Assessing vegetation productivity and environmental impact in: a remote sensing approach

Iuliia Polevschvhikova[1*], *Mahmud* Muminov[2,3], *Fedor* Svoikin[4], *Vladimir* Bozhbov[4], *Anatoly* Borozna[4], *Maria* Taraban[5], *Sergey* Sitnikov[6], *Sergey* Ogorodnikov[6], and *Ekaterina* Murmantseva[6]

[1]InfoGIS, Innopolis, 420500, Russia
[2]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, 100000, Uzbekistan
[3]Samarkand State University named after Sharof Rashidov, 140104, Uzbekistan
[4]St. Petersburg State Forestry University, , Institutskiy lane, 5, 194021, St. Petersburg, Russia
[5]Saint Petersburg State University of Architecture and Civil Engineering, 2nd Krasnoarmeyskaya street, 4, 190005, St. Petersburg, Russia
[6]Moscow Aviation Institute, Volokolamskoe highway, 4, 125993, Moscow, Russia

Abstract. This study explores the dynamic response of vegetation productivity in semi-arid foothill rangelands of Uzbekistan, focusing on the Normalized Difference Vegetation Index (NDVI) dynamics and its correlation with climatic and environmental variables. In contrast to established relationships reported in previous studies, our findings reveal distinctive seasonal patterns in NDVI values, with higher values observed during spring (0.150-0.300) and lower values in summer (0.100-0.130). The chlorophyll and carotenoid content of A. diffusa exhibited variations in response to seasonal changes, emphasizing the importance of considering seasonal factors in rangeland health assessments. Chlorophyll and green aboveground biomass are identified as key indicators of vegetation productivity, crucial for maintaining ecosystem balance and contributing to climate regulation. Significant relationships are observed between NDVI and water resources, including precipitation and soil moisture ($P \leq 0.0001$), highlighting the impact of climatic factors on vegetation cover. Positive correlations between NDVI and total green aboveground biomass underscore the relevance of NDVI as an indicator of vegetation health in foothill rangelands. This research project represents an initial step in investigating vegetation changes due to grazing in Uzbekistan, providing recommendations for sustainable rangeland utilization. Establishing an ecological monitoring system, incorporating GIS and Remote Sensing technologies, is proposed for comprehensive understanding and sustainable management of this complex ecosystem. Ongoing and future research endeavors aim to develop modern methods for rangeland vegetation monitoring, facilitating the identification of critical regions and offering solutions to prevent and mitigate desertification effects.

* Corresponding author: anatol-06@bk.ru

1 Introduction

Foothill rangeland is the most widely distributed vegetation cover on the arid and same-arid area, because high human pressure influence. What is the spatial distribution pattern of the rangeland aboveground biomass on the foothill and its relationship with the climate and soil moisture indicators. In arid and semi-arid ecosystems, rainfall is relatively low, highly variable, and unpredictable and occurs mostly as discrete events or pulses [1-4]. Continuous and unplanned utilization and overgrazing resulted to loss of species diversity, which followed by soil degradation in general. Foothill rangeland area is a very important economic region, from the important reasons of continuous and unplanned use of pasture recourses such as overgrazing, water and wind erosions, uprooting shrubs etc. [3, 5-9]. The rangeland vegetation of the arid and semiarid zones is rich and diverse, serving as a basic natural resource for the livestock and acts as a protection against degradation. Plentiful grasses on same-arid foothills rangelands allow the livestock to graze all year around. However, during the year a whole complex of different weather conditions considerably influence the grazing pattern. There is a necessity for multidisciplinary investigation of the foothill ecosystem to develop sustainable utilization of natural resources of rangelands. The article discusses the rangeland dynamics of vegetation productivities under different factors.

Green vegetation parameters, including green biomass, leaf area index, and vegetation cover, serve as crucial indicators of rangeland health. These parameters play a vital role in monitoring land condition and identifying processes of land degradation, particularly in semi-arid rangelands. Our study specifically focused on assessing the impact of environmental factors on plant parameters and their changes. The comprehensive evaluation of NDVI in our study provides valuable support for remote monitoring and understanding the dynamics of plant productivity [10-15]. This includes assessments of both annual and perennial aboveground biomass, chlorophyll content, and vegetative cover. Additionally, we explored the relationships between climate factors and NDVI in the rangeland, providing valuable insights into the complex interplay between environmental conditions and vegetation dynamics. The findings of our study emphasize the significance of these green vegetation parameters as effective tools for assessing and monitoring rangeland health [16-20]. The integration of NDVI and other related metrics enhances our ability to detect changes in plant productivity, offering valuable information for sustainable land management practices in semi-arid rangelands.

2 Materials and methods

Study area: The present investigation was carried out in the semi-arid Aktau foothill rangelands in Samarkand Province of Uzbekistan (40009'-N, 66039'-E, altitude 710m). This environment also has a local name as “adyr” which is characterized by low-high relief of study area. The pristine rangeland of study area is dominated by Artemisia diffusa around full vegetation period timing and *Carex pachystylis*, *Poa bulbosa* etc. in spring season. The vegetation period in the Aktau foothills rangeland area spans approximately 260–270 days, commencing in early March with the onset of the spring season and concluding in November with the end of the autumn season.

Numerous semi-shrub-ephemeral plant communities make up the vegetative cover. Among the prevailing perennials that thrive year-round are *Poa bulbosa* L. and *Carex pachystylis* L., flourishing especially during the rainy seasons [3, 5, 6]. The highest grazing load occurs in the spring and summer months. However, *Artemisia diffusa* (*A. diffusa*), due to its robust scent and intense fleeting fragrance, is consumed infrequently during these periods. Grazing pressure significantly diminishes during the autumn and winter months, with wormwood (A. diffusa) becoming the primary feed source for animals. In the summer months (June-August), certain spots in the study area witness a decline in plant cover, with only semi-shrubs like *A. diffusa* remaining (see Table 1). From March to May, the entire land is covered in greenery, including some deteriorated parts. However, during the fall season (September to November), the green cover is less frequent, and vegetation exhibits a very low level of greenness. A satellite image from the summer season reveals the degradation of the semi-shrub vegetation (mainly *Artemisia* and scarce *Alhagi*, *Iris*, and *Psoralea*) covering the area [6, 10]. The vegetation in the Aktoy foothill region is linked to *Artemisia Ephemera*, including *A. diffusa*, *P. bulbosa*, and *C. Pachystylis* [8, 13].

Table 1. The growth period of the main dominant plants in the study area. The shaded green area represents the growth period of the plant. (Source: Adapted from) [3, 5, 6].

	Plant species	**Jan.**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
	Main dominant plants species												
1.	*Artemisia diffusa L.*												
2.	*Carex pachystylis L*												
3.	*Poa bulbosa L.*												
4.	*Bromus tectorum L.*												
	Sparse-distributed plants species (ephemeroids)												
5	*Iris longiscapa Ldh*												
6	*Alhagi pseudalhagi (MB) Desv.*												

The foothill areas showcase a diverse and rich woody species of vegetation, such as *Pistacia vera* L., *Rosa spinosissima* L., *Amygdalus bucharica* L., *Punica granatum* L., *Atraphaxis spinosa* L., *Zygophyllum gontscharovii* L., and *various Ephedra* species. The northern slopes of these ranges receive more precipitation, fostering a nutritious carpet of *Carex pachystylis* and steppe vegetation with *Festuca spp*., *P. bulbosa* L., *Hordeum bulbosum L*., *Stipa spp*., *Aegilops triuncialis L*., and *Bromus teclorllm L*. grasses [1, 3, 8]. The altitudes of study area ranged from 500 to 1,600 m above sea level. The climate condition is quite different, because of diversity of landscape varieties. The climate of Aktau ridge relates to continental subtropical climates of Asia. Annual average air temperature varies between 12-14^0, means annual precipitation in mountain area reaches 350-400mm, in foothill is about 200- 385mm. The annual measurement of aboveground biomass focused on the green aboveground biomass of sub-shrub *A. diffusa* and ephemerals/ephemeroids along a discernible grazing gradient.

Satellite image data: This study was conducted from 2008 to 2010, covering an extensive study area represented by 2 scenes of Landsat images, each equal to 185 km². The satellite image data, obtained from Landsat 5 & 7 Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+), was used to analyze the rangeland condition of the Aktoy arid foothills (40°09'N, 66°39'E). Approximately 9 images from the study period (2008-2010) were processed, sourced online from the Landsat archive, to assess the current condition of rangeland vegetation.

Geobotanical data analysis: Geobotanical descriptions were performed on 10 m × 10 m transect plots, with three replicates at all nine sites. The coverage of individual shrubs was determined through a 10m-line intercept along the four edges of the 10m×10m plot. The total numbers of each subshrub species within the 10m²/plot were counted, and to obtain the total aboveground biomass of each subplot, density and biomass data were combined. The biomass of ephemerals and ephemerides was identified within 50×10cm frame quadrats, randomly distributed within 5 replications (Figure 2.).

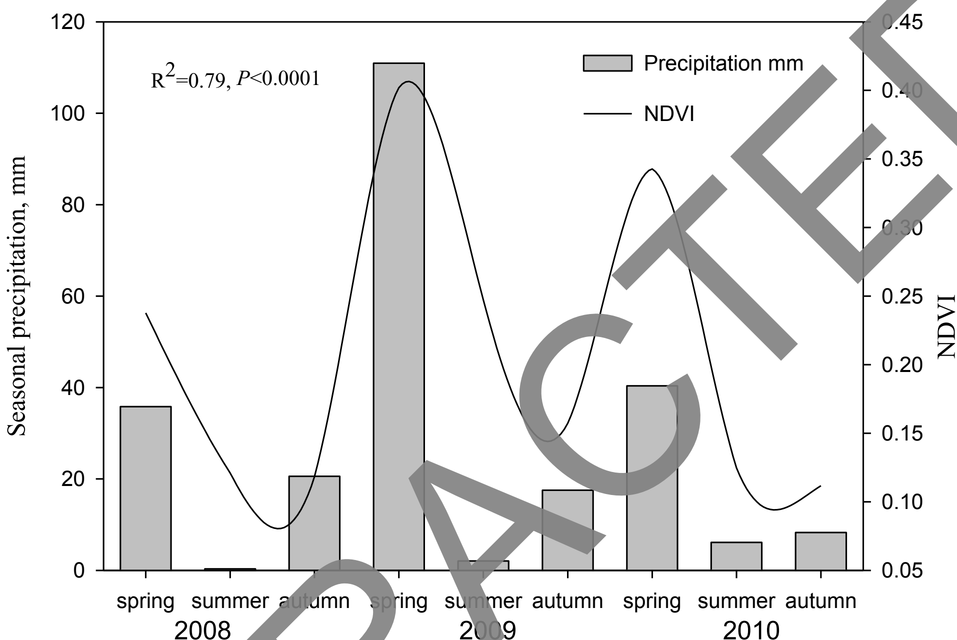

Fig. 1. Seasonal dynamics of precipitation and NDVI at vegetation period seasons of foothill rangeland. Significant differences from control, P< 0.0001.

Plant chemical data analysis: Chemical analyses were carried out on the dominant species A. diffusa to determine the content of chlorophyll a, b, and carotenoids using a Spectrophotometer (SF-26) after 100% acetone extraction [11]. Soil moisture was determined in profile horizons of 0-40cm, which were dried for 48 hours in a drying furnace. Climate data for the years 2008-2010 were obtained from the Kushrabad Meteorological Station in the Samarkand region.

3 Result and discussion

NDVI dynamics: In contrast to the well-established relationships between climate conditions and vegetation productivity reported by Andales et al. (2006), Valiyev et al. (2023) our results reveal distinct patterns in NDVI values across different seasons. Specifically, we observed that NDVI during the spring seasons is high, ranging between 0.150-0.300. In contrast, during the summer months, NDVI values are notably lower, reaching levels around 0.100-0.130 (Figures 3 and 4). The chlorophyll and carotenoid content of *A. diffusa* exhibited variations in response to climate changes. Specifically, the chlorophyll content across the three sites ranged from 0.81 to 0.93 mg/g in spring, 0.91 to 1.14 mg/g in summer, and 0.44 to 0.80 mg/g in autumn. Similarly, the carotenoid content showed seasonal changes, with values ranging from 0.21 to 0.33 mg/g in spring, -0.01 to 0.04 mg/g in summer, and 0.13 to 0.16 mg/g in autumn (see Figure 5.).

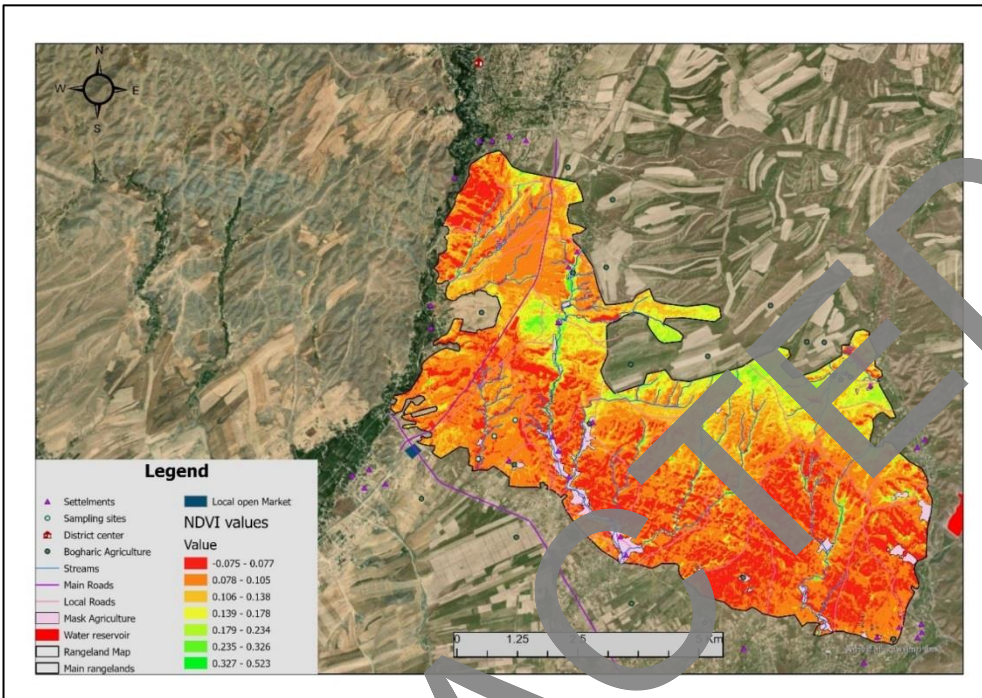

Fig. 2. NDVI map in study area.

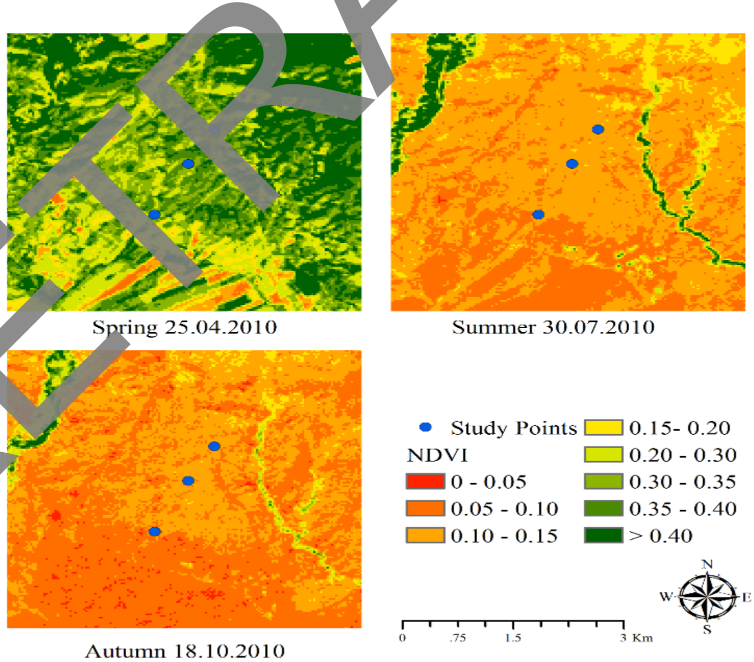

Fig. 3. NDVI map in three seasons.

Chlorophyll and green aboveground biomass represent key productivity indicators of vegetation, and both factors are closely related to the photosynthetic activity of plants.

These indicators play a crucial role in maintaining ecosystem balance, contributing to the regulation of climate, carbon storage, and the sequestration of potential productivity within the vegetation. The observed variations in chlorophyll and carotenoid content underscore the dynamic response of *A. diffusa* to changing environmental conditions across different growth seasons.

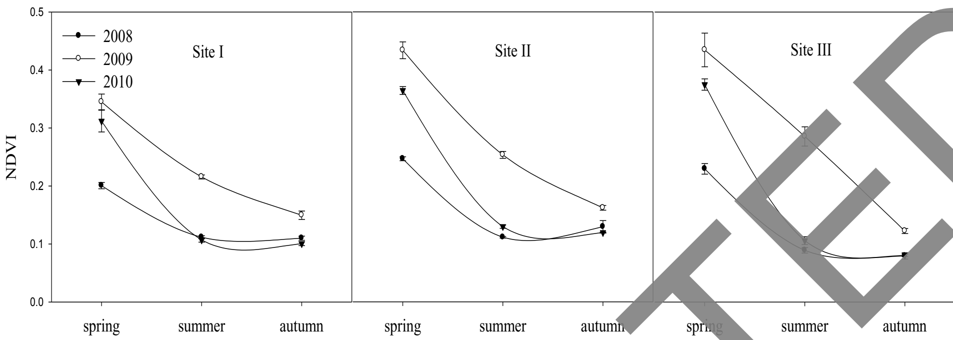

Fig. 4. Sessional dynamics of NDVI in study area for three year (2008-2010).

These seasonal variations in NDVI underscore the dynamic nature of vegetation productivity in response to changing climate conditions, emphasizing the importance of considering seasonal factors in the assessment of rangeland health and productivity. The timing of precipitation is particularly important for rangeland productivity, and it has influences on soil moisture. For plants phenology, water is a critical agent in advancing the green-up timing. It was noted that NDVI was higher in the spring of 2009 than other seasons, indicating the amount of precipitation was more than that of other grown seasons (Figure 1.).

Our results indicate a significant relationship between NDVI and water resources, including precipitation and soil moisture ($P < 0.0001$) as depicted in Figure 1 and Figure 5. We observed a positive correlation between NDVI and the total green aboveground biomass of vegetation in foothill rangelands ($P \leq 0.001$) as shown in Figure 5.

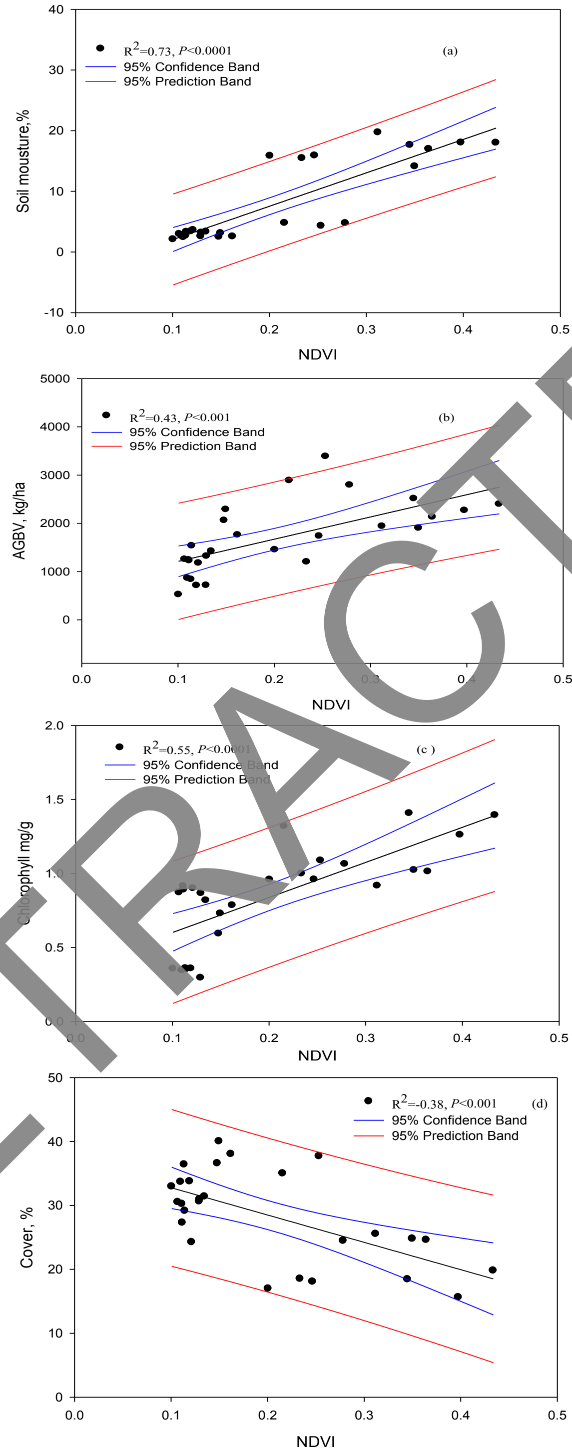

Fig. 5. Relationship between Vegetation Index (NDVI) and annual aboveground green biomass of vegetation AGBV, kg/ha (a), soil moisture, % (b), and with chlorophyll, mg/g (c) and percent cover,% (d) of dominant sagebrush of *A.diffusa* at spring, summer, autumn seasons of full vegetation period. The dashed lines show the 95% confidence interval.

The study revealed that NDVI at different grain sizes exhibited a significant correlation with the pooled annual aboveground green biomass of vegetation (AGBV) across the entire foothill rangeland. Furthermore, significant relationships were identified between the Normalized Difference Vegetation Index (NDVI) and key vegetation indicators, such as percent cover ($P < 0.01$) and foliar chlorophyll content ($P < 0.001$) of *A. diffusa* (Figure 5). This variation is attributed to the increased precipitation recorded during the spring of 2009 (refer to Figure 1.). The influence of precipitation on vegetation cover highlights the dynamic response of A. diffusa to climatic conditions, particularly in terms of seasonal changes in precipitation levels. This research project represents one of the initial steps in investigating vegetation changes due to grazing in Uzbekistan. The recommendations derived from this study aim to facilitate the initiation of sustainable utilization practices for rangelands. In the long run, the establishment of an ecological monitoring system is crucial to comprehensively understand the processes and characteristics of this complex ecosystem and to provide sustainable solutions. GIS and Remote Sensing play a vital role in ecological monitoring, enabling the interpolation of point measurements and the analysis of processes in both space and time. The advanced technology for computerized processing allows for the estimation of the past and present states of rangeland vegetation cover, unveiling the distribution of biomass on rangelands. Ongoing and future investigations into the development of modern methods for rangeland vegetation monitoring not only facilitate the identification of critical regions based on their ecological status but also provide recommendations for the rational use of rangelands and methods to prevent and mitigate desertification effects.

4 Conclusion

The utilization of NDVI methodologies for assessment presents an opportunity to unveil vegetation productivities and enables the acquisition of real-time information on plant conditions. Additionally, it allows for the evaluation of the impact of climatic and soil moisture factors on rangeland vegetation productivities. The key factors influencing the dynamics of plant productivity and soil parameters, such as soil moisture and precipitation, can be effectively monitored through a combination of ground measurements and remote sensing data. The influences of precipitation and soil moisture exhibit both seasonal and annual impacts on plant growth and chemical parameters. By judiciously leveraging this information, vegetation indices become potent tools for scaling up estimates of the environmental factors' impact on the dynamics of vegetation and their productivities in the semi-arid foothill rangeland of Uzbekistan.

References

1. A. Akhmedov, I. Rog, A. Bachar, et al., Perspectives in Plant , Evolution and Systematics **48**, 125586 (2021) DOI: 10.1016/j.ppees.2020.125586
2. A. A. Andales, J. D. Derner, L. R. Ahuja, R. H. Hart, Rangeland Ecology & Management **59**, 576-584 (2006)
3. G. Gintzburger, K. N. Toderich, B. K. Mardonov, M. M. Mahmudov, Rangelands of the Arid and Semi-Arid Zones in Uzbekistan. CIRAD, ICARDA, Montpellier, France, pp. 50-63 (2003)
4. Y. Jiang, J. Tao, Y. Huang, et al., Journal of Plant Ecology **8(1)**, 30-40 (2015)
5. M. Mahmudov, Country pasture/forage resource profiles for Uzbekistan. Food and Agriculture Organization of the United Nations (FAO) Crop and Grassland Service (2006)
6. M. A. Muminov, M. G. Nosirov, T. F. Rajabov, et al., Open Journal of Ecology **06**, 736–752 (2016)
7. M. Nosyrov, Karnab Chul, Samarkand, Uzbekistan: Frame Work of Assessment Methodology. In Proceedings of the Second International Workshop on Combating Desertification (SUMAMAD), Iran, UNESCO-MAB Drylands Series (No. 3.100-111) (2003)
8. A. Rahmatullaev, Landscapes Ridge Aktau, their use rational economic and protection. Tashkent, Uzbekistan. "FAN" Publisher, pp. 7-80. (1991)
9. F. Rajabov, B. Mardonov, M. Nasyrov, et al., Journal of Science and Engineering **4**, 78-82 (2010)
10. T. Rajabov, Ecological assessment of spatio-temporal changes of vegetation in response to piosphere effects in semi-arid rangelands of Uzbekistan. Land Restoration Training Programme, pp. 109-144 (2009)
11. N. N. Tretyakov, Practical work of plant physiology. Agropromizdat Press, Moscow, Russia, pp.86-94 (1990)
12. S. Valiyev, T. Rajabov, B. Avutkhanov, S. Ataeva, Changes of photosynthetic pigments of Artemisia diffusa under the influence of grazing stress of livestock grazing in Karnabchul semidesert, Plant Science Today (Early Access) (2023) DOI: https://doi.org/10.14719/pst.2430
13. P. K. Zokirov, Botanical geography piedmont of Kyzyl-Kum and Nuratau (Mountain) Range (Tashkent, "FAN" Publisher, 1971)
14. I. Polevshchikova, Monitoring and comparative analysis of land use changes on the example forest region of Finland. International Multidisciplinary Scientific GeoConference: SGEM **18(1.5)**, 727-731 (2018)
15. O. Vorobyev, E. Kurbanov, Y. Polevshikova, S. Leznin, Assessment of dynamics and disturbance of forest cover in the Middle Povolzhje by Landsat images. Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa **13(4)**, 124-134 (2016)
16. B. R. Nasibov, Y. A. Polevshikova, A. O. Xomidov, M. R. Nasibova, AIP Conference Proceedings **2612(1)** (2023)
17. A. D. Malik, M. C. W. Arief, S. Withaningsih, P. Parikesit, Global Journal of Environmental Science and Management **10(1)**, 245-266 (2024)
18. J. I. N. Nneka, A. A. Oyilieze, A. C. David, et al., Land and Environmental Management through Forestry, 47-75 (2023)
19. J. Wu, Y. Li, B. Zhong, et al., Science of The Total Environment **904**, 166738 (2023)

20. J. Abildtrup, E. Audsley, M. Fekete-Farkas, et al., Environmental Science & Policy **9(2)**, 101-115 (2006)