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Research Article

Faulting and Lithological Features in Vegetation Distribution: A Remote Sensing Asisted Case Study from SE Turkiye

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Abstract

In this study, the effect of lithological and tectonic parameters on vegetation density was investigated. In this context, two faults and their immediate surroundings in an area whose bedrock is flysch and limestone in the southeast of Turkey (south of Lake Van) were chosen as the sampling area. In the research area, generally, the extensional tectonic regime in NE-SW direction has developed many normal faults and these faults have gained oblique character in places. The aforementioned faults not only controlled the tectonic-morpho dynamics and geomorphic character of the research area, but also controlled the texture of the vegetative cover. For the target purpose of the study, field studies were carried out and remote sensing techniques were applied. GIS and remote sensing outputs (NDVI, lineament, lithological map) and field findings were compared. As a result, it was determined that there were significant relationships between vegetation density in the sampling area, fault lines and lithological features.

Keywords: Vegetation Lineament, Remote Sensing, Faulting

Introduction

Vegetation, which is the organic cover of the topography, has developed under the control of the physical and human parameters of the natural environment such as tectonism, relief, climatology, hydrography, soil properties, human impact (Hack and Goodlett, 1960; Atalay, 1994; Hara et al., 1996; Istanbulluoğlu and Bras, 2005; Duran and Günek, 2010; Esen and Avcı, 2020; Erkal and Taş, 2020; Smith and Bookhagen, 2021; Atalay et al., 2020; Mehta et al., 2021; Panchal et al., 2021). Among these parameters, especially tectonism and lithology have a positive effect on vegetation development due to the hydrogeological conditions and petrographic texture they provide. Some studies have shown the correlation between tectonic systems and vegetation development/density (Vogl and McHargue, 1966; Sipahioğlu et al., 1986; Trefois et al., 2004; Treiman et al., 2012; Burbank and Anderson, 2012; Wang et al., 2013; Harding and Berghoff, 2020; Roy et al., 2020; Çetin, 2020). Especially faulting, which is one of the tectonic movements, can regulate the vegetation texture in an interesting way. The unconsolidated mylonite (crush) zone (Yeats et al., 2006) between blocks, moving along the fault corresponds to areas where groundwater moves freely towards the surface by capillarity. Since mylonite fields are lines consisting of loose lithological material and soiling is high, they also positively affect the development of plant root systems (Karaman and Kibici, 2008).

As a matter of fact, the underground water resources, observed along the fault and the dense vegetation in such areas prove this. In addition, suitable topography conditions and the slope-aspect features on the falling block may cause such areas to remain more humid and thus present a denser pattern of vegetation. The uplifting fault block is the source of weathering products for the falling block. Materials moving down throughout the slope are deposited in colluvial form on the descending block. Such colluvial deposits in tectonic areas become soil and water source areas for plants (Bull, 2007).

The petrographic character of the rocks is another natural environment component that affects the development and distribution pattern of vegetation. Physico-chemical properties of minerals forming rocks determine the nutritional potential of lithology for plants, its cohesive character, resistance to erosive processes, diaclase development, etc. Diaclase structures in limestone lands positively affect the development of the root system and support intensive vegetation development in such areas. The rocks, which are formed by intercalation sandstone, marn and claystone and called flysch, can be areas where vegetation is observed intensively they allow the root system to develop easily and are rich in nutrients (Atalay, 1994; Avcı, 2005; Atalay et al., 2020). However, if the flysch layers are inclined and there is an anthropogenic interference with the natural balance, the erosion process accelerates. In addition, flysch is one of the rock types in which erosional processes are experienced intensely due to their low cohesion. The low resistance to erosion in such rocks shortens the decomposition time of the bedrock and prevents sticking the soil cover, hence the vegetation.

Space technology and geographic information systems have enabled remote sensing-based studies on vegetation, and many studies have been carried out on this subject in recent years (Billingsley 1984; Karabulut, 2006; Karabulut, 2019; Hu et al., 2021; KC et al., 2021). In such studies, problems such as the spatial variation of vegetation between years and how the vegetation density is, are trying to be solved by remote sensing systems. Based on all these, this study was prepared for the remote sensing-based analysis of the relationship between the distribution pattern of vegetation and faulting/lithology. In the study, vegetation distribution along fault lines was investigated in a sample area whose bedrock is flysch and limestone. The sample area is located in southeastern Turkey, south of Lake Van., the site, structurally located in the Bitlis Zagros Suture Zone, is located in the Botan Stream Basin, in the Sinebel Stream sub-basin, the west of the Kato Mountains (Figure 1).

Although studies on subjects such as tectonism and geomorphology have been carried out in the region (Erentöz, 1949; Altınlı et al., 1963; Türkünal, 1980; Öztürk, 2019; Öztürk and Zorer, 2019; Zorer and Öztürk, 2021), researches on the relationship between vegetation and faulting/lithology have not been done. In addition, there is no study on remote sensing assisted analysis of vegetation distribution based on faulty/lithological structure. Therefore, the main purpose of the study is the remote sensing assisted analysis of the relationship between vegetation distribution/density and faults and the lithology effect on vegetation distribution.

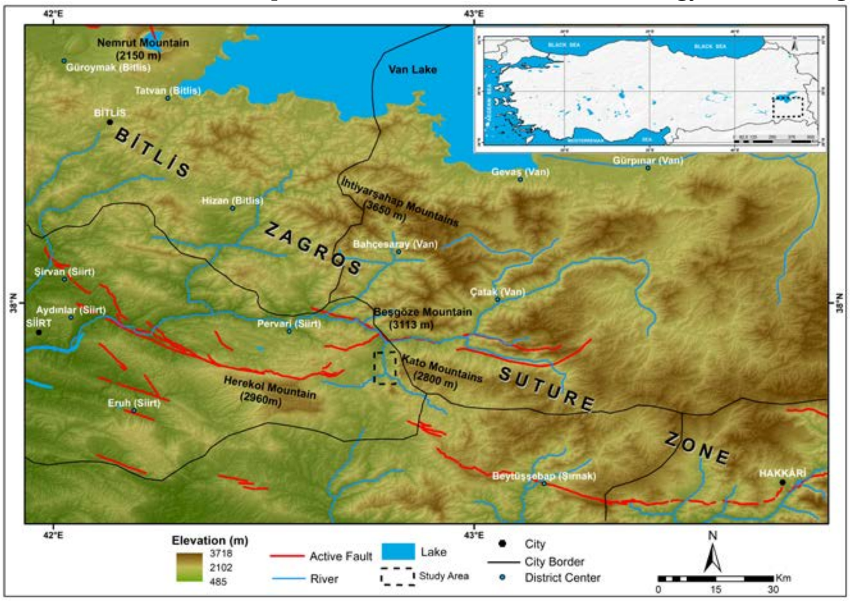

Fig. 1. Location of study area.

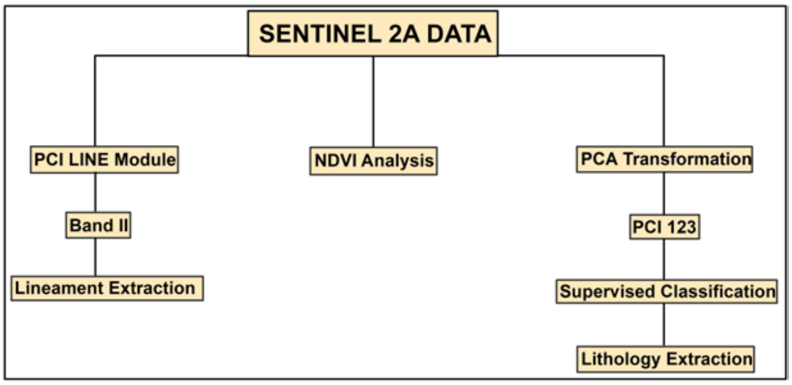

Fig. 2. Flowchart of the obtaining information from remote sensing data.

Materials and Methods

ENVI 5.3 was used for data processing and remote sensing, and PCI Geomatica LINE module was used for lineament extraction. ArcGIS 10.5 was used for general mapping and Sentinel 2A satellite images are available at https://apps.sentinel-hub.com/eo-browser downloaded from.

Image Processing

Preprocessing is applied on Sentinel2A data as resampling to 10 meters to the all bands on SNAP later bands were exported to the geotiff format for processing in ENVI 5.3 for lithological interpretation PCA transform was applied to 12 band Sentinel 2A data for geological correlation, and then PCA321 data were classified by supervised classification for geological mapping. Then geological correlation was made with other geological maps of the study area and then geological map was made. For lineament extraction, PCI Geomatica LINE module was used in random mode with 11th band on the Sentinel data lineaments were extracted as a shapefile. For NDVI analysis, (b8-b4)/(b8+b4) band arithmetic was applied to generate NDVI, then bright pixels were selected and output as shapefile (Figure 2).

Mapping

Vegetation, geology, lineaments, major faults, streams and rivers are used for general mapping in ArcGIS.

The basic features of the satellite image used in the study are given in Table 1. Here some spectral resolution known as Sentinel 2A has become spatial resolution, temporal resolution, and radiometric resolution. The spectral resolution range is 12 bands; the spatial resolution is between 10-60 m, the 10-day temporal resolution range, and the 12-bit radiometric resolution range.

Table 1. The main features of the satellite image

Satellite	Spectral resolution	Spatial resolution	Temporal resolution	Radyometric resolution	Reference
Sentinel 2A	12 bans	10-20-60 m	10 days	12 bits	(Url-1)

Results

Regional Tectonic and Lithology

The study area is located on the Bitlis Zagros Suture Zone (BZSZ) which was developed by the collision of Arabian and Eurasian plates in the middle Miocene (McKenzie, 1972; Şengör, 1980; Şaroğlu and Güner, 1981; Şengör and Yılmaz, 1981; Dewey et al., 1986). BZSZ is a wide morphotectonic belt extending for approximately 2000 km from the northeast of Kahramanmaraş in Anatolia to the Strait of Hormuz in the southeast (Yeats et al., 2006; Leturmy and Robin, 2010; Zebari et al., 2019). The compressional tectonic with a NW-SE direction along the BZSZ are characteristic with nappe covers and thrust faults from north to south. The compressional tectonic observed throughout the BZSZ have turned into a local extensional tectonic regime in the study area (Figure 3). The extensional tectonic regime in the NE-SW axis due to compressional tectonics generally in NW-SE direction and the structural systems related to this secondary tectonic regime were the main parameters controlling the topography of the research area (Figure 3). The study area is characterized by the development of many faults with dominant NW-SE strikes (Photo 1). The rising blocks of these faults have turned into horsts and local graben fields have developed. Çesali and Körkandil Mountains due to block faulting in the south of the study area represent a horst character, while Kato Mountain in the east represents a orographic structure in a semi-horst type (Figure 3, Photo 1). The faults in the study area have normal fault characteristics as a characteristic of the extensional tectonic regime. However, some faults in NE-SW and NW-SE directions in the region have oblique features.

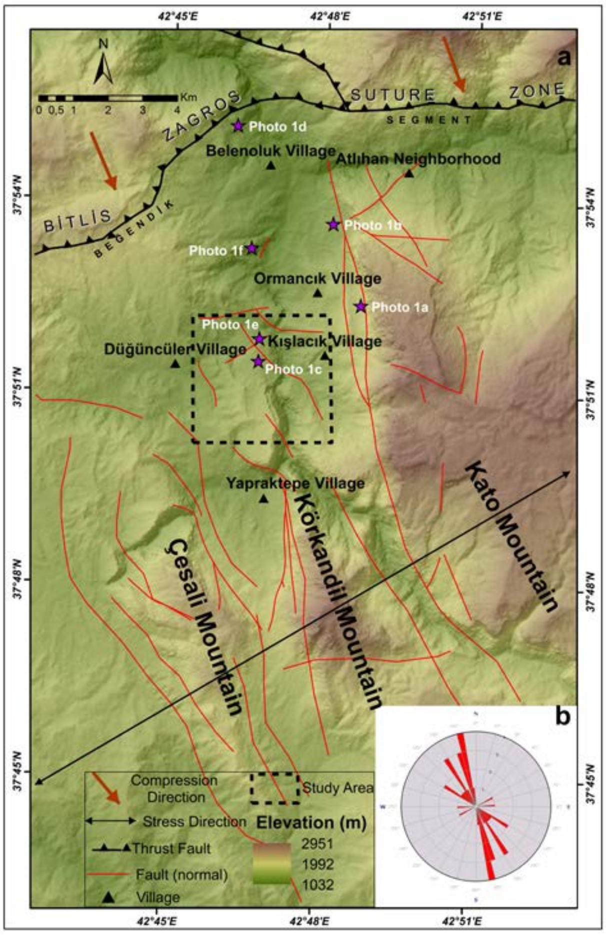

Fig. 3. a. the general tectonic structure of the study area and its immediate surroundings; b. rose diagram of the dominant extensions of the faults in the region (fault data were obtained from field observations and Şenel, 2008.)

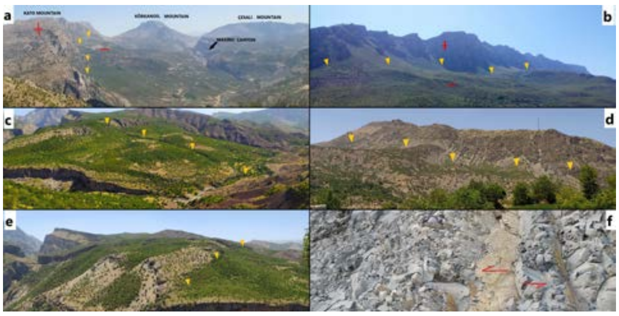

Photo 1.a: Mountainous areas (horsts) developed by block faulting in the study area, b: western flank of the Kato Mountain anticline collapsed as a result of block faulting and the mountain gained semi-horst character. c: NW-SE trending fault of the studied area (yellow arrows show the approximate location of the fault, linear vegetation anomaly developed along the fault) d: fault scarp that developed due to the Beğendik Segment of Bitlis Zagros Suture Zone in the north of the study area, e: SW-NE trending fault is the subject of this study (yellow arrows show the approximate location of the fault, vegetation intensification is seen along the

descending block of the fault.), f: micro left lateral fault developed in flysch in the north of the study area.

Another factor affecting the vegetation distribution in the study area is the lithological features. The main lithology in the area consists of Middle Jurassic-Middle Cretaceous limestones and Upper Cretaceous-Paleocene flysch (Şenel, 2008) (Figure 4). Limestones named as Latdağı and Sayındere formations (Şenel, 2008) are massive and have diaclase system. Karst shapes such as lapia, doline, karst canyon and cave have developed in limestones with petrographic texture suitable for karstification (Zorer and Öztürk, 2021). The flysch layers, on the other hand, consist of alternations of marn, sandstone and claystone, and present a red and gray landscape appearance in the topography. Due to intense erosional processes on the flysch called the Germav formation (Şenel, 2008), the bedrock crops out in most places.

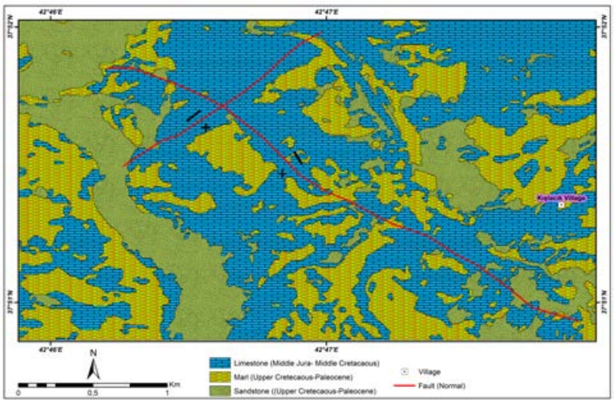

Fig. 4. Geology map of study area. (fault and lithological data were obtained from field observations and Şenel, 2008.)

Tectonic and lithological factors on vegetation

It is possible to detect the faults, when the trace of the fault in the topography is not covered by vegetation (Burbank and Anderson, 2012), however, some faulting processes can also be interpreted with the help of vegetation distribution (Karaman and Kibici, 2008). The change in groundwater flow caused by faulting movements, especially in strike-slip faults or oblique faults, is reflected in the topography as a linear vegetation texture (Figure 5). The change in vegetative cover along the fault plane is due to the different growth of plants in this area (Sipahioğlu et al., 1986). It is seen that some of the faults in the investigation area control the development of vegetation as well as the topography and geomorphic structure (Öztürk and Zorer, 2019; Zorer and Öztürk, 2021). Especially along a fault extending from the south of Kışlacık Village to northwest and a secondary fault extending in SW-NE direction by cutting this fault from its central part, vegetation shows density and linearity (Figure 6, Photo 1c, 1e, 2g, 2f). The density and linear distribution in the vegetative cover, which is distributed as dry forest communities and mostly consists of oak species, is due to the hydrogeological and topographic conditions provided by the mentioned faults. As a matter of fact, Erkal and Taş (2020) stated that plant species and communities are controlled by tissues that provide moisture and plant growth in the environment created by the geomorphic structure and topography. In the research area, the cutting of the groundwater table along the faults and the easy outflow of water to the surface with capillarity has been a parameter that supports vegetation development. The mylonite zone, which developed along these faults and consists of loose material, also enabled the root system to develop easily.

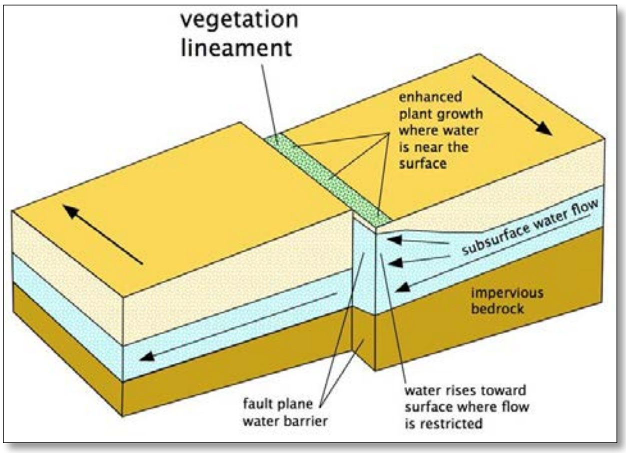

Fig. 5. Schematic representation of the formation of a linear vegetation anomaly on the surface between the fault blocks with the rise of groundwater to the surface (Source: Url 2)

Limestones are more resistant to erosive processes due to their petrographic texture. The fact that such rocks have diaclase systems associated with tectonic deformation systems creates suitable environmental conditions for plant root development (Atalay, 1996; Atalay, 2020). However, flysch (marn, sandstone, claystone, etc.) with low cohesion petrographic texture is more susceptible to erosive processes. This accelerates the dissolution process of the bedrock on the flysch layers, depending upon this process; the increased erosion removes the soil cover from the environment and causes the roots of plants to break. In the study area, it is observed that the erosion is quite rapidly on the flysch layers with increasing slope due to tectonic deformations and the vegetation is destroyed and the topography remains bare (Photo 2d, 2e, 2g). However, dense vegetation can be observed on the limestones (Photo 2a, 2b, 2c, 2f, 2g).

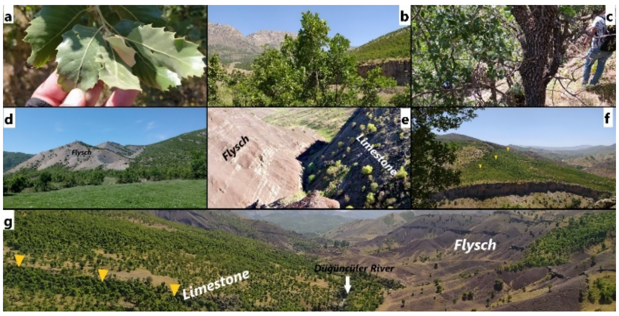

Photo 2. a,b and c: oak species (leaf and stem forms) developed along crack systems on middle Jurassic-mid Cretaceous limestones in the study area; d: The forest cover is gradually decreasing due to erosive processes on the gray inclined marl layers, which have flysch

characteristics; e: red colored sandstone (flysch) layers devoid of forest cover in the west of the study area and limestones where oak trees can hold (the seasonal stream is located at the contact point of these two different lithologies); f: fault with SW-NE extension (yellow arrows show the approximate location of the fault) (the forest cover is very sparse on the rising block of the fault, while the descending block is covered with dense forests, here also linear vegetation anomaly can be seen along the fault line); g: In the west of the study area, Middle Jurassic-Middle Cretaceous limestones are covered with dense vegetation, while Upper Cretaceous-Paleocene flysch (sandstone) is mostly bare. (The fact that the flysch is largely devoid of vegetation is related to the inclination of the bedding. Düğüncüler Stream is located at the contact point of two different lithologies. In the photo, the yellow arrows show the fault line and the vegetation density along the fault draws attention).

Vegetation Density in the Study Area

According to Atalay (1996) and Dönmez and Aydınözü (2012), while forests represent the dominant vegetation in the research area and its immediate surroundings, oaks (acorn oak, thuja oak) in the form of degraded dry forest communities constitute the most common tree species. The vegetation density in the study area develops largely under the control of climatic, lithological, topographic and tectonic features. The forests in the region, mostly consist of trees in the form of bushes. The annual average precipitation in the research area is 682.9 mm (Öztürk, 2019). This data shows that forests develop sub-humid climatic conditions.

The areas where the vegetation density is high in the research area are the area where Kışlacık Village is established, south and north of the village. In addition, there are dense forest areas in patches and lineaments to the west of the Sinebel Stream (Figure 6). The dense vegetation in Kışlacık settlement is due to tree planting throughout the settlement area and the weak anthropogenic pressure on the forest cover in the mentioned area. It is noteworthy that the vegetation cover is dense in the south and north of the Kışlacık Village (Figure 6). These densely forested areas are mostly developed on horizontal or near-horizontal thick flysch layers. This is due to the fact that flysch is rich in plant nutrients (Atalay, 1994) and because of the lack of slope in these areas, the flysch layers are not exposed to erosion as much as other areas. The presence of areas devoid of vegetation cover in the north of Kışlacık village is due to the fact that these areas are cultivated by fluvial processes and therefore erosional processes remove the soil cover (Figure 6).

The areas where there is no vegetation cover on the marl and sandstone layers are noteworthy due to the high slope conditions in the west of the Sinebel Stream (Figure 4, 6). The westward inclination of the layers in these areas accelerated the erosive processes, and the soil cover was swept away in the flysch layers with low cohesion. These parameters led to the absence or sparse vegetation in the study area. It is seen that the vegetation density is more developed on the limestones with low slope in the relevant area. In the west of the Düğüncüler Stream, the vegetation on the red flysch is rather sparse (Figure 6, Photo, 2g).

In the study area, it is seen that the vegetation is concentrated along the faults and presents a linear pattern. The reason for this is due to the appropriate hydrological, topographic and edaphic factors, along the fault lines (Figure 6, 7).

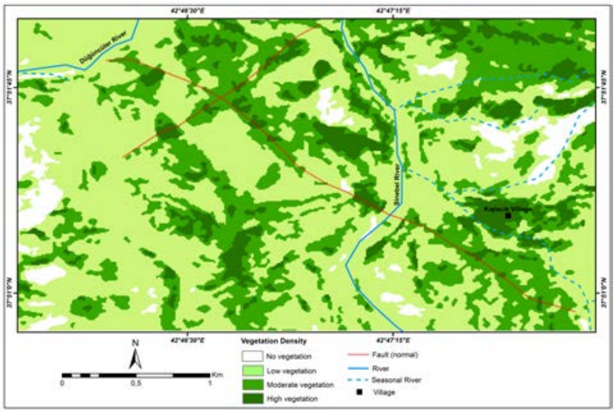

Fig. 6. Vegetation density map of study area

Fig. 7. Google Earth satellite image of linear vegetation anomaly along the fault lines in the study area (tips of the arrows are facing the ascending block) (image date 09-04-2012)

Remote Sensing Results

In this study, besides field studies on the effects of faulting processes and lithological parameters on vegetation distribution, remote sensing technologies were also used. For this purpose, NDVI analysis, which is widely used in monitoring vegetation change (Çelik and Karabulut, 2013), was performed, the lineaments of the region were extracted and the vegetation density was trying to be revealed. The most popular vegetation index, NDVI (Rouse et al., 1974), was produced by the development of the SR index. It is accepted that the ratio of the difference between the radiation in the red band and the radiation in the NIR band to the sum makes the index more general. It is accepted that the NDVI index eliminates the effect of atmospheric attenuation and seasonal sun angle changes (Ghosh et al., 2018).

Also, NDVI provides good predictive results for LAI (Jones, 2010). It is known that very little of the energy in the red and blue wavelengths is reflected, and most of the energy in the green and NIR bands is absorbed. The red border bands the nitrogen content of the vegetation and is heavily correlated with the vegetation tissue and chlorophyll content (Heermann et al., 2010; Mitchell et al., 2010). Later studies observed that the correlation of NDVI value with nitrogen decreased in the later phenological stages of vegetation (Narin, 2019). While the correlation of the red edgebands continues with the red edgeband satellites with increasing spectral resolution in optical satellites, the calculated facility indices have started to be used. In particular, the presence of three bands in the red border region of the Sentinel-2 satellite has made it even more usable (Lif et al., 2014; Kross et al., 2015).

It provides a great advantage for the vegetation of the Sentinel-2A satellite in the "red edge" region, which provides important information in the case of agricultural applications. The spatial resolution is 10 meters in the visible bands (RGB) and Near Red Infrared (NIR) band and can enable packet-based operation.

Relevant spatial resolution ranges used in the study and vegetation recognition levels across a range of image scales were evaluated as 10 m, respectively (revised from Wulder et al. 2009) (Table 2). The preferred vegetation index chart for Sentinel 2A satellite data preferred in the study are in Table 3.

Table 2**.** In this study some of spatial resolution ranges and vegetation recognition levels, image scales.

Data	Spatial resolution	Vegetation cover level
Medium resolution	10 (Sentinel 2A)	Constant separation of evergreen masses against deciduous forests (Stand level features)

Table 3. The preferred vegetation index chart for Sentinel 2A Satellite

Equality	Vegetation index name	Reference
(B8-B4)/ (B8+B4)	NDVI	Jordan (1969)

In the study, it was determined that there were significant relationships between vegetation and faulting/lithology with remote sensing-based mapping studies. With the NDVI analysis, it has been revealed that the direction of the fault lines and the lithological features are effective on the vegetation distribution pattern. As a matter of fact, this harmony can be seen when Figure 4, 6 and 8 are compared. In the study area, areas with limestone and fault/lineament zones show areas where vegetation is dense, while vegetation is relatively sparse in areas with flysch. Even bare bedrock crops out on the inclined flysch layers (Figure 4, 6 and 8).

Buffer analysis was applied to the two faults discussed in the study on the NDVI map and it was observed that the vegetation showed lineament and the density was high throughout the buffer zone (Figure 9c). This significance shows that the appropriate edaphic, hydrogeological and topographic structure along the fault lines directly affect the vegetation development throughout a certain belt.

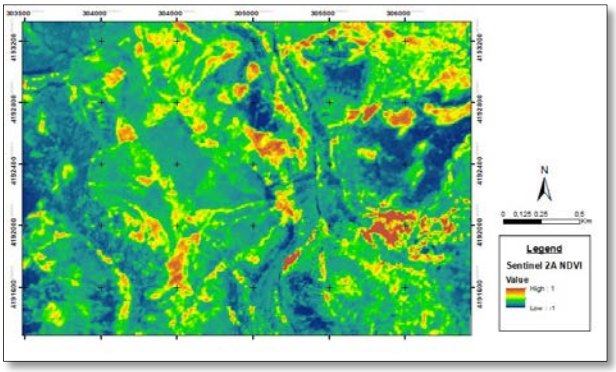

Fig. 8. NDVI analysis map of study area.

Topographic lineaments evolved by morphodynamic processes are generally accepted as linear structures associated with tectonic deformations (Florinsky, 2012; Ahmadi and Pekkan, 2021). For this reason, linearity analysis was applied in the study and its compatibility with fault directions was questioned. In this context, the lineaments added on the NDVI map showed that dense vegetation areas generally followed the lineaments (Figure 9a, 9b, 9d). These maps are also important in that they show that vegetation is concentrated in the valleys, slope bottoms, fault lines and fault scarps fronts.

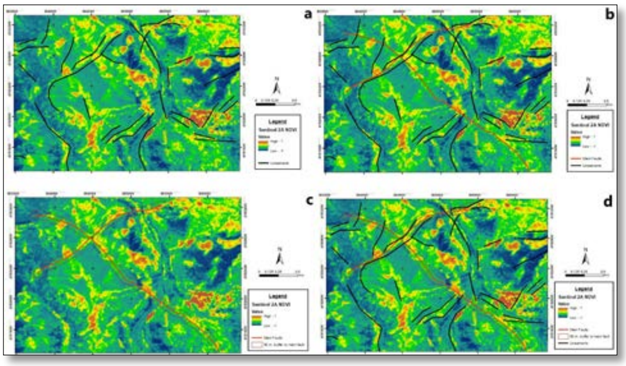

Fig. 9. a: NDVI analysis and lineaments, b: NDVI analysis, faults and lineaments, c: NDVI analysis and fault buffer zone (50m), d: NDVI analysis, lineaments and overlapping of fault buffer.

Conclusion

In this study, in which the lithology and the fault effect on vegetation development and distribution were examined, significant relationships were reached between the field findings and remote sensing outputs. In the study area, linear and dense vegetation distribution pattern along the normal faults in NW-SE and NE-SW directions have developed due to appropriate hydrogeological, edaphic and topographic features.

It is understood that lateral slip as well as dip slip develops along the fault due to the formations in the topography of the faults, which are effective on the plant distribution pattern in the research area. In particular, the fact that the fault in NW-SE direction bends the

Düğüncüler Valley right lateral at the NW end shows that this fault has an oblique character. The condensation of vegetation and its linear texture along these faults is due to the fact that the groundwater can easily rise to the topography surface with capillarity along the fault planes (Figure 9, 10; Photo 1c, 1e, 2g, 2f). The mylonite (crush) zone developed between the moving fault blocks corresponds to an area where the upward movement of groundwater occurs easily due to its loose petrographic texture. Figure 6 illustrates this difference in vegetative pattern.

The loose material in the mylonite zone between the fault blocks has been a lithological parameter that positively affects the development of the root systems of the oak communities in the study area. More soiling of these areas compared to the fault blocks (Karaman and Kibici, 2008) provides ideal edaphic conditions for plant life. In addition, the crack systems developed between the blocks facilitated the development of the root system of oak species.

The dominance of dip slips rather than lateral slip of the faults discussed in this study produced uplifting and falling blocks in the topography. The fact that the façades of the uplifting blocks face north as a wall causes the falling blocks to receive less sunlight and therefore to remain more humid. In addition, soil material carried from the uplifting block to the falling block by erosive processes also contributes to the development of the plant root system. While the materials stacked in colluvial tanks facilitate the development of the root system, the high permeability properties of these warehouses also facilitated the access of plants to water. These parameters, seen in the lithology, slope and aspect characteristics, helped the vegetation to hold more on the falling blocks.

As a result of the comparison of the lithology map and the vegetation density map (Figure 10), it was seen that the dry forest communities and forest cover, mostly consisting of oaks, were concentrated on limestone lands. However, flysch layers consisting of marn and sandstone and inclined due to tectonic movements were found to be devoid of vegetation cover or to be covered with sparse vegetative cover. This parameter shows that the resistance strength of limestone and flysch against erosive processes is not the same. Despite the slope of the limestone land in the research area, the fact that it is not devoid of vegetation proves this selectivity in fluvial erosion. This is due to the fact that the flysch layers are composed of elements with low cohesion. Due to its petrographic character, intense erosive activities and numerous landslides have developed on the flysch, thus the vegetation has largely disappeared.

Field studies and remote sensing data revealed that vegetative closure is high along the limestones and fault planes in the sample area; the closure rate is lower on the inclined flysch layers away from the tectonic lines. In this study, it has been proven that linear and dense vegetation can be an important indicator in recognizing faults.

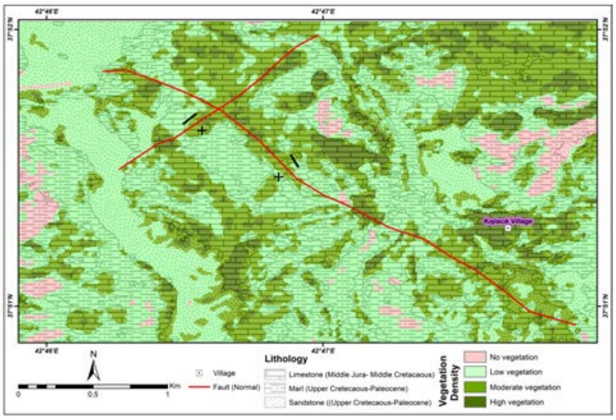

Fig. 10. NDVI analyze, lithology and map where faults overlap.

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