THE ROLE OF HILLSHADE, ASPECT, AND TOPOSHAPE IN THE WOODLAND DIEBACK OF ARID AND SEMI-ARID ECOSYSTEMS: A CASE STUDY IN ZAGROS WOODLANDS OF ILAM PROVINCE, IRAN

ALI NAJAFIFAR*[1], JAAFAR HOSSEINZADEH[2] AND ABDOLALI KARAMSHAHI[3]

[1]Assistant professors, Agricultural Research, Extension and Education, Agriculture and Natural resources Research Center of Ilam, Iran, Tel: +98 9188401480; Fax: +988433332501
[2]Associate professors, Department of Forest Sciences, Faculty of Agriculture, University of Ilam, Iran
[3]Associate professors, Department of Forest Sciences, Faculty of Agriculture, University of Ilam, Iran
**Corresponding author e-mail: alinajafifar@yahoo.com*

Received: 3rd December 2018, **Accepted:** 31th May 2019

ABSTRACT

Soil moisture plays a key role in the ecological capability of arid and semi-arid woodland. Reducing soil moisture due to frequent droughts causes pest prevalence and disease outbreak and the consequence of forest dieback. On the other hand, soil moisture is strongly correlated with the amount of radiation received on the Earth's surface. The sun's radiation is traditionally described often by aspect and sometimes by toposhape. The use of the hillshade map for estimating solar radiation is possible through developing GIS. The present study aimed to compare the relationship and the ability of these indices to describe the phenomenon of arid and semi-arid woodland decline better and more accurately in a case study in the west of Iran. To this aim, the aspect and toposhape layers were generated in 5 and 12 classes, respectively. Then, the hillshade map in range of 0-255 was made during the peak of summer heat. The comparison of the dieback ratio in the three characteristic histograms showed that the shade index, unlike the other two indicators, had a significant effect on forest drought (R2=0.91 for linear equation and R2=0.94 for quadratic equation). The results indicated that the application of hillshade in describing and analysing ecological processes by relying on soil moisture such as woodland dieback is superior to the other two indicators. It is suggested that this index be used to obtain a risk model to predict woodlands dieback which are under the pressure of frequent droughts due to climate change or other mortal factors.

Keywords: Arid ecosystems, Aspect, Dieback, Decline, Hillshade, Toposhape, Zagros woodland

INTRODUCTION

Solar radiation is one of the crucial factors affecting on the composition and pattern of plant species. In addition, the aspect plays an important role in evaporation and temperature change and often is used as a criterion for assessing the solar radiation exposure. Conventional methods to provide the information related to measuring aspect and slope in the site are unable to analyse daily and annual solar radiation changes and local shading. Therefore, using these types of static parameters is not considered as useful means to observe spatial and temporal heterogeneity of vegetation pattern in landscapes scale (Pierce *et al.*, 2005)

Although the discrete variables like toposhape and the aspect (four main classes and eight subclasses) have been considered as two main effective topographic factors in controlling soil moisture and vegetation development by plant ecologist for many years, the hillshade map was implied by Guth (1999) and suggested by Wise (2001) (Cadell, 2002). Therefore, few studies have been reported in plant ecology related to the hillshade phenomenon. Using hillshade regime is more convenient than using aspect in ecological studies due to its ability to observe daily and annual solar radiation regimes and the ability to represent the statistical analysis in fuzzy sets (Najafifar *et al.*, 2017).

Most of the studies have focused on showing the effects of various sunlight regimes on the survival or growth of forest tree under natural canopy conditions or synthetic shade provision. These studies highlighted the significant role of various shade values in growing and surviving oak seedlings (Karimidoust, 2001; Espahbodi & Tabari, 2004; Jahanpour *et al.*, 2007; Najafifar *et al.* 2011; Jaafari *et al.* 2013; Gianini,1971; Lyapova & Palashev,1982; Groess,1983; Sagheb-Talebi, 1995; Weinreich, 2002; Gardiner & Hodges, 1998; Farque *et al.*, 2001; Guo *et al.*, 2000). In another study, the relationship between ecological and topographic attributes was determined by using linear models. The results indicated that vegetation distribution in subtropical forests, Southern California relies on the soil moisture balance, which is itself controlled by topographic indices such as slope, aspect, curvature of the land, elevation, and other complex topographic facets such as solar radiation and soil moisture (Franklin *et al.*, 2000).

In addition, in another study implemented in Japanese pine forests, the locality index was modelled based on 14 classified solar radiation indices, humidity index, and topographic radiation index in the form of linear multivariate regression. In this research, the most suitable model was obtained in relation to the Digital Elevation Model (DEM) with a spatial resolution of 12 meter and R2 = 0.692. The results confirmed that soil moisture plays an effective role in the fertility of the habitat and the sunlight is the most important limiting factor (Horsch, 2003).

Further, Pierce *et al.* (2005), in their studies on landscape scale, calculated the total value of the hillshade in different hours of a specific day in each month. Then, the average daily and monthly solar regime and finally seasonal regime were used as the indicators to estimate the amount of growth and composition of vegetation. The result indicated that the hillshade indicator was more efficient than other three indicators.

In a case study in France, the distribution model of several forest species was mapped based on the slope, aspect, altitude, shadow, global climate, cloudiness, and latitude parameters (Piedallu & Claude, 2007).

The Ohio woodland in the United States was emphasized in another study in which Site Index and the combination of woodland trees were prepared based on the soil moisture content index. In this study, the highest weight (40 %) was assigned to the layer of hillshade map. This index was proposed to manage arid and semi-arid woodlands where humidity is regarded as the limiting factor (Iverson *et al.*, 1997).

In Iran, the map of soil sub-criteria was generated by using hillshade to evaluate the ecological capacity of Zagros woodland region (Ahmadi Sani *et al.*, 2011). Furthermore, the role of hillshade factor in canopy density and ecological capacity of Zagros woodlands was studied and compared with the aspect. Based on the studies, using hillshade map is recommended as the key factor in assessing ecological capacity in the Zagros woodland.

To the best of our knowledge, there is no scientific report on observing the comparison of aspect, toposhape, and hillshade or about the role of hillshade on forest dieback. Thus, the present study aimed to investigate and compare the impact of these factors on dieback of arid and semi-arid woodlands in the case study in Zagros region of Ilam province in Iran.

Over the past few decades, the large part of the Zagros woodlands has lost its natural capacity and changed into deforested area. In addition, the occurrence of frequent droughts, pest prevalence, and disease outbreak resulted in increasing deforested area in recent years. In order to protect the forests, recognizing the ecological factors affecting the forests is highly important. The lack of soil moisture is the most limiting factor in semi-arid conditions of Zagros region. In addition, measuring and mapping soil moisture are regarded as costly and difficult task. Therefore, the soil moisture difference in shady hillside (north-facing hillside in northern hemisphere) and sunshiny hillside (South-facing hillside in northern hemisphere) is traditionally evaluated by aspects maps.

In the studies related to vegetation ecology, using an indicator which can reflect the changes of land moisture is important because surveying soil moisture in a wide area is a challenging job. In this regard, the study of the role of effective topographic factors is essential (Najafifar *et al.*, 2015).

A relatively comprehensive research has recently been conducted to find the reasons why Zagros woodlands are declining and water and soil agents are considered as the most affecting factor on damaging the forest. In this regard, conducting a research in Barm plain, Kazeroon showed that poor rainfall significantly influenced forest decline (Hamzehpour *et al*., 2010).

The soil survey in Ilam province showed that light texture soil with a high specific gravity and low saturation percentage are more prone to decline trees than other types of soils (Soleimani *et al*., 2014). Rainfall pattern may change ecological processes more significantly than other climatic factors in dry tropical woodlands (Murphy & Lugo, 1986; Sukumar *et al.*, 2005; Holmgren *et al*., 2006). A large number of studies demonstrate that tree destruction in the wet tropical forest may increase after a low rainfall period in the wet season (Laurance *et al*., 2001; Condit *et al*., 2004; Breda *et al*., 2006; Mitsuda *et al*., 2007). Dry tropical forest which grows in region with a great rainfall changes may resist more too low rainfall in comparison with wet tropical forests (Suresh *et al*., 2010). Hosseinzadeh *et al.*, (2017) studied the drought phenomenon in Zagros woodlands, Ilam province, which occurred along with severe and abnormal climatic changes like a reduction in precipitation and humidity, a rise in temperature, and a decrease in dust.

MATERIALS AND METHODS

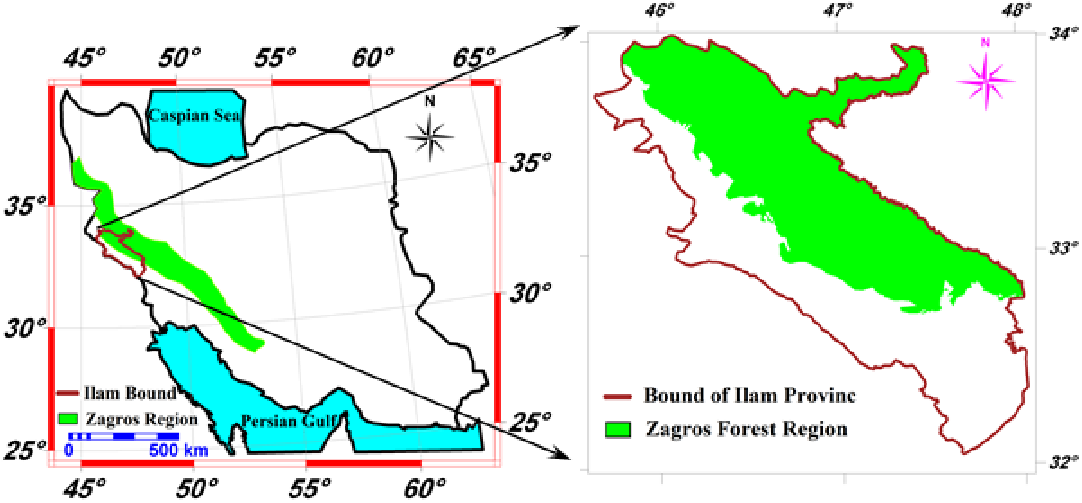
Study area

The studied area is a part of Zagros woodland, which is located in Ilam province. Ilam province with 19727.9 km^2 is in the South west of Iran, between 45° 39' to 48° 1' east longitude and 32° 3' to 34° 2' north latitude. It is bounded on the south by Khuzestan province, on the east by Lorestan province, on the north by Kermanshah province, and on the west by Iraq country. Fig. 1 illustrates the location of Ilam province and Zagros region in Iran.

The average rainfall of the 30 year period (1986-2016) is 572.1 mm, based on Ilam Meteorological Station data. The ombrothermic diagram of the station indicates that the region has a dry period (the vegetative period of the trees) from mid-May to late October. The drought started in Ilam province since 1998. The average precipitation in the period 1998-2014 (485.8 mm) was about 30 % less than the average rainfall in the previous period

(689.8 mm) in the Ilam province (Najafifar *et al.*, 2015). The decline of the Zagros forests has started since 2001 (Sagheb-Talebi, 2011).

Fig. 1: The map of Ilam province and Zagros Vegetation region



Research layers

The canopy map of Zagros woodland area with decline pats of its, was generated by using SPOT6_Pleiades Satellite Image with 83 % total accuracy and 0.80 Kappa coefficients. The DEM map of the studied area was extracted from 1:25000 topography maps. Using the DEM map, aspect map was generated in 5 classes (4 main aspects and plain area with no hillside direction) and Toposhape map were generated in IDRISI Kilimanjaro environment.

In the next step, the Hillshade map was prepared at three different times during the first day of August 2014 (the peak heat of the summer) in ArcGIS software. In this procedure, it is necessary to calculate the solar condition in three different periods of time. The position of the sun in any location of the earth and at any time can be determined by the illumination angle (Altitude) and radiation angle (Azimuth). The daily and annual variations of these two angles depend on the latitude of the site. The hillshade index at a specific location depends on both the altitude and azimuth factors. Maximum solar thermal energy occurs at maximum altitude (zenith). At the same time, hill sunshine is dependent on the azimuth angle in the each point of the earth. In the pre-Zenith situation Southwestern aspects and in the post-Zenith situation south-eastern aspects are exposed to more sunlight in the northern hemisphere. Accordingly, the Hillshade map was prepared in three situation including zenith (Azimuth = 179.92 °), before and after zenith (179.92 ° ± 56.02 °). Finally, the average of the three maps was used in the study. The above-mentioned parameters were calculated for the geographical location of 33.089° north latitude and 47.005° east longitude (approximate center point of study area) by using the NOAA Solar Calculator software (http://www.esrl.noaa.gov). In the first August, 2014, the sun rose at 6:36:16 at Azimuth 67.87° on and set at time 20:20:00 at Azimuth 248.49°. In this path, three points with equal distances including azimuths of 123.89°, 179.92°, and 235.94° were selected, respectively. Then, the altitude and time of sun passage were calculated from these three selective azimuths using the mentioned software. Table 1 indicates the related data. In the next stage, the hillshade map for the three different times was prepared using IDRISI software. Then, the average value of the three maps in the ArcGIS 9 software was generated. All output maps are represented by ILWIS software.

Table 1: Azimuth and altitude in three different conditions

No	Time	Azimuth	Altitude
1	12: 05: 24	123.89°	65.96°
2	13: 28: 40	179.92°	74.84°
3	14: 51: 15	235.94°	65.99°

Calculating the canopy dieback in different statuses

In this research, equation 1 was used to express the previous method suggested by Najafifar *et al*, (2017) in order to calculate canopy dieback percentage. In this regard, canopy dieback percentage (D_i %) was calculated in each status of toposhape, aspect and hillshade layers from pixel based maps by Cross command of ILWIS software and based on equation 1. Thus, each of the toposhape, aspect, and hillshade maps were crossed binary with canopy map. Then, a number of canopy dieback pixels in each status (NDPi & NLPi) were determined by of the data in cross-table in the software.

$$D_i\% = \frac{NDP_i * 100}{NDP_i + NLP_i} \qquad \text{eqn 1}$$

where,
Di %: Percentage of canopy dieback in the status i
NDPi: Number of canopy dieback pixels in the status i
NLPi: Number of live canopy pixels in the status i

RESULTS

Fig. 2 illustrates the distribution map of live and dieback canopy in Ilam forests of Zagros region. As shown in Fig. 3, there are four generated maps including the hillshades related to radiation 123.89°, 179.92° degree, 235.94°, and mean hillshade map. The maps of toposhape and aspect in the live and dieback canopy are displayed in Fig. 4. The percentage of canopy dieback in different aspects and toposhapes are shown in Figs. 5 and 6, respectively. It is worth noting that the areas with a slope less than 10 % were assumed as plain areas in the map in Fig. 5. Fig. 7 displays dieback canopy percentage in hillshade classes and Fig. 8 shows the graph and the linear and quadratic equation of correlation dieback percentage related to the hillshade values.

Fig. 2: Distribution of live and dieback canopy in Zagros woodland lands of Ilam province

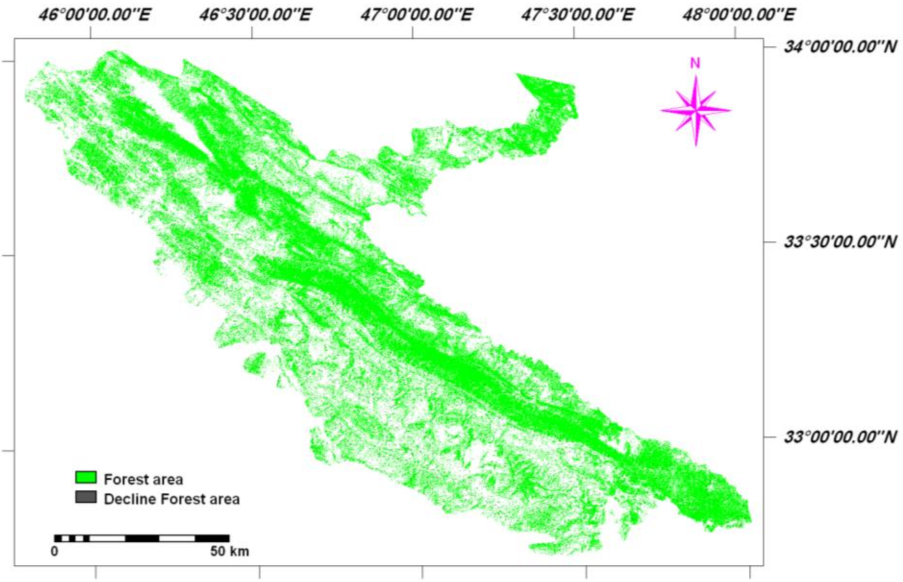


Fig. 3: Hillshade maps, first (upper right), second (upper left), third (bottom right) and mean hillshade (bottom left)

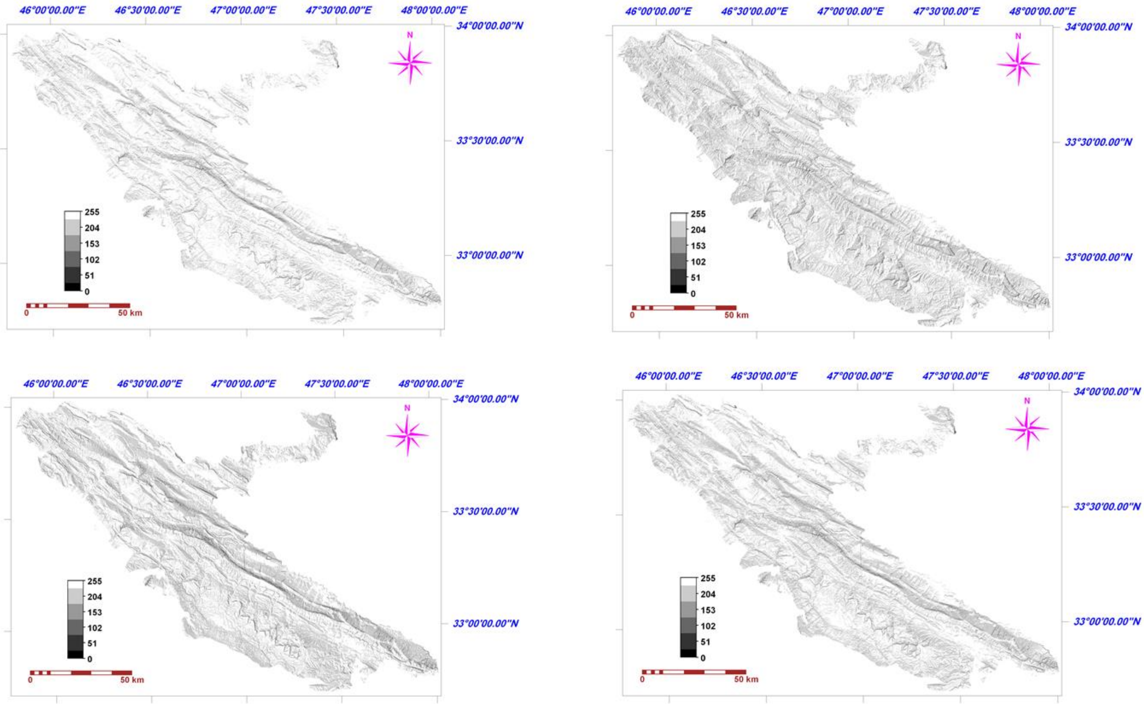


Fig. 4: Crossed maps with forest cover map (Figure 2):
Toposhape map (b), aspect map (a)

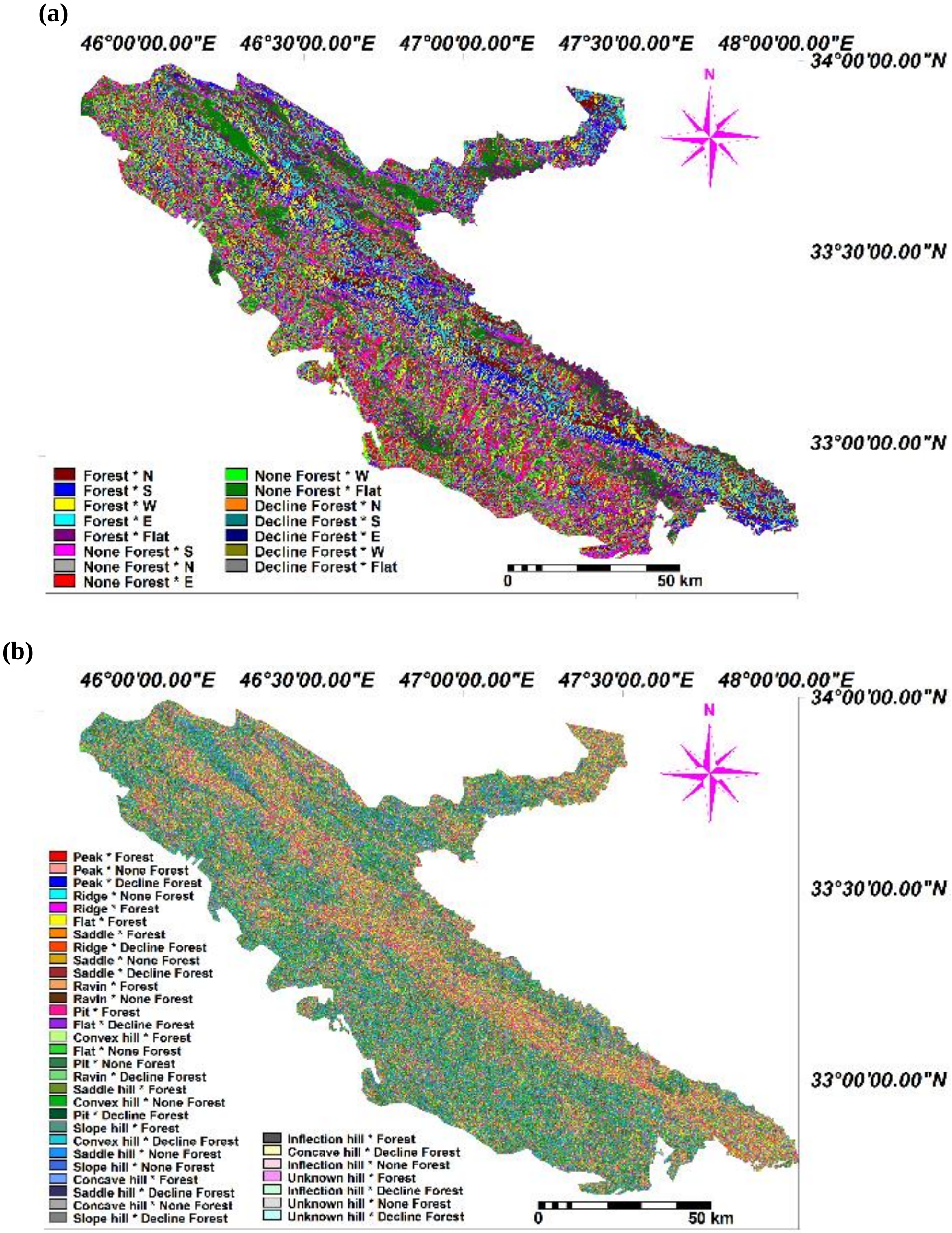


Fig. 5: Dieback canopy percentage in the main aspects

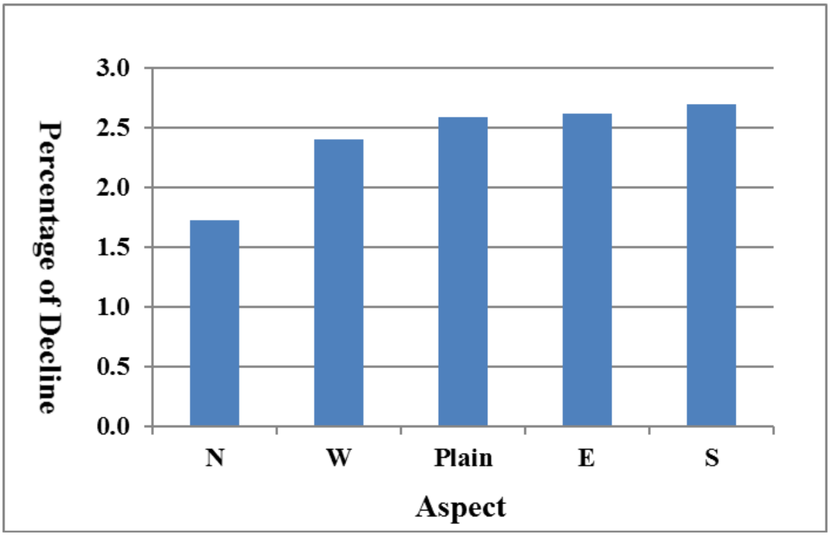


Fig. 6: Dieback canopy percentage in toposhapes

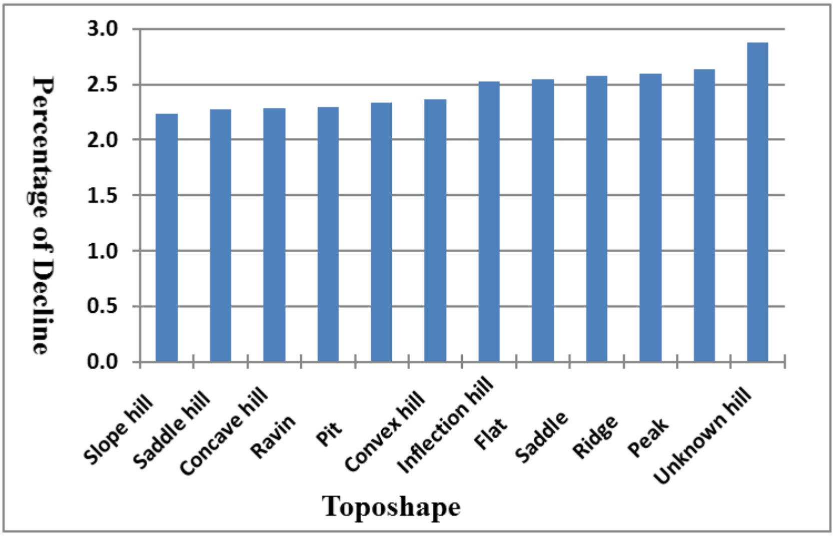


Fig. 7: Dieback canopy percentage in hillshade classes

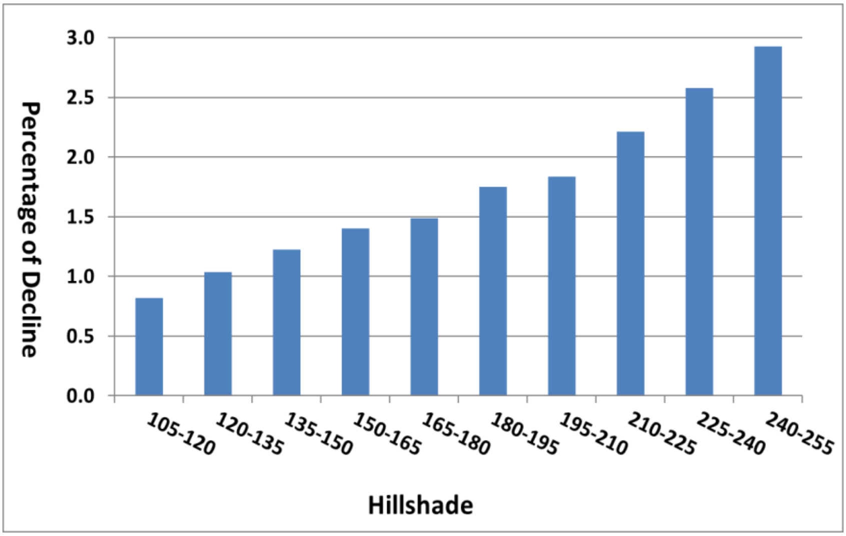
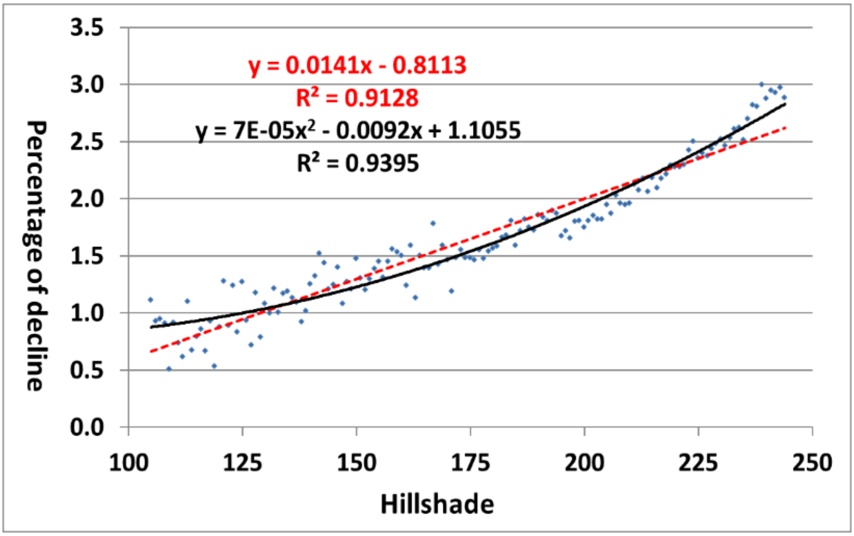


Fig. 8: Function and coefficient of determination for dieback percentage and hillshade



DISCUSSION

Comparing the graphs presented in Figs 5, 6, and 7, it is concluded that the hillshade played a special role in the drying conditions of oak trees in Ilam province, compared to aspect and toposhape. As shown in Fig. 7, the continuous increasing trend indicated the efficient performance of hillshade criterion in assessing and analysing the Zagros woodland dieback because the hillshade map is considered as a more accurate factor to display soil moisture variation. Using the hillshade factor as a continuous quantitative variable in ecological studies give more accurate results related to the Zagros study in comparison with other factors.

The results of this study are in line with those of a similar study related to the role of two hillshades and aspect factors in forest growth in some parts of the Zagros basin forests. The results emphasized the efficiency of using hillshade factor in forest ecosystem analysis, especially in arid and semi-arid areas (Najafifar *et al.*, 2017).

It is worth noting that the data derived from satellite images and Digital Elevation Model were free from sampling errors. Therefore, the correlation function between the hillshade regime and the canopy percentage in the whole area indicated the most accurate correlation (no sampling error) between the various factors.

Regarding the high correlation between the hillshade index and drying percentage (Fig. 8), it is suggested that this index can be used in modelling the prediction of the risk of woodlands dieback which are under the pressure of frequent droughts due to climate change or other mortal factors.

Regarding the relationship between hillshade factor, temperature, and soil moisture, it is concluded that forest dieback occurs more often in soils with less shading in warmer and drier soil (Fig. 6). Hosseinzadeh *et al.* (2015) and Hamzehpour *et al.* (2010) concluded that the main reason for declining oak trees in Barm plain (Kazeroun, Iran) was low precipitation and pest and disease outbreak. Some other studies reported that change in rainfall pattern caused dieback in dry tropical forests (Sukumar *et al.*, 2005; Holmgren *et al.*, 2006). Thus, the main cause of oak canopy dieback is related to recent droughts leading to the prevalence of various pests and diseases in the region. As a management instruction, the researchers recommended implementing reserve storage projects in order to maintain soil moisture and reduce the evapotranspiration percentage.

In the present study, the effect of hillshade was first evaluated in forest canopy dieback and compared with aspect and toposhape parameters. Accordingly, the results confirmed the results of few studies related to the hillshade map application in various forest ecology fields. In many cases, hillshade map were recognized as preferable means in forest researches (Iverson *et al.*, 1997; Fu & Rich, 1999; Horsch, 2003; Pierce *et al.*, 2005; Akpinar & Usul, 2005; Piedallu & Claude, 2007; Molly Barth, 2010; Cioban *et al.*, 2013).

In general, providing a hillshade map in ecological studies is regarded as a useful tool. It is suggested that hillshade map can be considered as a convenient means in predicting woodland dieback in arid and semi-arid regions. Using the hillshade criterion in the methodology will increase the accuracy and scope of the analysis of changes in plant ecosystem parameters against climate change and global warming.

REFERENCES

Ahmadi, Sani, N., Babai, Kafaki, S. and Mataji, A., (2011). Evaluation of ecological capability of northern Zagros woodlands for ecotourism activities using Multi-Criteria Decision Making. *Town And Country Planning,* 3(4): 45-64, (In Persian).

Akpinar, E. & Usul, N., (2005). *GIS in Forest Fires*. ESRI Intern. User Conf., on CD.

Breda, N., Huc, R., Granier, A., Dreyer, E., (2006). Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. *Annals of Forest Science*, 63: 625–644.

Cadell, W., (2002). *Report on the generation and analysis of DEMs for spatial modelling*. Retrieved September 15, 2002, from www.macaulay.ac.uk.

Cioban, A., Criveanu, H., Ioana Pop, F.M., Rotaru, A., (2013). Aspects of Solar Radiation Analysis using ArcGis. *Bulletin UASVM Horticulture*, 70(2): 437-440.

Condit, R., Aguilar, S., Hernandez, A., Perez, R., Lao, S., Angehr, G., Hubbell, S.P., Foster, R.B., (2004). Tropical forest dynamics across a rainfall gradient and the impact of an El Nin˜o dry season. *Journal of Tropical Ecology* 20, 51–72.

Espahbodi, K. & Tabari, M., (2004). Determination of the most suitable shade conditions for the cultivation of Fagus orientalis seedlings in mountain nurseries of Malek Sangheh, Iranian *Journal of Natural Resources*. 57(3): 439-446.

Farque, L., Sinoquet, H. and Colin, F., (2001). Canopy structure and light interception in Quercus petraea seedlings in relation to light regime and plant density. Article summary. *Tree physiology*, 21: 1257-1267.

Franklin, J., McCullough, P., and Gray, C., (2000). Terrain variables used for predictive mapping of vegetation communities in Southern California, In J.P. Wilson & J.C. Gallant (eds.), *Terrain Analysis: Principles and Applications* (331-353p), John Wiley & Sons, New York.

Fu, P. & Rich, P.M., (1999). *Design and implementation of the Solar Analyst: an ArcView extension for modeling solar radiation at landscape scales*. Proceedings of the 19th Annual ESRI User Conference, San Diego, USA.

Gardiner, E.S. & Hodges, J., (1998). Growth and biomass distribution of cherrybark oak seedling as influenced by light availability. *Forest Ecology and Management*, 108: 127-134.

Gianini, R., (1971). Survival and growth of Various Tree Seedling as Affected by Light Intensity, Annli, *Accademia Lataliana di Scienze Forestali*, 20: 201-225.

Groess, H., (1983). *Untersuchungen Zur kunstlichen verjungung des Bergmisschwaldes*. Forchungsberichte Forstl., Forschungsanstalt Muenchen, 55: 206p.

Guo, Y., Shelton, M.G. and Zang, H., (2000). *Effects of light regimes on 1-year-old Sweetgum and Wateroak seedlings.* Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, 373-376p.

Guth, P.L., (1999). Contour line "ghosts" in USGS level 2 DEMs, photogrammetric. *Engineering & Remote Sensin*g, 65(3): 289-296.

Hamzepour, M., Kia-dalari, H., and Bordbar, S.K., (2010). Preliminary Study of Iranian oak necrosis in Barm prairie of Kazeroon, *Fars province, research and spruce forests of Iran*, 19(2): 352-363.

Holmgren, M., Stapp, P., Dickman, C.R., Gracia, C., Graham, S., Gutierrez, J.R., Hice, C., Jaksic, F., Kelt, D.A., Letnic, M., Mauricio, L., Lo´ pez, B.C., Meserve, P.L., Milstead, B.W., Polis, G.A., Previtali, M.A., Richter, M., Sabate´ , S., Squeo, F.A., (2006). Extreme climatic events shape arid and semi-arid ecosystems. *Frontiers in Ecology and Environment*, 4: 87–95.

Horsch, B. (2003). Modeling the spatial distribution of mountain and sub alpine forests in the central Alps using digital elevation models. *Ecological Modeling*. 168: 267-282.

Hosseinzadeh, J. & pourhashemi, M., (2015). Investigation on relationship between crown indices and the severity of decline in Ilam Oak forests. *Iranian Journal of Forest*, 7(1): 57-66.

Hosseinzadeh, J., Pourhashemi, M. and Sagheb-Talebi, Kh., (2017). *Investigation of effective factors on Oak (Quercus brantii) decline and strategies in forests of Ilam province*. Research Project Report, Research Institute of Forests and Rangelands, 304pp.

Iverson, L., Dale, M., Scott, C. and Prasad A., (1997). A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forests (U.S.A.). *Landscape Ecology* 12: 331–348.

Jafari, M., Pourhashemi, M., Hosseinzadeh, J., Norouzi, A.A., Mirakhorloo, Kh. And Mohamadpour, M., (2013). *Province Recognition and zoning of stands affected by oak decline using GIS & RS in Ilam*. Research Project Report, Research Institute of Forests and Rangelands, 304pp.

Jahanpour, F., Fatahi, M., Khademi, K., Sohrabi, S.R., Karimian, R. and Beiranvand, R., (2007). *Investigation on the effect of light on the survival of pistachio seedlings in Lorestan province*. Research Project Report, Research Institute of Forests and Rangelands, 66pp.

Karimi- Dost, A., (2001). An Investigation on the Effect of awning and Seed Origin on Oak Seed in Nursery of Khorasan. Abstract Results of 1200 projects, *Natural Resources*, Vol. 1: 501-500.

Pierce K., Lookingbill, T., and Urban, D., (2005). A simple method for estimating potential relative radiation (PRR) for landscape-scale vegetation analysis. *Landscape Ecology*. 20: 137-147.

Laurance, W.F., Williamson, B.G., Delamonica, P., Oliveira, A.A., Lovejoy, T.E., Gascon, C., Pohl, L., 2001. Effects of a strong drought on Amazonian forest fragments and edges. *Journal of Tropical Ecology*, 17: 771–785.

Lyapova, I. and Palashev, I. (1982). Growth of Seedling of *Platanus orientalis*, *Sorbus torminalis* and *Corylus avelana* to Light. *Gorsko-Stopanstvo*, 44(1): 24-25.

Mitsuda, Y., Ito, S. and Sakamoto, S., (2007). Predicting the site index of Sugi plantations from GIS-derived environmental factors in Miyazaki Prefecture. *Journal of Forest Research*. 12(3): 177-186.

Molly, B., (2010). *Environmental correlates of tree species distribution in old-growth forests*. A thesis submitted in partial fulfillment of the requirements for the degree of Bachelors of Science. University of Washington

Murphy, P.G. & Lugo, A.E., (1986). Ecology of tropical dry forest. *Annual Review of Ecology and Systematics* 17: 67–88.

Najafifar, A., Hoseinzadeh, J. and Pourhashemi, M., (2015). *The effect of topography and habitat ecological capability in forest dieback in Ilam province*. Research Project Report, Research Institute of Forests and Rangelands, 74p.

Najafifar, A., Moayeri, M.H., Shatai-Joybari, Sh and Salman-Mahini, A., (2017). The role of hillshade regime on canopy density and evaluation of ecological capability in the Zagros woodlands (Case study: Kabirkooh forest of Badreh city, Ilam province). *Iranian Journal of Forest and Poplar Research* Vol. 25 (1): 23-34.

Najafifar, A., Sagheb-Talebi, KH. and Saeb, K., (2012). The role of light intensity on survival of *Quercus branti* saplings in relation to slope aspect and distance from seed trees in Ilam province forests. *Journal of Forest and Wood Products*, 64(4): 1-14 (In Persian).

Piedallu, Ch., & Gégout, J.C., (2007). Multiscale computation of solar radiation for predictive vegetation modelling. *Annals of Forest Science*, DOI : 10.1051/forest, 64: 899-909.

Sagheb-Talebi, Kh., (1995). Study of some characteristics of young beeches in the regeneration gaps of irregular shelterwood (Femelschlag). In: Madsen, S.F., Genetics and silviculture of beech. Denmark. *Forskingscerien*, Nr. 11: 105-116.

Sagheb-Talebi, KH., Pourreza, M., Khan Hosni, M., (2011). Check oak forest habitat in Kerman province. *Scientific – research Iran's natural ecosystems*. 2: 54-57 (In Persian).

Sukumar, R., Suresh, H.S., Dattaraja, H.S., Srinidhi, S., Nath, C., (2005). Dynamics of a tropical dry forest at Mudumalai (India): climate, fire, elephants and the evolution of life history strategies. In: Burslem, D., Pinard, M., Hartley, S. (Eds.), *Biotic Interactions in the Tropics* (510–529 p.). Cambridge University Press, UK.

Suresh, H.S., Dattaraja, H.S., Sukumar, R., (2010). Relationship between annual rainfall and tree mortality in a tropical dry forest: Results of a 19-year study at Mudumalai, southern India. *Journal of Forest Ecology and Management*, 259: 762–769.

Teymourzadeh, A., Akbariniya, M., Hosseini, S.M., Tabari, M., (2003). The effect of shades on survival and growth of Persian oak (*Quercus macranthera*) Seedlings. *Journal of Pajouhesh & Sazandegi*, 16(4): 12-17.

Weinreich, A., (2002). Regeneration of oak in Gaps: Comparative Studies of quality and stem-development of young Oaks libel, Grown under different light condition. *Journal of Ecology,* 82(2): 227-237.

Wise, S.M., (2001). *Error assessment for digital terrain models*. Retrieved September 8, 2003, from: http://www. shef. ac.uk/geography/staff/wise_stephen/dtm/dtm.htm.