DETECTING INEFFICIENT LIGHTING SOLUTIONS:

Step-by-Step Geographic information system (GIS) Technique

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Abstract. Outdoor lighting is used to illuminate roadways, parking lots, yards, sidewalks, public meeting areas, signs, work sites, and buildings. It provides us with better visibility and a sense of security. When well designed and properly installed, outdoor lighting can be and is very useful in improving visibility and safety and a sense of security, while at the same time minimizing energy use and operating costs. But, because nobody thought at this, most street lights shine light not only on the nearby ground, where is needed, but also miles away and skywards. Thus a large fraction of the light is lost, at consumer expense and without his/her consent. In the other hand, shortage in street light may cause more crimes as well as accidents. Most of the wasted or short light comes from the poorly designed street lights. Billboards, decorative lights, poorly shielded security lights are part of the problem too, but the main culprit for the waste and ugly glow one sees above one's head at nights is from the streetlights. Thus, recent computer technology gives us tools to be employed for testing the quality of light. Geographic Information System (GIS) software could be utilized to achieve that mission through applying mapping technique. This technique could analyze digital photographs and define light polluted areas as well as bad lighted. This paper reveals that step by step technique, which employs hybrid technologies to solve such problem for better planning decisions.

1. Introduction

Light is necessary for vision, since it creates a world of visual information, in spit of that, Lighting should provide visual conditions in which people can function effectively, efficiently, and comfortably. Consequently artificial light is a flexible medium with great potential to improve nighttime safety,

security, aesthetics and visual character.

Although artificial lighting is one of the great hallmarks of civilization, which enhances our world, but may also cause annoyance by unwanted light intruding into our homes or shines onto our eyes or waste unnecessary amounts of energy and, therefore, money. The poles, columns, brackets and luminaires all remain visible during the day and, without careful design, may be unsightly. But the harms are recognized at night and can negatively effects in many ecological, environmental issues from side, and in human health, activities and aspects from other side.

Over the last many scientists have modeled light pollution in various ways, creating maps showing the sky glow at different altitudes and azimuths from different observation sites, or mapping artificial sky brightness in large territories (Chalkias et al., 2006).

Chalkias et al. (2006) maps the light pollution utilizing remotely sensed imagery and GIS as a media and a tool, respectively.

Inefficient and unwanted lighting flux may occur when buildings or streets are lit too brightly, and have too many lights or have misdirected light. These inefficient solutions may as described before may cause what is so called 'Light Pollution.'

Detecting and identifying Light Pollution in our streets utilizing Geographic Information System (GIS) application is the main interest of this research. The research provides a new idea of applying conventional GIS analysis technique for vertical digital photos to detect inefficient lighting proposals and in turn light polluted ones. This new idea helps urban designers, lighting designers and decision makers to evaluate lighting projects.

Briefly, to tackle this objective of the research some technical and analytical steps would be undertaken. First, light pollution would be reviewed to understand the difference between poor and privileged light proposals. GIS detecting technique, which is divided into two main steps: First, are data collection and preparation steps, and second step is implementing detecting technique.

2. Inefficient lighting Solutions and Light Pollution

Poor lighting systems most probably cause what is so called 'Light Pollution.' Light pollution is an issue, which has been recently taking place in our life. Light pollution is a generic term that encompasses many different aspects of improper lighting (Shaflik, 1997). Lmdc, Panynj, and Nyserda (2005), Unsworth (2003), and Warburton (2001) define light pollution as the that is escaping from luminaires or reflecting off of surfaces and not serving a lighting purpose; in other hand; it is the projection of light onto a surface

or space to which it is not intended, causing an unwanted effect to persons and/or environments expose".

Also The Institution of Lighting Engineers (ILE) (2003) refers to light pollution, whether it keeps you awake through a bedroom window or impedes your view of the night sky, is a form of pollution and could be substantially reduced without detriment to the lighting task.

Hence, light pollution is due to several factors but most effective factors are: 1) Flux of lamp (intensity), and 2) Direction of lamp (flux direction).

Elaborately, light pollution is unwanted or unintended outdoor lighting, which can present serious physiological and ecological problems (ILE, 2003). It could be described into three specific environmental parameters. In the following part, these parameters are discussed.

2.1. LIGHT POLLUTION ENVIRONMENTAL PARAMETERS

Light pollution environmental parameters are lighting pollutions effects on human and natural, which are involved with the subject matter of outdoor lighting system and constituting light pollution phenomenon. CIE, ILE and IESNA divide them to three major environmental parameters (Figure 1).

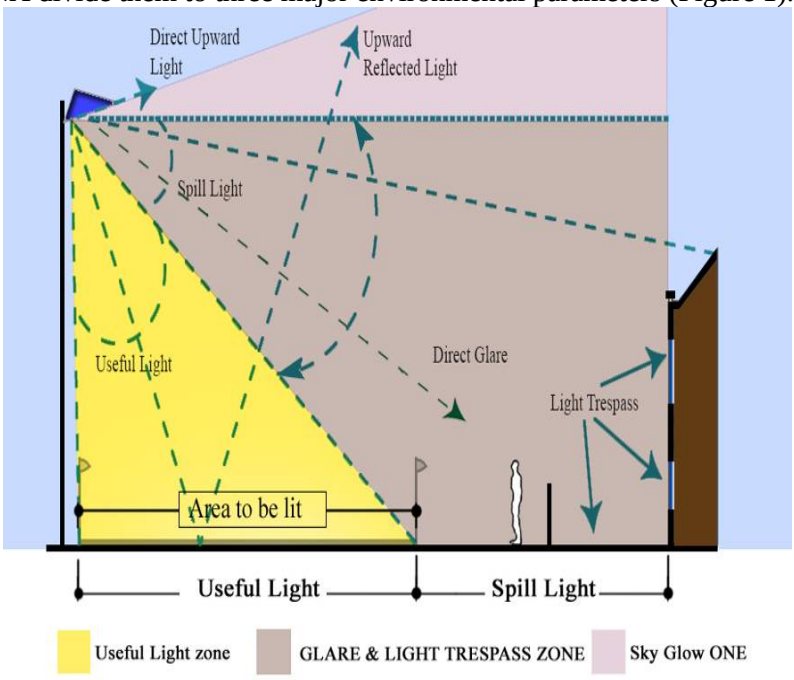


Figure 1: Shows the spill light which create light pollution effects from glare, light trespass and sky glow. Elaborated upon House of Commons Science and Technology Committee, 2003, Light Pollution and Astronomy, Seventh Report of Session 2002-03, Volume I, 15 September 2003, P. 18.

2.1.1. Sky Glow

Sky glow is the composite illumination brightness, which lights night sky. It presents the most wasteful form of lighting, because it serves no purpose at all. It looks like an orange glow seen over towns and cities.

2.1.2 Light Trespass

It can be described as uncontrolled light that spills and shines outside the area that it is designated to illuminate and onto neighboring properties where it is not wanted. An ordinance from Skokie , it has been classifies light falling on residences from a roadway lighting system in excess of 3 lux as a public nuisance. Although these limits cover a wide range of values they serve to illustrate that light trespass is being taken seriously as an environmental problem (Shaflik, 1997).

2.1.3 Glare

Light spilling beyond the boundary of the property on which a light is located, sometimes shining through windows and curtains (Texas transportation Researcher Center, 2004).

However, International Dark-Sky Association (IDA) establishes a theoretical module what is so called 'GULT.'

GLUT = Glare + Light Trespass + Uplight+ Too Much Light

Individually and collectively, the components of "GLUT" represent wasted energy. Finally the previous parameters can be measured and identify by using many techniques.

3. Step-by-Step GIS Analysis Technique

In the following part the detecting inefficient light solution GIS analysis technique would be described. To clarify the analysis technique two lighting poles with different hanging types have been chosen. The two poles have gone through two-step procedures, first, Data Collection and Preparation procedure, and second, analysis procedure. In the following part these points would be clarified.

3.1 DATA COLLECTION AND PREPARATION PROCEDURE

This section is divided into two key steps: 1) Data collection Survey, which investigates selected lamp (wattage), luminaire type (theoretical distribution pattern), and 2) Photometric Survey, which investigates lighting output on vertical surfaces.

3.1.1 Data collection survey procedure

Data collection sequence include investigating the unit that producing light, which give us required information about 'luminaire location' from building, 'luminaries housing type' for lamps (horizontal, vertical or what else), while investigating about 'lamp wattage,' manufacture and catalogue numbers and any others provided data.

3.1.2 Photometric survey procedure

Photometric survey procedure is mainly about light output, hence The chosen instrument for this research survey was Minolta T-10 Luminance Meter as shown in figure 2, which is recommended by Wright and Higgins (2003) for use in outdoor lighting survey. This instrument is designed to respond to artificial illumination in much the same way as the human eye. It is sensitive across the visible spectrum, with peak sensitivity around 580 nanometers, while it is used for measurement of a wide range of luminance from 0.01 to 299,900 lux photometer.

Figure 2: Illuminance Meter T-10 with standard receptor head. **Source:** Minolta, 2000, Luminance Meter T-10 Series, Minolta, Japan.

The suggest procedure is to determinate vertical changes of light illumination intense light output with neglecting other lighting installation effects, in each illumination point five reading has been taken as follows:

First, to ensure that all luminaires have reached normal operating conditions all readings were made at least one hour after sunset and before sunrise, thus all ambient light measured have come from the installed luminaires, not from remaining sunlight. A photometer reading also has been taken in dry environment with minimum humidity and fog.

Second, vertical light levels reading for each investigated point has been taken, where meter almost placed on 200 cm above ground on facades, from immediately adjacent to luminaires to central locations where there was the least amount of light as shown in figure 3.

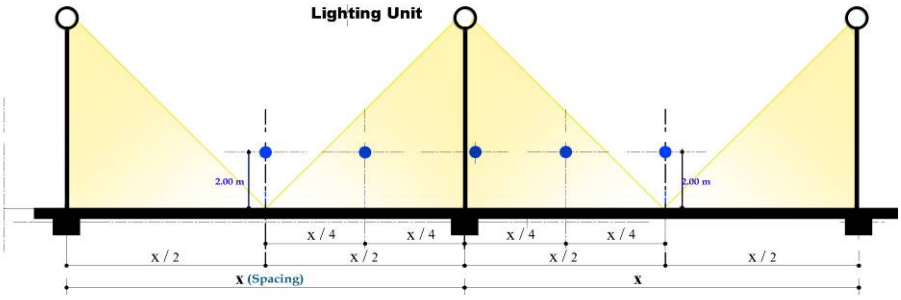


*Figure 3:*Vertical section shows lightinbg survey grid points used in the case study 1and 2

Then, using digital camera (Sony DSC-F717) to illustrate lighting pattern on residential facades with same color and texture, and same shutter speed 1/1000 sec. and same ISO sensitivity. In same environmental condition, from specified known locations and direction from 180 centimeter above ground level. Directions of the luminaires are also defined.

3.2 ANALYSIS PROCEDURE

Analysis procedure is designed, as shown in figure 4, to show several points. It shows that there is a difference between data input, data output, and operation and re-operation.

Vertical Flux intensity are indicated by point shape file (vector), so we convert it to raster through interpolation to raster using Inverse Distance Weighted (IDW) method. It is an appropriate method more than:

- SPLine method, which needs specific direction; and
- Kriging, which needs extreme data whether too small or too large.

The output of the IDW is flux intensity map, which needs reclassifying operation to be able to analyze re-classified flux intensity map.

In other hand establishing point shape file representing direction of lamp flux (vector), so we convert it to raster through interpolation to raster using SPLine method. The output is a direction of lamp flux Map. Reclassifying output to be able to analyze it through a re-classifying operation gives a re-classified direction of lamp flux Map.

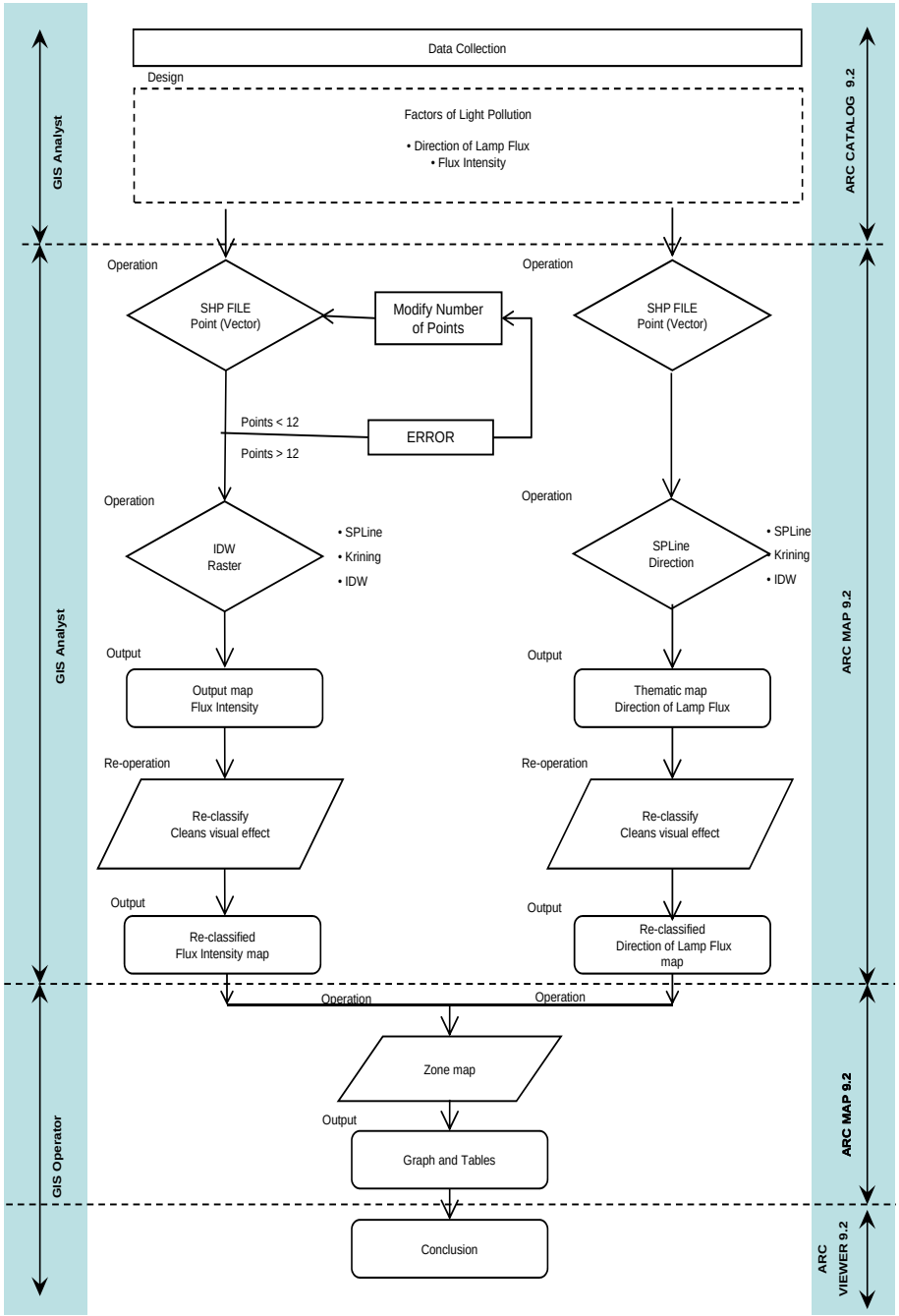


Figure 4 : GIS analysis procedure flow chart

All previous procedures have made in each case study to reach the

following results:

4. Case study

4.1 CASE STUDY 1

In this case as shown in figure 5 a light pole near a residential building is posted. According to figure 3, five reading points are recorded as shown in table 1.

Light is distributed on façade and officially direct on roadway pavement.

Table 1:Reading points valuses table case study 1

Reading Point	1	2	3	4	5
Values (lux)	5	8	14	9	6.5

High light pollution is seen white in analyzed figures, while black indicates low pollution as shown in figure 6.

Figure 7 represents the step of intrapolation to raster using IDW method, it is the most approperate method, where it indicates high perecentage of pollution around lamp. The reclassfy step which provides clean visual black and white graduation from whiteness very powfer vertical flux to blackness minimum vertical flux (figure 7). While, figure 8 represents the step of intrapolation to raster using SPLine method where it indicates the distribution of light and amount of pollution in same previous concepts.

Figure 5 (left): Façade with the lighting fixture posted on front of it (case study 1)

Figure 6 (right): Low and High luminance. White indicates high luminance and black indicates low luminance.

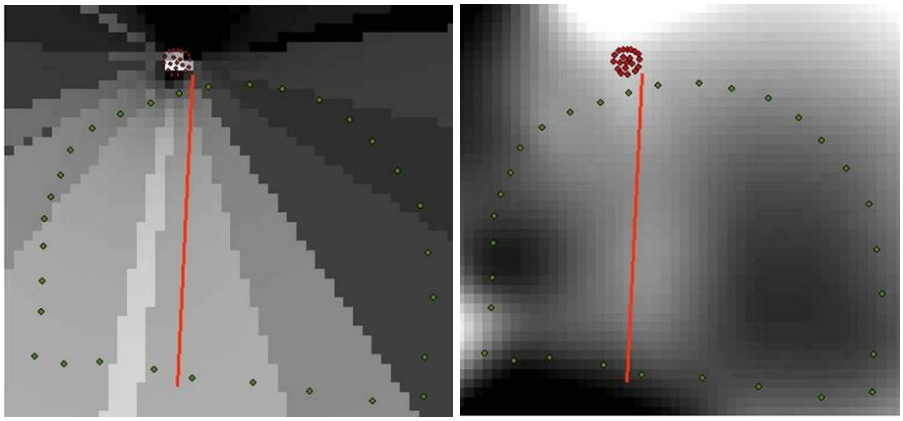
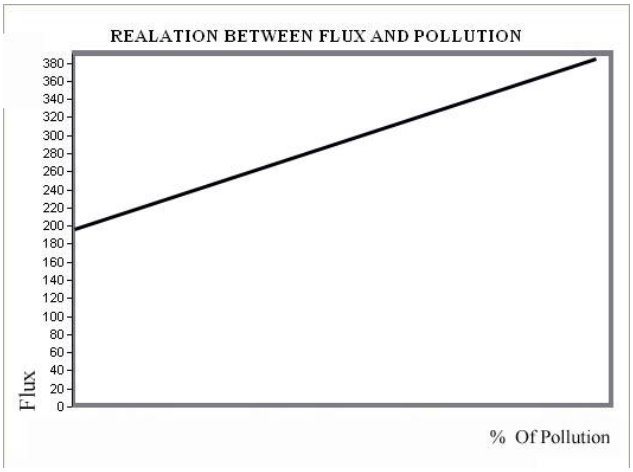


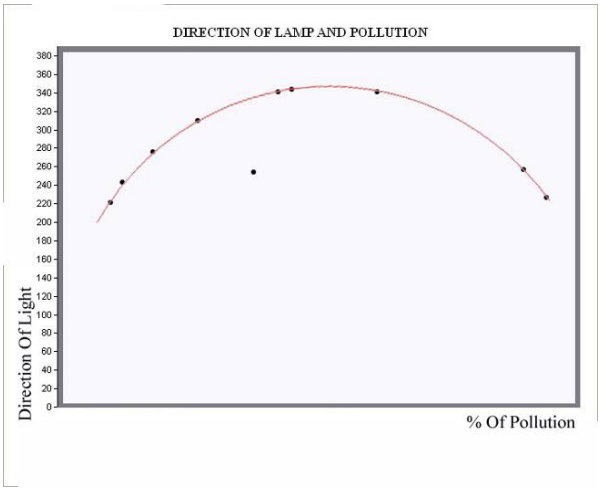
Figure 7 (left): The IDW step which indicates pollution around light fixture.

Figure 8 (right): The SPLine step which indicates distribution of light and amount of pollution.

From GIS the previous output analysis can summarized into two graphs, graph 1 indicates the relationship between the intensity flux and related expected light pollution by using fairly accurate value of flux 400, the relationship illustrated by straight line. Graph 2 indicates the relationship between the light distribution angular values and related light pollution by using fairly accurate value of 400, the relationship illustrated by curved line.



Graph 1: Indicates that as flux increases it cause light pollution to increase.



Graph 2: Indicates that distribution of light all over the facade.

4.1.1 Case Study1 Evaluation:

According to photometric survey the max was 14 lux and min was 5 lux which is not accepted light trespass for apartment in first floor ,and second floor , as seen GIS analysis in figure 6, in all up building it is accepted because it minimum then 3 lux.

4.2 CASE STUDY 2

Pollution due to high flux used in lamp, and direction of lamp so light is distributed all over the façade. According to figure 3, five reading points are recorded as shown in table 2.

Table 2:Reading points valuses table case study 2

Reading Point	1	2	3	4	5
Values (lux)	7	12	9	10	6

Figure 9 represents the façade of case study 2, while figure 10 represents the step of intrapolation to raster using IDW method, where it indicates high perecentage of pollution around lamp. Whereas, figure 11 represents the step of intrapolation to raster using SPLine method where it indicates the distribution of light and amount of pollution.

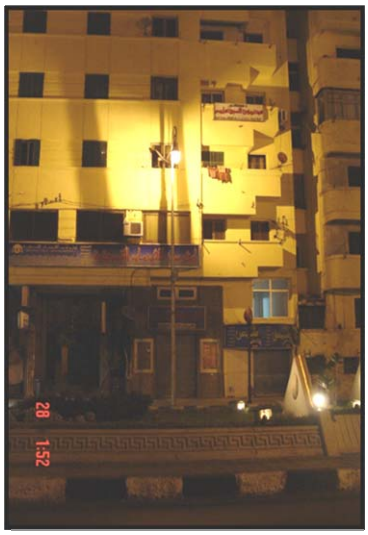


Figure 9: Façade with the lighting fixture posted on front of it (case study 2).

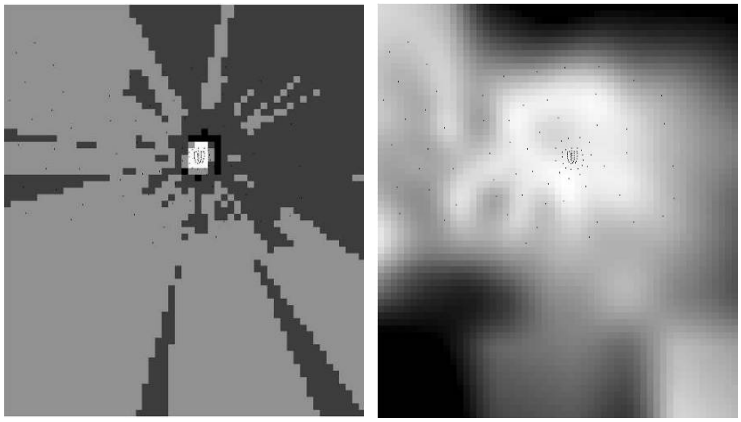
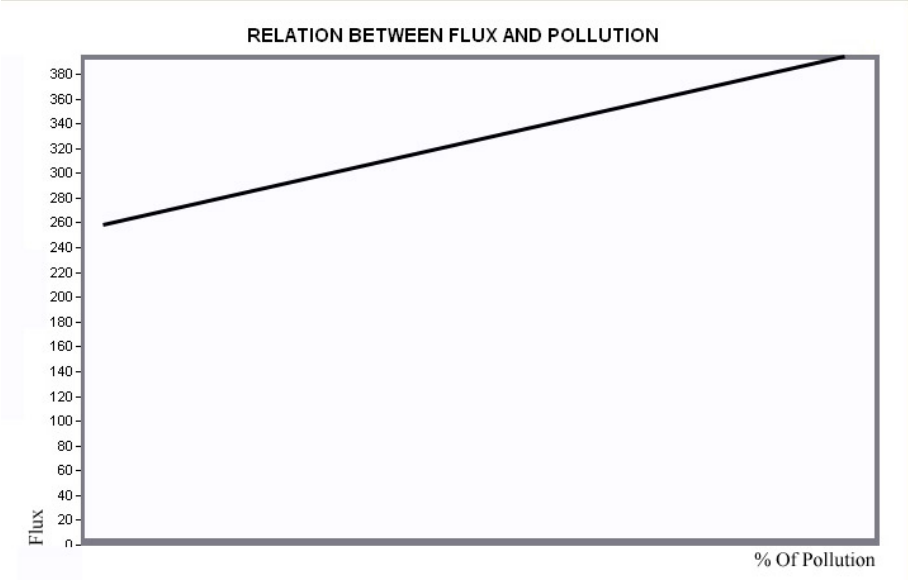


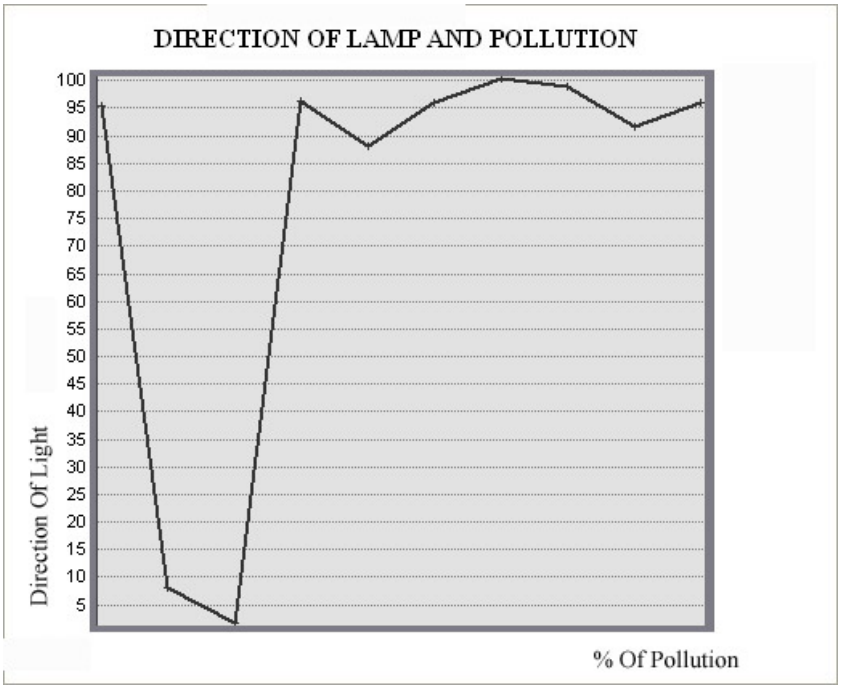
Figure 10(left): The IDW step which indicates pollution around lamp.

Figure 11(right): SPLine step which indicates distribution of light and amount of pollution.

From GIS the previous output analysis can summarized into two graphs, graph 3 indicates the relationship between the intensity flux and related expected light pollution by using fairly accurate value of flux 400, the relationship illustrated by straight line. Graph 4 indicates the relationship between the light distribution angular values and related light pollution by using fairly accurate value of 400, the relationship illustrated by uneven line.



Graph 3: Indicates light pollution increasing by increasing flux.



Graph 4: Indicates the distribution of light all over façade.

4.2.1 Case Study 2 Evaluation

According to photometric survey the max was 12 lux and min was 6 lux which is not accepted for apartment in all exposed floor which extended from ground floor to 5th floor, as seen in figure 9. where it indicates high perecentage of pollution.

5. Discussion

Finally the primary purpose of fixed roadway lighting is promoting safety at night by enhancing visibility for vehicular drivers and pedestrian on road pavement and sidewalks, respectively. High degree of uniformity of lighting distribution is a major principle of design, which allows the drivers' or pedestrians' eyes to stabilize easier and faster without need to adjust to great differences in vertical or horizontal illumination. Properly designed roadway lighting can also provide other benefits that are desirable. With minimum light pollution problems such as glare and light trespass.

GIS analyses technique is important as using only digital photos as shown in figure 5 and 9 never gives the right analysis. Looking at figure 5 and 9 gives the impression that light pollution is all over the two facades (case study 1 and 2). Although, figure 8 visually indicates that distribution of light is accepted on the façade and amount of pollution is just around the light fixture. While, figure 11 visually indicates that distribution of light is not accepted on the façade and the façade is highly light polluted.

Graph 2 (case 1) indicates the relationship between the light distribution angular values and related light pollution, the relationship illustrated by curved line. This means that light is fairly distributed on the façade.

Graph 4 (case 2) indicates the relationship between the light distribution angular values and related light pollution, the relationship illustrated by uneven line, which means that light is unjustly distributed on the facade.

6. Conclusion

Detecting inefficient lighting solutions and light pollution through utilizing GIS technology and vertical digital photos is a new idea. In the conventional technique of light pollution detection the horizontal digital remote sensed maps are employed, but, in our technique, a hybrid technology from conventional GIS analysis technique as well as digital vertical photos and lighting measures techniques are employed.

Digital photos are not enough to detect light pollution, but, GIS analysis procedure is needed.

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