The analysis of groundwater table variations in Termez district of Surkhandarya region, Uzbekistan: a spatio-temporal approach

Aybek Arifjanov[1*], *Luqmon* Samiyev[1], *Navruz* Eshboyev[1], *Shaxida* Xodjimuxamedova[1], *Jamoliddin* Akramov[2], and *Bekzod* Makhmudov[1]

[1]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, Tashkent, Uzbekistan
[2]Research Institute of Environment and Nature Conservation Technologies, Tashkent, Uzbekistan

Abstract. The trend analysis of the study was acquired by selecting multiyear seasonal groundwater table data and monitors the wells in each sub-area under the study area. To calculate and assess the spatial differences in the inanition of groundwater table, geostatistical methods was applied based on data from 14 groundwater wells during the period from January 2000 to December 2021 which were obtained from a secondary source, "Uzbekhydrogeology" State Institution. The geographic information system was used to assess the spatial change in order to find the level of groundwater. In this study, Inverse Distance Weightage was applied for estimating the attribute values of locations that are within the database using known data values. Then the interpolated data values were extracted for Statistical Analysis using Man-Kendall's Test. Finally, based on the results of the Mann-Kendall test (Z) and Sen's Slope (Q), seasonal changes of the groundwater level were determined, and electronic maps of the area were created using the IDW interpolation method.

1 Introduction

Groundwater is a critical resource for sustaining agricultural, industrial, and domestic activities, particularly in arid and semi-arid regions where surface water resources are limited. The groundwater levels are influenced by various natural and anthropogenic factors, leading to significant spatio-temporal variations. Understanding these variations is essential for effective groundwater management and planning (Hughes et al., 2012; Mussá et al., 2015). Groundwater depletion is a growing concern globally, driven by increasing water demand and climatic changes, resulting in reduced recharge and over-extraction (Goodarzi et al., 2016).

The study of groundwater trends provides insights into the long-term changes in groundwater storage and availability. Trend analysis helps in identifying patterns of groundwater fluctuations over time, which is crucial for predicting future water availability and developing sustainable management practices (Famiglietti and Rodell, 2013). The Mann-

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[*] Corresponding author: luqmonsamiev@mail.ru

Kendall test and Sen's slope estimator are commonly used statistical tools for detecting and quantifying trends in hydro-meteorological time series (Wu et al., 2008; Jain and Kumar, 2012).

Groundwater drought, characterized by prolonged periods of low groundwater levels, poses significant challenges for water resource management. It is influenced by both natural factors such as precipitation variability and anthropogenic factors like groundwater extraction (Mishra and Singh, 2010; Gleeson et al., 2012). The Standardized Groundwater level Index is a useful tool for assessing groundwater droughts, providing a standardized measure to evaluate the severity, duration, and intensity of drought events (Bloomfield and Marchant, 2013).

In recent years, numerous studies have focused on groundwater level trends and droughts in various regions, employing different methodologies and analytical techniques. For instance, Tabari et al. (2012) investigated seasonal and annual groundwater trends in Iran, while Rahman et al. (2017) examined long-term groundwater decline in Bangladesh. In India, Singh and Kasana (2017) reported significant groundwater depletion in the Haryana state due to intensive agricultural activities. These studies highlight the importance of continuous monitoring and trend analysis for effective groundwater management.

Termiz district, located in the Surkhandarya region of Uzbekistan, is characterized by its semi-arid climate and reliance on groundwater for various uses. The region has experienced significant changes in groundwater levels due to fluctuating precipitation patterns and increasing groundwater extraction. This study aims to analyze the spatio-temporal variations and trends in groundwater levels in Termiz district, employing statistical methods to understand the underlying patterns and implications for groundwater management. The objectives of this study are to:

1. Analyze the spatial and temporal variations in groundwater levels across Termiz district.
2. Identify trends in groundwater levels using the Mann-Kendall test and Sen's slope estimator. [1-15]

2 Materials and Methods

2.1 Study area

Termez district is located in the southernmost part of the republic, near the city of Termez. The eastern part of the district is occupied by the continuation of the Hisar mountain range, Toyintog, Kaykitog and its foothills, Khotinrabot and Kyzirik deserts and its continuation - the Karaqir, Uchkizil, Kattakum massif, the hills and hills of Old Termez. These lands are used as pasture. The southern and western part of the Surkhandarya river flows into the Amudarya and consists of the banks of the Amudarya and Surkhandarya rivers. The soil is barren and salty. It was founded on September 29, 1926. It borders Afghanistan to the south and west, Tajikistan to the east, Angor and Jarkurgan districts of the region to the north, and Muzrabot districts to the northwest (**fig. 1**). The area is 0.86 thousand square kilometers.

Table 1. Average annual rainfall and temperature values (from 1981 to 2020)

Months	J	F	M	A	M	J	J	A	S	O	N	D	Total
Average rainfall (mm)	36.92	25.68	24.74	34.98	7.98	1.74	0	0	0	0.8	8.08	21.94	169.8
Average temperature	4.5	7.4	13.7	19.9	25.8	29.8	31.2	28.7	23.8	17.2	10.5	5.4	18.1

(^0c)													

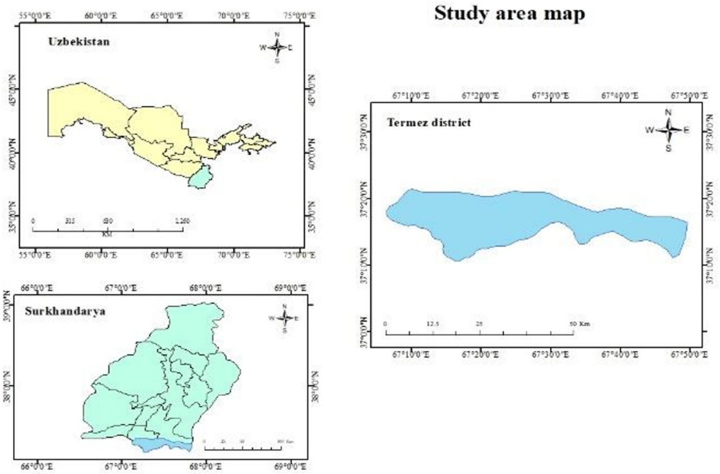

Fig. 1. Location map of the study area

2.2 Data collection

Data was obtained from the State Institution "Uzbekhydrogeology" of the Ministry of Mining and Geology of the Republic of Uzbekistan and the hydrogeological station of the Surkhandarya region and created a spatial database in MS-Excel for the years 2000 to 2021.

Secondly, data was imported in ArcGIS software and Inverse Distance Weightage (IDW) was applied for estimating the attribute values of locations that are within the range of available data using known data values. The area of Termez district was clipped from the interpolated data using Model Builder. These values were extracted to MS-Excel for statistical analysis. The missing data were calculated using the preceding and succeeding data using the following formula:

$$a + \frac{(b-a)}{3}$$

where, a = preceding year data value, b = succeeding year data value.

2.3 Methods of Analysis

The Mann-Kendall and Sen’s slope estimator test were employed for trend analysis and the slope of the trend line.

2.3.1 Mann-Kendall test

The Mann-Kendall trend test for assessing the trend present in the data. Initially, this test was used by Mann (Beniston 2003) and Kendall (Beniston et al. 1997) and subsequently derived the test statistics distribution (Brown at al. 1992, Chaouche et al. 2010). This hypothesis test is nonparametric, rank-based method for evaluating the presence of trends in time series data. The data are ranked according to time and then each data point is successively treated as a reference data point and is compared to all data points that follow in time. Compared with parametric statistical tests, nonparametric test is thought to be move suitable for nonnormally distributed data (Dash and Hunt 2007). Since the time series data used in the study is mostly nonnormally distributed as evident from the skewness and kurtosis values given in Table 2 the nonparametric test was used in the study.

The Mann-Kendall test statistics is given by

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn\ (\chi_j - \chi_i)$$

Where χ_j and χ_i are the sequential data values, n is the data set record length, and

$$sgn(\theta) = \begin{cases} +1, & if\ \theta > 0 \\ 0, & if\ \theta = 0 \\ -1, & if\ \theta < 0 \end{cases}$$

The Mann-Kendall test has two parameters that are of importance to the trend detection. These parameters are the significance level that indicated the trend's strength and the slope magnitude estimate which indicates the direction as well as the magnitude of the trend.

For independent, identically distributed random variables with no tied data values, we have E(S) = O;

$$\text{Var (S)} = \frac{n\,(n-1)(2n+5)}{18}$$

When some data values are tied, the correction to Var(S) is

$$\text{Var}(S) = \frac{n\,(n-1)(2n+5) - \sum_{i=1}^{n} t_i\,(i)(i-1(2i+5)}{18}$$

Table 2. Groundwater level trend in the different wells of Termez district

Well ID	**Season**	**Mann-Kendall Test**				**Sen's Slpoe Estimate**		**Trend**
		First year	**Last year**	**N**	**Test Z**	**Significance**	**GWL (m/year)**	
777	Winter	2000	2021	22	-1.89	+	-0.008	decreasing
	Spring	2000	2021	22	-2.43	*	-0.021	decreasing
	Summer	2000	2021	22	1.19		0.006	increasing
	Autumn	2000	2021	22	0.79		0.005	increasing
783	Winter	2000	2021	22	3.61	***	0.031	increasing
	Spring	2000	2021	22	4.37	***	0.057	increasing
	Summer	2000	2021	22	4.23	***	0.086	increasing
	Autumn	2000	2021	22	4.51	***	0.071	increasing
783A	Winter	2000	2021	22	4.62	***	0.037	increasing
	Spring	2000	2021	22	4.65	***	0.078	increasing
	Summer	2000	2021	22	5.41	***	0.109	increasing
	Autumn	2000	2021	22	5.16	***	0.077	increasing
751	Winter	2000	2021	22	-0.37		-0.011	decreasing
	Spring	2000	2021	22	0.56		0.007	increasing

	Summer	2000	2021	22	1.33		0.027	increasing
	Autumn	2000	2021	22	0.28		0.004	increasing
751A	Winter	2000	2021	22	2.59	**	0.024	increasing
	Spring	2000	2021	22	3.33	***	0.047	increasing
	Summer	2000	2021	22	2.71	**	0.059	increasing
	Autumn	2000	2021	22	2.93	**	0.041	increasing
769A	Winter	2000	2021	22	-1.04		-0.009	decreasing
	Spring	2000	2021	22	-0.42		-0.007	decreasing
	Summer	2000	2021	22	-0.25		-0.003	decreasing
	Autumn	2000	2021	22	-0.11		-0.006	decreasing
774	Winter	2000	2021	22	-2.79	**	-0.013	decreasing
	Spring	2000	2021	22	-0.65		-0.004	decreasing
	Summer	2000	2021	22	0.00		0.000	no trend
	Autumn	2000	2021	22	0.23		0.000	increasing
775	Winter	2000	2021	22	5.41	***	0.056	increasing
	Spring	2000	2021	22	4.57	***	0.055	increasing
	Summer	2000	2021	22	4.74	***	0.065	increasing
	Autumn	2000	2021	22	5.02	***	0.062	increasing
775A	Winter	2000	2021	22	5.22	***	0.064	increasing
	Spring	2000	2021	22	4.51	***	0.061	increasing
	Summer	2000	2021	22	4.12	***	0.068	increasing
	Autumn	2000	2021	22	4.96	***	0.070	increasing
18	Winter	2000	2021	22	3.19	**	0.014	increasing
	Spring	2000	2021	22	1.83	+	0.014	increasing
	Summer	2000	2021	22	4.18	***	0.027	increasing
	Autumn	2000	2021	22	3.41	***	0.038	increasing
19	Winter	2000	2021	22	1.86	+	0.008	increasing
	Spring	2000	2021	22	1.44		0.007	increasing
	Summer	2000	2021	22	1.69	+	0.010	increasing
	Autumn	2000	2021	22	2.99	**	0.012	increasing
20	Winter	2000	2017	18	5.08	***	0.070	increasing
	Spring	2000	2017	18	3.86	***	0.108	increasing
	Summer	2000	2017	18	4.28	***	0.112	increasing
	Autumn	2000	2017	18	4.13	***	0.083	increasing
48	Winter	2000	2021	22	0.11		0.003	increasing
	Spring	2000	2021	22	0.73		0.016	increasing
	Summer	2000	2021	22	1.66	+	0.042	increasing
	Autumn	2000	2021	22	1.64		0.032	increasing
48A	Winter	2000	2021	22	4.74	***	0.045	increasing
	Spring	2000	2021	22	4.65	***	0.067	increasing

	Summer	2000	2021	22	5.19	***	0.069	increasing
	Autumn	2000	2021	22	4.62	***	0.068	increasing
776	Winter	2000	2021	22	0.68		0.003	increasing
	Spring	2000	2021	22	-0.93		-0.009	decreasing
	Summer	2000	2021	22	0.51		0.005	increasing
	Autumn	2000	2021	22	1.13		0.012	increasing

*** if trend at α=0.001, ** if trend at α=0.01, * if trend at α=0.05, + if trend at α=0.1 level of significance.

Here, increasing indicates rising of water table depth or depletion of groundwater level, decreasing implies declining of water table depth or rising groundwater level.

Where ti denotes the number of ties of extent i. For n larger than 10, the test statistic.

$$Z_S = \begin{cases} \frac{S-1}{[Var(S)]^{0.5'}} & if\ S > 0, \\ , & if\ S = 0, \\ \frac{S+1}{[Var(S)]^{0.5'}} & if\ S < 0; \end{cases}$$

Zs follows the standard normal distribution (Beniston et al. 1997).

2.3.2 SEN'S slope estimator

The magnitude of trend slopes can be also calculated using the Mann-Kendall test as follows:

$$\beta = Median\ (\frac{\chi_j - \chi_i}{j-i})$$

Where χ_j and χ_i are considered data value at time j and i (j>i), correspondingly. The median of these N values of β_1 is represented as Sen's estimator of slope which is given as

$$Q_i = \begin{cases} & \beta_{N+1)/2} & when\ N\ is\ odd \\ \frac{1}{2} & (\frac{\beta N}{2} + \frac{\beta(N+2)}{2} & \text{when N is even} \end{cases}$$

A positive value of Q indicates an upward trend, whereas a negative value represents a downward trend.

2.4 Geostatistical method

Geostatistics is defined as the branch of statistical sciences that studies spatial-temporal phenomena and capitalizes on spatial relationships to model possible values of variables at unobserved and unsampled locations (Caers, 2005). As stated, geostatistics is a subset of statistics specialized in the analysis and interpretation of geographically referenced data (Goovaerts, 1997). Spatial statistics is a process of extracting data summaries from spatial data and comparing these to theoretical models that explain how spatial patterns originate and develop (Ripley, 2004).

2.4.1 IDW interpolation method

In this method, the value of a variable at a point not sampled from its adjacent points is estimated using the relation. In this method, weights are determined with respect to the distance of each known point to the unknown point, and regardless of the position and how the points are scattered around the point of estimation. As a result, the nearer the points will be given more weight and the farther points will be given less weight. In fact, the shorter the distance, the greater the impact. This method assigns a weight to each of the measured samples for estimating the unknown point.

$$Z^* = \sum_{i=1}^{n} \lambda_i \cdot Z\,(x_i)$$
$$\lambda_i = \frac{1}{h_i^n}$$

Where Z^* is the estimated spatial variable value, $Z\,(x_i)$ is the spatial variable observed at the point, λ_i is the statistical weight assigned to the sample x_i and indicates the significance of the i-point estimate, h_i the distance between the points x_i and the point at which the variable is estimated and n is the distance power (Childs, 2004). [15-25]

3 Results and discussion

3.1 The results of the analysis of multi-year seasonal changes of the depth of the groundwater level using the IDW interpolation method

The dataset provided encompasses groundwater level fluctuations across various seasons for multiple wells, denoted by their respective identifiers. This section presents an analysis of the observed changes in groundwater levels over the years, highlighting seasonal variations and potential implications.

Winter:

During the winter months, groundwater levels exhibited diverse trends across the wells. Wells 776, 777, 783, 783A, 751, and 751A generally experienced stable to slightly declining groundwater levels. However, well 774 showed a significant decrease in groundwater levels during winter, indicating potential factors such as reduced recharge or increased extraction during this period (**fig. 2**).

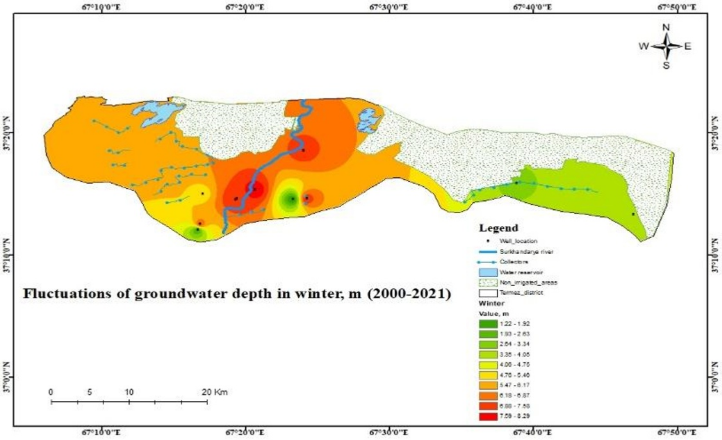

Fig. 2. Changes in the depth of the underground water level in the winter season, m (2000-2021)

Spring:

Springtime witnessed mixed responses in groundwater levels among the wells. Wells 776, 777, 783, 783A, 751, and 751A showcased relatively consistent levels compared to winter, suggesting a minor recovery from the seasonal low. In contrast, well 774 displayed a noticeable increase in groundwater levels, possibly due to enhanced recharge from precipitation or reduced demand for irrigation (fig. 3).

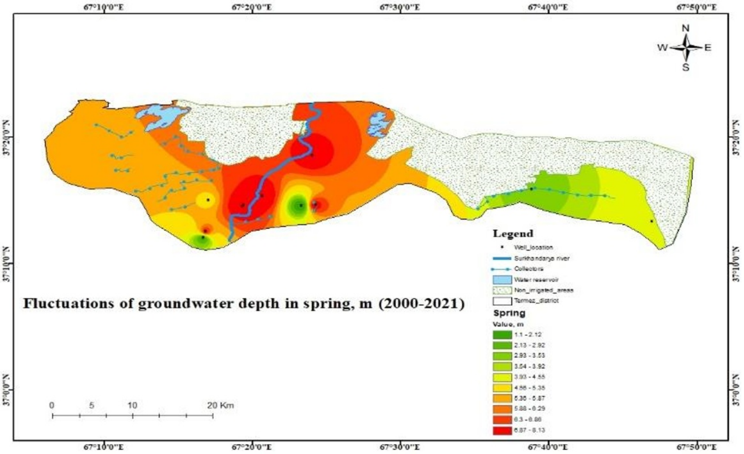

Fig. 3. Changes in the depth of the underground water level in the spring season, m (2000-2021)

Summer:

The summer season posed considerable challenges for groundwater sustainability across the wells. A general declining trend in groundwater levels was observed during this period. Wells 774, 775, and 775A experienced substantial decreases, reflecting heightened demand for water resources, particularly for agricultural purposes, coupled with limited replenishment from natural sources. Wells 18, 19, and 20 also exhibited declines, albeit to a lesser extent, indicating varying degrees of vulnerability to summer water stress (fig. 4).

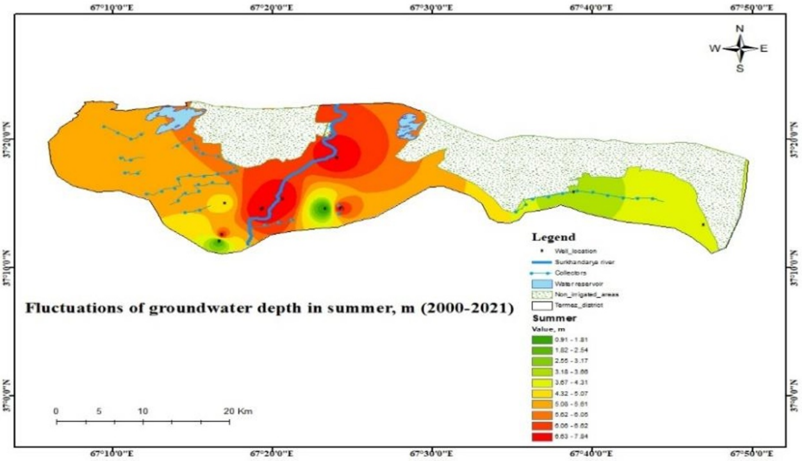

Fig. 4. Changes in the depth of the underground water level in the summer season, m (2000-2021)

Autumn:

Autumn displayed a mixed scenario of groundwater level dynamics, influenced by seasonal transitions and agricultural practices. Wells 776, 777, 783, 783A, 751, and 751A demonstrated relatively stable levels, possibly owing to reduced irrigation demands and moderate precipitation. However, Wells 774, 775, and 775A continued to experience declines, underscoring the lingering impact of summer water deficits and the onset of drier conditions (fig. 5).

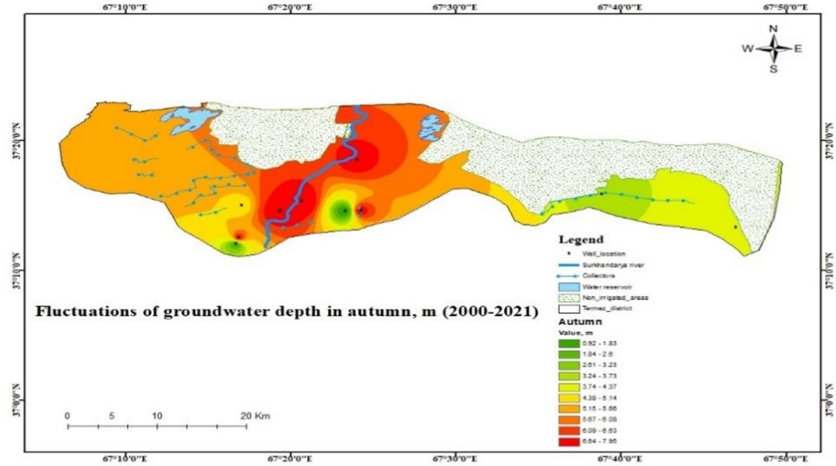

Fig. 5. Changes in the depth of the underground water level in the autumn season, m (2000-2021)

3.2 Result of Mann-Kendall test

The Mann-Kendall trend test was employed to analyze the long-term trends in groundwater levels across different seasons for each well. The results reveal significant insights into the temporal variations and potential implications for groundwater management and sustainability. The Mann-Kendall trend test identified diverse trends in groundwater levels during the *winter* months across the wells. Wells 776, 783, 783A, 775, and 775A exhibited positive trends, indicating an increasing pattern in groundwater levels over the long term.

Conversely, Wells 777, 751, 774, 18, and 20 displayed negative trends, signifying a decreasing trend in groundwater levels during winter. These findings suggest spatial variability in groundwater recharge dynamics and underscore the importance of localized management strategies to address winter water deficits (fig. 6).

Springtime trends in groundwater levels displayed a mixture of positive and negative patterns across the wells. Wells 776, 777, 783, 783A, 775, 775A, 18, and 20 showed significant positive trends, indicating consistent increases in groundwater levels during spring over the long term. Conversely, Wells 751, 751A, 774, 19, 48, and 48A exhibited negative trends, suggesting declining groundwater levels during this season. These findings highlight the complex interplay between hydrological processes and land-use practices, necessitating integrated approaches for sustainable groundwater management (fig. 6).

Analysis of summer groundwater level trends revealed predominantly positive patterns across the wells. Wells 777, 751, 751A, 774, 775, 775A, 18, 19, and 20 displayed increasing trends, indicating a long-term rise in groundwater levels during summer. Conversely, Wells 776, 783, 783A, 48, and 48A exhibited negative trends, suggesting declining groundwater levels over the *summer* months. These findings underscore the seasonal variability in groundwater recharge dynamics and emphasize the need for adaptive strategies to mitigate summer water stress (fig. 6).

Autumn groundwater level trends portrayed a mixture of positive and negative patterns across the wells. Wells 776, 783, 783A, 775, 775A, 18, and 20 demonstrated significant positive trends, indicating increasing groundwater levels during autumn over the long term. In contrast, Wells 777, 751, 751A, 774, 19, 48, and 48A exhibited negative trends, suggesting declining groundwater levels during this season. These results underscore the seasonal fluctuations in groundwater recharge and extraction dynamics, necessitating targeted interventions to ensure sustainable resource utilization (fig. 6).

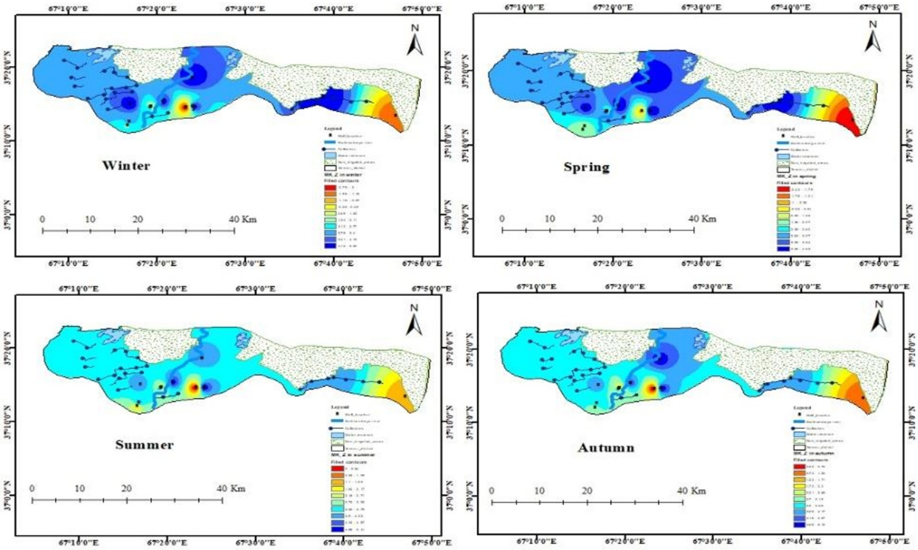

Fig.6. Spatial distribution of groundwater seasonal trends in Termez district (2000-2021) (MK Z test)

3.3 Result of Sen's Estimator of Slope

The Sen's slope test was applied to analyze the seasonal trends in the dataset comprising numerical values representing different quarters across various categories. The results reveal significant insights into the temporal variations observed within the data. Upon conducting the Sen's slope test, distinct trends emerge across the four seasons: Winter, Spring, Summer, and Autumn.

The computed slopes provide a quantitative measure of the direction and magnitude of the trends exhibited by each category across these seasons. Among the categories examined, several demonstrate consistent and statistically significant trends across multiple seasons.

For instance, categories such as 20, 775, and 775A display notable positive slopes across all seasons, indicating a consistent upward trend over time. Conversely, categories like 777 and 774 exhibit negative slopes, suggesting a declining trend in their values across the seasons.[25-30]

Moreover, certain categories showcase varying trends depending on the season. For instance, category 751 displays a fluctuating pattern with both positive and negative slopes across different seasons, suggesting seasonal variability in its values. Similarly, category 48 demonstrates an increasing trend in Spring and Summer but stabilizes in Autumn, highlighting the seasonal dynamics influencing its behavior.

Furthermore, categories such as 783 and 783A illustrate an overall positive trend, albeit with slight fluctuations in magnitude across seasons, indicating a relatively stable but progressively increasing pattern over time (fig. 7). These findings underscore the importance of considering seasonal variations when analyzing temporal trends in datasets.

The Sen's slope test proves to be a robust method for detecting and quantifying such trends, providing valuable insights into the dynamics of the data over different time periods.

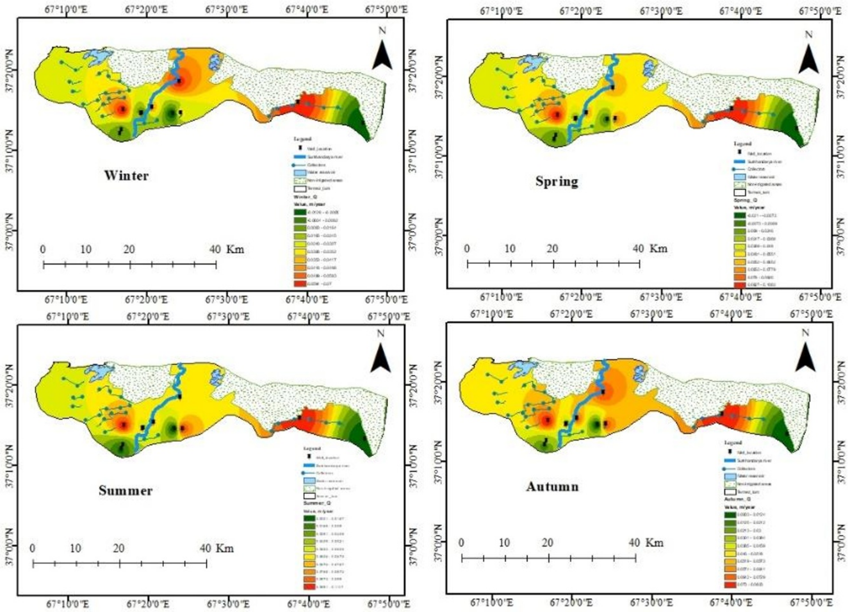

Fig. 7. Spatial distribution of seasonal trends of groundwater level depth (Sen's Slope) in Termez district (2000-2021)

4 Conclusion

The analysis conducted on the groundwater level data observed in Termez District, Surkhandarya Region of the Republic of Uzbekistan provides valuable insights into the seasonal variations and long-term trends in groundwater levels. Through rigorous statistical methods such as the Mann-Kendall trend test and Sen's Slope test, coupled with spatial visualization using the IDW interpolation method of ArcGIS, significant patterns have emerged.

Across the seasons, notable fluctuations in groundwater levels have been observed. The data reveals distinct seasonal variations, with Winter and Spring generally exhibiting higher groundwater levels compared to Summer and Autumn. This cyclic pattern suggests a strong seasonal influence on groundwater recharge and discharge processes within the region.

Furthermore, the trend analysis indicates both positive and negative trends in groundwater levels over the years. While certain periods show an increasing trend, indicating potential groundwater recharge or management practices, others display a decreasing trend, highlighting potential concerns for groundwater sustainability and resource management.

Specifically, areas such as Winter Z and Spring Z demonstrate consistent positive trends, suggesting effective recharge mechanisms or improved management practices. Conversely, areas like Summer Z and Autumn Z exhibit negative trends, indicating potential challenges such as increased abstraction or reduced recharge rates.

The Sen's Slope test further confirms these trends, providing robust statistical evidence for the observed changes in groundwater levels over time. This comprehensive analysis underscores the importance of continuous monitoring and proactive management strategies to ensure the long-term sustainability of groundwater resources in the Termez district.

The integration of statistical analysis techniques with spatial visualization tools has enabled a comprehensive understanding of groundwater dynamics in the study area.

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