

A Photographic Investigation of Tehran's Light Pollution from North and East Directions

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ABSTRACT: Tehran is the most affected town by light pollution in Iran. In this study, the role of the regional topography in the distribution of light pollution in Tehran was evaluated by recording digital images and analyzing the obtained images from Tehran sky-glow by East and South in standard image-processing software. The scale of Tehran's glowing dome as measured by South is 17 mag/arc sec² or 0.017 cd/m², and 18.7 (mag/arc sec²) or 0.0035 cd/m² by East. Considering the approximately equal distance of the two viewpoints from the center of Tehran city, the calculated scale of Tehran's glowing dome by South is 1.36 times larger than from the East point.

Keywords: Light Pollution Measurement, Sky-glow, Artificial Light, Digital Photography

INTRODUCTION

From a long time ago, light has had a particular place in a human's worldview. Since the invention of the electric lamp 137 years ago, humans' attitude towards light has evolved. Ever since this invention, there is also the problem of its misuse, later called light pollution. The term "Light pollution" was about forty years ago, also by violating lighting standards. Since then environmental researchers gradually have come to the conclusion that light pollution had destructive effects on behavior, physiology, and morphology of wildlife with ever growing adverse effects following urbanization. In the past century, the extent and intensity of artificial light has increased so much that it has a major impact on the ecology of different species. However, it should be noted that there is a difference between astronomical light pollution that would limit the view of the sky and ecological light pollution that alters natural light affecting ecosystems (Longcore, and Rich, 2004). This means that, by modifying the light incidence angle, we may have a dark sky for the purpose of astronomical observations, but the effects of the artificial light on the ecosystem can still not be ignored. Meanwhile, it is a well-known fact that light causes certain tragic consequences on groups of species, which includes the death of migratory birds in the cities on route and sea turtles' getting lost due to the lights in their nesting beaches. The mentioned effects are only but

a small number of direct effects of light pollution. However, the exhaustion of fossil fuels through energy consumption and waste is considered another type of indirect effects of light pollution on the environment. An account of the impact of artificial light on ecological behaviors and populations reveals the necessity to protect pristine areas.

In the world dealing with development and economic growth, environmental degradations are inevitable. Nowadays, different progressive methods of measuring light pollution are used. These methods are in progress from year to year in terms of complexity and accuracy in measurement. The ultimate purpose of light pollution measurement is controlling energy consumption and maintaining the quality of sensitive ecosystems around cities. In recent years satellite instruments and complex computer models have been used to study light pollution. For the present study we made use of simple, accessible methods using a digital camera as a measurement instrument (Craine, 2012). This study aims to calculate the amount of light pollution in Tehran using digital images. Afterwards, its distribution is compared from the Eastern and Southern directions at a distance of 70 km from the geographical center of Tehran. To the North and to the West Tehran is bordering with Alborz Mountains and other towns, respectively, making such measurements practically impossible. As mentioned above there is a difference between astronomical and



biological light pollution but in general, any misuse or imbalance brings about certain damages; and there is no exception for light. According to the current standards, low or excessive lighting is one of such malpractices that are obviously in nobody's interest. Wherever artificial light is used in a non-standard manner, we will face light pollution; outdoors or indoors. For example, when unsuitable light is used for studying or walking outdoors or light is conspicuously emitted into the sky, there will be light pollution. In astronomy, light pollution refers to all man-made lights that impair observations of astronomers. In this respect, when it comes to light pollution, it is better to specify the concept that has been caused by interior or exterior lighting (Longcore and Rich, 2004), because the general principles and structure of lighting are different in these two spaces and, as a result, there will be different solutions for its alleviation.

It is useful to go through the definitions of light pollution in different countries: International Dark-Sky Association defines light pollution as:

“Any adverse effect of artificial light including sky-glow (brightening of the night sky over inhabited areas), Glare (excessive brightness that causes visual discomfort), Light trespass (light falling where it is not intended or needed), Accent light (excessive light used to draw attention), Clutter (bright, confusing and excessive groupings of light sources), and energy waste.” (Rajkhowa, 2012)

Jan Hollan, a member of Research Center for Climatic Change in Zech, defines light pollution as: “Light pollution is the alteration of light levels in an outdoor environment due to man-made sources of light (Hollan 2009).”

Martin Morgan Taylor proposes the following definition to the Department for Environment, Food and Rural Affairs in UK:

“Light pollution might be defined as any form of artificial light which shines outside of the area it is intended to illuminate, including light that is directed above the horizontal into the night sky creating sky-glow (which blocks out the night time stars) or which creates a danger by glare (Morgan 2006).”

In Iran, Afshin Danekar¹ defines light pollution as follows (Mahtabi, 2013):

"Light pollution is the release of electromagnetic radiation in the environment that disrupts ecological processes and functions and interferes with human comfort and activities".

Another definition, which we presented is: Light pollution refers to artificial lights that fail to meet the standards at an appropriate time or place and adversely affects the environment and pollutes the night sky (Mirzakhail, 2012).

It should be noted that in studies of light pollution, there is a difference between astronomical light pollution and biological light pollution. Artificial light may interfere with astronomical observations somewhere but they may be vital for human nightlife elsewhere. This creates often a conflict of interests which is very difficult to resolve. Here, with the help of light pollution measuring instruments, Tehran's light dome was measured and compared in the two directions of East and South.

METHODOLOGY OF LIGHT POLLUTION MEASUREMENT

There are two strategies for the determination of the light pollution of a city, estimation and amateur astronomical measurements (Mohajer, 2011). For the estimation of the light pollution models have been developed, which can be used by inserting some few parameters. Avoiding the painstaking work of field studies, the models are sufficiently developed to give an approximate estimate of the light pollution of a city. Some of these models are presented in Treanor (1973), Berry (1976), Pike (1976), Walker (1977) and Garstang (1986).

For the amateur astronomical measurements it is necessary for the observer to do the field work and use appropriate tools and analysis software to determine the extent of the light pollution of a city. One possible way is to use digital cameras. (Mirzakhail, 2014)

The study presented in this paper was conducted based on field observations and statistical analysis. After recording the images and processing in Adobe Photoshop software, the images were compared and analyzed against each other using ImageJ (Hiscocks, 2014).

We briefly introduce the image analysis procedure:

- Open Image/Image menu/Adjustment /Threshold

If you give a number in the threshold box, you can adjust the sensitivity to this effect. For example, the value in this article was started at 130 for the white area. As the number increases, the smaller area of sky-glow was selected.

It is better to keep the original layer or copy that with; Ctrl+J

After doing this effect, you have a black and white image. You should remove black area and keep bright area as a new layer.

- Select/Color Range/ok/Delete

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Image recording with fish eye lens (Hollan; 2006) in RAW format does not allow the disappearance and metamorphosis of the first-hand data. In this respect, the output data are more accurate and closer to reality. Accordingly, with this finesse, the image can be converted to Jpg format while more detailed information is preserved. (Hiscocks, 2014)

For taking the digital pictures, we followed the standards of data collection in measurement of sky-glow (Kollath, 2010, Elsahragty and Lee Kim, 2015)

The two images mentioned in this article were taken under conditions which follow the rules and principles below:

1. The Sun is at least 18 degrees below the horizon (astronomical twilight)
2. Moonless night
3. No cloud, fog or dust* (Kyba et al. 2011, Garstang 1991, Lolkema et al., 2010)
4. The two points targeted in the South and East of Tehran is chosen at a direct (air) distance of 70 kilometers away from Tehran's center
5. The two points were studied with corresponding equal imaging conditions including:

- Image specifications:

- Nikon D700
- Nikon 14-24 mm
- Exposure: 10 sec, ISO 200, f: 2.8, RAW format

- No direct light from artificial sources reaches the detector of the device.

- Images were taken two hours after sunset and at two successive nights to avoid being affected by seasonal variation in the distribution of light pollution. Seasonal variation includes cloudy, or dusty air. We also aimed to reduce the effect of variations due to citizen's activity and the lights of the recreational centers.

It should be noted that the North and South directions were excluded from this study due to mountains overlooking and interference of the planned area with Karaj, respectively.

To simplify the model calculations we have assumed Tehran as point-like source, although it extends over 50 km from east to west and 30 km from north to south.

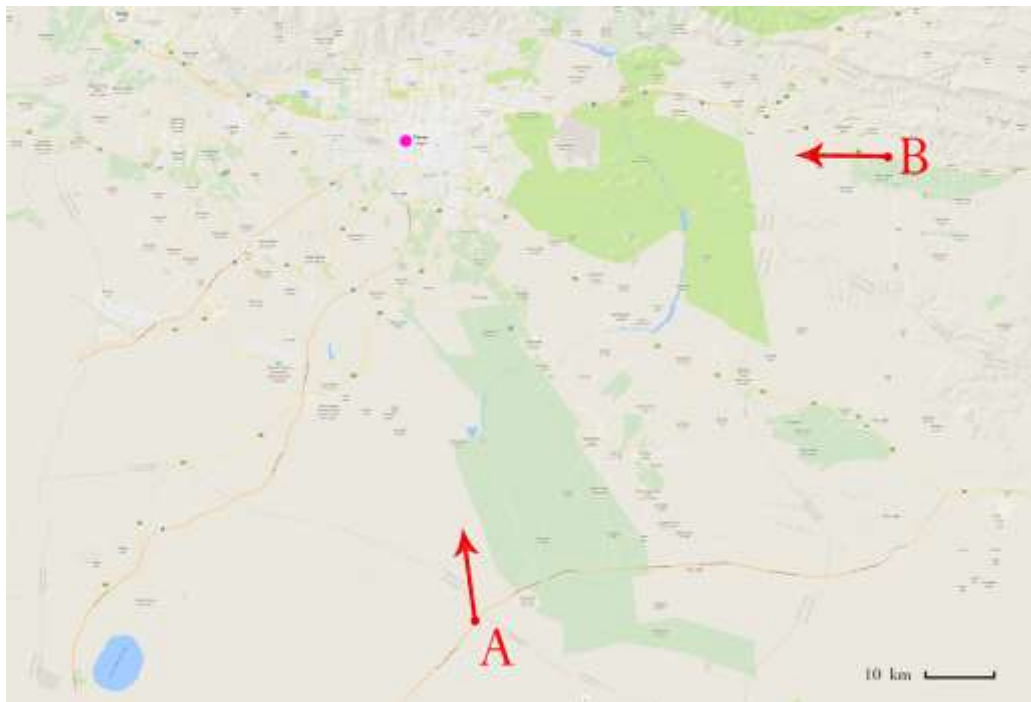


Figure 1. Location and directions of imaging within a radial distance of 70 km from Tehran center

A: Longitude E 51°25'8.66" and Latitude N 35°33'1.60"

B: Longitude E 52°57'9.48" and Latitude N 35°39'7.24"

Measuring light pollution using digital photography

At this time our measurements are concentrated on clear moonless nights with average

conditions. If such a night coincides with a national holiday the weather conditions may be dramatically different. For such purposes this study can later be

extended to cover the effects of variations of the sources of the light and air pollution.

Calculations of the sky-glow in Tehran’s Southern point

The sky-glow image of the Southern side indicates that the light dome of neighboring cities interferes with that of Tehran. Therefore, using sensitive layers in Photoshop and normal distribution and Pythagoras relationship, they were separated to ensure more accurate and reliable calculations.

Table 1. Environmental specifications Southernmost point in Tehran

Date	Hour	Longitude	Latitude	Elevation from sea level (m)	Temperature (C°)	SQM ² skyglow	SQM Zenith
Sep 12, 2015	22:15	E 51°25'8.66"	N 35°33'1.60"	825.84	+20	14.43	20.86

*SQM: Sky Quality Meter / Unihedron Com.

As an example for Eslamshahr the proportionality relationship is:

$$D_{TZ} = A \times SG_{TE} / L$$

Where A is the angle of camera lens, L is the length of the image (Figure 3) (mm), SG_{TE}^2 is the distance from the center of white areas of Tehran and Eslamshahr in the image (mm) and D_{TZ} is the angle between sky-glow of Tehran and Z point (degree).

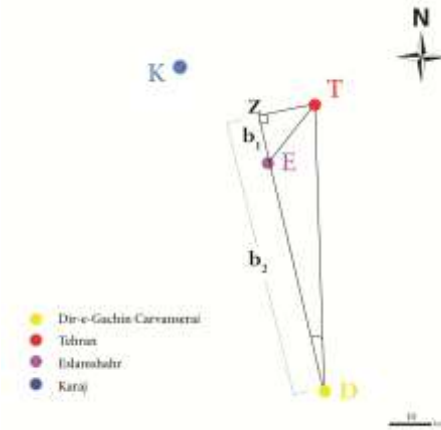


Figure 2. Geometrical construction of the distances between the agglomeration areas

As a result: $A = 90^\circ$ $SG_{TE} = 15 \text{ mm}$ $L = 150 \text{ mm}$

$D_{TZ} = 90 \times 15 / 150$ (1)
as a result $D_{TZ} = 9^\circ$ is the angle between Skyglow of Tehran and Z point.

² Skyglow

With the following equation, the length of b_2 is calculated:

$$b_2 = \cos D \times DT \quad (2)$$

$$b_2 = 69 \text{ km}$$

The length of b_1 is:
 $b_1^2 = (TE)^2 - (ZT)^2$ (3)
 $b_1^2 = (TE)^2 - (\sin D \times DT)^2$
 $b_1^2 = 25^2 - (\sin 9 \times 70)^2$
 $b_1^2 = \sqrt{504}$
 $b_1 = 22.5 \text{ km}$

The direct distance between the viewpoint the center of Eslamshahr is:

$$DE = b_2 - b_1 \quad (4)$$

$$DE = 69 - 22.5$$

$DE = 46.5 \text{ km}$ Direct from viewer to Eslamshahr
Our initial theory indicating that the middle skyglow belongs to Eslamshahr was proved after the verification of achieved distance between Tehran to Eslamshahr by Google Earth.

The same method is applied to detect the skyglow of Karaj.

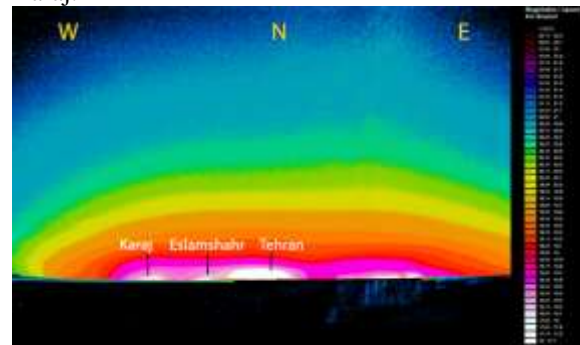


Figure 3. Separation of the skyglows of three cities of Tehran, Eslamshahr and Karaj using the software

Calculation of Tehran’s Southern skyglow using the normal distribution relationship:

T = Tehran
 l = Number of pixels smaller than a number of the skyglow (Here the white area is the first dome)
 $R = 70 \text{ km}$

$$L_T = I_T \times 4\pi^2_T$$

$$L_T = 384793 \times 4 \times 3.14 \times 70^2_T$$

$$L_T = 384793 \times 4 \times 3.14 \times 70^2_T$$

$$L_T = 23681700392$$

$$L_T = 23 \times 10^9$$

- According to the values of Appendix 1, the white light dome of Tehran's Southern side is equal to $17 \frac{mag}{arcsec^2}$ or $0.02 \text{ cd} / \text{m}^2$.

Calculations of the sky-glow in Tehran's Eastern point

Because of the heights on the Eastern side of Tehran, it was not possible to access the white area of the sky-glow dome. Moreover, Tehran's Eastern sky-glow did not overlap with another city's sky-glow.

Table 2. Environmental specifications of Eastern point in Tehran

Date	Hour	Longitude	Latitude	Elevation from sea level (m)	Temperature (C°)	SQM Sky-glow
Oct 12, 2015	22	E 52°57'9.48"	N 35°39'7.24"	2020,41	+10	16,74

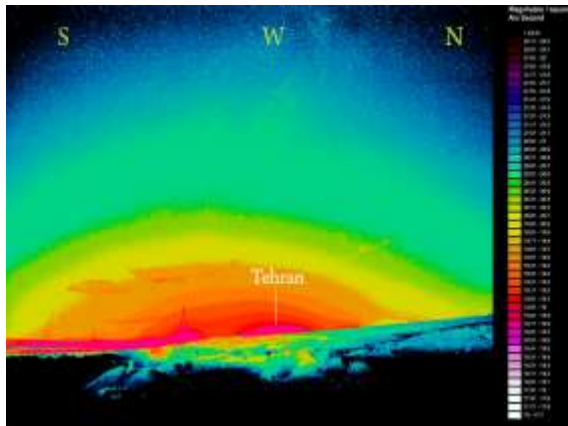


Figure 4. Simulation of Tehran sky-glow from the Eastern point

Possible effect of regional climate variations

As can be seen in fig. 1 the distance of points A and B is not large enough to significantly change the climate conditions with respect to Tehran. A rainy weather front would comprise the complete region.

Comparison of the results of the measurements in Tehran's East and South

The graphs of sky-glow intensity figure 1, extracted from ImageJ were used in this study to compare the two Southern and Eastern sky-glow of Tehran. Comparing Figures 2 and 3 as well as the graph 1, it was concluded that the heights in the Eastern side of Tehran reduce light pollution in the area and protect darkness-dependent ecosystems. Points A and B in Figure 1 represent the center point of Tehran sky-glow viewed from the two South and East directions, respectively. According to graph 1, the height and distribution of Tehran sky-glow in the Southern side is 1.36 times more than the Eastern side.

It is worth mentioning that other extreme points on these two graphs represent artifacts due to

lightings of roads that are close to the measurement location.

- According to the values of Figure 2, the first Eastern light $\frac{mag}{arcsec^2}$ dome of Tehran (the pink one) is $\frac{mag}{arcsec^2}$ equal to 18.7 or $0.004 \text{ cd} / \text{m}^2$.

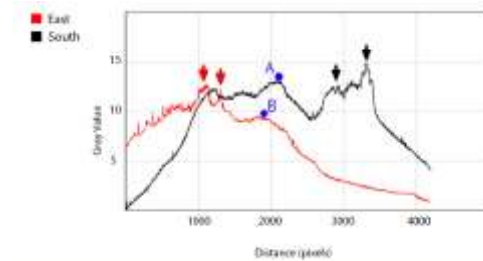


Figure 5. The graph comparing skyglow intensity in the Southern and Eastern side of Tehran. The arrows of red and black are the sources of artificial light which are close to viewer

Light pollution in Tehran

The growing trend of urbanization is among the causes of increasing light pollution. So it is required the light of the cities is continuously measured and monitored. Human beings as well as many animals and plants have developed in an environment where there were alternating periods of light and darkness during the day and seasons. This sequence has had very important effects on the performance and behavior of the organisms and the interactions between the organisms and the ecosystems. In this regard, degradation of the natural light patterns will leave significant impacts on the environment. In Iran, unfortunately, there is no sufficient awareness on the biological effects of light pollution on wildlife and plants, particularly at population and ecosystem level.

In the present study, it was necessary that the Eastern and Southern sides of Tehran be analyzed separately to measure the difference in

darkness of darkness-dependent ecosystems in either sides of Tehran.

Accordingly, given the absence of two similar areas for comparison (the white area of sky-glow), the lighting intensity graph (Graph 1) were used. The comparison of the two graphs shows that the light pollution distribution in Tehran on the Southern side is 1.36 times more than the Eastern side.

This value represents the fact that Tehran's Eastern heights act like a natural dam against the emission of light particles and keep the night ecosystems and better preserve the night sky's darkness. The highest elevations in East Tehran reach up to 2196 meters above sea level and are located at a distance of 21 kilometers from Tehran center. In contrast, the highest elevation³ is found in the Southern plain of Tehran measuring 1145 meters above sea level and is located in the Dir-e-Gachin Northwest Caravanserai, as given by the GPS coordinates location in the map. The viewpoints are 20 km and 63 km away from the mentioned elevation and Tehran center, respectively. Tehran's center is located over 1215 meters above sea level.

The use of light for lighting and accent lighting as dual purposes have two different purposes, each of which satisfies a certain requirement of urban life. The authorities' prioritization of light determines the amount of night lighting and should be aiming at night comfort. Unfortunately, in the past few years, more lighting has been used with the goal of providing security and the reduction of crime. As for the aesthetic aspects, no relaxing function is acknowledged for night lightings in Tehran. This type of lightings directly harms human health and ecosystems in addition to energy waste.

The results of the present study call attention to the critical situation in Tehran in terms of its population and vastness with respect to the amount of light pollution. Compared to the model of Walker (1970) we find that Tehran's light pollution is alarmingly high.

Walker's model predicts:

$$I = CPD^{-2.5}$$

$$I = 0.01 \times 8150000 \times 70^{-2.5}$$

$$I = 1.98\%$$

Where I is the sky brightness, C is a factor depending on the flux per inhabitant, P is the population and D is the distance from the center of the city.

Where: I=sky brightness, d = distance, P = population, C = depends on flux per inhabitant.

CONCLUSION

³ 55. 61'09" N 35" and 49.73'13" E 51"

Based on our findings, the light pollution of Southern Tehran is more than the East which may have some adverse effects on the ecosystem of that region. The brightness of night sky of South front is hazardous for the wildlife that sensitively relies on the night's darkness, given the fact that this area is on the birds' migration route. Therefore, much more attention has to be given to this problem by government authorities and there is a need to plan short- and medium-term programs to reduce light pollution in this region. The present study is just a starting step towards a long-term monitoring program involving more precise and professional equipment and with more profound modelling, taking into account the detailed topographic structure and the distribution of the population in Tehran.

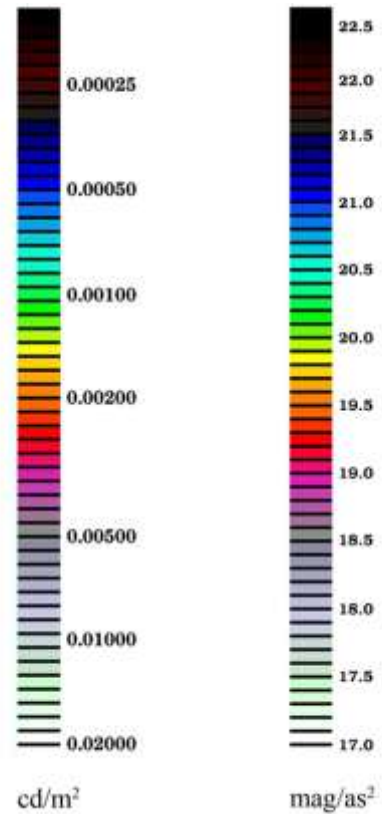


Figure 6: Table for values of candela per square meter and magnitude per arc seconds, color of sky-glow (Koll'ath 2010)

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