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RECENT APPROACHES IN ABOVE GROUND BIOMASS ESTIMATION METHODS

Toprak Üstü Biyokütle Belirlemede Güncel Yaklaşımlar

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Öz

Toprak üstü biyokütlenin belirlenebilmesi için birçok yöntem kullanılabilmektedir. Çalışmada, bu yöntemler incelenmiş ve hali hazırda var olan klasik yöntemlere bir alternatif olarak uzaktan algılama yönteminin kullanımı üzerinde durulmuştur. Pasif optik, radar ve lidar sistemlerin kullanıldığı uzaktan algılama yöntemi, arazi çalışmalarını en az seviyede tutarak geniş alanlarda biyokütlenin belirlenmesine olanak vermektedir. Yapılan literatür değerlendirmesi, biyokütle belirlemede uzaktan algılamanın yararlarını ortaya koymakla beraber, topografik koşullar, biyofiziksel özellikler ve çevresel koşullardaki farklılıkların biyokütlenin belirlenmesinde zorluklara neden olduğunu göstermektedir.

Anahtar Kelimeler: Biyokütle belirleme, orman, uzaktan algılama

Abstract

Numerous methods can be used for above ground biomass estimation. In this study, these methods were assessed and the use of remote sensing emphasized as an alternative to available classical methods. The remote sensing methods that use passive optical, radar and lidar systems, lets biomass to be estimated for large areas with minimum field work. The literature review has demonstrated the benefits of remote sensing for biomass estimation along with indicating topographic conditions, biophysical properties and environmental conditions may cause complexity.

Keywords: Biomass estimation, forest, remote sensing

Introduction

Biomass, regarding the forest biomass issue, expressed in terms of dry weight of organic matter, is an important indicator of ecosystem energy potential and productivity. Biomass, in general, includes the above ground and below ground living mass, such as trees, shrubs, vines, roots, and the dead mass of fine and coarse litter associated with the soil. Due to the difficulty in collecting field data of below ground biomass, most previous research on biomass estimation focused on above ground biomass (AGB) (Lu, 2006).

A forest ecosystem plays an important role in the global carbon cycle owing as it contributes 80% of above ground biomass. Nevertheless, forests are also discussed to have net positive CO_2 due to anthropogenic activities, such as land use change. However, the effect of land use change, particularly the tropical forest change, on the carbon cycle is difficult to determine and may lead to the underestimation of carbon balance.

Article 2.1. of the Kyoto Protocol, which was established to address the issue of global warming, forces nations to be responsible for the protection and enhancement of sinks and reservoirs of greenhouse gases, promotion of sustainable forest management practices, and afforestation and reforestation. In addition, the greenhouse gas emissions from sources and removals through sinks associated with those activities shall be reported in a transparent and verifiable manner. To that end, every country has started to prepare their carbon inventories. Consequently, recent researches have focused on biomass assessments with the purpose of reducing uncertainties of carbon cycle and carbon emissions.

When a forest is considered as a carbon sink that absorbs atmospheric CO_2, it is assessed in the Kyoto Protocol for one of the carbon sequestration options to reduce the amount of greenhouse gases (FAO, 2010). Apart from its scientific merit in understanding the global carbon cycle, accurate and precise quantification of emissions from land use change has also become a key issue for policy makers considering the recent developments associated with the reduction of the emissions caused out of deforestation and degradation (REDD) in developing countries as a climate mitigation strategy.

However, the main goal of previous biomass studies was to produce various data and information for renewable energy resources and to decrease dependence on fossil fuel (Alemdağ, 1981). In other words, the former approaches regarding biomass were in energy point of view. Biomass regression tables for each species were prepared to estimate the energy potential of forest biomass. Subsequently, biomass inventories have been calculated using these tables.

Despite the high precision of such inventories, they are designed to yield average wood volumes for administrative units; they do not provide maps of biomass at a resolution compatible with land use change. Hence, if the ‘average’ forest is cleared, logged, or burned, the use of average values will bias the calculated carbon sources and sinks (Houghton, 2005).

Yet, knowledge of the spatial distribution of biomass is required for to calculate the sources and sinks of carbon that result from converting a forest to cleared land (and vice versa). On the other hand, knowing the spatial distribution of forest biomass is also important to enable measurement of change through time.

Direct measurement of biomass with fieldwork is time consuming and hence is generally limited to 5-10 year intervals. The calculation/estimation of forest biomass using satellites is a promising alternative to ground based methods (Hese et al., 2005).

The purpose of this paper is to evaluate the improved understanding of biomass and carbon monitoring and review the capability of different remote sensing systems. The paper begins with the importance of biomass for the carbon cycle and describes our current knowledge of biomass.

The Importance of Biomass for the Carbon Cycle

Biomass is an object of interest for wide range of reasons. It is important for energy sector because of being renewable and being raw material of food and solid fuel.

However in the carbon cycle and climate change prospect, biomass gains importance for two main reasons. Firstly, the biomass in an ecosystem determines the carbon amount that will be emitted to the atmosphere in form of carbon dioxide, carbon monoxide or methane in the case of disturbance. Secondly, it is used for removal of carbon that is already available in the atmosphere. Additionally, half of the biomass amount is roughly equal to the carbon amount of vegetation. This feature lets biomass and carbon terms be used in similar meanings for biomass studies.

Therefore, the biomass on earth forms the sinks of carbon called “carbon pools”. The carbon pools in terrestrial ecosystem can be grouped in to five:

aboveground biomass, dead wood, litter, belowground biomass and soil carbon (Penman et al., 2003).

The organic matter in the soil generally holds approximately three times more carbon than biomass does but this carbon in soils is physically and chemically protected and not easily oxidized (Davidson and Janssens, 2006). But nonetheless, aboveground biomass can easily be released to the atmosphere with processes such as fire, logging, land use change, pests, etc.

Forests contain 70-90 % of terrestrial above ground and below ground biomass. As a consequence of being a large portion of biomass in forest ecosystem, trees, are more emphasized in the biomass studies (Cairns et al., 1997).

Therefore, in this study, the aboveground biomass we focused on includes the trees within forest ecosystem and we excluded litter, below ground biomass and soil organic matter.

Early Methods

The preliminary studies on biomass were conducted with the aim of estimating the above ground biomass by tree species in 1930s'. The methods used in these studies are called as "harvest method" due to harvesting the trees in a plot and weighting them after oven drying process (Brown et al., 1989). In practice, this type of destructive measurement becomes more difficult if the belowground biomass is also included with the study and/or if the vegetation includes large trees. The size of the plot also gains importance in this method. Small plots could overestimate average biomass density if they include large trees or vice versa. In general, using harvest method in high biomass density areas is not practical and repeating these measurements is not feasible (Houghton et al., 2009).

To eliminate these problems, researchers have developed indirect methods to estimate the above ground biomass. The most common approach uses empirically based allometric equations based on destructive samples that allow the estimation of tree biomass density from more easily measured properties, such as diameter at breast height (dbh) and height (Whittaker and Woodwell, 1968). Undoubtedly, the most commonly used mathematical model for estimating tree biomass is the allometric equation with the following power form (Kalaitzidis and Zianis, 2009):

$$Y = aX^b \tag{1}$$

where a and b are scaling parameters that vary with the variables under investigation; Y is the total tree biomass or one of its components and X a tree dimension variable (i.e. DBH, DBH^2, DBH^2H etc.; DBH implies diameter at breast height which is 1.3 m above ground and H is the tree height). By this way, using DBH or height data on species basis, the biomass of a tree and forest is calculated via various regression models. There is a vast number of generalized equations that were developed for biomass estimation at regional or national level and summarized in publications such as by Muukkonen (2007) for several species in European forests, Ter-Mikaelian and Korzukhin (1997) for North American tree species and Tolunay (2011) for Turkey's forests.

Remote Sensing Methods

The use of remote sensing method is the most practical and cost effective alternative to acquire data over larger areas. The advantages of remotely sensed data over traditional field inventory methods for biomass estimation were indicated by a number of publications (Sader et al., 1989; Roy and Ravan, 1996; Boyd et al., 1999; Nelson et al., 2000; Steininger, 2000; Lu et al., 2002).

Although remotely sensed observations do not directly measure biomass, the radiometry is sensitive to vegetation structure (crown size and tree density), texture and shadow, which are correlated with AGB (Baccini et al., 2008). Consequently, remotely sensed spectral reflectance measurements can be useful predictors of biomass. Most recently, Lidar (light detection and ranging) remote sensing has been successfully used to characterize vegetation vertical structure and height, and to infer AGB (Drake, 2002; Lefsky et al., 2005). The remote sensing technologies for biomass estimation can be grouped in to three: passive optical, radar, and lidar.

Passive Optical Systems

Optical remote sensing, theoretically, have limited ability to estimate forest biomass because the recorded spectral responses in optical images are predominantly related to the interaction between the sun radiance and vegetation cover. Since optical sensors use electromagnetic energy reflected or absorbed in the uppermost canopy layers, they are typically less sensitive to vegetation structure (Steininger, 2000).

Biomass estimation using passive optical data is usually implemented by determining the correlation between biomass and spectral responses and/or vegetation indices derived from multi-spectral images.

Previous studies have shown that visible bands are strongly related with biomass (Franklin, 1986; Lu et al., 2002). The correlation of forest biomass and other stand parameters with near infrared wavelength could be either positive (Spanner et al., 1990) or negative (Danson and Curran, 1993) because of the increase in canopy shadowing with larger stands and decrease in understory brightness due to dense biomass. Shadowing generally plays an important role in all bands.

To remove variability caused by canopy geometry, soil background, sun view angles, and atmospheric conditions on estimation of AGB, many studies have been developed on the relationships between various vegetation indices and forest biophysical parameters. It has been found that the perpendicular vegetation index (PVI) (Richardson and Wiegand, 1977), soil adjusted vegetation index (SAVI) (Huete, 1988), modified SAVI (MSAVI) (Qi et al., 1994), and global environmental monitoring index (GEMI) (Pinty and Verstraete, 1992) partially reduced background reflectance effects in the data. However, results vary, depending on the characteristics of the study area. The sensitivity of vegetation indices to variations in forest biophysical parameters was evaluated by many researchers (Wulder, 1998; Treitz and Howarth, 1999; Lu et al., 2004; Lu, 2006). In general, it can be concluded that, vegetation indices can partially reduce the impacts on reflectance caused by environmental conditions, thus improve correlation between AGB and vegetation indices, especially in those sites with complex vegetation stand structures (Lu et al., 2004)

Apart from vegetation indices, researchers have been trying various different remote sensing methods and obtained different level of success. For example, Foody et al., (2001) tested the neural network approach along with the normalized vegetation index. They found that a basic multilayer perception network provided estimates of biomass that were strongly correlated with those measured in the field (r=0.80). In a study in the Brazilian Amazon, Lu et al. (2002) found that neither individual Landsat bands, nor vegetation indices derived from the Landsat bands, could be used effectively to estimate AGB. They found good estimations (R^2=0.88) using a multiple regression model that uses spectral reflectance data along with the measures of 'texture'.

Radar Systems

The ability of radar systems to operate day and night, to penetrate clouds and to record backscattering from different layers of forest structure, including the upper canopy and woody biomass component, cause radar data to be used extensively in estimation of forest stand parameters. Many previous research has shown the potential of radar data in estimating AGB (Hussin et al., 1991; Saatchi and Moghaddam, 1995; Imhoff et al., 2000; Saatchi et al., 2007; Simard et al., 2008; Koch, 2010; Sexton et al., 2009; Ghasemi et al., 2011).

Different radar data have their own characteristics in relating to forest stand parameters. For example SAR data is acquired in X, C, L and P bands. The X band is scattered by leaves and canopy cover surface so it is suitable to extract information about the surface layer of the trees. The C band penetrates through leaves and scatters by small branches and under layer elements. The L band penetrates through the surface layers and is scattered by the trunk and main branches. The P band has the most penetration into the canopy cover and the major part of P band backscattering is caused by trunk and the ground reflectance. So the backscatters of the P and L band are the most related to the biophysical parameters of the trees (Ghasemi et al., 2011). In particular, SAR L band data have proven to be valuable for AGB estimation (Lu, 2006).

The other important parameter of SAR data is the polarization of the signals. The polarization is the direction of electric field in the electromagnetic waves and is the main factor into the interaction between signals and the reflectors (Ghasemi et al., 2011). Most of the microwave sensors emit the signals in horizontal (H) or vertical (V) polarizations. The SAR data may have four polarizations: HH, HV, VH and VV. The past studies have shown that longer wavelengths (L and P band) and the HV polarization have the most sensitivity to the AGB (Sun et al., 2002). Milne and Dong (2002) also argued that, for forest biomass mapping, longer wavelength bands are generally better than shorter wavelength bands since they have greater foliage penetration, better linear correlation with woody biomass and higher saturation levels of the backscattering response to AGB.

The saturation problem is also common in radar data. The saturation levels depend on the wavelengths (i.e. different bands, such as C, L, P), polarization (such as HV and VV), and the characteristics of vegetation stand structure and ground conditions (Lu, 2006). For example, P band backscatter has been shown to be sensitive to forest biomass up to a saturation level of 100-300 t/ha depending on forest type and making it suitable to map the biomass of most of the boreal forest and a large part of the temperate forests (GTOS, 2009) while L-band synthetic aperture radar is saturated at about 100-150 t/ha (Shugart et al., 2010). Kasischke et al., (1997) summarizes saturation problem in their review study as the saturation point is higher for longer wavelengths and the HV polarization is most sensitive while VV is the least.

The topography can considerably affect vegetation reflectance and backscattering values in rugged and/or mountainous regions. Thus some approaches have been developed for topographic correction of SAR data. For example Sun et al., (2002) found that multi-polarization L band SAR data were useful for AGB estimation of forest stands in mountainous areas. Soja et al., (2010) also tested various models for topographic correction for improved biomass estimation. They found that even with the best of the models they tested, AGB can be estimated with a root mean square error of 50 t/ha and 66 t/ha for HV and HH respectively.

Radar signals are highly affected by the variations of moisture in both canopy and soil which are often difficult to measure. Thus, the same stand could produce a significantly different radar backscatter value depending on environmental conditions that effect either soil moisture or canopy moisture.

Lidar Systems

Lidar (Light Detection and Ranging) is an active remote sensing technology, which emits laser pulses from the instrument on a platform towards a target and measures the reflected energy and/or time difference between the pulse emission and reception. The area illuminated by the laser pulse is known as the lidar “footprint” and the size of the footprint is determined by the laser divergence and the altitude of the lidar instrument (Rosette et al., 2012). Lidar systems can be grouped in to two: full waveform and discrete return systems. Full waveform lidar systems record the entire returned signal above a background energy noise threshold that is related to the vertical distribution of canopy structure (Dubayah and Drake, 2000) while discrete return systems record first and last returns or at times, also a number of intermediate points (Rosette et al., 2012).

There is a growing number of studies on AGB using full waveform or discrete return lidar systems and reviewed by Wulder (1998), Dubayah and Drake (2000), Lefsky et al. (2001), Lim et al. (2003), Koch (2010) and Rosette et al. (2012). The relationship between AGB and lidar comes from the idea that taller trees contain more wood and typically support more foliage and roots than shorter trees of the same species and on the other hand lidar enables to obtain height information from vegetation. This theoretical information lets lidar instruments to model biomass using vegetation heights. Additionally, full waveform lidar systems also measure the vertical distribution of the intercepted canopy elements.

In biomass estimation with discrete return lidar systems, lidar pulses represent the vertical layer between canopy top (first return) and ground (last return). Typically, two variables are extracted from lidar data: 1) Digital Surface Model (DSM) from the first return which represents the crown surface and 2) Digital Terrain Model (DTM), from last return, representing the ground (Hyyppa et al., 2004). Additionally mean canopy height can be obtained using various statistic models like percentiles or weighted averages.

On the other hand, AGB estimation with full waveform lidar systems such as the Geoscience Laser Altimeter System (GLAS) on Ice, Cloud, and Land Elevation Satellite (ICESat) provides information about not only the first and last return, but also the vertical structure of vegetation (fig. 1) depending on intercepted surface area, orientation and surface reflectivity, returned energy level changes in given height. Several researches (Drake et al., 2002; Harding et al., 2001; Lefsky et al., 2002) have shown that waveform shape is directly related to biomass and other biophysical parameters such as canopy height, crown size, vertical distribution of canopy, and leaf area index. For example Dubayah et al., (2000) showed that lidar measured heights are highly correlated with AGB in mixed deciduous-coniferous, pine, western hemlock, and in dense tropical wet forests.

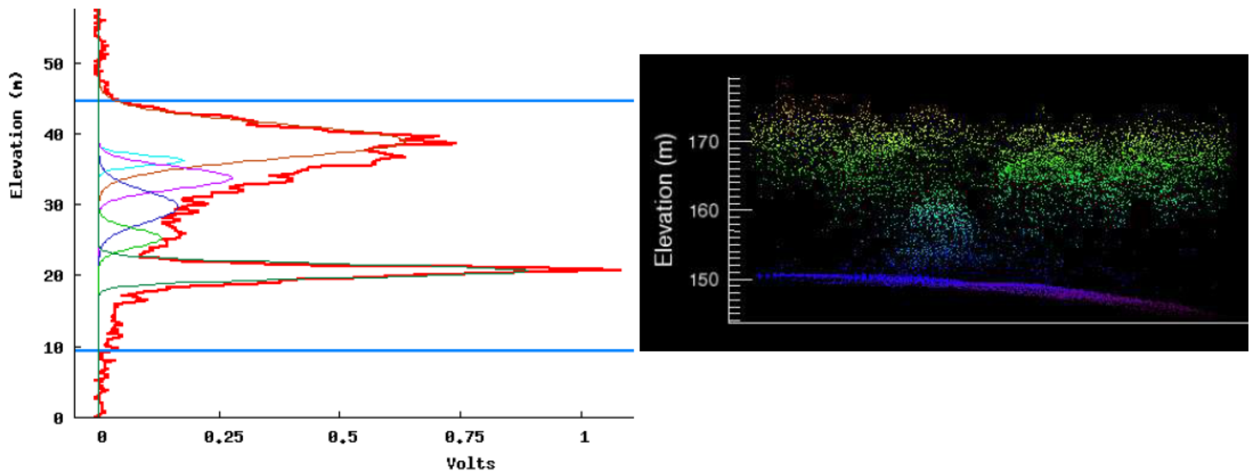

Figure 1: Full waveform (left) and discrete return (right) lidar data of coincided area Forest of Dean, Gloucestershire, UK (Rosette et al., 2012)

One of the most crucial steps in AGB estimation with full waveform lidar is accurate detection of ground return. Theoretically for full waveform airborne systems like SLICER and LVIS, and satellite data like GLAS, the ground peak can be determined as the centroid of latest Gaussian peak and works best in flat areas and open canopies. But however, in closed canopies or rough terrain, detection of ground can be complicated due to weakening of signal by canopy obstruction or widening of the waveform respectively. Rosette et al. (2008) suggested using latest Gaussian peak or the one before whichever has greatest amplitude in slopped areas. Lefsky et al. (2005) combined GLAS waveform and ancillary topographical data to estimate maximum forest canopy height in three ecosystems over sloping terrain and they found that the models could explain 59–69% of the variations of the field-measured forest canopy heights. Xing et al. (2010) the improved Lefsky's model and their improved model explained 56–92% of variation within the 0–30◦ terrain slope category. To reduce the effects of terrain Duncanson (2010) developed a methodology to estimate AGB in rugged relief or sloping terrain without using ancillary topographic data and showed that GLAS data can be used in these areas by classifying terrain relief using discriminant analysis. The latest studies also shows that GLAS data can be used for AGB estimation in areas with high slope but more research is still needed to reduce the effect of terrain on estimating maximum forest canopy height, using GLAS waveform data, especially in terrain with slopes larger than 15◦ (Xing et al., 2010).

Once the ground return is accurately determined, the height of the canopy can be calculated either as "maximum height" using the difference between signal begin and signal end (Drake, 2002; Sun et al., 2008) or "mean height" (Duong et al., 2008) using the difference between first and the last Gaussian peak. It has been proven that relative height (RH) metrics associated with energy quartiles such as RH25, RH50, and RH75 are also good predictors of biomass. One of the most used one of them is the RH50, which is also known as Height of Median Energy (HOME). HOME is the height above the ground elevation at which 50% of the returned energy in the waveform is above and 50% below (Dubayah et al., 2010). Because the HOME metric is partially determined by the amount of lidar energy that reaches the ground surface, it is sensitive to both vegetation vertical structure and horizontal canopy density (Drake et al., 2002). Latest studies also shows that RH50 is a better predictor of biomass than RH100 (maximum height) and AGB can therefore be estimated with good accuracy from lidar data.

Conclusions

Traditional methods of estimating biomass for forest inventory often rely on taking field measurements within sample plots, such as DBH or maximum tree height. These methods can be time, cost and labor intensive. Extrapolation of field measurements to all study area relies on representative sampling of trees within a land cover type and correct classification of land cover over large areas. The weakness of the traditional methods of estimating biomass lie within the statistical extrapolations made from the samples to the plot/field and the bias in the selection of representative samples. These statistical errors are known and are considered as acceptable.

However, this is the area where remotely sensed data can assist in the improvement of the accuracies of those biomass estimations. The state-of-the-art of the remote sensing methods provides spatial information crucial to characterize the spatial distribution of biomass density. Remote sensing is the most accurate tool for global and regional biomass studies not only due its ability to measure large areas and supply wall to wall maps, but also ability of periodic measurement of the area of interest.

A vast number of studies to estimate AGB implemented using various remote sensing methods including passive optical, radar and lidar data. Remote sensing based AGB estimation is a complex procedure in which many factors, such as atmospheric conditions, mixed pixels, data saturation, complex biophysical environments, insufficient sample data, extracted remote sensing variables, and the selected algorithms, may interactively affect AGB estimation performance (Lu, 2006).

Active remote sensing systems including radar and lidar are currently proposed as promising to measure three dimensional vegetation structure and AGB. Radar estimates of AGB are limited by a loss of sensitivity with increasing biomass, known as saturation (Zolkos et al., 2013). There is a potential of combined polarimetric and interferometric SAR (Pol-InSAR) to estimate biomass at higher densities (Goetz and Dubayah, 2011).

However lidar systems have strong relationship with biomass beyond levels of 1000 t/ha, far exceeding the normal saturation level of passive optical or radar sensors. Lidar systems can be used to retrieve tree height estimates, however the elevation differences within the footprint, especially for large footprint lidar data, can be significant in comparison with the predominant tree height and make it difficult to estimate tree height accurately. The height metrics derived from waveform lidar data can also be a good estimator of AGB. There are differences between types of lidar systems (airborne discrete return, spaceborne waveform etc.) and the results of the studies. A very recent study of Zolkos et al. (2013) showed that AGB models developed from airborne lidar metrics are significantly more accurate than those using radar or passive optical data.

The future research may focus on development of different methods with using multi source data and improving the use of active data such as radar or lidar. The upcoming missions such as ICESat-2 and DESDynl of NASA and BIOMASS of ESA will radically improve the current capability by providing direct measurements of AGB from active sensors.

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1. Ege Coğrafya Dergisi, yılda 2 kez yayınlanan (Haziran ve Aralık) hakemli bir dergidir. Derginin yayın dili Türkçe ve İngilizcedir.
2. Dergiye gönderilen yazılar, daha önce yayınlanmamış ve aynı anda başka bir yere gönderilmemiş olmalıdır. Ancak yurt dışında yabancı bir dilde yayınlanmış olmakla birlikte, Türkiye'de daha fazla okuyucuya ulaşmasında yarar görülen ve Türk coğrafyasına katkı sağlayacağı düşünülen makaleler, yayın kurulu kararıyla Türkçe yayınlanabilir.
3. Yazarlar, yazılarının hazırlanmasında, derginin yazım kurallarına uymalıdır. Editörler, bu kurallara uymayan yazıları geri gönderebilir.
4. Teslim edilen yazının çok yazarlı olması durumunda, aksi belirtilmediği sürece, yazışmalar ilk yazara gönderilir. Diğer yazarların yayın aşamalarından bilgilendirilmesi bu yazarın sorumluluğundadır.
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8. Gönderilen yazılar, çok özel durumlar dışında **20** sayfayı geçmemelidir. Fazlasıyla uzun makaleler, hakemlere gönderilmeden önce kısaltılması için geri gönderilecektir.
9. Editörlerin yeniden gözden geçirdiği yazılar, en az iki hakeme gönderilir.

Yazım Kuralları

Metin

- Dergiye verilecek yazılar, PC ortamında, Word'ün yeni versiyonlarında düzenlenmiş olmalıdır.
- Yazılar Times New Roman fontunda, 12 punto, 1,5 aralık, tek sütun olarak yazılmalıdır.
- Dip not kullanılmamalıdır. Sol marj 2.5, sağ marj 2 cm, üst ve alt marjlar 3 cm; Alt ve üst bilgi ise 2 cm olmalıdır.
- Metin içindeki başlıklara numara veya harf verilmemelidir. Metin içi vurgular (koyu, alt çizgili, italik vb.) yazarların tercihine bırakılmıştır.
- Metin üst bilgi bölümünde ve içinde yazarların kimliğini açığa çıkaracak bilgiler yer almamalıdır.

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1. Aegean Geographical Journal is published two issues/annum in June and December. Official languages of the Journal are Turkish and English.
2. Manuscripts submitted to this journal should not have been published or simultaneously submitted, elsewhere.
3. Authors should consult the journal's editorial and publication policies. Editors may return manuscripts that are grossly inconsistent with these policies.
4. Where the submitted manuscript is multi-authored, correspondence will be sent to first-named author, unless otherwise indicated. It will be the Corresponding Author's responsibility to ensure that all authors are informed of progress in the editorial process.
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6. The chief editor's judgement is final, with regard to suitability for publication.
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8. Papers will be limited to a maximum printed length of 20 pages, except in special circumstances. Excessively long papers will normally be returned for shortening before review.
9. Manuscripts are sent to least two referees.

Notes for Contributors

Main Text

- Manuscript should preferably be in PC Word format.
- All text should be on 1.5 line space at a minimum font size of 12 point with single column.
- Footnote must not be used. Left margins should be 2.5 cm, right margins should be 2 cm, top and bottom margins should be 3 cm; Header and Footer should be 2 cm.
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- Matematiksel ifadeler, denklemler numaralandırılmalı, denklemler sola, denklem numaraları ise parantez içinde sağa dayalı olmalıdır.
- Metnin hazırlanmasında şu sıra izlenmelidir. Başlık (ingilizce karşılığı ile), ingilizce abtract, keywords, türkçe öz ve anahtar kelimeler, ana metin, teşekkür bölümü, referanslar ve varsa ekler. Yazar adları, adresleri ve e-mailleri, metinden ayrı bir sayfada gönderilmeli, metin içinde yazarların kimliklerini belirten herhangi bir ibare bulunmamalıdır.

Başlık

Başlık mümkün olduğunca kısa olmalı ve makalenin içeriğini tam olarak yansıtmasına özen gösterilmelidir. Başlığın İngilizcesi mutlaka belirtilmelidir.

Abstract

Abstract İngilizce hazırlanmalı ve 300 kelimeyi aşmamalıdır. Makalenin kısa bir özeti ve sonuçlarını içermelidir. *Abstract*'ın sonunda *keywords* yer almalıdır. *Absract* metni sağdan ve soldan 1 cm boşluk bırakılarak, bloklu ve 11 punto ile yazılmalıdır.

Öz

Abstract'ın Türkçe karşılığı olmalı ve sonunda yine Türkçe hazırlanmış anahtar kelimeler bulunmalıdır. Sağ ve sol marj 1 cm olmalı ve 11 punto olmalıdır.

Şekiller ve Tablolar

- Metin içinde yer alan tüm çizim, harita, grafik ve fotoğraflar "şekil" olarak, çizelgeler ise "tablo" olarak isimlendirilir.
- Şekiller baskı boyutunda (maksimum 16,5 x 24 cm) olmalıdır.
- Bilgisayarda üretilen şekiller, en az 600 dpi çözünürlükte ve tiff formatında olmalı ve her biri ayrı dosyalar halinde kaydedilmelidir. Editöre gönderilen baskılar, yüksek kaliteli kâğıda lazer yazıcı ile basılmalıdır. Elle hazırlanan çizimler temiz olmalı, yazıları şablonla yazılmalı ve siyah mürekkep kullanılmalıdır. Çizimlerin orijinalleri gönderilmelidir.
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- Renkli şekil ve fotoğrafların basım maliyeti yazarlarına aittir. Bu konunun detayları editörlerden alınabilir.
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- Equations should be numbered serially in the right-hand side, in parentheses.
- The main text should be formed by following order: Title (both in Turkish and in English), Abstract in English, Keywords in English, Abstract in Turkish, Keywords in Turkish, Main text, Acknowledgements, References and appendices. Author(s)'s name, address, e-mail must be written on a separate page.

Title

Title should be brief and it should reflect the content of manuscript

Abstract

Abstract must be written in English (maximum length 300 words). It should summarize the entire paper, not the conclusions alone. It should be justified and both left and right margins should be 1 cm with 11 point font size.

Figures and Tables

- All drawings, maps, charts, diagrams and photos are to be referred to as figures, tables as tables in the main text.
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- Kaynaklar, metnin sonunda, kendi içinde alfabetik olarak verilmeli ve başlık olarak "Referanslar" kullanılmalıdır.
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- Ekler bölümünde, metin içinde verilemeyen uzun tablolar, kullanılan denklem veya yöntemlerin detayları yer alabilir.

- Titles of all tables and figures should be short and explanatory in both in English and in Turkish.

References

- All references should be aranged in alphabetical order and grouped together at the end of the paper.
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- Names of periodicals and books should be written out in full and italic. All authors' name must be complete in the reference section.
- Reference is made to more than one work by the same author published in the same year; identify each as (a) mark after the date.
- In the text, references should be cited by the author's name and the year in parentheses (Kayan, 1998). Where there are two or more references to one author in the same year, the following form should be used (Kayan, 1998a) or (Kayan, 1998b). Where references include three or more authors the form (Kayan vd., 1999) should be used. Example of the style follow:

Appendices

Appendices are encouraged for long tables, specific details of methods or mathematics.

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