# Improving the Methodology for Normative Valuation of Irrigated Agricultural Lands Based on Geospatial-Phase Methods

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Received: 22 Mar 2026 | Received Revised Version:18 Apr 2026 | Accepted: 06 May 2026 | Published: 31 May 2026

Volume 08 Issue 05 2026 | Crossref DOI: 10.37547/tajas/Volume08Issue05-33

## Abstract

*This article proposes a geospatial approach for determining the normative value of irrigated agricultural land that accounts for the land's reclamation (meliorative) condition, specifically the degree of secondary salinization. Using data from 286 observation wells in the Yuqori Chirchiq, O'rta Chirchiq and Quyi Chirchiq districts of Tashkent region for April, July and November of 2023 and 2025, groundwater level and mineralization were analyzed in a GIS environment using IDW and Kriging interpolation, while NDVI and NDSI indices were derived from Landsat-8 imagery. The four factors were objectively weighted using the entropy method and combined into a single salinization index (Si) and a corresponding reclamation coefficient (Cmel). Applying the coefficient to six farm plots in O'rta Chirchiq district within the existing normative valuation formula (based on Cabinet of Ministers Resolution No. 744) reduced the calculated normative value by an average of 34.7% (range 0–71%), demonstrating the method's ability to differentiate land quality objectively.*

Keywords: Normative valuation, secondary salinization, geographic information systems, IDW, Kriging, NDVI, NDSI, reclamation coefficient, cadastral valuation.



**Cite This Article:** Mukhtorov Uzbekhon Burhonovich, & Avezbaev Sadulla. (2026). Improving the Methodology for Normative Valuation of Irrigated Agricultural Lands Based on Geospatial-Phase Methods. The American Journal of Applied Sciences, 8(5), 232–239. https://doi.org/10.37547/tajas/Volume08Issue05-33

## 1. Introduction

The reclamation (meliorative) condition of irrigated land is one of the main factors determining the efficiency of agricultural production. A rise in groundwater level and an increase in its mineralization intensify secondary salinization processes [200]. Salinization can be divided into two types — primary and secondary. Primary salinization arises from natural causes (saline lakes, dense saline layers, and saline or moist saline soils). Secondary salinization, in turn, mainly results from anthropogenic factors — improper land development and the failure to apply scientifically grounded agrotechnical measures — and is widespread in the country's northern farming regions (the Republic of Karakalpakstan, and Khorezm, Bukhara, and Navoi regions).

Depending on the specific nature of the factors that influence the accumulation of salts in fields, the causes of secondary salinization can be divided into three groups: 1) irrigation with water containing salts; 2) groundwater levels lying close to the soil surface; 3) the rise of salts into the fertile soil layer under capillary pressure caused by applying water in excess of established norms. The practical value of this classification is that identifying which cause underlies the salinization of a given plot determines the corresponding countermeasures to be applied.

Worldwide, approximately 20–25% of agricultural land has been affected by some degree of salinization [5]; in Central Asia this figure reaches 40–50% in some areas [1; pp. 400–409]. In the current cadastral valuation system, the soil bonitet (quality) score, normative yield, and agroclimatic conditions are adopted as the main indicators, and under the classical approach the base cadastral value is determined as follows:

$$Kb = B \times Nd \quad (1)$$

where: Kb — base cadastral value; B — soil bonitet score; Nd — normative income. According to economic theory, land value is equal to the capitalization of the net income derived from the land [2]:

$$K = R / r \quad (2)$$

where: R — annual net income; r — capitalization coefficient. Because salinization reduces yield, land value also declines; however, the existing methods based on formulas (1) and (2) do not reflect the dynamic differentiation of reclamation condition across areas and seasons. It is therefore a scientifically grounded and pressing task to analyze groundwater level and mineralization using modern geoinformation methods and to integrate the results into cadastral valuation.

The purpose of this study is to develop, using geographic information systems and remote sensing data, an objective reclamation coefficient reflecting the meliorative condition of irrigated land (through groundwater level, mineralization, and vegetation and salinization indices), and to integrate it into the existing normative valuation model.

## 2. Methods

### 2.1. Study area and data source

The Yuqori Chirchiq, O'rta Chirchiq, and Quyi Chirchiq districts of Tashkent region were selected as the study area (Figure 1). Initial data on groundwater level and mineralization were obtained from observation wells maintained by the reclamation expedition under the Chirchiq–Ohangaron irrigation systems basin authority. Data from a total of 286 observation wells — 48 in Yuqori Chirchiq district, 87 in O'rta Chirchiq district, and 151 in Quyi Chirchiq district — for April, July, and November of 2023 and 2025 were entered into attribute tables and analyzed in ArcGIS.

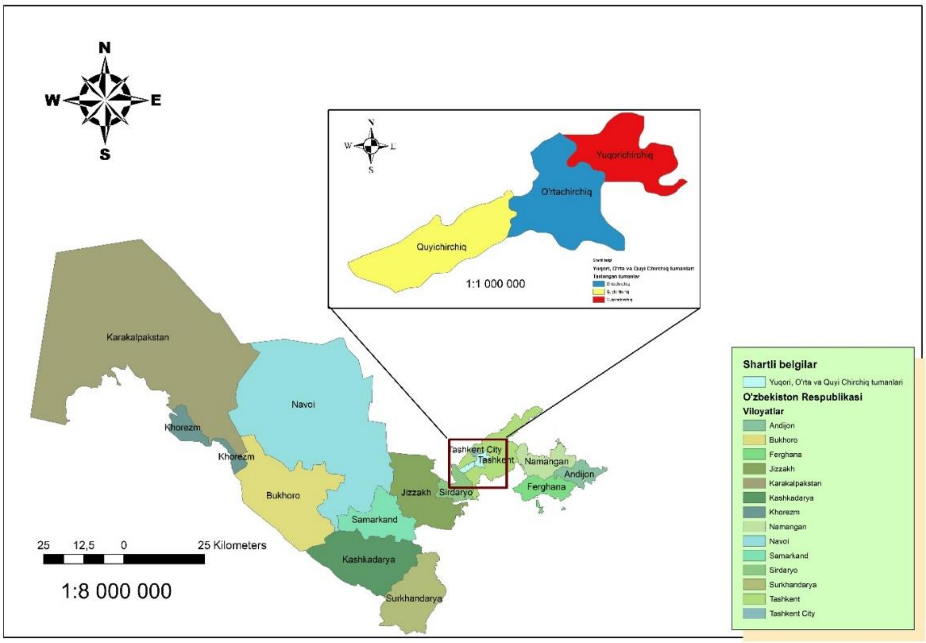


**Figure 1. Map of the selected study area**

**2.2. Geostatistical analysis of groundwater level and mineralization (IDW and Kriging)**

Two geostatistical methods were applied to convert the point data from observation wells into continuous surfaces. In the IDW (Inverse Distance Weighting) method, the degree of influence of each point is determined through an inverse function of the distance to it, and the value of the surface is calculated through a linear combination of the resulting values; it is a non-geostatistical method that enables fast and accurate analysis of large volumes of point data. The Kriging method, meanwhile, is carried out on the basis of the following expression:

$$Z(X_0) = \Sigma_{i=1}{}^{n}\ \lambda_i\ Z(X_i) \quad (3)$$

where: $Z(X_0)$ — the value being estimated at the point; $\lambda_i$ — weighting coefficients; $Z(X_i)$ — values at the observation points. The Kriging method accounts for the spatial correlation of surface variation based on the distance and direction between control points. Using both methods, and cross-referencing them against previously constructed topographic map data at matching locations, regional maps of groundwater level and mineralization were produced. To calculate the areas affected on the basis of pixel values, the results were converted to vector form using the "reclassify" function.

**2.3. Vegetation and salinization indices (NDVI, NDSI)**

To assess soil salinization in cropland and relate it to vegetation development status, NDVI and NDSI indices were calculated from Landsat-8 satellite imagery for April, July, and November of 2023 and 2025. NDVI is determined by the following formula:

$$NDVI = (Band5 - Band4) / (Band5 + Band4) \quad (4)$$

NDVI values range from −1 to +1: 0.6–0.8 indicates good vegetation condition, 0.3–0.5 indicates stress, and values below 0.3 indicate salinization or degradation; NDVI decreases as salinization increases. NDSI (Normalized Difference Salinity Index), meanwhile, is used to determine the degree of soil-surface salinization based on the difference in spectral reflectance between the red (R) and near-infrared (NIR) regions of the electromagnetic spectrum. Given the spatial resolution of Landsat-8 imagery (30×30 m, i.e., ~0.09 ha), the limited ability to detect salinized patches smaller than this resolution was taken into account as a limitation of the method.

**2.4. Determining the relationship between factors**

To determine the degree of relationship among groundwater level (GWT), mineralization, NDVI, and NDSI values, a correlation analysis was carried out using the corresponding statistical data at the points where the observation wells are located. The analysis was performed separately for 2023 and 2025, broken down by April, July, and November.

**2.5. Salinization index and reclamation coefficient model**

To combine the four factors — groundwater level (Hgw), mineralization (Min), NDVI, and NDSI — into a single indicator, a salinization index (Si) was proposed:

$$Si = w_1 \cdot f(Hgw) + w_2 \cdot f(Min) + w_3 \cdot f(NDVI) + w_4 \cdot f(NDSI) \quad (5)$$

Before being included in the model, all factors were normalized to the 0–1 range:

$$f(Min) = (Min - Minmin) / (Minmax - Minmin) \quad (7)$$

$$f(NDVI) = (NDVImax - NDVI) / (NDVImax - NDVImin) \quad (8)$$

$$f(NDSI) = (NDSI - NDSImin) / (NDSImax - NDSImin) \quad (9)$$

where the max and min values are determined in ArcGIS from the raster data of the selected plot. The weighting coefficients satisfy the condition $w1+w2+w3+w4 = 1$ and were determined not subjectively but objectively, through the entropy method (Shannon entropy weighting), based on the discriminating power (informativeness) of each factor across the selected plots. Based on the salinization index, the reclamation coefficient (Cmel) is calculated as follows:

$$Cmel = 1 - \alpha \cdot Si \quad (10)$$

where $\alpha$ is the impact-degree coefficient (ranging from 0.3 to 0.6), calibrated by linear regression based on the yield-loss percentages reported in source [127] according to the degree of salinization (15% for slightly salinized, 40% for moderately salinized, 60% for strongly salinized, and 70% for very strongly salinized land). The salinization index (Si) ranges from 0 to 1, where 0 indicates a good reclamation condition and 1 indicates a high risk of salinization.

### 2.6. Improved normative valuation model

The developed reclamation coefficient was integrated into the existing normative valuation model (the methodology set out in Cabinet of Ministers Resolution No. 744 of the Republic of Uzbekistan) in the following form:

$$Cn = Bb \times BHM \times Fr \times Mk \times Ck \times Hn \times Nh \times Im \times Cmel \quad (11)$$

where: Cn — normative value of irrigated cropland (thousand soums); Bb — soil bonitet score (0–100); BHM — 50% of the base calculation amount (thousand soums); Fr — profitability rate (10%); Mk — regional coefficient; Ck — water-supply coefficient; Hn — coefficient accounting for crop loss; Nh — normative yield of crops; Im — lease term of the land plot. The inclusion of the Cmel coefficient allows the effect of seasonal salinization on normative value to be introduced into the existing methodology on a scientifically grounded basis.

To test the model, six land plots on farms in O'rta Chirchiq district were selected. In this area, groundwater level was found to range from 1.2 to 3.5 m, mineralization from 1.5 to 5.8 g/L, NDVI from 0.38 to 0.74, and NDSI from 0.1 to 0.48.

## 3. Results

### 3.1. Spatial distribution of groundwater level and mineralization

The IDW analysis results showed that in April 2023 the groundwater level was somewhat higher, with most of the area falling within a rise range of 1.32–2.01 m; in July the rising trend continued, though slightly lower than in April. In November the rise was pronounced, with the main area falling within the 2.19–2.76 m range. Compared with 2023, the 2025 data showed a slight decrease in some ranges (0.00–2.00 m) and a slight increase in the higher ranges (2.55–5.04 m). Overall, groundwater level was relatively higher in spring and summer and lower in autumn, indicating a relationship between terrain elevation and groundwater level.

The Kriging method generally confirmed the IDW results and depicted the spatial distribution of areas with high salinization risk more precisely. The consistency between the two methods confirms the reliability of the geostatistical assessment.

### 3.2. NDSI and NDVI analysis results

According to the NDSI analysis results for the Yuqori Chirchiq, O'rta Chirchiq, and Quyi Chirchiq districts for 2023 and 2025, the degree of soil salinization was higher in November than in April and July in both years. Through reclassification based on pixel values, the areas corresponding to each salinization level were calculated; among the unsalinized, slightly salinized, moderately salinized, and strongly salinized groups, slightly and moderately salinized land occupied the largest area in both 2023 and 2025.

The NDVI analysis results likewise showed that areas with moderate and good vegetation-cover status were relatively larger in both 2023 and 2025. The correspondence between NDSI and NDVI dynamics indicates a relationship between the two indices, although this relationship manifests to varying degrees depending on the season (see Section 3.3).

### 3.3. Correlation relationships among factors

The correlation analysis for 2023 (Table 1) showed that no strong linear relationship was observed between groundwater level (GWT) and NDVI or NDSI across any of the months (coefficients ranging from −0.08 to +0.04, i.e., statistically close to zero). At the same time, a notable relationship was found between NDVI and NDSI within the same month: a strong positive relationship in April ($r = 0.97$) and a high level in July as well ($r = 0.83$), though this relationship declined markedly by November ($r = 0.29$).

**Table 1. Correlation coefficients among GWT, NDVI, and NDSI indicators in 2023**

| Indicator | GWT_April | GWT_July | GWT_Nov. | NDSI_April | NDSI_July/Nov. | NDVI_April | NDVI_July | NDVI_Nov. |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GWT_April | 1.00 | | | | | | | |
| GWT_July | 1.00 | 1.00 | | | | | | |
| GWT_Nov. | 0.71 | 0.71 | 1.00 | | | | | |
| NDSI_April | −0.01 | −0.01 | 0.01 | 1.00 | | | | |
| NDSI_July/ Nov. | −0.02 | −0.02 | −0.08 | −0.60 | 1.00 | | | |
| NDVI_April | −0.03 | −0.03 | −0.02 | 0.97 | −0.63 | 1.00 | | |
| NDVI_July | −0.02 | −0.02 | −0.07 | −0.62 | 0.83 | −0.63 | 1.00 | |
| NDVI_Nov. | 0.03 | 0.04 | 0.00 | −0.08 | 0.29 | −0.06 | 0.34 | 1.00 |

The 2025 results (Table 2) confirmed the overall trend: the coefficient between GWT and NDVI/NDSI ranged from −0.07 to +0.11 across all months, with no strong relationship identified. The relationship between NDVI and NDSI, however, varied sharply by season: strongly positive in April ($r = 0.95$), shifting to a negative direction in July ($r = -0.52$), and nearly zero in November ($r = -0.10$).

**Table 2. Correlation coefficients among GWT, NDVI, and NDSI indicators in 2025**

| Indicator | GWT_April | GWT_July | GWT_Nov. | NDSI_Apr/Jul | NDSI_Nov. | NDVI_April | NDVI_July | NDVI_Nov. |
|---|---|---|---|---|---|---|---|---|
| GWT_April | 1.00 | | | | | | | |
| GWT_July | 1.00 | 1.00 | | | | | | |
| GWT_Nov. | 0.90 | 0.91 | 1.00 | | | | | |
| NDSI_Apr/Jul | 0.08 | 0.08 | 0.11 | 1.00 | | | | |
| NDSI_Nov. | −0.05 | −0.05 | −0.07 | −0.50 | 1.00 | | | |
| NDVI_April | 0.06 | 0.06 | 0.10 | 0.95 | −0.54 | 1.00 | | |
| NDVI_July | −0.03 | −0.03 | −0.04 | −0.52 | 0.68 | −0.58 | 1.00 | |
| NDVI_Nov. | −0.02 | −0.02 | −0.03 | 0.06 | −0.10 | 0.05 | 0.36 | 1.00 |

The weak relationship of GWT with NDVI/NDSI, together with the variability of the seasonal relationship between NDVI and NDSI, indicates that the four selected factors (GWT, mineralization, NDVI, NDSI) represent independent and complementary, rather than redundant, dimensions of salinization risk. This independence is precisely what justifies the scientific necessity of combining them into a single weighted Si model — if all factors were strongly interrelated, there would be little practical value in accounting for them separately.

### 3.4. Weighting coefficients by the entropy method and the α parameter

The weighting coefficients w1, w2, w3, and w4 in the salinization index model were objectively determined through the entropy method (Shannon entropy weighting), based on the discriminating power of each factor across the six selected plots: w1(Hgw) = 0.225; w2(Min) = 0.266; w3(NDVI) = 0.251; w4(NDSI) = 0.258. The result shows that the four factors carry almost equal amounts of information, confirming that it is appropriate to include all of them in the model. The α parameter in the reclamation coefficient formula was calibrated by linear regression based on the yield-loss percentages by salinization degree reported in source [3], and $\alpha = 0.74$ was adopted.

**3.5. Test results using the example of farms in O'rta Chirchiq district**

The initial geophysical indicators of the six selected land plots are presented in Table 3.

**Table 3. Initial geophysical indicators of the selected plots**

| No. | Area, ha | Bonitet score | Groundwater level Hgw, m | Mineralization Min, g/L | NDVI | NDSI |
|---|---|---|---|---|---|---|
| 1 | 24 | 68 | 2.9 | 1.8 | 0.71 | 0.12 |
| 2 | 31 | 60 | 1.8 | 3.4 | 0.45 | 0.36 |
| 3 | 19 | 72 | 3.1 | 1.6 | 0.74 | 0.10 |
| 4 | 27 | 55 | 1.4 | 4.7 | 0.38 | 0.48 |
| 5 | 22 | 66 | 2.2 | 2.9 | 0.53 | 0.29 |
| 6 | 24 | 55 | 1.7 | 4.3 | 0.31 | 0.39 |

These data were normalized, and the salinization index (Si) and reclamation coefficient (Cmel) were calculated for each plot; on this basis, the normative values under the existing and improved methods were compared (Table 4).

**Table 4. Results of normative value calculated based on the reclamation coefficient (Cmel)**

| No. | Salinization index, Si | Reclamation coefficient, Cmel | Existing normative value, million soums | New (proposed) normative value, million soums | Value decrease, % |
|---|---|---|---|---|---|
| 1 | 0.07 | 0.94 | 272 | 257 | 6 |
| 2 | 0.67 | 0.50 | 240 | 121 | 50 |
| 3 | 0.00 | 1.00 | 288 | 288 | 0 |
| 4 | 0.96 | 0.29 | 220 | 64 | 71 |
| 5 | 0.48 | 0.64 | 264 | 170 | 36 |
| 6 | 0.86 | 0.36 | 209 | 75 | 64 |
| Total / average | — | — | 1,493 | 975 | 34.7 |

According to the results, while the total normative value of the six plots under the existing method was 1,493 thousand (million) soums, applying the reclamation coefficient reduced this figure to 975 thousand soums — an average decrease of 34.7%. The extent of the decrease varied widely across plots, from 0% (Plot 3, a reference plot that is effectively unsalinized) to 71% (Plot 4, highly salinized and highly mineralized). This demonstrates the proposed model's ability to clearly distinguish between the best- and worst-condition lands and enhances the practical value of the methodology.

**3.6. Mechanism for determining the reclamation coefficient**

Based on the study results, a mechanism was developed for determining the reclamation coefficient of irrigated land using geospatial-phase methods (Figure 2). The mechanism consists of the following main stages: 1) collecting geospatial data (observation wells, multispectral imagery) for the selected area; 2) analyzing the data using interpolation (IDW, Kriging) and spectral index (NDVI, NDSI) methods; 3) calculating the salinization index (Si) by normalizing the factors and weighting them using the entropy method; 4) determining the reclamation coefficient (Cmel) on the basis of the salinization index; 5) calculating the final normative value (Cn) by integrating the reclamation coefficient into the existing normative valuation model.

## 4. Discussion

The study results showed no strong mutual relationship among groundwater level, mineralization, NDVI, and NDSI, indicating that these four factors characterize the reclamation condition of land from different perspectives — hydrogeological (GWT, mineralization) and phyto-indicative (NDVI, NDSI). This is why combining them in a single model, particularly through an objective, non-subjective weighting method such as entropy weighting, allows for a comprehensive rather than one-sided assessment of reclamation condition. The instability of the seasonal relationship between NDVI and NDSI (especially the reversal of direction in summer) may result from the two indices reflecting different physical processes — vegetation condition and soil-surface characteristics — which once again confirms the need to base the model on all four factors rather than any single one.

The economic consequences of secondary salinization are very serious: according to scientists' estimates, yield loss amounts to 15% on slightly salinized land, 40% on moderately salinized land, 60% on strongly salinized land, and 70% on very strongly salinized land; overall, an average of up to 30% of cotton and grain output is lost on salinized cropland [1; pp. 102–118]. Financial losses caused by water-supply shortages combined with salinization, calculated for the example of Sirdaryo region, amounted to $1.7 million in 2004 and $2.49 million in 2007 [2; pp. 363–389], while in the Republic of Karakalpakstan, agricultural output losses of between $1.5 million and $15.9 million in various years [3; pp. 105–132] have been documented. Losses on this scale reveal the economic inequity of a valuation system that does not account for reclamation condition: salinized and unsalinized plots may end up with the same normative value, which can lead to incorrect bases for tax and lease payments, credit provision, and insurance pricing.

The proposed reclamation coefficient does not replace the existing methodology based on Resolution No. 744 but complements it — adding an objective correction coefficient, reflecting seasonal and regional dynamics, to the existing static valuation system based on the bonitet score. Although the test results (a decrease range of 0% to 71%) demonstrate the model's strong discriminating power, the method also has certain limitations: first, the IDW and Kriging results depend on the density of observation wells, and accuracy may decrease in areas where wells are sparsely located; second, the 30×30 m spatial resolution of Landsat-8 imagery hinders the detection of small salinized patches; third, the α parameter was calibrated based on a limited source [1] and it is recommended to re-verify it for other regions and crop types.

In practical terms, the proposed methodology can be applied in cadastral valuation, in assessing land collateral for credit provision, and in identifying priority areas when planning reclamation measures. By clearly identifying highly salinized plots whose value decreases sharply (for example, Plots 4 and 6), it becomes possible to allocate reclamation investment efficiently to priority areas at both the state and farm level.

## 5. Conclusion

Within the scope of this study, a geospatial approach was developed that comprehensively characterizes the reclamation condition of irrigated land through groundwater level, mineralization, NDVI, and NDSI indices, and this approach was integrated into the existing normative valuation model. The main conclusions are as follows:

1. Correlation analysis between groundwater level and mineralization (IDW, Kriging) and vegetation/salinization indices (NDVI, NDSI) showed that the four factors are independent, non-redundant sources of information, which scientifically justifies combining them into a single model.

2. The weighting coefficients objectively determined through the entropy method ($w1 = 0.225$; $w2 = 0.266$; $w3 = 0.251$; $w4 = 0.258$) confirmed that the four factors carry nearly equal informativeness.

3. The normative value calculated on the basis of the proposed salinization index (Si) and reclamation coefficient (Cmel), tested on six plots in O'rta Chirchiq district, decreased by an average of 34.7% (within a range of 0–71%) relative to the existing value, confirming the method's ability to clearly distinguish the actual reclamation condition of land.

4. The developed methodology enables the seasonal and spatial dynamics of salinization to be incorporated into the cadastral valuation system in a scientifically grounded, repeatable, and potentially automatable manner, thereby increasing the fairness of valuation in land taxation, leasing, and collateral-based financial services.

We believe that future research extending the study to other regions and crop types, recalibrating the α parameter on a broader dataset, and using higher-spatial-resolution imagery (such as Sentinel-2 or unmanned aerial imagery) will further improve the accuracy of the methodology.

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