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Sustainability of Irrigation through GIS-based Trend Analysis of Groundwater Depletion Bhiwani District, Haryana

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ABSTRACT: India is an agricultural-based country, and groundwater is the major water source for Indian farmers. A study has been conducted to examine the trends and variability of groundwater levels that occurred over the past 20 years from 1999 to 2018 in Bhiwani district, Haryana, India. To better understand the trends and variability, the duration is further divided into two halves from 1999 to 2008 and 2009 to 2018. It has been seen that over the 20 years, the groundwater level had decreased 0.178 meters yearly. The least-square method (LSM) has been used for the trend analysis and coefficient of variance for computing variability. Further, the seasonal groundwater well data were collected throughout the district. After mapping out the groundwater levels, it has been observed that, in the southern and western regions of the district depicting water scarcity condition whereas, in the district's northern and eastern region, the groundwater levels are fair enough. From the yearly analysis is has been seen that the groundwater depth has increased throughout the district. The highest groundwater depth in 1999 was 44.99 meters at Sodiwas, in 2009, 60.7 meters at Loharu, and in 2018, 81.83 meters at Singhan, respectively.

Keywords: Groundwater depletion, Remote Sensing and GIS, Trends, Variability, and LSM.

I. INTRODUCTION

Worldwide nearly 60% of irrigation in farming is dependent on groundwater resources. Globally, about 30% of groundwater is consumed for domestic use [1]. In many countries, more than 50% of the groundwater pulled out is used for household consumptions. In India, approximately 85% of rural household demands, 50% of the urban household demands, and 60% of the irrigation demands in agriculture are met by the available groundwater resources [2]. With the increasing population, industrialization, and urbanization throughout India, the water demand had increased exponentially. This groundwater exploration is more extensive throughout north Indian states *viz*. Uttar Pradesh, Punjab, Haryana, Rajasthan, and Delhi [3]. An increase in heavy precipitation occurred along with a decrease in precipitation occurred in the most northern and central states of India. It has been observed an increasing probability of floods is expected during August and September, but increasing water scarcity during March and April in most of the parts of India [4].

India is leading towards a new water crisis mainly due to improper management of water resources and environmental degradation, which has led to a lack of access to safe water for millions of people. The groundwater level dropped continuously in numerous places in India [5]. According to few estimates, very soon, there will be waterless aquifers in some places. Studies suggest that nearly 29 % of blocks in India are categorized under critical, semi-critical, or overexploited classes in terms of groundwater [6]. As stated by satellite-based indication, the groundwater is deteriorating at an average rate of 4.0 ± 1.0 cm/year in the Indian states of Rajasthan, Punjab, Haryana, and Delhi [7].

The state of Haryana is also concerned about the depleting groundwater level. The unmonitored overuse of groundwater in the north-eastern region of the district had caused groundwater depletion by 10-40 cm yearly. In contrast, the underuse of groundwater in the central and western regions of the state had led to the abundance of groundwater and rise in groundwater in some places [8]. The practice of cultivating water-intensive crops like paddy, cotton, and sugar cane is one of the main reasons for groundwater depletion in the region [9]. Eventually, this will happen to every place where the exploration of water is more by various means than the recharge of the aquifer by infiltration due to rainfall. This high rate of groundwater exploration and low rate of recharge of aquifer eventually causes continuous groundwater depletion [10]. The tube-well irrigation in Haryana contributes 61.2%, whereas canals meet 38.8% of irrigation requirements [11]. This continuous depletion of groundwater resources might be a threat for the long-term sustainability of agriculture based on irrigation, on which the state depends [12].

Further, there is a possibility that the aquifers lose their water storage capacity permanently [13].

II. MATERIALS AND METHODS

Study Area: The Bhiwani District is on the Southern-Western side in Haryana state, comprising 5140 sq. km. Area and is located between 28.19° N and 29.05° N latitudes and 75.26° E and 76.28° E longitudes. Bhiwani is ranked 3rd in Haryana for a population of 14,25,022. The population density is 298/ Sq. km.

One of the biggest reasons for water scarcity is no major river crossing over the district. The geographical setting of the district comprises of smooth and level plain disturbed by clusters of dunes, rocky ridges, and isolated hillocks here and there. A few inaccessible rocky ranges raised abruptly from the plain befall in the south-central part of the district. Dohan River is the only passing stream in the region due to precipitation [14]. The evolution time from September to October is termed the post-monsoon season.

Fig. 1. Study Area Map.

The winter season begins by the end of November and ends nearby, starting in March or so. The average yearly precipitation in the district is 420 mm, which is randomly dispersed [15].

Data and Methodology: The Depth of Groundwater level data is also collected from the India water portal (https://www.indiawaterportal.org/). The data are arranged, the yearly and seasonal (Pre-Monsoon, Monsoon, post- Monsoon Rabi, and Post - Monsoon Kharif) mean depth is computed for the district from 1999 to 2018. Further, the linear regression analysis and variability analysis have been performed to find out the trend and variability. To better understand the behavior of trend and variability, the data are categorized into three groups from 1999-2008, 2009-2018 and 1999-2018.

The main objective of this research is to compute and examines the trends and variability that occurred over the past 20 years from 1999 to 2018. The trend analysis has been done yearly and seasonally. The trends are computed using linear regression analysis and variability is computed using the coefficient of the variance process. The slope value slope value had computed the trends of groundwater yearly and the seasonal linear trend had computed the trends of groundwater yearly and the seasonal linear trend from the linear regression analysis performed. The yearly non-linear trend had also been established using the moving average and centralized moving average method. The data sets are categorized into two halves. The variability is calculated using co-efficient of variance given by (SD/Mean)*100 (SD, *i.e.*, Standard deviation). The trends and variability of both halves are also computed accordingly. Graphs, tables, and bar charts are created to depict the trend and variability throughout.

Further, the Station wise seasonal groundwater level data had been collected from India WRIS (https://indiawris.gov.in/) and Haryana Groundwater Board for 1999, 2009, and 2018. The data are arranged according to use. The station-wise data and adding in GIS format using ArcGIS software to perform the inverse distance weightage (IDW) interpolation technique, for a better understanding of the groundwater status throughout the district. The seasonal changes during 1999, 2009, and 2018 are assessed for the understanding of the changes that occurred in groundwater levels in the district.

III. RESULTS AND DISCUSSION

A. Yearly Trends

The average yearly groundwater level in the district from 1999 to 2018 has been listed out in the Table 1. It has been observed that in 2014 the GW level was at 16.10 meters which is the highest during the period. This means there were extreme water scarcity conditions in 2014, whereas in 2005, the GW level was 10.58 meters which is the lowest during the period this means that there was comparatively less water scarcity in 2005. However, it is also observed that there is a total change of 1.33 meters in groundwater level from 1999 to 2018.

Table 1: Average GW level in Bhiwani District from 1999-2018.

Years	Avg. GW level (m)	Years	Avg. GW level (m)
2018.00	13.94	2008.00	15.93
2017.00	13.84	2007.00	13.47
2016.00	14.90	2006.00	12.41
2015.00	15.69	2005.00	10.58
2014.00	16.10	2004.00	11.90
2013.00	15.82	2003.00	12.34
2012.00	14.54	2002.00	13.09
2011.00	14.28	2001.00	11.69
2010.00	14.10	2000.00	12.94
2009.00	15.15	1999.00	12.61

The yearly GW level trend from 1999 to 2018 is increasing at the rate of 0.178 meters/year. This means the groundwater level is getting deeper with time. Over 20 years, the average groundwater level in the district was 13.766 meters.

To better understand the yearly GW level trend, it is divided into two halves from 1999 to 2008 and 2009 to 2018. The trend analysis of the first half shows that the GW level was continuously decreasing at a rate of 0.177 meters/year. In 2005, there was a minimum GW level of 10.582 meters, and in 2008, there was a maximum GW level of 15.929 meters during the period. However, the average groundwater level during this period was 12.696 meters.

On the contrary, the GW level for 2009 to 2018 has been decreasing with a rate of 0.357 meters/year. This is almost equal to no change. Nevertheless, in 2016 the GW level was 16.097 meters. This is the maximum level during 2009-2018. Whereas the GW level in 2017 was 13.842 meters, which is the minimum during 2009-2018. However, the average groundwater level during this period was 14.866 meters. This means the groundwater level was deeper, resulting in more water scarcity than in the previous decade.

Seasonal Trends and Variability: After performing the seasonal trend analysis, it has been observed that during the last ten years from 2009 to 2018, the post-monsoon Kharif season, there is the highest trend in groundwater level at a rate of 0.095 meters/year, indicating the highest rate of groundwater depletion. During the entire period, the monsoon season has the lowest groundwater level trend at a rate of 0.101 meters/year. Whereas the post-monsoon Kharif season from 1999 to 2008 exhibits the lowest trend at a rate of 0.108 meters/year, during this period, the trends are GW level is continuously decreasing.

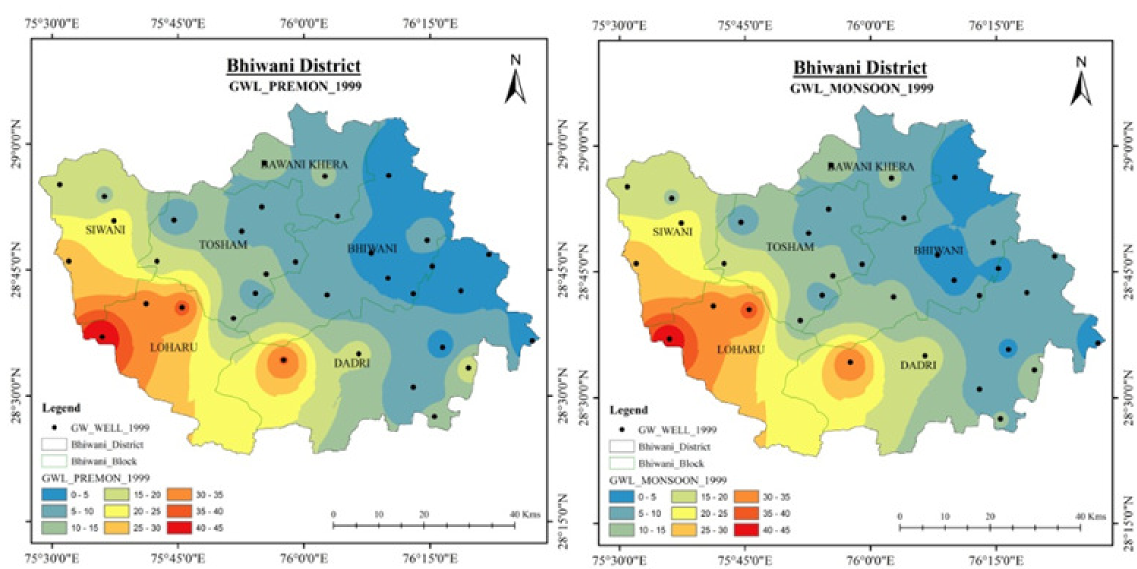
The detailed trends of each season during 1999-2018, 1999-2008, and 2009-2018 have been shown in Table 2.

After performing the seasonal variability analysis, it has been observed that during the last ten years from 2009 to 2018 the post-monsoon Kharif season there is the highest variability of 12.91% in groundwater level. In addition, for the entire period from 1999 to 2018 in the post-monsoon Kharif season, the variability is highest (17.287%), and in the monsoon season, the variability is lowest (11.706%). The lowest variability is in the pre-monsoon season (10.798%) from 1999 to 2008. The data also shows that the variability is consistent during the monsoon season since close range during all three periods. At the same time, the variability is inconsistent in pre-monsoon, post-monsoon rabi, and post-monsoon Kharif season because of the variability in all three periods and vastly different. The detailed variability of each season during 1999-2018, 1999-2008, and 2009-2018 have been shown in Table 2. The above statistical analysis gives the overall scenario of groundwater level in the district, but the statistical analysis does not provide an idea for the groundwater level throughout the district to assess the groundwater level in the district. For this purpose, the groundwater seasonal well data had been collected and interpolated using ArcGIS software for 1999, 2009, and 2018, which estimates the groundwater level scenario throughout the district. There was 33 well in 1999, 39 well in 2009, and 48 well in 2018.

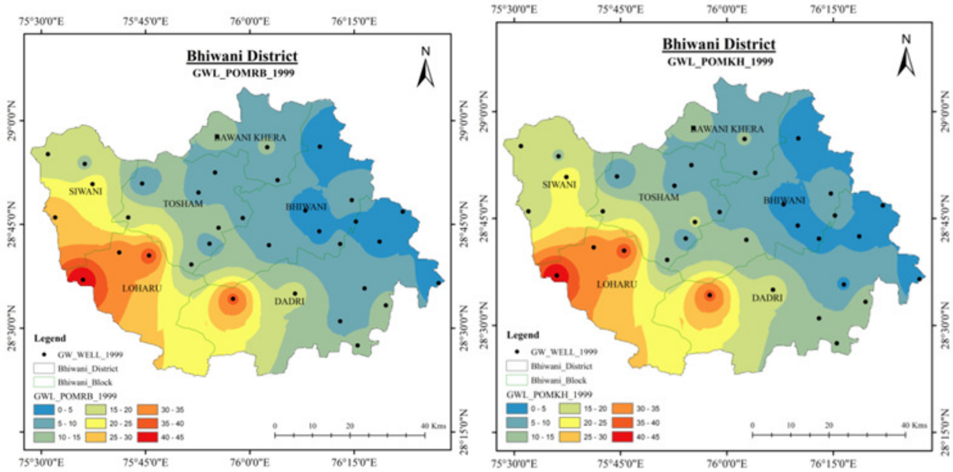
Seasonal Groundwater Level in 1999: After the interpolation of the Groundwater level of Bhiwani district in 1999, the depth of Groundwater level ranged from 0 – 45 meters. It can be seen the western regions of the district depicting water scarcity conditions, namely in Loharu, Siwani, and western parts of Dadri block. However, in the eastern regions, the groundwater level is good, namely Bhiwani, Bawani khers, Tosham, and the eastern part of Dadri. The same has been shown in Fig. 2.

Table 2: Seasonal trends and variability of GW Level in Bhiwani District.

Duration	20 years Trends (1999 - 2018)		first 10 years Trends (1999 - 2008)		last 10 years Trends (2009 - 2018)	
Seasons	**Trends**	**Variability**	**Trends**	**Variability**	**Trends**	**Variability**
MONSOON	0.101	11.706	0.231	11.816	-0.131	10.498
POMRB	0.150	13.077	0.189	15.853	-0.090	5.921
POMKH	0.269	17.287	0.108	12.395	0.095	12.910
PREMON	0.193	12.564	0.180	10.798	-0.017	8.617



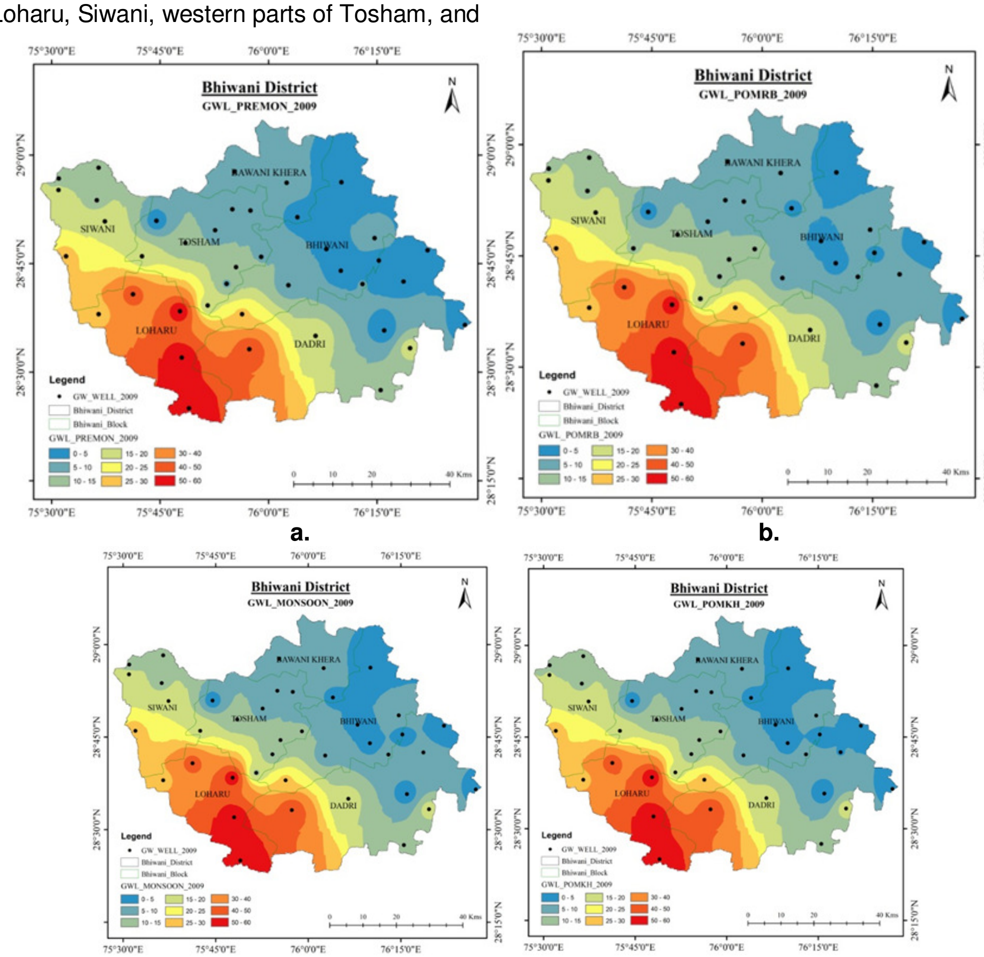
a. b.



c. **d.**

Fig. 2. Seasonal Groundwater level in 1999 in Bhiwani District.

Seasonal Groundwater Level in 2009. After the interpolation of the Groundwater level of the Bhiwani district in 2009, the depth of the Groundwater level was ranging from 0–60 meters. It can be seen the western regions of the district depicting water scarcity conditions, namely in Loharu, Siwani, western parts of Tosham, and western parts of Dadri block. However, the groundwater level is good in the eastern regions, namely Bhiwani, Bawani khers, the eastern part of Tosham, and the eastern part of Dadri. The same has been shown in Fig. 3.



c. **d.**

Fig. 3. Seasonal Groundwater level in 2009 in Bhiwani District.

Seasonal Groundwater Level in 2018: After the interpolation of the Groundwater level of Bhiwani district in 2018, the groundwater level depth ranged from 0 – 90 meters. It can be seen the western regions of the district depicting water scarcity conditions, namely in Loharu, Siwani, and western parts of Dadri block. However, in the eastern regions, the groundwater level is good, namely Bhiwani, Bawani khers, Tosham, and the eastern part of Dadri. The same has been shown in Fig. 4.

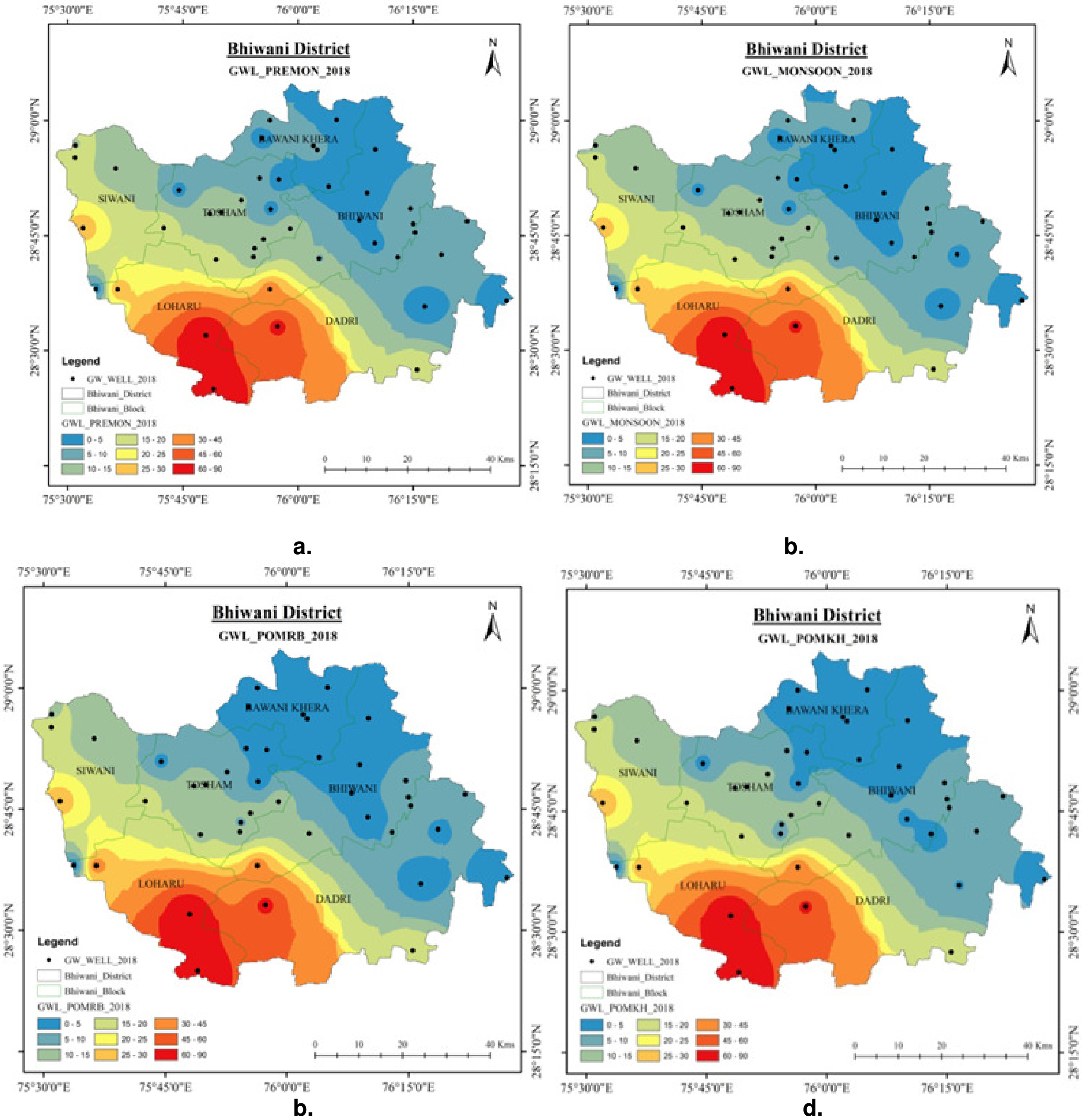


Fig. 4. Seasonal Groundwater level in 2018 in Bhiwani District.

This is evident from the range of groundwater level in 1999. The maximum range groundwater depth was 45 meters, in 2009 the maximum range groundwater depth was 60 meters, and in 2018 the maximum range groundwater depth was 90 meters. Secondly, the northern and eastern part of the district has less water stress condition. Whereas, in the southern and south-western parts of the district the water scarcity is very high. Particularly in the Loharu and western part of Dadri block.

CONCLUSION

The overall groundwater trend in Bhiwani district, the Groundwater depth had decreased from 2009-2018 at a rate of 0.036m/year. During this period, the highest and lowest average groundwater depth was 16.097 m in 2014 and 13.842 m in 2007. Although there is a decreasing trend, the average Groundwater depth is higher during this period. These are the seasonal groundwater level trend. During 1999-2018, in November, the trend was highest 0.269m/year, and during 2009-2018, In May, the trend was the lowest -0.131 m/year. After mapping out the groundwater levels, it has been observed that the southern and western regions of the district depict water scarcity conditions whereas, in the northern and eastern region of the district, the groundwater levels are fair enough. From the yearly analysis is has been seen that the groundwater depth has increased throughout the district. The highest groundwater depth in 1999 was

44.99 meters at Sodiwas, in 2009, 60.7 meters at Loharu, and in 2018, 81.83 meters at Singhan, respectively. More effective and focused planning is needed to rejuvenate the groundwater level in the above-mentioned water-stressed areas.

V. FUTURE SCOPE

The study has been carried out for finding out the relationship between groundwater and vegetation considering other factors affecting the groundwater level constant. In other words, the single variant analysis is done. But there are factors such as rainfall, temperature, humidity, soil types are other factors which affect the agricultural productivity or vegetation in a region. But for finding the relationship between groundwater and vegetation, only vegetation is considered. Future studies can be done to find out the impact of other variables such as rainfall, temperature, humidity, soil types on agricultural productivity or vegetation by multi-variant analysis.

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Conflict of Interest. The authors declare no conflict of Interest.

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