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STATUS OF QUANTITY AND QUALITY OF GROUNDWATER OF THE PROPOSED AMARAVATI CITY, ANDHRA PRADESH, INDIA

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ABSTRACT

The current study evaluates the groundwater quality and level trends for the proposed Amaravati city in the Indian state of Andhra Pradesh. Data from the Andhra Pradesh groundwater and water audit department and the WRIS [Water Resources Information System] site are used to assess trends in groundwater level and quality for the years 2000–2020 and 1996–2021, respectively. Sen's slope estimator and the Mann-Kendall [M-K] test are used to analyse groundwater level and quality trends. R programming and modified versions of the Mann-Kendall (M-K) test are used for trend analysis when the time series of a parameter exhibits autocorrelation. The majority of the trends, according to the trend analysis, are small and declining. At a 5% significance level, the groundwater level is declining in an insignificant way. At the 5% significance level, the groundwater level is declining at a negligible rate of 0.152 mm year. The results of this study show that fluoride levels are significantly rising, rising by 0.01 mg/l annually. These data can be used to assess the quality and level of groundwater in any city, current or planned.

Keywords: groundwater; Mann-Kendall test; Sen’s slope; R programming

INTRODUCTION

From resuscitation to release, groundwater is a complex system, and the lack of sufficient data sometimes leaves room for significant uncertainty in its analysis. It is also not accurately quantified and is not closely monitored. To determine the regime condition of groundwater sources, ongoing groundwater monitoring is required. To clarify groundwater availability, trend study of water quality and levels is crucial. Groundwater trends in terms of quality and level show variances in groundwater and contribute to its resilience and/or sustainability in the face of changes in urban land use and cover as well as climate change.

The current study aims to determine trends in groundwater quality and level for the proposed Amaravati metropolis in Andhra Pradesh, India, utilising Sen's slope, Mann-Kendall test, and R programming.

Groundwater Trend Analysis Studies

According to Broers' (2004) research, trends in the shallow level aquifer are growing in terms of monitoring the temporal variations in groundwater quality at the regional level. In 2009, Visser conducted a comparison of different approaches, including statistical techniques, groundwater dating, transfer functions, and deterministic modelling, for the identification and projection of trends in groundwater quality. It was discovered that there is no one best way to identify trends in groundwater quality across widely disparate catchments [Visser, 2009]. Using the Mann-Kendall test and the Sen's slope estimator, Tabari (2011) looked at the trends in groundwater level annually, seasonally, and monthly. She found that the groundwater level time series in the summer and spring showed stronger increasing trends than those in the autumn and winter. The piezometric investigation conducted by Ouhamdouch (2019) revealed a declining trend in water resources, which might be used to assess how climate change is affecting groundwater. Furthermore, the hydrogeochemical method revealed that an increase in salinity was associated with a decrease of groundwater quality [Ouhamdouch, 2019]. Anand (2019) used GIS [Geographical Information System] to look at long-term patterns in groundwater levels. The average annual groundwater level decreased beyond 15 m (below ground level) during all monsoon seasons, according to statistical trend tests, the Mann-Kendall test, and Sen's slope estimator [Anand, 2019]. This was due to decreased infiltration and increased groundwater exploitation. Farid (2019) used trend tests such the Mann-Kendall and Sen's slope estimator tests to evaluate seasonal and long-term changes in groundwater quality caused by overexploitation. To evaluate trends in groundwater level and quality for a prospective city, research employing several modified versions of the Mann-Kendall test and R programming have not yet been conducted.

New Aspects and Goals of the Current Research

As was said in the evaluation of the literature that is currently available, not many studies have been done to evaluate groundwater trends utilising many Mann-Kendall test iterations and R programming of a proposed city. The goal of the current study was to evaluate the trends in groundwater quality and level in the planned Indian state of Andhra Pradesh and to close any knowledge gaps.

STUDY AREA

The research area for this project is the city of Amaravati in the newly formed state of Andhra Pradesh, India, which split into two. In the Guntur district, Amaravati city is situated on the Krishna River's bank. The proposed city of Amaravati is situated at 16.51^0 N latitude and 80.52^0 E longitude, covering an area of 217.50 km^2. The projected metropolis will mostly consist of agricultural land, and the 29 current villages are spread throughout different mandals in the Guntur district.

The research study is taking into consideration the study area map [Fig. 1], which is the comprehensive master plan of Amaravati city, as supplied by the AP CRDA/AMRDA web domain. The master plan map of the study area is displayed below for easy access.

Hydrogeology of the study area

Groundwater is restricted to 60 m depth in study area. Permeability is in the range of 0.01 to 10 m/hr. Specific yield is in the range of 0.005 to 0.025. Type of soil within the major part of the study area is deltaic alluvial soil. Rock type varies from unconsolidated sand with/without clay, silt, and calcareous hard sedimentaries to non-calcareous sedimentaries. Also, permeability varies from cumulative high to low within the study area.

METHODOLOGY

Mann-Kendall test and Sen's slope estimator are being commonly applied for trend analysis of various parameters.

Mann-Kendall Test: Mann-Kendall test is based on testing the S statistic defined as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

where, $x_1, x_2 \ldots\ldots x_n$ represent n data points,

x_i and x_j are values of data at time i and j respectively.

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} -1 \text{ if } (x_j - x_i) < 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ 1 \text{ if } (x_j - x_i) > 0 \end{cases}$$

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

where, n is the number of data points, m is the number of tied groups, and t_i denotes the number of ties of extent i. MK standard statistic Z is defined as

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$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases}$$

A value of positive Z specifies an upward trend and a value of negative Z signifies a downward trend. The levels of significance (p-values) for every test to find trend can be attained as given in the below equation [Coulibaly and Shi, 2005]

$$p = 0.5 - \varphi Z$$

where, φ ( ) indicates the cumulative distribution function (CDF) of a standard normal variate. At a level of significance of 0.1, if $p \leq 0.1$, then the prevailing trend is regarded as statistically significant.

Sen's Slope Estimator

Sen's slope method is a nonparametric technique for determining trend scale in terms of trend slope. $x_i = x_1, x_2$ for a given time series...x_n, using N pairs of data, the slope is calculated as

$$\beta_i = \frac{x_j - x_k}{j-k}, \forall\, k \leq j \text{ and } i = 1,2 \;\ldots..N$$

Median of N values of β_i provides the Sen's slope estimator, β.

$$\beta = \begin{cases} \beta_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2}\left[\beta_{\frac{N}{2}} + \beta_{\frac{N+2}{2}}\right] & \text{if N is even} \end{cases}$$

Autocorrelation

A modified version (or versions) of the Mann-Kendall trend test must be used when a hydrological time series, like precipitation, exhibits considerable auto-correlation or serial correlation. The serial correlation coefficient (r_1) or lag-1 autocorrelation for any time series $x_i = x_1, x_2,..x_n$ is calculated as [Kendall and Stuart, 1968; Salas, 1980].

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - E(x_i)).(x_{i+1} - E(x_i))}{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x_i))^2}$$

where, $E(x_i)$ is the sample mean and n is the size of sample.

$$E(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The limits of probability for r_1 on the correlogram of an independent series is provided [Anderson, 1942] as

$$r_1 = \begin{cases} \frac{-1 \pm 1.645\sqrt{n-2}}{n-1} & \text{for the one - tailed test} \\ \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} & \text{for the two - tailed test} \end{cases}$$

A significant autocorrelation in the time series is absent when the lag-1 autocorrelation coefficient falls within the interval. The time series exhibits a substantial autocorrelation at the 5% level of significance if the lag-1 autocorrelation coefficient is outside of the interval.

Whenever precipitation time series data exhibit strong autocorrelation or serial correlation, trend analysis must take into account the modified Mann-Kendall test.

A modified version of the Mann-Kendall test is offered in several variations. Mann-Kendall trend test bootstrapped with optional bias correction prior to whitening Among the different modified Mann-Kendall trend tests, the bootstrapped Mann-Kendall trend test with optional bias corrected pre-whitening incorporates all the most recent techniques, including pre whitening, bias correction, and bootstrapping, to eliminate and resample significant autocorrelation in time series data.

The empirical distribution of the Mann-Kendall test statistic is ascertained by bootstrapped resampling in the bootstrapped Mann-Kendall trend test with optional bias corrected pre-whitening. One alternative to the default of pre-whitening before the bootstrapped Mann-Kendall test is applied is to employ the Hamed (2009) bias correction pre-whitening technique [Lacombe, 2012].

Re-sampling the time series one value at a time with replacement yields the estimated bootstrapped samples. According to Yue and Pilon (2004), the re-sampled data's pvalue (ps) is as follows:

$$p_s = m_s/M$$

For each set of resampled data, the Mann-Kendall test statistics (S) are calculated. The re-sampled S statistics vector that results is then sorted in ascending order, with ms being the rank associated with the greatest bootstrapped value of S being less than the test statistic value calculated from the real data. The total number of bootstrapped resamples is denoted by M. Although Yue and Pilon (2004) propose values between 1000 and 2000, the default value of M is 1000.

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R Programming

R Core Team, 2020; Patakamuri and O'Brien, 2020; and Wickham and Bryan, 2019 state that RStudio is being developed as an IDE [Integrated Development Environment] for R programming, a programming tool to perform statistical analysis that is also made accessible as open source.

DATA USED

The groundwater and water audit department of the Government of Andhra Pradesh state, as well as the WRIS [Water Resources Information System] portal, are the sources of groundwater data, including the depth below ground level and numerous quality metrics connected to the research region.

Data on groundwater levels are taken into consideration for the years 1996–2021. Data on groundwater quality for the years 2000–2020 are taken into consideration, using different factors. But because data for a few parameters—F, K, Na, NO_3, Residual Sodium Carbonate, SAR, and total alkalinity—isn't accessible, the time frame of trend study is limited to 2000–2018.

Table 1: Check for Significant Autocorrelation

Parameter	Upper Limit	Lag-1 Autocorrelation Coefficient	Lower Limit	Existence of Significant Autocorrelation
Groundwater Level	0.2182	-0.0106	-0.2616	False
Ca	0.4328	-0.0496	-0.7185	False
Cl	0.4059	-0.0697	-0.6281	False
CO_3	0.4464	-0.3081	-0.7797	False
F	0.4328	0.1204	-0.7185	False
HCO_3	0.4328	0.3609	-0.7185	False
K	0.458	-0.6805	-0.858	False
Mg	0.4328	-0.1061	-0.7185	False
Na	0.458	0.1792	-0.858	False
NO_3	0.4328	-0.1836	-0.8382	False
pH	0.4059	0.2111	-0.6281	False
Residual Sodium Carbonate	0.4623	-0.645	-0.9623	False
SAR	0.4623	-0.3572	-0.9623	False
SO_4	0.4328	0.2515	-0.7185	False
Total Alkalinity	0.4421	0.7801	-1.109	True
Total Hardness	0.4328	-0.0343	-0.7185	False

Table 2: Trend Results

Parameter	Mann-Kendall Static, Z	Sen's Slope	p Value
Groundwater Level	-0.4771	-0.0038	0.6333
Ca	-1.3822	-4.325	0.1669
Cl	-1.7889	-39.00	0.0736
CO_3	0.4704	0.134	0.6380
F	2.1032	0.1303	0.0354
HCO_3	0.1237	10.5714	0.9015
K	-0.3757	-13.6	0.7071
Mg	0.1237	0.0307	0.9015
Na	0.3757	24.25	0.7071
NO_3	-1.1135	-20.35	0.2655
pH	-0.9017	-0.03	0.3672
Residual Sodium Carbonate	0.245	1.475	0.8065
SAR	0.7348	0.3763	0.4624
SO_4	-0.9974	-13.225	0.3186
Total Alkalinity	1.6984	58.19	0.0894
Total Hardness	-1.2468	-18.8883	0.2125

Table 3: Parameter wise Characteristics of Trend

Parameter	Characteristics of Trend	Sen's Slope	Remarks
Groundwater Level	Insignificant Decreasing Trend	-0.0038	No Trend
Ca	Insignificant Decreasing Trend	-4.325	No Trend
Cl	Insignificant Decreasing Trend	-39.00	No Trend
CO_3	Insignificant Increasing Trend	0.134	No Trend
F	Significant Increasing Trend	0.1303	**Increasing Trend**
HCO_3	Insignificant Increasing Trend	10.5714	No Trend
K	Insignificant Decreasing Trend	-13.6	No Trend
Mg	Insignificant Increasing Trend	0.0307	No Trend

Na	Insignificant Increasing Trend	24.25	No Trend
NO_3	Insignificant Decreasing Trend	-20.35	No Trend
pH	Insignificant Decreasing Trend	-0.03	No Trend
Residual Sodium Carbonate	Insignificant Increasing Trend	1.475	No Trend
SAR	Insignificant Increasing Trend	0.3763	No Trend
SO_4	Insignificant Decreasing Trend	-13.225	No Trend
Total Alkalinity	Insignificant Increasing Trend	58.19	No Trend
Total Hardness	Insignificant Decreasing Trend	- 18.8883	No Trend

RESULTS AND DISCUSSION

Checks for substantial serial or autocorrelation in groundwater data, trend findings, and trend features of several parameters are presented in Tables 1 through 3. With the exception of total alkalinity, trend analysis reveals that no groundwater parameter exhibits serial or significant autocorrelation exits. At a significance level of five percent, trend analysis is conducted for all metrics, including water level. Any trend that shows up as an insignificant upward or downward trend indicates that there is no trend [Table 3]. At the 5% significance level, however, the groundwater level is declining at a negligible rate of 0.152 mm year. Ca is showing a negligible downward trend, falling by 0.21 mg/l annually.

Cl is showing a negligible downward trend, falling 1.86 mg/l annually. The trend for CO_3 is negligible, growing at a rate of 0.01 mg/l annually. F exhibits a noteworthy upward tendency, rising by 0.01 mg/l year. With a 0.5 mg/l annual increase, HCO_3 is showing a negligible upward trend. K is showing a negligible downward trend, falling by 0.72 mg/l annually. With an annual increase of 0.002 mg/l, magnesium is showing a negligible upward trend. With an annual increase of 1.28 mg/l, Na is showing a negligible upward trend. NO_3 is trending downward, but not significantly, at a rate of 1.07 mg/l year. pH is exhibiting a negligible

The amount of residual sodium carbonate is increasing at a negligible rate, 0.08 mg/l annually. With a 0.02 percent annual growth, SAR is showing a negligible upward trend. SO_4 is trending downward, but not much, by 0.63 mg/l year. The trend for total alkalinity is slightly increasing, rising by 3.06 mg/l annually. The overall hardness is showing a negligible downward trend, falling by 0.9 mg/l annually.

Changes in land use/land cover patterns, removal of vegetation and agriculture practice following lands are modified at few regions are altering groundwater levels and quality parameters as urbanization is commencing inside the research area. Additionally, trends in other groundwater characteristics, such as water level, are mostly driven by the utilisation of groundwater resources. The proposed city's ground surface is becoming increasingly impermeable due to urbanisation, which started in 2014. This has increased surface runoff, decreased infiltration, and further reduced groundwater availability.

The current groundwater trend analysis of levels and quality, which makes use of Sen's slope estimator, several modified versions of the Mann-Kendall test, R programming, and the Mann-Kendall trend test, is helpful in evaluating trends in groundwater parameters for any existing or planned metropolis.

CONCLUSIONS

Sen's slope estimator, R programming, the Mann-Kendall test, and the city area's groundwater trend analysis are used in this study. The majority of trends for several quality measures, such as the groundwater level below ground level, are found to be negligible and declining. Less precipitation, increased groundwater resource extraction, the start of urbanisation for the planned metropolis, climate change, and patterns of land use and cover could all be contributing factors to the diminishing trends. The determinants of trends, however, might be better understood by a parameter-wise analysis. At the 5% significance level, the groundwater level is declining at a negligible rate of 0.152 mm year. F exhibits a noteworthy upward tendency, rising by 0.01 mg/l year.Ca is with a negligible

Cl is showing a negligible downward trend, falling 1.86 mg/l annually. The trend for CO_3 is negligible, growing at a rate of 0.01 mg/l annually. The trend for total alkalinity is slightly increasing, rising by 3.06 mg/l annually. The overall hardness is showing a negligible downward trend, falling by 0.9 mg/l annually. The results of this study can be used to assess groundwater patterns in any metropolis, current or planned. Additional parameter-wise studies conducted at different stages of the proposed Amaravati city's urbanisation could provide more information about how urbanisation affects groundwater quality.

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