithms with Google Maps based on specific criteria. Where the Open Street Maps (OSM) database was used and implemented using Quantum Geographic Information Systems (QGIS). The results were represented by showing the best route that can be obtained between the source and destination and with the least distance and time. The energy of the networks in the body area has been harnessed wirelessly. Where the sensors are injected into the human body and controlled wirelessly, where the temperature, heart rate, blood sugar level and other sensors are collected. Some protocols were used for continuous wireless communication between the patient and the doctor in order to follow up on a specific case and prescribe a treatment for it. In addition, the choice of the protocol is important to reduce energy consumption and save energy[26].

Actually, the spread of Covid-19 is considered to have an impact on mobility in general and major, as Greater London was one of the affected cities. Data from health organizations, Google as well as the Greater London Authority were used to analyze and visualize how the pandemic will affect public mobility in 2020. And it was concluded that the areas most affected by this virus are the central commercial areas, disproportionately with the low rate of movement [27]. Similarly, in [14] huge human mobility data were analyzed during the time of the outbreak of the new Coronavirus before and after the lockdown in Italy and discovering how differences are related to human mobility and the results showed that areas with higher financial income were less influential than areas of daily and medium income where the lockdown affected the poorest segment of the population. Human mobility data in [18] were also analyzed in Tokyo, Japan to monitor human behavior and rates of human contact and its association in COVID-19 and its transmission. The movement data of more than 200,000 people were collected by an anonymous mobile phone in Tokyo.

In the first week, a drop of 50% from the initial rates was reached, as it also led to a decrease in the proportion of social contact in Tokyo to more than 70%. All of these challenges have led to a low transmission rate of COVID-19, and a decrease in its reproduction in Tokyo.

The Dataset Description

Many types of data can be used with these models such as immigrant and demographic data as well as mobile phone data playing a major role. Call Detailed Records (CDRs) data is more freely accessible than other network-related data such as GPS data since it is maintained by the majority of telecommunications service providers (TSPs). By examining it, one may discover the movement patterns of the majority of the individuals, resulting in more effective urban planning, disease and traffic control, and so on[28]. This work analyzed Iraqi data from Korek Telecom which includes 12 fields which are report_date, a_number, b_number, call_description, call_duration_seconds, governorate, site_id, site, longitude, latitude, date-time, destination and more than 10 million lines, for 6 months within $September$ 2020 $to\ February$ 2021. Furthermore, the observed data set covers 18 governorates through COVID-19 period, but unfortunately, it is not integrated, and does not concern subscriber positions. So, some preprocessing was performed on it, as well as merging it with other data sets to obtain data that fits the models used.

Methods and Materials

The radiation model is one of the important and specialized models for this type of task to analyze CDRs and get different results. Also, the purpose behind applying the radiation model is to overcome some of the limitations of the gravity model such as its requirement of past traffic data to match the parameters (β, α). In addition, the gravity model has methodological inconsistencies that are predictive. It also cannot explain the fluctuations in passenger numbers that occur between the two locations. The radiation model is used as a substitute to employment, as a person resides in a particular city and applies for a job in all the surrounding cities and collects various job offers as job opportunities are appropriate with the number of residents residing in that city, and each offer is represented by a random probability that is supposed to be greater from the possibility of the city in which the human resides, and on this basis, the individual will be choosing the nearest job opportunity offered to him [10]. So, the choice of opportunity depends on the number of population, and the number of opportunities, where the size of the city is great, the number of population is great, so the number of opportunities is better. Moreover, the radiation model [29] is based on a simple neutrino diffusion model, in which particles are generated at a certain location and are subject to a certain probability of absorption p from nearby places. The probability of absorption of a particle is independent of p, but relies just on the population of source and destination. Eq. 1 represents the general formula of radiation model,

$$T_{xy} = T_x \frac{m_x n_y}{(m_x + s_{xy})(m_x + n_y + s_{xy})} \qquad \dots \quad 1$$

Where m_x, represent the population of source, n_y the number of population of destination, and s_{xy} the population in the circle with center of origin and radius of distance (excluding $source$ and $destination$). Then, the number of travelers have been estimated, which is called T_{xy}, between position, x and position y as a portion of the people x, T_x. (Fig. 1) represents the general structure of the radiation model.
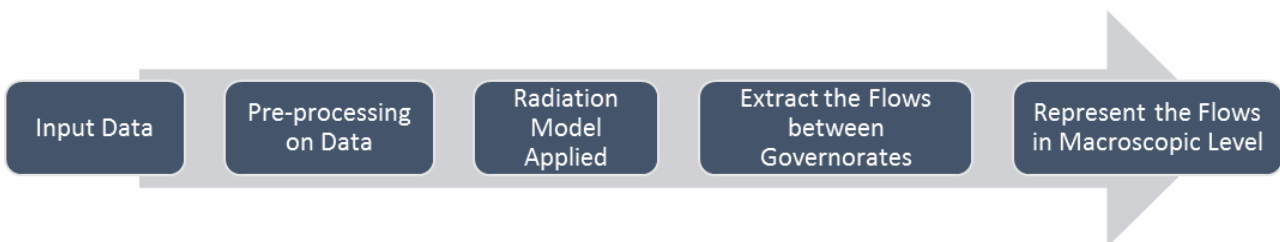

Figure 1. General Structure of Radiation Model

In addition, according to the skmob library for human analysis python, it plays a main role for applying the radiation model. So, based on the available data, the flows are obtained from the radiation model represented in (Table 1) as a sample of flows, and could be used as the input in the gravity model again.

Table 1. Radiation Flows Sample

Origin	Destination	Flows
2	15	831
11	7	86
10	3	1724
17	1	26
7	5	698

Where each number in the *Origin* and *Destination* columns represent the id for the governorate, such as 1 represents Anbar, 2 represents Babil, and 3 represents Baghdad and so on. Indeed, *Flows* column represents the number of flows from the origin to destination. Note that, the radiation model deals with integer number, not with string, and uses cellular network features to account the flows. The radiation model was used to enhance the row data.

The gravity model was also applied to the observed data sets. In this state, the city residents were used as a mass as an attractive formula in physics, as it is widely used in transportation and the study of the spread of epidemics. When using the gravity model, the sample is transferred from one place to another, for example, an individual or any type of virus and anything that can be moved in reality. Eq. 2 represents the general formula of the gravity model,

$$T_{ij} = \frac{m_i^\alpha n_j^\beta}{f(r_{ij})} \quad \quad \dots \quad 2$$

Where T_{ij} represents the sum of travelers who travel between places i and j every unit time is proportionate to the population's power of the source(m_i) and the destination (n_j) locations, with the distance between them (r_{ij}). Also, the model parameters α *and* β will be determined through multiple regression analysis. Since the available data set is not fit relative to the gravity model, the radiation model used to obtain the flows, and process some preprocessing with it to apply the gravity model. (Fig. 2) explains the group of data after proceeding,

	origin	destination	flow	month	MA_Oi	MA_Dj	MZ_Oi	MZ_Dj	lat_x	long_x	lat_y	long_y	Dij
0	1	14	22248	20-Sep	9600875.0	9659146.0	1595442.0	1605102.0	32.5598	41.9196	32.6027	44.0197	14.763257
1	1	17	11295	20-Sep	9600875.0	9667334.0	1595442.0	1606199.0	32.5598	41.9196	34.5338	43.4837	12.950157
2	1	10	13457	20-Sep	9600875.0	8214889.0	1595442.0	1389097.0	32.5598	41.9196	33.3152	44.3661	14.481997
3	1	9	1041	20-Sep	9600875.0	9611710.0	1595442.0	1598479.0	32.5598	41.9196	32.4682	44.5502	15.283343
4	1	5	580	20-Sep	9600875.0	9615659.0	1595442.0	1598326.0	32.5598	41.9196	32.0107	44.3265	15.468833
...	...	...	...	...	...	...	...	...	...	...	...	...	...
1829	18	8	7	20-Nov	9525713.0	9303088.0	1581166.0	1544424.0	32.6024	45.7521	35.4666	44.3799	15.885891
1830	18	1	8	20-Nov	9525713.0	9326033.0	1581166.0	1548625.0	32.6024	45.7521	32.5598	41.9196	16.140646
1831	18	6	10	20-Nov	9525713.0	7619638.0	1581166.0	1263032.0	32.6024	45.7521	36.1901	43.9930	15.290515
1832	18	16	5	20-Nov	9525713.0	7777677.0	1581166.0	1288004.0	32.6024	45.7521	36.2296	42.2362	14.456620
1833	18	12	3	20-Nov	9525713.0	8274296.0	1581166.0	1374896.0	32.6024	45.7521	36.8632	42.9885	14.506340

1834 rows × 13 columns

Figure 2. Sample of Data After Preprocessing

Where origin and destination refer to the labels of location i and j for individuals who are moving between them. Flows represent the total number of inflows and outflows. Month column is the date of a call. MA_Oi (macro_origin) and MA_Dj (macro_destination) refer to the number of origin and number of destinations at the macroscopic level. MZ_Oi (meso_origin) and MZ_Dj (meso_destination) refer to the number of origin and number of destinations at the mesoscopic level. Lat and Long represent the coordinates of the nearest tower to the call. In addition, the distance between the towers is represented as Dij. All in all, the gravity model depends on the number of population in every city and the distance between them. Whereas, (Fig. 3) represents the general structure of the gravity model.
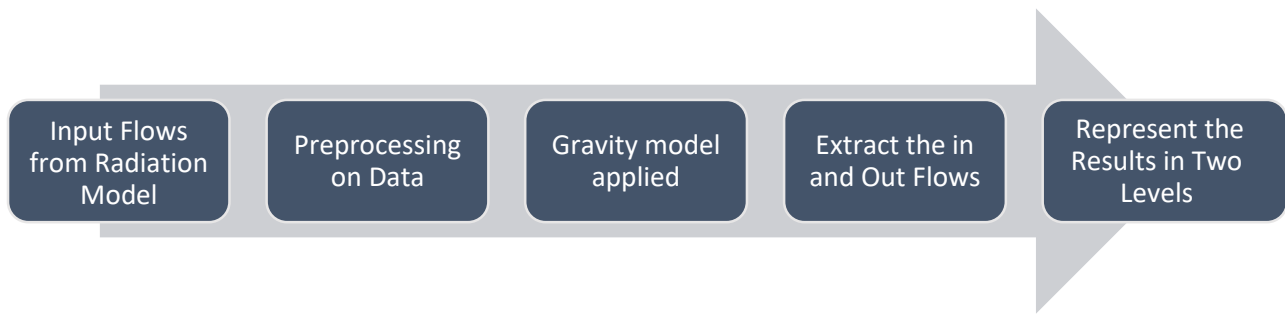
Figure 3. The General Structure of Gravity Model

The Results Discussion

In this work, the purpose behind applying the flow migration models is to obtain the flows between the Iraqi governorates using data from the wireless networks. These flows are represented in $folium$ map in three ways, using three functions for plot, tessellation, and gather them. (Fig. 4) represents the flows with plot function. Where, $origin$ represents the Id of the city, while $flow\ to$ represents the number of flows to the other city.
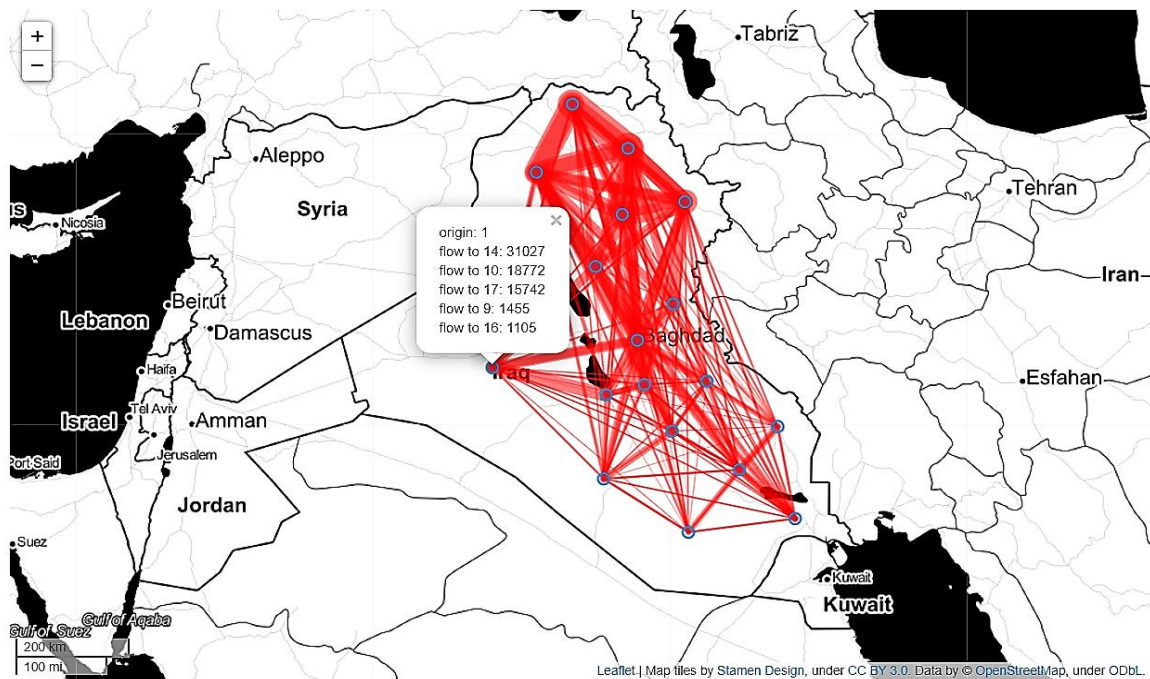
Figure 4. Flows Data Frame

Additionally, the flow dataframe was visualized by tessellation function, by identifying the constellations in the regions and considering the average between them as a meeting point for another region, also called Voronoi cell, as in (Fig. 5). Where, each city has $tile\_ID$ and number of population (pop).
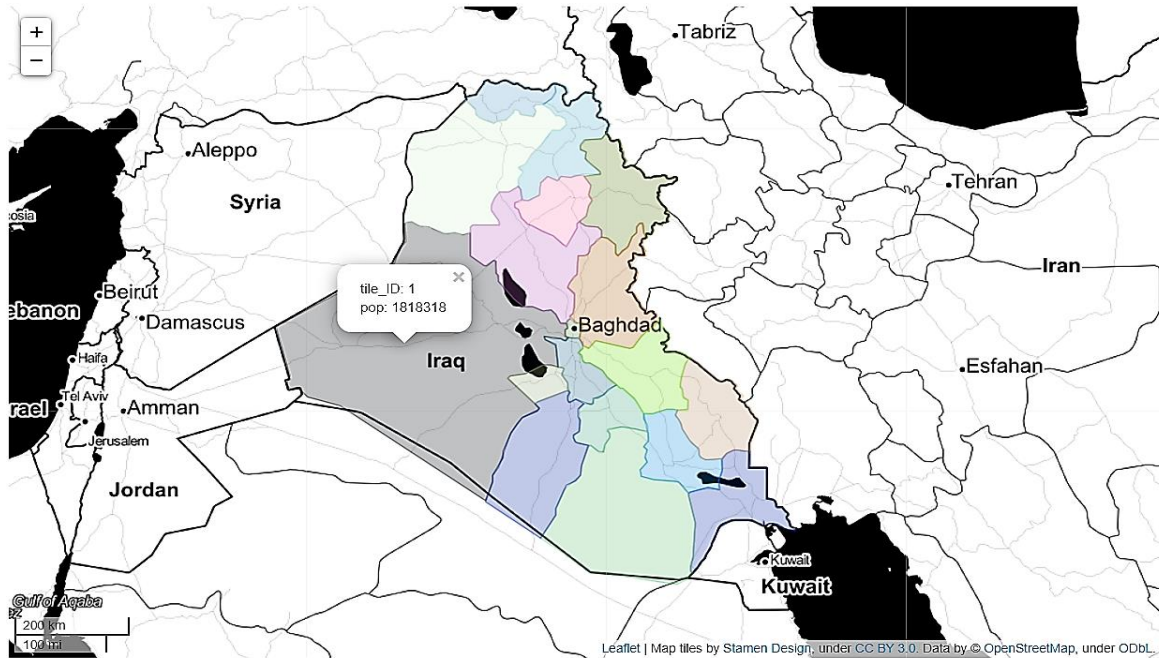
910

Figure 5. Tessellation Data Frame

Also, it could gather them in one plot as in (Fig. 6). Thus, a communication network was formed from north to south of Iraq based on the available data. It was shown from the following figures that a connected network was obtained, as the thickness of the line connecting the governorates without others represents the strength of communication or the density of subscribers to this network and these areas as well as others.
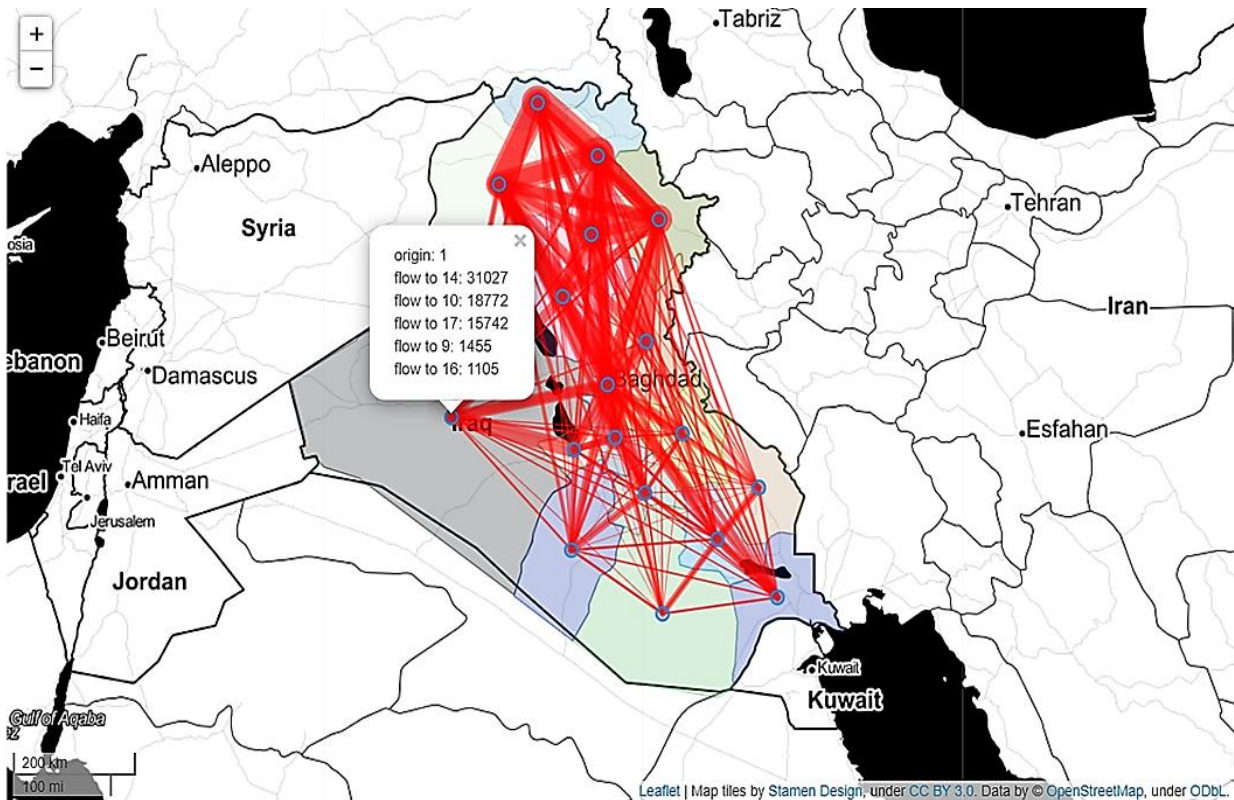

Figure 6. Flows and Tessellation Data Frame

In addition to the strong flow migration between the governorates, which constitutes the main goal or outcome of this model. And speaking of the thickness of the connecting lines, the flow is

concentrated between northern and central Iraq, in contrast to the northern south and southern Iraq, where migration in that period was already concentrated in the center and north, while the western regions were on average. Note that, it could not determine the flows with mesoscopic level, because the map is virtual and is not interactive for months. Also, the $folium$ map was displayed by the $Leaflet\ library$ with Stamen Design under a

Creative Commons license and $OpenStreetMap$ data under license $ODbL$. In addition, the sample of flows with month is illustrated in (Fig. 7), where the highest rate was between Sulaymaniyah (with id 7) to Kirkuk (with id 8) is 100930 flows, and the lowest rate was between Salahaddin (with id 17) to Muthanna (with id 4).
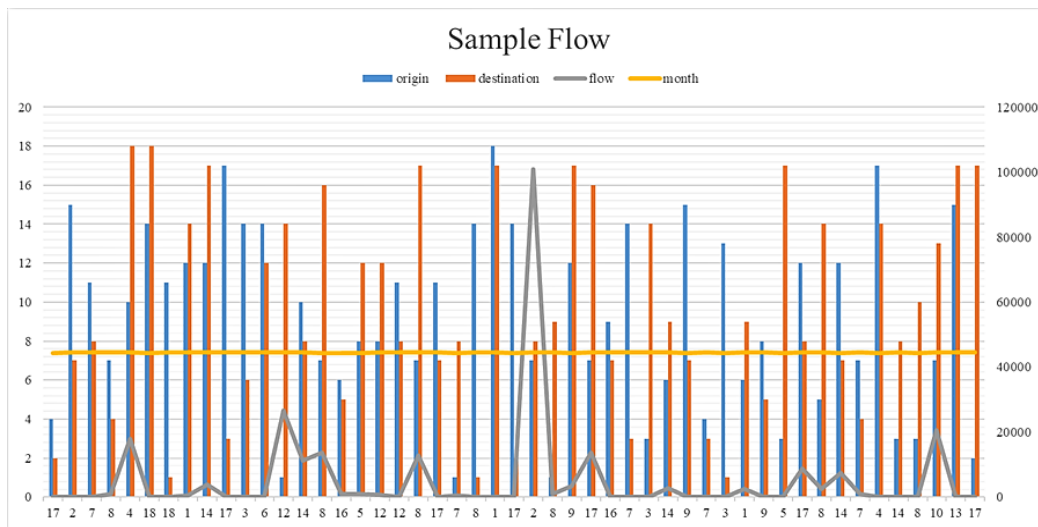

Figure 7. **Sample Flows with Month**

Indeed, the outputs obtained from the radiation model can be considered as inputs to the gravity model, since the radiation model gives realistic flows, and given that one of the most important inputs to the gravity model is the flows. As well as, the results are represented in two levels of abstraction (Macroscopic and Mesoscopic), and in two different methods as well. Where, at the macroscopic level, as shown in (Fig. 8) for example, in the northern governorates, the flow was very close, such as Dohuk, and Ninewa being

tourist cities. Ninewa is also the center of Mosul governorate, a commercial city, and the second largest governorate in Iraq. In addition to Erbil, Sulaymaniyah and Kirkuk, the inflow was high compared to the central governorates such as Najaf, Babil and Qadisiyah, where the flow was moderate. Taking into consideration that Babil governorate recorded the lowest human migration rate at that time as a movement rate between in and out flows, and the highest rate was in Dohuk governorate.
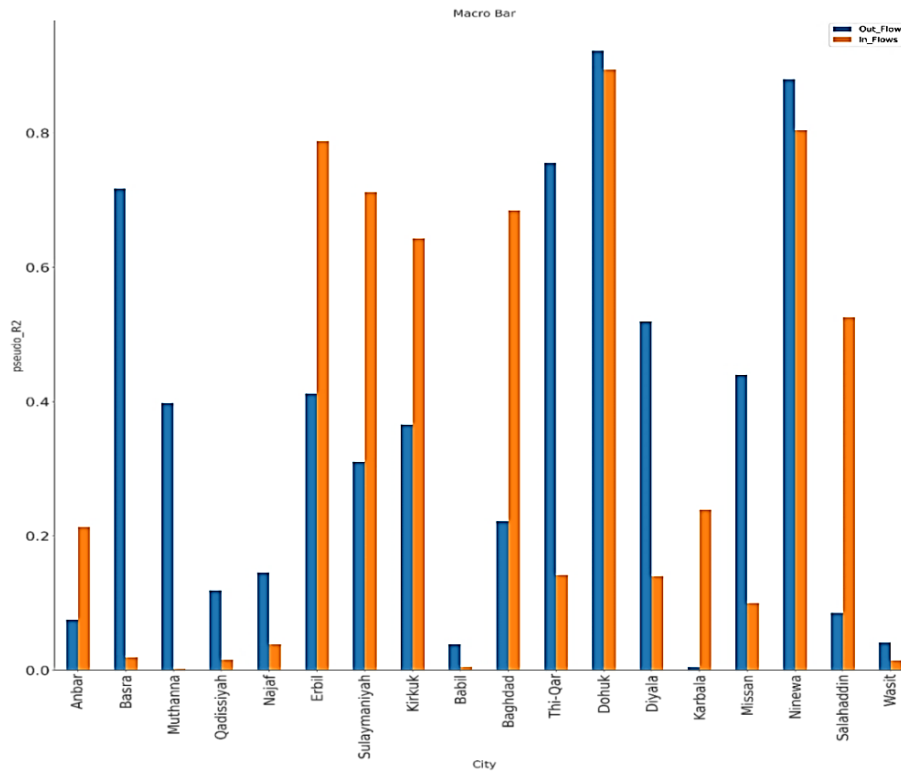
Figure 8. The Migration in-between Iraqi Governorates from Macroscopic level
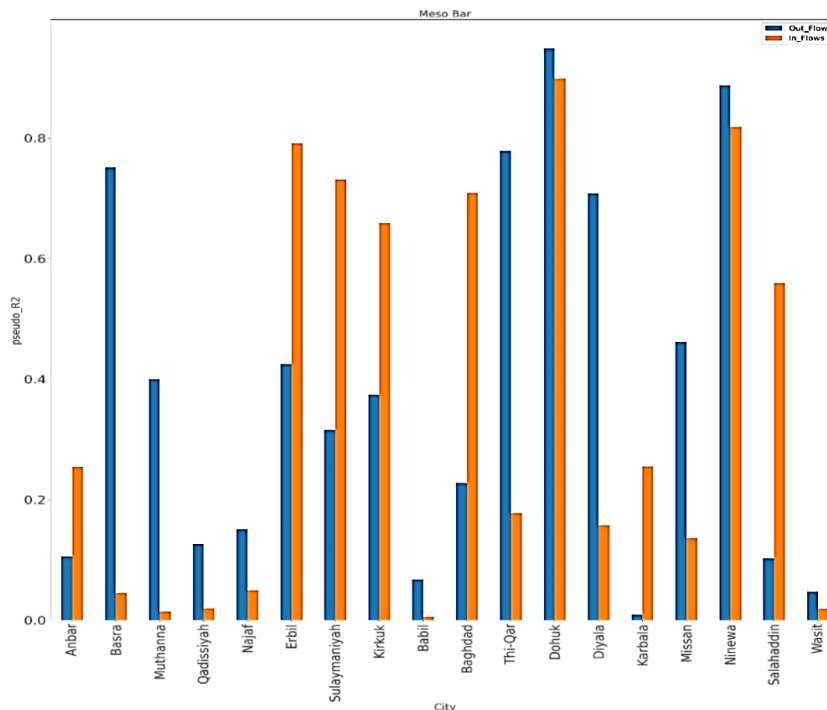

Figure 9. The Migration in-between Iraqi Governorates from Mesoscopic Level

The same applies to the mesoscopic level, with slight differences in the rates as shown in (Fig. 9). As well as, these statistics can be reflected on the maps to represent them on the ground as in the (Fig. 10) and (Fig. 11), which show the rates between in and out flows for each governorate, with the light color representing the low percentage of human migration, while the darker color the increase in human migration in the governorate, with two level of abstraction
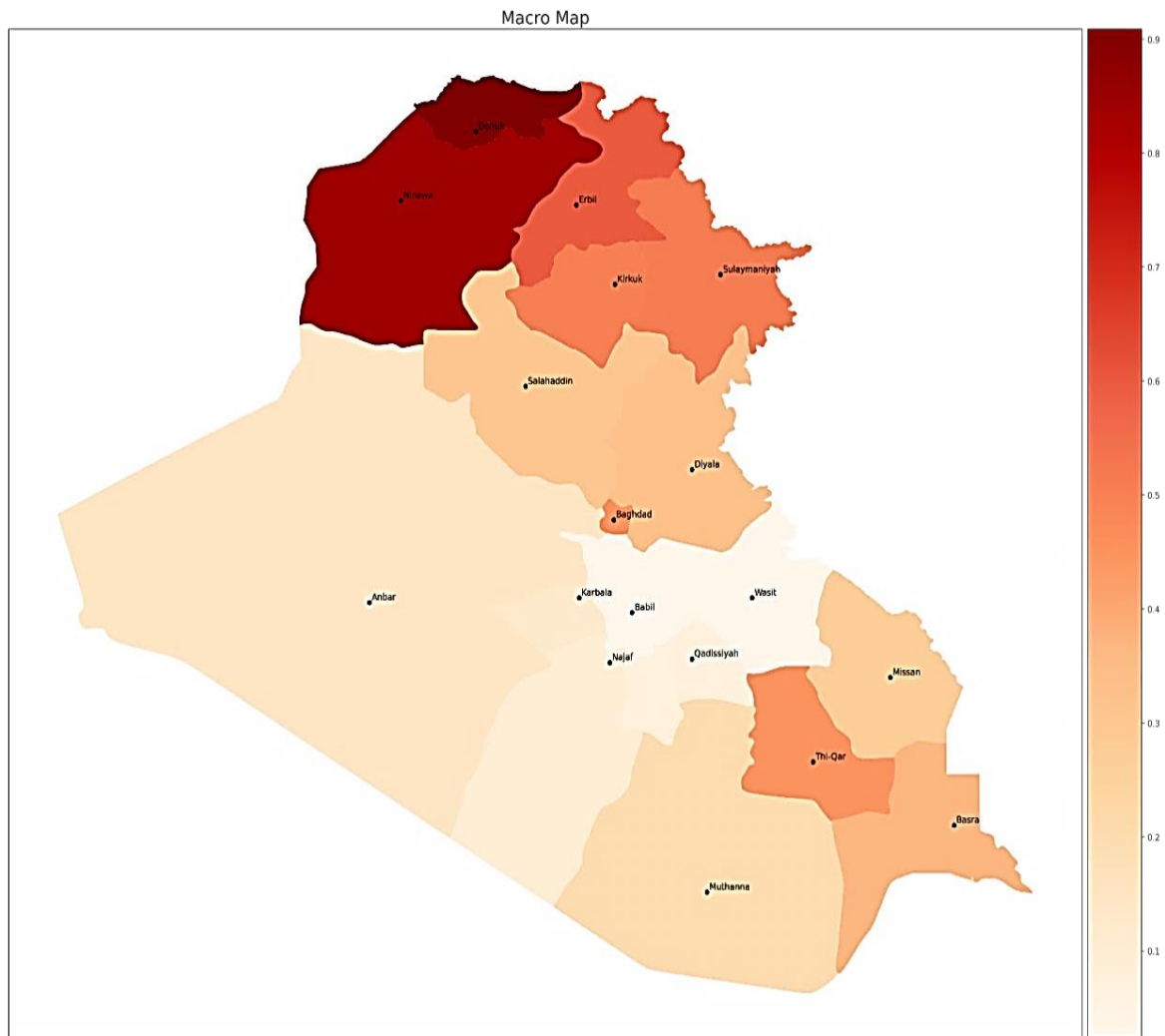
Figure 10. The Migration Map in-between Iraqi Governorates from Macroscopic Level
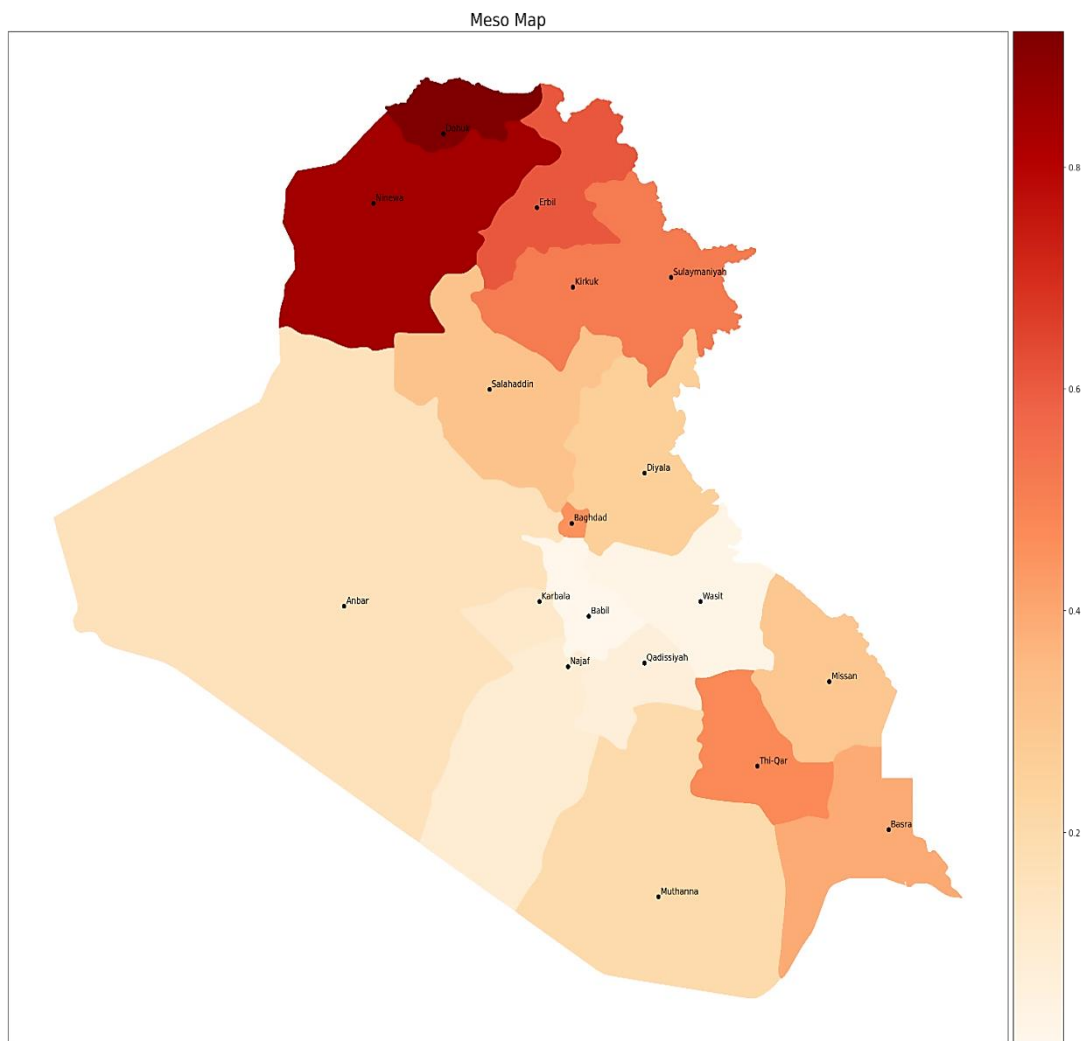
Figure 11. The Migration in-between Iraqi Governorates Map from Mesoscopic Level

In addition to the map, it is possible to show the rate of human migration between governorates as in the (Table 2), which were randomly selected from the obtained flows. As well, according to (Table 2), it could be representing the flows in a network as in (Fig. 12) as a complex network as it changes with the change in movement rates. Whereas, the lowest migration rate was between Wasit and Karbala governorates, reaching 7%, while the highest rate was between Nineveh and Thi Qar governorates, 64%. The reflected result was on the epidemic period. It is possible to improve the results or rely on a better method by using complex networks models for studying people migration.

Table 2. Sample of Migration between The Governorates

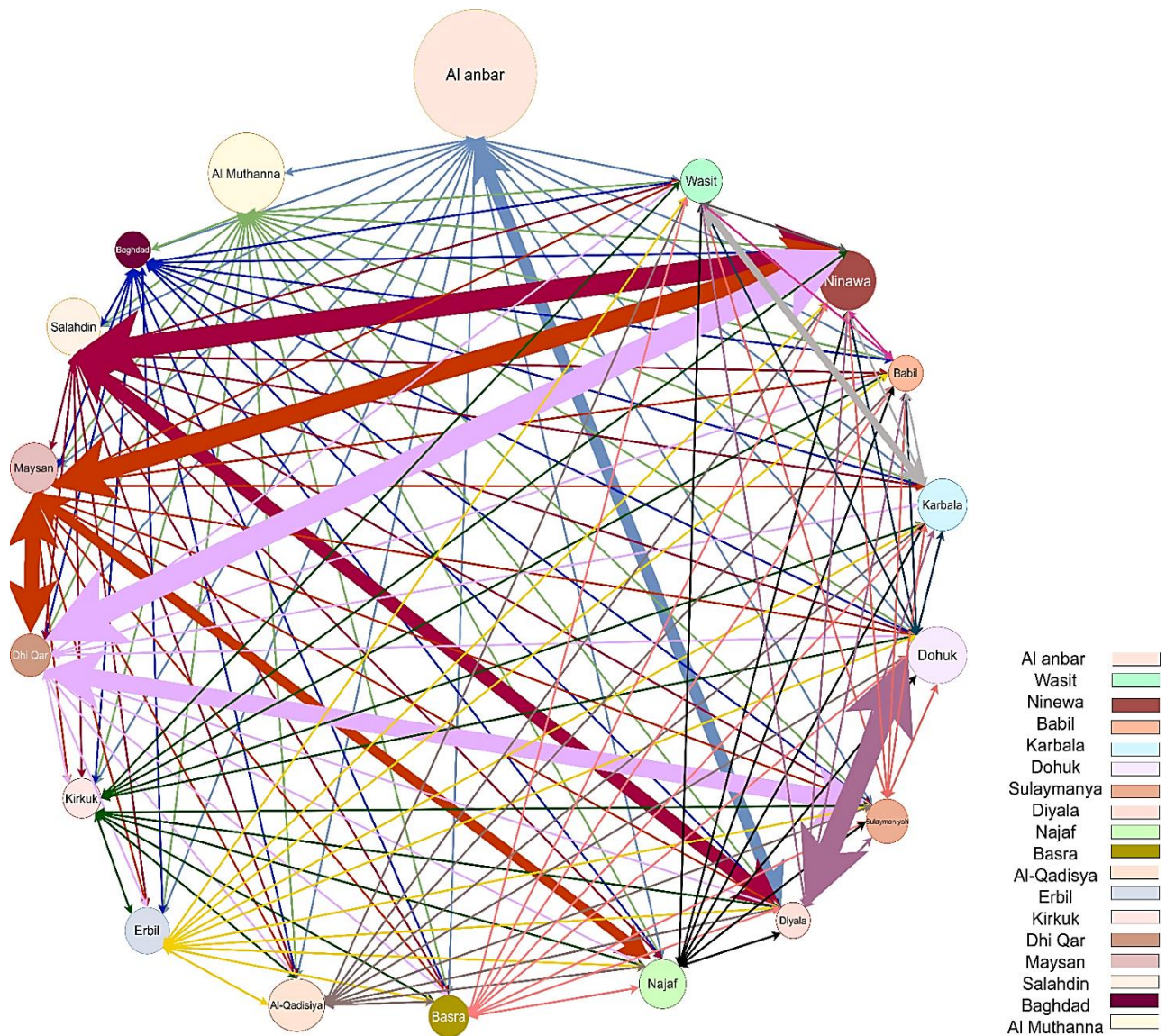| ID	Src.	Dst.	Mean	ID	Src.	Dst.	Mean
257	Ninewa	Thi-Qar	0.645479	210	Diyala	Salahaddin	0.317546
238	Missan	Ninewa	0.556204	110	Sulaymaniyah	Thi-Qar	0.480151
72	Najaf	Missan	0.181237	214	Diyala	Dohuk	0.619110
250	Missan	Thi-Qar	0.359630	1	Anbar	Diyala	0.236965
289	Wasit	Karbala	0.074788	286	Salahaddin	Ninewa	0.573832

Figure 12. *In/Out* **Flows as a Complex Network**

Conclusions

The aim of this work is to understand the individuals migration to simulate and model the average of flows among regions or locations, regarding that the phone network data are very useful to analyze urban life patterns. Hence, the observed data are Call Detailed Records (CDRs) shed light on the individual migration between Iraqi governorates during COVID-19 period using the gravity and radiation models. So, the gravity model predicts the movement of individuals between each two places depending on the population size, and the distance between these places. Indeed, the examination has been implemented in two levels of abstractions (Macroscopic and Mesoscopic). The present findings confirm that the radiation model extracts the number of flows according to the population size and the commuters who leave the place. Then, these flows are simulated sufficiently

through the gravity model. It has been found that there is a large discrepancy in the results of the gravity model, as the migration rate in Anbar governorate was 14% after extracting the flows from the radiation model, and also Baghdad governorate 45%, and so in the rest of the governorates. Eventually, these flows have been represented as a complex network.

In the future, it is recommended to use complex networks models for studying people migration, it could be very useful to investigate this kind of studies. As well as, we hope to expand the research ideas to cover the post-COVID-19 intervals to discover the bare truth of migration, and use more detailed data such as economic and social in order to go into depth details of human life and behavior. Although, this work has some limitations such as, the difficulty of obtaining real wireless network data from Iraqi companies due to privacy

and security reasons. Also, the obtained data for only 6 months, which is considered limited, and it is from only one communication company. As well as, the difficulty of dealing with the radiation model to obtain the flows in other levels of abstraction.

Authors' Declaration:

Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at the University of Baghdad.

Authors' Contribution Statement:

MKA-Q has role in this research was to design, analyze the results, proof editing, software development, and put forward the ideas to be organized to benefit from it in the future.
SFB was the supervisor of this research in terms of design, analyzing the results, following -up the researchers, and proof editing.
AS is designing and developing the software, in addition to the technical follow-up and solving the technical problems that faced the research.

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النمذجــــة الزمانيــــة المكانيـــــة فــي شبكـــــات الاتصـــــالات اللاسلكيـــــة

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الخلاصة:

تهدف هذه الدراسة إلى تحليل تدفق هجرة الأفراد بين المحافظات العراقية باستخدام بيانات مجهولة حقيقية من شركة كورك تيليكوم في العراق. الغرض من هذا التحليل هو فهم بنية الاتصال وجاذبية المدن أو المحافظات من خلال فحص هجرة التدفق والكثافة السكانية، لذلك من وجهة النظر هذه يتم تصنيفها على أساس الهجرة البشرية في وقت معين. تمت ملاحظة بيانات الهاتف المحمول من نوع المكالمات التفصيلية للمكالمات ((CDRs، والتي تقع في فترة 6 أشهر خلال COVID-19 في العام 2020-2021. وفقًا لطبيعة CDRs، تم تطبيق الخوارزميات المكانية والزمانية المعروفة: نموذج الإشعاع ونموذج الجاذبية لتحليل هذه البيانات، واتضح أنها مكملة للآخر بناءً على النتائج التي تم الحصول عليها. تم تمثيل النتائج من خلال استكشاف التدفقات لكل محافظة على مستويين من التجريد: الماكروسكوب والميزوسكوب. وجدت النتائج أن نماذج التفاعل الزماني المكاني مكملة للآخر، حيث تم حساب التدفقات بواسطة نموذج الإشعاع الذي سيتم استخدامه في نموذج الجاذبية. كما تم الحصول على ملخص للتدفقات بين المحافظات ولكل محافظة على حدة. واستناداً إلى العينة المأخوذة من إجمالي عدد التدفقات، كانت أعلى نسبة جذب بين محافظتي نينوى وذي قار وبلغت64 ٪ ، بينما كانت أقل نسبة جذب بين محافظتي واسط وكربلاء والتي بلغت 7% . بالإضافة إلى ذلك، أظهرت الخرائط النسبة المئوية لكل محافظة، في إشارة إلى لون كل محافظة، من اللون الفاتح الذي يعني انخفاض الجذب، إلى الغامق الذي يعني الجذب العالي. في المستقبل، من الممكن الحصول على بيانات أكثر تفصيلاً واستخدام خوارزميات الشبكة المعقدة لتحليل هذه البيانات.

الكلمات المفتاحية: سجلات تفاصيل المكالمات، كوفيد-19، تدفقات الهجرة، نموذج الجاذبية, سجلات اتصالات عراقية، نموذج الأشعاع