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The feasibility of ash and spruce forest plantations in the Northeast of Iran

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Abstract
In the present study, the feasibility of planting ash (*Fraxinus excelsior* L.) and spruce (*Picea abies* L.) tree species was investigated for rehabilitation of the Toroq Watershed in the northeast of Iran. The estimated land suitability indices ranged from 23.95 to 71.05, and 22.47 to 69.38 for ash and spruce plantations by parametric approach, categorized into moderately suitable (S2) in the east to not suitable (N) in the middle and western parts of the study area. The values of land indices by the AHP approach varied between 35.45 to 94.09 and 34.67 to 83.98 for ash and spruce plantations ranging from highly suitable (S1) in the east to moderately suitable (S2) in the middle and scattered parts in the east and not suitable (N) in the north and southwest of the basin. The results showed that the most important limitations were climate, elevation, soil depth, and soil texture. The regression coefficient (R^2) of land suitability indices between parametric and AHP approaches for the two spices was 0.894 and 0.866 respectively. The results of the two models revealed that the moderately suitable class S2 is dominant for ash and spruce plantations in the eastern parts of the basin, while the middle and western parts of the basin were not suitable for plantation of the trees. The findings of this study may help land-use planners to rehabilitate the watershed by expanding forest plantation which ecologically tolerates extreme conditions of the region.

***Keywords*: Land Suitability, Ash, Spruce, Zonation, GIS**

Introduction
Common Ash (*Fraxinus excelsior*) is a hard-wood deciduous tree species of the northern temperate zone. The northern boundary of the common ash is in the northern Europe at 64°N, and it outspreads south to the Mediterranean through the north-regions of Spain, Italy, and Greece as far as Iran. In Iran, the geographic range of common ash extends to 37°N. Common ash occurs in various forest types and forest communities (Dobrowolska et al., 2011), it grows well in nutrient-rich, moist and well-drained soils (Kerr and Cahalan, 2004; Weber-Blaschke et al., 2008). Ash is widespread in soils of high base status preferring calcareous soils such as limestone and chalk, where it may become abundant avoiding soils which are markedly acidic. It also requires soils rich in humus and mineral nutrients. Norway spruce (*Picea abies*) is native to northern and central Europe and it grows in a variety of soils and develops well in clay soils where pine and fir do not do well. This tree species grows in soils with a pH of up to 9, but grows well if pH is 7.5 or less. It can take more moisture compared to common ash. This tree grows well in areas mainly susceptible to heat and drought conditions due to its shallow root system; hence, is influenced by global warming conditions. Norway spruce requires full to partial sun, and suitable moist, acidic, well-drained soil, but the species can also grow in poor, clay, and dry soils with different pH conditions. The information required in land suitability evaluation is based on environmental data derived from soil or land resources surveys, including soil qualities/characteristics and climate data related to the growth requirements of the trees. Gholizadeh et al.

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(2019) investigated land suitability for oak and pine plantations by parametric and AHP approaches in the Toroq Basin, northeast of Iran. They showed that land suitability indices using the parametric approach ranged from 23.49 to 72.02 for oak and 28.27 to 69.67 for pine plantations while through the AHP approach the values changed between 34.48–87.11 and 37.98–78.20, respectively. These researchers demonstrated that the most limiting factors for plantation of the two species in the study area were altitude, aspect, soil depth, and soil texture. Bagherzadeh (2018) found that the values of land suitability indices for Norway maple and black locust plantations in the Toroq watershed, northeast of Iran by the parametric approach varied from 22.46 to 67.50 and 23.23 to 75.11 respectively while by the AHP approach they changed between 35.91 and 84.58 for Norway maple and from 32.87 to 94.31 for black locust plantations. Ekanayake and Dayawansa (2003) evaluated land suitability for forest productivity in Sri Lanka using climate, slope, soil, topography, and vegetation accessibility as important factors. Olarieta et al. (2006) studied land requirements for growing *Pinus radiata* in the Basque area, northern Spain. Their results showed that soil physical properties such as soil texture has a major influence on the growth rates of *Pinus radiata*. They revealed that loamy texture soils had higher rates of suitability than clay-rich soils. Here, suitability evaluation is based on interpretation and calculation of the ecological requirements of the selected tree species in terms of climatic requirements and land qualities including terrain and soil characteristics (Song Zhaomin and Meng Ping, 1993; Schuett et al., 1999; Shvidenko et al., 1996). The climate suitability analysis is classified into optimum (S1), sub-optimum (S2), and not suitable (N) categories based on the thermal and moisture requirements of tree species at each stage of the growing period. This research aims to assess land suitability for two tree species including ash (*Fraxinus excelsior*) and spruce (*Picea abies*) and investigate the extent the parametric and AHP models describe the suitability of ash and spruce plantations beyond the natural ecological occurrences of these trees in the northeast of Iran.

Material and methods

Study area

The Toroq Basin is located close to the south of Mashhad, Khorasan-e-Razavi Province, Iran. The study site is placed between the latitudes 36° 04′ N to 36° 16′ N and the longitudes 59° 18′ E to 59° 39′ E, consisting of an area of about 394 km^2 and a total mainstream length of 35 km. The geographic position of the basin extends in an SW-NE direction and lies closely on southward Mashhad Plain based on visual interpretation of the satellite imagery and field observations (Figure 1). The basin is covered mainly by shale and dark gray phyletic formation aged to the Jurassic period (>51%). The soil texture of the study area is commonly silty loam. The topographical elevation values of the basin vary between 1019-meter a.s.l in the east and 2653-meter a.s.l in the west. The semi-arid climate of the basin has a mean annual precipitation of 221mm and a mean annual temperature of 15.8°C. The slope varies between 0 and 82.79°, and the flat areas are observed mainly in the east while the steep slopes occur in the westward direction of the basin. The main aspects in northern parts are mostly south, southeast, southwest, and west while in the middle and southern parts of the basin the main aspects fall in the north, northeast, and east categories.

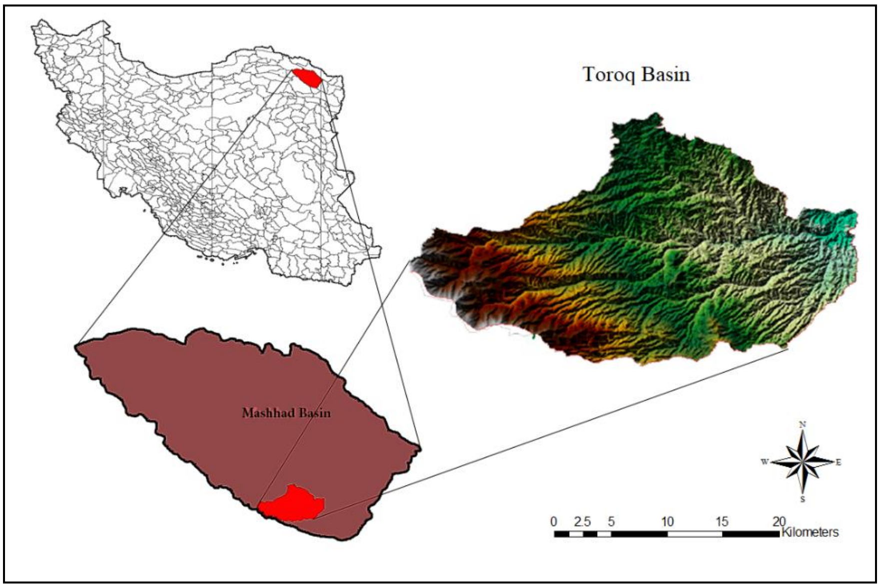


Figure 1. Location and geographical position of the study area

Data

Due to climatic data shortage in and around the study area, climatic factors were extracted from WorldClim (ver.2) in spatial resolutions of 30 seconds (~1km^2). The most important implication in estimating soil physical and chemical properties in the study area was reliable soil data; hence, we used soil data from SoilGrids 250 m (ver.2.0), which uses digital soil mapping of global collections of soil profile data and environmental layers. It serves as a collection of soil properties including soil physical and chemical attributes in 417 points up to 100 cm soil depth or to a restricted layer. The terrain values including elevation, slope, and aspect were estimated from the 30 m DEM of the study area. The shape files of flood hazard and erosion risk in Iran were used and processed by ArcGIS (ver.10.6) to show plantation limitations in the study area. The classes of drainage limitation were estimated through soil textural classes and the hydrological groups of soil at each study point.

Climate limitation analysis

The climate suitability was evaluated by considering temperature and precipitation requirements of tree species in the basin. For each tree species, three thresholds including optimal (S1 class), sub-optimal (S2 class), and not suitable (N class) conditions for tree growth were defined. Climate temperature requirements of ash and spruce tree plantations were derived from Thériaultet al., (1998); Burschel and Huss, (1997); Chartier et al. (1995); Schuett (1999); Stolbovoi et al., (1997); Woods and Hall, (1994) and exhibited in Tables 1 and 2. The climate indices (*CI*) and the climate rates (*CR*) at each study point were used for calculating a land index for tree species at each study point.

Land data analysis

The terrain and soil suitability were evaluated by considering soil requirements of the trees in terms of growth and biomass production. The values included elevation, slope, aspect, flood conditions, drainage, and soil erosion condition, soil physical factors including soil texture, coarse fragments and soil depth, soil chemical properties such as soil reaction (pH), soil salinity (EC), calcium carbonate content ($CaCO_3$) and organic carbon (OC). The next step was land evaluation by comparing land qualities/characteristics with the trees' requirements and classifying land suitability for each species (Tables 3 and 4). The feasibility of forest plantations in the study area was accomplished through evaluating land suitability for the two species in the study area.

Table 1. Climate requirements for Ash (*Fraxinus excelsior*) plantation

Criteria	Index	Classes		
		S1 100–75	S2 75–50	N 50–0
Climate	Mean temp. of the coldest month	> -8	-8 – -15	< -15
	Mean temp. of the Warmest month	25 - 18	18 – 16 25 – 30	< 16 > 30
	Minimum temp. of the coldest month (^oC)	> -15	-15 – -25	< -25
	Frost-free period (days with mean temp. > 10^oC)	>150	150 – 135	<135
	Periods of biological activity (days with T_{mean}> 5^oC)	>180	180 – 165	<165
	Accumulated temp. (base temp. of 5^oC)	>2500	2500 – 2250	<2250
	Accumulated temp. (base temp. of 10^oC)	>2000	2000 – 1800	<1800
	Length of growing periods (days)	>165	165 – 150	<150
	Annual precipitation (mm)	> 750	750 – 500	<500

Table 2. Climate requirements for Spruce (*Picea abies*) plantation

Criteria	Index	Classes		
		S1 100–75	S2 75–50	N 50–0
Climate	Mean Temp. of the coldest month	> -20	-20 – -25	< -25
	Mean Temp. of the Warmest month	18 - 14	14 – 12 18 – 20	< 12 > 20
	Minimum Temp. of the coldest month (^oC)	> -25	-25 – -30	< -30
	Frost-free period (days with mean temp. > 10^oC)	>105	105 – 90	<90
	Periods of biological activity (days with T_{mean}> 5^oC)	>135	135 – 120	<120
	Accumulated temp. (base temp. of 5^oC)	>1600	1600 – 1250	<1250
	Accumulated temp. (base temp. of 10^oC)	>1150	1150 – 1050	<1050
	Length of growing periods (days)	>135	135 – 120	<120
	Annual Precipitation (mm)	> 700	700 – 500	<500

Table 3. Terrain and Soil requirements for Ash (*Fraxinus excelsior*) plantation

Criteria	Index	Limitation class		
		S1 100–75	S2 75–50	N 50–0
Terrain	Elevation (m)	700 - 1100	600 – 700 1100 - 1200	<600 >1200
	Slope (%)	0-10	10-32	>32
	Aspect	N, NW, NE, Flat	W, E	S, SE, SW
	Flood hazard	F0	F1	F2, F3
	Erosion condition	Very Low, Low	Moderate	High, very High
Soil Physical characteristics	Soil texture	SiCL, CL, Si, SiL, SC, L, SCL	SiC, SL, LS	S, C
	Coarse fragments (%)	0 – 15	15 – 40	40 - 100
	Soil Depth (cm)	200 - 100	100 - 30	30 – 0
	Drainage	W, MW, I	SE, P	E, VP
Soil Chemical and Fertility characteristics	$CaCO_3$	0 – 10	10 - 30	>30
	ECe (ds/m)	0 – 2	2 – 4	>4
	Organic Carbon (%)	5.0 – 2.7	2.7 – 1.3	1.3 – 0.0
	pH	7.5 – 5.8	5.8 – 4.5 8.5 – 7.5	<4.5 >8.5

Table 4. Terrain and Soil requirements for Spruce (*Picea abies*) plantation

Criteria	Index	Limitation class		
		S1 100–75	S2 75–50	N 50–0
Land Terrain	Elevation (m)	700 - 1100	600 – 700 1100 - 1200	<600 >1200
	Slope (%)	0-10	10-32	>32
	Aspect	N, NW, NE, Flat	W, E	S, SE, SW
	Flood hazard	F0	F1	F2, F3
	Erosion condition	very Low, Low	Moderate	High, very High
Soil Physical characteristics	Soil texture	SiCL, CL, Si, SiL, SC, L, SCL, SL	SiC, LS	S, C
	Coarse fragments (%)	0 – 15	15 – 60	60 - 100
	Soil Depth (cm)	150 - 100	100 - 50	50 – 0
	Drainage	W, MW	SE, I	E, P, VP
Soil Chemical and Fertility characteristics	$CaCO_3$	0 – 30	>30	-
	ECe (ds/m)	0 – 8	8 – 10	>10
	Organic Carbon (%)	2.7 – 1.3	1.3 – 0.7	0.7 - 0
	pH	6.0 – 4.5	4.5 – 4.0 7.5 – 6.0	<4.0 >7.5

The parametric approach in land suitability evaluation

For parametric approach we used the “Framework for Land Evaluation” (FAO, 1976) and “land evaluation for forestry” (FAO, 1984), which distinguishes the climatic conditions and land features such as topography, wetness, soil physical and chemical properties, erosion hazard, soil salinity and alkalinity for each specific tree. The parametric approach determines the land suitability index and -class based on the limitation rate of climate and land qualities/characteristics requirements for each tree species, ranged from 0 to 100 (Table 5). The limitation value for each limiting factor is calculated by the following linear interpolation equation;

$$y = a + \frac{(b-a)(x-c)}{d-c} \qquad \text{eq(1)}$$

where, if the observed value of each land quality/characteristic (x) falls into the interval [a, b] in each limitation class it gets a limitation rate (y) that falls into the interval [c, d] which are the lower and upper threshold values defined for that limitation class. Finally, the land suitability index is computed through multiplying the geometrical mean of the limitation rate given to each land quality/ characteristic and land climate rate in the nth root of the interaction between these limitation rates using the following equation (Bagherzadeh and Paymard, 2015):

$$LI = \prod_{i=1}^{n} x_i^{\left(\frac{1}{n}\right)} \times \sqrt[n]{\frac{\prod_{i=1}^{n} x_i}{100^n}} \qquad \text{eq(2)}$$

where LI is the land index,
x_i is the limitation rate given to each land quality/characteristic, n is the number of land qualities/characteristics.

Table 5. Land suitability classes according to land index

Class	Intensity of limitation	Land index
S1	Highly suitable	75 -100
S2	Moderately suitable	50 -75
N	Not suitable	0 -50

AHP approach in land suitability assessment

The AHP is actually a one-level weighting system using a pair-wise comparison matrix between the parameters and has been illustrated by Saaty (1994) and Saaty and Vargas (2001). The AHP is used as a weighted linear combination approach to give the relative importance on a one-to-one basis of each decisive factor (Malczewski, 1999). For a better representation of the map, the scale assigns a linguistic expression to every equivalent numerical value. The weights of the factors were computed from the pair-wise comparison matrix based on the relative importance of climatic, terrain, and requirements of each tree through reviewing literature and the experts' knowledge. The results of the pair-wise comparison matrix and the factor weights are presented in Table 6. In the AHP approach the consistency ratio (*CR*) is the ratio between the matrix's consistency index and random index and employed to represent the possibility that the matrix judgments were randomly produced (Malczewski, 1999).

$$CR = \frac{CI}{RI} \qquad \text{eq(3)}$$

where *RI* is the mean of the resulting consistency index based on the magnitude of the matrix specified by Malczewski (1999), and *CI* is the consistency index and can be presented as:

$$CI = \frac{\lambda\max - n}{n - 1} \qquad \text{eq(4)}$$

where λmax is the major particular value of the matrix and can be simply computed from the matrix, and n is the order of the matrix. The value of *CR* varies from 0 to 1. The *CR* values close to 1 represent the possibility that the matrix's ranking was randomly produced. The value *CR* of 0.10 or less is a logical level of consistency (Malczewski, 1999). In our study, the *CR* value of the matrix among the 14 influential parameters affecting land suitability was 0.04. We multiplied the weight of each factor in the AHP approach to its layer and then summed up the weighted factor layers in GIS to arrive at the final suitability map for each tree species. The weights should add up to 1.0, as the linear weighted combination calculation requires.

$$\sum_{j=1}^{n} w_j = 1 \qquad \text{eq(5)}$$

Table 6. Pairwise comparison matrix for calculating factor weights

CR = 0.040	Climate	Elevation	Slope	Soil Depth	Soil Texture	Aspect	ECe	pH	OC	CaCO3	Coarse fragment	Drainage	Erosion	Flooding	Weight
Climate	1														0.270
Elevation	0.50	1													0.173
Slope	0.33	0.50	1												0.121
Soil Depth	0.33	0.50	0.50	1											0.093
Soil Texture	0.20	0.25	0.33	0.50	1										0.062
Aspect	0.20	0.25	0.33	0.50	0.50	1									0.054
ECe	0.20	0.25	0.33	0.33	0.50	0.50	1								0.046
pH	0.17	0.20	0.25	0.33	0.33	0.50	0.50	1							0.037
OC	0.17	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1						0.033
CaCO3	0.17	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1					0.029
Coarse frag.	0.14	0.17	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1				0.024
Drainage	0.13	0.14	0.17	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1			0.021
Erosion	0.13	0.14	0.17	0.17	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1		0.020
Flooding	0.11	0.13	0.14	0.17	0.17	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1	0.017

The zonation map of the land suitability

The kriging approach is known as a practical interpolation method in the land suitability evaluation studies (Bagherzadeh, 2018; Gholizadeh et al., 2019). In our study we employed the kriging approach in ArcGIS ver.10.6 software to map the spatial data and visualize the zonation of land suitability indices by the two approaches.

Results

Land suitability zonation by parametric approach

In the present study, the specific terrain, soil, and climate requirements for the given trees were determined based on FAO guidelines in land evaluation for forestry (1984). There were sub-optimal climate conditions in large regions of the study area, where the climate rate altered from 52.81 to 89.80 and 63.35 to 66.12 for ash and spruce plantations. The land suitability indices based on a parametric model for *Fraxinus excelsior* and *Picea abies* plantations varied between 23.95 to 71.05 and 22.47 to 69.38, respectively. The classes of land suitability for both trees in the study area were categorized into a sub-optimal class S2 and non-suitable class N. The zonation of land suitability for *F. excelsior* plantation revealed that 29.56% (116.73 km^2) of the basin was classified into sub-optimal suitability class S2 and 70.44% (278.21km^2) of the study area was categorized into N class (Table 7). The suitability map of *P. abies* plantation revealed that 26.03% (102.81 km^2) of the basin, categorized into S2 class, while 73.97% (292.13 km^2) of the region was not suitable for forestry (Table 8). The most important limiting parameters affecting tree growth in the study area were elevation and aspect for ash and elevation, aspect, and pH for spruce plantations. The zonation maps of the classes showed a similar pattern for tree species in which in an east to the west direction, limitations increased and the suitability classes reduced accordingly. As shown in Figures 2 and 3 in the west direction elevation, slope, and southward aspects increase constantly which associated decrease in the suitability of the region for forest species establishment.

Table 7. The surface area of suitability classes for Ash (*Fraxinus excelsior*) plantation by parametric and AHP approaches

Suitability Class	Parametric		AHP	
	Area (km^2)	%	Area (km^2)	%
S1	0	0	20.75	5.25%
S2	116.73	29.56%	268.11	67.89%
N	278.21	70.44%	106.08	26.86%
	394.94	100%	394.94	100%

Table 8. The surface area of suitability classes for Spruce (*Picea abies*) plantation by parametric and AHP approaches

Suitability Class	Parametric		AHP	
	Area (km^2)	%	Area (km^2)	%
S1	0	0	10.59	2.68%
S2	102.81	26.03%	257.31	65.15%
N	292.13	73.97%	127.04	32.17%
	394.94	100%	394.94	100%

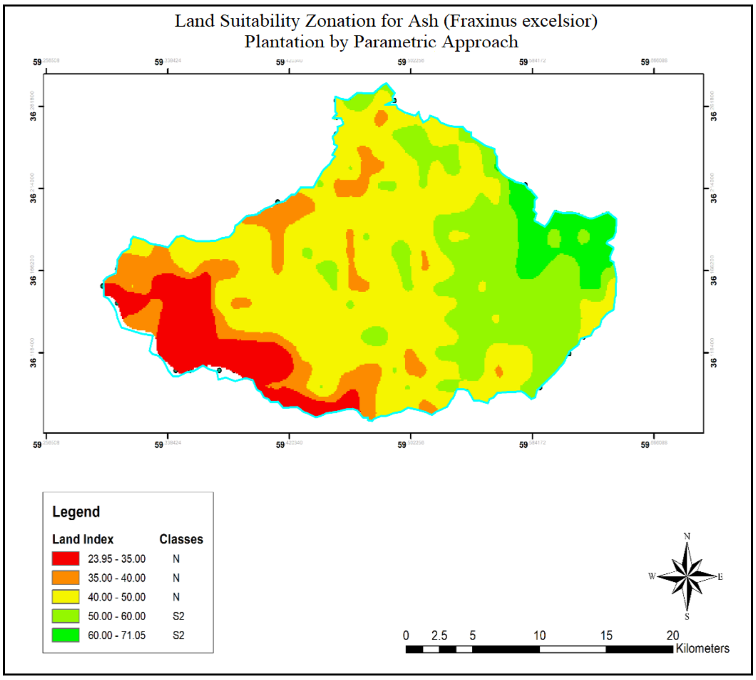


Figure 2. The land suitability zonation for Ash plantation using parametric approach in the study area

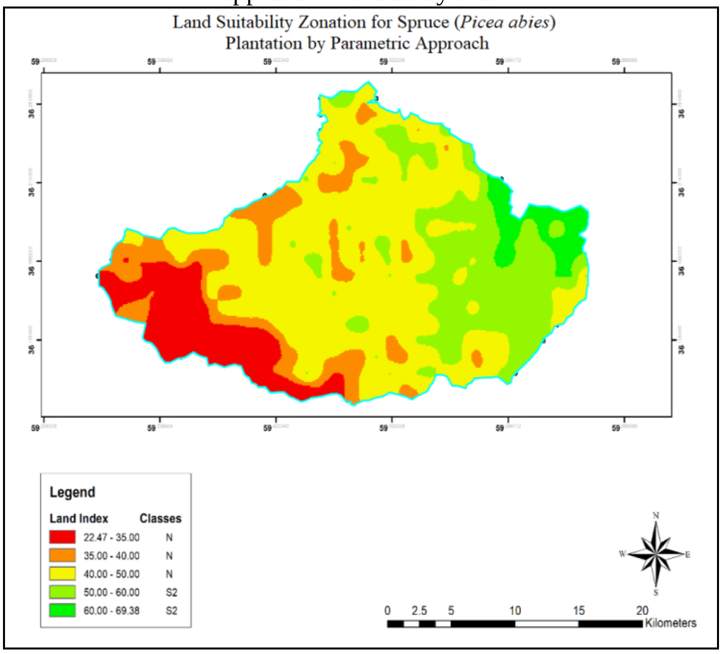


Figure 3. The land suitability zonation for Spruce plantation using parametric approach in the study area

Land suitability zonation by AHP approach

We applied the AHP approach to derive the weights for each land quality/characteristic and climate values. Then, the weights were multiplied to the factor layers and by summation function in GIS, the land index values were produced (Figure 4). The land suitability indices by the AHP approach ranged from 35.45 to 94.09 for *F. excelsior* plantation, which classified the basin into class N in the southwest and north of the study area, class S2 in the middle and the east, and class S1 at scattered parts in the east of the basin. The values of land indices for *P. abies* varied from 34.67 to 83.98, putting large areas in the north and southwest of the basin into class N whereas class S2 was allocated in the middle and eastern parts, and class S1 was found at scattered parts in the east of the basin (Figure 5). The land suitability map for *F. excelsior* trees demonstrated that 5.25% (20.75 km^2) of the surface area was classified into class S1, 67.89% (268.11km^2) into class S2, and 26.86% (106.08 km^2) into class N (Table 7). The suitability map of *P. abies* plantation revealed 2.68% (10.59 km^2) of the study area was categorized into class S1, 65.15% (257.31 km^2) into class S2, and 32.17% (127.04 km^2) of the basin into class N (Table 8).

Similarity cross analysis

The regression coefficient (R^2) between the land suitability indices for ash and spruce plantations by the two models varied between 0.894 and 0.866 respectively indicating a relatively high regression coefficient between the achieved results by the two models (Figure 6). Field observations also demonstrated similar correspondence of the approaches in describing the similarity of land suitability zonation for ash and spruce trees. The estimation of the land indices by the two approaches compared through calculating the coefficient of determination (R^2) defined by Nash and Sutcliffe (1970) as follows:

$$R^2 = 1 - \frac{\left[\sum_{i=1}^{n}\left((LI_{AHP}) - (LI_{param})\right)^2\right]}{\left[\sum_{i=1}^{n}(LI_{AHP}) - (\overline{LI}_{param})\right]^2} \qquad eq(6)$$

where $LI_{(AHP)}$ and $LI_{(Param)}$ are computed values of sample i, based on the parametric and AHP approach respectively and $LI_{(param)}$ is the mean of the measured values by the parametric approach. The coefficient of determination (R^2) estimated from the above formula in our study was $R^2 = 0.997$, which shows a high relationship between the land suitability indices by the two approaches.

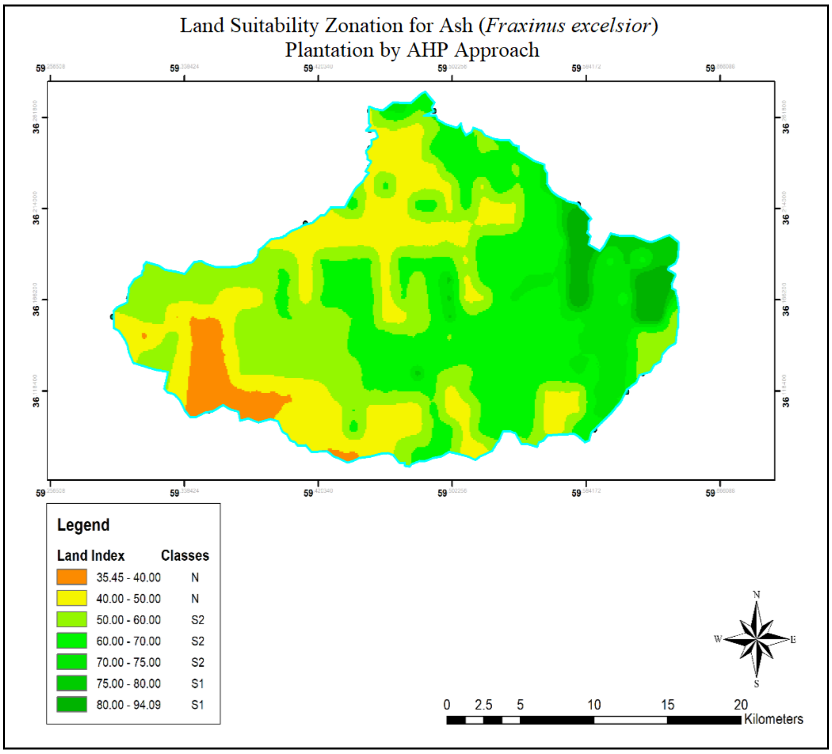


Figure 4. The land suitability zonation for Ash plantation using AHP approach in the study area

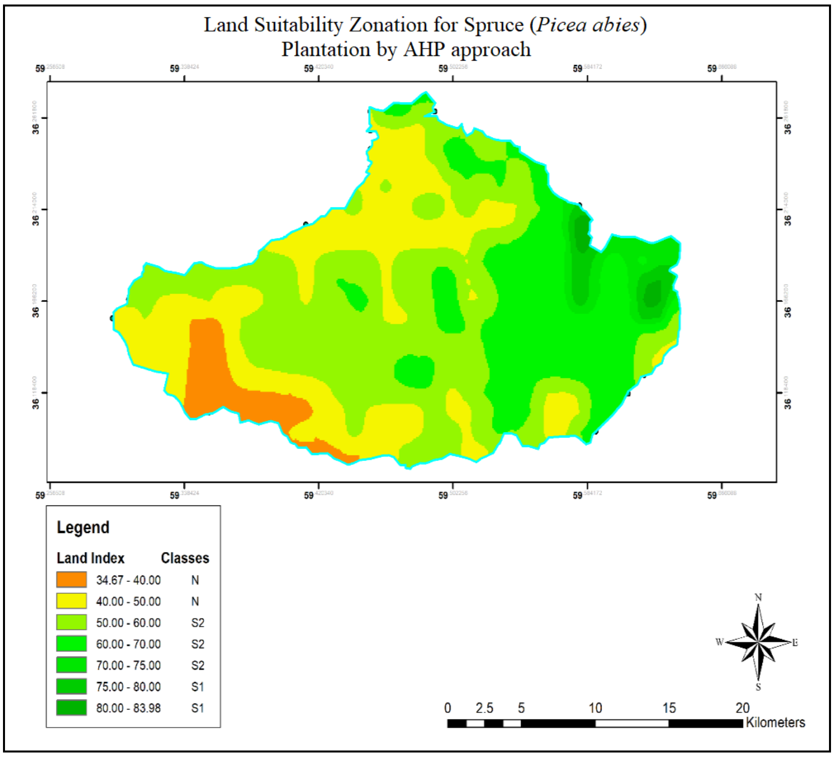
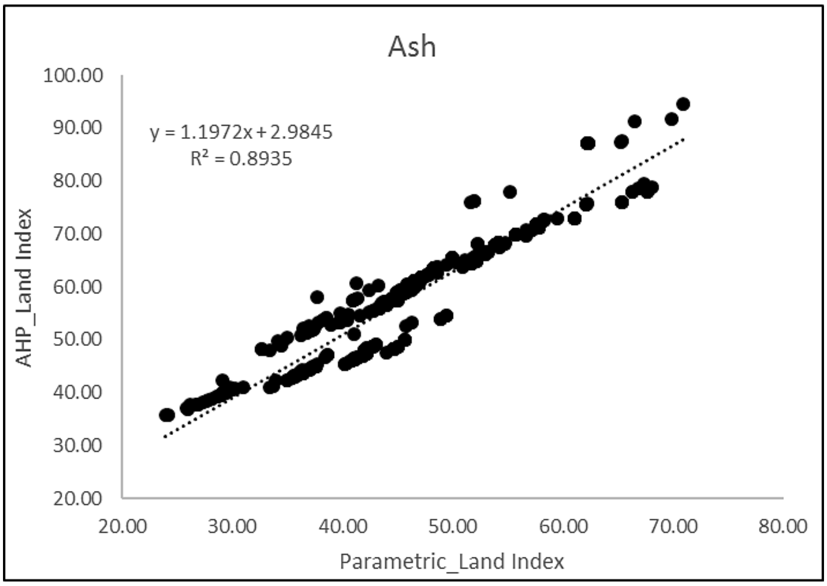


Figure 5. The land suitability zonation for Spruce plantation using AHP approach in the study area



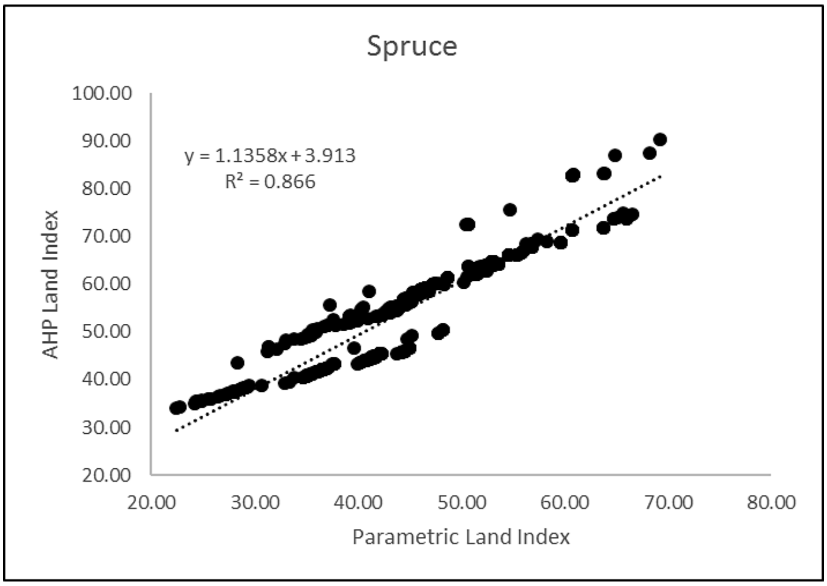


Figure 6. The regression between the land suitability indices by parametric and AHP approaches for Ash and Spruce plantations

Discussion

As shown above, the two approaches classified suitability of the area for the selected tree species into modestly suitable (S2 class) and not suitable (N class). This relates to the shallow soil depth, which can limit the water holding capacity of the soil making it more susceptible to drought. Also, steep slopes, the intensity of the southward aspects, especially in the middle and western parts of the basin, and semiarid climate conditions with <230 mm yr^{-1} precipitation, which is limited mainly to the winter months are considered as important restricting parameters influencing land suitability for the tree species in the basin. Field observations also revealed that the growth and productivity of the tree species in the study area corresponded well with the level of land suitability classes. According to Lavalle et al., (2009), there is a tight relationship between local climatic conditions and the growing requirements of the tree species. Our findings agreed well with those of Mueller et al., (2010), who state that natural climate factors such as solar radiation, air temperature, precipitation and evapotranspiration, explain the main indicators of forest plantation development. Other findings also showed that the tree species have different responses to the interaction between climatic factors, soil characteristics and land qualities in the region. This alludes to the fact that the soil and climate factors, especially precipitation have significant roles in supporting plant growth process and species productivity (Lavalle et al., 2009). In addition to the physical environmental parameters, land use management in the region has something to do with the suitability of the basin for tree species. According to Rounselvell and Reay (2009) ineffective land use reduces the productivity of the land. For instance, selecting suitable tree species for afforestation and implementing modern irrigation technologies can compensate for the effects of environmental factors such as climate and soil in rehabilitation programs of the region.

Conclusion

Land suitability assessment is one of the most effective approaches for forest plantations as it evaluates the suitability of the land for a specific goal. Land qualities/characteristics of the basin are determined based on climatic, soil, and topographic requirements of the trees. The climate, terrain, and soil physical and chemical characteristics required for the growth of ash and spruce plantations were chosen from the literature and formulated by parametric and AHP techniques to produce land suitability indices for 417 study points. The obtained results of both models revealed that the moderately suitable class of S2 is dominant for ash and spruce plantations in eastern parts of the basin, while the middle and western parts of the basin were not suitable for plantation of the trees. The data obtained from this study, showed that both trees can tolerate extreme climatic conditions in the study area to some extent. The findings of this study may help land-use planners to rehabilitate the study area by planting tree species that tolerate ecologically hard conditions of the region.

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