

## Research Paper

# The impacts of wind variability function on urban heat island Case study: Karaj city, Iran

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### Abstract

This paper examines the utility of the air pollution Model (TAPM) in simulating meteorology and dispersion of PM10 and wind data in order to assess The Impacts of Wind Variability Function on Urban Heat Island for the day of 25, November, 2012 in Karaj city that experienced severe degradation in air quality. Drawing, Skew-T diagrams, maps of surface pressure (500hp), omega (850hp) and atmospheric conditions at 300 – 900hp level are used for analysis. Due to wind patterns, the air pollution behavior is simulated regarding to resolution of 5 km for output amplitude. Simulations of the PM10 and wind data in ten metric levels from three point of city are prepared according to synoptic conditions. Meteorology and PM10 dispersion results indicate that in spite of prevailed wind direction (West to East) in the mentioned day the effect of wind threshold on the air filtration is reduced and heat island formation is occurred as a result of reduction in air flow speed in urban areas. Therefore, it is essential to consider adopted strategies to mitigate urban heat islands such as the principles of bioclimatic architecture, urban morphology, urban infrastructure-related measures (architecture and land use planning) for urban planning.

**Keywords:** Urban heat island, TAPM, Wind patterns, Bioclimatic architecture, Karaj, Iran.

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## 1. INTRODUCTION

Air pollution on the human life is revealed when people lived in concentrated communities in stable form. It has become as an international problem as a result of countries development. A range of experiments have been considered by international and regional organizations to prevent the extend of pollution. These procedures have been indicated good results and appropriate standards relating to urban air.

Inharmonic correlation between cities and industrial development in the past years is unfavorable especially in metropolitans. This matter has impacted the environment pollution in wide range particularly in urban that polluted days are more than of suburb [1].

Anthropogenic factors such as population growth rate, rural migration, expanding factories, traffics and geographical factors like geographical location, topography and temperature inversion are intensified Karaj air pollution.

Therefore, present study is completed by emphasizing

on a synoptic sample for extreme pollution day on December of 2012 and relative effect of wind.

The impact of wind flow model and wind threshold of Karaj on the Urban Heat Island formation are evaluated in order to enable urban officials for predicting the critical points in the future.

The temperature excess of cities that is caused by urbanization (the so-called urban heat island (UHI)) is a well-known and thoroughly researched phenomenon of urban climatology. In cities with the temperate climatic zone, structures and features of the UHI are well documented [2] [3].

Phenomena of heat island imply temperature intensify of concentrated community in each area, urban, suburbs against environs principals [4].

Studies illustrate that the temperature difference between urban and suburb in minimum temperature condition (nights, winter) will be more obvious. The average temperature in the city can be about 0.3 to 0.4 Celsius degrees and the average of minimum temperature from 1.2 to 1.7 degree more than suburb [5]. A number of reasons for this temperature differences can be release of anthropogenic global warming (caused by fossil fuels), the increase in urban pollution layer by absorption of long wave radiation emitted from the surface that part of it will

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emit to surface of land again, geometry of city with a unique three dimensional structure by high buildings causing air stagnation or slow speed of wind that make lower cold air entrance to cities, change in land shield, spoiling vegetation, making impermeable surfaces and constructed material such as asphalt and concrete that have upper heat capacity decrease evaporation ,transpiration and slowly release the absorbed energy [6].

Karaj city with population of about 2 million people as a megalopolis has been facing to rapid growth and unplanned development in the past decade. The lack of capability or enough time to organize urban fabrics and acceptable infrastructure have caused low qualitative features for population needs. However, the trend of population growth in Tehran (Capital of Iran) has declined over the past decade but Alborz province's population continues to rise about 300000 people and the displacement of migration process is from large city to small of province. Thus, regarding to especial situation of this city that is located between connection of capital and 15 provinces of north and west of country, a huge amount of public and private transportation with heavy traffic are active that the most of air pollution are caused by these matters. This position has disrupted reasonable balance between population, anatomy and activities in the region where the applying a coordinated policies to control and amend the physical development in incomplete hierarchy of activities has made very difficult. Therefore, exact understanding of the sources of air pollution and factors that led to discharge of pollutants in this city is essential.

Along with the other atmosphere conditions seems the factor of wind patterns concerning to direction and velocity of the emitting of pollutants for surveying of the process heat island forming are very essential. It is important to consider impact of the wind in managing of pollution and urban heat island. The urban heat island will be influenced by the wind patterns changes in urban and suburb of city which cause important effect such as air conduction and dispersal of the pollutants.

## 2. RESEARCH BACKGROUND

Emphasizing on living in a healthy environment and cleaned air has been considered by scientists and philosophers. The most important and effective public health benefits of clean were Hippocrates believes.

Avicenna believes that existence of dust in the air is one of reason for the failure of human life. Issued statement by Edward in 1330, saying "all those who can hear me, be aware that any one that burning coal is guilty and loss his head".

In the case of Hungary, studying of the maximum speed, direction of wind and monitoring of urban heat island formation lead to consider new policy for urban design, building restriction in the direction of the wind and reduction of anthropogenic heat [7].

Numerical modeling of the atmospheric Processes is regarded by entrance of computer into human life from 1970. But about two decade was needed in order to achieve the goal. Aldrin Numerical modeling has tried to

find a solution for estimating the relation between pollution parameters such as PM10 and NOX pollutants, traffic volume and meteorological variable. His model is based on hourly data and long range in the area of Oslo in Norway [8].

Abel et al is completed wind flow modeling and it's role on synthetic heat conducted in regional scale and has tried to assess pollution tools from past till now to get their efficiency and weaknesses [9]. He has presented a model of air pollution in order to take a new approach to this area.

Ashok et al has investigated air pollution by using PM<sub>10</sub> emissions during winter in Australia Lastun[10]. His aim was identifying the city capacity for acceptance of forests fuels by using TAPM model. The simulation results indicate that PM10 pollution in cities are revealed when 20 percent of city residents used forest fuels. In another study, he has estimated TAPM model and its efficiency through comparison between urban and rural areas regarding to pollution and it's actual data measurement.

In Iran, Khosravi and Ghobadi has studied located position of population, relative changes during two decades of census (1997, 2007) and it's affection on heat island function in urban area of alborz province [11]. The results confirm that there are correlation meaningful between fluctuations of population entropy and heat island intensity. more population are produced more non-natural heat that increase intensity of heat island . Thus, the migration of population from metropolitan to the cities is declining this trend concerning to wind threshold. Climate patterns elaborative are suggested in further.

Ranjbar et al have performed numerical simulations of the heat island in Tehran. that indicate prevailed wind pattern has weaken the heat island at night [5]. The simulations are completed for two different days; ones under dominated condition of polar cold air mass and the other under dominated the tropical air mass. In the presence of polar cold air mass, heat island is formed in the north of Tehran by high intensity but in the tropical air mass condition, heat island intensity is low. Arab Hoseini has surveyed the effect of surface roughness of boundary flux in dimension of 10 to 20 KM by using Boussinesq Equations in the suburb of Esfahan [12]. The simulation results show that generated winds in this region are strongly influenced by local factors. Mohseni has considered the effect of atmospheric factors on the Tehran air pollution[13].

Moghadam has considered the relation of air pollution and inversion for Tehran climate [14]. Pourahmad has surveyed the role of climate and geographical structure in the air pollution of Tehran [15]. Alijani has researched the effect of mountain on Tehran air qualities [16] and Amiri has considered the effect of factors and climate elements in the air pollution forming in Tehran [17].

## 3. MATERIAL AND METHODS

Synoptic station is located in the city of Karaj with longitude 50° 57' E and the latitude 35° 48' N. Alborz mountains have the most important role in modeling the

climate system of Karaj as in the cold season is affected by north, northwest, west and especially southwest systems which rainfall occurs by activities of these systems. Rain fall is started in the month of November and will be continue up to early may. Since, this province is located in initial entrance of Mediterranean Sea moisture. Therefore,

the convection rainfall is occurred because of especial condition of topography regarding to reception of radiation energy and orographic.

Due to general situation of state, north climate are moist and semi-moist in the region that is opposed with south climate which are dry and semi-dry.

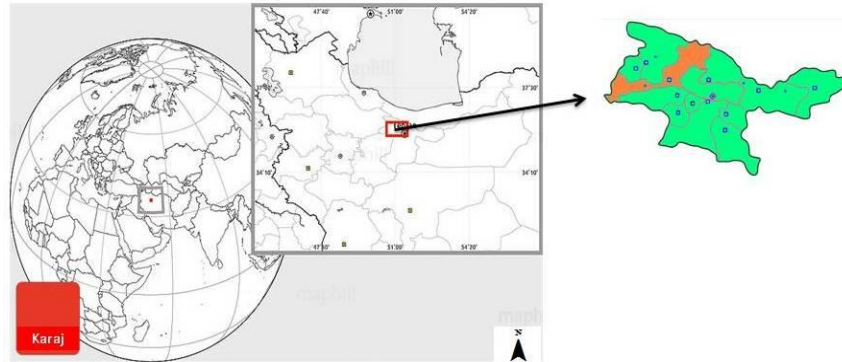


Fig. 1 Area of study

Climate and pollution data that are used for this study is obtained from Synoptic station and three other stations of air pollution assessment that are related to Karaj environmental organization.

Due to belief of scientific society about priority of dynamical results to statistical, therefore, the Model of TAPM is used in the present study to stimulate numerical model for air pollution and wind pattern. Model is developed by industrial research organization for regional and medium scale in Australia. Synoptic limitation of this study is 1000×1000 KM and height of 8 KM from atmosphere. Two sets of data are needed for this model. Ones, synoptic and climate data and other, surface data such as topography, vegetation, water and soil that are obtained with a resolution of 1KM \* 1 KM by supplier of model that is updated yearly. Thus, minimum coverage of synoptic model resolution is 75 KM.

Data can be feed in four ways into the program:

A –Spot approach: pollutants source and relative area are considered based on it's specification, such as factory.

B –Line approach: Road and streets are in this category

model is simulated by derived emission from roads that are given to program.

C –Regional approach: Model is simulated by especial dimension of regional that are given to program.

D –Network way: Combine of above methods can be done by program.

For study of pollution by TAMP model, Firstly, data of pollutants emission for the period of 2011 – 2012 are derived from stations of Mohitzist (51.08° long, 35.32° lat), Farhangsara (51.37° long, 35.47° lat), Metro (51.11° long, 35.32° lat). Two main pollutants (CO and PM )<sup>1</sup> are chosen for selected day. Then, (Skew – T) diagram, maps of surface in 500<sub>hp</sub> level and land surface for analysis of temperature variation and circumstance of process patterns are prepared . Thus, map of omega in 850hp level is used for analysis of vertical structure flow of atmosphere in selected day. Secondly, hourly wind data were derived from the synoptic station of Karaj. Finally, simulations of the wind data were performed by model. Then, analysis of the wind patterns by model, limit of wind threshold and their relation to formation of heat island were considered.

Table 1 Threshold of air pollutants

Type of pollutant	Average by weight micro (gram/m3)	Average by densit (ppm)	Average by time
SO2	350	.14	One hour
	100-150	.04-.06	Twenty four hours
	40-60	.015-.023	One year
CO	30	26	One hour
	10	9	Eight hours
NO2	400	.21	One hour
	150	.08	Twenty four hours
O3	150 – 200	.08-.1	One hour
	100 – 120	.05-.06	Eight hours
PM10	70		Twenty four hours

Source: Iran Department of Environment

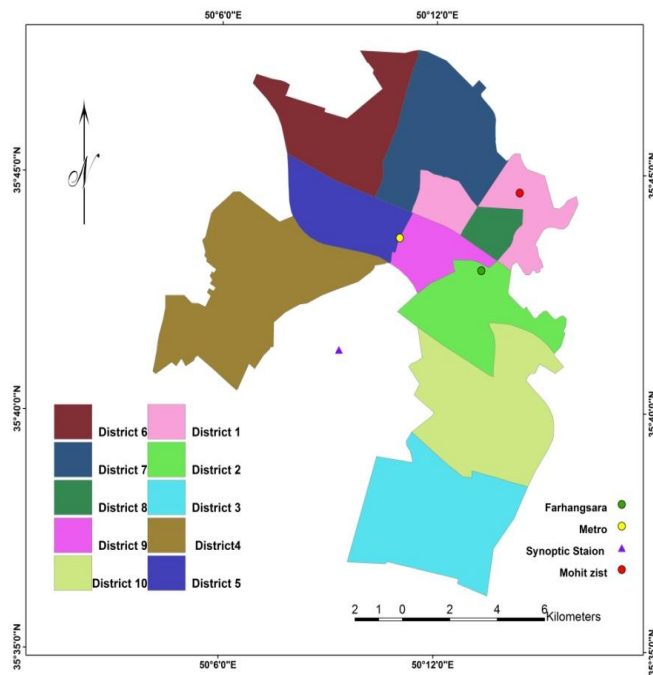


Fig. 2 Network of air pollution monitoring and synoptic stations of Karaj

#### 4. RESULTS AND DISCUSSION

Comparison of data with temperature inversion diagram and maps of omega in 850<sub>hp</sub> level are analyzed. Maps of surface in 500<sub>hp</sub> level are used for investigation of geopotential heights status. Table 1 shows air pollution thresholds that are confirmed by the Iran Department of Environment.

Fig. 3, indicate the diagram of temperature variation with height of (Skew T) in the day of study. Bold black curve in the right shows decreasing of environmental temperature that the existence or nonexistence of temperature inversion can be realized by it. If this curve deviates the right side imply the rise of temperature along

with increasing height. But the left side deviation shows that the temperature will be decreased however the height is increased. Temperature inversion is started from 850<sub>hp</sub> level that is continuing to 650<sub>hp</sub> level and depth of inversion at this day is about 1450 meter from height of 3000 – 4000 meter. Trend of increased temperature inversion layer is 10C° for each 1450 meter. There is another inversion layer in 450<sub>hp</sub> level that is not very intensive and trend of increased temperature is about 2C°. Temperature will decrease in 550<sub>hp</sub> level except another inversion layer in 350<sub>hp</sub> level that decreasing of temperature is about 12C°. Maximum humidity was observed in 500<sub>hp</sub>- 700<sub>hp</sub> that will be gradually decreased in upper level of 500<sub>hp</sub>.

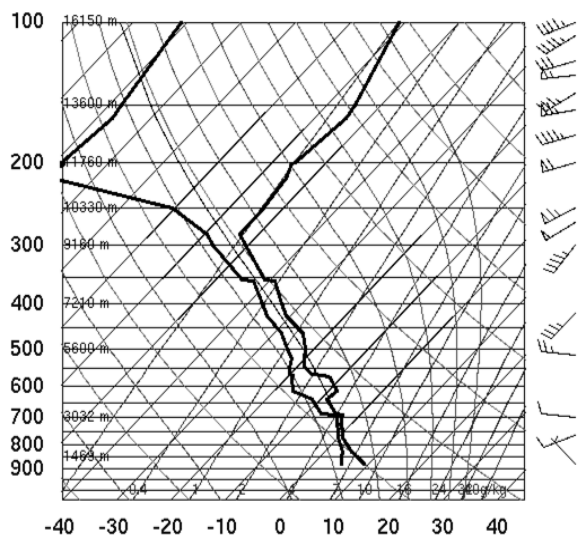


Fig. 3 Temperature variation graph with the height in the station

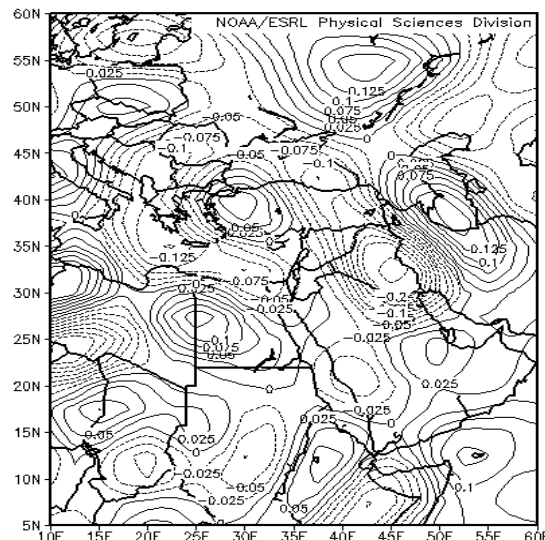


Fig. 4 Map of omega at 500hp level

Temperature inversion is occurred based on Height and thickness of layer that has the most impact on the pollution. As Fig. 4 is implied, Karaj air pollution is correlated with status of temperature inversion, pressure systems and vertical structure flow of atmosphere. Flow of air is descended for selected day and amount of omega is  $12_{hp}$  per second. Descending flow in  $850_{hp}$  level is outcome of inversion occurrence in the upper surfaces.

Fig. 5 shows distribution of Geopotential heights in  $500_{hp}$  level that Lines with the same height and far distance from each other that is indication of a deep ridge development. Mentioned Ridge is a part of high pressure system that is developed to west. Inversion in  $850_{hp}$  level is a type of radiation inversion and in  $650_{hp}$  level is a type of inversion that is caused by penetrating of bulk cold advection inversion.

Fig. 6, shows dominant of synoptic pattern at the surface. Iran is taken over by moving high pressure part of Siberian to south and south east that has created a stable condition in Karaj and northwest of country. Land surface maps in 18, Dec, 2012 clarify that the low pressure is located in the north coast of Caspian Sea and high pressure center is located in the other part of country. Such centers are reinforced during days of 19<sup>th</sup> and 20<sup>th</sup>. As maps show, cell of  $1017_{hp}$  is in the center of country. Thus, penetrating of temperature ridges to west can be seen.

Deriving the data and statistics about air quality of Karaj indicate unhealthy conditions at these times and in the days of 24<sup>th</sup> and 25<sup>th</sup> have been worse.

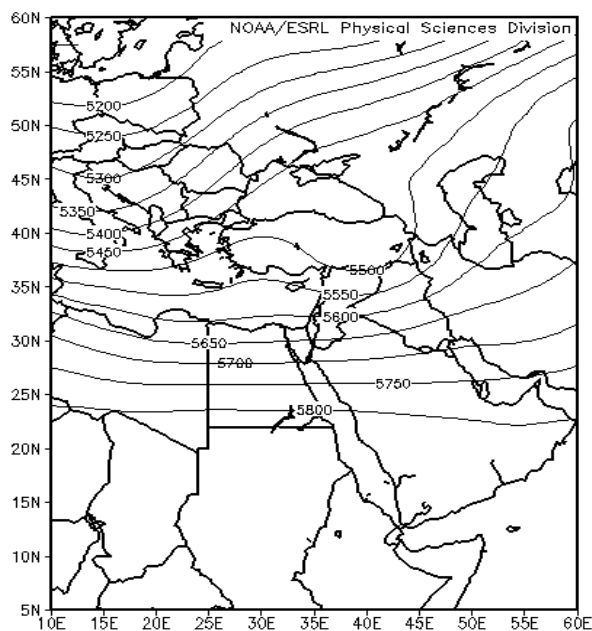


Fig. 5 Map of geopotential height at  $500_{hp}$  level

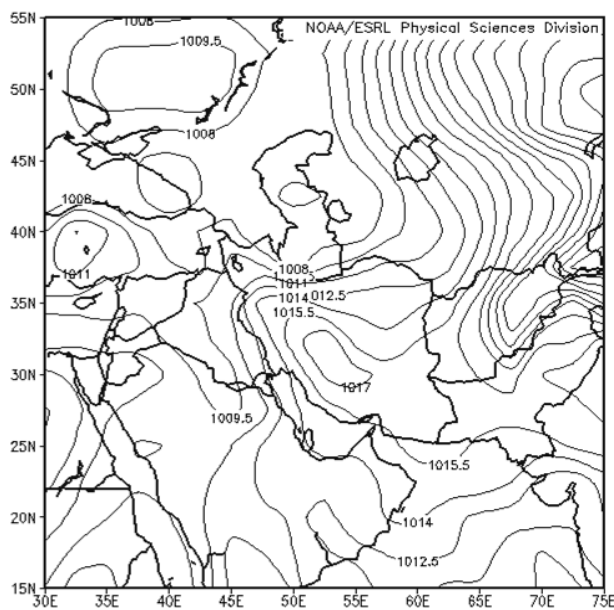


Fig. 6 Map of land surface pressure

Table 2 shows distribution of pollution for 18 to 28 of Dec. In all cases, 40% of pollution is near the surface of land, 20% in  $700_{hp}$  to  $800_{hp}$  level and others in the upper level are occurred.

#### 4.1. Dominant trend of wind pattern in the Karaj

Firstly, wind pattern dominance in the selected day is surveyed. The results show that the wind patterns have not constant cycle in 24 hours and different treatments are

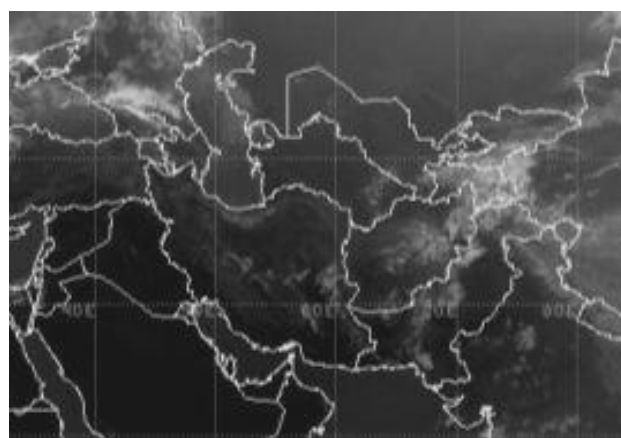


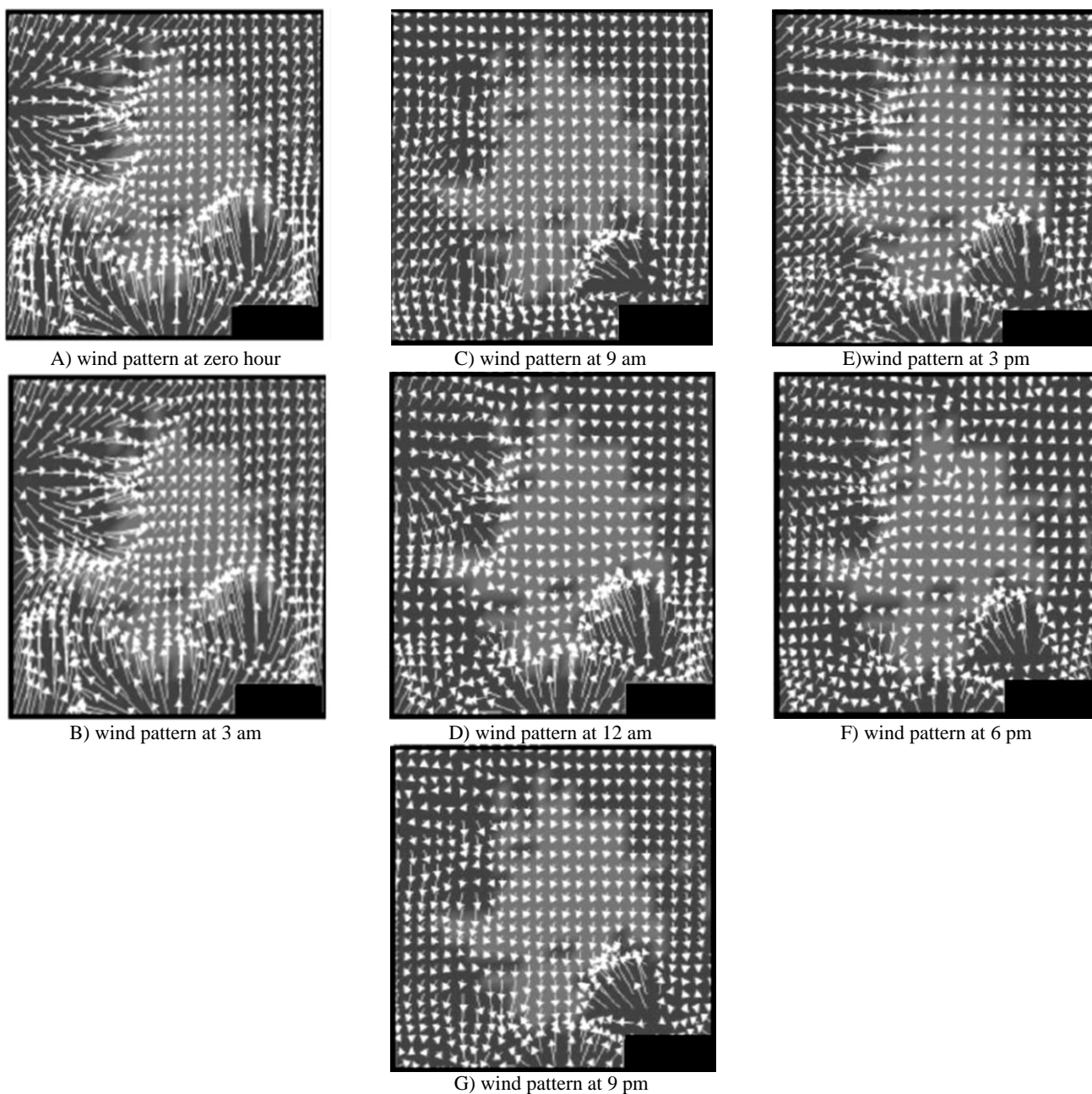
Fig. 7 In sat (KALPANA-I) Satellite picture of the research day

seen. As the wind flow is almost the same at night but it is changed at 9 am. The wind flow is dominated gradually to northwest and in the midnight is south and west in the city. These changes are confirmed by arranged images during of 24 hours. It seems that located mountain in the area are the main reason for these behaviors.

In order to ensure about function of presented model, wind patterns for selected day of research (Fig. 9) are plotted to show speed and direction of wind hourly.

**Table 2** Distribution of air pollution in the Karaj between days 18 to 28 of December 2012

Wind speed average	Wind direction	Inversion percentage	No inversion	Surface	Average	Intensive	Very intensive
1-6 Knots	West	%40	-	800-900	1	2	<b>1</b>
2-6 Knots	East - West	%20	-	700-800	1	1	-
4-10 Knots	East - West	%4	-	600-700	1	-	-
6-12 Knots	West	%10	-	500-600	-	1	<b>1</b>
20-12 Knots	West	%2	-	400-500	-	-	-
20-12 Knots	West	%2	-	300-400	-	1	-
<b>Total</b>		<b>%78</b>			<b>3</b>	<b>5</b>	<b>2</b>



**Fig. 8** Simulation of wind patterns in the 10-meter level on 25, November by Model

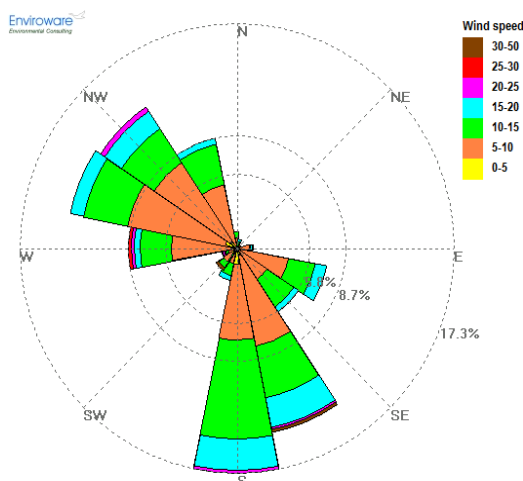


Fig. 9 wind directions of 18 to 28 December

Thus, the impact of synoptic systems on the wind patterns indicate rising trend of the wind speed and Relation between growth of wind speed and height.

Statistical measures, such as Root Mean Square Error (RMSE) and Index of Agreement (IOA) are used to evaluate TAPM’s performance [18]. The IOA is a measure of the skill of the model in predicting variations about the observed mean; a value above 0.5 is considered to be good. Table 3 shows performance statistics for the Meteorological component of TAPM. The Index of Agreement (IOA) between modeled and observed data is above 0.60 for all of the variables, with relative humidity scoring the lowest value (0.43) [19]. The wind speed, east–west direction and north–south of wind velocity score 0.65, 0.71, and 0.76 respectively. Although these values imply the correct performance of model but they are still lower than typical examples of simulation by TAPM from other locations [19] [20]. It is believed that one of the reasons for this performance by TAPM in Karaj is the relatively Significant sloping topography toward north of area and alborz mountains.

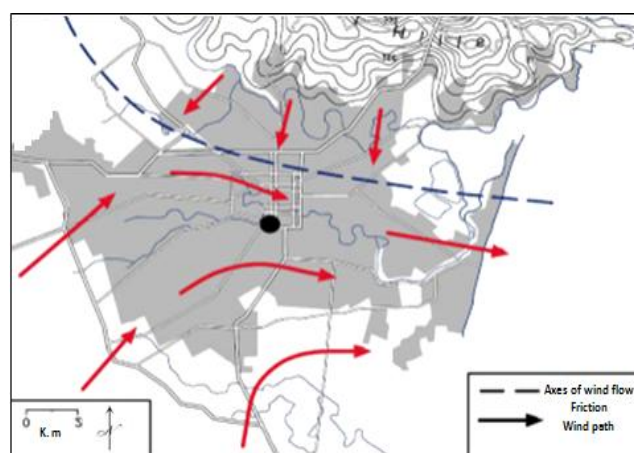


Fig. 10 Average trend of the wind movement over the urban density in research day

#### 4.2. Impact of the wind patterns on anthropogenic heat

After analyzing the wind pattern in the selected day, hourly pollutants data of CO and PM<sub>10</sub> are derived from stations of Environment (Mohitzist), metro and Farhangsara. (Table 4)

Table 3 Statistics for the TAPM simulation

MEAN_OBS	MEAN_OBS	MEAN_MOD	STD_OBS	STD_MOD	CORR	RMSE	IOA
Wind speed (m.s)	15.5	15.6	1.4	1.7	0.49	1.60	<b>0.65</b>
West–East (u) component of wind velocity (m.s)	6.3	6.4	2.3	2.4	0.54	2.33	<b>0.71</b>
North–South (v) component of wind velocity(m.s)	3.3	3.2	1.6	1.5	0.64	1.63	<b>0.76</b>
Relative humidity (%)	43	45	1.3	1.5	0.45	3.18	<b>0.62</b>

Table 4 Pollution detection in the day of research

Hour	Farhangsara		Metro		Mohitzist	
	PM10 (ug/m3)	CO (ppm)	PM10 (ug/m3)	CO (ppm)	PM10 (ug/m3)	CO (ppm)
1	53	6.5	46	4.5	10	1.5
2	52	6.3	45	4.3	8	1.3
3	57	7	50	5	7	2
4	59	10	52	8	6	.5
5	63	12	56	10	5	.7
6	67	14	60	12	5	.9

7	67	6.2	60	4.2	4	1.2
8	70	6.5	63	4.5	4	1.5
9	72	6.7	65	4.7	4	1.7
10	74	7	67	5	8	2
11	80	7.3	73	5.3	12	2.3
12	85	7.5	78	5.5	13	2.5
13	87	6.5	80	4.5	14	1.5
14	90	9.5	83	7.5	14	4.5
15	92	10.5	85	8.5	13	.55
16	80	11	73	9	12	6
18	69	10.5	62	8.5	13	5.5
19	68	6.5	61	4.5	14	1.5
20	59	7	52	5	13	2
21	53	6.2	46	4.2	13	1.2
22	42	6.3	35	4.3	13	1.3
23	43	6.4	36	4.4	11	1.4
24	40	6	33	4	11	1

There are no allocated data in the table for the south and northwest of city because of the lack of pollution measurement stations. As mentioned, the wind pattern direction in the greater part of day is to west and south. The data in table 4 show that the lowest amount of pollution is in the station of Mohitzist that have meaningful different with another stations data. metro station has lower amount of pollutants. But the growth rate of pollutions in the Farhangsara station is high. It seems that west and northwest direction of wind are dominated to Mohitzist station area. The impacts of city's fiber on the speed of wind are the reason for pollution in the Farhangsara station. These matter shows that direction of wind determine the amount of pollutants emission.

#### 4.3. Feasibility of the urban heat island formation

There is relation between the population and intensity of the heat island. Different idea is presented for it. Oke, has suggested the following equation for those cities that have been in Mid-latitude [21]. Since the population is a parameter for identifying the size of city. Therefore, Equation shows minimum variance (74%).The logarithm Equation between maximum intensity variations of heat island and population is as follow:

$$\Delta T_{\max} = 4.06 - \log p \cdot 2.01 \quad (1)$$

In above equation P is the population in the urban area. By supposing that population of Karaj is 1.8 million, the maximum temperature difference of urban and suburb will be 8.6 C°. Therefore, demographic data in two period of census are used to calculate the extent of wind threshold and intensity of heat island in order to analyze time variation of intensity.

The wind threshold is one of the most important quantities that have the main role to reduce the

concentration of air pollutants or increasing them. Therefore, the urban heat island formation is heavily affected by speed of wind. Amount of mixed cold air with warm air will be increased by raising the wind speed. As a result, intensity of heat island formation will be declined and formation of it will be difficult. Heat island formation is not possible at Threshold wind speed because of mixed air impact. Threshold wind speed is correlated to population of each area that is calculated by below equation [21] [22].

$$U_c = 3.4 \log p - 11.6 \quad (2)$$

P in the above equation represents the amount of population. Regarding to previous researches [11], the speed of wind threshold in the Karaj will be 8.61 meter per second by considering population of Karaj for about 1.8 million people.

**Table 5** Calculation of the threshold wind index and maximum heat island over the past two census periods in the city of Karaj

year	population	Uc	<sup>2</sup> ΔTmax
1997	940968	8.71	7.94
2007	1732275	9.61	8.47

Since the heat island formation is correlated to daily conditions, therefore using average of monthly data for analysis of this phenomenon is not appropriate. Hourly average in the relative station must be considered for calculation of the wind speeds.

According to table 6, the wind speed in the hours of 9:30am - 15:30pm is increasing; 9:30 am - 12:30pm is exceeded from limit of threshold. The wind speed In the 18:30pm, 6:30am and 21:30pm are relatively high and the heat island intensity has declined. So, it seems the best time for the heat island formation in the west area of Karaj is at 00:30am - 3:30am.

**Table 6** Average of hourly wind speed (knots) on the day of Research in the Station of Karaj

Karaj station	21:30	18:30	15:30	12:30	9:30	6:30	3:30	00:30
December	3.8	4.5	4.9	9.8	7.8	4.4	2.9	3.1



Referring to expressed threshold amount and variations of wind speed, maximum intensity of heat island has occurred between 9:30am and 3:30am and minimum values are mainly between hours of 12:30pm - 15:30pm.

In Fig. 11, Gray shading confirm the interaction between fluctuations in heat-island and changes of wind speed threshold

The results can be applied to predict air pollution of Karaj by consider of following assumption:

A-Air pollution in the city of Karaj is correlated to wind speed and direction patterns.

B - Intensity and extent of pollution are increased from west to East and South to North.

C - In case of synoptic system dominance, the wind pattern becomes more regular and the wind speed will increase by raising the height.

D - The wind pattern of daily is different of night on the Karaj. As its direction in the daily time is to the west and northwest while in the nightly time are to west and Southwest.

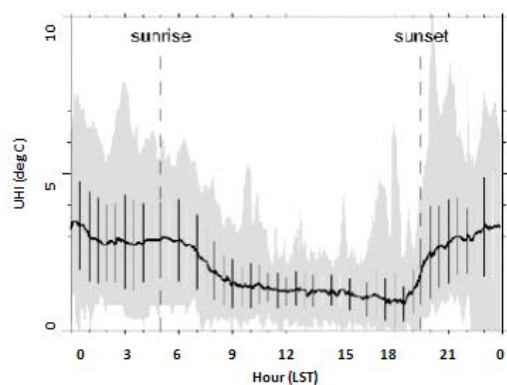


Fig. 11 UHI variations on research day

## 5. CONCLUSION

The accelerated development of the Karaj city has changed urban view. Surfaces have become impermeable and dry by replacement of vegetation to other spaces like asphalts. Continuation of this trend has warmed urban and suburb of region that create heat island with higher temperature. The intensity of urban heat island is impacting environment, life quality, gas pollutants emission and physical needs of urban as well as increasing the consumption of energy for cooling. The result shows the temperature difference between Karaj and suburb is an average of 3 - 6 Celsius degrees.

Maps of Sea level pressure and vertical structure flow of atmosphere for selected day indicate amount of pollutants that are more than the standard limitation. The temperature inversion occurs frequently near the surface of land which is impacted by surface radiation in the cold days of winter. This circumstance is illustrated the concentration of pollutants near the land surface that cannot be exhausted and transferred to upper level of atmosphere because of air subsidence. In the cold season, temperature inversion in troposphere middle levels is incoming to area from the upper latitude under the impact of the pressure systems.

Since direction of wind is from West to East, but concentration of building reduces the impact of wind flow in the cleaning of air. The amount of air pollution in Center and East of city are more than west and concentrated particulates of  $PM_{10}$  and  $CO_2$  pollutants are declined from North to South. Therefore, it is seemed that there is relation between intensity of inversion, spatial distribution of air pollution and it's incidence in the city.

The wind parameter is the most effective barrier against to heat island formation. Present study are identified the impact of wind patterns on the feasibility of heat island in selected day by using combined method and TAPM model. It can be concluded that the form and replacement of heat island are impacted when the wind velocity is lower than threshold. Thus, extent and location of maximum heat island intensity is controlled by the threshold wind velocity and the formation of heat island extend to area that has low wind velocity.

In the selected day, Dominance of wind in the suburb of city is considered as an obstacle in the heat island formation. But opportunity for the heat island formation on the other part of city is prepared because of decreasing of wind velocity intensity which is impacted by urban geometry.

Finally, In addition to the local climate, which is influenced by various meteorological parameters such as temperature, relative humidity and wind, a number of anthropogenic causes promote the emergence and intensification of urban heat islands. These causes are greenhouse gas emissions, gradual loss of urban vegetation cover, the impermeability and low albedo of materials, the thermal properties of materials, urban morphology and the size of cities as well as anthropogenic heat. Therefore, utilization of experts in the field that concerns about urban heat island mitigation strategies and Adopt the principles of bioclimatic architecture are strongly recommended in order to provides guidance for adapting buildings to the summer climatic conditions and decreasing the other causes of pollution and intensification of urban heat islands.

## NOTES

- 1- Atmospheric Aerosol
- 2- The temperature difference is based on C .

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