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# Research on spatial aggregation patterns of urban population in Almaty City based on heat map

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*Abstract*— **This paper presents a research study focused on analyzing the spatial aggregation patterns of urban population within Almaty City, Kazakhstan, using a heat map approach. With the emergence of the Smart City concept, understanding how populations aggregate within urban environments is crucial for effective urban planning and resource allocation. Leveraging geographic data collected from OpenStreetMap (OSM) and actual aggregated data obtained from the telecom operator, hourly loads on city quadrants measuring 500 by 500 meters were analyzed. The Python Folium library was employed to visualize these patterns, providing insights into the distribution of urban population density. By examining the heat map, this research sheds light on the spatial dynamics of population aggregation within Almaty City, offering valuable information for urban planners, policymakers, and researchers working towards the development of smarter and more sustainable cities.**

***Keywords:*** *Smart City, urban population, heat map, urban planning, OpenStreetMap, sustainability, urban development, resource allocation, infrastructure, data analysis.*

## I. INTRODUCTION

The methodologies for building a system of "smart cities" are determined by the fourth industrial revolution. With the rapid development of information technology, traditional methods of managing urban infrastructure and resources can no longer effectively meet the needs of modern societies. Smart cities are an urban planning paradigm focused on the implementation of advanced information and communication technologies to optimize urban infrastructure and improve the quality of life of citizens. On the other hand, many cities are urban ecosystems where integrated information and communication technologies penetrate all aspects of the lives of citizens, from infrastructure management to ensuring the quality of services and reducing negative impacts on the environment. The concept of a "smart city" reflects society's desire for a more sustainable, efficient and comfortable urban environment. It rethinks the way citizens interact with each other and with city infrastructure, making them more intelligent and efficient. Smart cities are an innovative approach to organizing urban life, based on the widespread use of modern information and communication technologies (ICT), as well as data analysis and process automation. However, building a smart city infrastructure is a more complex and multifaceted task than simply installing sensors and deploying the Internet of Things (IoT). It requires the integration of various technologies, cooperation between city authorities, the private sector and society, as well as taking into account the specifics of each specific city. During the analysis, it is necessary to pay special attention to the role of local authorities and the methodological potential of the international community in the design of "smart cities", the implementation of a systematic approach to the modeling and design of "smart cities", and the features of the implementation of the reference architecture methodology.

The advent of the Smart City paradigm has catalyzed a profound transformation in urban landscapes worldwide, emphasizing the integration of technology to enhance the efficiency, sustainability, and livability of urban environments. Central to the realization of this vision is a deep understanding of the spatial dynamics of urban populations, as their distribution shapes a myriad of social, economic, and environmental factors. In Kazakhstan, the city of Almaty stands as a pivotal center of urban development and innovation, embodying the complexities and challenges inherent in modern urbanization.

This paper endeavors to explore and analyze the spatial aggregation patterns of the urban population within Almaty City, Kazakhstan, employing a heat map methodology. The city's status as the largest metropolis in Kazakhstan, coupled with its diverse socio-economic landscape and rapid urbanization, renders it an ideal case study for investigating population distribution dynamics. By utilizing geographic data sourced from OSM and actual aggregated data obtained from the telecom operator, this research aims to provide a comprehensive understanding of how populations aggregate within the city.

The significance of this research lies in its potential to inform urban planning strategies, resource allocation decisions, and infrastructure development initiatives aimed at fostering more efficient, equitable, and sustainable urban environments. By elucidating the spatial patterns of population aggregation, this study seeks to contribute valuable insights to the discourse surrounding urban development in Almaty City and beyond.

## II. LITERATURE REVIEW

Three- level models of information technology structure in many cities are presented by the World Bank, Pwc and IDC companies [1]. Among the main stages of information processing, the following are distinguished. Collect data from various sources, including smart sensors, video cameras, mobile devices and social networks, GIS systems. Transfer of collected data via wired and wireless communication networks. Processing and analysis of the received data to clarify the current situation, forecast, develop management decisions and impacts in order to improve the quality of life and ensure sustainable development. Providing information to citizens,


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businesses, and authorities using web portals, online services, and mobile applications.

The United Nations defines a smart city as “an innovative city that uses information and communications technology and other tools to improve living standards, efficiency of city operations and services, and competitiveness while meeting the economic, social, cultural needs of present and future generations.” and environmental aspects" [2].

The definition of Smart Cities Council (Smart Cities Council, USA) states that “a smart city uses ICT to improve quality of life, working conditions and sustainable development. This is achieved through the use of technology in three areas: information collection; communications; information processing” [3].

A similar three-level model is used by the World Bank in its World Development Report 2016 [4] and by Merrill Lynch in its Thematic investing march 2017 guide [5].

In the International Data Corporation (IDC) model three stages can also be distinguished : Gather Data, Aggregate and Analyze Data and Execute Optimal response [6].

In the Price Waterhouse Coopers (Pwc) model there are three levels of the technological infrastructure of a smart city: the level of data sources; level of data processing, storage and analysis; level of use of the results [7].

Data received from sensors makes it possible to manage urban infrastructure more efficiently, improve the safety and quality of life of citizens, and optimize resource consumption. In this case, special attention is paid to the technical aspects of collecting, transmitting and analyzing IoT data, as well as the architectural principles and standards necessary for the integration of sensors in urban infrastructure [8, 14].

Various data sources, including IoT sensors, cameras, geospatial systems (GIS), and social media and mobile applications are essential for smart cities. Collection, storage and transmission of data, as well as their processing and analysis are based on the use of artificial intelligence and data analytics methods [9, 14].

AI is being used in smart cities, in particular in tasks such as transport management, energy management, security monitoring, data analysis and predictive analytics. Besides, machine learning methods and AI algorithms are used to optimize urban infrastructure and solve complex problems associated with the urban environment [10, 14].

For data exchange between IoT devices protocols and standards are used, such as MQTT, CoAP, HTTP. Compatibility and security issues must be taken into account [11].

Currently, there are many examples of successful projects and initiatives of smart cities in different European countries. However, smart cities face challenges such as data privacy, security, metropolitan governance and sustainability [12, 14].

In the article [13], Richard G. Hollands analyzes the concept of smart cities and the different approaches associated with smart cities. The historical development and evolution of smart cities is reviewed, from the first visions and plans to modern interpretations . The challenges and contradictions that may arise when implementing smart city strategies are discussed. When implementing a smart city, it is necessary to take into account modern cultural, political and social contexts [13].

## III. PROPOSED MODEL

Having analyzed existing models, we can distinguish three different approaches to the implementation of smart cities - robotization, analytics or a hybrid approach (robotics + analytics).

Smart cities can be implemented in different ways and tools. For example:

1. Smart stops – stops with modern USB connectors, solar panels and interactive maps of the city and routes. In this case, the “smart” component of the solution is achieved through an engineering solution - the stop is equipped with additional equipment, displays, batteries, etc.
2. Smart lighting – adjusting the brightness of street lamps by responding to the degree of sunlight. In this case, a robotic solution is used - a combination of sensors and drivers is used to control lighting.
3. Smart parking – checking available parking spaces using a mobile application. The “smart” component is achieved through digitalization of the process through a mobile application.
4. Smart planning - planning the allocation of buses to individual busy routes, selection of points for opening schools and kindergartens, intelligent selection of locations for public service centers or retail outlets. It is implemented using data analysis and machine learning technologies.

As we can see, there are quite a lot of tools for implementing the “Smart” city concept. As part of our research, we would like to focus on smart city planning. The solution to the problem of smart planning of urban infrastructure can be achieved using machine learning technologies. To implement the concept, the following steps may be involved:

**Data collection -> structuring data in a data warehouse -> data analytics and development of machine learning models -> development of a unified platform for decision-making in planning urban infrastructure processes**

As you can see, this approach correlates with the model proposed by IDC. We also set up data collection, analyze the data and build ML models, present the analysis results in a dashboard/map format, and eventually train the model.

**Collecting data from OSM**

During the data collection stage, geographic data for the city of Almaty is downloaded from OSM. This data includes


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information about road infrastructure, buildings, public spaces and other elements of urban infrastructure. The collected data will then be presented in the form of graphs for further overlay on a digital map of the city.

To represent data from OSM as graphs, you need to complete the following steps:

1. Extract data from OSM for the city under study.

2. Converting data into a graph. The graph represents points on the map (like intersections or other places), and the edges represent the roads between these points. It is necessary to take into account information about traffic directions on the roads (if it is available in the OSM data).

3. Determination of edge weights. The links to the edges of the graph can represent the distance between nodes, travel time, road type, or other parameters.

4. Saving the graph in the selected format. Commonly used formats are GraphML or JSON.

5. Using a graph for overlaying on a digital city map, for calculating optimal routes, analyzing the road network, estimating travel time and other tasks.

6. Visualization of the resulting graph on a digital map of the city. This project proposes the use of libraries and Python NetworkX.

Data from OpenStreetMap for the city of Almaty is presented as a file geo.json format, which have the following structure (fig.1.):


```
{'type': 'FeatureCollection',
 'features': [{'type': 'Feature',
   'properties': {'osm-relation-id': '2465058',
    'name': 'Almaty',
    'nameRu': 'Алматы'},
   'geometry': {'type': 'MultiPolygon',
    'coordinates': [[[[76.7826597, 43.3199019],
       [76.7734932, 43.3186465],
       [76.7714802, 43.3181553],
       [76.7719976, 43.3171591],
       [76.7723961, 43.3167519],
       [76.7603077, 43.3140048],
       [76.7536005, 43.3179699],
       [76.7415934, 43.3154189],
       [76.7382775, 43.314451],
       [76.7387238, 43.313583],
```


Figure 1. Data from OSM for the city of Almaty in the form of a file geo.json (URL: https://polygons.openstreetmap.fr/index.py?id=2465058)

The data on the map of the city of Almaty is current as of 2023-10-07.
In a private format, the data represents the coordinates of the boundaries of the city of Almaty, which will subsequently be divided into non-overlapping quadrants.

The boundaries of the city of Almaty based on the open data are given in figure 2:

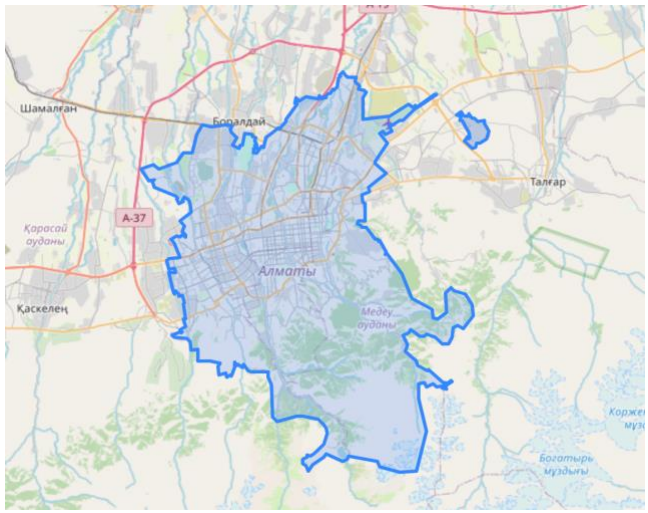



Figure 2. The boundaries of the city of Almaty.

The next step was to divide the city sector into equal quadrants of 500*500 meters, which was done using algorithms in Python (fig.3.).

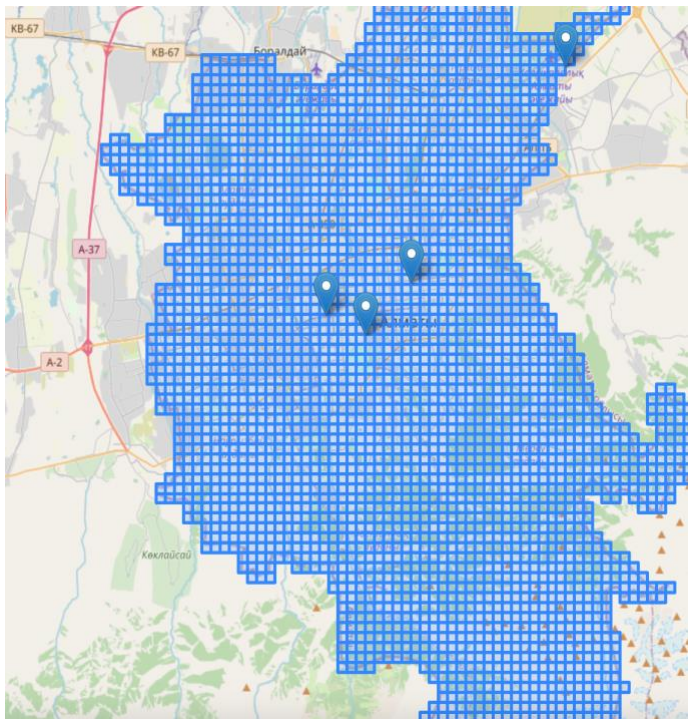



Figure 3. The quadrants of 500*500 meters of the city of Almaty.

Inside each quadrant a heat map is defined, which indicates the load on it at a certain hour (the red color means the more load on the quadrant, the blue one the less load on the quadrant) (fig. 4.).


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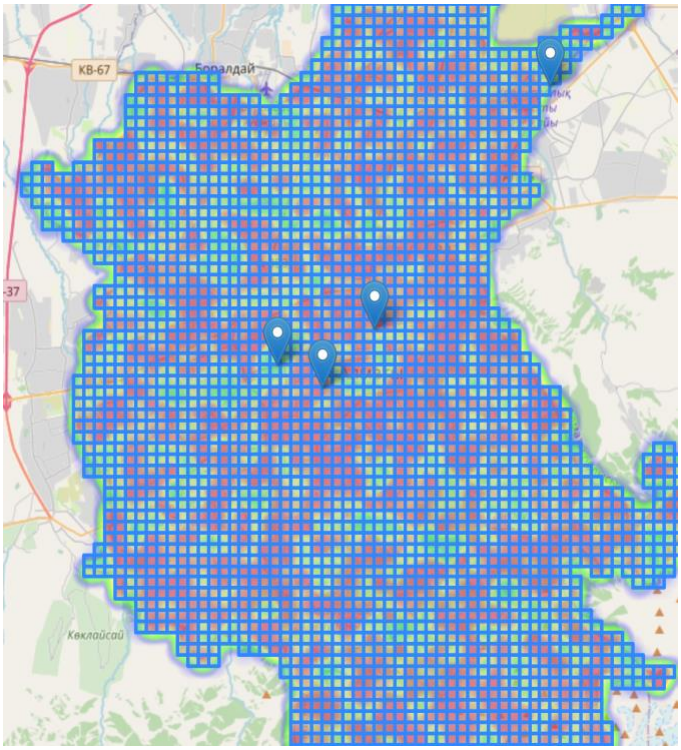



Figure 4. The heat map of the city of Almaty.

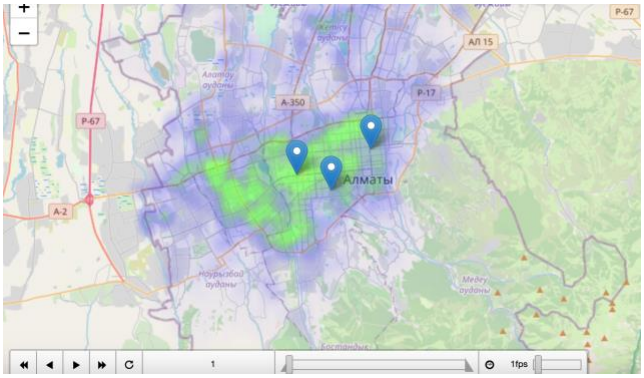



Figure 5. Heat map of pedestrian traffic load during the period from 01:00 to 01:59.

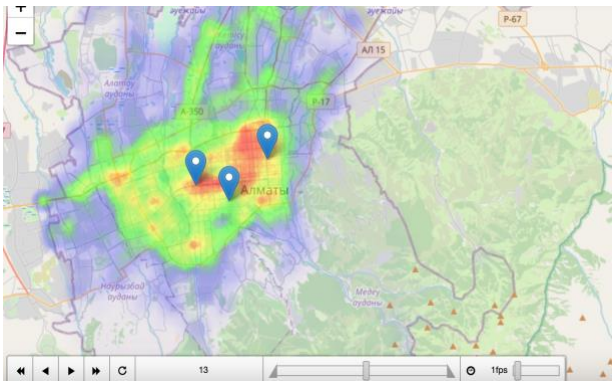



Figure 6. Heat map of pedestrian traffic load during the period from 13:00-13:59.

We see that the nighttime load on the city is significantly lower than during lunchtime.

## IV. Flat Structures of Objects

We gathered data on public transport routes and bus stops within the city of Almaty. The collected data included information on the routes themselves as well as details about bus stops.

Although the data exhibits a relatively well-structured format, usability presents a challenge. To enhance accessibility, a decision was made to consolidate the information into a single dataset containing bus route details, with each line representing a stop point along each route. The most straightforward structure for further utilization is a flat table.

To facilitate this conversion from an array of JSON objects, Python's functionality was employed. Subsequently, the pandas library was utilized to efficiently merge the two datasets. For future convenience, it was deemed practical to save the resulting dataset in Excel format, allowing for both visual analysis and compatibility with various other data processing systems.

Python code was developed to transform the structure of the JSON file containing route data, yielding a pandas dataframe as the output.

The resulting flat object in pandas dataframe format is illustrated as follows:

```
(work_venv_1) (work_venv_1) galym@MacBook-Pro-Galymzhan bus_routes % python3 main.py
   route_id route_name  route_direction_index  route_direction_distance  stop_id  stop_line_index  stop_offset_distance  stop_distance
0  20807817        236                      0                  47605.71219  3217600              0.0              0.000000             15
1  20807817        236                      0                  47605.71219  1093904             15.0             61.687711            466
2  20807817        236                      0                  47605.71219  1098006             15.0            349.548082            755
3  20807817        236                      0                  47605.71219  3792746             18.0             83.285838           1246
4  20807817        236                      0                  47605.71219  1421777             34.0             45.454925           2277
5  20807817        236                      0                  47605.71219  3744482             35.0             20.955860           2664
6  20807817        236                      0                  47605.71219  1425799             35.0            338.269824           2973
7  20807817        236                      0                  47605.71219  1427810             36.0             55.346468           3342
8  20807817        236                      0                  47605.71219  1431832             40.0            458.159760           4233
9  20807817        236                      0                  47605.71219  4068253             40.0            802.033997           4579
(work_venv_1) (work_venv_1) galym@MacBook-Pro-Galymzhan bus_routes %
```

Figure 7. Flat object on public transport routes in pandas dataframe format

Similarly, the structure of a JSON file containing data on bus stops was transformed into a pandas dataframe format.

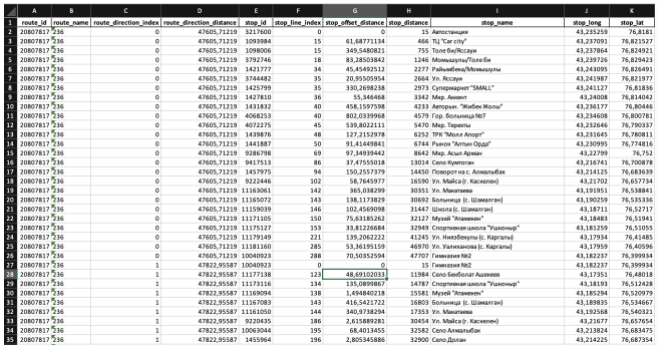
A flat object in pandas dataframe format appears as follows:

```
(work_venv_1) (work_venv_1) galym@MacBook-Pro-Galymzhan bus_routes % python3 main.py
   stop_id              stop_name  stop_long   stop_lat
0  2276452           Мкр. Водник  43.365114  76.852291
1  4502629          ЖК "Бай-Тал"  43.204574  76.869498
2  2270419  Боралдайский Аэропорт  43.355601  76.875335
3  2272430  Боралдайский Аэропорт  43.354778  76.876046
4  3485063          Село Жетыген  43.688565  77.126895
5  2057253              Дачи 4    43.204013  76.779832
6  2151770        Ул. Утемисова   43.309549  76.865689
7  2354881          Мкр. Акбулак  43.266359  76.829805
8  2688707          Зелёный базар 43.262731  76.955211
9  2736971        Ул. Кожабекова  43.200459  76.895008
(work_venv_1) (work_venv_1) galym@MacBook-Pro-Galymzhan bus_routes %
```

Figure 8. Flat object on bus stops in pandas dataframe format

Next, the resulting two dataframes are merged into a single flat structure using the left-join operation in the pandas library:


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| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | route_id | route_name | route_direction_index | route_direction_distance | stop_id | stop_line_index | stop_offset_distance | stop_distance | stop_name | stop_long | stop_lat |
| 2 | 20807817 | 236 | 0 | 47605,71219 | 3217600 | 0 | 0 | 15 | Автостанция | 43,235259 | 76,8181 |
| 3 | 20807817 | 236 | 0 | 47605,71219 | 1093984 | 15 | 61,68771134 | 466 | ТЦ "Сэ city" | 43,237091 | 76,821527 |
| 4 | 20807817 | 236 | 0 | 47605,71219 | 1098006 | 15 | 349,5480821 | 755 | Толе би/Ясауи | 43,237864 | 76,824921 |
| 5 | 20807817 | 236 | 0 | 47605,71219 | 3792746 | 18 | 83,28503842 | 1246 | Момышулы/Толе би | 43,239726 | 76,829423 |
| 6 | 20807817 | 236 | 0 | 47605,71219 | 1421777 | 34 | 45,45492512 | 2277 | Райымбека/Момышулы | 43,243095 | 76,826491 |
| 7 | 20807817 | 236 | 0 | 47605,71219 | 3744482 | 35 | 20,95505954 | 2664 | Ул. Ясауи | 43,241987 | 76,821977 |
| 8 | 20807817 | 236 | 0 | 47605,71219 | 1425799 | 35 | 330,2698238 | 2973 | Супермаркет "SMALL" | 43,241127 | 76,81836 |
| 9 | 20807817 | 236 | 0 | 47605,71219 | 1427810 | 36 | 55,346468 | 3342 | Мкр. Аккент | 43,24008 | 76,814042 |
| 10 | 20807817 | 236 | 0 | 47605,71219 | 1431832 | 40 | 458,1597598 | 4233 | Автошк. "Жибек Жолы" | 43,236177 | 76,80446 |
| 11 | 20807817 | 236 | 0 | 47605,71219 | 4068253 | 40 | 802,0339868 | 4579 | Гор. больница №7 | 43,234608 | 76,800781 |
| 12 | 20807817 | 236 | 0 | 47605,71219 | 4072275 | 45 | 539,8022111 | 5470 | Мкр. Тереты | 43,232646 | 76,790337 |
| 13 | 20807817 | 236 | 0 | 47605,71219 | 1439876 | 48 | 127,2152978 | 6252 | ТРК "Мега Аларт" | 43,231645 | 76,780811 |
| 14 | 20807817 | 236 | 0 | 47605,71219 | 1441887 | 50 | 91,41469841 | 6744 | Рынок "Алтын-Орда" | 43,230995 | 76,774816 |
| 15 | 20807817 | 236 | 0 | 47605,71219 | 9286798 | 69 | 97,34939442 | 8642 | Мкр. Асыл Арман | 43,22799 | 76,752 |
| 16 | 20807817 | 236 | 0 | 47605,71219 | 9417513 | 86 | 37,47555018 | 13014 | Село Кунтоган | 43,216741 | 76,700878 |
| 17 | 20807817 | 236 | 0 | 47605,71219 | 1457975 | 94 | 150,2557379 | 14450 | Поворот на с. Алмалыбак | 43,214125 | 76,681839 |
| 18 | 20807817 | 236 | 0 | 47605,71219 | 9222446 | 102 | 58,7645977 | 16590 | Ул. Майса (г. Каскелен) | 43,21702 | 76,657734 |
| 19 | 20807817 | 236 | 0 | 47605,71219 | 11163061 | 142 | 365,038299 | 30351 | Ул. Макпалеева | 43,191951 | 76,538841 |
| 20 | 20807817 | 236 | 0 | 47605,71219 | 11165072 | 143 | 138,1173829 | 30692 | Больница (с. Шамалган) | 43,190259 | 76,535336 |
| 21 | 20807817 | 236 | 0 | 47605,71219 | 11159039 | 146 | 102,4569098 | 31447 | Школа (с. Шамалган) | 43,18711 | 76,52717 |
| 22 | 20807817 | 236 | 0 | 47605,71219 | 11171105 | 150 | 75,63185262 | 32127 | Музей "Атажекен" | 43,18483 | 76,51941 |
| 23 | 20807817 | 236 | 0 | 47605,71219 | 11175127 | 153 | 33,81226684 | 32949 | Спортивная "Кыялчыр" | 43,181259 | 76,51055 |
| 24 | 20807817 | 236 | 0 | 47605,71219 | 11179149 | 221 | 139,2062222 | 41245 | Ул. Нижбекулы (с. Каргалы) | 43,17934 | 76,41485 |
| 25 | 20807817 | 236 | 0 | 47605,71219 | 11181160 | 285 | 53,36195159 | 46970 | Ул. Уалиханова (с. Каргалы) | 43,17959 | 76,40596 |
| 26 | 20807817 | 236 | 0 | 47605,71219 | 10040923 | 288 | 70,50352594 | 47707 | Гимназия №2 | 43,182237 | 76,399934 |
| 27 | 20807817 | 236 | 1 | 47822,95587 | 10040923 | 0 | 0 | 15 | Гимназия №2 | 43,182237 | 76,399934 |
| 28 | 20807817 | 236 | 1 | 47822,95587 | 11177138 | 123 | 48,69102033 | 11984 | Село Бакбакты Ашимова | 43,17351 | 76,48018 |
| 29 | 20807817 | 236 | 1 | 47822,95587 | 11173116 | 134 | 135,0899867 | 14787 | Спортивная школа "Кыялчыр" | 43,18193 | 76,512428 |
| 30 | 20807817 | 236 | 1 | 47822,95587 | 11169094 | 138 | 1,494840218 | 15581 | Музей "Атажекен" | 43,185294 | 76,520979 |
| 31 | 20807817 | 236 | 1 | 47822,95587 | 11167083 | 143 | 416,5421722 | 16803 | Больница (с. Шамалган) | 43,189835 | 76,534667 |
| 32 | 20807817 | 236 | 1 | 47822,95587 | 11161050 | 144 | 340,9738294 | 17353 | Ул. Макпалеева | 43,192568 | 76,540321 |
| 33 | 20807817 | 236 | 1 | 47822,95587 | 9220435 | 186 | 2,615889281 | 30454 | Ул. Майса (г. Каскелен) | 43,21677 | 76,657654 |
| 34 | 20807817 | 236 | 1 | 47822,95587 | 10063044 | 195 | 68,4013455 | 32582 | Село Алмалыбак | 43,213824 | 76,683475 |
| 35 | 20807817 | 236 | 1 | 47822,95587 | 1455964 | 196 | 2,805345886 | 32900 | Село Долан | 43,214225 | 76,687354 |

Figure 9. Merged flat data structure on public transport routes and bus stops

In the future, this flat Excel file will be utilized to visualize the routes of Almaty City using the Folium Python library.

## V. CONCLUSION

In this article, we reviewed existing smart city models from well-known companies such as the World Bank, Pwc and IDC. This study has provided valuable insights into the spatial aggregation patterns of urban population within Almaty City, Kazakhstan, through the utilization of a heat map methodology. By analyzing data on public transport routes and bus stops, we have gained a deeper understanding of how populations distribute throughout the city during different periods of the day.

The findings reveal notable variations in population density, with nighttime exhibiting significantly lower loads on the city compared to the bustling activity observed during lunchtime. This information is crucial for urban planners, policymakers, and stakeholders involved in the development and optimization of urban infrastructure, transportation systems, and public services.

Furthermore, the conversion of data into a structured format using Python and pandas has facilitated efficient analysis and visualization, laying the groundwork for future research and decision-making processes. The resulting flat Excel file provides a valuable resource for further exploration and modeling, particularly in the context of Smart City initiatives.

Moving forward, the insights gleaned from this study can inform targeted interventions aimed at enhancing the efficiency, sustainability, and livability of Almaty City. By harnessing the power of data-driven approaches and advanced technologies such as the Folium Python library, we can strive towards the creation of more resilient, inclusive, and vibrant urban environments for current and future generations.

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