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Study of Aerodynamic Surface Roughness for Baghdad City Using Signal-Level Measurements

Saja A. Haraj *Monim H. Al-Jiboori**

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Abstract:

Roughness length is one of the key variables in micrometeorological studies and environmental studies in regards to describing development of cities and urban environments. By utilizing the three dimensions ultrasonic anemometer installed at Mustansiriyah university, we determined the rate of the height of the rough elements (trees, buildings and bridges) to the surrounding area of the university for a radius of 1 km. After this, we calculated the zero-plane displacement length of eight sections and calculated the length of surface roughness. The results proved that the ranges of the variables above are Z_H (9.2-13.8) m, Z_d (4.3-8.1) m and Z_o (0.24-0.48) m.

Key words: Geometric height of roughness elements, Morphometric analysis, Surface roughness length, Urban area, Zero-plane displacement length.

Introduction:

Evaluation of surface roughness over cities is of fundamental parameters in urban areas for many applications, such as air pollution modeling and wind-engineering activities, vertical structures, installing wind turbines and urban planning for vital areas, spatially-varying surface roughness, ground level air quality determination, and environmental pollution. In atmospheric boundary–layer theory, surface roughness is parameterized through the roughness length (Z_o) at which the mean wind speed becomes zero (1). It is approximately a third of the height of the roughness elements, with values ranging from 0.0001 m for ice or water surface, up to a few meters for large urban areas and 0.1 m for park lands (2). The Z_o parameter is a function of the spatial density, orientation, and height of obstacles to the wind.

The topography of any natural and man-made surfaces is typically described by surface roughness elements, roughness lengths and zero-displacements. The change in the surface structure over a certain time will lead to changing micrometeorological parameters such as Reynolds stresses for the mean wind speed profile, and consequently, alter the vertical wind shear in both speed and direction.

Department of Atmospheric Science, College of Science, Mustansiriyah University, Baghdad, Iraq.
*Corresponding author:
monim.atmsc@uomustansiriyah.edu.iq

Many studies have reported a wide range of anemometric and morphometric techniques such as (3-5). Many researchers and authors have studied the surface roughness of different sites. Specifically, Grimmond and Oke studied the characteristics of wind movement on urban surface and analyzed the shape of the surface divided by the methods adopted by the previous researchers. The treatment methods were studied in 11 cities within 7 different states in the United States (6). Pelliccioni *et al*. developed an improved model for the wind-speed profile, which is valid for urban boundary layers after calculating the vertical profile of Z_0 under neutral conditions (7). Roughness lengths were also evaluated for Kalpakkam site, India, using terrain features by Jesan *et al*. They observed maximum and minimum roughness lengths of 0.48 m to 0.26 m, respectively (8). Finally, Chen *et al.* calculated roughness length using an approach based on digital building model of Tainan city using an approach based on Voronoi cells by applying the microclimate (9).

In the recent paper carried out by Al-Jiboori and Al-Draji (10), Z_o had been calculated for the Baghdad city center (Bab Al-Mhadham area) using the meteorological observations for wind speed, its direction and air temperature under neutral conditions, measured by classical equipment at two heights of 15 and 20 m, found that Z_o ranged from 0.7 to 1.7 m, with an average value of 1.2 m. In this paper, three dimensions ultrasonic anemometer was mounted on the roof of atmospheric science department building at Mustansiriyah university, which is located in the Waziriya area. Based on the fast–response data measured by the above device, the following objectives were emphasized: 1) a general survey of the roughness elements and measurement of the length, width and height; 2) calculating the mean geometric zero displacement heights; 3) calculating the possible lengths of the surface roughness in several wind directions.

Material and Methods:

There are several methods based on geometric analysis of the surface and related to the air dynamic scale. In this study, one of them is based on factor such as the plan aerial index (λp) to describe density the fraction of plan area, which can be expressed as

$$\lambda p = \frac{A_P}{A_T} = \frac{l*w}{A_T} \quad \ldots\ldots\ldots\ldots 1$$

where A_P = plan area of roughness elements (m^2) = l*w with l is the length (m) and w is the width (m), A_T=Total surface area (m^2) $= \pi r^2$ with r is the radius. These areas can be explained in Fig. 1.

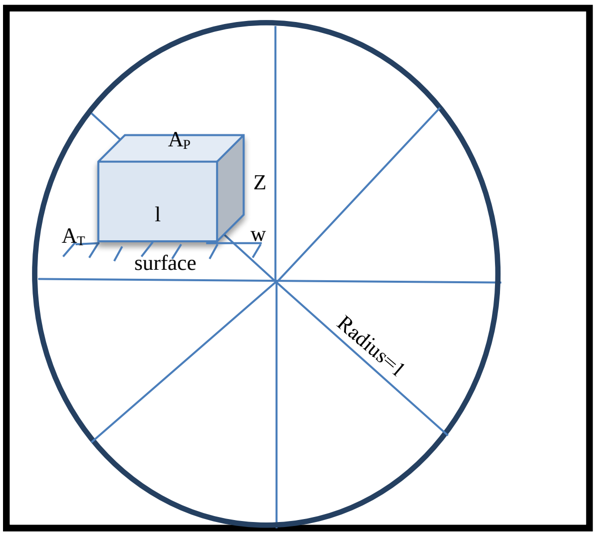

Figure 1: Dimensions how to calculate (A_p, A_T).

At λp=0.1, this means the elements are so close and they merge to form a new surface (9). For this method, the most important benefits are that the values of the length of roughness which can be calculated without the need for high towers, as well as their means. The length of the roughness of any circumference can also be calculated at the study site. Some problems are that the formulas used in this way are often the result of situational relationships derived from experiences of hobby spending (wind tunnel) in which the flow is constant in terms of direction as well as the order of the elements of roughness is in a systematic manner and this does not correspond to reality (11).

Roughness density does not give values of Z_d. We present a new, and this method yields values of Z_d at Z_o and the latter decline at higher densities beyond single peak (11).

$$\frac{Z_d}{Z_H} = 1 + \alpha^{\lambda p}(\lambda p - 1) \quad \ldots\ldots\ldots 2$$

where ∝: is an empirical coefficient equal to 4.43.

In this research, a mathematical formula will be used to calculate the roughness of the wind logarithm method. It is designed for slow response and for a single height level and the formula under neutral condition for wind speed, U, at any height, z, can be written as follows:

$$U(z) = \left(\frac{u_*}{\kappa}\right) \ln\left(\frac{Z_H - Z_d}{Z_o}\right) \quad \ldots\ldots\ldots 3$$

The measured wind speed at the height of the Earth's surface and the natural logarithm conversion to the exponential function produced by us.

$$Z_o = (Z_H - Z_d)\exp\left(\frac{-U(z)*\kappa}{u_*}\right) \quad \ldots\ldots\ldots 4$$

where is the von Kármán constant (taken as 0.4) and u_* is the friction velocity given as

$$u_* = \sqrt{\left|-\overline{u'w'}\right|} \quad \ldots\ldots\ldots\ldots 5$$

where u' and w' are the fluctuations of longitudinal (u-$\bar{u}$) and vertical (w-$\bar{w}$) components of wind. Here, u and w are the instantaneous values of longitudinal and vertical velocities. Furthermore, $\bar{u}$ and $\bar{w}$ are mean values of them.

The Site Study

The site of Mustansiriyah University was chosen at the center city of Baghdad to conduct the research. The city of Baghdad is located on latitude 33.14^O North and longitude 44.20^O East. The area in the study contains various roughness elements. The study area extends to a radius of 1000 m and the center of the circle is located on the building of the department of atmosphere science at Mustansiriyah university, located at northeast of Baghdad. The area was divided into eight sectors, each measuring 45^O, as shown in the aerial picture taken from the top in Fig. 1 and 2. The division was selected due to the shape, where there is heterogeneity evident in surface roughness, which can be linked with other variables.

The study site is featured as a mixture of high buildings and trees which are medium height. There is also a set of parking lots with some open spaces and lastly there is a bridge in section NW-N near to the measurement site as show in Fig. 3.

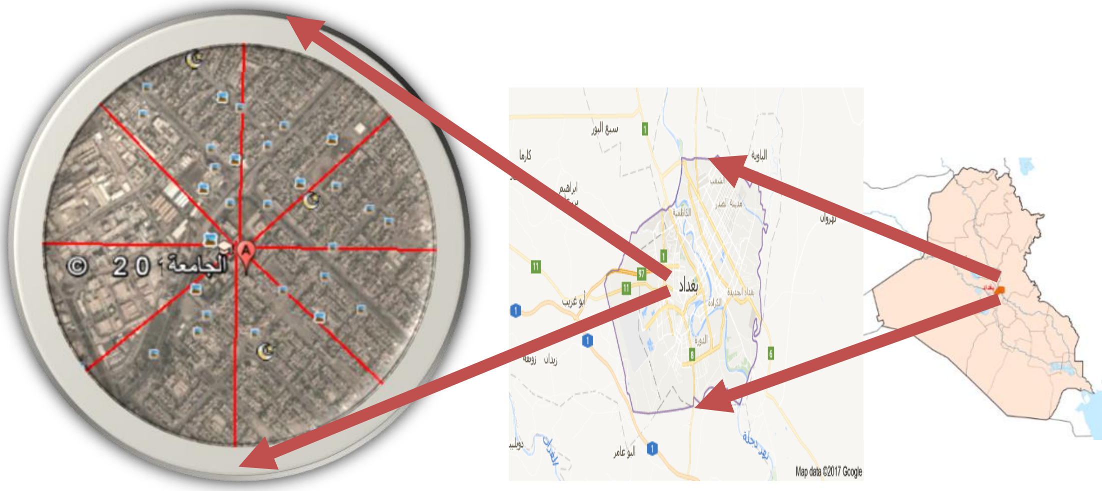

Figure 2: Maps of Iraq, Baghdad city and the site of study.

Using these images and divisions to find values (Z_o), engineering analysis depends on the size and shape of roughness elements surface area. These images and divisions were used to find the values of the geometric analysis based on the area and shape of the surface roughness elements of the area.

Figure 3. Photographs of surface features surrounding the study site.

Mustansiriyah university was chosen for the proximity of the center of the city of Baghdad and to contain types of elements that are composed of rough elements such as medium-rise buildings and residential and industrial communities as well as trees. Thus, the length of roughness calculated in this area can be considered as roughness the surface of Baghdad.

Results and Discussion:

Figure 4 shows the height of the elements of roughness of the city of Baghdad. Note that there are no significant differences in height values across all directions, except for section 7, (NWW) with a height of 14 m. The height range is with (9-14 m) with the is Z_H across all directions (10.8 m).

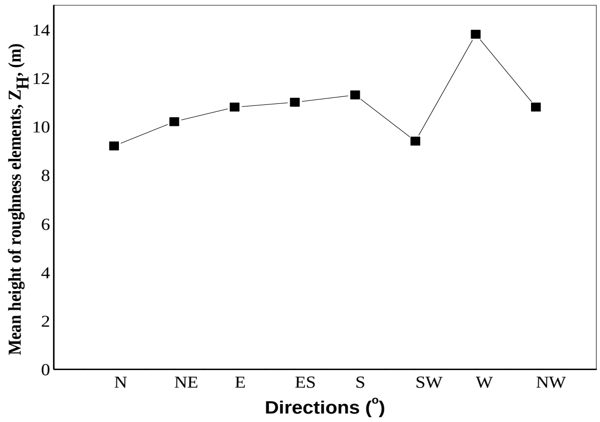

Figure 4: Average heights of buildings and trees directional sections around the site.

The height of buildings (Z_H) was calculated according to the eq. 2 with all the rough areas (buildings, tree and car).

We could calculate the plan area (A_P) of roughness elements via aerial image taken from above using Google Earth, with the drawing scale for each block, and then taking the average $\overline{Ap}$ in each section. Lastly, the packing density of roughness elements using λp was determined by using eq. 1 for each section. The values of λp corresponding to directions were plotted in Fig. 5; they ranged from 0.22 to 0.44. The large values of λp is at section 4 (NNE), which means it has high density roughness elements.

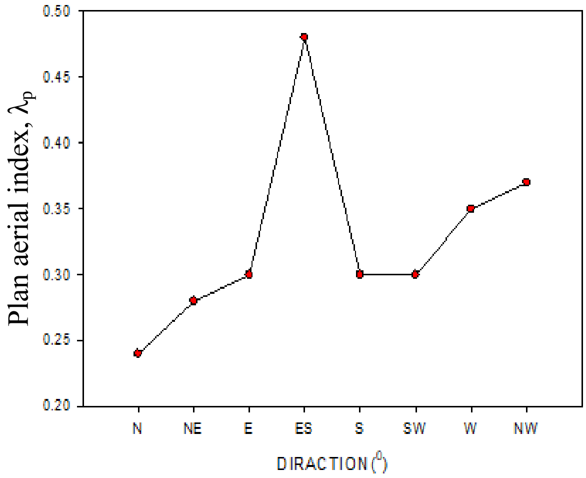

Figure 5. Variation of plan aerial index, λp, with directions.

The zero-plane displacement length

The zero-plane displacement value (Z_d) is very important in calculating surface roughness using standard methods. Based on the λp values mentioned in the previous topic, Z_d is calculated using eq. 1, which are plotted according to the direction as shown in Fig. 6; where is a change in Z_d values with the directions and where Z_d is the highest value in direction east.

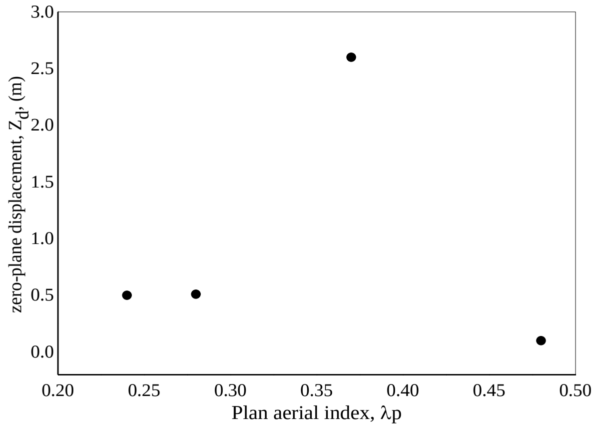

Figure 6. Variation of Z_d with plan aerial index, λp.

Fig. 6 represents that value of the zero-plane displacement length (Z_d), as well as the rate of the average height of the roughness elements, Z_H, in the site. Through the figure we note that the values of the length of the zero-displacement rate rise and the zero displacement increases with growth rate of height buildings. In addition, the top the value of the Z_d was 8.1 m at the height 13.8 m and for direction SSE, the value of the length of the zero-displacement was 5.5 m at the height of 11 m.

Surface roughness length

After the surface analysis of roughness parameters (Z_H and Z_d) and u_* at Baghdad city described in previous section, the values of surface roughness length, Z_o, were obtained by the method derived from the logarithmic from of wind speed change with length height, as seen in eq. 3. As for the method of finding the Z_o by the logarithm of the wind, we have chosen the study site in conformity with the site chosen for estimating roughness length.

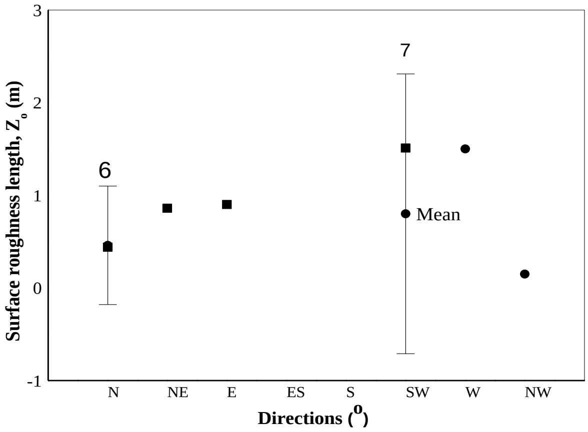

Figure 7. Variation of surface roughness length according to wind directions.

The friction velocity u_* was also calculated using eq. 5. The calculation of this parameter is necessary in this work, because it is necessary to calculate roughness length and air stability. The results of u_* were roughly constants with an average value of 1.3 m/s. This is expected because these values are under neutral conditions.

During the analyzed period for this work, only six directional sectors were obtained, except for two directions east south and south. The Z_o results are plotted in Fig. 7 according to wind directions. In the north and southwest directions, the average values of Z_o with their standard deviation are denoted by vertical bars. However, the Z_o values are in the range of 0.24-1.6 m with an average of 0.8 m. As shown in the figure, a large Z_o is detected in this area, which is covered by tall government and hospital buildings.

Considering the result obtained by Al-Jiboori and Al-Draji (10) of average roughness length =1.2 m across wind directions as well as our result (Z_o = 0.8 m) for this work, as another area in Baghdad city. We could represent the possible average of roughness length for the city to be about 1 m. It should be noted that instead of fixed roughness-length values, a variable roughness length is much better for a given area in operable roughness-length is much better for a given area in operation the atmospheric models.

Conclusions:

Through the precision of ultrasonic devices and the slow response device to calculate the surface roughness of the city of Baghdad, the following results were obtained. The mean height of the elements of roughness Z_H and after taking it to all directions in the study area is 9.6 m. The zero-plane displacement height of all directions in the study area is 6 m. The surface roughness length of Baghdad city varies from 0.24 to 1.6 m with the average across all wind directions. It can be verified that the roughness length strongly depends on the spatial density of the surface elements. The city of Baghdad is classified by the length of the roughness of its surface and the height of the buildings of falling within the cities of roughness and medium density, which are urban areas.

Conflicts of Interest: None.

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دراسة خشونة السطح الايروديناميكية لمدينة بغداد باستخدام قياسات المستوى المنفرد

سجى علي حرج **منعم حكيم خلف**

قسم علوم الجو، كلية العلوم، الجامعة المستنصرية، بغداد،العراق.

الخلاصة:

يعتبر طول خشونة السطح أحد المتغير الاساسية في دراسات الانواء الدقيقة والدراسات البيئية لوصف خصائص التطورات للمدن والبيئات الحضرية. باستعمال بيانات جهاز الاستجابة السريعة ذات الابعاد الثلاثة المعتمد لقياس مركبات الرياح ودرجة حرارة الهواء. بالاعتماد على رصدات جهاز مرياح الاتراسونك الثلاثي الابعاد الدقيق جداً المنصوب في الجامعة المستنصرية تم تحليل هذه البيانات لحساب معدل ارتفاعات عناصر الخشونة (اشجار وأبنية ومجسرات) للمنطقة المحيطة بالجامعة لدائرة قطرها 1 km وبالتعاقب ايضاً تم حساب طول الازاحة الصفرية للاتجاهات الدائرة اعلاه ذات المقاطع الثمانية فضلاً عن حساب طول الخشونة السطحية. اثبتت النتائج ان المديات للمتغيرات أعلاه: Z_H (9.2-13.8) m و Z_d (4.3-8.1) m و Z_o (0.24-0.48) وان المعدلات هي على الترتيب $\overline{Z_H}$(10.8 m) و$\overline{Z_d}$ (6 m) و$\overline{Z_o}$(0.8 m)

الكلمات المفتاحية: طول خشونة السطح، ارتفاع الازاحة الصفرية، الارتفاع الهندسي لعناصر الخشونة، التحليل الموروفومترك، المناطق الحضرية.