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ORIGINAL RESEARCH PAPER

Investigation of spatial-physical development model based on spatial analysis, GIS and Holdern entropy model

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ABSTRACT

BACKGROUND AND OBJECTIVES: Irregular and unplanned development of cities has led to some difficulties with the natural environment and human well-being reflected in the inappropriate spatial structure. Perception of physical-spatial pattern leads to the invention of appropriate policies to equitable distribution of services in urban areas and achievement of balanced development. This study aims to analyze the physical-spatial pattern of the Mashhad City from 1986 to 2016 conducted based on GIS data of the census blocks of Mashhad.

METHODS: The current study was performed using descriptive-analytical method. In order to achieve that, spatial statistics tools including Moran coefficient, hotspots and directional distribution (standard deviational ellipse) have been used on ArcGIS PRO 2.5 software as well as Holdren model. Population is one of the prominent variables affecting growth and physical-spatial development of the city, therefore, the population has been considered as an indicator in this research.

FINDINGS: The obtained values of the Moran Index (1986=0.13, 1996=0.14, 2006=0.15, and 2016=0.15) represented that the population pattern of the city was clustered, compact and continuous. Likewise, Hotspots revealed high population density in the continuous area from east to northwest in addition to the neighborhoods around the Vakil Abad highway. Standard deviational ellipse of population illustrated that the population distribution was heading to northwest. Applying Holdren model and data analysis showed that Mashhad experienced the horizontal and sprawl growth.

CONCLUSION: Obtaining balanced future development and avoiding unplanned encroachment of the city boundary are integral issues. As a result, the current and legal city limit must be maintained and inner development and compact pattern must be implemented.

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INTRODUCTION

In recent decades, cities, in particular metropolises, have developed unprecedentedly. In many cases, the physical growth outweighs the population one, so that the ratio of increased area exceeds the ratio of increased population. Therefore, the fertile agricultural lands are being swallowed up by physical development of cities (Noori Nejad *et al.,* 2016). As a result, the rapid growth of metropolises in both on scale and size culminates in the instability of urban life (Maleki, 2018) and the complexity of managing urban growth has become one of the most important challenges of the 21st century (Cohen, 2004). Amid the increase of population, cities expand invariably, so city limits and its physical space develop quantitatively and qualitatively (Ibrahim Zadeh and Rafi'I, 2009). Urban growth is a complex and dynamic process, moreover it involves changes in physical and functional components of built environment (Sahana *et al.*, 2018) and is affected by various indicators such as economy, society, nature, management etc. Unplanned urbanization leads to large-scale changes in land use affecting the sustenance of natural resources. Monitoring the development of the city necessitates an understanding of spatial patterns of urbanization to implement appropriate mitigation measures (Aithal and Ramachandra, 2020). In general terms, development means gradual flourishing, revealing the components of everything and the growth of something that exists, a relative attribute which is defined over time in a specific place (Papoli Yazdi and Rajabi Sanajerdi, 2017). In other words, moving from the current situation to the one in which more opportunities and facilities are provided to sharpen the society (Javaheri Taghados *et al*., 2019). Physical expansion is described as a rise in quality and quantity of uses and physical spaces of a city in the horizontal and vertical directions over time (Bemanian and Mahmoodi Nezhad, 2008). The horizontal physical development encroaches the non-urban spaces around the city, therefore it deals with one of the most limited resources named land which is available to human beings (Gherekhlu and Zanganeh Shahraki, 2009). On the other hand, the spatial development is the embodiment of human's determined and sensible effort or their arbitrary effort in response to their needs in society (Massumi Eshkevari, 2006) and the quantitative and qualitative improvement of urban life so without considering the multi-faceted policies such as physical, social, economic and political aspects and reinforcement of which, this kind of development will be impossible (Abdi Daneshpour, 2017). Anderson *et al.* (1996) possessed the conviction that physical and spatial developments were essential and defined urban form as the spatial pattern of human activities at a certain point in time. Therefore, the physical-spatial development can be interpreted as a process of physical growth, transformation of uses and urban activities and changes in urban per capita to meet citizens' needs (Hatami Nezhad *et al*., 2012). The physical-spatial development might occur not only horizontal (decentralized and scattered growth) but also vertical (concentrated and compacted) (Tsai, 2005) or even the mixture of both. These patterns depending on the type of expansion they create in the city result in denser use of urban space or encroachment of non-urban space which transform the urban environment as well as surrounding countryside. Urban sprawl is described as a specific form of urban development with low-density, dispersed, auto-dependent and environmentally and socially-impacting characteristics (Hasse and Lathrop, 2003) which expands towards the margins of the city and countryside (Wassmer, 2002). As a result, vast areas of agricultural and natural lands around the city will convert and urban per capita will increase. Almost all theories about urban distribution point to the uncontrolled use of land and the uncontrolled expansion of cities in this type of development, from theories that considered the horizontal expansion of the city as a solution for future cities in response to population demands to theories Which is considered it as an unplanned and uncontrolled spatial growth (Table 1).

Harvey and Clark (1965) suggested three main types of urban sprawl patterns: ongoing scattered development with low density in large parcels, linear development (mostly non-residential activities) alongside the major highways and leapfrog development which forms nearby available areas in vacant lots close to the city. All of the types are subject to automobile and citizens have to bear the long distance (type 1 and 3) and heavy traffic (type 2). The vertical expansion or compact development was originated from Le Corbusier's idea of a radiant and contemporary city. The idea of compact city aims to enhance the quality of life, create cities

Table 1: Urban sprawl characteristics

Theorists	characteristics
Mouratidis (2017)	Low-density development can offer quietness, access to nature, higher perceived safety and cleanliness, and stronger neighbor ties
Bramley and Power (2009)	Urban sprawl can decrease land and dwelling prices, cause reduce congestion in transport
Menon (2004)	Scattered and self-reliant expansion outside of urban dense centers and around highways and suburbs
Nozzi (2003)	Unscheduled, low-density and intermittent development and functionally not connected to uses around the city
Wassmer (2002)	Low-density and scattered development to outside of the city limits and suburbs based on car
Peiser (2001)	Improper and inefficient use of land, uniform, fragmented and leapfrog development
Hadly (2000)	City expansion towards the margins and villages or alongside the motorways in an unplanned and uncontrollable way
Brueckner (2000)	The necessity for spatial development to accommodate population increase
Ewing (1997)	A partly new pattern in human settlements resulting from the aggregation of low-density, auto-dependent residential units
Doxiadis (1968)	Ecumenapolis as a horizontal city with low population density and a continuous system of buildings and neighborhoods in a universal biological complex
Lloyd Wright (1932)	Low population density as a suitable environment for the American society

with high density without the difficulties of modern ones (Newman and Kenworthy, 1989). With the introduction of sustainable development, this pattern was considered and became one of the ways of achieving 'sustainable urban development' (Jenks and Burgess, 2004). The compact form not only maintains the rural lands around the city but also reuses and optimizes the lands inside of the city (Seif Aldini *et al*., 2012). Compact city approaches define as; to increase built area and residential population densities; to intensify urban economic, social and cultural activities and to manipulate urban size, form and structure in pursuit of the environmental and social sustainability benefits (Jenks and Burgess, 2004). There are numerous viewpoints on concept of compact city that majority of theorists agree on concentrated development (Tsai, 2005) (Table 2).

Horizontal and vertical development is a relative concept, in the real world the urban development is not purely horizontal or vertical and the combined form of urban development is close to reality (Hatami Nezhad *et al*., 2012). The physical-spatial development is a complex system of physical, economic, social and environmental aspects. This type of development occurs due to different parameters such as distance from centers and workplaces and residential areas, access to communication networks, population density, land use zoning status, infrastructure development, the ratio of urban lands to undeveloped lands in neighboring areas, topography and natural disasters and economic factors (ownership rate, lease, per capita income, employment rate, poverty, etc.). Table 3 describes the factors affecting the physical-spatial urban development from the perspective of experts.

Cities must develop physically and spatially to accommodate the population increase therefore, the physical-spatial development is influenced by the changes, distribution and density of population. As a result of population increase, changes occur in the use of urban land and surrounding areas in order to meet the population's needs. Urban development is a complicated dynamic process, which involves various physical, social and economic factors. As a result, modeling an urban development pattern is the prerequisite to understand the process (Jianquan and Masser, 2001). Urban simulation, since its inception in the 1950s, was enabled and stimulated by developments in digital computing. The influence of the computer, moreover, was both direct and indirect through the role that digital computing played in making possible the present scope of statistical and other methods used in research (e.g., mathematical programming) (Páez and Scott, 2004). There are plentiful models using different indicators, however, Holdren entropy model has been justly considered to identify the pattern of the city. Spatial analysis techniques are applied in many research namely urban planning, Sociology, geography, environmental science et cetera. In academic term, spatial analysis is defined as an application of the quantitative methods in the study of point, line and surface patterns on

Table 2: Compact city characteristics

Theorists	characteristics
Bibri and Krogstie (2020)	As a desirable form, the compact city indeed secures a development that is environmentally sound, economically viable, and socially beneficial
Knudsen (2018)	Compact city has gained prominence, as it represents an alliance between ecological and economic perspectives
Westerink *et al*. (2013)	Compact city emphasizes urban form as a determining factor in shaping sustainable societies and adheres to concrete growth boundaries to curtail sprawl
Holden and Norland (2005)	High-density development which happens inside or in the vicinity of urban center with combination of residential and business uses and workplace centers
Burton (2000)	High density, divers uses and proper public transportation which encourages citizen to walk and cycle
Williams *et al*. (2000)	A city with increased population and density in conjunction with investment in public transportation
Breheny (1995)	High density, a city with various uses where growth occurs inside the urban boundaries
Elkin *et al*. (1991)	A vertical city with an appropriate form and size for walking, cycling, public transportation and density that encourage social interactions.
Newman and Kenworthy (1989)	More use of land use, concentrated activity and higher density
Le Corbusier (1925)	A city with extremely high density (30000 N/H) where official buildings cover only 5% of the area and surrounded by wide open spaces and residential apartments encompass the official buildings

Table 3: Factors affecting the physical-spatial urban development

Experts	Factors of physical-spatial urban development
Bibri *et al.* (2020)	Population density, Land use zoning status, Access to communication networks and sustainable transportation.
Mahamud *et al.* (2016)	Distance from public amenities and workplace, Cheap housing price, Economic factors
Li *et al.* (2013)	Access to communication networks, Economic factors
Poelmans and Van Rompaey (2010)	Distance from centers and workplaces, Access to communication networks, Land use zoning status, Topography and natural disasters, Economic factors
Huang *et al.* (2009)	Distance from centers and workplaces and residential areas, Access to communication networks, Population density, Land use zoning status, Topography and natural disasters
Batisani and Yarnal (2009)	Access to communication networks, Population density, Land use zoning status, Infrastructure development, Topography and natural disasters
Shamsaini and Yaakup (2007)	Population density, Land use zoning status, infrastructure development, Topography and natural disasters
Hu and Lo (2007)	Distance from centers and workplaces, Access to communication networks, Ratio of urban lands to undeveloped lands in neighboring areas, Topography and natural disasters, Economic factors
Braimoha and Onishi, (2007)	Distance from centers and workplaces, Access to communication networks
Verburg *et al*. (2004)	Ratio of urban lands to undeveloped lands in neighboring areas
Šliužas (2004)	Topography and natural disasters, Population density, Economic factors
Cheng (2003)	Distance from centers and workplaces, Access to communication networks
Barredo *et al.* (2003)	Distance from residential areas, Population density

a map. In other words, it means the dexterity of cartography and statistical methods which help to process and analyze the spatial data and a description of the spatial pattern (Momeni and Mostafavi, 2019). At first, Iran's cities experienced organic growth and slight physical development (Seif Aldini *et al*., 2012), however the ongoing rise of growth of the cities affected by the population increase and urban migration has led to unplanned constructions and many changes in the spatial structure of cities in the recent decades. The addition of oil revenue to urban economy, the physical growth and constructions

based on land trade (not on demand) (Majedi, 1999) spark off disordered urban land market, the disused part of lands inside the city, the horizontal expansion of cities (Athari, 2000), the destruction of rural agricultural lands as well as the development of informal settlements which entail paying heed to physical-spatial growth pattern of the city and directing the urban development wisely in order to prevent the loss of lands around the cities, especially in metropolises. Mashhad is known as the center of Khorasan Razavi province and the second largest metropolis of Iran. Initially, Mashhad's development was confined to the surrounding area of the shrine of Imam Reza in the shape of a star then it expanded to the west in a chess-shaped form. After the revolution, rapid population increase and immigrants have unbalanced the ratio between population and the physical growth of the city (Farnhad Consultancy Engineers, 2011). By comparing the ratios, it seems like the city has grown too horizontal. This paper focuses on the spatial analyses and Holdren entropy model to study the pattern of physical-spatial development of Mashhad during the previous decades (from 1986 to 2016). Accordingly, the following questions have been raised as the core of this study:

1. Is there any spatial autocorrelation of population in Mashhad?

2. How is the physical-spatial pattern of Mashhad? Which of the factors (population or horizontal expansion) have the strong influence of the city growth?

According to questions raised, the research hypotheses are as follows:

The conditions of spatial physical development of Mashhad city show that the population lacks spatial autocorrelation and a sprawl pattern. Also, the city growth is more influenced by population however, the impact of that on the development of the city will reduce gradually.

Literature Review

The previous studies and research related to this paper are described as below:

Yang *et al*. (2021) carried out a study on the spatial distribution pattern of Pro-Poor Tourism (PPT) villages in China. In their study, the spatial autocorrelation of 22651 pro-poor tourism villages was calculated using Moran's I. The outcome demonstrated that the spatial distribution of villages was roughly divided by the Hu line, likewise there was an uneven agglomeration pattern of villages which was dense in the southeast and sparse in the northwest with six high-density core areas. Khodadad Bonab (2020) studied the pattern of spatial and physical growth of the Gorgan City in Iran using spatial statistics on GIS. The indicators including population, employment and density through different methods of spatial statistics namely cluster analysis, Moran and Gary Coefficients, general G and hotspots analysis were applied. The results indicated that Gorgan had a random spatial pattern with two hotspots located in the east and the south as well as one cold spot in the north. Abdi Torbeqan *et al*. (2019) investigated the physical pattern of the Kashmar City in Iran during 20 years using Shannon-Holdren entropy models and Moran coefficient. Their studies resulted in sprawl and disperse pattern of the city. Moran's I of population, household, residential unit and density represented cluster distribution and abnormal distribution of variables in the city. According to Koprowska *et al*. (2019) green spaces could act as a driving force affecting on housing demand and triggering city sprawl therefore, they assessed the linkages between urban sprawl and green space availability within the Lodz City in Poland. In this research, the city was divided into three zones. Urban Green Spaces (UGS) availability (especially forest and park) is one of the significant factors of housing development on the periphery of the city likewise, hotspots show the high density around the green spaces. By moving from the peripheral zone to center, UGS availability diminished as a result, the cold spots emerged showing the low residential density. Therefore, the rise of UGS availability in the peripheral zone of the city was connected to city sprawl. Cheng *et al*. (2019) applied three tools such as time-space cube, spatial autocorrelation, and hotspot analysis for exploring the traffic crash characteristics and identifying crash hotspots. The results illustrated that the traffic crash hotspots of road intersections were mainly distributed in the Northeast of Wujiang's urban area in China, while the crash cold spots were concentrated in the Southwest of Wujiang indicating low density of crashes at intersections. Hatami Nejad *et al*. (2017) analyzed the physical pattern of Khorramabad City in Iran using Shannon and Holdren entropy models. The findings represented that 24% and 76% of Khorramabad's growth originated from population and sprawl pattern respectively from

1989 to 2011. Newman and Kim (2017) conducted research on the spatial distribution of Non-productive Spaces (NPSs) of the city of Fort Worth in USA using GIS spatial analysis and directional distribution. The study aims to analyze the influence of NPSs on the fragmented urban core despite the growth of population and economy. Vacant land distributions were concentrated primarily on the eastern side of the city from 1990 to 2000, although they drastically relocated back to the center of the city for years afterwards, also hotspots analysis visualized the shifted direction. Parcel size and regeneration potential in the city center also decreased and resulted in a fragmented urban core by disconnected and irregularly shaped parcels of NPSs which are difficult to regenerate. Khakpoor *et al*. (2016) studied influential factors on unbalanced physical growth of Rasht City in Iran using Holdren model and GIS between 1976 and 2006. The results showed that 57% and 43% of the city's growth stemmed from population and sprawl sequentially. Also, the contradiction between status quo and current plans and approved detailed ones played a role in the unbalanced development of the Rasht City. Sahneh *et al*. (2015) used spatial statistics methods such as cluster analysis, Moran and Gary Coefficients, general G and hotspot analysis to examine the spatial growth pattern of Aq-Qala City in Golestan (Iran) and the findings showed that the pattern of population and employment was randomly scattered. The current study has been carried out in Mashhad in 2021.

MATERIALS AND METHODS

This study falls into the category of quantitative researches and in terms of purpose, it is practical. The research method is descriptive-analytical one and data collection methods are based on library and documents. Due to the fact that generated maps using layers of census blocks produce massive quantities of data, techniques of exploration of information such as data mining seem suitable for spatial data such as urban development maps (Regin *et al*., 2021). Spatial statistics are a set of exploratory techniques for describing and modeling spatial distributions, patterns, processes, and relationships. In other words, they include statistical methods so that integrates space and spatial relationships into the mathematical calculations (Pimpler, 2017). Spatial statistics help to understand the behavior of geographical phenomena (Asgari, 2011). Understanding the behavior of urban dynamics with the insights of the region's carrying capacity would aid in evolving appropriate strategies towards the design of sustainable cities and estimating resources necessary for the future population (Aithal and Ramachandra, 2020). The statistical analysis tools used to study the pattern and trend of data, mainly seek to find the answer to the question of whether the distribution of the studied geographical features occurred arbitrary or experienced a particular trend (Asgari, 2011). Consequently, data analysis has been carried out using Holdren model and spatial statistics analyses such as Moran coefficient, hotspot analysis and directional distribution on ArcGIS Pro software. Holdren model identifies the urban sprawl growth (Hekmatnia and Mousavi, 2017). The model shows what percentage of the city growth originates from population and urban sprawl. The Moran's index measures spatial autocorrelation for a series of distances (Pimpler, 2017) and this Coefficient is used to evaluate the sprawl pattern of urban population. Hotspot analysis illustrates the scattering patterns of features and their characteristics on a map. Moreover, hotspot detection evolved from the study of point distributions or spatial arrangements of points in a space (Chakravorty, 1995). To identify the high population (high density) and low population (low density) in a city, hotspot and cold spot analysis have been applied. Directional distribution indicates that whether the distribution of geographical features in space is directional or not. Therefore, calculating the variances of the x and y axes precisely and independently, the distribution of phenomena in space can be represented. Applying this tool shows the direction of population in research (Asgari, 2011).

RESULTS AND DISCUSSION

The city of Mashhad located in the northeast of Iran (Fig. 1), it has been described as a regional city and in some cases with national function in the approved documents. The initial core of Mashhad was gradually constituted of integration of three centers, namely Noghan City, the village of Sanabad and the holy shrine of Imam Reza. After the development of street networks during the period of First Pahlaavi and social and economic transformations originated from World War II, the development of Mashhad accelerated swiftly in 1941s. Before 1976, Mashhad developed initially surrounding area of

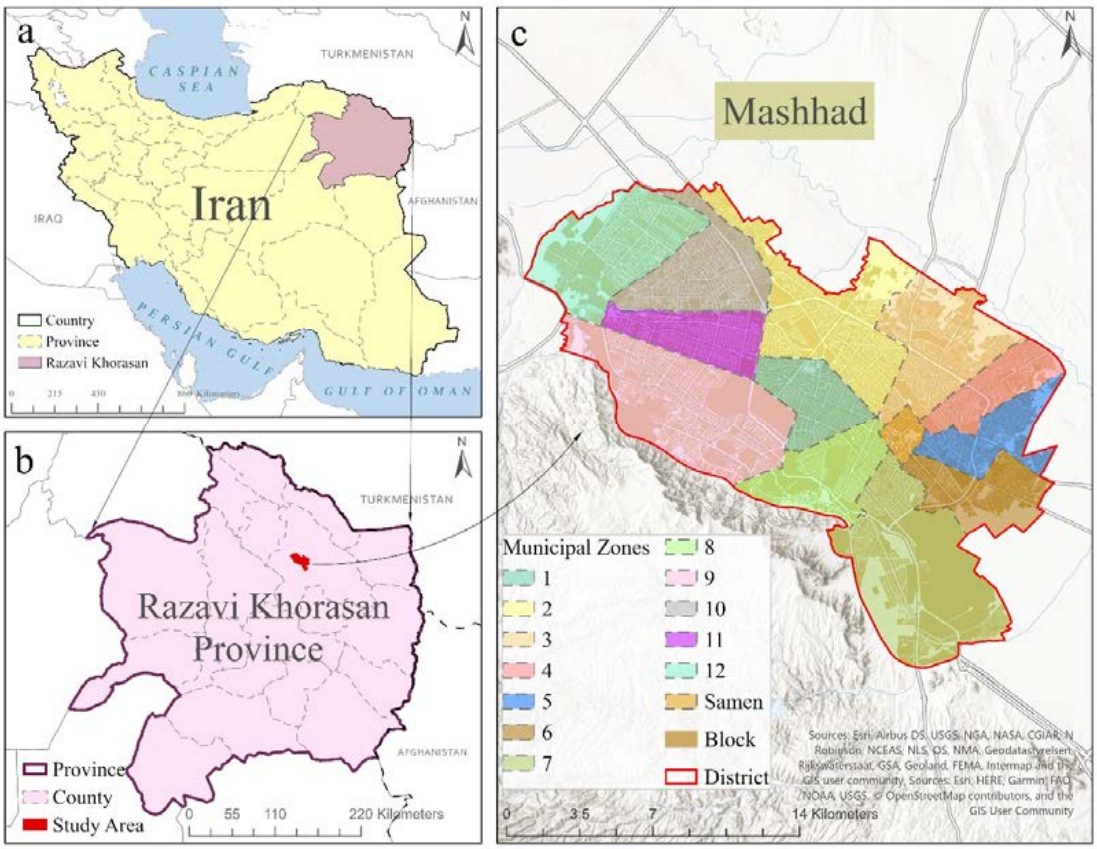

Fig. 1: Map of the study area. (a) Iran, (b) Razavi Khorasan province, (c) Mashhad

the shrine of Imam Reza in the shape of a star and the limit of the development was confined to Azadi highway. Afterwards with expansion to the west and development towards the western areas of Azadi highway, the development transformed to a chess-shaped form and Vakil Abad highway was the spatial axis of that. As a result of an increase in the number of migrants and pilgrims owing to expansion of transportation facilities and offering up-to-date services in the surrounding geographical areas as well as changes in construction which imbalance the corresponding between population and the physical extent of the city (Farnhad Consultancy Engineers, 2011).The purpose of current study is analyzing the physical-spatial pattern which has been carried out in the city of Mashhad (Iran) between 1986 and 2016. The research results help to grasp the population pattern and the city development of Mashhad better, so they are practical to monitor and manage urban development, which are integral for urban planners and managers. The population of Mashhad was equal to 1463500 and 3001184 million people in 1986 and 2016 respectively (Management and Planning Organization of Khorasan Razavi Province, 2017) and it doubled during 30 years. The percentage of urbanization was approximately 43% and 89% in 1986 and 2016 sequentially. The area of the city went up by almost 166 times during the period indicating that as well as rapid growth of urban population, the area of that developed significantly. Therefore, Mashhad City faces the sprawl, unplanned and rapid development currently and does not proceed with the particular physical pattern. This kind of development has consequences namely, improper use of land (building constructions), loss of agricultural lands, imbalance in population distribution, inequality between resources and population, imbalance between population and economic activities, air pollution and water crisis.

Table 4: Moran's Index results of Mashhad

Year	1986	1996	2006	2016
Moran's Index	0.13	0.14	0.15	0.15
z-score	108.04	125.57	146.37	168.08

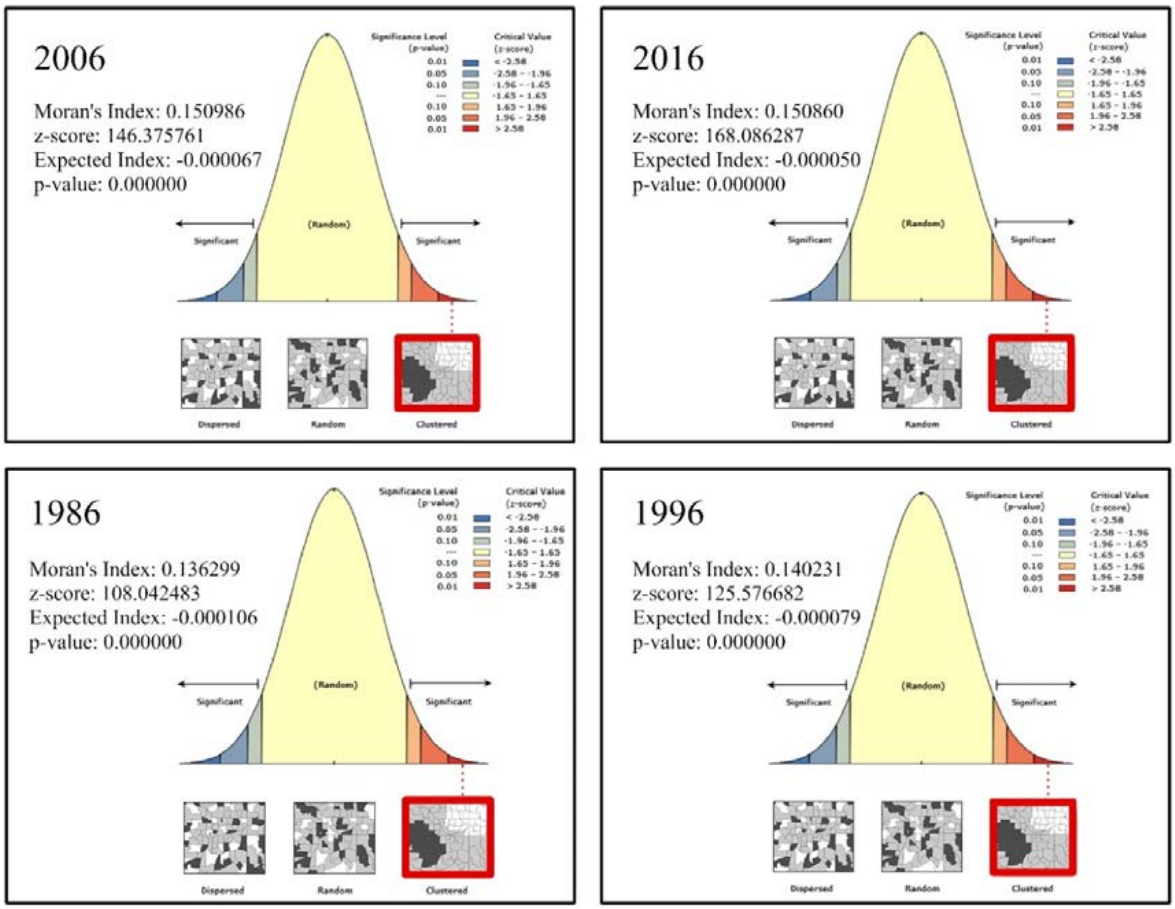

Fig. 2: Spatial autocorrelation reports

The analyses which have been carried out on the data of census blocks of Mashhad between 1986 and 2016 are describes as below; Moran's Index can be calculated as Eq.1 (Lee and Shengwen, 2016) where n is defined as the number of census blocks, a, is population, w is the spatial weight of census block in this case. The Moran coefficient ranges from +1 to -1 which a high positive value indicates clustering as well as high density (Tsai, 2005). In this case, according to Table 4, The Moran's Index values obtained from 1986 to 2016 are positive and greater than zero but the values cannot be scrutinized in isolation, therefore the z-score and p-value must be factored in which are defined as Eqs. 2, 3 and 4 (Asgari, 2011) so that the larger the z-score is the more intense the clustering. In view of positive values of Moran's index, high z-score (Table 4) and the low p-value, the correctness of the first hypothesis has been examined and the basic assumption of spatial randomness are rejected. In other words, the population pattern of Mashhad is clustered and continuous in some parts and is not dispersed through the city. Therefore, it is concluded that the population of different segments of the city has a spatial autocorrelation during 10-year intervals.

If population was scattered in 2016, the Moran's I would be negative value of 0.000050 (Fig. 2).

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(a_i - \bar{a}\right)\left(a_j - \bar{a}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(a_i - \bar{a}\right)\left(a_i - \bar{a}\right)} \quad (1)$$

$$Z_i = \frac{I - E[I]}{\sqrt{V[I]}} \quad (2)$$

Where:

$$E[I] = -I/(n-1) \quad (3)$$

$$V[I] = E\left[I^2\right] - E[I]^2 \quad (4)$$

The Getis-Ord Gi statistic for each feature in a dataset is calculated by the Hot Spot Analysis tool which is derived from the Eqs. 5, 6 and 7. Where x_j is the population of feature j and w_{ij} is the spatial weight between features i and j (census blocks) and n is the total number of census blocks in each year. The Gi statistic is also known as a z-score. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot) and vice versa (Esri, 2014). Table 5 represents the minimum and maximum of the calculated Gi for each year. The maximum values of Gi increased over time indicating that the number of clusters and hot spots was heightened. In 1986, the hotspots of population were in the northeast region (neighborhoods of Isar, Tolab, Resalat, …), afterwards in 1996, the hotspots did not develop significantly, only one hotspot appeared in the northwest of Mashhad (Azadshahr and Zibashahr neighborhoods), however, the number of hotspots increased and scattered in 2006, so that in 2016, these spots were located in a contiguous area from east to northwest and west reflecting high population concentration (Fig. 3). In view of spreading hotspots, it is concluded that the large part of population density is made up of Informal Settlements and worn-out urban textures (neighborhoods of khatam Alanbiya, Imam Hadi, …) and the west part of the city affords optimal housing and appropriate access to services accordingly, the accessibility to main roads (vakil Ababd highway, Toos boulevard and 100-meter ring road) plays a prominent role in housing. Cold spots or places with low population densities are located in the city center and northwest, which have the potential to accommodate future populations. Recognizing these spots offers an opportunity for urban planners to adopt a decision of service allocation which leads to improvement of city functionality.

$$G_i = \frac{\sum_{j=1}^{n} w_{ij}x_j - \bar{x}\sum_{j=1}^{n} w_{ij}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2}{n-1}}} \quad (5)$$

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (6)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \bar{x}^2} \quad (7)$$

The Standard Deviational Ellipse tool created a new Output Feature Class containing elliptical polygons, one for each census block. The attribute values for these ellipse polygons include x and y coordinates for the mean center, two standard distances (long and short axes according to Eq. 8 and Eq. 9), and the orientation of the ellipse (Eqs. 10, 11, 12 and 13) (Esri, 2014) (Asgari, 2011). According to standard deviational ellipse, the developed distance along the X axis started at 5959.39 in 1986 and reached 9119.12 in 2016 and the expansion along the

Table 5: The calculated values of Gi statistic for each census block of Mashhad

Year	Gi (Z score)	
	Min	Max
1986	- 8.95	14.89
1996	- 11.73	17.71
2006	- 12.41	19.72
2016	- 12.30	14.46

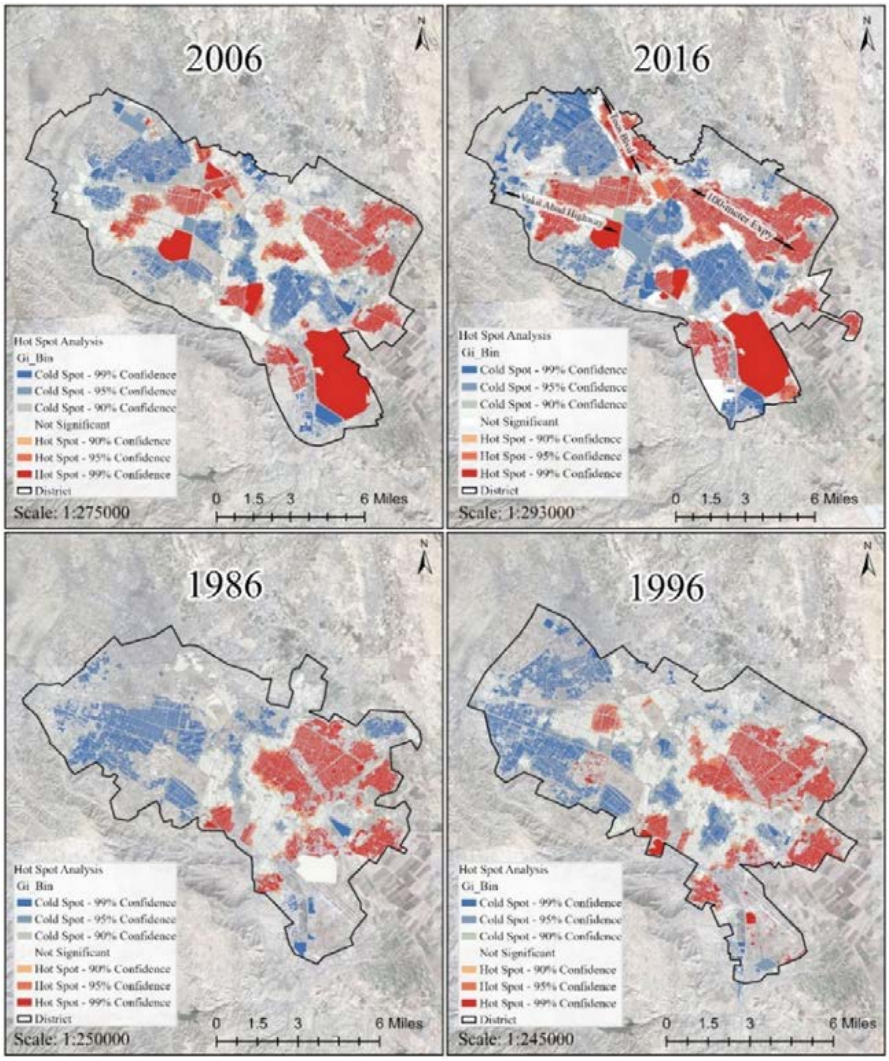

Fig. 3: Hotspot analysis output on the census block showing clustering of population

Y axis went up by 921.76. As a result, through time, Mashhad expanded through both axes with rotation of 0.16 radian between 1986 and 2016, although the expansion along the X axis is more considerable in comparison to Y axis (Table 6). The rotation degree depicts that population ellipse has revolved clockwise across the X axis. In other words, the location of studied feature (population) has altered across the X axis. Consequently, the diffusion of population is heading to the northwest.

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{X}\right)^2}{n}} \quad (8)$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{Y}\right)^2}{n}} \quad (9)$$

$$\tan\theta = \frac{A+B}{C} \quad (10)$$

Table 6: Directional distribution results

Year	1986	1996	2006	2016
X standard distance	5959.39	7589.24	8300.99	9119.12
Y standard distance	3699.03	3939.04	4258.83	4620.79
Rotation ($\tan\theta$) (rad)	1.87	1.94	1.94	2.03

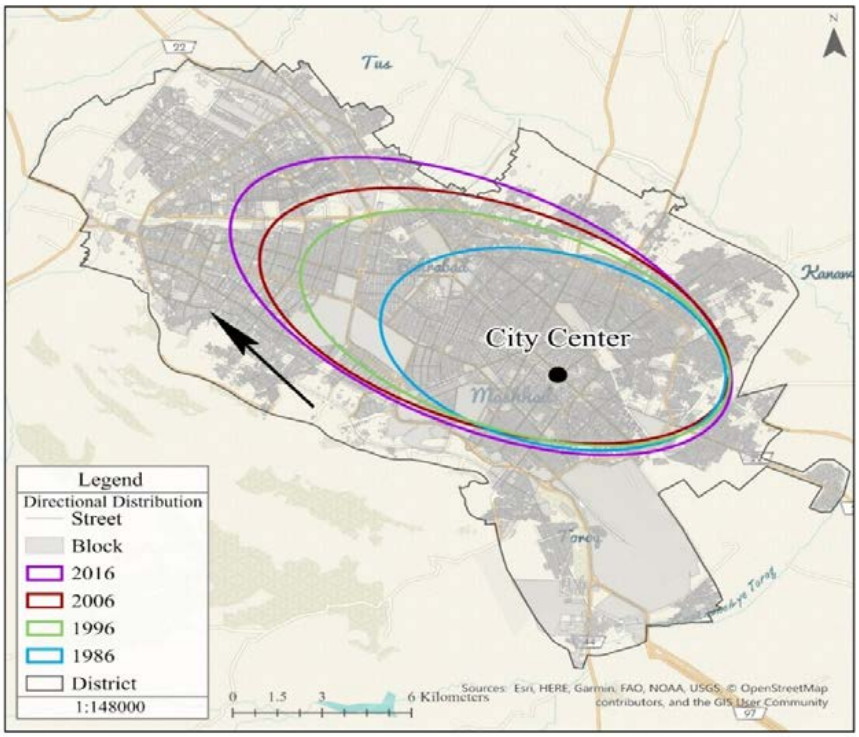

Fig. 4: Directional distribution output showing population patterns in studied years

$$A = \sum_{i=1}^{n} \tilde{x}_i^2 - \sum_{i=1}^{n} \tilde{y}_i^2 \quad (11)$$

$$B = \sqrt{\left(\sum_{i=1}^{n} \tilde{x}_i^2 - \sum_{i=1}^{n} \tilde{y}_i^2\right)^2 + 4\left(\sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i\right)^2} \quad (12)$$

$$C = 2\sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i \quad (13)$$

Table 7 indicates a moderately rising trend in the population of Mashhad from 1463500 to 3001184 people in 1986 and 2016 successively. Considering the reduction in per capita and upward trend in Gross urban density, it is apparent that the population growth outweighs the increase in urban are. According to the Holdren model (Eq. 14) (Hekmatnia and Mousavi, 2017), the natural logarithm of population remained stable at 0.25% in the first twenty years beginning from 1986 however after a slight drop in 2006 it reached 0.28% in 2016. The calculated natural logarithm of per capita shows a slight growth by 0.18% during studied years. The sum of natural logarithm of population and per capita demonstrates the natural logarithm of urban area which started with 0.35% in 1986 and finished with 0.54% in 2016. The entropy values obtained were 74% of population growth and 26% of dispersed growth in 1986, which reached 51% and 49% respectively in 2016. Generally

Table 7: Basic statistics of Holdren entropy model

Year	Population	Per Capita	Gross urban density	Urban area (m^2)
1986	1463500	126	79	185 000 000
1996	1887400	138	72	261 000 000
2006	2427300	122	81	300 000 000
2016	3001184	103	97	307 900 000

Table 8: The calculations of Holdren entropy model

Year	Ln (Population)	Ln (Per Capita)	Ln (Area)	Population Growth	City Sprawl
1986	0.25	0.09	0.35	74%	26%
1996	0.25	0.12	0.37	67%	33%
2006	0.21	0.17	0.38	56%	44%
2016	0.28	0.27	0.54	51%	49%

Table 9: The comparison between annual growth rate of population and urban area

Period	Annual population growth rate	Annual growth rate of the urban area
1986-1996	2.58 %	3.5 %
1996-2006	2.54 %	1.4 %
2006-2016	2.14 %	0.3 %

speaking, the large segment of Mashhad's growth resulted from population, despite the fact that the rate of city sprawl went up gradually. To be specific, the percentage of population growth decreased by 23% which added to urban sprawl (Table 8). This trend will lead to unplanned and disperse growth, reduction of gross urban density and an increase in per capita in the not-so-distant future. From 1986 to 2016, not only did the annual population growth rate fall by roughly 0.45% but also the annual growth rate of the urban area slumped sharply by 3.2% (Table 9). Considering the gradual decrease in annual population growth rate during studied periods, it is self-evident that population will have minor influence on Mashhad's growth and its development. Also, the annual growth rate of Mashhad's area sharply slumped and considering reduction in population growth rate, it is derived that the increased ratio of the city area has been added to rate of city sprawl.

$$\ln\left(\frac{\text{population of end period}}{\text{population of stat period}}\right)+ \ln\left(\frac{\text{per capita of end period}}{\text{per capita of start period}}\right)= \ln\left(\frac{\text{urban area of end period}}{\text{urban area of start period}}\right) \quad (14)$$

Comparing the analyses, Mashhad City confronts unscheduled growth which confirms the hypothesis about a sprawl pattern. Spatial autocorrelation of population and its clusters can be observed more in the east to northwest area which might result from low dwelling prices and the vicinity of 100-meter ring road. Therefore, this area mainly includes fine-grained residential areas and informal settlements which are located among agricultural farms. Likewise, the standard deviation ellipse of population is the embodiment of horizontal development. In view of the locations of cold spots, there is an opportunity for Endogenous development and compaction mainly in the northwest zone. Also, the existence of cold spots in the city center (around the shrine) shows a chance for interior development however in status quo, high-rise buildings and uses related to tourism and hospitality such as hotel and small business associated to shrine are placed there. Moreover, illegible urban context, low permeability of this area to Checkered texture of the northwest, the heavy traffic during rush hours and crowds of pilgrims have made it difficult for physical intervention and inner development in the zone. The main difference between the current research and the conducted studies in the literature review such as Yang *et al*. (2021), Khodadad Bonab (2020), Abdi Torbeqan *et al*. (2019), Cheng *et al*. (2019) and Newman and Kim (2017) is that the directional

distribution as well as Moran coefficient and hotspot analysis have been applied, simultaneously. Moreover, the spatial statistics analyzes have been surveyed in a long-term period (30 years). The results of spatial statistics tools and Holdren model are consistent and show the horizontal growth with a random and scattered pattern representing high density of population clusters. Which is similar to the one of conducted studies in other Iranian cities which were previously mentioned in the literature review such as the study of Khodadad Bonab (2020), Abdi Torbeqan *et al*. (2019), Koprowska *et al*. (2019) and Sahneh *et al*. (2015). Also, based on the results of the Holdern model, it has been determined that the expansion of Mashhad, like other major cities in Iran, is more affected by population growth and the final hypothesis is confirmed. survey of the directional distribution and the location of hot spots show that proper access and the existence of highway networks are the main factors in the spread of Mashhad. Although many areas of development are located around agricultural lands, it could not be reconciled with the study of Koprowska *et al*. (2019), who consider green spaces as the main factor in urban development. Because these areas are informal and poor settlements that have invaded the agricultural lands around the city. Therefore, it can be concluded that among the factors affecting the physical-spatial urban development (Table 3), the physical-spatial development of Mashhad is more affected by access to communication networks, population density and economic factors.

CONCLUSION

The analysis of the development of Mashhad has been carried out using spatial statistics analyses and Holdren model during previous decades (from 1986 to 2016). Taking the positive values of Moran coefficient into consideration, it comes to the conclusion that the population of Mashhad is clustered and there is spatial autocorrelation. Consequently, the population accommodation has accumulated to some particular locations over time, in other words, it is not homogeneously distributed and it is moving to the northwest. Likewise, the obtained hotspot analyses obviously represent the dense population from the east to the northwest. The analysis of population direction using standard deviational ellipse reveals that the distribution of population has a direction in urban space and population is proceeding to the northwest from a certain point. The values of Holdren model indicate that population has a profound impact on the development of Mashhad from 1986 to 2016 successively but due to reduction in the percentage of growth stemmed from population and the rise in percentage of city sprawl, the percentage of city sprawl will exceed the population and act as a dominant factor on the development of the city for the foreseeable future. Hence, Mashhad which is recognized as the second most populous metropolis, faced a horizontal pattern during 30 years, on the other hand owing to natural barriers such as southern and southwestern heights, plenty of agricultural lands in the east, Kashafrud River and Binaloud County in the north and west sequentially, proceeding according to this pattern has culminated in encroachment of physical-spatial development to fertile agricultural lands and reduction in groundwater aquifers as well as disruption to the ecological order. Based on the results of this study, the following suggestions are put forward to improve the planning of the Mashhad's development:

- The control of the migration rate from rural to urban areas;
- Governing and maintaining the legal city limit;
- Inner city development (allocation of capital to the development of areas with low population density);
- Invention of proper building regulations and prevention of unplanned and non-standard constructions;
- Lending support to Energy efficient constructions;
- Adjust residential densities based on environmental compatibility;
- Expansion of public welfare amenities, health, educational and ... facilities in the city;
- Reduction in commuting from workplace to residence and leisure facilities;
- Improvement and development of public transportation network corresponding with population;
- Implementing Incentive policies to make citizens use more public transportation;
- Adopting appropriate policies to address issues such as traffic congestion in areas with high population density (monitoring the rise of building density, Widening streets, …).

AUTHOR CONTRIBUTIONS

M. Jahanbani helped in the research method and performed the literature review and compiled the data as well as generating maps, the manuscript preparation, analyzing and interpreting the data, preparing the manuscript text and manuscript edition. E. Lashkari was the mentor and performed the introduction and research method, helped in preparing manuscript and its edition as well as interpreting the data and proposed constructive comments.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

$\bar{a}$	is the mean of all a
a_i	the attribute value of geographic object i
a_j	the attribute value of geographic object j
Eq.	Equation
Gi	Getis-Ord statistic
I	index
ln	Natural logarithm
m^2	Square meters
n	the number of geographic phenomena
NPS	Non-productive Space
PPT	Pro-poor Tourism
p-value	Probability value
rad	radian
SDE	Standard deviational ellipse
$tan\,\theta$	Orientation of the ellipse
UGS	Urban Green Space
w_{ij}	a weight defined for events i and j (spatial weights)
x	coordinates for the mean center
x_j	the population of feature j
y	coordinates for the mean center
z	z-score

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