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Spatiotemporal analysis of urban sprawling using change detection: a case study of Shaki district, Azerbaijan

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ABSTRACT

Introduction. The contemporary globalized world characterizes the rapid population growth, its significant concentration in cities, and an increase in the urban population. Currently, many socio-cultural, economic, environmental, and other challenges are arising in modern cities. Cities are therefore emerging from the common understanding and displaying new characteristics: reduced density, dispersed development, poor accessibility and monofunction. However, the concentration of population in cities also brings its own set of issues.

The purpose of article. The purpose of the study was to identify Shaki City's urban development process, and how its land use has evolved over time. It examines the population growth in the region and the increase in the specific weight of the urban population between 2016 and 2023, analyzing the population growth trend over a 20-year period. The direction and extent of urban land use has been studied by determining the relationship between the growth rate of the urban population and the extension of the urban area, and by analyzing the changes which have occurred during the period of land use.

Research methods. Statistical data has also been used for this purpose, together with data from the Azersky satellite. Machine Learning (ML), which is widely used in remote sensing systems, was applied, Support Vector Machine Learning (SVM), and image classification and processing were performed. On the basis of the obtained data, a comparative analysis of the previous and current conditions was carried out and the area of changes in the area between the classified areas was calculated. Simultaneously, the changes between categories during the use of the area and the recent changes in the direction of land use were shown. Classification performance has been assessed, user and producer accuracies have been determined and kappas have been calculated.

Main findings. The increase in the population of the Shaki district led to an increase in the specific weight of the urban population and the extension of the town to the south and south-east where the population previously lived sparsely. It is mainly due to construction of new housing estates in region, as well as construction of a central clinic, an ASAN service, and a regional education division. A 'flight to the centre' was observed, resulting in noticeable changes in the land use structure between 2016 and 2022, in line with the growth rate of urbanisation and economic development. The decoding of the distribution images of the region shows that there has been an increase in the area of settlements over the six-year period. By 2016, settlements cover 22.4 per cent of the city, and by 2022, the figure rises to 39 per cent. From 34% to 32.9%, the total area of forest reserves decreased.

Scientific novelty and practical value The article describes for the first time the urban sprawling and territorial transformations in Shaki district in the context of population growth by using change detection analyses. The practical value of the study is the possibility of using its algorithm and method to conduct similar studies in other cities of Azerbaijan. The results of the study are significant in the context of justifying regional measures to adapt urban expansion to population growth.

Keywords*: urbanization, Shaki city, Azersky, kappa coefficient, population growth, spatial planning, land use, change detection, urban sprawling.*

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Introduction

Today, the process of urbanizing the world is resulting in sprawl development, which is gradually becoming a concern for researchers and planners. In recent years, the rate of urbanisation has accelerated and it is expected that by 2050, two thirds of the world's population will be living in metropolitan areas [4]. More than half of the world's population will live in cities, and this will be unevenly distributed across the world [13]. Cities are therefore emerging from the common understanding and displaying new characteristics: reduced density, dispersed development, poor accessibility and monofunction. However, the concentration of population in cities also brings its own set of problems. This raises questions about limited natural resources, food availability, transport and energy. While all this is happening, land use is being affected, so the problem of diminishing land reserves has arisen in parallel.

Population growth and the implementation of 'regional development programmes' are commonly understood to be an expansion of the general area of the city. Statistics show that the urban population accounted for 40 per cent of the district's population in 2000, 38 per cent in 2015, and 36,8 per cent in 2023 in the Shaki city [7]. These trends show that urban expansion is driven by total population growth rather than urban population growth. Therefore, their distribution in a particular city and the relevant spatiotemporal dynamics should be a prime concern for municipalities and planners.

The novelty of the present research is to study the expansion area of the city with the increase in population in the Sheki region. Nonetheless, representative relevant research based on digital tools and technologies has not been accomplished for any urban territory in Azerbaijan yet.

1.1 Literature review

Research on urban sprawl has been in existence since the 1960s and the term "urban sprawl" was first proposed by Whyte [33] in 1958. The process of urban sprawl began in France in the 1960s and is now spreading to the outskirts of cities, regardless of their size, as economic growth continues.

In the early 21st century, governments at all levels greatly accelerated urban sprawl by investing heavily in transportation and other public facilities [5]. There are a number of approaches to urban sprawl, and most research focuses on four aspects. The first aspect is the delimitation of urban sprawl [31]. Whyte [33] defined urban sprawl as the therapeutic development of suburban areas. Anderson etc. [1] divides urban sprawl into the following categories by characterizing it as the separation of the residential area from other land uses due to its location on the outskirts of the city:

a) General reduction of land use intensity;

b) Developed transport network;

c) Expansion of city boundaries.

Summarizing the mentioned ideas, expansion: low density, inaccessibility, scattered development, and functional inefficiency are manifested.

The second aspect is the measurement of urban sprawl. Two types of metrics are commonly used to measure urban sprawl, a single index, and a composite index method to measure multidimensional aspects of sprawl. The most popular single index is the sprawl index, which was used to measure the sprawl ranking status of metropolitan areas in the United States in 2000 (SI) [22]. Ewing et al. [11] used principal component analysis to examine 22 highly correlated variables, from which he formed four factors: residential density, the extent of land use, the intensity of economic centers and urban centers, and accessibility of neighborhood networks.

Later, new measurement models were developed by adding other factors to measure the spreading coefficient. Torrens [30] measured urban sprawl with seven aspects, including urban growth, with a total of 42 factors. The composite index method also includes a dynamic model, spatial model, measurement model, statistical model, and integrated model. Zhou et al. [34] investigated the factors influencing vertical urban expansion by building regression models from the perspectives of government, developers, and residents. Das and Angadi [6] combined spatial landscape metrics and the Shannon entropy model to analyze the spatial assessment of urban sprawl.

The third aspect is the study of the factors influencing the expansion of cities mainly from two aspects: natural conditions and socio-economic conditions. Wang et al. [31] studied urban decentralization and urban renewal as socio-economic factors behind urban expansion. Fan and Zhou [12] believed that the expansion of fiscal competition among governments in cities, competition for investment, and competition for environmental promotion are factors that positively influence cities. Multiple scenario simulations were used to explore the potential impact of population growth and job sector expansion and planning on urban growth [8,16]. Based on the model of least resistance, Guan et al. [15] simulated urban expansion conditions under different scenarios considering resource level, environmental barriers, environmental resistance, and urban expansion, and made suggestions to guide sustainable urban development. Morar et al. [23] developed and used an original integrated approach using urban remote sensing (URS) and GIS for changes detection to evaluate the current state and monitor spatial transformations of the Urban Green Areas and found out UGAs were not expanding and partially shrinking during 2000-2020 in Kharkiv, Ukraine.

Niemets et al. [25] analyzed the current state and prospects of the world cities in terms of the sustainable development concept, identified opportunities, threats, strengths and weaknesses of the world cities, determined the role of cities in the contemporary global world and consider further research of the world's cities. The authors noted that highly developped cities have more chances to quickly implement the sustainable development concept compared to medium-sized cities due to larger financial resources. Gavrilidis et al. [14] used hierarchical analysis to evaluate green space proposals in urban areas and proposed a methodological framework for controlling urban sprawl. Menzori et al. [24] argued that governance capacity affects the geographic location of urban growth and in turn the level of urban expansion. Tan et al. [29] concluded that innovation policies do not promote urban sprawl.

Research on urban sprawl is comprehensive and covers diverse areas such as quantity, mechanism, impact, and regulation [19]. The concepts put forward in these studies are mainly in the direction of the expansion of cities with the provision of social economic development, the creation of new jobs, and the improvement of the quality of life. Ensuring regional and local development is based on the principles of proper planning of the territory. The main issue is that the scarce territory and land should be taken according to the above-mentioned requirements. The size of the city affects population growth, and as a result, the expansion of the city takes place. In other words, urbanization and the expansion of the city should be dealt with in a complex way.

1.2 Previous studies

A brief analysis of previous research demonstrates the considerable attention to studying the specific aspects of the land cover in Azerbaijan have mainly focused on the use of supervised remote sensing maximum likelihood classification methods using Landsat 5 and 7 TM satellite images of 1998 and 1999 [17,21]. However, the results of the studies are not available for comparative analysis. In particular, Bayramov [3] conducted a study on land use and changes in land resources in the Republic, mainly observing the increasing and decreasing trend of forest cover and greenery in 2014-2015 (Landsat 8) green areas functioning.

Most of the studies conducted have focused on changes in forest cover and historical periods, and have not considered urban sprawl and its scale. The aim of this study is to have a better understanding of the urban development process of Shaki City and the evolution of its land use over time. In terms of the content of the research, the following questions have been proposed to fill the scientific gap: What is the relationship between population growth and urban sprawl, and what changes have occurred in the district in terms of land use?

2. Material and Method

2.1 Study area

Shaki district is one of the largest regions of the Republic of Azerbaijan with a total area of 2488 km2 (Figure 1). It is bounded by the Republic of Dagestan of the Russian Federation to the north, Oguz District to the east, Yevlak District to the south and Gakh District to the west.

Shaki belongs to the group of medium-sized cities, lagging behind Baku, Sumgait and Ganja as regards its level of social and economic development

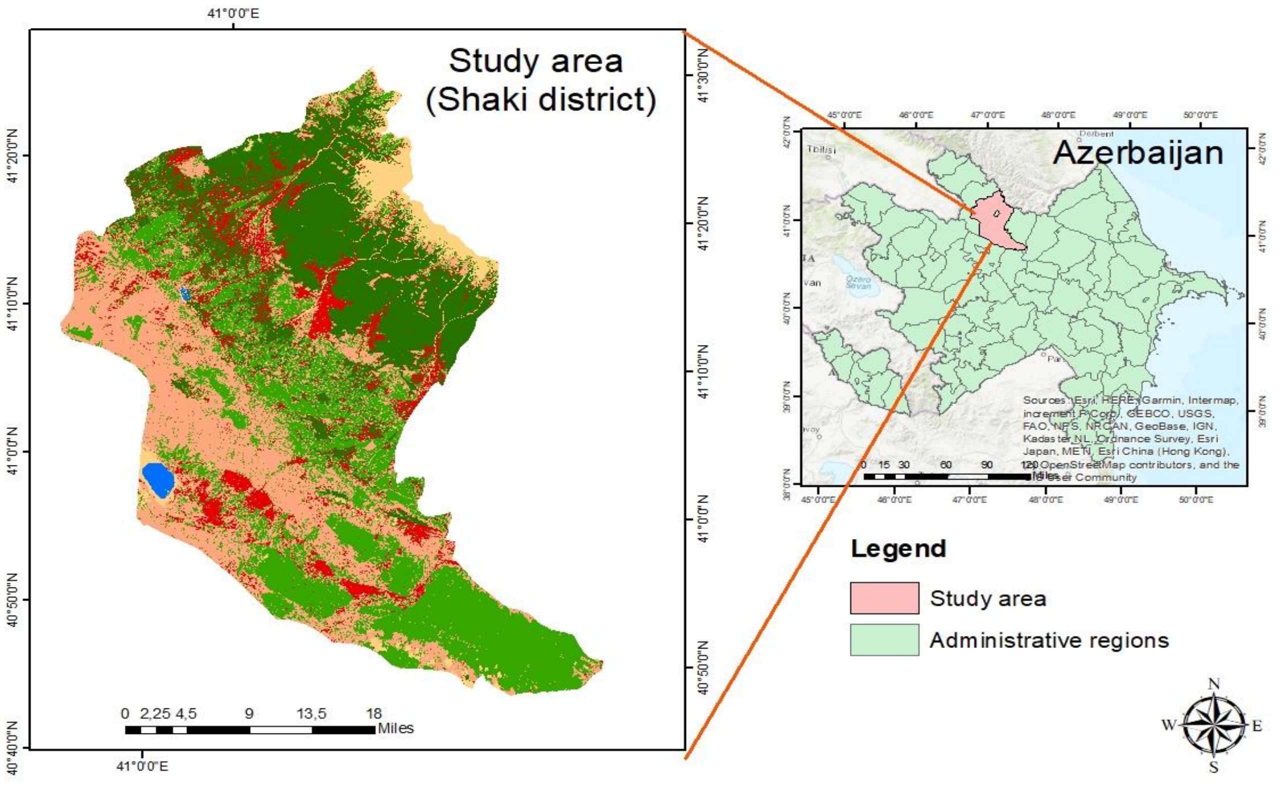

Fig. 1. The area of research

and population [9]. Nevertheless, in the classification of cities, Shaki is considered to be a regional urban center. However, recently it was removed from the group of medium cities and included in the group of big and large cities due to the increase in population, formation of large industrial areas and multi-sectoral industrial structure [10].

2.2 Data analysis

First of all, let's look at the statistical indicators of the district in order to measure the level of urbanization in the region and determine the expansion area of the city. The indicators of the population of Shaki for the years 2010 and 2020 have been taken from the database and calculations have been performed using them. It should be noted that the 2020 information is of an intermediate nature and does not reflect the most recent statistical information, as the population census was conducted twice (1999 and 2009) [26,28].

In the period 2010-2020, the population of Shaki district is on the increase. Thus, in 2010 the population was 173.5 thousand persons, in 2015 this indicator reached 182.7 thousand persons, and in 2020 it will reach 189.1 thousand persons, representing an increase of 3% over the previous year [7]. The population growth rate has fallen sharply over the same period. By 2020, the number of inhabitants will have decreased by 53 per cent, from 1,852 to 864. Furthermore, the growth rate of the population per thousand inhabitants decreased from 10.2% to 4.6%. Conversely, the difference between births and deaths is decreasing. In 2015, there were 3 003 births and 1 151 deaths in the region. In 2020, the interval between them gradually decreased, the number of births reached 2208, and the number of deaths reached 1344 people, which is a factor that directly affects the natural growth of the region (Fig 2).

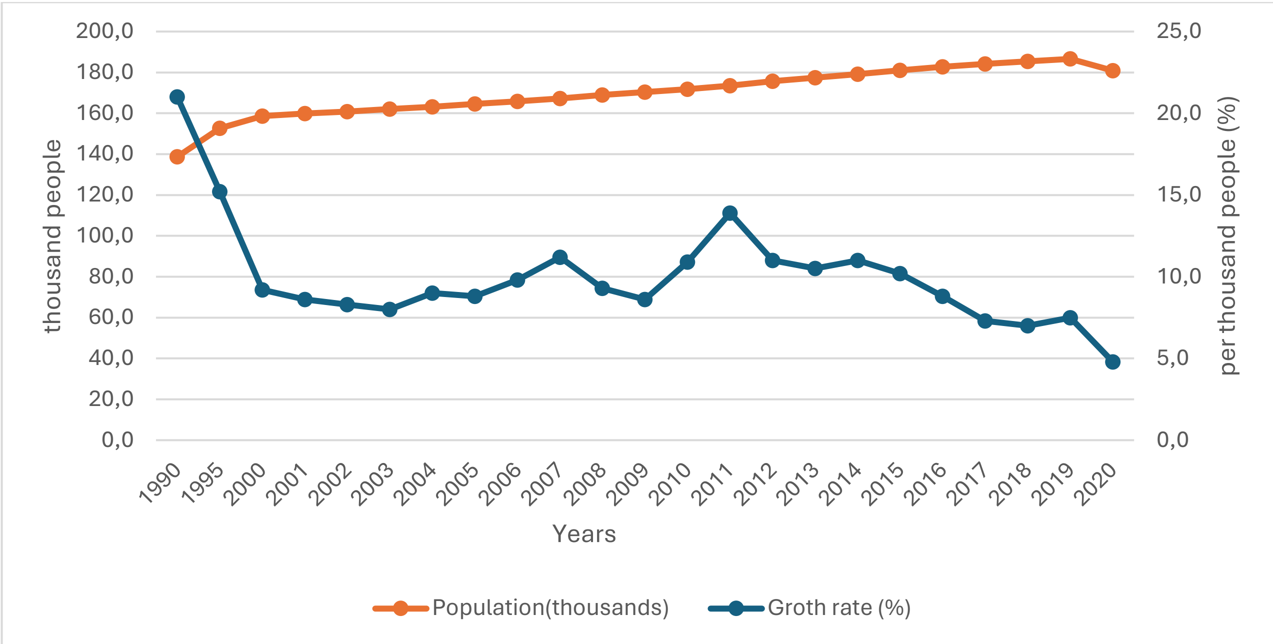

Fig. 2. Population growth indicator of Shaki region over the years (thousands of people) growth rate 4.6 % (per thousand people) Source: Prepared based on statistical data [7,28]

Villages and settlements make up the majority of the population of the region. According to the growth rate, Shaki region has been undergoing the process of construction of new housing estates, commissioning of service facilities and opening of new jobs. Currently, the expansion of the city and the corresponding changes in the use of the territory are taking place.

2.3 Method

The main method of the research is the remote sensing and Geospatial Information System (GIS) techniques that are operated on the basis of satellite images (Table 1) and their processing. The aim of these techniques is the classification and mapping of the land use/land cover of the study area, and the evaluation of the accuracy of the classification procedures to determine how well they have been carried out and also to understand how to interpret the utility of the classification. This study was carried out with ArcGIS Pro, version 2.8.4. The following methods have been used in the research:

-Inductive and deductive methodologies (for the logical understanding and processing of available data and information on the city, its condition, role and changes).

-Benchmarking method (the author used this method at almost all stages of the study for the determination of the current state of the city and the comparison of their development levels).

-Visualisation technique (the author used this technique in combination with the graphical technique to visualise the dynamic changes in LULC for different time scales).

-Content analysis method (to analyse the spatial changes and transformations of Shaki's urban sprawl through the use of support vector machine (SVM)).

The sequence of the process and the development methodology are carried out in Figure 3. Although the approach is the same, some parameters and/or additional calculations may be performed later. It depends on the number of data used, the indicators of the parameters, and the applied methods [2].

For this purpose, the Azersky satellite was used, and supervised classification was performed using the SVM method. The aforementioned SVM (support vector machine) method is considered the highest level of machine learning (ML) and is often used in

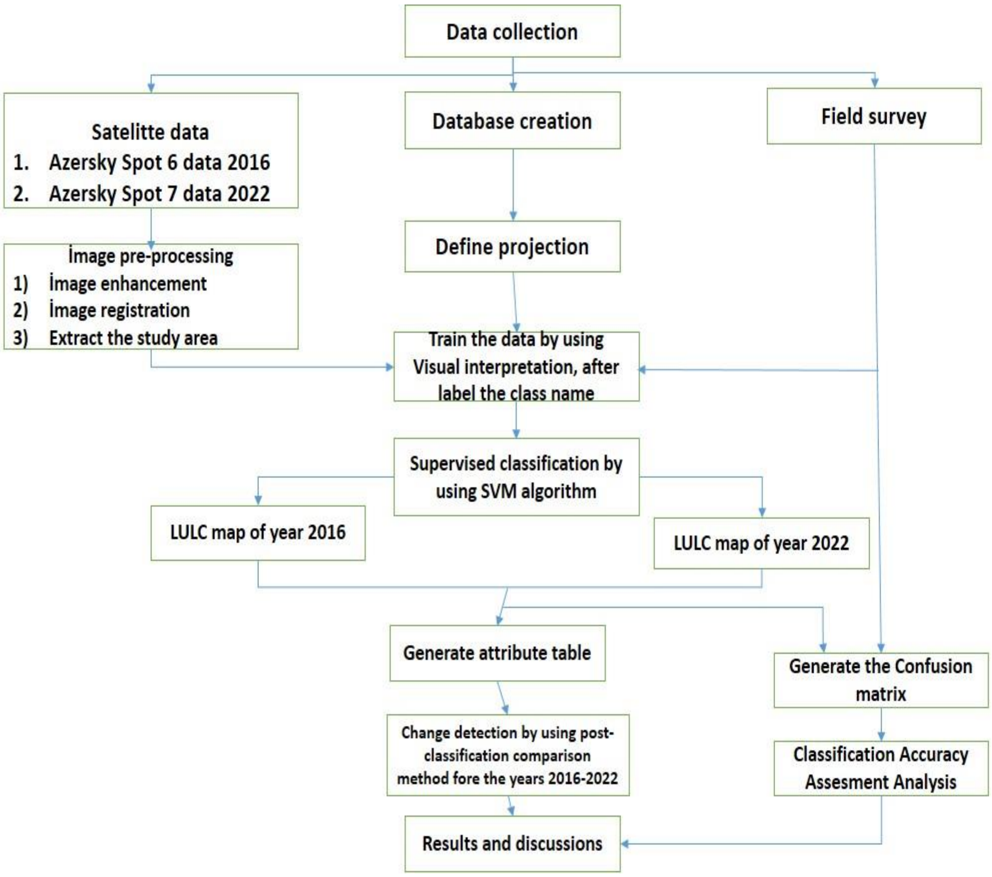

Fig. 3. The methodology and sequence of the satellite image decoding

Table 1

Satellite images were used. Source: Satellite images provided by Azercosmos to support scientific research

Name	Achieved	Name of Platform	Type	Band number
Azersky	2016	SPOT6	Orthophoto	4
Azersky	2022	SPOT7	Orthophoto	4

the process of processing satellite images. The classification of the obtained data was carried out in the following way:

- *Settlement*: it includes residential areas of the population, social infrastructure areas, transport infrastructure and its units, industrial enterprises, and agricultural production areas;
- *Forest*: Greenery, park areas, trees, and bushes in backyards were classified as forest areas during image processing;
- *Bareland*: Areas classified as low productivity, areas with no vegetation or broken areas, temporarily formed due to the reduction of the flow area of rivers and not suitable for any agricultural area, are included in this category;
- *Agriculture*: This category includes agricultural fields and vineyards around the city;
- *Water*: Classification of the river flowing in the city of Shaki was carried out.

3. Results and Discussion

3.1 Analysis of classification results

After deciphering the distribution images obtained in the region, it can be seen that there have been significant changes in the share of individual areas in the general area (Fig. 5). Thus, the area of the settlements began to increase in the six-year period.

In 2016, residential areas (including residential areas, social infrastructure areas, industrial enterprises, and buildings) covered 22.4% of the city, and in 2022, this indicator increased by 39% (Table 2). However, during classification, some areas such as football pitches, airport grounds, and outdoor sports fields are classified as residential areas. However, these areas can also be considered fallow areas and agricultural areas.

Although GIS information systems are considered an important planning tool in spatial planning, they cannot explain change or substitution in detail. Thus, the physical changes occurring in the area are explained by social and economic processes along with geographical components. For example, it can be justified by the measures taken within the framework of the "Social and economic development of Regions" State program implemented in the region during the years 2016-2022, including the newly commissioned facilities and service areas.

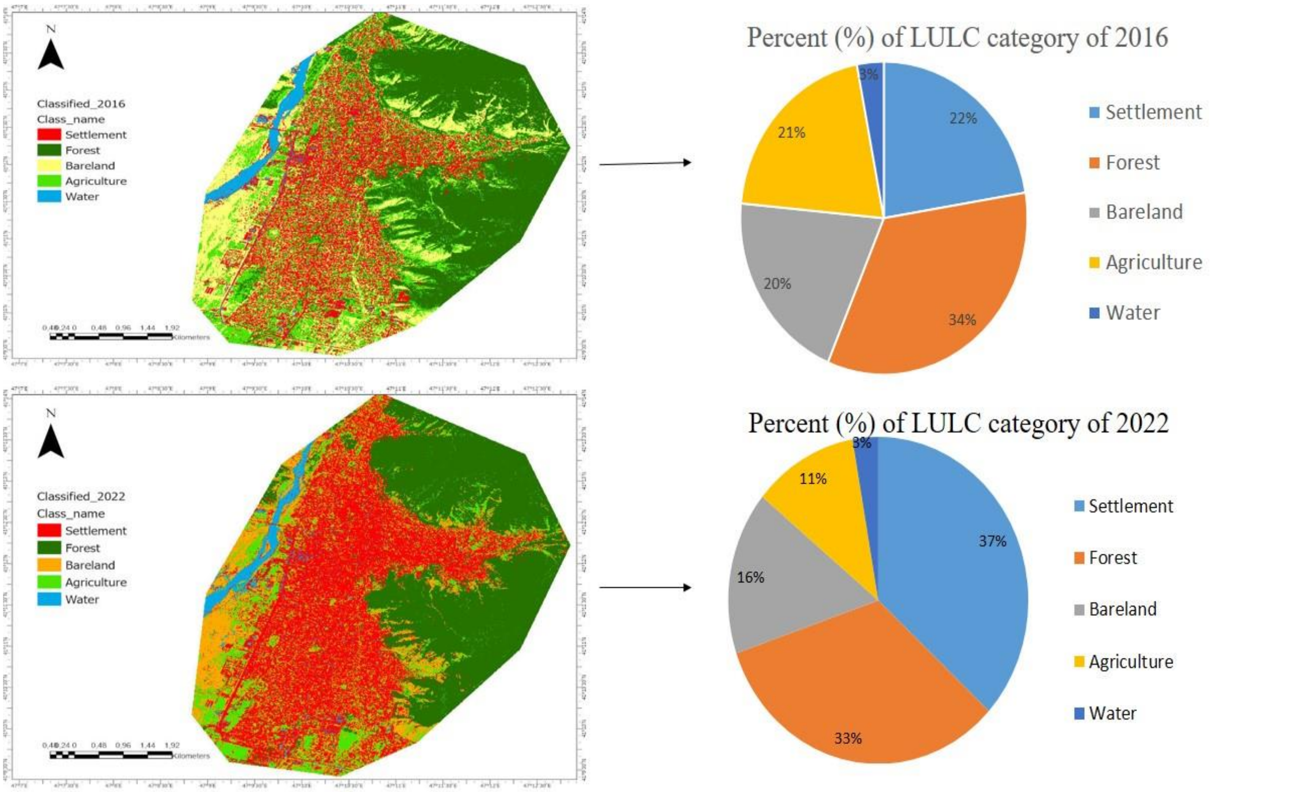

Fig. 4. Satellite images of the Shaki region in 2016 and 2022.
An image decoded using the SVM method by the author Discussion

A reduction in the total area of forest reserves is observed. So, if forests covered 34% or 1105 ha of the total area in 2016, in 2022 this number has sharply decreased to 32.9% in urban and surrounding areas. In the decoding of the forest area in the study region, the classification according to the category of sparse and dense forest was not carried out and it was evaluated as a single forest area.

A decrease in the extent of arid and unusable areas was recorded in the city of Shaki. In 2016, these areas, which were 654.4 ha, covered 20.1% of the city, but in 2022, this indicator decreased sharply to 128.9 ha, which constituted 16.2% of the area. One of the factors affecting the increase and decrease in the area of wasteland is the recent decrease in the water level of the river flowing in the region, resulting in the formation of areas in the form of small fields, which have been recorded in dry areas or unused areas.

On the other hand, as a result of the social economic development programs of the regions, the provision of gas to the population in the area has been accelerated and a large part of the gas needs of the region has been completely met, as a result, the destruction of forest resources has been prevented. In areas classified as unusable and arid, there is a decrease in the total share of arid areas due to the natural formation of bushes. In the indicated period, the number of areas without wounds decreased by 20%.

The most serious change in the use of the territory was recorded in agriculture. Thus, a decrease in the agricultural use of the territory is seen during the years 2016-2022. The general indicators of agriculture, including arable land, were 665.4 ha in 2016, and decreased to 367.6 ha in the next six years. This means a 45% or 297.8 ha decrease in the mentioned period.

There was no significant change, replacement or decreasing trend in the total area of water basins. In 2016, the area of the river flowing in the urban area was 3% (98 ha), but in 2022 these indicators were

2.8% (89.6 ha), which is quite weak and not to an appreciable extent.

3.2 The extent and direction of change

During the use of the area in the Shaki region, a transition or change between areas was observed. *Figure 5* shows the categorical change, which shows the transition of land use in which sector to which sector during 2016-2022 after classification. No changes have been recorded in the areas shown in white on the map, and the areas that have changed are marked with color intensification. Although you see a transition in all areas, except for the sharp change in the above-mentioned areas, the changes in other categories are insignificant or negligible.

Table 2

Quantitative indicators of land use (2016-2022)

No	Class name	2016		2022	
		Area(ha)	% of area	Area(ha)	% of area
1	Settlement	727,7	22,4	1196,7	36,8
2	Forest	1104,7	34	1071	32,9
3	Bareland	654,4	20,1	525,5	16,2
4	Agriculture	665,4	20,5	367,6	11,3
5	Water	98	3	89,6	2,8
Total		3250,2	100	3250,4	100

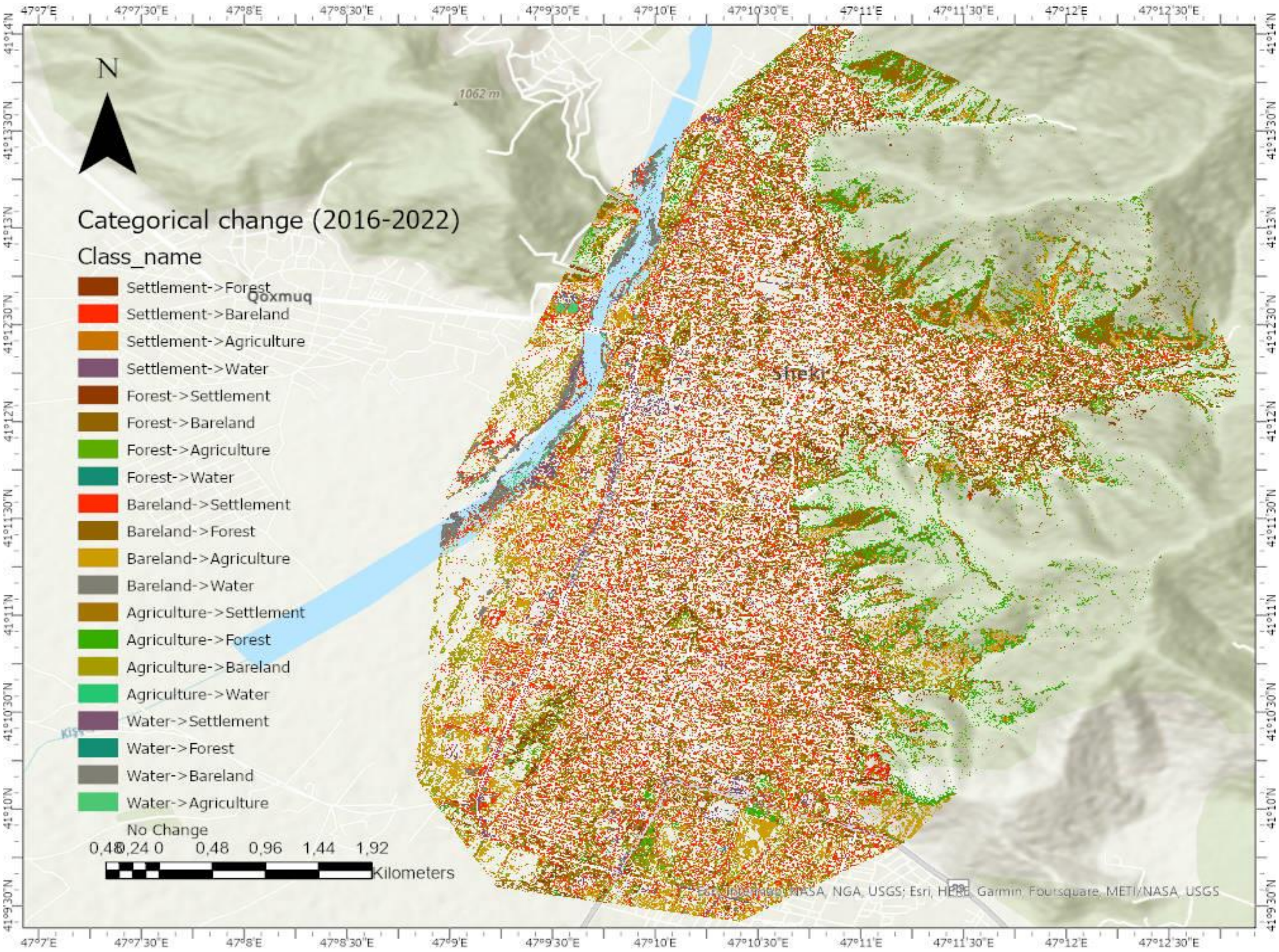

Fig. 5. Areas that have changed and remained stable during the use of land in Shaki district (2016-2022)

3.3 Performance Evaluation and Accuracy Analysis

Accuracy assessment is considered the last step in the data analysis in the remote sensing method, which allows you to check how accurate the obtained results are and is carried out after the decoding of satellite images. The main goal here is to evaluate the accuracy of the thematic maps or classified images known as asthmatic or classification accuracy. During the accuracy analysis, 100 points were determined by the Random Forest method in the classified area, its user (UA) and producer accuracy (PU) were calculated, and the average accuracy and Kappa effect value for the area were obtained. For this, a confusion matrix (Table 3) has been constructed for the area.

3.3.1 Confusion and Error Matrix

A confusion matrix is a multiple array of rows and columns used to evaluate the accuracy of a processed image. It has a two-dimensional structure, where rows represent reference data and columns represent classified data. The manufacturer's accuracy is defined as the probability of correctly classifying any pixel in that category [27] (Equation 1).

For example, the water category in Table 3 has an accuracy of 0.93, which means that about 93% of the pixels in the watershed classification appear as classified water pixels.

After the user accuracy is calculated (Equation 2), we can see that the forest cover areas are correctly classified (Table 3). The general accuracy analysis is expressed as follows (Equation 3).

The average accuracy after classification was found to be 0.88% (Table 3), indicating that the land use map was correctly classified in 88%.

$$\text{Accuracy (Producer's Accuracy)} = \frac{\text{Total number of correct pixels in a category}}{\text{Total number pixels of that category derived from reference data}} \quad (1)$$

$$\text{Accuracy (User's Accuracy)} = \frac{\text{Total number of correct pixels in a category}}{\text{Total number pixels of that category derived from reference data}} \quad (2)$$

$$\text{Overall Accuracy} = \frac{\text{Sum of the diagonal elements}}{\text{Total number of accuracy sites (pixels)}} \quad (3)$$

Table 3

Confusion Matrix obtained from classification

Class Value	Settlement	Forest	Bareland	Agriculture	Water	Total	U_Accuracy	Kappa
Settlement	19	0	0	0	1	20	0,95	0
Forest	0	20	0	0	0	20	1	0
Bareland	2	0	18	0	0	20	0,9	0
Agriculture	0	2	0	18	0	20	0,9	0
Water	6	0	1	0	13	20	0,65	0
Total	27	22	19	18	14	100	0	0
P_Accuracy	0,703704	0,909091	0,947368	1	0,928571	0	0,88	0
Kappa	0	0	0	0	0	0	0	0,85

3.3.2 Kappa analyses

Error and Confusion matrix is a discrete multivariate method used to evaluate classification accuracy. Kappa analysis produces a kappa coefficient, or K_{hat} statistic, with values ranging from 0 to 1. The kappa coefficient (K_{hat}) is a measure of agreement between two maps that takes into account all elements of the error matrix[18] and is defined by the following equation(4):

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x + Xx_{+1})}{N^2 - \sum_{i=1}^{r}(x_{ii}\, Xx_{+1})} \quad (4)$$

where;

r = number of rows and columns in error matrix, N = total number of observations (pixels)

X_{ii} = observation in row i and column i,

Xi+ = marginal total of row i, and X+i = marginal total of column i

Looking at the Kappa coefficient after the classification of satellite images, we see that this number is equal to 0.85 (Table 3) and according to the rating criteria (Table 4) it is quite high and considered near perfect[19].

Table 4

Ranking criteria of Kappa statistics

No	Kappa statistics	Strength of agreement
1	<0.00	Poor
2	0.00 - 0.20	Slight
3	0.21 - 0.40	Fair
4	0.41 - 0.60	Moderate
5	0.61 - 0.80	Substantial
6	0.81 - 1.00	Almost perfect

Conclusion

The achieved overall accuracies for the land-cover classification for 2016 and 2022 were 85 %. They were considered sufficient for land-cover quantification and change detection analyses. The supervised classification was performed using SVM method. The images were classified into five classes; Agriculture (367,6 km2), water body (89,6km2), built up areas (1196,7 km2), mixed forest (1071 km2), and Barren/bare land (525,5 km2). Settlement was the dominant type of Landuse classified which covers about 37% of the total study and rised up 469 ha. At the same time, agricultural land has decreased by 297.8 ha, which could pose a problem for supplying the city with food.

The research questions above are fully explained by the results obtained. To explain *the first question*, population growth in the region has a positive correlation with urban growth. As the population has grown, the number of new buildings has risen, and this growth has occurred at the expense of Bare land, agricultural land and woodland. The expansion of the city continued, although the population did not rise dramatically. And the extension of the town to the south and south-east where the population previously lived. It is mainly due to construction of new housing estates such as Central clinic, an ASAN service, and Regional education division within “Social and Economic Development of Regions” State programs.

The *second part of the study's task* has been the identification of changes that have taken place in the district in terms of land use. For this purpose, the land use/land cover of the study area was classified and mapped using remote sensing and GIS techniques and change detection analysis, and the accuracy of the classification procedures was evaluated to assess their performance. The research shows that as a result of the 'flight to the centre', people have gathered in the suburban areas, noticeable changes have occurred in the land use structure between 2016 and 2022. This resulted in a decrease of 33.7 ha, 128.9 ha and 297.8 ha in woodland, bare land and agricultural land respectively.

The available satellite images for the study area cover only two years. This is not enough to predict the future. Also, the borders of the city itself (city area) are not specifically defined. That is, during the research, it was analyzed together with the surrounding villages, including Okhut, Kish, Gishlag. When the aforementioned is fully provided, it is possible to make accurate calculations on the growth index (SI) of the city, and for this, more information is needed.

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Просторово-часовий аналіз розростання міст із використанням виявлення змін на прикладі Шекінського району Азербайджану

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Сучасний глобалізований світ характеризується стрімким зростанням населення, його значною концентрацією в містах, збільшенням міського населення. Нині в сучасних містах постає багато соціокультурних, економічних, екологічних та інших викликів. Таким чином, міста виходять із загального розуміння та демонструють нові характеристики: знижена щільність, розосереджена забудова, погана доступність і монофункціональність. Однак концентрація населення в містах також приносить свої проблеми. Метою дослідження було визначити процес міського розвитку міста Шакі та те, як його землекористування змінювалося з часом. Досліджується приріст населення в регіоні та збільшення питомої ваги міського населення між 2016 і 2020 роками, аналізується тенденція зростання населення за 20-річний період. Напрямок і масштаб міського землекористування вивчали шляхом визначення зв'язку між темпами зростання міського населення та розширенням міської території, а також шляхом аналізу змін, що відбулися протягом періоду землекористування. Для цього також використовувалися статистичні дані, а також дані супутника Azersky. Було застосовано машинне навчання (ML), яке широко використовується в системах дистанційного зондування, було виконано машинне навчання опорних векторів (SVM), класифікація та обробка зображень. На основі отриманих даних проведено порівняльний аналіз попередніх і поточних умов і розраховано площу зміни площі між класифікованими територіями. Одночасно показано зміни між категоріями під час використання території та останні зміни у напрямі використання землі. Було оцінено ефективність класифікації, визначено точність користувача та виробника та розраховано каппа. Збільшення населення Шакінського району призвело до збільшення питомої ваги міського населення та розширення міста на південь і південний схід, де раніше населення проживало мало. В основному це пов’язано з будівництвом нових житлових масивів в області, а також будівництвом центральної поліклініки, служби АСАН, обласного управління освіти. Спостерігалася «втеча до центру», що призвело до помітних змін у структурі землекористування між 2016 та 2022 роками відповідно до темпів зростання урбанізації та економічного розвитку. Розшифровка розподільних знімків регіону показує, що за шестирічний період відбулося збільшення площ населених пунктів. До 2016 року населені пункти займають 22,4% території міста, а до 2022 року – 39%. З 34% до 32,9% зменшилась загальна площа лісо-заповідного фонду. У статті вперше описано урбаністичні та територіальні трансформації Шакінського району в контексті зростання населення за допомогою аналізу виявлення змін. Практична цінність дослідження полягає в можливості використання його алгоритму та методики для проведення аналогічних досліджень в інших містах Азербайджану. Результати дослідження є значущими в контексті обґрунтування регіональних заходів адаптації розширення міст до зростання населення.

Ключові слова: *урбанізація, місто Шакі, Azersky, коефіцієнт Каппа, зростання населення, просторове планування, землекористування, виявлення змін, розростання міст.*

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