Application of GIS technologies in the investigation of soil salinity

Ilkhomjon Abdullaev[1*], *Abdumanap* Nasirov[1], *Gayrat* Yakubov[1] and *Nargiza* Abdullaeva[2]

[1]National University of Uzbekistan, University str. 4, 100174, Tashkent, Uzbekistan
[2]Republican center of aerogeodesy, Xalqabad str. 8, 100000, Tashkent, Uzbekistan

Abstract. Soil salinization is the major problem affecting the productivity of irrigated lands. In Uzbekistan, irrigated area amounts to 4.5 million hectares or about 10% of Uzbekistan's total area and almost 46.6% of these lands are affected by increasing salinity. The main reason for these conditions of irrigated land is the effect caused by natural factors (primary salinity) - inefficient natural drainage, saline groundwater, high evapotranspiration rates, and high capillary capacity of the soil. Moreover, human-induced processes (so-called "secondary salinity"), which lead to the enrichment of mineralization of groundwater. The objectives of this study iarethe soil salinity monitoring of irrigated lands and the mapping of the temporal and spatial distribution of salt-affected soils for the Arnasay district of Jizzakh province in Uzbekistan to support land management. Field data collected in 2017- 2018 was analyzed and based on the analysis soil map was developed. In the research area, based on these maps changes in soil salinity were identified. The results indicate that inefficient irrigation activities in the region would affect to the enrichment of salts in the top soils and reduce soil productivity. The GIS technologies are efficient tools for monitoring salt-affected lands.

1 Introduction

In recent years, economic reforms have been carried out in the country, which is one of the important directions in ensuring the sustainable development of agriculture. Irrigated agriculture plays a critical role in the economic development of Uzbekistan. Irrigation is therefore the basis of food security, rural well-being, increasing land fertility and productivity, as well as a rapidly developing agro-industrial complex. In this regard, special attention is paid to the rational and efficient use of land resources in agriculture. The proper and efficient use of land as a means of production depends in many respects on the comprehensive study of its most important properties. For this purpose, land cadaster works are carried out in Uzbekistan. As a result of the work carried out the cadastral data were collected. These data are updated periodically and used to register ownership and ensure guarantees of rights to land plots, economic development, rational use, land conservation, and rehabilitation [1].

* Corresponding author: ilkhomjon.abdullaev@gmail.com

According to the statistics for the year, 2020 46.25% of the total area is used for agriculture. The irrigated land area in the country is 4329 thousand hectares, which is 9.6% of the total area. 95% of all agricultural products are produced in irrigated areas [1]. One of the main criteria in conducting land cadaster is the assessment of soil quality. It is important to take into account the level of soil salinity and melioration status in the assessment work. Soil salinity is one of the most important problems on a global scale as it negatively affects the productivity and sustainability of agriculture. Salinity problems arise in all climates and are the result of natural or anthropogenic movements, if irrigation methods are carried out without planning and proper management, this can trigger an increase in soil salinity [2].

Natural soil salinity comes through rising groundwater levels and the high evaporation of moisture. Secondary salinization means soil salinization due to human activities in irrigated agriculture. Soil salinization has a negative impact on land use, as soil quality degradation, and delays in studying the causes of salinization and its elimination can jeopardize the integrity of the soil's self-management capacity and lead to negative consequences. It is impossible to quickly eliminate soil salinity, but the use of modern technologies in the field of assessment and monitoring will allow observing and a better understanding of how salinity develops and development measures to reduce it. All work related to land conditions in the territory of the Republic of Uzbekistan is carried out on the basis of large-scale maps. In particular, large-scale maps are the main sources in the state land cadaster for land evaluation, accounting for each land user, monitoring, and other various survey activities.

In the last decade, there has been an intensive application of Geoinformation technologies for data processing, soil salinity analysis, and soil mapping. As a rule, this is due to their greater possibilities of visualization, analysis, and modeling of geographic objects and phenomena in comparison with traditional methods. Geographic Information Systems and remote sensing are important in creating these maps. The use of these technologies allows the provision of complete, efficient, and high-quality geospatial data on land resources in solving the problems of accounting, planning, and management of land resources [3,4].

Distinctive features of Geographic Information Systems are a high degree of formalization of all stages of the development of cartographic models based on geospatial databases, reducing costs and increasing the speed of mapping objective monitoring of reliability of results and empowering content analysis of soil-landscape relationships, as well as the possibility of obtaining new data [5,6,7,8,9]. GIS and remote sensing techniques for the delineating of salt-affected lands give excellent results in terms of accuracy, cost-effectiveness, speed, as well as labor savings [10,11].

Modern spatial analysis tools are considered highly effective for the detection, monitoring, and mapping of salt-affected areas and their Spatiotemporal variations. Spatial analysis tools have been used to analyze the spatial distribution of soil salinity by interpolating the results of laboratory analysis of soil samples [12,13,14,15,16,17].

In this work, the soil salinity maps were compiled, and the spatial dependence of soil salinity data was analyzed using geospatial analysis methods. These analyses allowed us to better assess the salt-affected soils and to monitor the spread of soil salinity in the irrigated area of the Arnasay district.

2 Materials and methods

2.1 Study area

As a research area was chosen irrigated land of Arnasay district which is located in the north of the Jizzakh Region of Uzbekistan at the latitude of 40°25'N - 40°45'N, the longitude of 67°42'E - 67°57'E, absolute height 256 m above sea level (Figure 1). Its borders were formed in 1975 and have not changed until now. The total area of Arnasay district is 492.73 km2, wherein the 481.67 km2 is used in agriculture. The relief of the region consists mainly of plains. The surface gradually rises from north and northwest to south and southeast. The study area has an extreme continental climate, with four seasons. The average temperature in January is from -1-5 degrees and up to 30 degrees in July. The average annual rainfall is 150-300 mm. Lake Aydar is located in the northern part of the Arnasay region. The soil is mostly Gray-brown, with partial salinity in the northeastern part.

Fig. 1. Location map of the study area.

2.2 Methods

In total, 624 soil samples were collected at different soil horizons (from depths: 0-30, 30-70, and 70-100 cm) from 208 different points for the period April, October 2017, and April, October 2018 with the envelope method (Table 1). In addition, groundwater samples were taken from these locations to determine the level and salinity of groundwater, in order to study their effect on soil salinity. The coordinates of the field survey points were recorded using a Trimble Juno 3B GPS navigator. Subsequently, soil samples at a depth of 0–30 cm were analyzed in the laboratory to obtain data on salinity.

Table 1. Soil salinity data.

№	2017	2018	№	2017	2018	№	2017	2018	№	2017	2018
1	3.83	4.04	**53**	4.61	6.38	**105**	4.86	4.22	**157**	3.31	6.03
2	2.47	2.32	**54**	6.28	6.20	**106**	3.96	3.48	**158**	4.23	4.09
3	3.74	5.29	**55**	4.68	3.90	**107**	3.36	6.02	**159**	3.58	4.10
4	4.33	4.89	**56**	4.21	4.49	**108**	2.40	2.44	**160**	4.33	4.78
5	3.27	5.13	**57**	4.96	5.00	**109**	4.83	9.99	**161**	3.60	4.77
6	3.46	5.05	**58**	4.77	4.35	**110**	4.65	3.91	**162**	4.18	5.68
7	4.18	4.65	**59**	4.35	4.16	**111**	7.41	5.74	**163**	3.00	3.22

8	2.92	2.95	**60**	3.05	4.59	**112**	4.40	5.30	**164**	3.41	7.30
9	4.82	5.06	**61**	5.21	5.55	**113**	1.44	4.63	**165**	3.47	4.00
10	4.29	3.44	**62**	4.27	5.98	**114**	2.57	5.69	**166**	4.25	5.43
11	7.12	6.00	**63**	3.57	4.36	**115**	3.34	3.65	**167**	5.37	4.67
12	5.52	4.77	**64**	4.66	3.55	**116**	3.62	2.53	**168**	4.10	5.67
13	4.01	3.33	**65**	2.88	5.06	**117**	3.72	4.34	**169**	2.45	5.13
14	7.14	4.97	**66**	2.31	3.83	**118**	2.94	3.79	**170**	2.98	3.91
15	7.25	8.78	**67**	2.12	2.78	**119**	3.19	5.46	**171**	3.54	4.27
16	3.37	3.57	**68**	3.06	3.90	**120**	3.54	3.15	**172**	2.53	3.94
17	3.85	4.70	**69**	1.91	3.00	**121**	4.09	3.85	**173**	3.85	4.48
18	4.47	7.11	**70**	3.79	3.06	**122**	4.18	4.33	**174**	8.38	4.78
19	5.49	6.10	**71**	2.80	2.94	**123**	8.77	4.26	**175**	3.67	3.50
20	4.15	4.29	**72**	3.50	7.66	**124**	4.24	3.48	**176**	4.00	4.10
21	3.63	6.10	**73**	3.79	2.94	**125**	3.64	4.45	**177**	4.06	2.53
22	3.90	4.57	**74**	5.16	3.84	**126**	3.36	4.69	**178**	4.66	4.86
23	4.92	4.71	**75**	3.42	4.60	**127**	4.55	4.31	**179**	3.78	3.50
24	5.08	5.91	**76**	4.36	4.79	**128**	5.17	6.70	**180**	4.93	6.73
25	4.38	5.36	**77**	3.37	5.61	**129**	5.72	5.43	**181**	2.73	3.93
26	4.18	8.79	**78**	2.47	3.41	**130**	4.25	4.46	**182**	3.62	5.72
27	4.52	7.27	**79**	3.57	5.10	**131**	4.07	4.10	**183**	2.27	4.54
28	4.31	5.90	**80**	2.88	2.61	**132**	3.28	4.57	**184**	4.15	5.29
29	4.66	4.59	**81**	4.24	3.22	**133**	4.65	3.83	**185**	2.47	2.95
30	5.35	5.30	**82**	4.50	4.61	**134**	3.73	6.26	**186**	4.99	3.44
31	2.84	3.75	**83**	6.94	4.34	**135**	3.37	3.44	**187**	4.71	5.97
32	3.25	3.86	**84**	4.91	2.99	**136**	3.89	6.92	**188**	2.94	4.96
33	4.42	7.64	**85**	4.63	3.43	**137**	4.87	3.44	**189**	3.28	3.42
34	4.95	4.50	**86**	4.07	4.93	**138**	3.82	4.90	**190**	5.33	5.75
35	4.96	5.48	**87**	2.39	3.66	**139**	2.94	4.58	**191**	4.18	4.13
36	4.27	3.09	**88**	3.56	4.26	**140**	3.84	3.67	**192**	3.86	6.31
37	3.80	4.55	**89**	2.76	3.30	**141**	4.21	4.72	**193**	3.83	4.63
38	3.97	2.93	**90**	2.78	4.41	**142**	5.20	3.30	**194**	3.64	5.10
39	3.35	3.88	**91**	3.86	4.30	**143**	3.34	3.11	**195**	2.14	4.15
40	3.27	3.96	**92**	4.72	4.29	**144**	4.97	4.19	**196**	6.47	6.81
41	4.60	3.78	**93**	3.31	4.85	**145**	3.41	4.30	**197**	3.30	6.24
42	3.20	5.27	**94**	4.27	3.46	**146**	4.57	4.23	**198**	3.83	3.03
43	3.77	2.95	**95**	4.48	5.05	**147**	2.69	3.54	**199**	2.95	4.94
44	4.10	5.31	**96**	4.15	4.32	**148**	5.00	3.82	**200**	4.38	5.64
45	10.65	3.90	**97**	2.82	2.72	**149**	3.72	8.15	**201**	3.68	5.23
46	4.74	6.12	**98**	3.41	3.27	**150**	3.27	4.46	**202**	4.41	3.53
47	5.51	6.57	**99**	4.00	4.80	**151**	7.33	2.88	**203**	4.22	9.63
48	4.83	6.05	**100**	4.08	4.77	**152**	3.21	4.66	**204**	3.88	3.99
49	3.47	4.87	**101**	3.70	12.26	**153**	3.13	3.39	**205**	4.88	4.22
50	5.21	6.92	**102**	4.90	3.42	**154**	2.73	3.26	**206**	4.01	5.33
51	5.43	4.90	**103**	7.48	2.55	**155**	4.38	6.14	**207**	2.55	5.93
52	4.68	4.01	**104**	5.82	4.14	**156**	4.34	4.10	**208**	3.16	3.59

3 Results and discussion

Using IDW spatial analysis tools, thematic digital maps were created which indicate spatial distribution and salinity level of soil in the territory of the Arnasay district (Figure 2 and Figure 3).

The soil salinity level map derived from the geospatial analysis revealed four classes of salinity levels with different extents of area, such as the non-saline, slightly saline, moderately saline, and highly saline soils.

According to these maps, it was revealed that in the Arnasay district in October 2017, non-saline and highly saline soils covered 1.17% and 1.81%, respectively of the total irrigated area, and were found scattered throughout the study area (Table 2). The slightly saline soil area was the largest in extent (17478 ha), which was 52.14% of the total irrigated area. Moderately saline soil covered 44.88%, which was mainly in the central and northern parts of the study area.

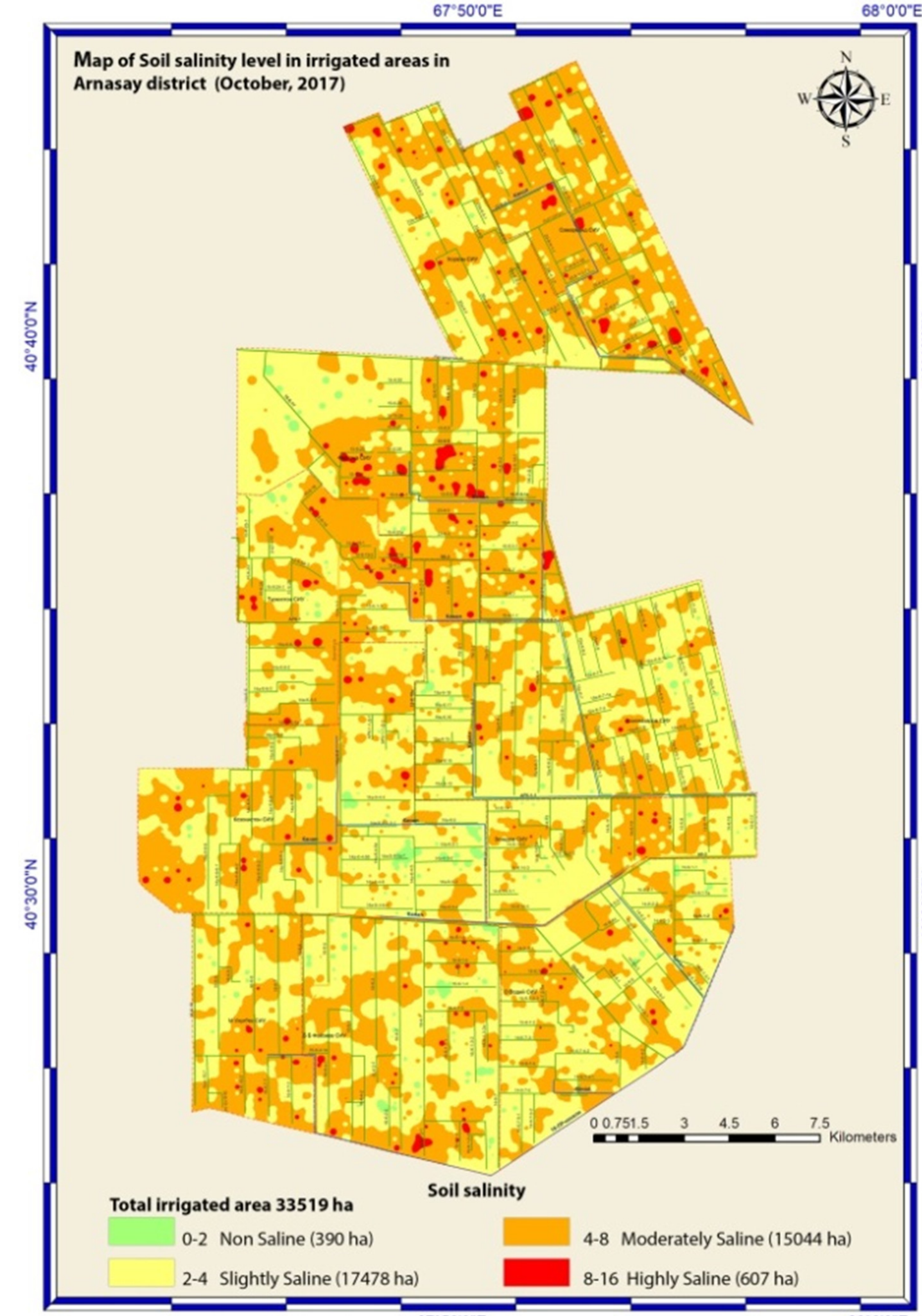

Fig.2. Map of Soil salinity level (scaled-down version).

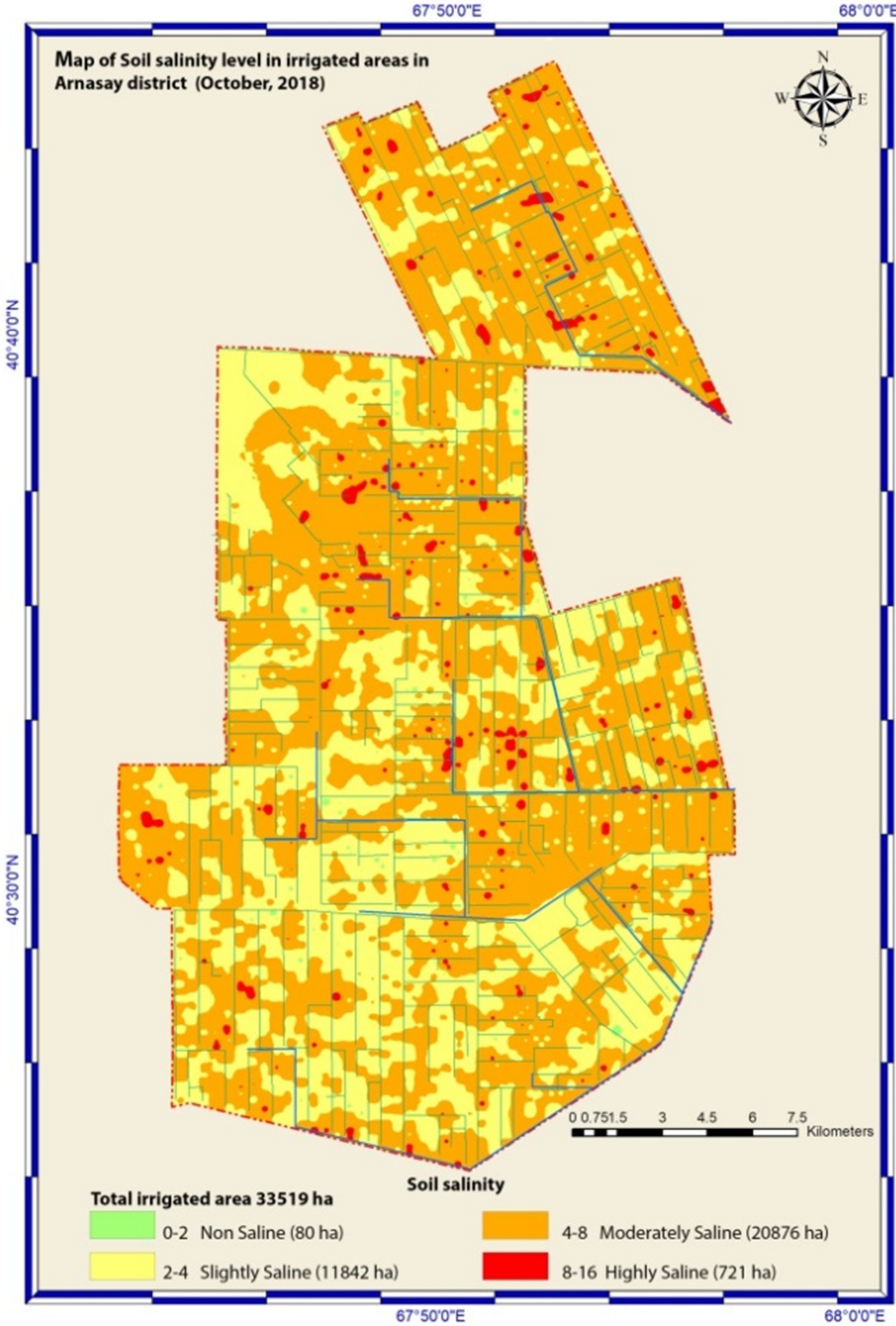

Fig.3. Map of Soil salinity level (scaled-down version).

And in October 2018, non-saline and highly saline soils covered 0.24% and 2.15% of the total irrigated area (Table 2). Slightly saline soil covered 35.33% and moderately saline soil area was the largest in extent (20876 ha), which was 62.28% of the total irrigated area.

Table 2. Area extent of soil salinity level derived from the map.

Salinity level (mS/cm)	Salinity extent	Area (ha) 2017	Area (%) 2017	Area (ha) 2018	Area (%) 2018	2018 as % of 2017
< 2	Non-saline	390	1.17	80	0.24	-79.49
2-4	Slightly saline	17478	52.14	11842	35.33	-32.24
4-8	Moderately saline	15044	44.88	20876	62.28	38.77
>8	Highly saline	607	1.81	721	2.15	18.78
Total		**33519**	**100**	**33519**	**100**	

4 Discussion

In this study, both the maps of soil salinity showed that slightly saline soils are largely concentrated in the southern and central parts, and the moderately saline soils are in the northern and central parts of the study area. Non-saline and highly saline soils are scattered throughout the study area.

In 2018 the areas of moderately and highly saline soils increased by 38.77% and 18.78%, and areas of non-saline and slightly saline soils decreased by 79.49% and 32.24%, respectively, compared to 2017. The analysis indicates that the condition of the irrigated lands of the Arnasay region is deteriorating, that is, the area of non-saline and slightly saline soils decreasing, while the area of moderately and highly saline soils is increasing.

According to the conditions of recharge and outflow of groundwater, this region belongs to the hydrogeological region of intensive external inflow and hindered outflow of groundwater. In addition, on-farm canals, collectors, and vertical drainage wells are in poor condition, their parameters do not correspond to design standards, which contributes to an increase in the level of groundwater. Especially the groundwater level rises due to the Aydar-Arnasay system of lakes and subsequently, the groundwater is close to the soil surface, and the rate of evaporation increases, which are largely contributing to the soil salinity.

Since the land of Arnasay district has been under irrigated agriculture for a long time, which is the major cause of the soil salinization in the study area. For more effective management of salt-affected soils, it is necessary to monitor the soil salinity. Soil salinity is influenced by many factors. Prediction of salt-affected areas can be made using the overlay soil salinity model developed based on factor layers, such as topography, geomorphology, meteorological conditions, human activities, hydrology, especially groundwater level and its mineralization, land use type salt-affected

5 Conclusions

In this study, we investigated the spatial distribution of soil salinity in the Arnasay district for October 2017 and 2018. The spatial distribution of salt-affected soils was analyzed with Geographic Information System, and IDW interpolation was conducted to illustrate the spatial distribution of soil salinity. The integration of Geoinformation technologies with traditional soil surveys leads toward a more accurate approach that is efficient and time-saving for digital mapping and predicting because it is currently the fastest and most reliable method of obtaining and geoprocessing data on the spatial distribution of salinity. Moreover, this is essential for assessing, analyzing, and significance the results of soil salinity monitoring, while ensuring temporal and spatial comparability between the indicators monitored.

The contributions of this study are summarized as follows:

1) this methodology is well established as a cost-effective manner on an operational basis to extract precise and timely information on different levels of salt-affected lands;

2) the results demonstrate a practical method and technique for mapping soil salinity monitoring;

3) these maps are of great importance in the timely detection and monitoring of soil salinity distribution in order to take the necessary mitigation measures.

The results of this study are necessary to take into account the areas of salt-affected soils, for cadastral and reclamation assessment of soil salinity, as well as monitoring salinity changes, which plays an important role in predicting further salinization, as well as detecting salinization in a timely manner before it harms the environment and hence can be used in similar areas that are experiencing problems with salinization.

References

1. *National report about the status of the land resources of the Republic of Uzbekistan*, National report The State Committee of the Republic of Uzbekistan on Land Resources, Geodesy, Cartography and State Cadaster (2020)
2. G. A. Tolipov, Kh. G. Gulomov, J. M. Maksudov, I. A. Akramov, *Land cadaster of the Republic of Uzbekistan* (1994)
3. G. Fan, H. Qiang, S. Xiaoyi, Y. Zhenglong, *Study on dynamic changes of the soil salinization in the upper stream of the Tarim River based on RS and GIS* J. Procedia Environmental Sciences, **11,** 1135-1141 (2011)
4. G. Aredehey, H. Libsekal, M. Brhane, K. Welde, A. Giday, *Top-soil salinity mapping using geostatistical approach in the agricultural landscape of Timuga irrigation scheme, South Tigray, Ethiopia* J. Cogent Food & Agriculture **4**(1) ,1514959 (2018)
5. T. Gorji, A. Tanik, E. Sertel, *Soil salinity prediction, monitoring and mapping using modern technologies* J. Procedia Earth and Planetary Science, **15**, 507-512 (2015)
6. M. Grunstra, O. Auken, *Using GIS to display complex soil salinity patterns in an inland salt marsh* J. Developments in Environmental Science*,* **5 (**2007)
7. R. A. MacMillan, D. E. Moon, R. A. Coupé, *Automated predictive ecological mapping in a Forest Region of B.C., Canada, 2001–2005* J. Geoderma **140**(4), 353-373 (2007)
8. Z. Shegena, K. Suryabhagavan, Balakrishnan, *Geo-spatial Approach for Soil Salinity Mapping in Sego Irrigation Farm, South Ethiopia,* J. Saudi Society of Agricultural Sciences, **16**(1), 16-24 (2017)
9. Y. G. Wang, C. Y. Deng, Y. Liu, Z. R. Niu, Y. Li, *Identifying change in spatial accumulation of soil salinity in an inland river watershed, China*, J. Science of the Total Environment**, 621**, 177-185 (2018)
10. S. I. Mohamed, A. R. Mohammad, S. Nahid, N. Biswajit, P. Alak, *Using geospatial techniques to assess the salinity impact on agricultural landuse: a study on Shyamnagar Upazila, Satkhira* J. Agriculture and Environment for International Development, **106**(2), 157-169 (2012)
11. A. Yaseen, Al-Mulla, *Salinity Mapping in Oman using Remote Sensing Tools: Status and Trends,* Monograph on Management of Salt- Affected Soils and Water for Sustainable Agriculture **(4)** pp 17–24 (2010)

12. A. Akramkhanov, D. Brus, D. Walvoort, *Geostatistical monitoring of soil salinity in Uzbekistan by repeated EMI surveys,* J. Geoderma*,* **213,** 600-607 (2014)
13. P. Desai and Sh. Giraddi, *Soil salinity mapping tool* J. International journal of emerging trends in computer science and electronics, **14**, 571-578 (2015)
14. P. Juan, J. Mateu, M. M. Jordán, J. Mataix-Solera, I. Meléndez- Pastor, J. Navarro-Pedreño, *Geostatistical methods to identify and map spatial variations of soil salinity,* J. Geochemical Exploration**, 108**(1), 62-72 (2011)
15. D. Khaksaran, A. Waismoradi, S. Moradi, H. Rahmati, *Spatial and temporal changes in soil salinity with geostatistics: A case study in Urmia Plain*, International Journal of Agriculture and Crop Sciences, **5**(3), 285-91 (2013)
16. L. Pozdnyakova, R. D. Zhang, *Geostatistical analyses of soil salinity in a large field,* J. Precision Agriculture**, 1**(2), 153-165 (1999)
17. H. Triki Fourati, M. Bouaziz, M. Benzina, S. Bouaziz, *Detection of terrain indices related to soil salinity and mapping salt-affected soils using remote sensing and geostatistical techniques*, J. Environmental Monitoring and Assessment**, 189**(4), 177-189 (2017)