Mansouri Daneshvar et al. Environ Syst Res (2019) 8:23
https://doi.org/10.1186/s40068-019-0152-2

Environmental Systems Research

RESEARCH

Open Access

Assessment of urban sprawl effects on regional climate change using a hybrid model of factor analysis and analytical network process in the Mashhad city, Iran

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Abstract

Background: Urban sprawl, as an unsustainable urban expansion, relates to direct and indirect impacts on regional climate change in urbanized regions. In this paper, the effect of urban sprawl on regional climate change has been studied using a hybrid factor analysis (FA) and analytical network process (ANP) model in Mashhad city, Iran. The methodology was divided into two main parts based on the identification of 18 urban sprawl characteristics and six climatic parameters during three time-windows of 1996, 2006, and 2016.

Results: Based on the FA, a set of chosen sprawl characteristics were reduced into five factors with a maximized total variance of the loading variables and were weighted by ANP super-matrix. Results of urban sprawl index (USI) indicated that Mashhad city had experienced rapid horizontal growth by values from 0.47 to 1.74 within 1996–2016, revealing an indication of unsustainable urban sprawl during the last decades. Based on the correlation test, a positive relation between four climatic parameters (surface temperature, surface long-wave flux, total ozone, and black carbon density) and urban sprawl was observed (R from 0.827 to 0.981). In parallel, a negative relationship between two climatic parameters (total precipitation and convective precipitation) and urban sprawl was estimated (R from −0.691 to −0.805).

Conclusions: The result confirmed the possible effects of urban sprawl on climatic variations. This outcome relates to a chain of urban sprawl effects on growth of construction, transportation, the assumption of fuels and subsequently high emission of greenhouse gasses such as ozone concentration, long-wave flux, and carbon density in the urban atmosphere.

Keywords: Urban sprawl index (USI), Analytical network process (ANP), Factor analysis (FA), Climate parameters, Mashhad city

Introduction

The spatial dynamics of urban growth are essential topics of analysis in urban studies (Bhatta 2009). Urbanization is an alteration process from a rural society to an urban civilization life with crowded population and migration. Accordingly, the rapid expansion of the geographical extension of urbanization results in urban sprawl shapes (Sudhira et al. 2004). According to Chin (2002), the urban sprawl is measured against an ideal type of compact city generating the form of suburban growth, ribbon scattered development, leapfrogging, and spatial segregation of land uses (Pichler-Milanović 2007). Land use change and segregation through the urban sprawl influence on environmental degradation (Arsanjani et al. 2013).

The impacts of urban sprawl may lead to a change in climate with some extreme natural events (Emadodin et al. 2016). Urbanization has resulted in climate perturbations in recent decades (Bazrkar et al. 2015). Anthropogenic

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activities in urban areas play an important role in thermal and dynamical changes (Fan and Sailor 2005; Makar et al. 2006). There are many arguments about the quota of urbanization in emissions of greenhouse gasses (Dodman 2009), in effects on climate (De Sherbinin et al. 2007), and its responses to future climate change (UN-Habitat 2011; World-Bank 2010).

In the last decades, the Iranian urbanization has potentially changed the Middle East climate by the release of total greenhouse gas emissions nearly to 616,741 million tons of CO_2 (Mansouri Daneshvar et al. 2019) and with the high contribution of urbanized people to total population nearly to 70% (Mansouri Daneshvar and Hussein Abadi 2017). Urban expansions in Iran and population growth since the 1970s have influenced to natural land degradation, the variation of surface reflectance, and waste generation concerning climate change effects (Amiri and Eslamian 2010).

Hitherto, there are not enough researches concerning sprawl effects on environmental change and climate change at regional scale in Iran, while worldwide analysts have made considerable progress in quantifying the urban sprawl impacts on the environment and landscape metrics (Epstein et al. 2002; Wei et al. 2006; Yu and Ng 2007; Schneider and Woodcock 2008; Singh 2014; Effat and El-Shobaky 2015). For instance, the impacts of urban sprawl on the land use/cover changes have been researched frequently (Mundia and Aniya 2006; Jat et al. 2008; Dewan and Yamaguchi 2009; Liu et al. 2014). These studies have revealed the substantial changes in environmental conditions and climate change at regional and global scales (Nagendra et al. 2004; Phan and Nakagoshi 2007; Sun et al. 2013; Bhat et al. 2017).

The present paper aims to indicate an integrated procedure of factor analysis and analytical network process named as F'ANP model to measure urban sprawl in Mashhad city, Iran in order to overcome the lack of interdisciplinary research regarding the relationships between urban sprawl and regional climate change in Iran. Simultaneously, remotely sensed climatic data were extracted from some global coverage data to measure climate variations within three time-periods of 1996, 2006, and 2016. The proposed model in this research tries to present a hybrid geo-statistical analysis to lead policymakers and planners assessing environmental changes at the local/regional scale.

Data and methods

Study area

The case study of the present study is the Mashhad city as the capital city of Khorasan-e-Razavi province located in northeastern Iran, with 3,000,000 populations (Statistical Center of Iran 2016). The study area is laid between northern latitudes from 36°37′ to 36°58′ and eastern longitudes from 59°26′ to 59°44′ with a total surface area of about 300 km^2 (Fig. 1). This city is located in the semi-arid region with a sensitive climate that experiences mean annual temperature of 14 °C and annual precipitation of 260 mm based on a long-term time-period of 1966–2016 (Iranian Meteorological Organization 2017). The spatial analysis of urban topography in geographical information system (GIS) indicated that the mean elevation values vary between 920 and 1340 m above sea level in northeast and southwest, respectively. In recent years, Mashhad city has been considered as an exciting research case of development modeling such as simulating urban growth (Rafiee et al. 2009), building height construction modeling (Mansouri Daneshvar et al. 2017a), carrying capacity of urban green spaces (Mansouri Daneshvar et al. 2017b), urban transportation modeling (Bikdeli et al. 2017), urban sprawl modeling (Rabbani et al. 2017), and urban flexibility (Sarvari and Esnaashari 2018). Besides, the present paper focuses on hybrid modeling to assess the sprawl effects on climate parameters.

Data preparation

Urban systems are developed in different shapes during the temporal and spatial scales based on dynamical interaction between socio-economical and environmental processes. All effective variables of physical and geo-spatial indices should be surveyed in order to understand the main role of urban sprawl shapes and its effects on

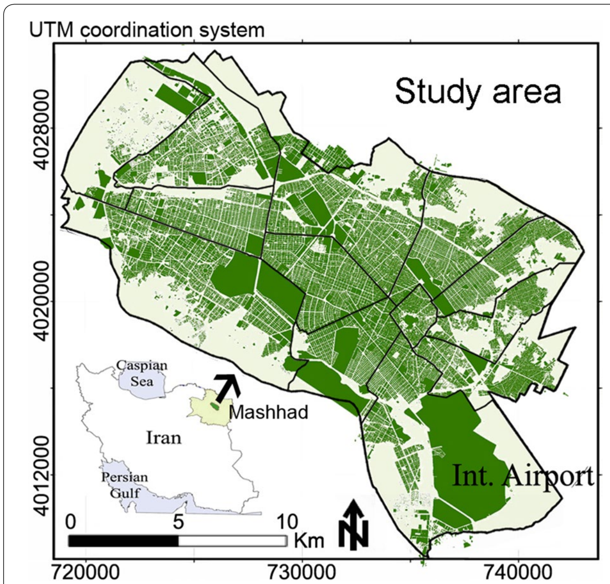

Fig. 1 Geographical location of the study area (at UTM coordination system)

environmental change. For this purpose, some effective variables were selected to investigate the urban sprawl shape of Mashhad city, Iran (Table 1). All requirements data were collected via from official documents of Mashhad municipality reports, the statistical survey of the population (SCI 2016), and open spatial GIS layers (GSI 2016). Owing to the official discrete release of data in the Statistical Center of Iran authorized statistical data, and open spatial GIS layers are available just for three time-windows of 1996, 2006, and 2016.

Climate change provides a unique challenge for urban regions and their growing population. For instance, Urbanization makes the quantifiable impression of climatic parameters such as temperature, precipitation, radiation, etc. (Collier 2006). Hence, remotely sensed and re-analyzed data were extracted for the spatial position of Mashhad geographical pixel (36°–37°N × 59°–60°E) from two global coverage data sets for three time-windows of 1996, 2006, and 2016. First, the Goddard Earth Sciences data and information services center of National Aeronautics and Space Administration (NASA/GES) was considered to visualize and measure four atmospheric parameters including land surface temperature, surface long-wave flux, total ozone column, and black carbon column density. For this, the MERRA-2 Model measurements [version 5.12.4] were compiled according to NASA Geospatial Interactive Online Visualization, and Analysis Infrastructure (Giovanni) remotely sensed data hosted by the NASA via http://giovanni.sci.gsfc.nasa.gov/giovanni.

Second, the National Centers for Environmental Prediction at the National Oceanic and Atmospheric Administration (NOAA/NCEP) was considered to visualize and measure two atmospheric parameters, including total precipitation rate and convective precipitation rate. For this, the NCEP reanalysis data were compiled according to Asia Pacific Data Research Center (APDRC) data set hosted by the NOAA via http://apdrc.soest.hawaii.edu/las/getUI.do.

Urban sprawl modeling

Urban sprawl characterization includes appropriate quantification and statistical summarization like as patchiness, landscape metrics, factor analysis, analytical network process, regression analysis, etc. (Rabbani et al. 2017). The present study generates an urban sprawl modeling for 3 years based on geospatial data and statistical hybrid procedure of factor analysis and analytical network process (F'ANP). For this purpose, a schematic

Table 1 The effective variables for urban sprawl and their contribution to sprawl shape

No.	Variable title	Variable symbol and unit	Measurements	Contribution to sprawl
1	Population density ratio	PDR (p/m^2)	Population ratio per area's unit	Negative
2	Net population density	NPD (p/m^2)	Population ratio per residential area's unit	Negative
3	Small urban blocks	SUB (%)	% of urban blocks smaller than 1 Ha	Negative
4	Real-estate density	RED (%)	% of real-estate contribution to per area's unit	Negative
5	Residential parcel size	RPS (m^2)	Average parcel size of residential building	Positive
6	Average block size	ABS (Ha)	Average block size	Positive
7	Accessibility to elementary schools	AES (%)	% of persons with accessibility to elementary schools at 1000 m radius	Negative
8	Distance to urban center below than 1 km	DUC1 (%)	% of settled persons with low distance to urban center at below than 1000 m radius	Negative
9	Distance to CBD greater than 3 km	DUC3 (%)	% of settled persons with more distance to urban center at greater than 3000 m radius	Positive
10	Accessibility to commercial centers	ACS (%)	% of persons with accessibility to commercial centers at 500 m radius	Negative
11	Residential land area	RLA (%)	% of residential area from total area	Positive
12	Industrial land area	ILA (%)	% of industrial area from total area	Negative
13	Public land uses	PLU (%)	% of urban public land uses from total area	Negative
14	Mixed land uses	MLU (%)	% of urban mixed land uses from total area	Negative
15	Special land uses	SLU (%)	% of urban special land uses such as urban manufactories from total area	Negative
16	Tourism and recreation area	TRA (%)	% of urban touristic and recreational land uses from total area	Negative
17	Distance to bus station	DBS (m)	Distance to the nearest bus station	Positive
18	Distance to metro station	DMS (m)	Distance to the nearest metro station	Positive

diagram of the research model based on the applied procedure was generated in Fig. 2. The model starts from an affected study area and ends to present sprawl effects on climatic variations using a correlation coefficient. Two main characteristics of the model depend on (1) spatial and statistical analysis of sprawl effective variables and (2) temporal survey of remotely sensed climatic parameters in order to obtain a correlation between sprawl index and climatic variations. To present the effective variables of the model, calculation of F'ANP, and extraction of remotely sensed data, Super-Decisions, SPSS, APDRC, and GIOVANNI programs were used to make the database.

A hybrid model of factor analysis and analytical network process (F'ANP)

The proposed F'ANP model is a hybrid model composed of two procedures of factor analysis (FA) and the analytical network process (ANP). In the first step, factor analysis (FA) is considered as a multivariate analytical technique to uncover the underlying structure of a set of variables. It is used to derive a subset of 18 variables into lesser factors that explain the variance observed in the original dataset. In this research, a set of 18 chosen effective variables were reduced into five factors according to Varimax rotation, which maximizes the total variance of the loading variables (>72%) with eigenvalues greater than one. The advantage of a Varimax rotation is that it keeps the principle components uncorrelated (Jolliffe 1986; Wilks 1995; Paschalidou et al. 2009). In factor analysis, the factor scores for each case were calculated by the Varimax rotation with Kaiser normalization, principal component analysis method, and rotation converge (Mansouri Daneshvar et al. 2013). The final step of the approach is to project the data on the rotated significant factors and distributed loading values.

In the second step, analytical network process (ANP) proposed by Saaty (1980, 2001) as a nonlinear structure with bilateral relationships is considered to detect factors' weights. According to Mansouri Daneshvar et al. (2017a), the application of ANP can be described in some steps. Firstly, the construction of a conceptual model is produced to determine relationships between criteria. The criteria are compared pair-wisely using Super Decisions software in order to form an un-weighted initial super-matrix. In the conventional procedure of ANP, pair-wise comparisons are made with the priority grades ranging from 1 to 9 (Vasiljević et al. 2012).

Nevertheless, in this study, the loading values explained by each extracted factor in FA are used as the priority of each extracted factor to calculate pair-wise comparison. The loadings obtained by FA in SPSS software are used as the importance of each component in the comparison matrix instead of expert judgments. The obtained values interfere in the initial super-matrix that includes the entire network components and represents their interrelationships (Lee et al. 2009). Finally, weighting values are calculated in order to weigh the factors and their variables based on a complicated process of initial and weighted super-matrixes carried out by Super Decision. Consistency ratio of pair-wise matrix like the AHP must be less than 0.1 (Şener et al. 2011). The main advantage of the proposed F'ANP model is the restriction of the bias of the ANP system. It often seems that it is a subjective analysis due to personal expert judgments. To overcome this problem, F'ANP model tries to interfere systematic loading values of the variables, which obtained by FA in SPSS software without any subjective personal judgment. Contrarily, the main disadvantage of the F'ANP model is its complicated statistical process that depends on PC programs entirely.

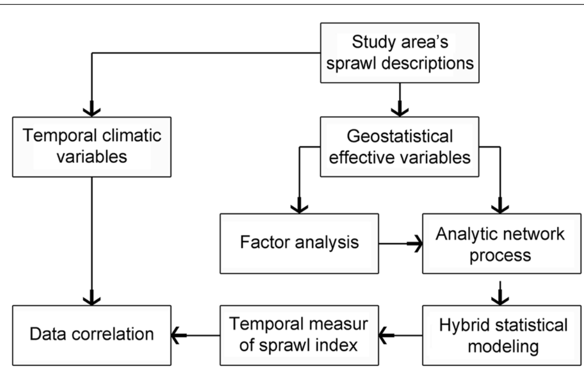

Fig. 2 Urban sprawl modeling of the present study

Urban sprawl index (USI)

After determining the weights of the effective variables as explained factors, a weighted sum method is used to calculate all values (Zebardast 2009). The weighting values of F'ANP are used to compute the urban sprawl index by a weighted sum method based on the below equation:

$$USI = \sum_{i=1}^{n} (Wi \times Si) \quad (1)$$

where, USI is the urban sprawl index score for Mashhad city, Wi is the weighting values of ith variable or factor obtained from the F'ANP super-matrix, Si is the standardized raw value of ith variable or factor and n is the number of variables or factors, which are 18 and 5, respectively in this study.

Results and discussion

Concerning the FA

Using SPSS software, a factor analysis (FA) was concerned for 18 chosen effective variables. For this purpose, Bartlett's sphere test (BST) and the Kaiser–Meyer–Olkin (KMO) measurements of overall sampling adequacy were controlled (Sharma 1996). The BST and KMO values were calculated equal to 1176.9 and 0.618, respectively, indicating the suitability of the performance of the factor analysis.

The Kaiser criterion (Kaiser 1960) was applied to determine the total number of extracted factors of the analysis. After this principle, only factors with eigenvalues greater than or equal to one are accepted as possible sources of the total variance. When the factor analysis was carried out by Varimax rotation, a particular factor structure with five factors is generated, explaining 72.379% of the total variance (Table 2). The explained variances of these factors are varied from 21.993 to 8.317% for Factors 1 and five after the Varimax rotation, respectively. Furthermore, each factor showed different loadings for each variable, which are shown in this table. Factor 1, with four variables mainly comprised city center characteristics explained 21.993% of the total variance. Factor 2, with four variables mainly comprised density characteristics explained 16.552% of the total variance. Factor 3, with three variables contained most land use characteristics explained 15.289% of the total variance. The other two factors related to activity and structural characteristics with five variables entirely explained 18.545% of the total variance. It should be mentioned that through FA, two variables titled as tourism and recreation area (TRA) and Distance to metro station (DMS) due to their incompatibility with other variables were removed from the rotation and analysis process. Hence, from 18 chosen variables were remained 16 residual variables.

Estimating the ANP

The weighting values and pair-wise values of comparison matrix were prepared for 16 residual variables in the analytical network process (ANP) (Table 3). The pair-wise values of the comparison matrix and the weighting values were calculated based on a complicated process of initial and weighted super-matrixes carried out by Super Decision software in preference type and verbal mode. The obtained consistency ratio (CR) of the matrix for pair-wise comparisons between five factors was obtained lower than 0.1, indicating an acceptable ratio. The super-matrix provides a significant weight of influence for each effective variable. Based on the results of Table 3, structural characteristics of the average block size (ABS) and small urban blocks (SUB) have the most heavily weights with values equal to 1.0. In the status quo (2017), the physical and structural characteristic of urban block size has the main role in controlling or leading the urban expansion.

Calculating the USI

Firstly, the raw values of 16 residual variables were extracted for three time-windows of 1996, 2006, and 2016 in the study area (Table 4). Then after Eq. 1, estimation scores for the five extracted factors of urban sprawl and

Table 2 Distributed loading values for factor components and their explained variance

Factor component	Variable component	Rotation loading		
		Variance (%)	Cumulative (%)	Loading value
(1) City center	DUC1	21.993	21.993	0.688
	DUC3			0.693
	DBS			− 0.763
	RED			0.459
(2) Density	PDR	16.552	38.545	0.860
	NPD			0.822
	RPS			0.558
	RLA			0.608
(3) Land use	ILA	15.289	53.834	0.896
	PLU			0.370
	MLU			− 0.958
(4) Activity	AES	10.228	64.062	0.683
	ACS			0.842
	SLU			0.361
(5) Structure	ABS	8.317	72.379	0.818
	SUB			− 0.693

Table 3 The pair-wise values and weighting values of each variable based on F'ANP model

Variables	Pair-wise values	Weighting values
DUC1	0.2567	0.0514
DUC3	0.2716	0.0543
DBS	0.2296	0.0459
RED	0.2420	0.0484
PDR	0.2751	0.0550
NPD	0.2498	0.0500
RPS	0.2374	0.0475
RLA	0.2377	0.0475
ILA	0.3517	0.0703
PLU	0.4494	0.0899
MLU	0.1989	0.0398
AES	0.3060	0.0612
ACS	0.3675	0.0735
SLU	0.3266	0.0653
ABS	0.5000	0.1000
SUB	0.5000	0.1000
Sum	5.00	1.00

Table 4 The raw values of each variable within three temporal sequences

Factor	Variable (unit)	1996	2006	2016
(1) City center	DUC1 (%)	7.7	5.3	3.5
	DUC3 (%)	60.8	69.8	67.5
	DBS (m)	261	163	96
	RED (%)	100	120	150
(2) Density	PDR (p/m^2)	72	81	87
	NPD (p/m^2)	427	302	233
	RPS (m^2)	143	170	181
	RLA (%)	69.2	78.1	80.9
(3) Land use	ILA (%)	6.8	7. 9	6.9
	PLU (%)	3.7	4.6	5.1
	MLU (%)	7.6	11.3	23.7
(4) Activity	AES (%)	51.4	65.9	78.4
	ACS (%)	52.0	60.9	74.0
	SLU (%)	3.9	4.1	5.2
(5) Structure	ABS (Ha)	0.68	0.85	0.73
	SUB (%)	33.9	38.9	41.7

the composite indicator of urban sprawl index (USI) was calculated in Mashhad city within three time-windows of 1996, 2006, and 2016 (Table 5). USI values indicated that Mashhad city had experienced rapid horizontal growth by values from 0.47 to 1.74 within 1996–2016, revealing an indication of unsustainable urban sprawl during the last decades.

During the study period, developed areas in Mashhad city have expanded very faster than the growth of the population. In this regard, the area of real estate in the study area has been increased from 105 to 300 km^2 during 1996–2016, respectively. However, the population of the residential area has been increased from 1,800,000 to 3,000,000 during 1996–2016, respectively. This sprawling development is influenced by irregular and solid urban planning leading to expanded land development without consideration to available brown-fields in the central part of the city.

Survey of climatic parameters

In this paper, six climatic parameters titled as surface temperature, surface long-wave flux, total ozone, black carbon density, total precipitation, and convective precipitation were considered for analysis of urban climate change of the study area (Table 6). In this regard, the mean annual summarization of aforementioned climatic parameters was calculated within three time-windows of 1996, 2006, and 2016 in Mashhad city (Figs. 3, 4).

Table 6 Mean annual values of climatic parameters during three time widows of 1996, 2006, and 2016 in the study area

Climatic parameters	Years		
	1996	2006	2016
Surface temperature (K)	277	279	280
Total precipitation (mm)	218	48	31
Convective precipitation (mm)	79	18	25
Total ozone (Dobsons)	289	293	294
Black carbon density (μg/m^2)	424	604	631
Surface long-wave flux (W/m^2)	325	329	331

Table 5 Estimation of the factor scores and urban sprawl index (USI) within three time windows of 1996, 2006, and 2016 in Mashhad city

Years	Factors					USI
	(1)	(2)	(3)	(4)	(5)	
1996	− 0.058	− 0.16	0.59	0.042	0.064	0.47
2006	0.63	0.53	− 0.08	− 0.15	− 0.04	0.89
2016	0.37	0.31	0.94	− 0.8	0.92	1.74

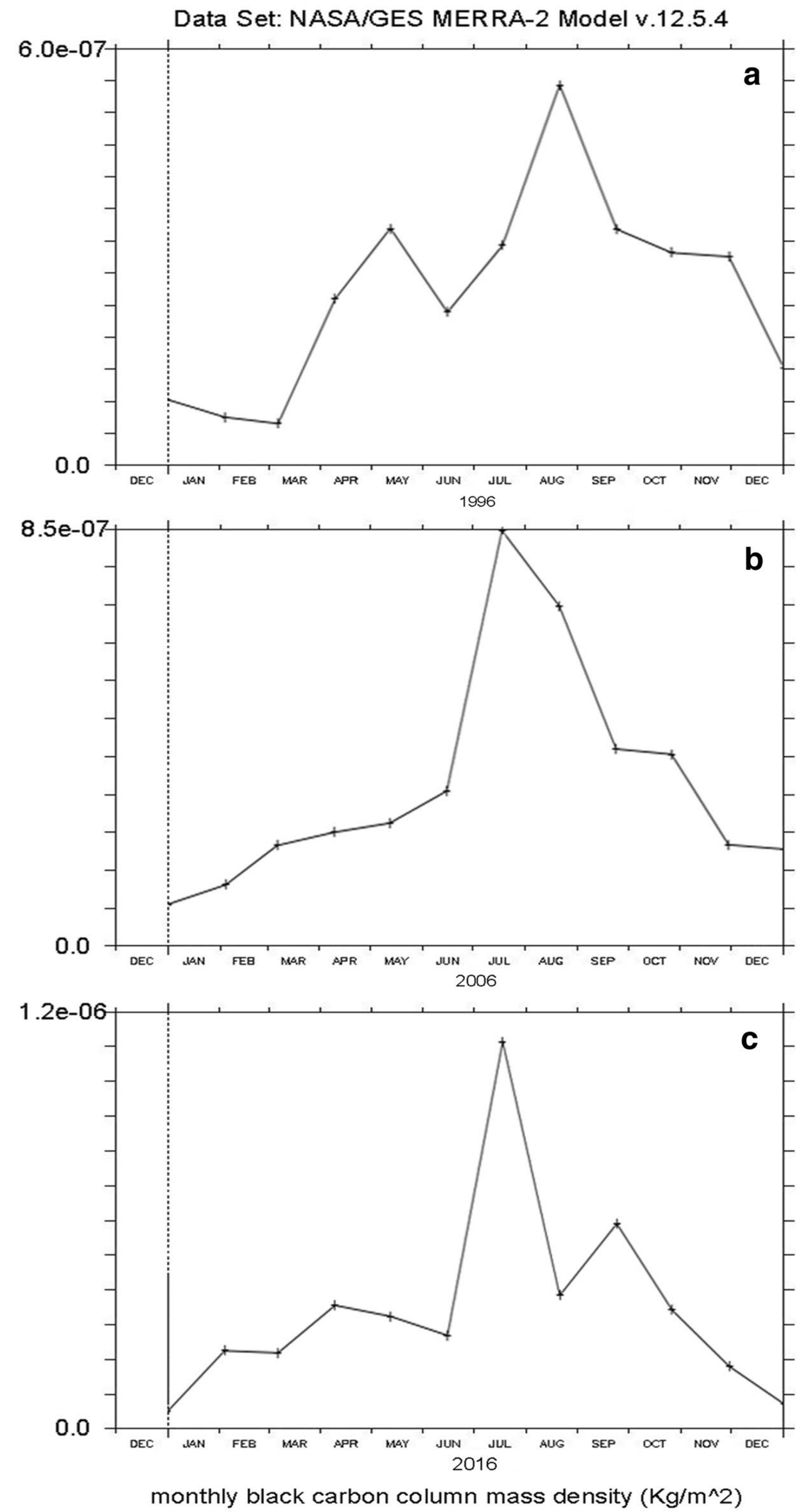

Fig. 3 Monthly black carbon column mass density extracted from NASA/GES MERRA-2 model for three time windows **a** 1996, **b** 2006, and **c** 2016

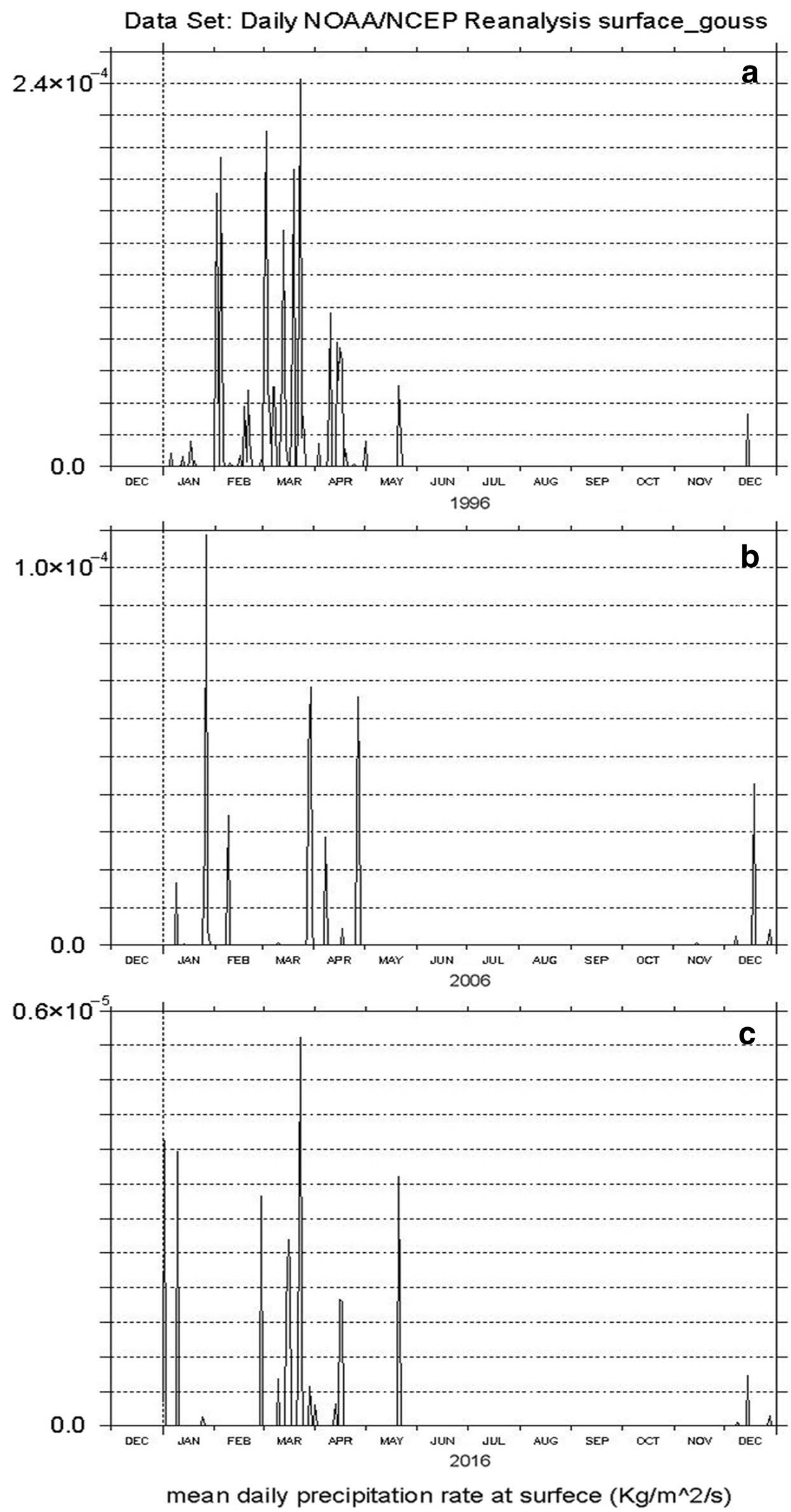

Fig. 4 Daily precipitation rate at surface extracted from NOAA/NCEP reanalysis data for three time windows **a** 1996, **b** 2006, and **c** 2016

Based on the variations of climatic parameters, four parameters of surface temperature, surface long-wave flux, total ozone, and black carbon density have continuously increased during 1996–2016. For instance, black carbon density in the atmospheric column has enhanced from 424 to 631 μg/m^2, indicating a primary signal of air pollution and regional climate change.

Contrarily, two parameters of total precipitation and convective precipitation have suddenly decreased in the same period. Mean annual total precipitation has decreased from 218 to 31 mm, while the quota of convective precipitation has enhanced from 36 to 80% in the same period. Temporal change of climatic parameters within three decades indicated the average values of +3 K, +5 Dobsons, +6 W/m^2, 207 μg/m^2, − 187 mm and − 54 mm for mean surface temperature, total ozone, surface long-wave flux, black carbon density, total precipitation, and convective precipitation in the study area. This evidence could be accounted for as signals of regional climate change affected by urban growth.

Data correlation test

A correlation test was calculated to reveal statistical evidence of the urban sprawl effect on regional climate change (Table 7). This table suitably confirmed a positive relationship between four climatic parameters (surface temperature, surface long-wave flux, total ozone, and black carbon density) and urban sprawl based on three temporal sequences in the study area (*R* from 0.827 to 0.981). In parallel, a negative relationship between two climatic parameters (total precipitation and convective precipitation) and urban sprawl was estimated based on three temporal sequences in the study area (*R* from − 0.691 to − 0.805). Consequently, this result confirmed the possible effects of urban sprawl on regional climatic variations. A correlation test was calculated to reveal statistical evidence of the urban sprawl effect on regional climate change (Table 7). This table suitably confirmed a positive relationship between four climatic parameters (surface temperature, surface long-wave flux, total ozone, and black carbon density) and urban sprawl based on three temporal sequences in the study area (*R* from 0.827 to 0.981). In parallel, a negative relationship between two climatic parameters (total precipitation and convective precipitation) and urban sprawl was estimated based on three temporal sequences in the study area (*R* from − 0.691 to − 0.805). Consequently, this result confirmed the possible effects of urban sprawl on climatic variations.

Table 7 The correlations between urban sprawl index and climatic parameters

Parameters	Pearson test	Urban sprawl index	Surface temperature	Total precipitation	Convective precipitation	Total ozone	Black carbon density	Surface long-wave flux
Urban sprawl index	R	1	0.981	− 0.805	− 0.681	0.865	0.827	0.927
	Sig.		0.123	0.404	0.523	0.335	0.380	0.244
	N	3	3	3	3	3	3	3
Surface temperature	R	0.981	1	− 0.904	− 0.809	0.945	0.920	0.982
	Sig.	0.123		0.281	0.400	0.212	0.257	0.121
	N	3	3	3	3	3	3	3
Total precipitation	R	− 0.805	− 0.904	1	0.983	− 0.994	− 0.999	− 0.969
	Sig.	0.404	0.281		0.119	0.069	0.024	0.160
	N	3	3	3	3	3	3	3
Convective precipitation	R	− 0.681	− 0.809	0.983	1	− 0.957	− 0.975	− 0.905
	Sig.	0.523	0.400	0.119		0.188	0.143	0.279
	N	3	3	3	3	3	3	3
Total ozone	R	0.865	0.945	− 0.994	− 0.957	1	0.998	0.990
	Sig.	0.335	0.212	0.069	0.188		0.044	0.091
	N	3	3	3	3	3	3	3
Black carbon density	R	0.827	0.920	− 0.999	− 0.975	0.998	1	0.977
	Sig.	0.380	0.257	0.024	0.143	0.044		0.136
	N	3	3	3	3	3	3	3
Surface long-wave flux	R	0.927	0.982	− 0.969	− 0.905	0.990	0.977	1
	Sig.	0.244	0.121	0.160	0.279	0.091	0.136	
	N	3	3	3	3	3	3	3

R: correlation ratio, Sig.: significance, N: number of three temporal sequences

Potentially, a widespread urban metabolism can increase the exhaustion of air pollutions such as total ozone and black carbon in the expanded place. The extended release of mentioned pollutants can induce air greenhouse effect and consequently increase the surface long-wave flux and urban heat island, which enhance the surface temperature critically. The urban sprawl development can affect negatively on precipitation parameters, perhaps due to the effects of widening urban heat island on dehydration of cloud cover and water condensation. In a recent paper, the role of urbanization effects on the regional climate change has been identified in the Mashhad city and some major cities of Iran (Sarvari 2019). On this basis, the significant positive relationships ($R=+0.814$ to $+0.998$) were observed between temperature and upward long-wave radiation and urban population in addition to the negative correlations ($R=-0.375$ to -0.949) between precipitation and population. It is observed that the results of the present study are in accordant to the indications by Sarvari (2019).

Conclusion

The main purpose of the present study was to study the urban sprawl and its impacts on regional climate change in Mashhad urban region. For this purpose, an integrated procedure of factor analysis and analytical network process named as F'ANP model was considered to measure urban sprawl within three time-periods of 1996, 2006 and 2016 in Mashhad, northeastern Iran. Based on the urban sprawl index, in the last decades (from 1996 to 2016), Mashhad city has experienced a rapid horizontal growth resulted to the growth of population, the high volume of physical construction, expanded transportation, and land degradation. The urban sprawl indicates a significant change in the urban lithosphere and atmosphere during the last decades. For instance, a researcher revealed a significant and positive relationship between the aggregated urban growth pattern index and air pollution in most parts of China (Mou et al. 2018).

Increase in urban population reflects an increase in demand for physical construction, transportation, and assumption of fuels such as oil and natural gases. Accordingly, the level of urban pollution, heat islands, and greenhouse gases such as ozone concentration, long-wave flux, and carbon density in the urban atmosphere are increased. This chain of variations plays the main role in the increasing temperature (Alpert et al. 2005). The urban sprawl impact is evident in the surveyed trends of temperatures over the many urbanized regions of Iran, including Mashhad (Choobari and Najafi 2018). Similar results of climate changes have been observed repeatedly in other urbanized regions of the world (Da Silva et al. 2010). In addition to surface temperature, the urban sprawl can effect on decreasing trend of precipitation and its change to convective type due to the expansion of heat island impacts. In this regard, the correlation test confirmed possible effects of urban sprawl on the aforementioned climatic variations in the study area within three temporal sequences of 1996, 2006, and 2016.

Abbreviations

USI: urban sprawl index; FA: factor analysis; ANP: analytical network process; F'ANP: factor analysis and analytical network process; GIS: geographical information system; SCI: Statistical Center of Iran; IMO: Iranian Meteorological Organization; NASA: National Aeronautics and Space Administration; GES: Goddard Earth Sciences; Giovanni: Geospatial Interactive Online Visualization, and Analysis Infrastructure; NOAA: National Oceanic and Atmospheric Administration; NCEP: National Centers for Environmental Prediction; APDRC: Asia Pacific Data Research Center.

Acknowledgements

We thank anonymous reviewers for technical suggestions on data interpretations.

Informed consent

Informed consent was obtained from individual participant included in the study.

Authors' contributions

All authors were equally involved in analyzing and editing the paper. All authors read and approved the final manuscript.

Funding

This study was not funded by any grant.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon request.

Ethics approval and consent to participate

This article does not contain any studies with participants performed by any of the authors.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no Competing interests.

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Received: 5 March 2019 Accepted: 3 June 2019
Published online: 11 June 2019

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