Spatiotemporal Analysis of Vegetation Cover and Its Response to Terrain and Climate Factors in Duhok Governorate, Kurdistan Region, Iraq

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Abstract

The integration of remote sensing techniques and Geographic Information System has a wide use to quantify the spatial and temporal distribution of vegetation cover. Over the last decade, a remarkable change was noticed in both climate and vegetation cover in Duhok. The Modified Soil Adjusted Vegetation Index (MSAVI2) was extracted from Landsat satellite images over the 20 years (2000 to 2019). For analyzing the vegetation changes, the terrain data including elevation, slope, and aspect and climate data temperature and precipitation are used. The result shows that from 2000–2019, the average mean MSAVI2 is 0.361 and the trend increased in 77.9% of the study area. The northern and northeastern areas of the study area revealed a significant increase in vegetation, while in the low land areas it is decreased. The amount of precipitation and temperature degree affect the spatiotemporal distribution of vegetation cover. The MSAVI2 showed a positive relationship with precipitation and temperature. At elevation less than 2000 m, with increasing elevation the MSAVI2 is increasing, but when the elevation reaches 2000 m, the MSAVI2 is decreasing and negatively related to elevation. The vegetation has a positive relation with slopes less than 45°, and at slopes higher than 45°, the MSAVI2 is decreased. The impact of aspect on the vegetation figured out that the largest MSAVI2 is detected in the shady slope due to relatively less evapotranspiration.

Keywords: Vegetation cover change; Terrain factor; Climate factor; Statistical analysis

1. Introduction

The spatial distribution of vegetation in high-altitude areas is very important as it reduces soil erosion and affects climate change. Vegetation cover effectively protects the environment against the risk of natural hazards such as rockslide, floods, shallow landslides, and debris flows (Brang et al. 2001). Spatial and temporal variations in vegetation cover are significant in the ecosystem changes (Shi et al., 2019). Terrain factors (elevation, slope, and aspect) and climate factors (rainfall and temperature) have an impact on the spatiotemporal distribution of vegetation cover and vegetation growth (Jirjees et al. 2020; Liu et al. 2018). Therefore, understanding the spatial and temporal distribution of vegetation growth along with the affecting factors have been studied worldwide (Zhu et al. 2011; Chen et al. 2006; Othman et al. 2020; Mustafa and Ismail, 2019). To have a comprehensive overview of spatial and temporal analysis of vegetation analysis within a large area, satellite remote sensing data and Geographic information system (GIS) would be the most suitable techniques to be used. Remote sensing (RS) and

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GIS are appropriate techniques for analyzing the spatiotemporal distribution of vegetation and other natural resources (Ochege et al. 2017). This can be performed by using mathematical relationships between and among satellite bands to create so-called indices. Among the many RS indices, Modified Soil Adjusted Vegetation Index (MSAVI2), is used to identify the vegetation cover and growth. The MSAVI2 is a widely used vegetation index, derived from reflectance measurements in the red and near-infrared spectral bands (Qi et al., 1994). The MSAVI2 corrects the reflection of areas with a large amount of exposed soil. When applied to areas with a high level of the exposed soil surface, it aims to resolve some of the shortcomings of the Normalized Different Vegetation Index (NDVI). In bare soil areas, the MSAVI2 index is more powerful than the NDVI for vegetative area delineation. This behavior of MSAVI2 is more useful for vegetation studies in the Iraqi Kurdistan Region, where much of the soil is exposed (Gaznayee and Al-Quraishi, 2020). Gaznayee and Al-Quraishi (2020) used MSAVI2 to identify drought status in Duhok Governorate. Liu and Wang (2005) used MSAVI2 as an indicator to monitor desertification in China. Moreover, MSAVI2 is used to evaluate the impact of drought on the spatiotemporal distribution of vegetation on the San Carlos Apache Reservation in Arizona (Wu et al. 2016). Therefore, this research selected the MSAVI2 index along with climate data from 2000-2019 to analyze the trend and spatiotemporal distribution of vegetation cover in Duhok Governorate. The aim of the research is to assess the spatiotemporal changes of vegetation in Duhok Governorate from 2000-2019, to explore the responses of MSAVI2 with respect to the elevation, slope, and aspect, and to investigate the relationships between vegetation distribution and climatic factors.

2. The Study Area

Duhok is located in the northwestern part of the Iraqi Kurdistan Region. It is located within latitudes 36°18′ - 37°20′N, and longitudes 42° 20′ - 44°17′E (UTM 280000 - 400000 Easting and 4080000 - 4140000 Northing), at altitude 291 to 2574 m above sea level, and it covers an area of 6,600 km² (Fig. 1). Duhok has four Districts; Amadiya, Duhok, Zakho, and Sumail. Geologically; the study area is located in the high folded zone and imbricated zone according to the tectonic division of Iraq. It is characterized by a series of asymmetrical double plunging anticlines trending NW-SE with different extensions (Jassim and Gailani, 2006). The soil of the study area is classified according to chemical composition as a none saline soil (Buringh, 1960). The climate of the study area is similar to that of the Mediterranean region. According to Koepppe and De Long (1959), the Mediterranean climate is characterized by a moderate amount of rainfall in winter and dry summer. It is distinguished by mild to cool wet winter, and warm to hot dry summer. The annual average temperature in Duhok Governorate over the study period ranges from 19.3 to 21.2°C, as in winter between 0°C (min.) and 15°C (max.), and in summer between 20°C (min) and 37°C (max). The average annual precipitation is about 500–1000 mm. The forest ratio in Duhok is 28.4% and the agricultural lands are mostly around the villages (FAO, 2003).

3. Materials and Methods

3.1. Data Sources and Image Pre-Processing

The meteorological data including annual rainfall and average temperature were collected over the 20 years (2000-2019) from 15 different weather stations within Duhok (Fig. 1). The climate data were provided by the General-Directorate of Meteorology and Seismology of the Iraqi Kurdistan Region. In this research, a digital elevation image (DEM) of Duhok with 30 m resolution was applied to get information about terrain factors including elevation, slope, and aspect through a GIS spatial analysis tool. The DEM was downloaded from the websites of Earth Data of the National Aeronautics and Space Administration (NASA).
Moreover, Landsat 5 (TM), 7 (ETM), and 8 (OLI) satellite images with a spatial resolution of 30 m and 16 days’ intervals, for a period of 20 years (2000 to 2019) were used in this research. The imagery scenes with the least cloud cover percentage were found from websites of Earth Explorer of the United States Geological Survey (USGS). The images that have been used are acquired in May and June. They are used to calculate the MSAVI2, and for that purpose, those images passed through image pre-processing. This step has been applied to correct the images from radiometric and atmospheric noises using the Fast Line of Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) function of the ENVI 5.3 program. The required coefficients were acquired from the metadata of the images. Atmospheric and radiometric corrections are required for deriving accurate quantitative surface information from satellite imagery (Liang et al. 2002). Subsetting the study area and other pre-processing steps were accomplished. These steps were applied for all 20 images. The steps of the methodology are clearly shown in Fig. 2.

3.2. Spatial and Temporal Analysis of the MSAVI2

Vegetation index, representing vegetation information by using different satellite reflectance band combinations that are sensitive to vegetation (Baret et al., 1989). In this research, MSAVI2 was used as the main vegetation index to calculate the spatiotemporal vegetation coverage in the studied area. The values of MSAVI2 ranging from -1 to +1 and are computed upon pixel basis as in equation (1) (Qi et al. 1994).

\[
MSAVI2 = \frac{2 \times \rho_{NIR} + 1 - \sqrt{(2 \times \rho_{NIR} + 1)^2 - 8 \times (\rho_{NIR} - \rho_{Red})}}{2}
\] (1)
Where $\rho$ is the reflectance in the NIR and Red bands.

According to the basic area calculations, the area of vegetation is calculated for each year. This is conducted by selecting a threshold experimentally for each MSAVI2 image each year. For the 20 years, the threshold values range 0.11 – 0.25. To find the spatial variation in MSAVI2 trends, the linear trends from 2000 to 2019 were examined on a pixel basis. It attempts to model the relationship between variables (x) and time (y), by fitting a linear equation to observed data (equation 2).

$$y(x) = a + bx$$  \hfill (2)$$

where $a$ is the intercept and $b$ is the slope of the line. To calculate the slope from linear regression, equation (3) is applied (Li et al., 2015):

$$b = \frac{n \times \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \times \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}$$  \hfill (3)$$

A value of less than zero represents a decreasing MSAVI2 trend, a value equal to zero represents that the MSAVI2 is constant, and a value greater than zero represents an increasing MSAVI2 trend.
3.3. Determining the Terrain Factors

The terrain factors were considered as a primary aspect that influencing the MSAVI2 variation. The elevation, slope, and aspect are selected as the main three terrain factors. For this purpose, the DEM is reclassified to different classes and the information is extracted for each terrain factor; elevation, slope, and aspect. The highest elevation in the area is 2574 m and the lowest is 291 m and the slope ranges from 0°–76°. Table 1 shows the terrain factors divisions in the study area.

Table 1. The division of terrain factors

<table>
<thead>
<tr>
<th>Elevation classes</th>
<th>Elevation m</th>
<th>Slope bins</th>
<th>Type of Slope</th>
<th>Aspect Quadrants</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-400</td>
<td>&lt; 5°</td>
<td>flat</td>
<td>Shady Slope</td>
<td>N315°–45°</td>
</tr>
<tr>
<td>2</td>
<td>400-800</td>
<td>5°-10°</td>
<td>Gentle</td>
<td>Sunny Slope</td>
<td>S135°–225°</td>
</tr>
<tr>
<td>3</td>
<td>800-1200</td>
<td>10°-20°</td>
<td>Moderate</td>
<td>Semi-sunny</td>
<td>SE 90°–135°</td>
</tr>
<tr>
<td>4</td>
<td>1200-1600</td>
<td>20°-30°</td>
<td>Moderate Steep</td>
<td>Slope</td>
<td>SW 225°–270°</td>
</tr>
<tr>
<td>5</td>
<td>1600-2000</td>
<td>30°-45°</td>
<td>Steep</td>
<td>Semi-shady</td>
<td>NE 45°–90°</td>
</tr>
<tr>
<td>6</td>
<td>&gt; 2000</td>
<td>&gt; 45°</td>
<td>Very steep</td>
<td>Slope</td>
<td>NW 270°–315°</td>
</tr>
</tbody>
</table>

3.4. Determining the Climate Factors

Annual rainfall and average temperature data were collected from 15 weather stations of the 20 years (2000-2019), which are distributed over the study area. The linear interpolation method has been used to interpolate the climate data to grid cells with a resolution of 30 m the same with MSAVI2 pixel resolutions. Equation 4 was used to find the Pearson correlation coefficients between MSAVI2 and climate variables data (rainfall and temperature).

\[ r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \]  

where \( r_{xy} \) is the correlation coefficients between \( x \) and \( y \), \( x \) is the MSAVI2, \( y \) is the rainfall for one side to investigate the relationship between MSAVI2 and rainfall. Moreover, to investigate the relationship between MSAVI2 and temperature, \( x \) is assigned to MSAVI2, and \( y \) is assigned to temperature. \( n \) is the sample number, \( \bar{x} \) and \( \bar{y} \) are the average values of \( x \) and \( y \), respectively.

4. Results

4.1. Spatiotemporal Variation of Vegetation Changes

The temporal variation of vegetation in the study area according to MSAVI2 results is increasing. The average mean MSAVI2 is 0.361; the maximum and minimum mean MSAVI2 values (0.443 and 0.306) were obtained in 2019 and 2008, respectively. The means MSAVI2 displayed a rising trend over the 20 years of 0.030 year\(^{-1}\). In 2001-2006, the value of MSAVI2 changes gradually. While, in 2007-2015, the MSAVI2 varied with high and low values. The trend reaches maximum values from 2016 to 2019. Based on a pixel calculation the spatial variation in MSAVI2 from 2000 to 2019 was analyzed (Fig. 3). The findings indicate that the average spatial vegetation coverage is 62.8% and non-vegetation coverage is 37.2%. Table 2 shows the spatial pattern of vegetation coverage from 2000 to 2019.
The sharpest decrease was figured out in 2008. This year has been reported as the most significant drought event throughout the twenty years (Gaznayee and Al-Quraishi, 2020; Eklund and Seaquist, 2015).

**Fig. 3.** Spatial variation of the MSAVI2-based vegetation from 2000 to 2019

### 4.2. Climate Factors and MSAVI2 Correlation

In order to clarify the response of vegetation growth to climate change, the variations in climate and MSAVI2 have been studied over the past 20 years in the study area. Fig. 4 demonstrates the variations in mean MSAVI2, annual mean temperature, and annual precipitation in the study area during 2000-2019. Overall, the trend of MSAVI2 increased, with an increase of 0.003 ($R^2 = 0.28; p = 0.016$). Annual mean temperature and annual precipitation also demonstrated an increased trend, with an increase of 0.0298 $\degree C$ ($R^2 = 0.14; p = 0.099$) and 13.825 mm temperature correlation with ($R^2 = 0.21; p = 0.041$) per year, respectively (Fig. 4b and c).
Table 2. The statistical results of MSAVI2 values in the study area for the years 2000-2019

<table>
<thead>
<tr>
<th>Year</th>
<th>Max MSAVI2</th>
<th>Min MSAVI2</th>
<th>Mean MSAVI2</th>
<th>Vegetated area (km²)</th>
<th>Vegetative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.65</td>
<td>0.19</td>
<td>0.318</td>
<td>3657</td>
<td>55.3</td>
</tr>
<tr>
<td>2001</td>
<td>0.62</td>
<td>0.2</td>
<td>0.351</td>
<td>4027</td>
<td>60.9</td>
</tr>
<tr>
<td>2002</td>
<td>0.62</td>
<td>0.2</td>
<td>0.336</td>
<td>3857</td>
<td>58.3</td>
</tr>
<tr>
<td>2003</td>
<td>0.71</td>
<td>0.18</td>
<td>0.372</td>
<td>4287</td>
<td>64.8</td>
</tr>
<tr>
<td>2004</td>
<td>0.64</td>
<td>0.15</td>
<td>0.339</td>
<td>3883</td>
<td>58.7</td>
</tr>
<tr>
<td>2005</td>
<td>0.85</td>
<td>0.24</td>
<td>0.365</td>
<td>4198</td>
<td>63.5</td>
</tr>
<tr>
<td>2006</td>
<td>0.77</td>
<td>0.25</td>
<td>0.339</td>
<td>3905</td>
<td>59.1</td>
</tr>
<tr>
<td>2007</td>
<td>0.66</td>
<td>0.19</td>
<td>0.396</td>
<td>4555</td>
<td>68.9</td>
</tr>
<tr>
<td>2008</td>
<td>0.61</td>
<td>0.14</td>
<td>0.306</td>
<td>3527</td>
<td>53.3</td>
</tr>
<tr>
<td>2009</td>
<td>0.64</td>
<td>0.16</td>
<td>0.364</td>
<td>4184</td>
<td>63.3</td>
</tr>
<tr>
<td>2010</td>
<td>0.46</td>
<td>0.14</td>
<td>0.334</td>
<td>3844</td>
<td>58.1</td>
</tr>
<tr>
<td>2011</td>
<td>0.68</td>
<td>0.2</td>
<td>0.396</td>
<td>4237</td>
<td>68.7</td>
</tr>
<tr>
<td>2012</td>
<td>0.71</td>
<td>0.19</td>
<td>0.368</td>
<td>4237</td>
<td>64.1</td>
</tr>
<tr>
<td>2013</td>
<td>0.81</td>
<td>0.18</td>
<td>0.345</td>
<td>3970</td>
<td>60.1</td>
</tr>
<tr>
<td>2014</td>
<td>0.45</td>
<td>0.11</td>
<td>0.34</td>
<td>3915</td>
<td>59.2</td>
</tr>
<tr>
<td>2015</td>
<td>0.78</td>
<td>0.17</td>
<td>0.361</td>
<td>4162</td>
<td>62.9</td>
</tr>
<tr>
<td>2016</td>
<td>0.85</td>
<td>0.16</td>
<td>0.383</td>
<td>4409</td>
<td>66.6</td>
</tr>
<tr>
<td>2017</td>
<td>0.85</td>
<td>0.18</td>
<td>0.349</td>
<td>3996</td>
<td>60.4</td>
</tr>
<tr>
<td>2018</td>
<td>0.87</td>
<td>0.23</td>
<td>0.413</td>
<td>4735</td>
<td>71.6</td>
</tr>
<tr>
<td>2019</td>
<td>0.84</td>
<td>0.2</td>
<td>0.443</td>
<td>5072</td>
<td>76.7</td>
</tr>
<tr>
<td>Average (20 years)</td>
<td>0.361</td>
<td>0.1482</td>
<td></td>
<td>4148.2</td>
<td>62.8</td>
</tr>
</tbody>
</table>

In the MSAVI2 trends, many significant variations occurred despite the obvious MSAVI2 increases. For instance, the MSAVI2 values were small in 2008 but large in 2019 (Fig. 4a). As it is seen from the trend fluctuation (Fig. 4a and b), the precipitation patterns corresponded closely to the trend of MSAVI2 fluctuation. The correlation coefficients of the mean MSAVI2 versus the two climate variables were calculated, taking into account the relationships between the mean MSAVI2 and the annual precipitation and annual mean temperature. The correlation coefficients between the mean MSAVI2 and the annual precipitation is 0.797 (P < 0.01), it is greater than that between the mean MSAVI2 and the annual mean temperature, which is 0.043 (P >0.1) (Fig. 5a and 5b). Therefore, precipitation compared with temperature is the superior climatic factor influencing the growth of vegetation.

4.3. Terrain Factors and MSAVI2 Variations

From the analysis of the three terrain factors (elevation, slope degree, and aspect), the variations in the spatiotemporal distribution of vegetation coverage in the study area were obtained.

4.3.1. The influence of elevation on the MSAVI2

According to the DEM data of Duhok (Fig. 6), the study area was divided into six elevation bins: <400 m, 400–800 m, 800–1200 m, 1200–1600 m, 1600–2000 m, and >2000 m. Each elevation bin compared with correlated MSAVI2 values from 2000-2019, the vegetation distribution in different elevation bins was explored and plotted (Fig. 7).
Fig. 4. Variations in MSAVI2 and climate over the period 2000–2019. (a) mean MSAVI2, (b) annual precipitation, and (c) annual mean temperature.
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**Fig. 5a.** The correlation between the mean MSAVI2 and the annual precipitation

**Fig. 5b.** The correlation between the mean MSAVI2 and the mean annual temperature

**Fig. 6.** Elevation distributions of the study area retrieved from DEM
The average spatiotemporal vegetation coverage (MSAVI2) of low elevation areas which is between <400 m and 400–800 m was 0.22 and 0.49, respectively. The medium elevation areas (800–1200 m, 1200-1600, and 1600–2000 m) showed the highest average of spatiotemporal vegetation coverage (0.77, 0.89, and 0.93). The average vegetation coverage (MSAVI2) of high-altitude areas >2000 was 0.74.

The trends of MSAVI2 have been analyzed from 2000 to 2019 for all elevation ranges (Fig. 8). The results show that the MSAVI2 change rates are above zero for the elevation gradients that exceeding 400 m, and for elevation < 400 m is less than zero which indicates that the MSAVI2 trend is decreasing. However, in the ranges of 400-800, 800-1200 m, and 1200-1600m, the value of MSAVI2 increased from 0.40 to 0.97, with a rate of change 0.052 year⁻¹, 0.085 year⁻¹, 0.075 year⁻¹ respectively. These elevation bins showed the most pronounced increasing trend. The elevation bin 800-1200 m had the most increasing trend. Based on the MSAVI2 trend results, the highest relation between elevation and vegetation is noticed in elevation 1200-1600 m and the lowest relation is in elevation below 400 m (Fig. 8). At elevations under 400 m, the value of MSAVI2 ranged from 0.03 to 0.60, with a change rate of (-0.025 year⁻¹) and the increasing trend in this elevation range was the smallest. At elevations of 1600-2000 m, the MSAVI2 value ranged from 0.81 to 0.97, with a change rate of 0.035 year⁻¹. The MSAVI2 trend was 0.029 year⁻¹ at elevations above 2000 m.

Overall, the MSAVI2 increased rapidly in the medium elevation ranges and increased slowly in lower and higher elevation areas. According to Eklund et al. (2017); Amin and Shnichal, (2020), the lower elevations areas around Zakho and Sumail are greatly affected by human activities and agricultural uses, which suggests that these lands are a part of the urban expansion process and crops during the harvest months in May and June, making the MSAVI2 to reduce rapidly. Therefore, the vegetation coverage MSAVI2 in the range of elevations under 400 m is the weakest. While the medium elevation ranges are widely covered by grasses and open forests, in which the Oak trees are predominant (Shahbaz, 2010; Mustafa et al. 2015). Thus, the MSAVI2 in the ranges of 400-800, 800–1200 m, and 1200-1600m are the highest. However, at a higher altitude, the vegetation is sensitive to climate changes. The temperature decreases, air pressure is less and carbon dioxide is greatly reduced (Wang et al., 2014). Hence, the MSAVI2 at an elevation greater than 2000 m increased slowly.
4.3.2. The influence of slope on the MSAVI2

DEM data used to extract the information about slope degrees (Fig. 9). The study area was divided into six slope groups: <5°, 5–10°, 10–20°, 20–30°, 30–45°, and >45°. The area of each slope degree compared with the correlated MSAVI2 values from 2000-2019, the vegetation distribution in each slope degree group was explored and plotted (Fig. 10).
Fig. 10. Vegetation coverage distributions in different slope bins

The average spatiotemporal vegetation coverage (MSAVI2) of flat, gentle, and moderate slope areas (<5°, 5°–10°, and 10°–20°) was 0.37, 0.55, and 0.73 respectively. The moderate steep and steep slope (20°–30° and 30°–45°) have the highest average of spatiotemporal vegetation coverage (MSAVI2) (0.79 and 0.81). The MSAVI2 of very steep slope areas >45° was 0.72. In specific, due to the human activities in low slope areas, the average vegetation coverage of flat, gentle, and moderate slope areas is less compared with moderate steep and steep slope areas. Nevertheless, in the very steep slope areas >45°, which is restricted in the cores of the high anticlines, such as Gara and Matin anticlines in Amadiya District and Barbahar and Bekher anticlines in Duhok District (Al-Kubaisi and Shakir, 2018; Barazani and Al-Qayim, 2019), where steep structural slopes, erosional cliffs, and structural scarps are well developed, the vegetation coverage decreased remarkably (Sissakian et al., 2014). These slopes occur along the gorges, canyons, and deeply cut valleys. The terrain became increasingly steep with the increase in the slope degree, percentages of vegetation cover areas with slope degree gradually increases and reaches their maximum value of about 0.81 at 30°–45° and then decreases in slope areas >45°.

The trends of MSAVI2 have been analyzed from 2000 to 2019 for different slope ranges (Fig. 11). The result shows that the MSAVI2 change rates are increasing over the 20 years except for slope <5° which is less than zero, indicating that the MSAVI2 trend is decreasing. Among the slope ranges, the ranges of 20°–30° and 30°–45° showed a significant increase in the MSAVI2, with values of MSAVI2 ranging from 0.52 to 0.92 and a trend of 0.098 year⁻¹ for the latter and a trend of 0.093 year⁻¹ for the former. The values of MSAVI2 in regions with flat terrain (less than 5°) were distributed between 0.20 and 0.65, with a change rate of (−0.015 year⁻¹), and the MSAVI2 trends for slope angles of 5°–10°, 10°–20°, and >45° were 0.024, 0.076, and 0.067 year⁻¹, respectively. The highest relationship between vegetation and slope classes is obtained in a moderate slope 10°–20°, while the lowest relationship is in flat slope <5° (Fig. 11).

In general, the MSAVI2 increased rapidly in the medium slope ranges and increased slowly in areas with lower and higher slopes. The flat slope areas (less than 5°), which is mainly located in Zakho District and almost the whole Sumail District Plain in the southwestern and western parts of the study area, the MSAVI2 is very low. This is because the majority of the land types in these two Districts are cultivated lands (Eklund et al., 2017; M. Amin and Shnichal, 2020). Slopes less than 20° are mainly distributed throughout the plains around Mangesh Village, which is located in Mangish Sub-districts and the central part of the study area (Fig. 9). The slope of these areas is gentle and moderate, and it is cultivated land; hence, the average MSAVI2 is low.

The vegetation coverage MSAVI2 at gradients of 20°–30° and 30°–45° showed a good growth trend, this is due to the convenience of these slope angles for vegetation growth and human activities that are very rare in these areas (Liu et al., 2018).
4.3.3. The influence of aspect on the MSAVI2

Information about aspect was extracted based on DEM data (Fig. 12). The four quadrants methods have been used to divide the study area into four parts, namely sunny slope, shady slope, semi-sunny slope, and semi-shady slope. Based on MSAVI2 results from 2000-2019, vegetation coverage was calculated for different aspect groups. Based on Fig. 13, the spatiotemporal vegetation cover areas (MSAVI2) of the NE 0–45° and NW 315-360° aspect groups were 0.67 which is the largest and located in the shady side. This is because, in the semi-arid areas, much less evapotranspiration (ET) is expected in the shady side (Jin et al. 2008). Whereas in other aspect groups the percentage of vegetation coverage (MSAVI2) did not vary significantly.

Moreover, the MSAVI2 trend clearly shows that the shady slope is slightly higher than the other three quadrants (Fig. 14). In shady slope, the values of MSAVI2 ranging from 0.60 to 0.74 and a trend of 0.035 year\(^{-1}\), while the MSAVI2 variation trends for the other three quadrants are consistent with each other, and the MSAVI2 difference is very small. The highest relationship between vegetation and aspect is obtained in shady slope and the lowest is on the sunny slope side (Fig. 14).
5. Discussions

In Duhok and especially in mountainous ranges, the vegetation cover is very sensitive to climatic components (precipitation and temperature). The effects of precipitation and temperature on vegetation have been analyzed across Duhok (Mustafa, 2020). Landsat satellite imagery is an important tool to document the spatiotemporal distribution of vegetation coverage and to investigate and analyze its change over different elevation areas. MSAVI2 is a vegetation index that has been used to get the spatiotemporal distribution of vegetation coverage for 20 years. The advantages of MSAVI2 correct the reflection of areas with a large amount of exposed soil (Qi et al., 1994). The MSAVI2 is more effective than the NDVI in delineating the vegetative area, especially in barren soils. This behavior of MSAVI2 is more useful for vegetation studies in the IKR, where much of the soil is exposed (Gaznayee and Al-Quraishi, 2020).
In recent years, the vegetation coverage on Duhok increased, which is positively correlated to the increased amount of precipitation, especially in the elevation above 400 m. Geographically Duhok is highly elevated and rich in open forests. It is the most dominated vegetation province in the IKR (Mustafa et al. 2015; Mustafa, 2020). The results showed that the MSAVI2 increased about 77.9% of the study area, and the rate of increase ranged from 0 to 0.0085/a. The spatiotemporal distribution of vegetation cover has been analyzed concerning the main three topographic factors; elevation, slope, and aspect. Compared with that in 2000, the MSAVI2 increased in the majority of the area in 2019. However, in Zakho and Sumail Districts in the southwestern and western parts of the study area, which are the flattened areas and elevated below 400 m, the MSAVI2 decreased. This is due to the impact of urban expansion and agricultural uses; the results were consistent with Eklund et al. (2017).

The results showed that with increasing elevation, the vegetation cover increased and reaches its maximum values at elevation 800-2000 m with an annual increase of 0.08 and $R^2=0.92$, while in elevation higher than 2000 m the vegetation cover declined. This is due to the temperature and precipitation changes significantly with elevation. Urban construction, resource extraction, and human activities are the main limitation for the growth of vegetation in lower elevation areas, which is also confirmed in previous studies (Eklund et al. 2017; M.Amin and Shnichal, 2020). The slope also influenced the vegetation growth and distribution over the study area, the terrain became very steep with the increase in the slope degree. The percentages of vegetation cover area dropped sharply in very steep areas $>45^\circ$. This is restricted in the cores of the high anticlines in Amadiya and Duhok Districts, as the steep structural slopes, erosional cliffs, and structural scarps are well developed (Sissakian et al. 2014). Furthermore, the effect of aspect in the spatiotemporal distribution of vegetation coverage of shady slopes was slightly larger than other aspect groups. this is because much less evapotranspiration is expected in shady slope areas. The decreased evapotranspiration in the shaded side is important for the growth of vegetation in the study area as it belongs to the semi-arid region. The same result was reported by Jin et al. (2008). The annual precipitation and temperature increased from 2000-2019, with significant changes in different stages. During the period 2000-2019, the study area was affected by the most severe drought event in 2008-2009 throughout the Twenty years. Related studies have also confirmed that the results were consistent (Gaznayee and Al-Quraishi, 2020; Mustafa, 2020; Fadhil, 2011). The Amadiya, Duhok, and Zakho Districts had much higher precipitation than the Sumail District, this is because the District of Sumail lies in the south of the mountains, and is therefore in rain shadow (Eklund and Seaquist, 2015). In addition to the implementation of terrain and climatic factors, the activities of humans are also important which affects the spatiotemporal distribution of vegetation cover, especially in low-lying areas.

6. Conclusions

This study was conducted to explore the spatiotemporal variations of vegetation coverage in Duhok from 2000 to 2019 by using the MSAVI2 index. The main conclusions are as follows:

- The elevation is the main controlling factor for the growth of vegetation. With increasing elevation, the MSAVI2 value increases and reaches the largest value of 0.93 at 1600-2000 m, which is the best elevation for vegetation growth. The MSAVI2 value is declined to 0.70 when the elevation is greater than 2000 m. When the elevation is less than 400 m, the MSAVI2 value is 0.22, and the growth of vegetation is small.

- In small slope degree areas mainly in flat and gentle slope $<5^\circ$ and 5-10° bins, the MSAVI2 values are 0.37 and 0.55 respectively, and vegetation cover was relatively low. At slope 30-45°, the MSAVI2 value was 0.81, which is the maximum percentage of vegetation growth and then declined in very steep slope areas $>45^\circ$. 

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The relationship between MSAVI2 and aspect indicates that the best vegetation cover is distributed in the NE 0°-45° and NW 315°-360° aspect groups were 0.67 which is the largest value and located on the shady side.

Based on the trend analysis method, the increasing trends of the vegetative areas are located in elevation greater than 400 m, whereas the decreasing trends are distributed in the areas less than 400 m. Areas of remarkable increases in the spatial distribution of vegetation cover are lies at elevation 1600-1200 m.

The MSAVI2 findings exhibited a positive relationship with both the rainfall and the temperature.

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