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Estimation of roughness and zero-displacement heights over Baghdad utilizing remote sensing and GIS techniques

Key words: digital surface model, digital elevation model, zero-displacement height, roughness element height, Baghdad, GIS

Introduction

The determination of both zero-displacement height (Z_d) and roughness element height (Z_H) has special importance in micrometeorology when calculating surface roughness length (Z_o). These aerodynamic parameters in urban areas are important in many applications, such as air pollution modelling, wind-engineering activities, and can be considered as the main factors in describing the development of urban cities (Grimmond, King, Roth & Oke, 1998).

The surface roughness length is the height wind speed becomes zero in the logarithmic wind-speed profile, in the absence of Z_d (Al-Jiboori, 2010). Thus, any single object research that did not rely on the value of Z_d in estimating the values of roughness length was considered unacceptable. When the roughness elements (e.g. buildings, trees, bridges, etc.) are closely aligned to the surface it appears to have displaced the surface of the earth to some height. For example, some forests where trees are very close make a block of circumference size that blocks the wind when colliding with it (Hicks, Hyson & Moore, 1975).

The methods for analysing any natural and manmade surfaces can be classified into two major methods. The first classification requires observations of wind, and the second is based on the morphology and spatial arrangement of surface roughness elements, and this is referred to as morphometric analysis (Grimmond et al., 1998). The changes in the surface feature over a certain time can lead to changing micrometeorological parameters, such as Reynolds stresses and heat fluxes for the mean wind speed profile; and consequently, alter the vertical wind shear in both velocity and direction (Bradford, 2015).

The methods used in calculating the urban roughness that dependent on morphometric parameters have improved radically because the anemometer equipment depends has limited observation in certain directions. These are considered the most accurate and active. However, installing the devices and designing the site experiment is complex and costly. On the other hand, morphometric methods are easy to operate and less costly. Remote sensing and geographic information system (GIS) techniques have reduced the complexity associated with these methods, and helps us to decrease time and exertion in calculating Z_d and Z_H (Jhaldiyal, 2015).

Remote sensing refers to various observation and exploration activities of the Earth's surface, through satellites and aircrafts fitted with sensors to capture images of Earth's surface. Those images are used to generate digital elevation model (DEM) and digital surface model (DSM), among others (Guo, Alessandro & Goodchild, 2019). Digital elevation model is defined as the altitude above mean sea level, measured in meters. When the surface is bare, the values of minimum and maximum elevation are equal. For scarce vegetation structures, the depth of the vegetation canopy results in the difference between the lowest and highest elevations. Therefore, it is possible to separate the land surface topography, represented by the DEM, from an elevation of the top of the vegetation canopy. Digital surface model refers to the altitude of features/objects on the surface of the earth. Both digital models have spatial resolution of 30 m (Desbarats, Logan, Hinton & Sharpe, 2002). The difference between DEM and DSM is that the first one is a land surface model that assuming the surface is bare while the second is an elevation model that contains the top of surfaces or features on earth such as treetops, towers, buildings, and ground (Zhou, 2016).

Many researchers and authors have studied the surface roughness parameters of different sites. For example, Grimmond and Oke (1999) studied the characteristics of wind movement on the urban surface and analysed the shape of the surface by the morphometric method. The displacement height was defined using one of the methods for evaluating displacement height from velocity profile measurement (Petersen & Parce, 1994). Al-Draji & Al-Jiboori (2010) calculated Z_d for the Baghdad city center (Bab Al--Mhadham area) using the standard criteria and through the Bottema formula, found that Z_d ranged from 4 to 17.9 m with a mean value of 7.5 m.

In a recent study conducted by Haraj and Al-Jiboori (2019), utilizing three-dimensional ultrasonic anemometer installed at Mustansiriyah University to calculate zero-displacement length on eight sections, the results Z_H (9.2–13.8 m) and Z_d (4.3–8.1 m). Previous studies have focused on Z_d for most cities of the world, including Baghdad city centre and at Mustansiriyah University. However, no study has estimated the surface height of roughness element and zero-displacement height elements for the city. This study sought to estimate zero-displacement height and the height of roughness element over Baghdad, and for each municipality using GIS tools and techniques (ArcGIS 10.4.1 software). The study also analysed the relationship between Z_H and Z_d. The study estimated the roughness parameters for all municipalities of Baghdad.

Study area

Baghdad is the capital of the Republic of Iraq and is located in the central region on the banks of the Tigris river. Geographically, Baghdad is situated at latitude 33.22°–33.48° N, longitude 44.17°–44.50° E and 30–38 m above mean sea level. The area of the municipality of Baghdad city 877 km^2 (Al--Salihi, 2018). The borders of the municipality of Baghdad include 15 municipalities, seven in Karkh east of Tigris and eight in Rusafa west of Tigris as shown in Figure 1. The architecture of Baghdad ranges from traditional two or three story brick houses to modern steel, glass and concrete structures, and has about 12 bridges spanning the river-joining the east and west of the city (Hashim & Sultan, 2010). The climate of Baghdad can be described as subtropical, continental, and semiarid, characterized by cool winter, short springs as well as hot, dry and long summer. For the last 30 years, the average maximum temperature has been 31.95°C, and the average minimum temperature has been 18.05°C. The annual range of mean daily sunshine duration is about 10–14 h, with a mean of 7 h. Rainfall has never been recorded in summer and annual rainfall is almost restricted to the period of November–April (Saleh, 2011).

Data source

Data was acquired from three sources. Digital elevation model image for Baghdad, as shown in Figure 2, was acquired from the USGS earth explorer website, while DSM image for Baghdad, as shown in Figure 3, was obtained from the satellite global digital surface model "ALOS World 3D – 30M" (AW3D30) on 2 July 2019. Shapefile of the boundary of the municipality of Baghdad city, which comprises fifteen municipalities, was obtained from Baghdad municipality.

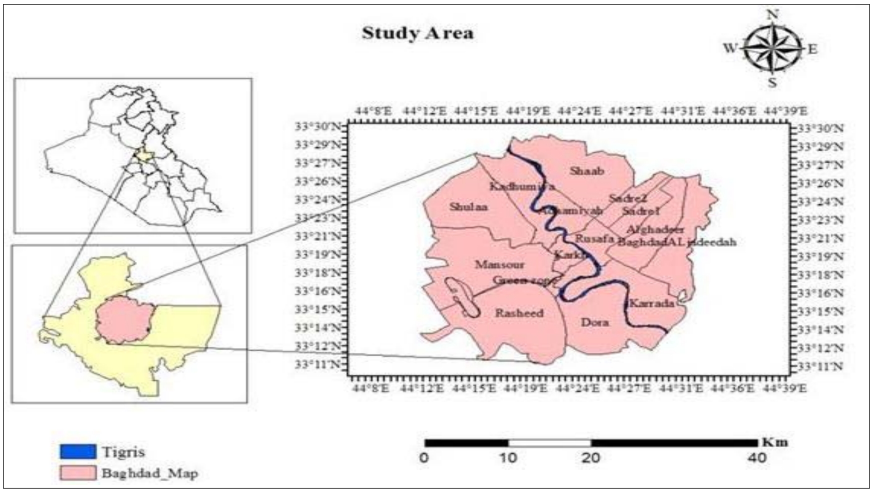


FIGURE 1. Maps of Iraq, Baghdad city and the site of study

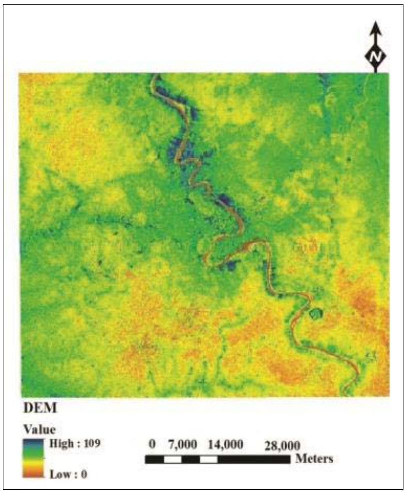
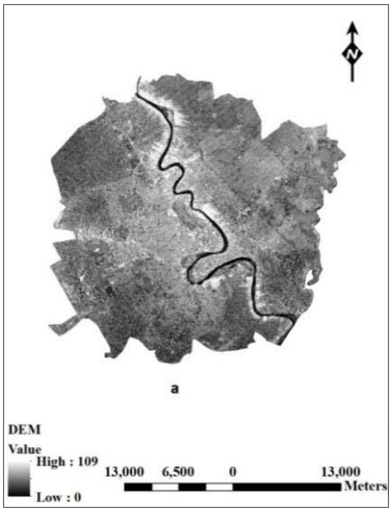


FIGURE 2. Digital elevation model image of Baghdad city



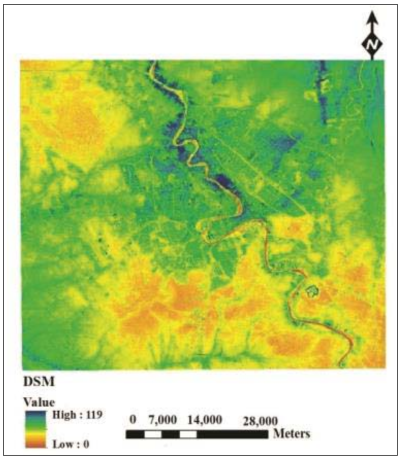


FIGURE 3. Digital surface model image of Baghdad city

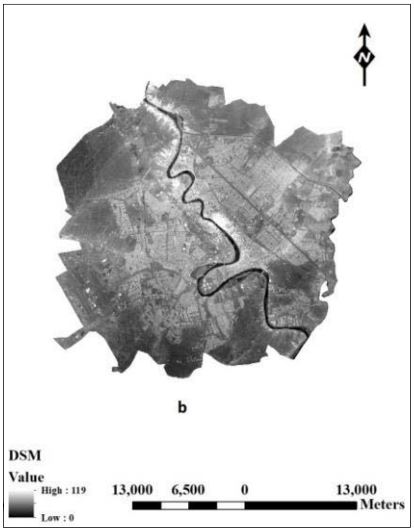


FIGURE 4. Baghdad city after extraction: a – digital elevation model; b – digital surface model

Pre-processing

Models of digital elevation and surface were extracted from the respective original images by masking them out using the shapefile for Baghdad city (Fig. 4).

The height was derived by computing the difference between DSM and DEM following Eq. (1) using GIS. The height is referred to as digital height model (DHM), and is shown in Figure 5. Digital height model represents the height of roughness element – Z_H (Dutra et al., 2006).

$$DSM - DEM = DHM \tag{1}$$

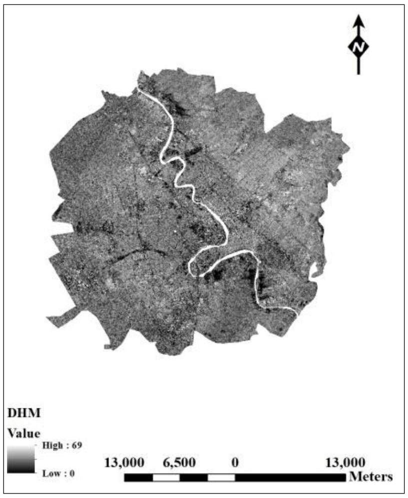


FIGURE 5. Digital height model of Baghdad city

Processing

There are several methods based on geometric analysis of the surface, which are related to the air dynamic scale. The method adopted in this study depends on the plan aerial index (λ_P), which describes the density of the fraction of the plan area. Plan aerial index is the ratio of the horizontal area occupied by roughness elements ('roof' or vegetative canopy) to the total area under consideration (Kent, Grimmond & Gatey, 2017), and is expressed using the following equation:

$$\lambda_P = \frac{A_P}{A_T} \tag{2}$$

where:
A_P – plan surface of the roughness elements [m^2],
A_T – total surface area [m^2].

The plan area index is attached to the significance of interfering space between the roughness elements. For an array of the equivalent height of roughness element, an excess of λ_P can lead to the excess of the displacement height and a reduction of the roughness of the obstacle array as λ_P, tends to 1. This means that the elements are so close that they merge to form a new surface (Chen, Fröhlich, Matzarakis & Lin, 2017). The ratio of displacement height over the roughness element height is given as:

$$\frac{Z_d}{Z_H} = 1 + \alpha^{-\lambda_P}(1 - \lambda_P) \tag{3}$$

where:
Z_d – displacement height, which is mainly a function of λ_P [m],
Z_H – height of roughness element height [m],
α – empirical coefficient equal to 4.43 (Grimmond & Oke, 1999).

Figure 6 presents the flow chart of the calculation method for *DHM* (= Z_H) and Z_d.

Results and discussion

Average roughness height

The average height values for satellite image varies from one municipality to another, due to the presence of buildings, trees and towers, and their different spatial distributions in Baghdad. The height values of DSM are greater than DEM, where DEM includes the height of the land and does not take into consideration the height of the towers, trees and buildings, while DSM includes the height of the surface and everything on it. Digital height model is the result of

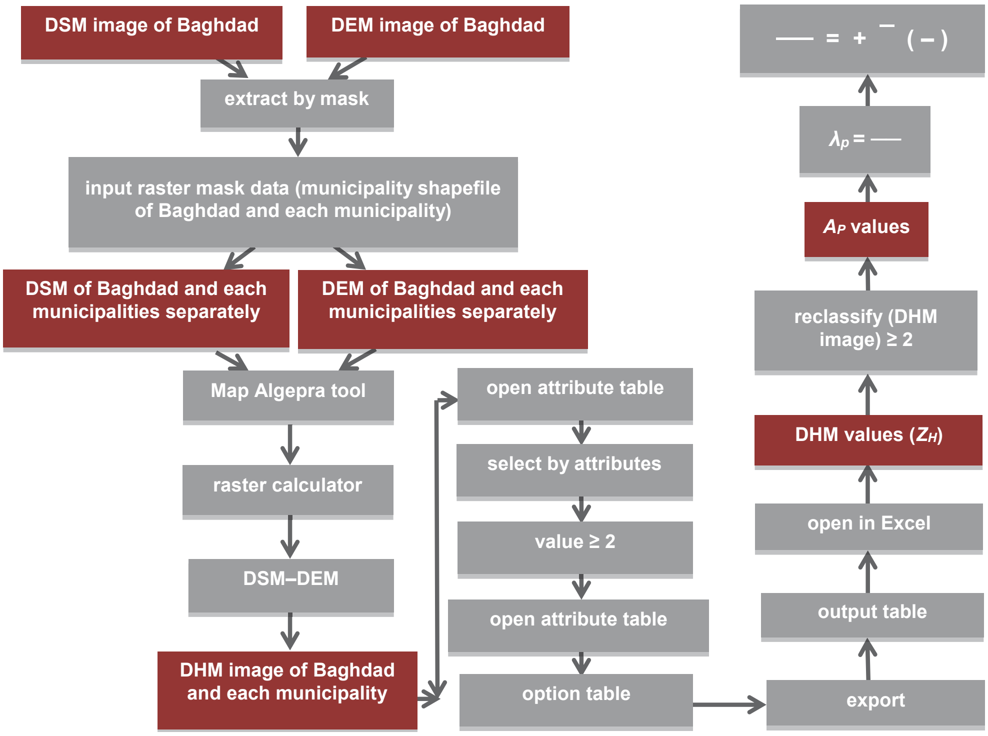


FIGURE 6. Flow chart of methodology

difference between them which represent Z_H.

Figure 7 and the values shown in Table 1 show the height of the roughness elements of every municipality were calculated from Eq. (1) by ArcGIS. It should be noted that the highest value was in Mansour with 28.7 m because of the many numbers of tall buildings and trees in this municipality, and the lowest value in Sader1 with 8.6 m due to the lack of tall buildings. It is also found that there are municipalities with almost similar values such as Sader 1 and

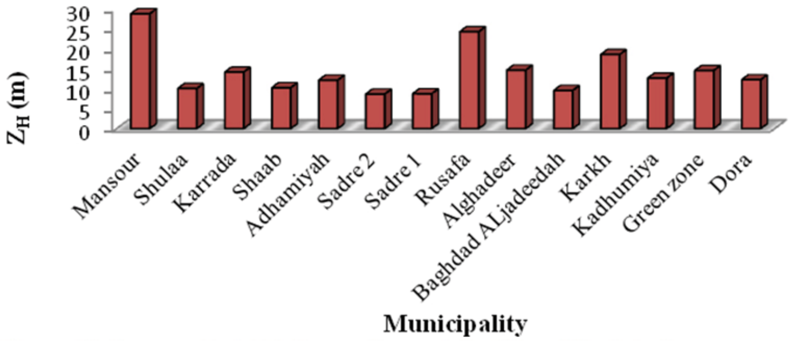


FIGURE 7. Average heights for each municipality of Baghdad

TABLE 1. Average of height values for satellite images of digital surface and elevation models and roughness element height

Municipality	DSM [m]	DEM [m]	Z_H [m]
Rasheed	35.8	35	18.4
Mansour	38.3	37.4	28.7
Shulaa	36.7	35.7	10
Karrada	37.2	36.5	14.1
Shaab	38.3	36.9	10.2
Adhamiyah	40.8	39.9	12.1
Sadre 2	39.2	37	8.6
Sadre 1	40.3	37.6	8.7
Rusafa	40.9	38.8	24.2
Alghadeer	39.1	36.8	14.6
Baghdad Aljadeedah	38.5	38	9.5
Karkh	39.8	39.5	18.5
Kadhumiya	40	39.1	12.6
Green zone	38.2	38	14.5
Dora	36.1	35.9	12.2

Sader 2, Dora, Adhamiyah and Kadhumiya. Shaab, Shulaa and Baghdad Aljadeedah municipalities are approximately similar in value, and finally Karrada, Algadeer and Green zone are found to close to the same values for roughness element heights.

Zero-displacement height

The zero-displacement values based on the Z_H and λ_P values are computed using Eq. (3) should previously calculated Z_H values and then λ_P. First step, the plan area (A_P) of roughness element which represents the area occupied by objects on the surface of the earth, such as buildings and trees calculated through ArcGIS. The height data was classified from DHM images for the roughness elements with heights greater or equal to 2. This classification was chosen ensuring that low-level street furniture (e.g. signage), vehicles, etc. are removed, to determine the plan area index consistent with the study of (Kent, Grimmond, Gatey & Hirano, 2019). Areas of pixels with heights equal to or greater than 2 were calculated for each municipality. This was followed by calculation of the total area (A_T) and packing density of the roughness elements λ_P for each municipality was determined by using Eq. (2).

Figure 8 ~~shows~~ the reclassified roughness heights for each municipality. The black colour shows areas of height values ≥ 2 which represents A_P distributions, and green colour shows the area of height values < 2.

As stated in Table 2, the values of A_P, A_T, and the results of both λ_P and Z_d shows that the values of λ_P ranged from 0.17 to 0.63. The largest value of λ_P was in Sader 1 which means it has high-density roughness elements and the lowest value was in the green zone. The average value of λ_P was 0.35 for the entire Baghdad. Zero-displacement height ranges from 4.5 to 15.8 m, with an average value of 8.4 m for the whole Baghdad.

Figure 9 shows the relationship between the length of zero-displacement and the average of the roughness elements height. There was a very strong positive correlation between the two parameters, with $R^2 = 0.7484$, $p < 0.05$. It was noted that the values of Z_d increases with increasing height of buildings in an area. The highest value of the length of the zero-displacement height Z_d was 15.8 m with Z_H of 24.2 m

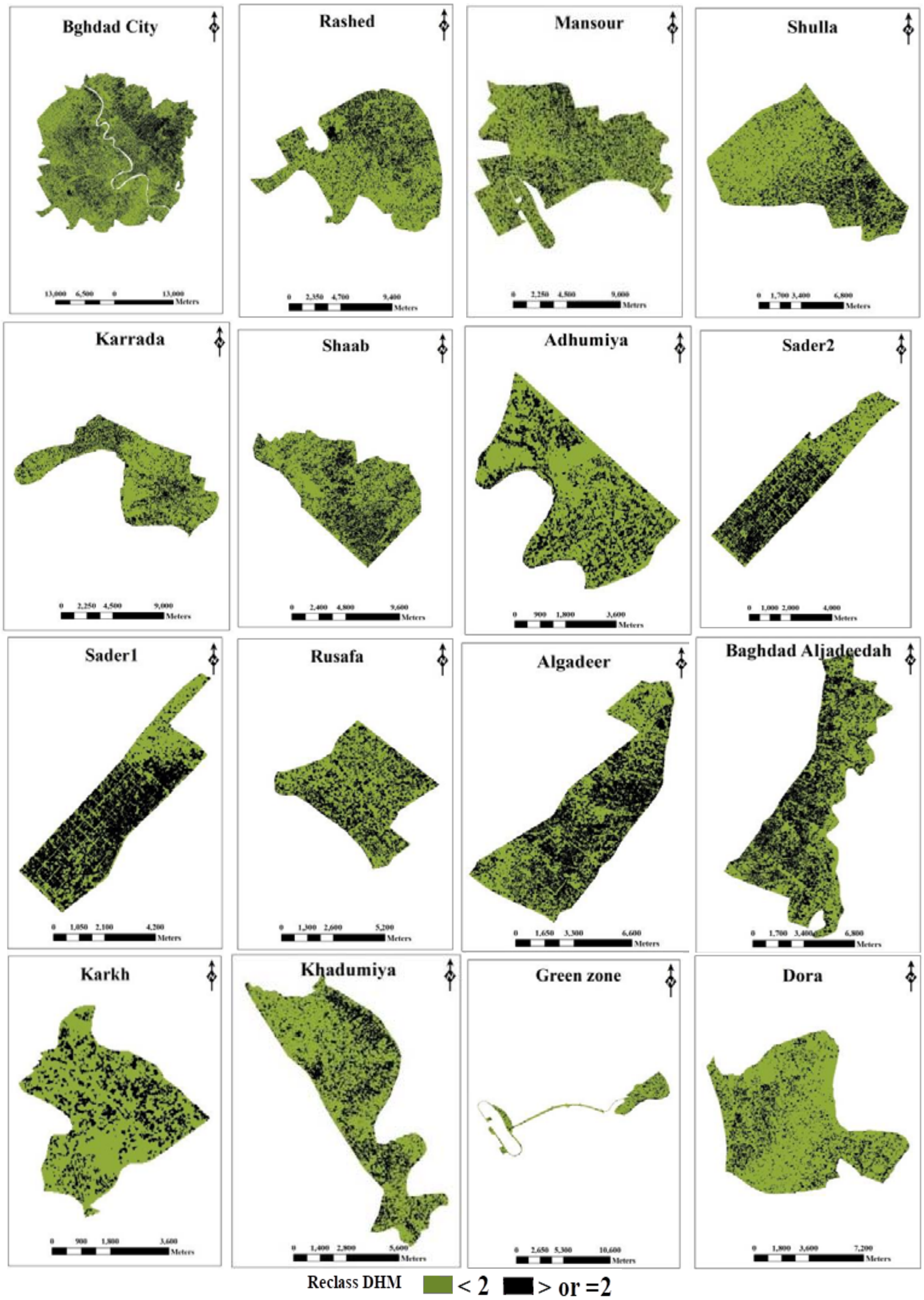


FIGURE 8. Maps present the distributions of plan area for Baghdad and each municipality

TABLE 2. Values of plan area, total area, plan aerial index and zero-displacement height for each municipality in Baghdad

Municipal	A_P [km^2]	A_T [km^2]	λ_P [-]	Z_d [m]
Rasheed	36.3	123.3	0.29	10.0
Mansour	36.3	123.3	0.29	15.6
Shulaa	4.6	90.2	0.27	5.1
Karrada	18.6	69.3	0.27	7.2
Shaab	35.6	99.2	0.36	6.3
Adhamiyah	8.3	27.3	0.3	6.7
Sadre 2	10.7	20.9	0.51	6.7
Sadre 1	14.5	23	0.63	7.5
Rusafa	9.1	23.7	0.38	15.8
Alghadeer	27.2	51.5	0.53	11.5
Baghdad Aljadeedah	29.9	65.3	0.46	6.9
Karkh	3.9	14.8	0.26	9.2
Kadhumiya	16.3	56.1	0.29	6.8
Green zone	2.8	16.7	0.17	5.1
Dora	15.2	82.1	0.19	4.7

Z_H values among all municipalities, the highest value is for Mansour (28.6 m), and the least value is for Sader 2 (8.6 m). This is due to the presence of high buildings in Mansour municipality, unlike in Sader 2 municipality. Zero-displacement height varies from 4.7 to 15.8 m across the municipality. The results of this research differ from the results of the previous two studies (Al-Draji & Al-Jiboori, 2010; Haraj & Al-Jiboori, 2019) which conducted for Bab Al-Muadham and Mustansiriya University, which these are part of the Rusafa municipality of Baghdad and with study areas of 1 km^2, while this study covered a very large area of 877 km^2 and 15 study points. Depending on the values of Z_d and Z_H, Baghdad city can be classified as having a medium height with a density of the urban surface consistent with results obtained by Grimmond and Oke (1999).

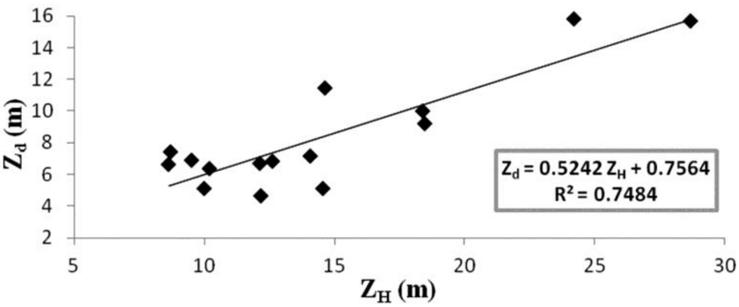


FIGURE 9. Variation of zero-displacement height with roughness element height

in Rusafa, while least value of the length of zero-displacement was 4.7 m with 12.2 m Z_H in Dora.

The following observations were noted in the study. The average Z_H was 14.5 m and Z_d was 8.4 m. Comparing

Conclusions

The determination of urban surface aerodynamic parameters is an important question in the researches of urban wind field characters, planning for vital areas, and microclimate. Using remote sensing and GIS resources and techniques, the study estimated zero-displacement height (Z_d) and roughness element height (Z_H) for each municipality in Baghdad city. Therefore, the importance of this study lies in the development of a simple method for estimating the roughness parameters (Z_H, Z_d). Besides, the use of GIS technology in this study contributed to obtaining more accurate results than the results of previous studies. According to our final results we recommended using another parameter such as frontal index to calculate zero-displacement and surface roughness lengths for municipalities of Baghdad.

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Summary

Estimation of roughness and zero-displacement heights over Baghdad utilizing remote sensing and GIS techniques. The objective of this study was to estimate the height of roughness element (Z_H) and zero--displacement length (Z_d) for Baghdad city using remote sensing and GIS techniques and resources such as DEM, DSM, and shapefile. The difference between DEM and DSM produced digital height model which represents the height of the roughness element for the region, which was used to determine the zero-displacement height. The results showed that the variations in Z_d values depend strongly on Z_H. Rusafa had the highest Z_d (15.8 m) while Dora had the lowest values (4.7 m). Thus, Baghdad city has medium density classification according to the results of Z_d and Z_H values.

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