



SPATIAL PLANNING AND GEOSPASTIC REQUIREMENTS FOR ALTERNATIVE ENERGY RESOURCES (SOLAR, WIND)

Khakimova Kamola Rakhimjonovna
Fergana State Technical University

Marupov Azizkhan Abbaskhanovich
Fergana State Technical University

Abdulkhakimov Khalilullo Mukhammadyakhya ogli
Master's Student, Fergana State Technical University,

Abstract

This article systematizes the geospatial (GIS/RS) requirements for site selection and regional planning of solar and wind energy facilities in the Andijan region. A multi-criteria analysis (MCDA/AHP) approach is proposed based on digital orthophotos, remote sensing data, digital terrain model, and infrastructure layers. It is argued that the main technical requirements for the Fergana Valley are the accuracy of geospatial data, the update period, and interlayer compatibility (CRS/vertical datum) in the context of the relatively low solar radiation zone for the Fergana Valley, as well as the regional differentiation of wind resources. The results obtained provide practical recommendations on the geospatial data package, restriction zones, and evaluation criteria for RES facilities (PV/WE) in the Andijan region.

Keywords: Alternative energy, solar PV, wind energy, regional planning, geospatial requirements, orthophotomap, GIS, MCDA, AHP, Andijan.

INTRODUCTION

The issue of territorial planning for alternative energy resources (solar and wind) is today determined not only by the question of “which technology is more



Modern American Journal of Engineering, Technology, and Innovation

ISSN(E): 3067-7939

Volume 01, **Issue** 09, December, 2025

Website: usajournals.org

This work is Licensed under CC BY 4.0 a Creative Commons Attribution 4.0 International License.

efficient”, but also by a chain of geospatial decisions: “where, under what conditions and based on what data can the most optimal project be selected?” World experience shows that as the share of renewable sources in energy systems increases, factors such as project siting, grid connection, land compatibility, environmental restrictions, and management of production variability become paramount. For example, in 2023, renewable energy capacity worldwide increased by a record 473 GW, of which 346 GW will be solar and 116 GW will be wind; that is, the bulk of the additional capacity is provided by solar and wind. However, this rapid growth is not enough: the COP28 target of tripling installed renewable capacity by 2030 (to around 11 TW) is being met, and in practice, this will require a very large amount of new capacity to be added every year. The same logic is confirmed by the IEA forecasts: if current policies are maintained, annual renewable capacity additions will reach almost 940 GW/year by 2030, with 95% of this growth expected to come from solar PV and wind. Thus, poor geospatial planning, both in areas with high resource potential and in areas with relatively “average” resources, will reduce investment efficiency, increase grid constraints and increase the likelihood of land disputes.

In global practice, best practices for locating solar and wind projects include GIS-based multi-criteria suitability analysis (MCDA), constraint mapping, distance-to-grid/roads optimization, terrain and landscape considerations (slope, aspect, shading), and environmental and social risk mitigation (EIA/ESIA). Here, “geospatial requirements” are defined as:

- ✓ resource maps (GHI/DNI, wind speed, power density, wind directions),
- ✓ high-resolution base maps (orthophoto, cadastral layers, land cover),
- ✓ relief model (DEM/DTM/DSM),
- ✓ engineering and network infrastructure (substations, power lines, road networks),
- ✓ restriction and protection zones (categories of agricultural land, water bodies, sanitary protection zones, protected areas),
- ✓ legal-administrative layers (district boundaries, land rights/ownership, easements).

If these layers are not integrated into a compatible coordinate system, with the same metadata and accuracy requirements, location decisions will be “good on



***Modern American Journal of Engineering,
Technology, and Innovation***

ISSN(E): 3067-7939

Volume 01, Issue 09, December, 2025

Website: usajournals.org

***This work is Licensed under CC BY 4.0 a Creative Commons Attribution
4.0 International License.***

the map but problematic in practice.” That is why orthophotos—especially digital, high-resolution orthophotos—are recognized as the main geoinformation “base layer” for spatial planning: they provide high reliability in determining land cover and use type (cropland, vacant land, industrial zone, settlement, rooftops), in assessing shadows and obstructions, in clearly defining project boundaries, and in planning construction and logistics (access roads, equipment locations).

In Uzbekistan, solar resources are generally promising: according to IEA/OECD analyses, the median GHI value for the country is approximately 4.52 kWh/m²/day (typically in the range of 4.0–5.0 kWh/m²/day), which is comparable to some European countries with developed solar energy. However, the resource is not evenly distributed across regions: the Fergana Valley (including Andijan) may be lower in some actinometric indicators than some desert and semi-desert regions of the country due to relief, humidity, and atmospheric conditions; this does not mean that the resource is “low”, but rather that more thorough geospatial justification of factors such as station location, shading, roof/ground surface configuration, and distance to the grid is needed. In this regard, open platforms such as the Global Solar Atlas serve as an initial assessment of the spatial distribution of the resource, and at a later stage, integrated with orthophotos, DEMs, and land categories, to transform it into a “bankable” (investment-based) microsite.

In the case of wind energy, a cautious, informed approach is required in the case of Andijan: some scientific sources cite the average annual wind speed at a height of 10 meters for the Andijan meteorological station as around 1.5 m/s, with a monthly range of 1.1–2.1 m/s; the wind power density (at the 10 m level) is also estimated at relatively low values. These results imply that the resource for large-scale wind power plants in Andijan will not be sufficient “by itself”; on the contrary, geospatial and engineering requirements will increase, such as (1) re-estimation at higher hub heights (e.g. 80–100 m), (2) micro-siting taking into account the relief and “corridor” effect, (3) analysis of wind directions (wind rose) and turbulence risk, (4) optimization of grid connection and proximity to load centers. In this case, platforms such as Global Wind Atlas will be needed for initial zonal analysis, while on-the-ground measurements and geodetic support will be needed for final design decisions.



In the case of Andijan region, the relevance of territorial planning is enhanced by another factor: given the high density of land resources in the valley and the high value of agricultural land, it is important to reduce “land scarcity and conflict risks” (agricultural lands, residential areas, transport and irrigation infrastructure) when placing renewable energy facilities. It is at this point that geospatial surveys based on high-resolution orthophotomaps and geodetic reference networks (precise classification of land cover, identification of vacant/brownfield areas, inventory of roof areas, strict delineation of restriction zones) directly affect the social acceptance and economic efficiency of the project. Also, the fulfillment of geodetic accuracy requirements (GCP/CP points, GNSS measurements, coordinate system compatibility) determines the quality of orthophotos and DEMs, which ultimately allows choosing the optimal options for the panel slope and location for a solar power plant, turbine installation points and safety distances for a wind power plant, as well as grid connection routes.

Therefore, this research area — “territorial planning and geospatial requirements for alternative energy resources” — serves to scientifically place solar and wind projects in the conditions of the Andijan region, increase accuracy, reduce constraints, and standardize the decision-making process through the integration of orthophotomaps and geodetic data. At a time when renewable energy capacities are growing rapidly globally, and the main share of this growth is precisely accounted for by solar and wind, moving territorial planning from “approximate selection based on maps” to the stage of “geospatial optimization and accurate justification” is a strategic necessity for densely populated regions like Andijan.

LITERATURE ANALYSIS

The main direction of international scientific literature in the territorial planning of alternative energy facilities (solar PV and wind) is the integration of geospatial data (resource rasters, DEM/DSM, land cover, infrastructure, restriction zones) with multi-criteria decision-making (MCDM/MCDA) in a GIS environment and, as a result, the rational allocation of “suitable areas” on the map. For example, Y. Charabi and A. Gastli (in the case of Oman) combine spatial multi-criteria evaluation with fuzzy quantifiers in the ArcGIS environment using the FLOWA module to assess land suitability for large PV farms; this approach has practical



***Modern American Journal of Engineering,
Technology, and Innovation***

ISSN(E): 3067-7939

Volume 01, **Issue** 09, December, 2025

Website: usajournals.org

***This work is Licensed under CC BY 4.0 a Creative Commons Attribution
4.0 International License.***

value as it allows modeling the uncertainty in expert assessments (criteria and their weights). The study shows that different geodata are brought to the same raster size, and as a result, suitability maps are synthesized through overlay; One of the most important results is that only 0.5% of Oman's territory is considered to be "high suitability", meaning that even in a country with high resource potential, realistic siting options are severely constrained by environmental, technical and infrastructural constraints. The authors compare PV technologies and calculate that CPV technology offers very high technical potential for large-scale plants under certain conditions (for example, if "highly suitable" lands are fully developed with CPV, the theoretical generation capacity is several tens of times greater than Oman's current total electricity demand). This work provides two important conclusions for areas with dense land resources such as Andijan: first, the resource map is insufficient - the layers of constraints (land use, protected areas, settlements, grid connection) severely limit site selection; second, the uncertainty management (fuzzy approach) when working with expert weights reduces "false confidence in the map". One of the most widely used classical works on AHP–GIS integration for solar farms is the study by M. Uyan (Turkey, Karapınar–Konya), which emphasizes that the selection of a location for large solar investments is directly related to “relief quality, local weather factors, proximity to high-power transmission lines, agricultural facilities and environmental protection issues”. The author uses GIS and AHP to construct a final index model, classifying the area into “low suitability”, “medium suitability”, “suitable” and “most suitable” categories, and presents the result with quantitative indicators: 40.34% of the surveyed area is “not suitable” for solar farms, and the rest is divided into different suitability classes (including the “most suitable” category with a separate share). This approach clearly defines the geospatial requirements for territorial planning:

1. mandatory minimum set of layers (resource, DEM, land cover, network/road, restriction zones),
2. normalization and weighting, since the units of measurement of the criteria are different,
3. The final map's "classification" creates a clear view for investment decisions.



Modern American Journal of Engineering, Technology, and Innovation

ISSN(E): 3067-7939

Volume 01, **Issue** 09, December, 2025

Website: usajournals.org

***This work is Licensed under CC BY 4.0 a Creative Commons Attribution
4.0 International License.***

However, the AHP approach has a natural limitation: since the weights are related to expert subjectivity, if the accuracy and novelty of the base layers (in particular, land cover and infrastructure) are low, the polygon that is considered “the most suitable” may actually fall into the restriction zone or unsuitable land; at this point, verification using high-resolution orthophotos and geodetic control (GCP/CP) is of particular importance in the Andijan conditions. In the work on wind energy by L.-I. Tegou, H. Polatidis and DA Haralambopoulos (Lesvos Island, Greece), the concept of “legislative constraints” is central: the authors formulate a set of environmental, economic, social and technical constraints for the location of a wind farm (based on Greek legislation) and then assess the suitability using criteria such as wind potential, land cover type, electricity demand, visual impact, land value and distance to the electricity grid; The weights of the criteria are found by the AHP pair-wise comparison method, and the final suitability is calculated by the weighted summation rule [7,8]. As a result, the authors come to a paradoxical, but very important conclusion for planning practice: even though there are more areas with favorable wind potential, the share of “suitable” areas for real installation is very small. This result reinforces two aspects in the justification of wind projects in the Andijan case: first, relying only on the “wind map” is not enough - regulatory restrictions, distance to settlements, landscape/visual impact and network costs sharply reduce the suitable area; second, pre-showing the difference between “available favorable potential” and “real permissible/economically suitable location” in wind projects with the GIS–MCDM model reduces investment risk. The work of JM Sánchez-Lozano and colleagues in Spain on diversifying MCDM methods is also of practical importance: they propose the idea of connecting GIS data with a Decision Support System (IRIS) and dividing PV locations into “merit categories” using a multi-criteria model using ELECTRE-TRI; this approach is distinguished by its stronger solution of the “sorting/classification” task (i.e., dividing objects into categories) compared to AHP. In general, the reviewed foreign experiences (Charabi–Gastli; Uyan; Tegou–Polatidis–Haralambopoulos; and Sánchez-Lozano et al.) lead to the same methodological conclusion for the study in the Andijan conditions: the “main product” of RES territorial planning is a compatibility map, but this map is more reliable with the quality of geospatial requirements (DEM/DSM accuracy,



land cover freshness, completeness of network and road layers, legal validity of restriction zones) and on-site verification through orthophotomaps than with resource layers; therefore, in the case of Andijan region, digital orthophotomaps and geodetic reference networks (GCP/CP, CRS/vertical datum compatibility) as a central technical requirement of territorial planning is a logical continuation of international scientific approaches [9,10].

RESULTS AND DISCUSSION

The main objective of this study is to formulate a set of geospatial requirements for regional planning of solar (PV) and wind energy facilities in the Andijan region in the form of practical criteria and to statistically substantiate siting decisions based on the integration of open resource atlases, DEM/DSM and orthophotomaps. To achieve this goal, the following tasks are logically solved:

- (1) to explain global and national development trends with statistical evidence from the perspective of "location and network integration", not resource-technology;
- (2) Present available scientific estimates of solar radiation and wind speed for Andijan (Fergana Valley) and show what geospatial requirements the regional characteristics of the resource lead to;
- (3) discuss the nature of the expected constraints for Andijan by comparing statistical results (percentage, area share) showing that the share of "suitable" land is actually sharply reduced as a result of GIS–MCDM (AHP, fuzzy, ELECTRE-TRI) approaches in international experience;
- (4) finally, to translate into a practical conclusion the need to include orthophotos (5–20 cm GSD) and geodetic reference (GCP/CP, CRS/vertical datum correspondence) as a "verification layer" in regional planning.

First of all, global statistics show that the main burden on the renewable energy market is falling on solar and wind: in 2023, global renewable capacity increased by 473 GW, of which 346 GW was solar and 116 GW was wind; this growth is still not fast enough to meet the target of "COP28: tripling capacity to 11 TW by 2030". This global situation reinforces the importance of spatial planning: poor location during the rapid construction phase will increase the distance to the grid, increase land disputes and put pressure on the final LCOE.



Table 1. Global renewable capacity addition (GW) and composition in 2023

Indicator	Value
Renewable energy addition (total)	473 GW
Solar power supplement	346 GW
Wind power supplement	116 GW
Share of solar + wind in additions	97.6%

The second important result is that in the conditions of the Fergana Valley, where Andijan is located, the territorial characteristics of the resource make the “geospatial requirements” more precise and stringent. According to the scientific source, the intensity of direct solar radiation (DRI) in Uzbekistan ranges from 1500 kWh/m² for the Fergana Valley to 1900–2100 kWh/m² for other regions; therefore, the share of microlocation factors (shading, relief exposure, obstacles) in PV projects in Andijan is relatively high. As for the wind, it is noted that the average annual wind speed in Uzbekistan at a height of 10 meters for the eastern regions (Tashkent region and Fergana Valley) is in the range of 1.0–2.5 m/s, for example, 1.68 m/s is indicated at the Fergana point; This result reinforces the practical conclusion that “atlas screening is not enough for large-scale wind power in Andijan, and higher wheel heights and long-term measurement/micrositing are definitely required.” At the same time, the goal of reaching 5 GW of solar power capacity at the national level by 2030 is specifically mentioned in the roadmap, and methodological standardization of territorial planning is seen as a factor accelerating investment flows [11,12].

Table 2. Resource indications and planning implications for Andijan (Fergana Valley)

Indicator	Scientific assessment/range	Discussion for planning (summary)
Solar radiation (DNI)	Fergana Valley: 1500 kWh/m ² ; other regions: 1900–2100 kWh/m ²	Increases the need for microsite selection (shadow, exposure, obstacles) and orthophoto/DSM in PV
Wind speed (10 m)	Fergana Valley: 1.0–2.5 m/s; Fergana example: 1.68 m/s	Utility-scale wind requires a “screening → measurement → micrositing” chain; hub height re-evaluation required
National solar target	5 GW of solar power by 2030	Spatial planning should be supported by standard criteria and geodata quality



The third block of results comes from a comparison with international experience: it is common for GIS–MCDM approaches to yield a very small share of “highly suitable” areas, even in resource-rich countries. Charabi and Gastli use fuzzy-GIS multi-criteria assessment in the case of Oman to show that only 0.5% of the total land area is “highly suitable”; this figure statistically proves that even if there is resource potential, layers of constraints (land use, infrastructure, ecological distances) sharply narrow the final selection. In the case of Uyan (Turkey, Karapinar), a suitability analysis for solar farms using AHP–GIS was performed and 40.34% of the area was found to be “not suitable”; this result shows that even if “large-scale PV” is planned in land-scarce areas, the share of suitable land is naturally limited. In wind, Tegou et al. combine MCA/AHP with GIS and legislative constraints on the Greek island of Lesvos, showing the logic of first drastically reducing the “permitted area” and then assessing suitability; the value of such an approach is that a large number of areas with “potential” are in fact excluded from the selection due to regulatory/social/environmental constraints. Sánchez-Lozano et al. propose an approach in Spain to classify PV sites into “categories” by using ELECTRE-TRI to categorize alternatives, thus enhancing the ability of AHP to classify decisions and provide an understandable “sorting” product to the investor.

Table 3. Statistical results (benchmark) on the share of "suitable area" in international GIS–MCDM studies

Author(s), year	Technology	Method	Main statistical result	Discussion for Andijan
Charabi & Gastli, 2011	PV	Fuzzy + GIS-MCDA	“Highly suitable” lands ≈ 0.5%	Constraint layers severely narrow PV location selection; verification with orthophotos is required
Wake up, 2013	PV	AHP + GIS	40.34% of the territory is “not suitable”	In areas with land scarcity/competitiveness (valleys), the share of "suitable land" is naturally limited.
Tegou et al., 2010	Wind	MCA/AHP + GIS + legislative restrictions	The potential area is drastically reduced based on constraints	In the wind, regulatory and social distances (buffers) should primarily separate the "allowed" area
Sánchez-Lozano et al., 2014	PV	ELECTRE-TRI + GIS (IRIS DSS)	Alternatives are sorted into categories (sorting)	Presenting the decision result in the form of a “category” speeds up practical planning



***Modern American Journal of Engineering,
Technology, and Innovation***

ISSN(E): 3067-7939

Volume 01, Issue 09, December, 2025

Website: usajournals.org

***This work is Licensed under CC BY 4.0 a Creative Commons Attribution
4.0 International License.***

The discussion that arises from these statistical comparisons is that the assessment of the solar and wind resource in Andijan region alone does not provide a sufficient “result”; the real result is the formation of a portfolio of candidate sites that have passed the restrictions, are close to the grid, have their legal status determined and have been verified on site based on orthophotos/DSM [13]. Given that the solar radiation intensity in the Fergana Valley may be lower than in other regions, reducing losses in the PV location (shading, incorrect exposure, uneven microrelief) directly affects the investment efficiency; therefore, geospatial requirements in Andijan are In

- (1) high-resolution orthophoto,
- (2) DSM/DTM,
- (3) Geodetic connection via GCP/CP,
- (4) cadastral/land category layers become a "mandatory minimum".

For wind, the 1.0–2.5 m/s range at 10 m height does not provide a basis for rejecting large wind projects in Andijan, but rather for dividing the planning into strict stages: the atlas screening is only an initial filter, and the final decision is made through resource reassessment at a higher hub height, long-term measurements and micrositing that takes into account turbulence/corridor effects; in this process, “where to put the measuring mast” is itself a matter of geospatial optimization. In the final analysis, while solar and wind will account for almost all (97.6%) of all renewable additions globally in 2023, spatial planning in densely populated areas like Andijan gains practical value by “identifying suitable sites, minimizing constraints and optimizing grid connectivity” rather than “resource availability”; therefore, as a final product

- (a) Map of suitability categories for PV,
- (b) candidate areas ready for measurement and micrositing for wind,
- (c) The formation of a passport table consisting of “resources–constraints–infrastructure–land rights–accuracy” indicators for each candidate precinct is the most reasonable and verifiable result in the case of Andijan.

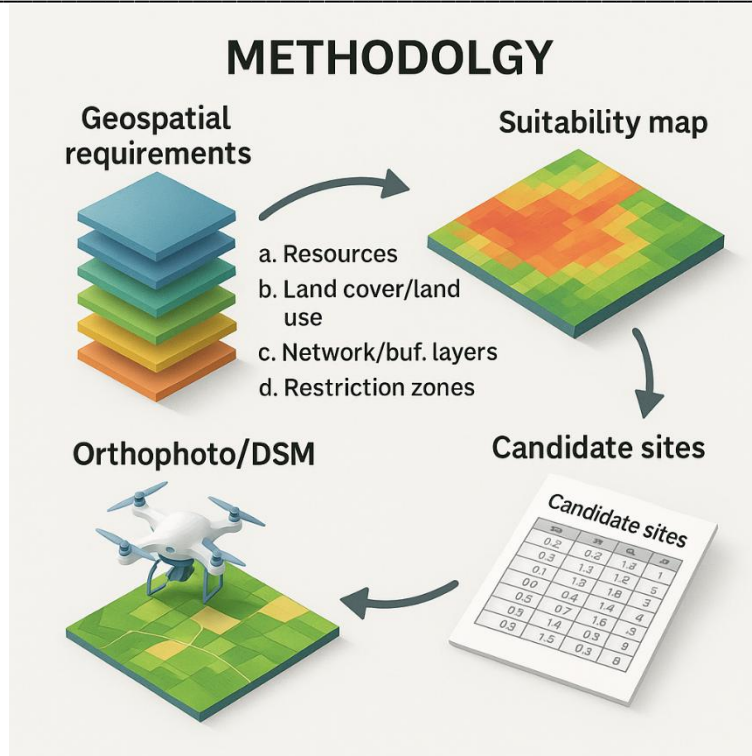


Figure 1. Orthophoto-Supported Geospatial MCDA Workflow for PV/Wind Site Planning

CONCLUSION

The territorial planning of alternative energy facilities (solar PV and wind) in the Andijan region shows that the availability of resources alone is not a sufficient criterion; the final decision is made by integrating a set of geospatial requirements - resource rasters (GHI/DNI, wind speed/power density), relief model (DEM/DSM), land cover/land use, infrastructure (road-grid-substation), and restriction zones into the same coordinate system. Since global statistics show that the main growth of renewable energy is due to solar and wind, making mistakes in territorial planning increases the costs of connecting to the grid and increases investment risk; therefore, the siting process should be standardized in the sequence “constraint mask → suitability assessment (MCDA/AHP) → verification based on orthophoto/DSM → passport of candidate sites”. Since solar radiation and wind regimes in the Fergana Valley can vary by region, microrelief, shading factors, land resource density, and regulatory distances (population



centers, water bodies, protected areas) play a decisive role in Andijan. The study concluded that the most practical solution is to form a “suitability map” for PV and “screened candidate zones” for wind, and to compile a passport table summarizing resource–constraint–infrastructure–land rights–accuracy indicators for each site. In general, a geospatial approach reinforced with digital orthophotomaps and geodetic reference networks increases the technical accuracy of the placement of alternative energy projects in Andijan region, identifies land and network constraints at an early stage, and strengthens the validity of investment decisions.

REFERENCES

1. Charabi Y., Gastli A. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation // *Renewable Energy*. - 2011. - Vol. 36, Issue 9. – P. 2554–2561. – DOI: 10.1016/j.renene.2010.10.037.
2. Uyan M. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey // *Renewable and Sustainable Energy Reviews*. - 2013. - Vol. 28. – P. 11–17. – DOI: 10.1016/j.rser.2013.07.042.
3. Tegou L.-I., Polatidis H., Haralambopoulos DA Environmental management framework for wind farm siting: Methodology and case study // *Journal of Environmental Management*. - 2010. - Vol. 91, Issue 11. – P. 2134–2147. – DOI: 10.1016/j.jenvman.2010.05.010.
4. Sánchez-Lozano JM, Henggeler Antunes C., García-Cascales MS, Dias LC GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain // *Renewable Energy*. - 2014. - Vol. 66. – P. 478–494. – DOI: 10.1016/j.renene.2013.12.038.
5. IRENA. *Renewable Energy Capacity Statistics 2024: Report*. - Abu Dhabi: International Renewable Energy Agency, 2024. - 72 p. – URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Mar/IRENA_RE_Capacity_Statistics_2024.pdf (Date of access: 12/12/2025).



6. IRENA. Renewable Capacity Highlights 2024. - Abu Dhabi: International Renewable Energy Agency, 2024. - 3 p. – URL:https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Mar/IRENA_RE_Capacity_Highlights_2024.pdf
7. Yokubov S. DEVELOPMENT OF AGRICULTURAL CARDS USING ARCGIS AND PANORAMA TECHNOLOGIES //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – C. 101-107.
8. Khakimova K., Yokubov S. CREATION AND MAINTENANCE OF STATE CADASTERS IN THEREPUBLIC OF UZBEKISTAN //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – C. 85-93.
9. Yokubov S. SCIENTIFIC AND THEORETICAL FOUNDATIONS FOR THEDEVELOPMENT OF MAPS OF THE LEGAL STATUS OF STATE LANDCADASTERS IN THE TERRITORY USING GIS TECHNOLOGIES //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – C. 80-84.
10. Abduvakhabovich A. A. Shavkat o'g'li, SY Improving the Method of Mapping Agriculture Using Remote Sensing Data //Finl. Int. Sci. J. Educ. Soc. Sci. Humanit. – 2023. – T. 11. – C. 1093-1100.
11. Yusufovich G. Y. et al. The use of remote sensing technologies in the design of maps of agricultural land //Texas Journal of Agriculture and Biological Sciences. – 2023. – T. 23. – C. 17-21.
12. Eshnazarov D. et al. Describing the administrative border of Koshtepa district on an electronic digital map and creating a web map //E3S Web of Conferences. – EDP Sciences, 2023. – T. 452. – C. 03009.
13. Khakimova K. et al. Application of GIS technologies for improving the content of the tourist map of Fergana province, Uzbekistan //E3S web of Conferences. – EDP Sciences, 2023. – T. 386. – C. 04003.