SJSS
SPANISH JOURNAL OF SOIL SCIENCE

Land degradation vulnerability assessment based on land use changes and FAO suitability analysis in Jordan

Evaluación de la vulnerabilidad a la degradación del territorio basada en cambios de uso del territorio y análisis de idoneidad de la FAO en Jordania

Avaliação da vulnerabilidade de degradação do território com base nas alterações do uso da terra e análise de aptidão no quadro da FAO na Jordânia

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Received: 21.03.2019 | **Revised:** 18.06.2019 | **Accepted:** 08.07.2019

ABSTRACT

The objective of this research was to investigate the pattern of land use change and its impact on land degradation in the Mediterranean regions of Jordan. Land use was interpreted using aerial photos and high-resolution satellite images and fieldwork carried out in 2018. Assessment of the degradation vulnerability degree was based on comparing the current land use with the potential suitability of the land by using FAO framework and spatial analysis techniques. The pattern of land use change from 1958 to 2018 showed that the area of rangeland and field crops declined by 16.1%, and 13.5% respectively; while the potential suitability for land utilization showed that 80% of the catchment is highly suitable for forest and rangeland in classes S1 and S2 respectively. The degree of vulnerability for land degradation under the current land use was assessed based on the erosion hazard, slope percent, and soil depth. The highest vulnerability class represents 10%, the medium vulnerability class covers 24%, the slightly moderate vulnerability class covers 31%, and the low vulnerability class consists of about 22% of the catchment area. In summary, the main constraints contributing to land degradation are improper land use by cultivation under high erosion hazard and slope degree followed by shallow soil depth.

RESUMEN

El objetivo de este trabajo fue investigar el modelo de cambio de uso del territorio y su impacto en su degradación en regiones mediterráneas de Jordania. El uso del territorio se evaluó mediante foto aérea, imágenes de satellite de alta resolución y trabajo de campo realizado a lo largo de 2018. La evaluación del grado de vulnerabilidad a la degradación se realizó a través de la comparación del uso actual del territorio con su potencial idoneidad utilizando el esquema de la FAO y técnicas de análisis espacial. El patrón de cambio de uso del territorio desde 1958 a 2018 mostró que las áreas dedicadas a pastizal y cultivos disminuyeron en un 16,1% y un 13,5%, respectivamente. Por su parte, la potencial idoneidad del uso del territorio indicó que el 80% de la zona de estudio es altamente adecuada para uso forestal y pastizal dentro de las clases S1 y S2, respectivamente. El grado de vulnerabilidad a la degradación del territorio bajo su uso actual se evaluó utilizando parámetros como el riesgo a la erosión, la inclinación de la pendiente y la profundidad del suelo. La clase de vulnerabilidad más elevada representa el 10% del territorio, la de vulnerabilidad media cubre el 24%, la de vulnerabilidad ligeramente moderada un 31% y la clase de vulnerabilidad baja ocupa alrededor del 22% del territorio considerado. En resumen, las principales limitaciones que contribuyen a la degradación del territorio son el uso inadecuado mediante cultivo con elevado riesgo de erosión y alta inclinación de la pendiente, seguidos de poca profundidad del suelo.

DOI: 10.3232/SJSS.2019.V9.N2.05

RESUMO

O objetivo deste trabalho foi o de investigar o padrão de mudança no uso do território e o seu impacto na degradação das regiões mediterrâneas da Jordânia. O uso da terra foi interpretado usando fotografia aérea, imagens de satélite de alta resolução e trabalho de campo realizado em 2018. A avaliação do grau de vulnerabilidade da degradação foi baseada na comparação do uso atual da terra com a sua aptidão potencial usando técnicas de análise espacial e no âmbito do quadro da FAO. O padrão de alteração do uso da terra desde 1958 a 2018 mostrou que as áreas dedicadas a pastagem e cultivo diminuíram, respetivamente, de 16,1% e 13,5%. Por outro lado, a aptidão potencial para o uso da terra mostrou que 80% da zona de estudo é altamente adequada para floresta e pastagem, respetivamente, dentro das classes S1 e S3. O grau de vulnerabilidade e a degradação do território em função do seu uso atual foi avaliado com base em parâmetros como o risco à erosão, o declive e a profundidade do solo. A classe de vulnerabilidade mais elevada representa a 10% do território, a de vulnerabilidade média cobre 24%, a de vulnerabilidade ligeiramente moderada corresponde a 31% e a classe de baixa vulnerabilidade ocupa cerca de 22% do território considerado. Em resumo, as principais limitações que contribuem para a degradação do território são o uso inadequado da terra por cultivo com elevado risco de erosão e declives acentuados, seguido pela baixa profundidade do solo.

KEYS WORDS
Current land use, FAO framework, satellite images, spatial analysis.

PALABRAS CLAVE
Uso actual del territorio, esquema de la FAO, imágenes de satelite, análisis espacial.

PALAVRAS-CHAVE
Uso atual da terra, quadro da FAO, imagens de satélite, análise espacial

1. Introduction

Land degradation is a worldwide issue that affects the planet and the fate of humankind (Choudhury et al. 2016; Ferreira et al. 2016; Sadeghi et al. 2017). Several processes affect the sustainability of the ecosystem, from soil erosion to soil compaction, deforestation, climate change, soil and water pollution (Mengistu et al. 2016; Mukai 2016; Fava et al. 2016). Land degradation is a dynamic process that refers to the loss of the productive capacity of the land (IUCN 2015) and responds to changes in the land quality and soil productivity (Li et al. 2015). It becomes a serious problem particularly under rainfed agricultural systems in Mediterranean regions as land resources are managed traditionally under complex land use systems (Bernhard and Schmidt 2007; Makhamreh 2018). The land-use/cover changes become the most important facets of environmental change on different scales (De Sherbinin 2002; Jennings and Harris 2017); particularly, the impact of urban expansion on the available land for agriculture which has increased rapidly in the last few decades (Yang and Zhi 2005; Salvati et al. 2014).

The sustainability concept indicates that there is a relationship between suitability and the ecosystem vulnerability to various degradation processes (Sánchez-Marañón et al. 2002; Padilla et al. 2015; Sonter et al. 2017; Tóth and Hermann 2018). Hence, land use planning attempts to balance the rate of economic growth with maintaining the environmental resources on a sustainable basis (Mathijs and Wauters 2004; El Baroudy 2016). The environmental degradation caused by improper land use is a worldwide problem that has received considerable attention in the context of sustainability issues and sustainable resource management (Shah et al. 2014; Ariti et al. 2015). One of the central elements of sustainability is the proper land use planning of environment resources (Turner et al. 2003; Wang et al. 2014; Abu Sirhan et al. 2015), which lead to minimization of environmental deterioration by allocating the land into its optimal use (Li et al. 2017). This should take into consideration the potential suitability of land resources (Ziadat and Al-Bakri 2006; Jin et al. 2015). Evidently, land use planning touches different aspects of sustainability as it focuses on optimization of land use and minimization of land vulnerability (De la Rosa and Diepen

2002; Grandmont and Giberyen 2012; Bhaskar et al. 2015).

Land degradation in Jordan takes different forms such as loss of soil fertility and productivity (Khresat et al. 1998; Farhan and Nawaiseh 2015), overgrazing and water erosion (Taimeh 1999; Alkharabsheha et al. 2013), and improper land use practices (Schmidt et al. 2006; Mohawesh et al. 2015), lack of land use planning (Abu Sirhan et al. 2015). Land evaluation combined with GIS and remote sensing analysis techniques can help to describe, analyze and predict land performance considering the different land information constraints in arid regions and Jordan (Makhamreh 1996; Bagheri et al. 2013; Hegazy et al. 2012; Rashid et al. 2011; Aburas et al. 2017). Applying the land evaluation concept will make it possible to define the degree of vulnerability for the current land use, especially given the lack of quantitative measurements (FAO 2002; Zolekar and ShivajiBhagat 2015; Makhamreh 2018; Mazahreh et al. 2018). Therefore, the main objective of this paper is to investigate the pattern of land use changes in the highland Mediterranean regions of Jordan in the timespan from 1958 to 2018, and to analyze the impact of current land use on land degradation vulnerability using FAO suitability evaluation and spatial analysis.

2. Materials and Methods

2.1. Study area

Figure 1 shows the location of the Ziqlab catchment area that is located in the Northern highlands of Jordan. It extends from 32º 23"-32º 34" North to 35º 33"- 35º 50" East, with a total area of 105 km². The prevailing climate is Mediterranean semi-arid with remarkable variation in precipitation within the Eastern and Western parts of the catchments that varies from 360-510 mm/year. The average maximum and minimum mean temperatures are 29.7 ºC and 17.6 ºC in the Western part; and 18.3 ºC and 9.8 ºC in the Eastern part (Department of Meteorology (DoM) 2018). The dominant land cover in the catchment is pasture, with common fruit tree plantations in addition to the cultivation of field crops and vegetables (Ministry of Agriculture (MoA) 2018). The tree canopy cover is dense in the catchment with different types of oak species, such as stone-oak "*Quercus Petraea*" and tabor-oak "*Quercus ithaburensis*" (Tillawi 1989). The study area is a typical watershed in the highland regions of Jordan, which has faced changes in land use types and socio economic conditions over the last few decades. The dominant soil types in the study area are Xerochrepts, Haploxererts, and Xerorthents, which are developed on limestone parent material, except for some vertic soils that are developed from clay mineral materials (MoA 1995). The soil database contains soil observations, which were collected during the fieldwork for each map unit. The measurements for the soil erosion are descriptive and there is a lack of quantitative data relating soil erosion to land use type. Therefore, the soil attributes used in the suitability analysis are limited to soil depth, total available water holding capacity, slope percent, erosion type and class (water erosion: sheet, rill, and gully, and wind erosion severity as determined in the field), surface cover type and percentage. These parameters are sufficient for conducting general suitability analysis and prediction of the limitations for agricultural production, and has been used in many studies in Jordan (Hatten 1998; Makhamreh 2005; Ziadat and Al-bakri 2006; Abu Sirhan et al. 2015; Mazahreh et al. 2018)

2.2. Land use change analysis

Land use planning attempts to balance the uses of land between different sectors of the economy. Lack of efficient land use planning in Jordan (Abu Sirhan et al. 2015) leads to improper land use allocation, especially urban expansion (Makhamreh and Almanasyeh 2011; Qtiashat et al. 2018). Therefore, the need for updated information on land use change is the central element of sustainability. It involves detection of the effect of land use changes over time on potential agricultural production and land degradation. In order to detect land use changes over time, this study used five different aerial photos taken in 1958, 1978, and 1993 at a 1:25000 scale. The land use mapping in 2008

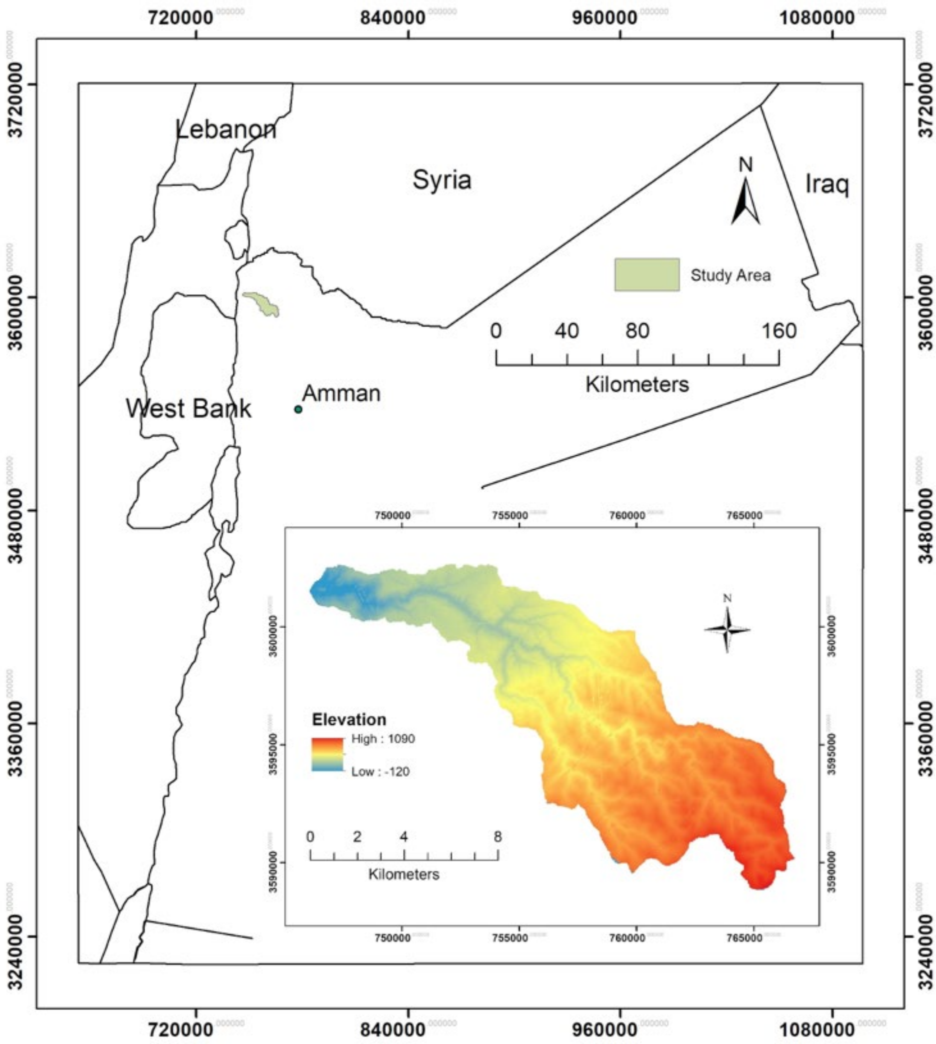

Figure 1. Location map of Ziqlab catchment's in the Northern highlands of Jordan.

and 2018 was based on high-resolution satellite images at a 1 m resolution. A reconnaissance survey and fieldwork were carried out in 2018 to get an understanding of the land-use and land-cover types in the catchment and to collect a reference database for the interpretation process. In addition, the land cover database, available from the Ministry of Agriculture, was used to aid the interpretation of aerial photographs and satellite images (MoA 1995). Table 1 describes the data used in this study.

2.3. Potential suitability assessment

Land evaluation is an interpretation of land properties in terms of land suitability for different uses (Aburas et al. 2015). This involves the interpretation of land resources in terms of the requirements of alternative forms of land use (Bagdanaviciute and Valiunas 2013; Feizizadeh and Blaschke 2013). The first step starts with the selection of the land utilization types, which have been determined by the current land use types in the catchment: field crops (LUT1), fruit trees (olives and orchards trees) (LUT2), rangelands (LUT3), and natural forests (LUT4). The second

Table 1. List of data set used in this study

No.	Data Type	Year	Scale/Resolution	Source
1.	Topographic Maps	1995	1:25000	Royal Jordanian Geographic Center - RJGC
2.	Soil map and attributes	1995	1:10000	National soil map and land use project – Ministry of agriculture
3.	Air Photo	April 1958	1:25000	RJGC
4.	Air Photo	March 1978	1:25000	RJGC
5.	Air Photo	April 1993	1:25000	RJGC
6.	High resolution satellite images	April 2008	1.0 meter	Ministry of Municipalities
7.	High resolution satellite images	Mach 2018	1.0 meter	Ministry of Municipalities

step is to determine the crop requirements, which have a direct influence on crop viability and success. Five types of land limitations were matched with the requirements of the land utilization types; these limitations are Climate (c), Soil (s), Erosion (e), Topography (t), and Rock/Stones (r). **Tables 2** to **5** show the class limits of land use requirements for the selected land utilization types. The third step of the evaluation process is the matching process, which involves the comparison of the requirements of each land utilization type with land characteristics, resulting in suitability classifications (Van Lanen et al. 1992).

2.4. Vulnerability-suitability concept

The vulnerability concept of land degradation necessitates a comparison between the current land use in 2018 and the potential constraints of the land for suggested LUTs in order to assess the vulnerability degree to land degradation. The need of this information is very vital for the land use planning sections in the cities and decision makers; the importance of such information is required for better understanding the effect of land use on the resource utilization and improving the management process. The main land qualities that are used to evaluate the vulnerability of the ecosystem to land degradation are topography, erosion hazard, and soil depth. The class limits of the vulnerability classes are indicated in Tables 2 to 5. The vulnerability classes reflect degrees of constraints within orders (S_1, S_2, S_3, Ns) and the estimated productivity levels as shown in **Table 6**. The degree of vulnerability was classified into five classes; these classes are the high vulnerability class, moderate vulnerability class, slight vulnerability class, low vulnerability class and no vulnerability class. Ratings of the vulnerability degree are defined based on soil criteria in terms of constraints and potential productivity of land use. This has been done using GIS and spatial techniques (Hishe and Assen 2016; Yalew et al. 2016; Sarath et al. 2018) and has been used in this study. **Figure 2** illustrates a schematic diagram for the evaluation of potential vulnerability for land degradation in the study area.

Table 2. Land suitability criteria for field crops (modified after MoA 1995; Hatten 1998; Makhamreh 2005) (S_1 is highly suitable; S_2 is moderately suitable; S_3 is marginally suitable; and Ns is not suitable)

Land Quality/Land Characteristics	Unit	S_1	S_2	S_3	Ns
Climate (c): Mean Annual Rainfall	mm	> 350	300-350	250-300	< 250
Winter Growth Potential (WGPT)	deg.day > 8 ºC	> 400	250-400		
Soil (s)					
Total Available Water Holding Capacity (AWHC)	mm/100 cm	> 125	90-125	60-90	< 60
Soil depth	cm	> 90	60-90	30-60	< 30
Erosion (e)					
Erosion hazard as estimated in the field water erosion (2=Rill or 3=Gully)	Class	1 (nil)	2 (slight)	3 (moderate)	4 (severe)
Water erosion (Sheet = 1) 4 = Wind 5 = Undifferentiated	Class	2 (slight)	3 (moderate)	4 (severe)	
Topography (t)					
Slope	%	< 4	4-8	8-16	> 16
Rockiness (r)					
Rock outcrop (Surface cover type = 2)	%	< 5	5-10	10-20	> 20
Stone at the surface (Surface cover type = 3, 4, 5)	%	< 20	20-40	40-60	> 60
Stoniness: Stone content of surface horizon	%	< 10	10-20	20-30	> 30

Table 3. Land suitability criteria for the fruit trees (modified after MoA 1995; Hatten 1998; Makhamreh 2005) (S_1 is highly suitable; S_2 is moderately suitable; S_3 is marginally suitable; and Ns is not suitable)

Land Quality/Land Characteristics	Unit	S_1	S_2	S_3	Ns
Climate (c): Mean Annual Rainfall	mm	> 400	300-400	250-300	< 250
Winter Growth Potential (WGPT)	deg.day > 8 ºC	> 400	250-400		
Soil (s)					
Total Available Water Holding Capacity (AWHC)	mm/100 cm	> 125	90-125	60-90	< 60
Soil depth	cm	> 150	100-150	50-100	< 50
Erosion (e)					
Erosion hazard as estimated in the field water erosion (2=Rill or 3=Gully)	Class	1 (nil)	2 (slight)	3 (moderate)	4 (severe)
Water erosion (Sheet = 1) 4 = Wind 5 = Undifferentiated	Class	2 (slight)	3 (moderate)	4 (severe)	
Topography (t)					
Slope	%	< 16	16-25	25-40	> 40
Rockiness (r)					
Rock outcrop (Surface cover type = 2)	%	< 10	10-20	20-35	> 35
Stone at the surface (Surface cover type = 3, 4, 5)	%	< 20	20-40	40-60	> 60
Stoniness: Stone content of surface horizon	%	< 15	15-35	35-50	> 50

Table 4. Land suitability criteria for rangelands (modified after MoA 1995; Hatten 1998; Makhamreh 2005) (S_1 is highly suitable; S_2 is moderately suitable; S_3 is marginally suitable; and Ns is not suitable)

Land Quality/Land Characteristics	Unit	S_1	S_2	S_3	Ns
Climate (c): Mean Annual Rainfall	mm	> 300	200-300	100-200	< 100
Winter Growth Potential (WGPT)	deg.day > 8 ºC	> 400	250-400		
Soil (s)					
Total Available Water Holding Capacity (AWHC)	mm/100 cm	> 90	60-90	30-60	< 30
Soil depth	cm	> 50	35-50	10-35	< 10
Erosion (e)					
Erosion hazard as estimated in the field water erosion (2=Rill or 3=Gully)	Class	1 (nil)	2 (slight)	3 (moderate)	4 (severe)
Water erosion (Sheet = 1) 4 = Wind 5 = Undifferentiated	Class	2 (slight)	3 (moderate)	4 (severe)	
Topography (t)					
Slope	%	< 25	25-40	40-60	> 60
Rockiness (r)					
Rock outcrop (Surface cover type = 2)	%	< 20	20-50		
Stone at the surface (Surface cover type = 3, 4, 5)	%	< 30	30-60		
Stoniness: Stone content of surface horizon	%	< 20	20-50		

Table 5. Land suitability criteria for forest (modified after MoA 1995; Hatten 1998; Makhamreh 2005) (S_1 is highly suitable; S_2 is moderately suitable; S_3 is marginally suitable; and Ns is not suitable)

Land Quality/Land Characteristics	Unit	S_1	S_2	S_3	Ns
Climate (c): Mean Annual Rainfall	mm	> 350	250-350	200-250	< 200
Winter Growth Potential (WGPT)	deg.day > 8 ºC	> 400	250-400		
Soil (s)					
Total Available Water Holding Capacity (AWHC)	mm/100 cm	> 90	60-90	30-60	< 30
Soil depth	cm	> 150	100-150	50-100	< 50
Erosion (e)					
Erosion hazard as estimated in the field water erosion (2=Rill or 3=Gully)	Class	1 (nil)	2 (slight)	3 (moderate)	4 (severe)
Water erosion (Sheet = 1) 4 = Wind 5 = Undifferentiated	Class	2 (slight)	3 (moderate)	4 (severe)	
Topography (t)					
Slope	%	< 25	26-60		
Rockiness (r)					
Rock outcrop (Surface cover type = 2)	%	< 35	35-60		
Stone at the surface (Surface cover type = 3, 4, 5)	%	< 50			
Stoniness: Stone content of surface horizon	%	< 20	20-35	35-60	> 60

Table 6. Suitability and vulnerability classes based on the limitation level (Nwer et al. 2013)

Suitability degree	Code	Symbol	Description	Productivity Rating (%)	Vulnerability degree
Highly suitable	1	S_1	Land without any significant limitations to the sustained application of the defined use.	75-100	Low
Moderately suitable	2	S_2	Land with limitations, which will reduce production levels but is still physically and economically suitable for the defined use.	50-75	Slight
Marginally suitable	3	S_3	Land with limitations, which will reduce production levels such that it is economically marginal for the defined use.	25-50	Moderate
Not suitable	4	Ns	Not suitable for the agricultural production	0-25	High

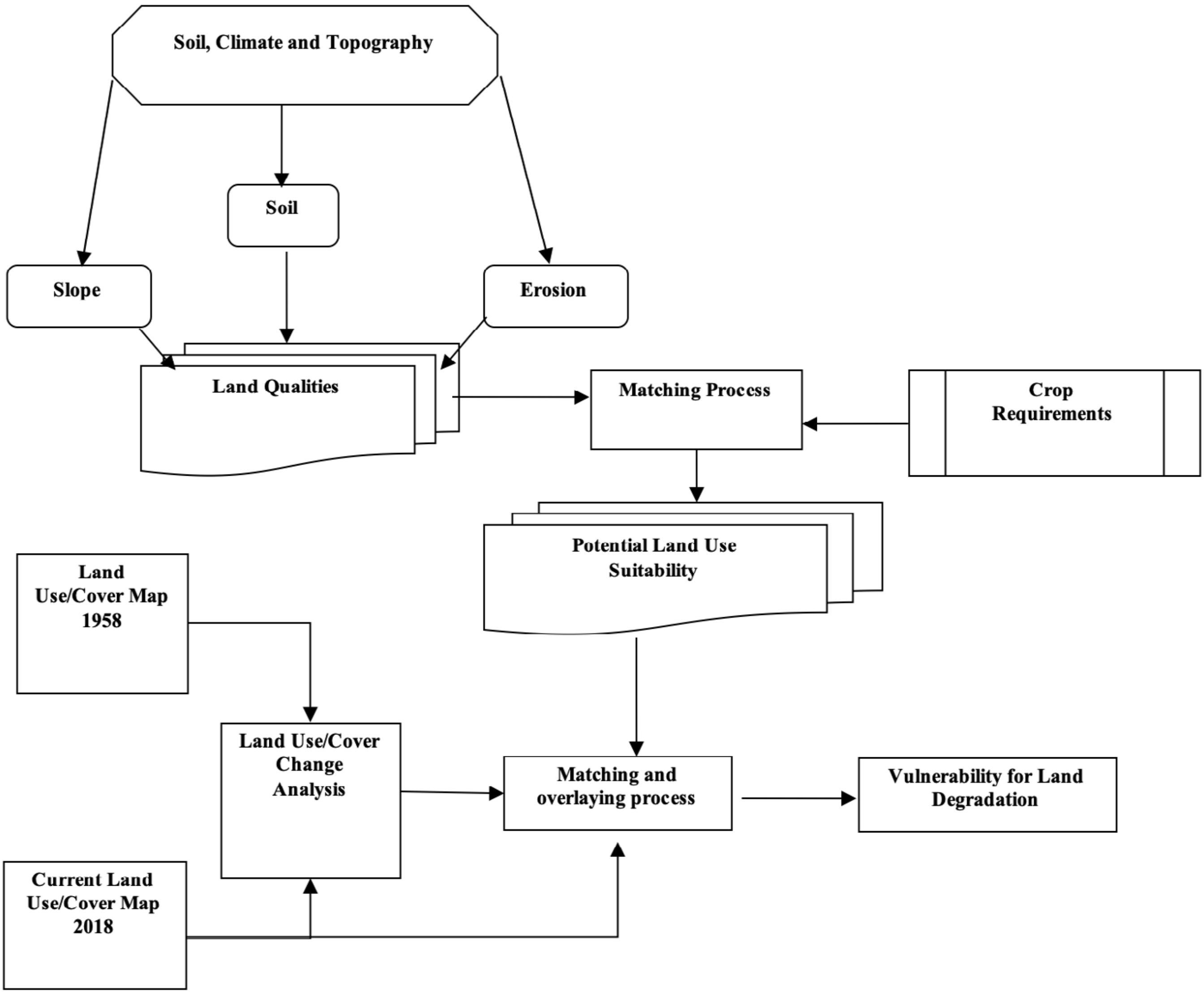

Figure 2. Schematic diagram for the evaluation of potential vulnerability for land degradation in the study area. (The boxes of the land qualities refer to the spatial layers of the soil, slope, and erosion).

3. Results and Discussion

3.1. Land use dynamics between 1958-2018

As shown in **Figure 3**, there were eight classes identified in the watershed in 2018. The natural vegetation (forest) had the largest coverage and accounted for about 2812 hectares (ha) (26.8%), followed by rangeland with about 2240 ha (21.3%). Fruit trees consisted mainly of orchards and olive trees and extended over 2947 ha (28.1%), while field crops were confined to a comparatively small area of only 1224 ha (11.7%). The urban areas occupied about 1074 ha (10.2% of the study area). Finally, the mining areas, irrigated trees, and water dams covered 117, 75, and 11.7 ha respectively. The land use classes in 2018 were used for comparison purposes with the other periods of the study in order to detect the changes in land use and standardize the comparative analysis.

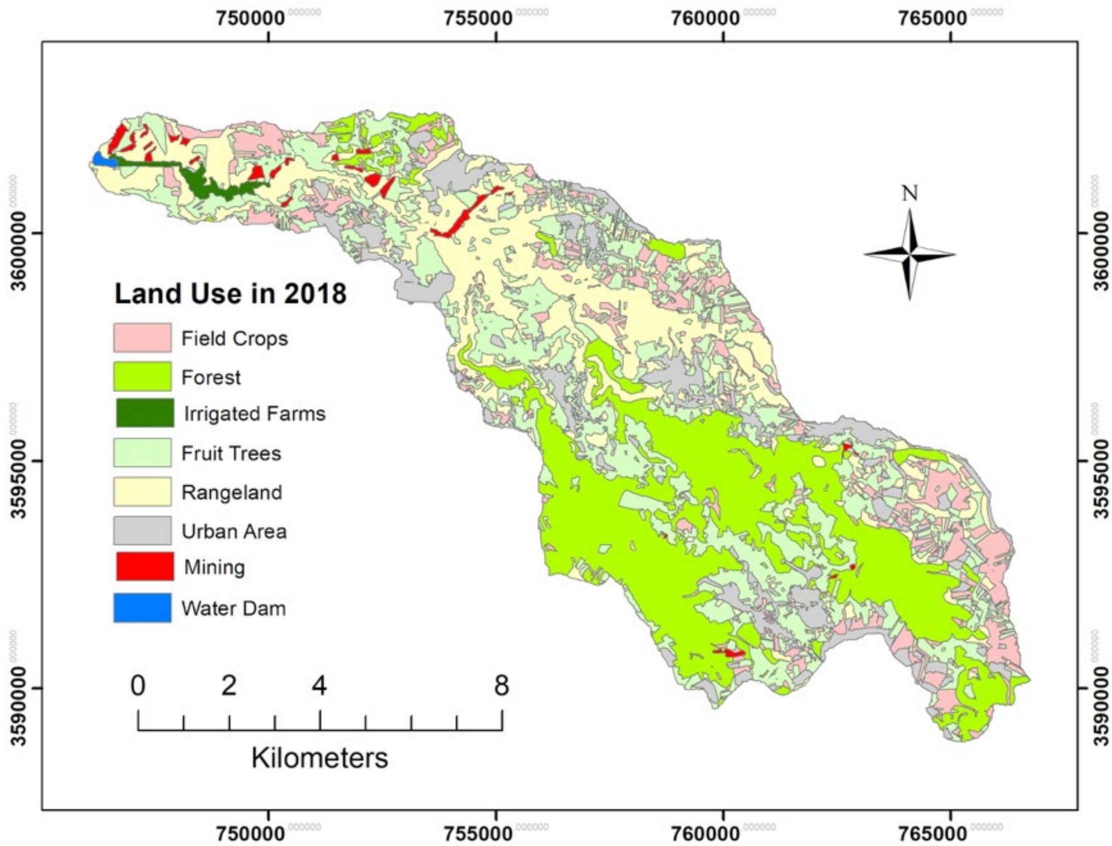

Figure 3. Spatial distribution of current land use types in 2018 in the Ziqlab catchment in the Northern highlands of Jordan.

Figure 4 shows the land use change in the study area over the years 1958, 1978, 1993, 2008 and 2018. The analysis of land use changes in these years shows that the majority of the examined area in 1958 was under natural vegetation and consisted of rangeland and forestland. The rangeland area accounted for 3929 ha (37.4%), while forestland was at 3410 ha (32.5%). The human effect was reflected in the land use types of field crops, fruit trees (orchard and olive) and urban area classes which were 2650 ha (25.1%), 390 ha (3.8%), and 119 ha (1.1%), respectively. In addition, there were 3 ha or less (0.1%) of land under irrigation near the main springs.

The comparative analysis of land use dynamics between 1958 and 2018 reveals a detectable change that occurred in the watershed over the

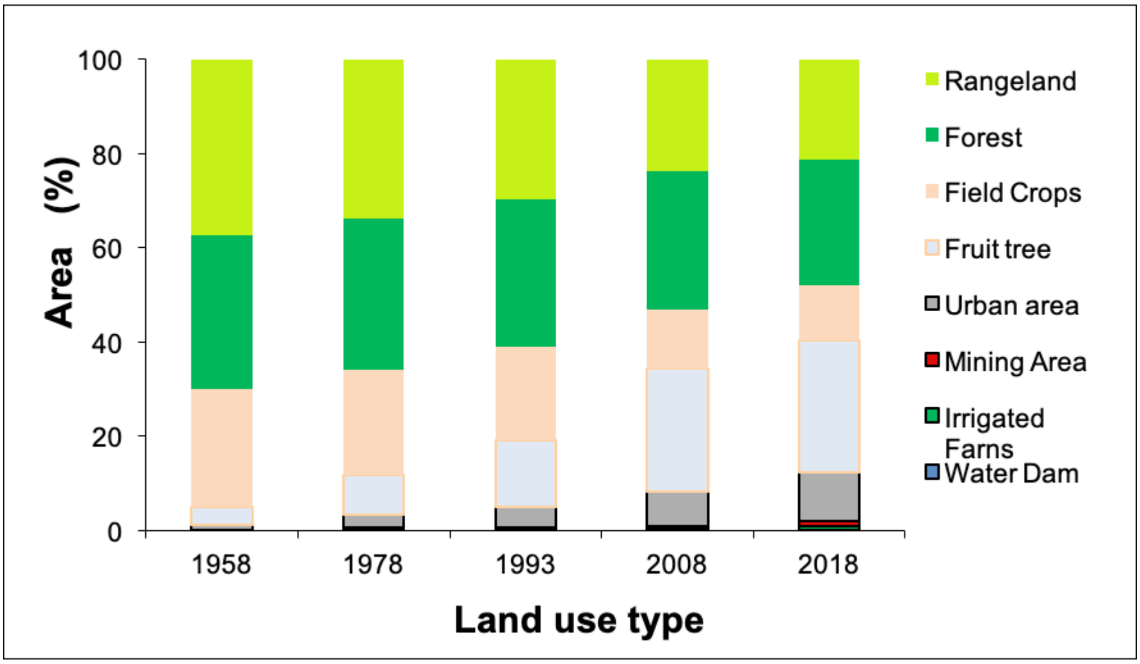

Figure 4. Percentages of each land use type in the Ziqlab catchment in the Northern highlands of Jordan in the monitored time from 1958 to 2018.

last sixty years. The area of rangeland, field crop and forestland in the catchments has declined by 16.1%, 13.4% and 5.7% respectively in the monitoring time. On the other hand, fruit trees, urban areas and irrigated farms increased significantly during the study period by 24.3%, 9.1% and 0.6% respectively of the total catchment area. It is noticeable that a large proportion of the rangeland, field crops and forestland (1689, 1414. and 598 ha) was replaced with olive trees and orchards (2547 ha) during the monitoring periods. Investigating the urban area expansion shows that this class occupied about 119 ha in 1958, which increased to reach 1074 ha in 2018. The remarkable change is the expansion of urban areas into the cultivated land, as it increased by about 954 ha (9.1%). Moreover, few changes happened within the monitoring periods such as the irrigated farms whose size increased to reach 75 ha, as well as the mining area which reached about 117 ha.

3.2. Potential land use suitability

The potential suitability for each land utilization type has been assessed in order to investi-gate the type and degree of its constraints and vulnerability. **Figure 5** shows the spatial distribution of suitability analysis for field crops land utilization types as an example for the suitability analysis.

Figure 6 shows the percentage of land suitability based on each land utilization type. The potential land suitability evaluation for field crops shows that only 3.8% of the total catchment area is classified as S_1, 26% is classified as S_2 with soil and topography limitations, 19% is classified as S_3 with soil, topography and depth limitations, and 39% is classified as not suitable because of soil erosion and topography limitations. The potential land suitability evaluation for tree crops shows that there is no area classified as S_1 for fruit tree planting, and about 49% of the total catchment area is classified as S_2 with water available capacity as a main limitation. In addition, there is 39% of the total catchment area that is classified as not suitable with shallow soil and topography limitations; and small areas have other limitations such as erosion risk and rock outcrops.

The potential land suitability evaluation for rangeland shows that there is 3.8% of the total catchment area classified as S_1, and about

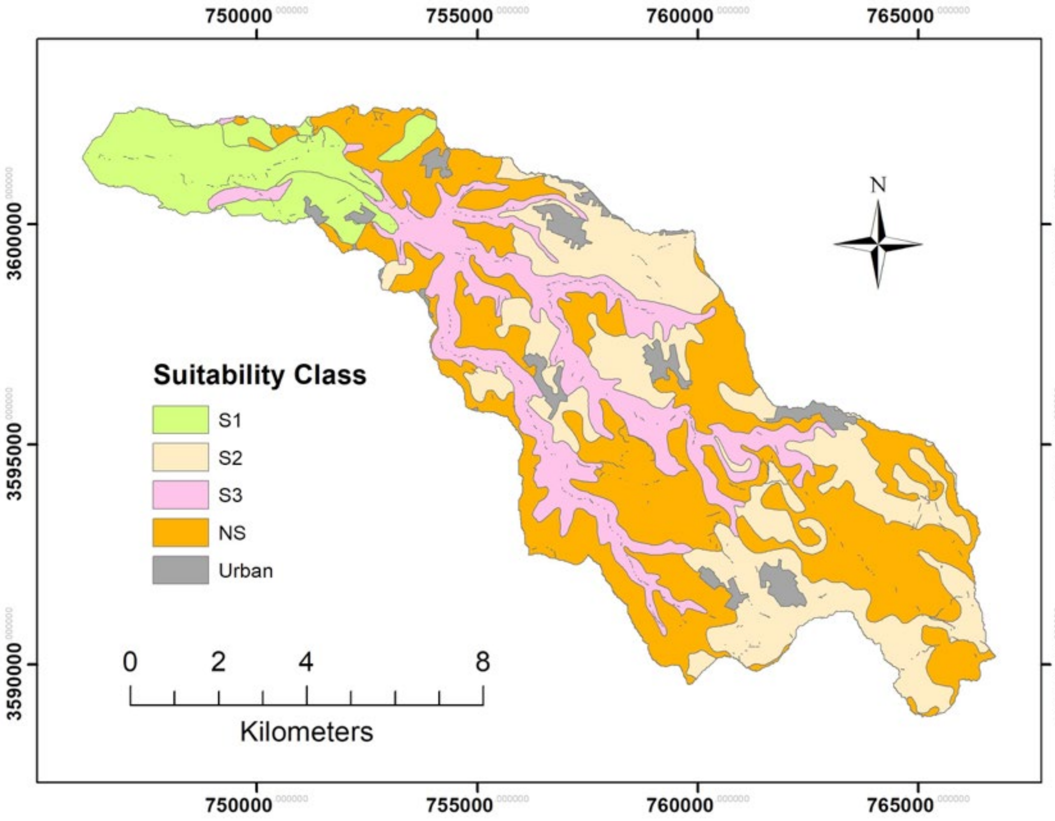

Figure 5. Potential suitability of land utilization types for field crops in the Ziglab catchment in the Northern highlands of Jordan.

45.2% classified as S_2 with climate and erosion limitations, and about 39% classified as S_3 with topography and soil limitations. The land suitability evaluation for forest shows that 49.1% of the total catchment area is classified as S_1, and 39% classified as S_3 with shallow soil and low water available capacity as limitations. The potential land suitability evaluation for irrigation shows that there is only 3.8% of the total catchment area classified as S_1 for drip irrigation and about 26% classified as S_2, while 19.7% is controlled by climate and topography, and about 6.7% is controlled by climate, topography and rock conditions.

3.3. Land use vulnerability

The analysis of the current land use shows that the dominant agricultural activities consist mainly of field crops and fruit trees which comprise about 40% of the total catchment area. In 1958, the rangeland and field crops were the most important land use in the catchment, converting over time to fruit tree production and urban settlements, while the natural forest area slightly changed, as discussed in the previous section. These changes play an important role in the evolution of land degradation risks in the watershed and are related to the socio-economic transformation in Jordan, climate change and land fragmentation (Potter et al. 2009; Makhamreh 2014; Khlaifat et al. 2018). In addition, the suitability analysis shows that at the beginning of the monitoring period the majority of field crops were planted mainly in S_1, S_2, S_3 and a small area in Ns classes, and then the field crop areas decreased to reach 13.5% of the total area. However, the spatial distribution of field crops shows a trend of increasing plantations in Ns class, and decreasing plantations in S_2 and S_3 suitability classes.

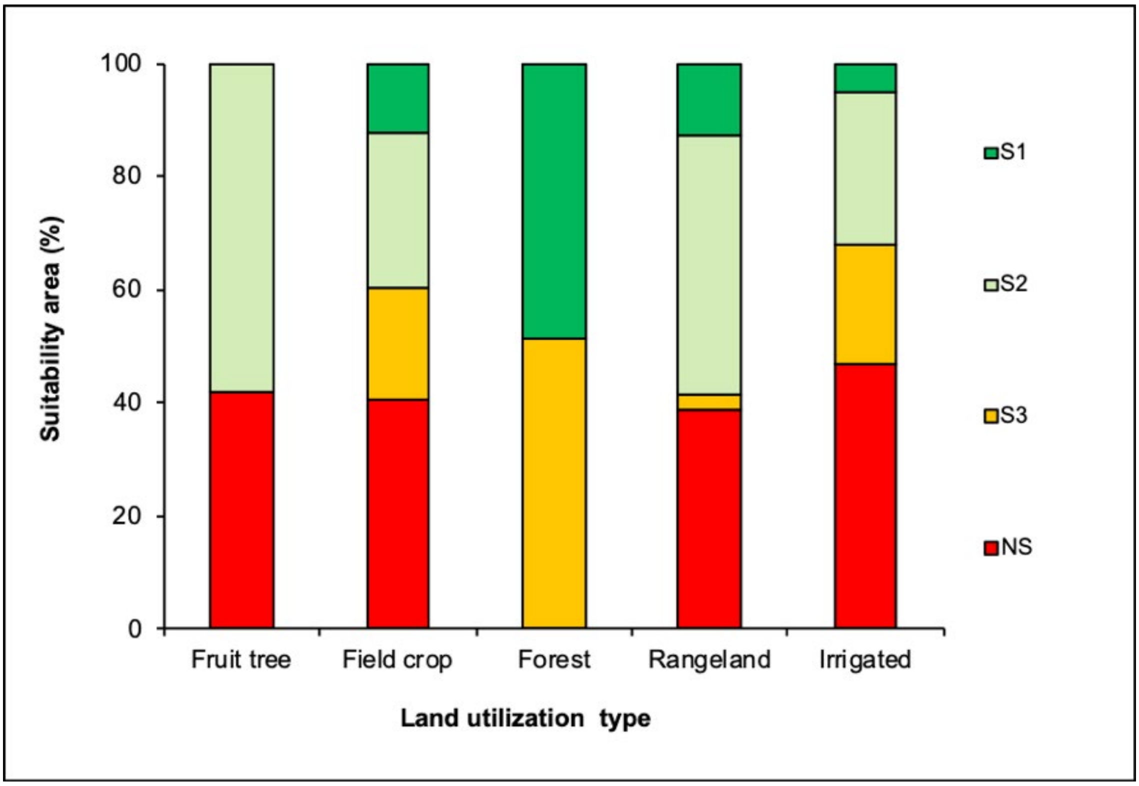

Figure 6. Areal percentage of potential land use suitability and degree of limitations for each land utilization type in the Ziqlab catchment in the Northern highlands of Jordan. The classes S_1, S_2, S_3, Ns represent the degrees of suitability within land suitability orders.

The results show that the fruit tree planting areas increased over the monitoring period from 3.7% in 1958 to 28.1% in 2018. The expansion of fruit tree plantations is concentrated in the S2 and Ns suitability classes. The spreading of fruit tree plantations in the Ns class is due to the most limiting factor in this class which is the soil depth. However, the expansion of the rural house pattern, using modern technology and supplementary irrigation enabled the planation of fruit trees in this suitability class (Muhawish 2010). However, these types of changes coupled with insufficient agricultural practices to manage the soil erosion are contributing to the acceleration of land degradation processes in the catchment. The irrigated farms indicate that there were only 2.4 ha planted in 1958, and increased to 75 ha in 2018; however, this increase has not significantly contributed to the degradation vulnerability.

The importance of this approach is due to the comparison between the changes in land use and potential utilization to detect the vulnerability to land degradation. The majority of rangeland exists under S_2, S_3, and only 3.8% of S_1 class in 1958, and then it dropped to 1.1% in 2018. The comparison between current and potential land uses for forestland shows that the general suitability for forestland classified S1 and S3 are 49.1%, and 39.2% respectively. The comparison indicates that the forestland had decreased for a period between 1958 and 2018 to cover only 26.8% of the catchment due to deforestation of some private areas, which were planted with orchards and olive trees instead. In this case, the comparison between current and potential land uses for natural vegetation indicates a significant decrease in rangeland areas and a slight decrease in the forest area over the monitoring time. These type of changes over long time often lead to loss of general biodiversity and land degradation.

Figure 7 illustrates the degree of vulnerability and its areal proportions for each current land use type. The vulnerability to land degradation under natural vegetation shows a low to moderate degree. The forest has a higher vegetation canopy, providing better protection for the soil surface against the raindrop impact in the winter season; therefore, it is expected that the actual vulnerability will be lower than the potential degree. In addition, most of the rangeland lies in the slightly and moderately vulnerable classes, while its main constraints are high slope percentage and sheet erosion hazards. These two types represent the lowest vulnerability degree in the catchment, as they grow naturally under sizable limitations and can tolerate harsh landscape conditions. However, the expansion of urban areas does not take into consideration the potential suitability of the land, since around 60% of the expansion takes place on agricultural land - about 23% from class S_1 and 37% from class S_2, leading to a permanent loss of agricultural land for production.

The vulnerability analysis of fruit tree indicates that 15% lies in the slight vulnerability class and 17% in the moderate vulnerability class of the total land use. The major factors contributing to the vulnerability in this class are the erosion hazards and slope degree as dominant constraints. Consequently, this situation could negatively influence the vulnerability of the ecosystem to land degradation processes. On the other hand, the degree and type of limitations are quite different in the case of the field crops. About 10% of the field crops lie in the moderately vulnerable class and 5% in the slightly vulnerable class. The main limitations for field crops are erosion hazards represented by rill and sheet types, improper slope conditions followed by shallow soil.

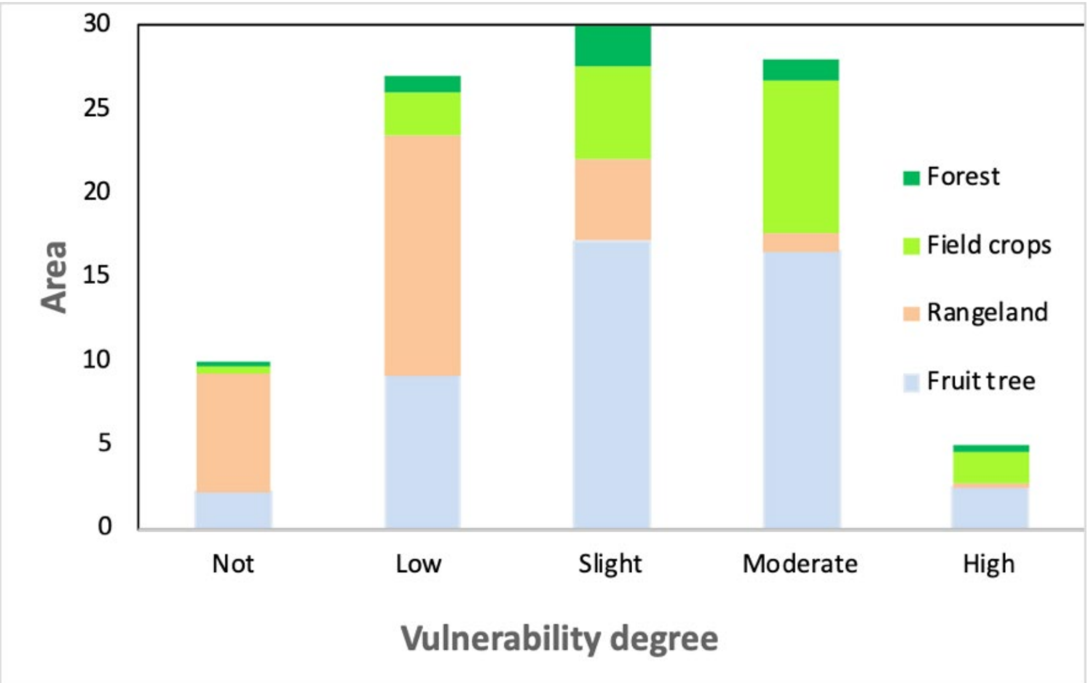

Figure 7. Degree of vulnerability and areal proportion for each current land use in 2018 of Ziqlab catchment in the Northern highlands of Jordan.

The high vulnerability class is characterized by interaction between different factors such as steep slopes, and high erosion hazards. Gully type erosion is the dominant risk with different degrees of severity. However, the spatial distribution of this class represents only 10% of the total area. The moderate vulnerability class is the second most important vulnerability class, which covers 24% of the total study area. The main constraints contributing to the vulnerability of this class are rill erosion and slope percent followed by shallow soil. However, the most dominant class in the catchment is the slightly vulnerability class, which covers 27% of the total area. The main constraints contributing to the vulnerability of this class are slope and sheet erosion. The low vulnerability class comprises 26% of the total area. The main constraints contributing to the vulnerability of this class are sheet erosion with low levels of severity and the slope constraints are the second most important factor contributing to the vulnerability in this class. The last class is the no vulnerability class. The areal spatial distribution of this vulnerability class accounted of for 13% of the total area. The main constraints contributing to the vulnerability of this class are the sheet erosion with low severity levels.

4. Conclusions

The landscape in the Mediterranean is characterized by complex interactions between human activities and natural resources. The increasing population growth and changing patterns of human life and their activities have accelerated the environmental degradation through different processes in the highland agro-ecological zone in Jordan. The suitability – sustainability - vulnerability paradigm was used to assess the vulnerability of the landscape to degradation by comparing the changes in land use with the potential suitability of the land under consideration, which show its effectiveness in detecting the vulnerability to land degradation in arid and semi-arid regions where data availability is limited. Quantitative assessment of the land use changes and suitability of the soil units was carried out to assess the vulnerability of land degradation under different land utilization types. The landscape dynamic within a period of over 60 years shows a decrease in the natural vegetation areas and a positive increase in fruit trees and urban areas. As the rate of loss of rangeland and woodlands rises, so does the risk of land degradation with a knock-on effect on the human-ecosystem that depends on them. In addition, the spreading of agricultural activities on moderate and low suitability land affects the agricultural production and increases the environmental degradation. These changes in land use type and pattern reflect the changes in socio-economic factors and illustrate the pattern of transformation in the Jordanian society over the last six decades. Most of the changes in the landscape occurred on the cultivated land, which has accelerated the loss of high potential land for agriculture and increased the degree of vulnerability for land degradation in the medium and moderate vulnerability classes. The prevailing land use system in the region influences the vulnerability of the land to various degradation processes. Therefore, this study underlines the need to focus on halting unplanned urbanization, introducing suitable conservation measures and developing land use planning based on proper land use planning that allocates land to its potential land use suitability.

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