GIS-based monitoring tool for decision-making on land and water management in Uzbekistan (Central Asia)

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ABSTRACT

Land and water resources monitoring is important to cope with salinization in Uzbekistan yet it is under-developed. Despite availability of widely-distributed spatial and long-term temporal data, managerial decisions are limited to current-and-previous-year analyses and output paper maps. Presently no state-of-the-art knowledge- and/or software-based decision support systems are available.

The spatio-temporal analysis of the groundwater table and salinity in Khorezm revealed that approx. 20% of the area experienced a rapidly increasing groundwater salinity above average levels (defined as “hotspots”), overlooked by standard methods. It is concluded that new analysis tools should be used for reliable decision-making.

Keywords: Salinization, Amu-Darya River, Khorezm, groundwater salinity, hotspots, GIS analysis

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1. INTRODUCTION

Salinization is a danger of arid and semi-arid irrigated agriculture (GHASSEMI et al. 1995). When not taking care, salinity may have a negative impact on land productivity and crop yields and leads to ecological degradation of land and water resources (HILLEL 2000). In Central Asian Uzbekistan, around 50% of the irrigated areas are saline to a different degree (MAWR unpublished annual reports); the remaining areas are prone to salinity. Salinization processes are especially acute in Khorezm region, located south of the ecologically endangered Aral Sea region, in the Amu-Darya River delta.

Two principal sources of salinity are surface waters as well as groundwater (GW) (KATS 1976). While the salinity of the surface waters in Khorezm during the growing period is 0.6 – 0.7 g l^{-1}, that of GW is much higher (MAWR unpublished annual reports). Hence the Government of Uzbekistan (GoU) maintains an intensive GW monitoring system and continuous records are provided for both GW depth and salinity. In addition, many other variables including soil salinity, irrigation and drainage quantities and their salinities have been annually collected. More than 87% out of the total of 275,000 ha of irrigated land in Khorezm are under the control of a large number of staff in each district. Every year, substantial funds are directed to the maintenance and operation of more than 2000 monitoring wells, irrigation and drainage networks and the other management and monitoring facilities from the state budget given to water management agencies.

Despite the importance and relatively large investments into the monitoring of GW and other variables, the analysis of this information is under-developed. After processing the data, it takes weeks, if not months, to manually draw paper maps of the GW table. The last base paper maps were prepared more than 15 years ago (pers. comm.) and are extremely outdated, which adds inaccuracy in the maps. The readings are recorded and then transferred manually to create maps, which obviously is subject to errors. Moreover, the controlling opportunities are reduced. Maps are drawn based on the linear interpolation between data values utilizing the method of triangulated irregular networks (TIN). Therefore, the final maps contain large errors, they become rapidly outdated as GW fluctuations are very dynamic, which significantly limits the management decisions.

Computerized data processing approaches are not yet introduced aside from a data coding procedure and data analysis is restricted to a simply static comparison of the readings of previous with those of current years. Modern GIS and geostatistical techniques (e.g., see WILSON et al 2001) allow handling of large datasets to perform analyses of both spatial and temporal changes. These techniques allow not only a quick visualization and mapping of the variables of interest, but also show the accuracy of the interpolation (ISAAKS & SRIVASTAVA 1989). GIS allows bringing together various variables for the subsequent cause-effect analyses. A multivariate statistical approach was applied to detect general long-term trends in a savannah landscape in Ghana to identify the human-induced land cover changes (PARK et al. 2003). The study showed accelerated changes locally ("hotspots"), while the majority of land surfaces showed gradual transitions or evolution from one state to another. Identification of such "hotspots" may greatly enhance an ability to identify significant processes underlying dynamics of investigated variables and allow more site-specific and targeted ecological and policy interventions. Yet, this procedure has not been employed at larger scale areas and in an irrigation landscape.

This study was conducted to compare the traditional (current) and modern GIS and geostatistical methods of GW table data analysis, and characterize the long term changes in GW salinity over the region with the aim to recommend the changes in current practices of data analysis for better monitoring and management of the land and water resources.

2. AREA DESCRIPTION

2.1 Environmental conditions of the region

The Khorezm region (Figure 1) is located in the northwestern part of Uzbekistan between latitude 40o27` and 41o06` north, and longitude 58o31` and 61o24` east (MUKHAMMADIEV 1982). The region is surrounded by the deserts Karakum and Kizilkum in the south, southwest and west and has an extremely arid continental climate. The Amu-Darya River makes the northeastern border of the region.

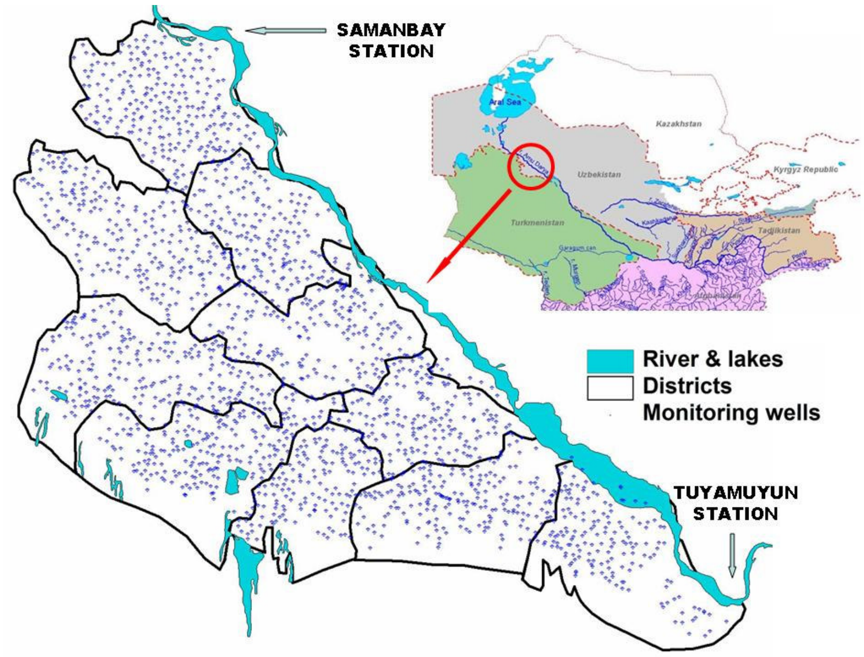


Figure 1: Khorezm region, The Amu-Darya River and distribution of monitoring wells and irrigation and drainage networks

The high temperature of 33°C and more (Figure 2) and the low relative humidity occur between May and August, leading to the highest water demand of the crops. Long-term precipitation is 100 mm and does not have a significant influence on surface and ground waters. Potential evaporation is extremely high, exceeding precipitation ca. 14 times (MUKHAMMADIEV 1982). Evaporation rises already in April reaching its maximum in July.

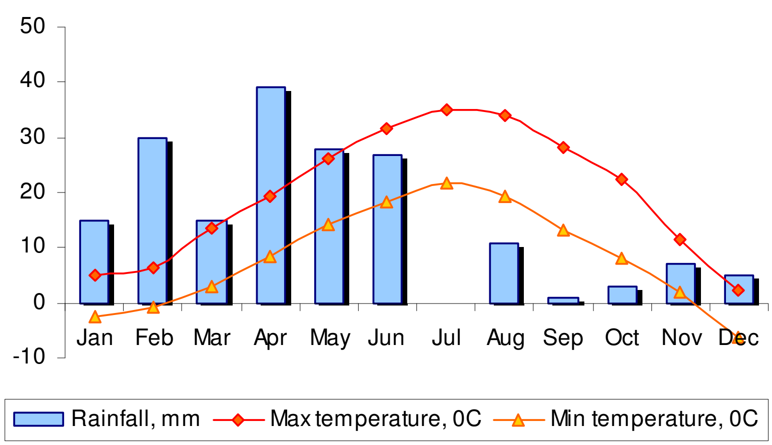


Figure 2: Monthly average air temperature and precipitation at the study site for the period 2002-2003. Long-term annual rainfall mean is 100 mm. (Source: LAMERS et al. 2005).

Khorezm region is mostly flat and distinguished by elevation points in the range 112 – 138 m asl (KATS 1976). Because of the flatness the meandering Amu-Darya River intensively affected the soil lithologic structure throughout the region (NURMANOV 1966). Coarse-textured particles deposited along the river banks have created levees, whereas finer textures deposited in the lowlands have given rise to heavy soils. After flooding periods, temporary streams changed into lake water causing soil stratification that ranged from a few centimeters to some meters (TURSUNOV & ABDULLAEV 1987; POPOV et al. 1992). According to POPOV et al. (1992) quaternary depositions filled the depressions with the thickness 20 – 100 m. Underlying tertiary and cretaceous strata form an impervious layer for the upper-stratum waters. The thickness of the upper loamy-clayey, sometimes sandy-loamy horizons is 1.5 – 2.0 m, which increases to 3 – 4 m over the ancient river beds, and to 6 – 8 m in the southern periphery of the region. This difference has a great influence on the GW table and salinity dynamics (KHODZHIBAEV 1979; MUKHAMMADIEV 1982).

Upland cotton (*Gossypium hirsutum*) is the dominant crop in Khorezm (54.2% of the whole irrigated area in 2000) followed by winter wheat (9.4%) and rice (8.2%). The crops are irrigated with surface furrow and flood irrigation. Water is supplied through a complex-hierarchy irrigation network consisting of main, inter-farm and on-farm canals only 10.9% of which was lined (VODPROJECT 1999), which leads to GW rise (DZHABAROV 1990). Leaching is practiced throughout the region; water is applied from as much as ca. 4000 m^3 to the low saline fields up to ca. 6000 m^3 to the strongly saline areas. The open horizontal drainage network is used to remove excess infiltrated water and GW from the fields.

GW salinity is characterized by lower values in the vicinity of the Amu-Darya River, being of predominantly sulphate – hydrocarbonate and sulphate type. In contrast, the GW salinity level in the Ozerny region is of the chloride type (KATS 1976; MUKHAMMADIEV 1982).

2.2 Data collection

GW table and salinity datasets were obtained from the Hydrogeological Melioration Expedition (GME) of the Khorezm Department of Agriculture and Water Resources, Uzbekistan. The data had been collected from 1987 monitoring wells during a period of 11 years (1990 – 2000). These wells were evenly distributed over most of the area (see Figure 1).

The GW table was measured every 5 days during the growing periods from March – August and every 10 days outside the growing period. Monthly-averaged data were used in the study. The depth is measured using a tapeline with a cylinder that flaps when it reaches the water surface in the well. A correction for the absolute elevation point for each well is performed by the GME staff for each measurement.

GW salinity measurements are conducted three times a year every first day in April, July, and October. The reason for conducting measurements in April is to assess the influence of leaching practices conducted in February – March on the dynamics of salinity in GW over time. Because July is a peak and October falls outside the irrigation period, the influence of intensive irrigations and their absence on GW salinity dynamics can be assessed. The water samples are analyzed for total dissolved solids (TDS) and chloride content; TDS measurements were used for this study to characterize the GW salinity.

3 METHODS OF ANALYSES

3.1 Spatial analysis of groundwater table

The dataset of GW table and salinity was analyzed using both the kriging and TIN interpolation techniques. Following the exploratory data analysis and removal of outliers (these were less than 5%) an experimental and model variograms of the GW table were constructed. The existence of the *nugget variance* was analyzed and taken as an indicator of the spatial data density, existence of micro-scale variability and measurement errors. Cross-correlation was performed to identify the accuracy of the kriging performance. In contrast to kriging, validation was performed using the training and test dataset in the TIN method. The test dataset consisted of 10% of all of the data, and the training dataset of 90%.

3.2 Spatiotemporal analysis of groundwater salinity

Detection of changes was performed with the purpose to identify any directional changes within the study region. Sixteen randomly selected measurements of the GW salinity in April, July and October were chosen for analyses. A description of the change detection method can be found in Park et al. (2003). In order to separate the long term directional changes from the seasonal and error terms the mean of the GW salinity measurements was correlated with its variance. The changes were then separated following the residual analysis.

4 RESULTS

4.1 Spatial estimation of groundwater table with kriging

Analysis of the variogram showed no trend (global change) in GW data. However, there was anisotropy (local change in data) in all the measurement periods. The variogram in the direction east – west had a clearer structure with a longer range (distance of autocorrelation), which was therefore chosen to estimate the GW table at the unmeasured locations (Figure 3).

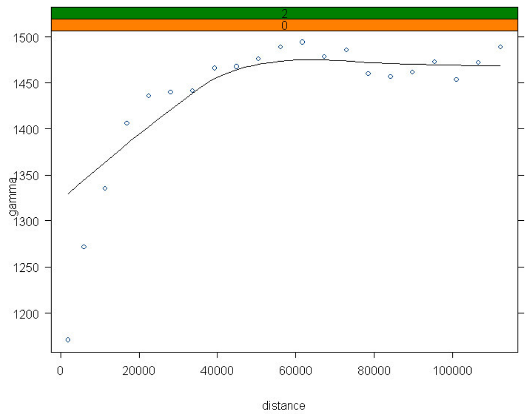


Figure 3: Variogram of the GW table in the east-west direction

A large nugget variance is seen in the chosen variogram in Figure 3 as was the case in the variograms for all the measurement periods. This is indicative of the high variability of the readings taken from the nearest monitoring wells. The most likely reason is the too coarse spacing between the monitoring wells as well as the possible influence of canals, drains and other environmental factors on the readings. Table 1 shows the parameters of the kriging model with the example of measurements taken in April, July and October in 1990, 1994 and 2000.

Table 1: Parameters of kriging interpolation method for groundwater table

Year	Measurement period	Range	Sill	Nugget	Function
	April	17373.15	337.81	1515.85	Spherical
1990	July	7407.20	513.99	1304.83	Exponential
	Oct	883672393.27	6703365.10	2314.94	Spherical
	April	8454.38	402.80	1084.75	Exponential
1994	July	8337.90	498.64	1465.85	Exponential
	Oct	28242.53	659.08	1965.62	Spherical
	April	9383.39	724.68	1594.78	Exponential
2000	July	16839.51	1227.36	1818.76	Exponential
	Oct	454006.37	14789.35	2435.15	Exponential

Table 2 shows the prediction and standard errors of the estimated (predicted) versus measured values of GW table. The values of average standard errors for most measurement periods were close to the associated root mean square errors. This is indicative of the correct assessment of the variability in the data by the chosen parameters of the kriging model. Greater average standard errors over the root mean square errors indicate that the model in most cases slightly overestimated the variability of interpolated values. The variability of estimations in all the measurements in 2000 and in 1990 (except for the measurement in April) were overestimated, those in 1994 were underestimated. Similar information is contained in the root mean square standardized error. The standardized mean and root mean prediction errors were close to zero and one, respectively in all the measurement periods, which indicates that the model parameters were chosen correctly.

Table 2: Prediction and standard errors of estimated versus measured values of groundwater table with kriging interpolation method

Year	Measure-ment period	Mean Errors	Root-Mean-Square Errors	Average Standard Errors	Mean Standardized Errors	Root-Mean-Square Standardized Errors
	April	0.053	40.89	40.58	0.00133	1.007
1990	July	0.006	38.67	39.73	0.00006	0.973
	October	-0.005	46.94	49.25	-0.00048	0.953

	April	-0.114	37.04	36.17	-0.00313	1.023
1994	July	-0.196	40.99	40.59	-0.00463	1.009
	October	0.043	44.04	43.9	0.0007	1.004
	April	-0.039	42.35	42.59	-0.00095	0.994
2000	July	-0.15	44.4	45.59	-0.00337	0.974
	October	-0.189	47.22	48.08	-0.00412	0.983

However, the root mean square prediction error was close to or exceeded 40 cm for most estimated measurements. This shows that although the model parameters were chosen correctly, the model estimated values with a large error. Cross-validation revealed that the error (subtraction of estimated and measured values) varied from 0 to 150 cm. Examination of the prediction standard error map clearly reveals higher errors in sparse data areas, whereas low errors were associated with the denser data areas. Low (close to zero) estimation errors proved that kriging performs well in delineating the spatial distribution of GW table, whereas high errors showed the need for denser measurements in Khorezm to improve accuracy of mapping.

Figure 4 shows the maps of the GW table estimates in April, July and October 1990 using the kriging method. The areas with extremely shallow GW appear in the southern, western and north-western districts of the region, namely in the Pitnyak, Khazarasp, part of Bogot and Yangiarik, Khiva, Shavat and Gurlan districts. A GW table at the distance of 1 m to the soil surface is regarded as a critical level as it may influence secondary salinization problems due to intensive evapotranspiration.

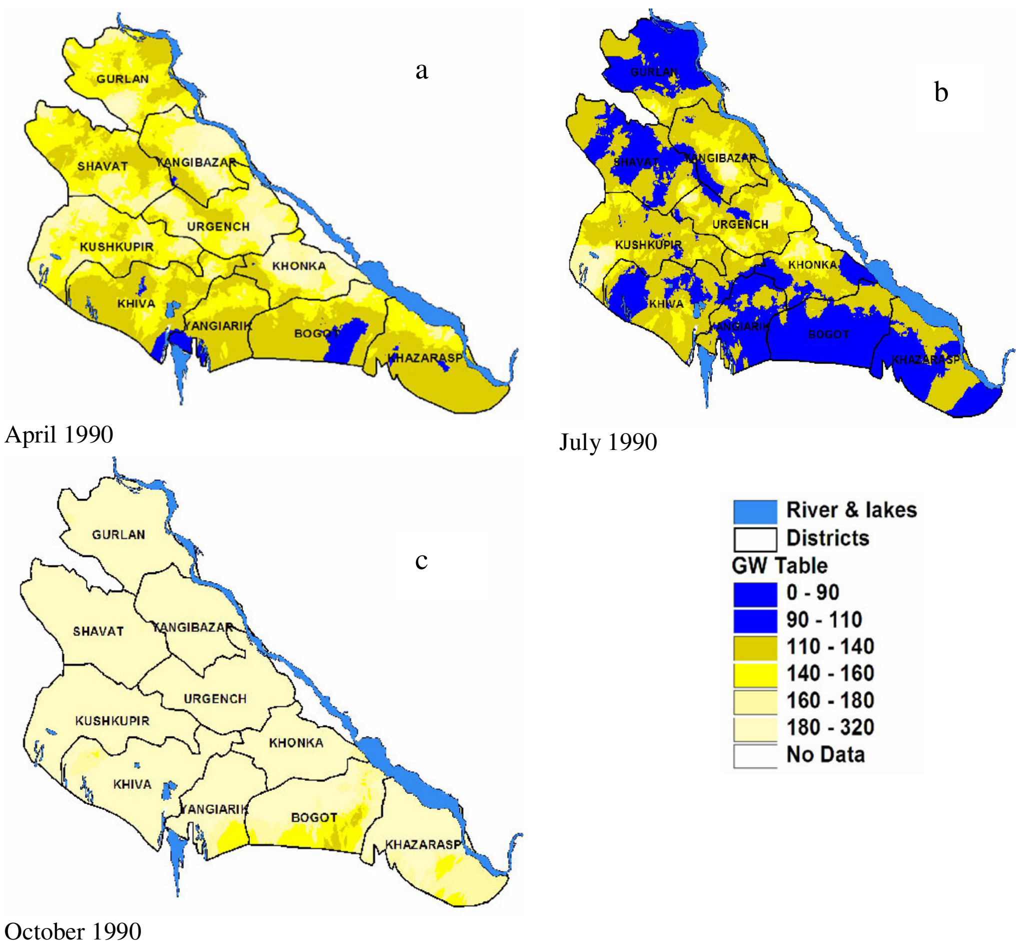
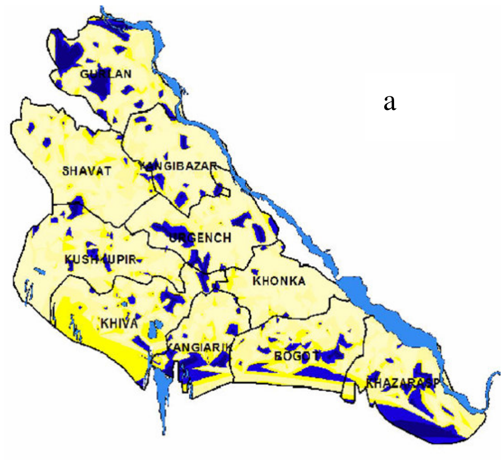


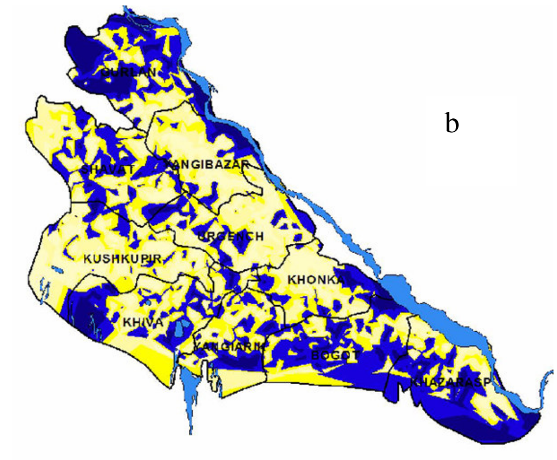
Figure 4: Maps of groundwater table in April (a), July (b) and October (c) 1990 produced with kriging interpolation method. The areas with GW tables at 1 m below the ground surface and shallower are marked dark.

4.2 Spatial estimation of groundwater table with TIN

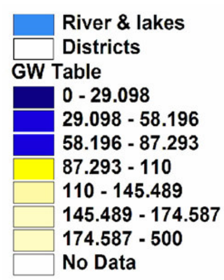
Figure 5 (a, b and c) shows the GW table interpolated for April, July and October 1990. The spatial distribution of the GW table is patchy, without clear spatial domains. The patterns of the more shallow GW tables in the southern and western parts of the region are not as pronounced as with interpolations using kriging.



April 1990



July 1990



October 1990

Figure 5: Maps of groundwater table in April (a), July (b) and October (c) 1990 produced with TIN interpolation method. The areas with GW tables at 1 m below the ground surface and shallower are marked dark.

Table 3 shows the prediction errors of the TIN from the training and test datasets and a comparison with the errors produced by the kriging method. The prediction errors produced by the TIN were much higher compared to the kriging method, indicating that TIN is not acceptable for the spatial assessment of GW table and salinity in Khorezm as it may produce improper estimates with large estimation errors.

Table 3: Errors of estimated versus measured values of groundwater table in April, July and October 1990

Measurement period	Mean error		Root-Mean-Square error	
	TIN	Kriging	TIN	Kriging
April	8.85	0.053	889.79	40.89
July	-4.698	0.006	882.4	38.67
October	-1.298	-0.005	1021.04	46.94

5. IDENTIFICATION OF SPATIAL PATTERNS OF GROUNDWATER SALINITY

5.1 Change detection method

The relationship between the mean and standard deviation of the GW salinity was linear with a high coefficient of determination (Figure 6). While most points in Figure 6 are scattered along the regression line, some significantly deviate both in positive and negative directions. It is assumed that the areas that show significant deviation from the regression line reflect significant, possibly human-induced, GW salinity changes, which were caused by other than seasonal land management and measurement errors.

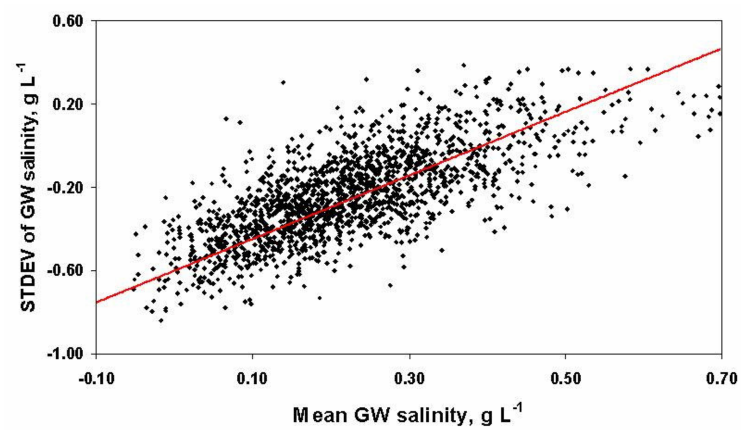


Figure 6: Relationship between mean and standard deviation of GW salinity

The residuals of the GW salinity are presented in Figure 7. A standard deviation scale was chosen for the legend, which separates both positive and negative values from the mean. The scale indicates the relative intensity of GW salinity changes (salinity change index) over the last 10 years. A higher positive salinity change (red color) indicates increasing temporal trends in GW salinity, whereas a negative change (grey color) indicates decreasing trends.

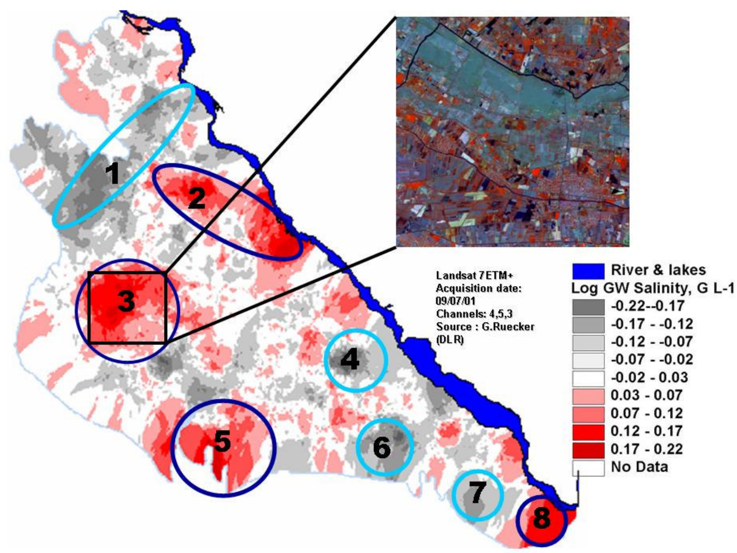


Figure 7: Identified local areas with rapid temporal changes (hotspots) of groundwater salinity during the study period

The existence of the spatial domains indicated that there were some relatively large areas that have experienced negative changes in GW salinity during the study period. The magnitude of the hotspots is approximately 20% of the irrigated area or some 50 – 55 thousand hectares.

6 DISCUSSION

6.1 Interpolation methods

The introduction of the spatial assessment of GW table and salinity occurred in Uzbekistan as early as 1969 (Zhelobaev and Gofman 1969). To develop a GW monitoring network it was necessary to take into account the possible influence of the irrigation and drainage canals, changes in soil lithology, stratification, salinity and many other factors on GW table and salinity dynamics. Where the changes of GW table and salinity were insignificant, environmental conditions similar, etc., the methodology allowed one monitoring well over 100 ha.

The development of the monitoring network in Uzbekistan continued from 1970s till 1990s. After the breakdown of the Soviet Union in 1990s and economic difficulties the construction of the new and maintenance/renewal of the existing wells rather reduced. As a result, the spatial coverage of the wells was 140 – 150 ha. Taking into account the wide distribution of heavy, medium and light texture and stratification in the soils of the region (Tursunov and Abdullaev 1987), different cropping patterns and water supplies, and huge water losses through the laterals of the irrigation canals (Dzhabarov 1990) among other factors, even a complete observance of the regulations of 1969 would not decrease the small-scale variation revealed by the kriging method. Rather than investing only into the construction and maintenance of a monitoring network, the government could encourage the farmers to conduct the GW table and salinity measurements as these are the prerequisites of increased management opportunities for better crop yields. The water management agencies may than concentrate on providing technical support for example in the form of maps of the spatial distribution of GW table and salinity and recommendations concerning the best possible changes in cropping patterns based on the GW assessment.

Although the kriging interpolation method proved to produce more accurate maps compared to the TIN method, it requires knowledge of statistics and geostatistics. The method of inverse distance weighting (IDW) also requires the knowledge of statistics as an exploratory data analysis is necessary prior to estimation. However, the IDW method is easier to investigate and implement. During the interpolation the influence of the irrigation and drainage networks to the spatial distribution of GW table and salinity must be taken into account by limiting the internal interpolation through lines of canals and drains (defining line theme in ArcView GIS as a barrier theme).

6.2 Spatiotemporal changes of groundwater salinity

The analysis of the GW salinity revealed the occurrence of the areas where the salinity levels were increasing above average levels over the study period. Environmental conditions in the region (e.g., heterogeneous stratified soils, spatial influence of irrigation/drainage network, local agricultural practices, etc.) may easily promote more pronounced negative salinization processes over some areas, whereas the changes can be smoothened over other areas. As Dzhabarov (1990) claimed, soil stratification over most of the irrigated areas in Khorezm causes GW to move primarily in a vertical direction within the upper soil profile, whereas lateral GW flow is unconfined in the lower soil stratum. This causes salt accumulation in the top GW layer and then in the soil rooting zone, whereas in the sandy soils where such a mechanism does not exist.

GW table and salinity samples were drawn from the wells, which have different, inhomogeneous depths, but in most cases perforate much deeper than 3 meters. Dzhabarov (1990) investigated the soil conditions in Khorezm between 1960s and 1980s through analysis of the data from the monitoring wells of GME. He showed that the readings of the GW salinity from the monitoring wells rarely exceeded 2–3 g l-1, whereas the salinity readings taken just near the monitoring wells but from upper heavier textured horizons are 2 to more than 4 times higher than those taken from the monitoring wells. Own samplings as well as other studies (Forkutsa pers. comm.) in 2001 showed similar results. This may indicate that the hotspots might not exist in reality. However, the governmental dataset is the only official source of information on GW table and salinity, based on which the decisions concerning land and water management are made. With the current practice of data analysis, hotspots can never be identified and so, the changes will remain undetected.

The changes in agricultural practices after breakdown of the former USSR in 1990s could be characterized as being probably more negative than positive (FAO 2000). As reported by missions of FAO and European Bank of Reconstruction and Development (EBRD), drainage ditches become degraded due to the difficult financial situation of the majority of private farmers and state farms. According to law, the farmers are responsible for cleaning the on-farm irrigation and drainage canals. However, facing a severe lack of financial support, the farmers will probably pay more attention to cleaning the irrigation canals than to cleaning the drainage ditches. Furthermore, to improve their financial situation, the farmers put more emphasis on growing more remunerative crops such as rice (Djanibekov 2005), which requires more water. In areas farther away from the canals farmers may block the drains to artificially raise the GW table to provide sufficient soil moisture for plants to grow. In some cases this could lead to a certain yield without irrigation at all (Forkutsa et al. 2004)

Such changes in agricultural practices are difficult, sometimes impossible to prevent by the management agencies. However, once the negative changes are detected and presented to the farmers, the necessary actions can be taken as to what the government should do to alleviate the situation and what the farmers should change in their practices. If the methodology of the data analysis were based on up-to-date techniques then the occurrence of the hotspots in Khorezm could probably have been foreseen at a much earlier stage and could eventually have been avoided.

7. CONCLUSION

7.1 Prediction and accuracy of interpolation

The current practice of GW delineation and mapping produces only partly the real situation of its spatial distribution, which may lead to improper decisions regarding amounts of water applications and drainage maintenance. In opposite, using long term data the kriging method produced maps of GW table with a substantial accuracy although the occurring errors are associated with the distance between the closest monitoring wells and other factors. The maps produced utilizing the TIN method, were patchy, without clear patterns. Therefore, choosing the proper method of spatial estimation and automating this process on the computers is an important prerequisite for faster and reliable data analysis and subsequent decision-making. Surely, the use of geostatistical methods should be applied to spatial estimation and mapping not only of GW table but also of the other environmental variables e.g., soil moisture, salinity.

The kriging method proved to be a reliable method for delineating the GW table and salinity in Khorezm, yet it requires the knowledge of statistics and geostatistics as well as computers powerful enough to handle a large number of data points. Inverse distance weighting (IDW) interpolation method also requires computer processing, but from the practical viewpoint this may be the best interpolation method for the conditions in Khorezm. The analysis of the estimation errors (not shown) showed that the accuracy of the IDW method is similar to that of kriging. A more precise (i.e., denser) sampling is an important factor whatever interpolation method is chosen.

The use of an incorrect interpolation method or large prediction errors can have serious negative implications. The large estimation errors indicate that GW table and salinity in Khorezm are improperly delineated, which leads to the incorrect assessment of the magnitude and location of the problem areas. Since the water management agencies face a severe lack of resources the over-estimation of areas at risk will scatter the scarce resources to areas where perhaps agricultural production is not actually jeopardized by shallow or saline GW.

7.2 Long term spatiotemporal changes

GW salinity increase may easily occur in any place of the region thus leading to the environmental degradation of scarce land and water resources and affecting farmers' incomes. Moreover, accelerated negative changes over some areas may create the need for extra investments, natural and human recourses, which at the end can be prohibitively expensive. Having an updated methodology and (GIS) tools of a long term monitoring it becomes possible to detect any negative changes at the early stages.

REFERENCES

Ghassemi, F, Jakeman, A and Nix, H. 1995. Salinisation of Land and Water Resources. Human causes, extent, management and case studies, Oxford, CAB International. Pp 2-16, 240-267.

Hillel, D. 2000. Salinity management for sustainable agriculture: Integrating science, environment, and economics. The World Bank. Washington, DC.

Kats, D. M. 1976. The influence of irrigation on the groundwater. Kolos Pub, Moscow. (in Russian).

(MAWR) Ministry of Agriculture and Water Resources of Uzbekistan

Wilson, J. P, Mitasova, H. and Wright, D. J. 2000. Water Resource Applications of Geographic Information Systems. URISA Journal. Vol. 12 (2).

Isaaks, E. H. and Srivastava, R. M. 1989. An introduction to applied geostatistics. Oxford University Press, Inc. New York.

Park, S. J., van de Giesen, N. and Vlek, P. L. G. 2003. Optimum spatial scale for modeling land use change processes in a savannah landscape in northern Ghana. Agriculture, Ecosystems and Environment

Mukhammadiev, U. K. 1982. Water resources use. Tashkent, Uzbekistan (in Russian).

Zhelobaev, A. A., and Gofman, O. N., 1969. Posobie k vremennoy instruktsii po otsenke i uchetu meliorativnogo sostoyaniya oroshaemih i osushennih selskohozaystvennih ugodiy i technicheskogo sostoyaniya gidromeliorativnih sistem (1-ya redaktsiya). Moskow (in Russian).

Lamers J.P.A., Khamzina A. and Worbes M. 2005. The analyses of physiological and morphological attributes of ten trees species as determining components for their suitability in the rehabilitation of degraded landscapes in the Aral Sea Basin of Uzbekistan. Forest Ecol Manage (forthcoming).

Nurmanov, A. N. 1966. Salinization and waterlogging of land in the Amu-Darya River Delta. Nukus, Karakalpakia (in Russian).

Popov V. G., Sektimenko, V. E. and Tursunov A. A. 1992. Soil cover change in the contemporary Amu-Darya River delta under the influence of anthropogenic desertification. Fan, Tashkent, Uzbekistan (in Russian).

Tursunov, L. T. and Abdullaev, C. 1987. Soil-physical characteristics of the lower Amu-Darya (in Russian). Fan, Uzbekistan, Tashkent

Khodzhibaev, N. N. 1979. Natural flow of groundwater in Uzbekistan. Fan, Tashkent, Uzbekistan (in Russian).

Vodproject 1999. "VodProject" Production Association, Ministry of Agriculture and Water Resources, Uzbekistan. Annual report.

Dzhabarov, H. 1990. The analysis of the indicators of ameliorative conditions in irrigated areas of Khorezm region. PhD Thesis, NPO SANIIRI, Tashkent Uzbekistan.

FAO 2000. FAO/WFP crop and food supply assessment mission to the Karakalpakstan and Khorezm regions of Uzbekistan. http://www.fao.org/documents/show_cdr.asp? url_file=/docrep/004/x9188e/x9188e00.htm

Djanibekov, N, 2005. Agricultural Producers in Khorezm Region: Three Farms System. Proceedings of the workshop "Institutional and Socio-economic Aspects of Land and Water Use in Uzbekistan". Bonn

Forkutsa, I, Shirokova, Y and Tischbein, B, 2004. Using Hydrus-1D to develop guidelines for an improved irrigation management in the Aral Sea Basin (Uzbekistan). Proceedings of the DesertNet conference. Bonn, Germany

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