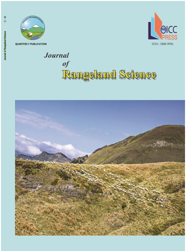

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Modeling of aboveground net primary production using topography factors in Siahpoush and Ganjgah rangelands of Ardabil Province, Iran

Mehdi Moameri[1]*, Pashmineh Mohammadnezhad[2], Ardavan Ghorbani[2], Farid Dadjou[2], Vadood Mohammadi[2]

[1]*Department of Plant and Medicinal Plants, Meshginshar Faculty of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran.*

[2]*Department of Rangeland and Watershed Management, Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Iran.*

***Corresponding author**: moameri@uma.ac.ir

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Abstract:
Aboveground Net Primary Production (ANPP) is one of the most important characteristics of rangeland ecosystems that is involved in important issues such as carbon balance. The aim of this study was to model the ANPP of Plant Functional Types (PFTs) and total ANPP with topographic factors in Siahpoush and Ganjgah rangelands of Ardabil province, Iran. Sampling was performed in one square meter plots in three elevation classes, three sloping classes and six geographical directions by clipping and weighing method. ANOVA was used to investigate the relationship between ANPP and topographic factor and ANPP maps were modeled in ArcGIS software using the extracted regression relationships. Results showed that the shrubs ANPP has a significant relationship with elevation. The highest ANPP of grasses and total ANPP which were 1008.27 and 1650.00 kg/ha, respectively were observed in the middle elevation (2107 – 1877 m). The shrubs ANPP was directly related to the slope and 209.86 kg/ha was estimated at slopes higher than 30%, but the ANPP of grasses and forbs decreased with increasing slope. The highest ANPP of Shrubs (266.25 kg/ha) in the northwest, forbs (458.51 kg/ha) in the eastern direction, grasses (853.44 kg/ha) and total ANPP (1447.00 kg/ha) were observed in the southwest direction. Topographic indices including Topographic Wetness Index (TWI), Stream Power Index (SPI) and Plan Curvature Index (PCI) had no significant effect on variation of ANPP. Assessing the accuracy of the modeled maps was acceptable. These results can provide basic information for estimating ANPP to support rangeland management and balance supply and demand with rangeland products.

Keywords: Aboveground net primary production; Plant functional types; Slope; Elevation; Simulation

1. Introduction

Rangelands are an important part of terrestrial ecosystems and provide numerous ecosystem services such as forage production (the palatable plants for grazing livestock). In addition, some studies have measured livestock grazing capacity based on rangeland productivity [1–3]. Many rangeland ecosystem services depend on their production, so it is important to analyze the characteristics of the net primary production (NPP) in terms of time and place. Examining the variations and accurately measuring the amount of production can provide valuable information about the performance of rangelands and grasslands so that they can be exploited more effectively. Finally, this issue is important in improving the sustainable development of rangeland ecosystems [4, 5]. In addition, aboveground net primary production (all photosynthetic rangeland plants on the ground) is known to be a key factor in describing plant activity, plant composition, ecological balance, and ecosystem health. It's also an important part of the carbon cycle, which controls ecological functions and processes [6–9]. The ANPP is the amount of organic matter

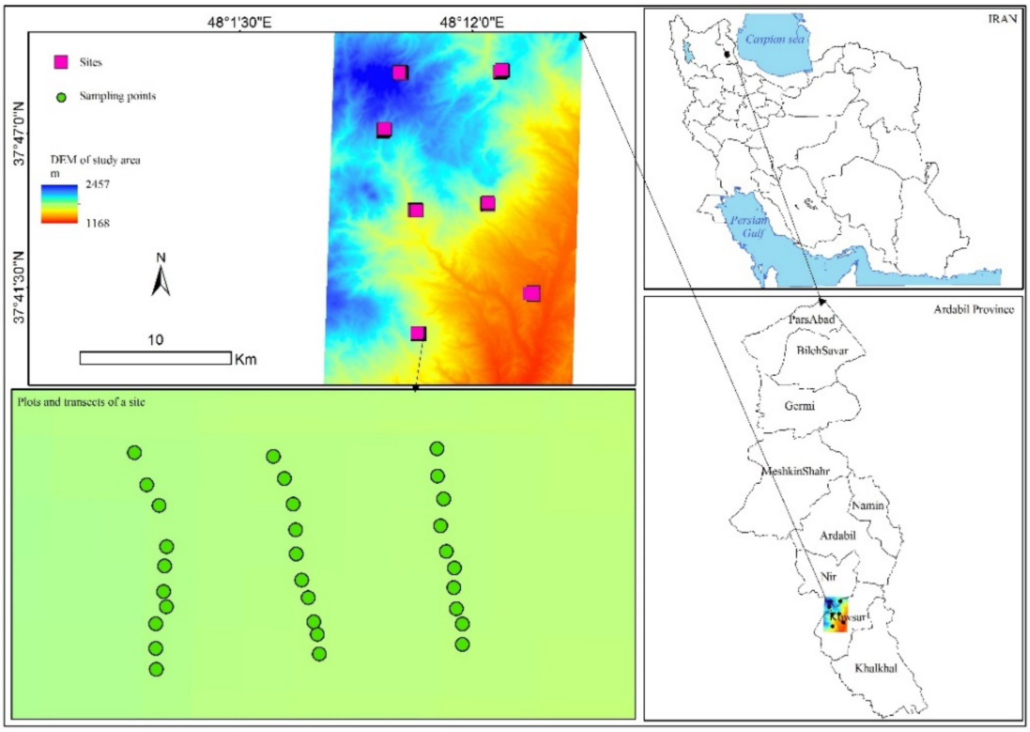

Figure 1. Digital Elevation Models (DEM) of Siahpoush and Ganjgah rangelands and sampling sites in the Ardabil province, Iran.

collected by plants per unit area and time [10]. ANPP reflects the net rate of carbon production in vegetation during a certain period of time and indicates the interaction of environmental factors, human activities and climatic factors such as temperature, rainfall and relative humidity [11]. Different types of vegetation have emerged in mountainous regions as a result of drastic variations in environmental variables (elevation, slope, and geographical directions) over short distances [12, 13]. The distribution of vegetation cover, which is the most important component of all natural ecosystems, particularly rangelands, is strongly affected by environmental conditions. Climate, soil, and topography are all ecological elements that influence the presence or absence of plant species in a given ecological region [14, 15]. Plants, in general, modify their production to suit their ecological conditions and make the best use of the limited resources available [16]. This demonstrates that the ANPP reacts to climatic, biotic, and abiotic factors directly [17]. Because one of the most important indicators of vegetation performance in relation to topography is ANPP, in order to improve the accuracy of ANPP estimation, sufficient knowledge on topographic conditions and other important ecological elements is required [18]. The topography of a region is one of the most critical environmental elements that influences ANPP variations [19, 20]. Plant functional types (PFTs including grasses, forbs, and shrubs) and total ANPP of rangeland plants is affected differently by topographic conditions [19]. As a result, describing PFTs and total ANPP forecast in response to important ecological parameters can be utilized as a guide for better rangeland ecosystem managements [19, 21].

Several studies including those done by Krumhardt et al., Koju et al., Hadian et al. and Aldezabal et al. have looked into the relationship between environmental factors and rangeland productivity, and have found that topography plays an important role in rangeland productivity [22–25]. Zhao et al. in a study of the spatial and temporal variations of NPP in China's Inner Mongolia between 2000 and 2014 found that NPP shows a gradual increase from southwest to northeast as well as a negative correlation between ground surface temperature and precipitation [2]. Wang et al. reported that NPP in the China Three-River Basin has increased from northwest to southeast [26]. Loza-Parra investigated the effect of climatic factors and topography on the simulation of semi-arid Mediterranean rangelands productivity and revealed that the slope is an effective element on NPP [27]. Moreover, Ma et al. found that temperature variations had bigger impact on growth and NPP than rainfall in the sandy parts of northern China, but solar radiation had negative impact on regions with medium and low latitudes [28]. Zeng et al. stated that shrubs are broadly dispersed on the southern slopes whereas forbs are better distributed on the northern slopes in the Taihang rangelands of northern China [29]. Their findings also indicate that medium slopes have the least amount of species variety while low slopes have the most amount [29]. Because of climatic area, and direct input radiation, the middle slopes receive the most sunshine compared to other directions. In another study, Azhdari et al. found the highest values of NPP in the western directions and the lowest values in the eastern directions for the southern regions of Iran [30]. Zarekia et al. investigated the monthly diversity of the main species in the arid rangelands of Saveh, Iran and found that NPP of key species differed

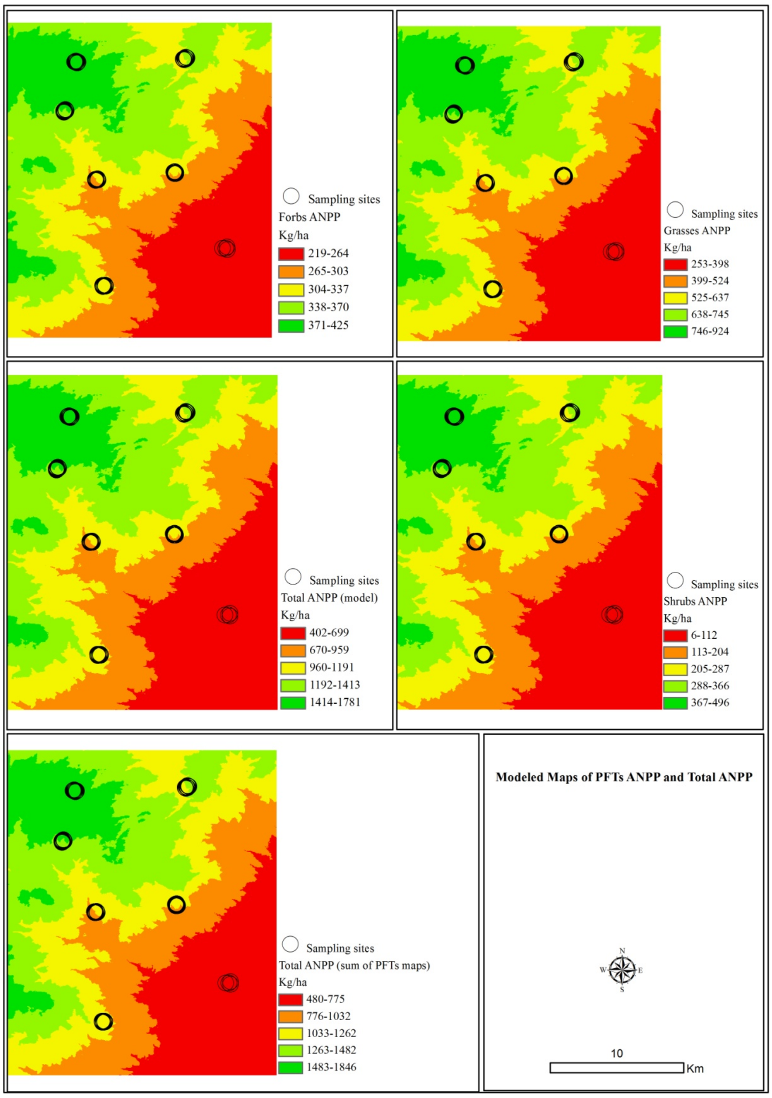

Figure 2. Derived maps of the plant functional types and total aboveground net primary production (Kg/ha), in Siahpoush and Ganjgah rangelands of Ardabil province, Iran, at June 2019.

significantly ($p<0.05$) [31]. They concluded that rainfall had greater impact on grasses than on shrubs, and that high rainfall diversity had significantly reduced ecosystem NPP. Ghorbani et al. in Hir-Neur rangelands of Ardabil province, Iran found that ANPP had a direct relationship with elevation and rainfall and inverse relationship with temperature, and the slope factor had the greatest effect on it [32]. Hassanzadeh et al. concluded that the highest amount of grasses ANPP of the first classes of topographic indices and the highest ANPP of verbs in the third class, which is due to humidity conditions, in the mountain grasslands of Namin region of Ardabil province, Iran [33]. Saeedi Gorgani et al. reported that Slope, direction, and latitude were factors affecting vegetation changes in Noor county rangelands of Mazandaran province, Iran [34]. In addition, Ahmadi et al. in their study stated that the elevation and climatic factors have the greatest impact on vegetation cover in mountainous regions [35]. Abbasi Khalaki et al. in a study of the effect of physiographic parameters on Ferula orientalis density, canopy cover, and productivity in the Dare-Shohada rangelands of Urmia of West Azerbaijan province, Iran discovered that the highest density of this species was found in the elevation range of 1700 to 2300 m [36]. Furthermore, the highest amount of species distribution was detected in the slope class of more than 70%, with the eastern direction having the highest distribution. They have stated that the reason for the mentioned content is the lack of over-exploitation.

In general, environmental factors can control and affect plant ANPP both directly and indirectly. Given that ANPP is one of the most important services provided by rangeland ecosystems in terms of maintaining ecological balance, it is critical to research and determine the most important factors affecting rangeland ANPP. It should be noted that in current study, the effects of climate and soil on ANPP have not been addressed. According to the study area which has a variety of topographic conditions and is used for livestock, the main objectives of this study are: a) to investigate the effect of topographic factors (elevation, slope, direction and topographic indices) on changes of the PFTs and total ANPP, and b) to model the forecasting relationship and simulation of PFTs and total ANPP maps in Siahpoosh and

Table 1. Flora of the study area.
(G: grasses, F: forbs, Sh: shrubs, Th: throphyte, He: hemicryptophyte, Ge: geophytes, Ch: chamephyte)

Family	Species Name, type and life form
Amaryllidaceae	Allium akaka (F, Ge)
Apiaceae	Eryngium billardieri (F, He), Chaerophyllopsis sp (F, He), Torilis sp (F, Th), Zosima absinthifolia (F, He)
Apocynaceae	Vinca sp (F, He), Vinca herbacea Waldst. (F, He)
Asparagacea	Ornithogalum brachystachys (F, Ge), Ornithogalum narbonense (F, Ge), Ornithogalum oligophyllum (F, Ge)
Astraceae	Achillea sp (F, He), Achillea vermicularis (F, He), Aeschynomene bullockii (F, He), Anthemis atropatana (F, Th), Centaurea solstitialis (F, He), Chardinia orientalis (F, He), Cousinia sp (F, He), Crepis sancta (F, Th), Crepis candeli (F, Th), Crupina crupinastrum (F, Th), Crupina sp (F, He), Filago arvensis (F, Th), Gundelia rosea (Sh, He), Helichrysum oligocephalum (F, He), Inula britannica (F, He), Lactuca sp (F, He), Leontodon hispanicum (F, He), Onopordum sp (F, He), Scariola orientalis (F, He), Tanacetum polycephalum (F, He), Trogopogon sp (F, He)
Boraginaceae	Anchusa italica (F, Th), Lappula (F, He), Onosma microcarpa (F, He)
Brassicaceae	Alyssum linifolium (F, Th), Alyssum minus (F, Th), Arabis anachoretica (F, Th), Erysimum (Sh, He)
Campanulaceae	Campanula stevenii (F, He)
Caryophyllaceae	Arenaria gypsophiloides (F, Th), Arenaria serpylloides (F, He), Gypsophila polyclada (F, He), Minuartia hamata (F, Th), Silene conoidea (F, He), Silene marschallii (F, He), Silene siderophila (F, He), Silene spergulifolia (F, He), Stellaria sp (F, He)
Cistaceae	Helianthemum salicifolium (F, Th)
Clusiaceae	Hypericum perforatum (F, He)
Crassulaceae	Sedum subulatum (Sh, Ch)
Dipsacaceae	Scabiosa persica (F, Th)
Ephorbiaceae	Euphorbia sp (F, He)
Fabaceae	Aeschynomene bullockii (Sh, Ch), Astragalus beckii (Sh, Ch), Astragalus caprinus (Sh, He), Astragalus craigi (Sh, He), Astragalus curvirostris (Sh, He), Astragalus chrysostachys (Sh, He), Astragalus hohenackeri (Sh, Ch), Astragalus iranicus (Sh, He), Astragalus microcephalus (Sh, Ch), Astragalus sp (Sh,He), Sophora alopecuroides (Sh, He), Vicia cracca (F, Th)
Geraniaceae	Erodium oxyrhinchum (F, Th)
Hyacinthaceae	Hypericum scabrum (F, Th)
Lamiaceae	Lamium amplexicaule (F, He), Lallemantia iberica (F, Th), Marrubium astracanicum (F, He), Mentha clinopodiifolia (F, He), Nepeta heliotropifolia (F, He), Nepeta sp (F, He), Nepeta speciosa (F, He), Nepeta ucranica (F, He), Phlomis herba-venti (F, He), Teucrium polium (Sh, He), Thymus kotschyanus (Sh, Ch), Thymus trautvetteri (Sh, He), Ziziphora tenuior (F, Th)
Liliaceae	Gagea fragifera (F, Th), Gagea dubia (F, Th)
Malvaceae	Malva neglecta (F, He)
Papaveraceae	Papaver macrostomum (F, He)
Plantaginaceae	Veronica arvensis (F, He)
Plumbaginaceae	Acantholimon gilliatii (F, Th)
Poaceae	Bromus densiciliatus (G, Th), Bromus tectorum (G, Th), Dactylis glomerata (G, Th), Echinaria (F, He), Elymus abolinii (G, Th), Elymus hispidus (G, Th), Festuca valdesii (G, He), Hordeum bulbosum (G, Th), Poa bulbosa (G, Ge), Stipa caucasica (G, Th), Triticum durum (G, Th)
Primulaceae	Adonis aestivalis (F, Th), Androsace maxima (F, Th)
Rosaceae	Potentilla bifurca (F, He), Potentilla recta (F, He), Rubus sp (Sh, Ch), Sanguisorba minor (F, He)
Rubiaceae	Asperella oryzoides (G, Th), Galium tenuissimum (F, He), Galium verum (F, He)
Scrophulariaceae	Cheilophyllum macranthum (F, He)
Serophulariaceae	Verbascium sp (F, He)
Targioniaceae	Targionia lorbeeriana (F, He)
Violaceae	Viola modesta (F, Th)

Ganjgah rangelands of Nir and Kowsar counties in Ardabil province, Iran.

2. Materials and methods

2.1 Study Area

The study area is in the Ganjgah and Siahpoosh rangelands, which are located in the Ardabil province's Nir and Kowsar counties and range in elevation from 1168 to 2457 m above sea level (Fig. 1). According to information obtained from meteorological stations of Nir and Kowsar counties, and its surroundings, this region has semiarid to semi-humid cold climatic conditions, with an average annual precipitation of 352 mm, with the lowest value of 5.5 mm in August and the highest value of 46.83 mm in May. In addition, the region's temperature ranges from 2.17 to 11.77º C, with an average of 8.5º C. The soil in the research area is deep and productive, with a loamy clay texture [37]. The most common plant families in the region are Astraceae with 28 species, Lamiaceae with 21 species and Fabaceae with 16 species, which include 18.5%, 13.9% and 10.6% of the total vegetation in the region, respectively [38]. The scientific names of the plants of the study area are presented below (Table 1):

2.2 Research Method

Seven sites were chosen for sampling from the study area, based on the access condition and elevation gradient. Random-systematic sampling method was used. For this purpose, three transects of 100 m at a distance of 50 m were placed at each site, according to the vegetation structure. The first transect was placed at random, while the following transects were placed in a systematic order parallel together and perpendicular to the slope. Along each transect, 10 one-square-meter plots were established at a distance of 10 m. Each site had 30 plots sampled, with a total of 210 plots sampled across the entire area. According to the vegetation structure and the number of required samples, as well as previous research in the area and surroundings, the number and size of the plot were determined [33,39–42]. Sampling was performed in June 2019 when the dominant plants were at the peak of the growing season. Thus, according to the purpose of the study, the ANPP of PFTs and total ANPP were conducted by harvesting method. ANPPs of grasses and forbs were harvested from five centimeter above the soil surface while shrubs were harvested from same year's growth. Samples were transported to Mohaghegh Ardabili University's rangeland laboratory and air dried, the samples were weighed on a digital scale, and the ANPP amount was determined as kg/h. The location of each plot was also recorded using GPS. A Digital Elevation Model (DEM) map with 20×20 pixel dimensions was created using 1:25000 maps and ArcMap software, and it was used to create maps of elevation, slope, and geographical directions. Then, three topographic indices including Topographic Wetness Index (TWI; Equation 1), Stream Power Index (SPI; Equation 2), and plan curvature index (PCI) were calculated. The plan curvature tool in ArcMap software was used to create these indices, and the numerical value of these maps was extracted for each plot's location.

$$\mathrm{TWI} = \ln(\frac{\alpha}{\tan\beta}) \quad (1)$$

where TWI = Topographic Wetness Index, α is the amount of accumulation of upstream flow, and β is the slope angle [43,44]

$$SPI = As \times \tan(b) \quad (2)$$

where SPI = Stream Power Index, As is the target area's area, and b is the slope's degree. Upstream pathway erosion, soil organic matter, acidity, soil horizons, silt, sand, and vegetation distribution are all controlled by this index.

To conduct this study, three elevation classes were selected and the basis of sampling was conditions of the study area in terms of elevation diversity: first, second and third classes were altitude of $1877-1647$ m, $2107-1877$ m, and $2334-2107$ m, respectively . Also, sampling from the plots was done in six geographical directions: a) east, b) southeast, c) south, d) southwest, e) west, and f) northwest, and in three slope classes: a) less than 15%, b) 15 to 30%, and c) 30 to 60%. The physical parameters of the sampled sites are shown in Table 2.

2.3 Statistical analysis

One ANOVA was used to evaluate the effect of independent variables (elevation, slope, geographical directions, and topographic indices) on the ANPP of dependent variables including PFTs, and total ANPP, and the comparison was made using a Duncan's Multiple Range test [45].

The simple linear regression relationship was used to model the PFTs and total ANPP, taking into account the significance of independent factors (Equation 3), and the linearity test between independent variables was used to determine the most important effective factor. To map the study area, the height factor was chosen. The variance inflation factor (VIF) between independent variables was utilized to find the most relevant effective factor, and the elevation factor was chosen to map the study area based on the highest correlation [46].

$$\mathrm{Y} = \mathrm{a} + \mathrm{bx} \quad (3)$$

where Y is the predicted value of the dependent variable (PFTs and total ANPP), a is a constant, b is the regression coefficients, and x is the value of the independent variable. Then, using the obtained regression equations for the PFTs and total ANPP, in the $\mathrm{ArcGIS}_{\mathrm{Ver.10.1}}$ software, the ANPP map for the study area was predicted [47].

Simulation was carried out using two approaches to identify the optimal method for preparing the total ANPP map: a) utilizing the equation extracted from regression model and b) summing simulated maps of PFTs ANPP. Finally, the accuracies of the maps were examined using the Mean Absolute Error (MAE), Mean Deviation Error (MDE), and Root Mean Squared Error (RMSE) (Equations (4), (5), and (6), respectively [48,49]. If the value of these indicators is closer to zero, it means that the model's calculated values are more accurate and closer to their actual values. A total of 85% of the data was utilized for modeling, and 15% of the data was used for accuracy assessments of the simulated maps [50]. $\mathrm{SPSS}_{\mathrm{Ver.20}}$ was used for data analysis, and

Table 2. Description of the selected sites at Ganjgah and Siahpoosh rangelands.
(TWI: topographic wetness index, SPI=stream power index, PCI: plan curvature index)

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Location (°N; °E)	48.22-37.88	48.21-37.74	48.16-37.74	48.16-37.67	48.13-37.79	48.14-37.82	48.22-37.82
Elevation (m)	1706	1756	1704	1756	2095	2312	1933
Slope (%)	33	37	36	14	35	32	36
TWI	4.93	4.93	5.63	6.39	5.63	5.11	5.16
SPI	23.41	23.41	21.84	37.25	52.36	23.46	34.45
PCI	0.81	0.81	0.52	0.00	-0.50	0.24	0.12

$\text{ArcGIS}_{\text{Ver.10.1}}$ was used for mapping.

$$\text{MAE} = \Sigma\frac{|\text{P}_i - \text{O}_i|}{\text{n}} \quad (4)$$

$$\text{MDE} = \Sigma\frac{(\text{P}_i - \text{O}_i)}{\text{n}} \quad (5)$$

$$\text{RMSE} = \sqrt{\Sigma\frac{(\text{P}_i - \text{O}_i)^2}{\text{n}-1}} \quad (6)$$

where P_i was the predicted ANPP values of the maps, O_i was the observed ANPP at the field, and n was the number of data points.

3. Results

The results of the analysis of variance and means comparison of average PFTs and total ANPP based on elevation classes, slope, slope direction, and topographic indices are present in Table 3. The results of ANOVA showed that the amount of the grasses ANPP of different elevation classes had a significant difference ($p<0.01$) so that the grasses ANPP in the middle elevation class ($2107-1877$ m) had the highest value and it was increased by enhancing elevation.

The amount of grasses ANPP in different classes of slope, on the other hand, was not significantly different, and it was close to each other. Moreover, the results revealed that the highest grasses ANPPs were associated with the southwest, northwest, and west directions with a significant difference ($p<0.01$). Furthermore, there was no significant difference between the grasses ANPP in various topographic indices classes (TWI, SPI and PCI).

The results of the effect of elevation factor on the forbs ANPP showed that the amount of forbs ANPP was variable in elevation and slope classes, and elevation and slope variation had no significant effect on the forbs ANPP. The results demonstrated that changes in the values of topographic indices (TWI, SPI, PCI) had no significant impact on the forbs ANPP, despite the increase in ANPP of this PFT with increasing values of TWI and PCI indices. The effect of elevation on the shrubs ANPP also revealed that as elevation was increased, the shrubs ANPP significantly increased ($p<0.01$). Changes in the shrubs ANPP in different slope classes, on the other hand, were not significant. The highest shrubs ANPP was found in northwest directions, and there was a significant difference in shrubs ANPP for various geographical directions ($p<0.01$).

In addition, none of the topographic indices TWI, SPI, or PCI had a significant effect on the shrubs ANPP in the region. It also revealed that the total ANPP in different elevation classes was significant ($p<0.01$), with the middle elevation class having the highest total ANPP ($2107-1877$ m). The total ANPP was not affected by slope variations in a statistically significant effect; however, the maximum total ANPP was found at lower slopes. The total ANPP was significant ($p<0.01$) in different classes for aspect and the maximum (1447.00 Kg/ha) and minimum (854.78 Kg/ha) were obtained in the southwest and south directions, respectively. The TWI, SPI, and PCI indices had no significant effect on the total ANPP. Equations (7) to (10) exhibit the ANPP prediction models for grasses, forbs, shrubs, and total ANPP using simple linear regression. Information of analysis of variance of regression, and coefficient of determination is presented in Table 3. At this stage, a collinearity test was conducted between six factors of elevation, slope, direction, and three topographic indices, and it was observed that the parameters were found to be collinear. Therefore, a correlation was made between all topographic parameters, and PFTs, and total ANPP, and it was observed that the elevation factor had the strongest correlation; as a result, this factor was chosen for modeling.

$$\text{GrassesANPP} = 0.52(\text{Elevation}) - 353.64 \quad (7)$$

$$\text{ForbsANPP} = 0.16(\text{Elevation}) + 32.83 \quad (8)$$

$$\text{ShrubsANPP} = 0.38(\text{Elevation}) - 526.86 \quad (9)$$

$$\text{TotalANPP} = 1.07(\text{Elevation}) - 847.68 \quad (10)$$

where GrassesANPP was aboveground net primary production of grasses; ForbsANPP was aboveground net primary production of forms; ShrubsANPP was above-ground net primary production of shrubs; TotalANPP was above-ground net primary production of total and Elevation was elevation above sea level. It should be noted that these equations must be recalculated in other regions and in other years.

The results of forecasting PFTs and total ANPP in kg/h using equations derived based on the elevation factor, as well as the total ANPP map created using two approaches equation and a set of PFTs ANPP of maps is shown in Fig. 2. Moreover, using the RMSE, MAE, and MDE criteria, the accuracy of the created maps was evaluated, and the

Table 3. Results of the analysis of variance and mean comparison of plant functional types and total aboveground net primary production in different classes of topography.
($*$ sig p<0.05; **p<0.01; ns: no significant.
In each column for each trait means followed by common letter, are not significantly different.)

Topographic factors	Class	Number of plots	Grasses ANPP (kg/ha)	Forbs ANPP (kg/ha)	Shrubs ANPP (kg/ha)	Total ANPP (kg/ha)
Elevation (m)	1877 – 1647	100	$447.67^{c} \pm 19.39$	$319.29^{a} \pm 23.22$	$134.75^{b} \pm 20.22$	$931.71^{c} \pm 30.04$
	2107 – 1877	59	$1008.27^{a} \pm 5.05$	$411.12^{a} \pm 46.48$	$230.61^{ab} \pm 49.92$	$1650.00^{a} \pm 73.36$
	2334 – 2107	51	$693.78^{b} \pm 42.33$	$337.56^{a} \pm 47.52$	$321.95^{a} \pm 51.66$	$1353.29^{b} \pm 51.10$
	F values		66.52^{**}	1.85^{ns}	7.45^{**}	67.48^{**}
Slope (%)	8.26 – 92.92	76	$649.05^{a} \pm 33.94$	$399.46^{a} \pm 4.00$	$191.76^{a} \pm 33.38$	$1240.27^{a} \pm 45.05$
	26.44 – 92.92	74	$655.96^{a} \pm 37.29$	$303.94^{a} \pm 26.98$	$189.04^{a} \pm 28.86$	$1148.94^{a} \pm 51.77$
	44.63 – 92.12	60	$600.00^{a} \pm 64.57$	$341.89^{a} \pm 48.11$	$209.86^{a} \pm 48.45$	$1151.76^{a} \pm 94.58$
	F values	F	0.35^{ns}	2.44^{ns}	0.07^{ns}	0.83^{ns}
Aspect	East	42	$517.66^{cc} \pm 31.32$	$458.51^{a} \pm 7.98$	$230.85^{ab} \pm 39.65$	$1207.02^{ab} \pm 46.15$
	Southeast	18	$632.39^{bc} \pm 40.21$	$382.83^{ab} \pm 42.25$	$191.74^{ab} \pm 3.62$	$1206.96^{ab} \pm 61.76$
	South	45	$512.11^{c} \pm 51.91$	$180.00^{c} \pm 28.24$	$162.67^{ab} \pm 29.36$	$854.78^{c} \pm 63.97$
	Southwest	41	$853.44^{a} \pm 4.98$	$344.44^{ab} \pm 47.69$	$249.11^{a} \pm 59.14$	$1447.00^{a} \pm 81.63$
	West	39	$678.82^{abc} \pm 69.30$	$396.76^{ab} \pm 41.62$	$77.06^{b} \pm 29.91$	$11.52.65^{b} \pm 95.64$
	Northwest	25	$735.31^{ab} \pm 91.85$	$303.44^{bc} \pm 60.88$	$266.25^{a} \pm 5.35$	$1035^{ab} \pm 109.76$
	F values	F	6.93^{**}	5.46^{**}	1.96^{*}	8.25^{**}
TWI	3.5 – 86.97	75	$622.41^{a} \pm 27.77$	$323.69^{a} \pm 21.19$	$200.09^{a} \pm 21.58$	$1146.19^{a} \pm 37.10$
	5.8 – 97.08	91	$735.00^{a} \pm 49.83$	$413.33^{a} \pm 45.89$	$195.97^{a} \pm 55.92$	$1344.31^{a} \pm 79.60$
	8.10 – 80.19	44	$690.83^{a} \pm 80.02$	$506.67^{a} \pm 193.87$	$0.00^{a} \pm 0.00$	$1197.50^{a} \pm 224.69$
	F values	F	1.61^{ns}	2.53^{ns}	2.50^{ns}	
SPI	2.102 – 67.67	90	$641.38^{a} \pm 25.13$	$343.42^{a} \pm 20.23$	$195.48^{a} \pm 20.57$	$1180.28^{a} \pm 35.06$
	102.202 – 67.67	64	$688.33^{a} \pm 117.16$	$361.11^{a} \pm 99.31$	$261.67^{a} \pm 107.38$	$1311^{a} \pm 133.54$
	202.363 – 67.61	56	$653.00^{a} \pm 102.85$	$348.00^{a} \pm 144.01$	$0.00^{a} \pm 0.00$	$1001.00^{a} \pm 186.30$
	F values	F	0.07^{ns}	0.01^{ns}	1.39^{ns}	0.66^{ns}
PCI	4.0 – 86.0	66	$670.98^{a} \pm 34.12$	$317.93^{a} \pm 30.72$	$171.90^{a} \pm 28.66$	$1160.82^{a} \pm 51.67$
	0.2 – 0.00	71	$635.50^{a} \pm 37.57$	$356.55^{a} \pm 27.75$	$209.60^{a} \pm 30.69$	$1201.65^{a} \pm 48.96$
	2.3 – 00.81	73	$549.44^{a} \pm 67.66$	$410.83^{a} \pm 59.80$	$216.39^{a} \pm 56.05$	$1176.67^{a} \pm 101.00$
	F values	F	0.16^{ns}	0.47^{ns}	0.98^{ns}	0.96^{ns}

level of model error was found to be acceptable, indicating the validity of the model utilized (Table 4). According to the model's map, the average ANPP estimation for grasses, forbs, shrubs, and total ANPP were 631.76, 336.03, 193.24 and 1179.97 kg/h, resectively.
Results of regression relationships based on elevation for each of the PFTs and total ANPP are summarized in Table 4. The R^2 value indicates how strong the correlation between the two variables, and states and how much the dependent variable (ANPP) can be explained by the independent variable (topographic factors). The Table shows that the highest $R^2 = 70\%$ for total ANPP, followed by $R^2 = 52\%$ for grasses ANPP, $R^2 = 48\%$ for shrubs ANPP, and $R^2 = 37\%$ for forbs ANPP, all of which were significant except for forbs (p<0.01).

4. Discussion

The findings of the analysis of variance revealed that topographic parameters such as elevation, slope, geographical directions, and topographic indices had various effects on PFTs and total ANPP. Only the factors of elevation and slope directions had a significant effect (p<0.01) on PFTs and total ANPP of the area. In addition, it is guessed that the elevation has indirect effects on ANPP by affecting temperature and rainfall. This is consistent with the findings of [51]. The impacts of slope variables and topographic indices on the PFTs ANPP were different, but not significant. This is most likely due to erosion and the degree of exploitation in different slope classes. In fact, variations in elevation and slope affect moisture stability; nevertheless, the way moisture is provided, as well as the distribution of nutrients, are both factors in the dynamics of the PFTs. This

Table 4. Summary of regression models and assessment of the plant functional types and total aboveground net primary production maps created by topography factors.
(*∗p<0.01; ns: no significant, MAE: Mean Absolute Error, MDE: Mean Deviation Error, RMSE: Root Mean Squared Error)

PFTs	R^2	F	Observed ANPP Field data (Kg/h)	Estimated ANPP Model (Kg/h)	RMSE	MAE	MDE
Grasses	0.52	25.16*∗	643.66	631.76	0.41	0.24	0.67
Forbs	0.37	$0.15^{n}s$	344.30	336.03	0.28	0.34	0.55
Shrubs	0.48	18.79*∗	193.66	193.24	0.05	0.10	0.44
Total (Model)	0.70	62.10**	1181.61	1179.97	0.07	0.08	0.17
Sum of PFTs maps	-		1181.61	1186.56	0.09	0.05	0.14

is consistent with the findings of [52].
Grasses ANPP increased with altitude up to 2107 m, with the maximum Grasses ANPP (1008.27 kg/ha) in the middle altitude classes (2107 – 1877 m), accounted for about 61% of the total ANPP at this altitude. Grasses ANPP is limited at lower elevations, which are easier to access by barriers such as overgrazing and trampling livestock; thus, the increase in grasses ANPP in the middle class appears to be related to the stability of conditions in this area. Another reason for this is annual and perennial plants' dependence on rainfall, which due to their PFT, grasses react to rainfall distribution that is itself a function of elevation [53]. The distribution of grasses ANPP was unaffected by increasing the slope; nevertheless, the highest value was found on a slope of less than 30%. Grasses have a shallow root system and hence have less deep rooting capability, so its abundance diminishes in shallow soils due to their inability to establish. According to Heidari et al., the most important variable impacting the presence of Bromus tomentellus Boiss was elevation while the most important variables affecting the presence of Festuca ovina were temperature and slope [54]. Grasses ANPP varies significantly in different directions, but the maximum amount was found in the southwest, indicating that grasses in this region had better growing conditions.
The forbs ANPP was significantly affected by elevation, which rose as the elevation was increased. The increase of forbs ANPP continued until the limitations of temperature, short vegetation season, and steep slope were no longer a barrier. The difference between the forbs ANPP of the upper elevations and the first elevation classes showed more favourable conditions for vegetation forms at high altitudes, and like grasses, overgrazing affects the reduction of their ANPP. Cirimwami et al. found that forbs have a strong and positive relationship with elevation, and that their distribution and growth increase as altitude increases [55]. Gilliam introduced forms regarded as an important aspect of mountain ecosystems, according to some researchers because of their unique characteristics and capacity to resist harsher environmental conditions at higher elevations [56]. Moreover, results of the current study showed the maximum forbs ANPP was found on slopes less than 15%. The forbs growth appears to be slowed by increasing the slope. This is inconsistent with the findings of Aghaei et al. who found that middle slopes and moderate elevations are suitable for forbs growth [57]. Khajeh also notes the impact of slope on herbaceous species density [58]. Chen et al. believe that topographic factors including slope and altitude can account for more than half of variation in PFT of grasses [59]. According to the findings of this study, the maximum forbs ANPP was recorded in the eastern direction in this region, indicating the presence of appropriate growing conditions in terms of soil moisture. In this regard, Abbasi-Khalaki et al. founded that the maximum density, canopy cover, and production of Ferula orientalis were observed in the eastern direction of Urmia rangelands, which is consistent with the findings of the current study [36].
The shrubs ANPP increased with altitude, reaching its greatest value (325.95 kg/ha) in the altitude class of 2334 – 2107 m. High shrubs ANPP at high altitudes depends in part on their vegetative form, which can help their ability to adapt to variables like wind, temperature variations and direct sunlight. Because the maximum shrubs ANPP was observed in this study on slopes more than 30%, it seems that the slope factor could not prevent the distribution of shrubs at high altitudes. This could be due to the area's dominant livestock, which is mainly cattle, sheep, and occasionally goats. Because cows prefer flat areas such as valleys and meadows, versus high and steep lands. Tamartash consider the slope to be the most important factor in the cattle dispersal in Mazandaran's rangelands [60]. As a result, the shrubs ANPP at lower elevations can be attributed to grazing pressure (overgrazing) from more palatable plants on lower slopes. Another important factor in the frequency of shrubs ANPP at high elevations is their deep root system in comparison to grasses and forbs. As previously said, soil depth reduces in regions with high slopes, and declines the ability to establish grasses and forbs with shallow roots while providing conditions for shrubs growth and distribution. According to Heidarian Aghakhani et al., the most essential factor in increasing shrubs is grazing intensity [61]. Shrubs increase as a result of livestock grazing on palatable forbs and a lack of livestock grazing on shrubs and non-palatable plants.

Total ANPP had the highest amount in the middle altitude classes (2107 – 1877 m), and studies by Pournemati et al. in Sabalan rangelands of Ardabil province, Iran [19]. Saeedi Gorgani et al. in Yazi Noor rangelands, Iran, and Tamartash in Mazandaran rangelands, Iran all emphasize estimating the maximum amount of production in the middle altitudes (2000 – 2500 m) [34, 60]. Hua also found that the plant richness is maximum in China's Hubei province in mid-altitude of 800 and 1400 m, and that the reduction in species richness above 1600 m is mainly due to ecophysiological restrictions such as a shorter growing season, low temperature, and low ecosystems productivity [62]. The ANPP of all PFTs decreased in the first elevation class (1867 – 1647 m) due to easier access in terms of vicinity to the village, roads, and unlawful exploitation, compared to the upper elevations, which have better plant stability. Grasses, however, accounted for around half of total ANPP; hence, it had direct impact on total ANPP. The total ANPP decreased as the slope increased, with the highest values found on the southwestern slopes, indicating that grasses' dominance in plant composition has influenced total ANPP. In this regard, Fadl et al. identified slope and altitude as the most important environmental elements influencing plant distribution in Saudi Arabia's Sarawat region [63].

It is critical to identify the effects of factors such as topography on vegetation parameters such as the ANPP of rangeland plants [18, 59, 64]. In this study, an appropriate equation was derived using regression test to estimate the ANPP and then, create a map. Results indicate that the $R^2 = 52\%$, $R^2 = 37\%$, $R^2 = 48\%$ and $R^2 = 70\%$ were obtained for prediction of grasses, forbs, shrubs and total ANPP based on topographic parameters, respectively. These results indicate that the extracted models for estimating ANPP have acceptable accuracy, which is in line with Ghorbani et al. [47]. In this regard, Mohammadi et al. used several vegetative indices and environmental variables in South Khorasan of Iran to forecast the performance of alfalfa species [38]. They reported that the estimation yield model has a good adaptability to actual alfalfa yield, according to model validation data. Based on the regression relationships obtained from this study, it can be concluded that altitude played a significant role in the ANPP in the Siahpoush and Ganjgah rangelands of Ardabil province, but in order to achieve more appropriate relationships, it is required to investigate many soil, climatic, and other data, which can be predicted with more accuracy when management factors are taken into account.

5. Conclusion

In general, the findings of this study revealed that diverse topographies in the Siahpoush and Ganjgah rangelands provided different conditions for ANPP, resulting in uneven rangelands utilization. The results of this study showed that each PFT based on the characteristics of the ecological region, its ecological needs, and tolerance range has a significant relationship with some topographic factors, and as a result, they have different ANPP that should be considered at the time and amount of rangeland utilization. The modeled equations must be examined on other spatial and temporal scales as well. The findings will be useful in providing valuable information about ecosystem improvement and biodiversity protection under topographic changes, as well as basic information for rangeland sustainability and estimating ANPP to support rangeland management.

Conflict of interest statement:
The authors declare that they have no conflict of interest.

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