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TRENDS OF GROUNDWATER LEVEL AND QUALITY OF THE PROPOSED AMARAVATI CITY, ANDHRA PRADESH, INDIA

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ABSTRACT

In the present study, the trends of groundwater level and quality for the proposed Amaravati city of Andhra Pradesh state, India are assessed. Trends of groundwater level and quality are evaluated using data from WRIS [Water Resources Information System] portal and groundwater and water audit department, Andhra Pradesh for the period 1996-2021 and 2000-2020, respectively. Mann-Kendall [M-K] test and Sen's slope estimator are applied to perform trend analysis of groundwater level and quality. When the time series of a parameter is auto correlated modified versions of Mann-Kendall (M-K) test and R programming are used for trend analysis. The trend analysis indicates that most of the trends are insignificant and decreasing. Groundwater level is having an insignificant decreasing trend at 5% significance level with a decline of 0.152 mm per year. Fluorides are with a significant increasing trend with an increase of 0.01 mg/l per year the findings of the present study can help to determine trends of groundwater level and quality for any existing and/or proposed city.

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

INTRODUCTION

Groundwater is an intricate system from revive to release, and its analysis is frequently subject to huge ambiguity due to inadequate data. It is also meagerly monitored and not precisely quantified. Constant monitoring of groundwater is needed to identify the regime condition of the sources of groundwater. Trend analysis of water levels and water quality is essential to elucidate the groundwater availability. The trends of groundwater in terms of level and quality present variations in groundwater and give its sustainability and/or resilient characteristics towards climate change and land use/land cover changes in urban environments.

The present study is aimed at determination of trends of groundwater level and quality using Mann-Kendall test, Sen's slope and R programming for the proposed Amaravati city, Andhra Pradesh, India.

Groundwater Trend Analysis Studies

Broers and van der Grift (2004) studied monitoring of temporal changes in groundwater quality at regional level and found that the trends are increasing in the aquifer at depth of shallow level. Visser (2009) compared various methods for the identification and projection of groundwater quality trends such as statistical methods, groundwater dating, transfer functions and deterministic modelling. It was found that there is no single optimal method to perceive trends in quality of groundwater across extensively varying catchments [Visser (2009)]. Tabari (2011) examined the trends in groundwater level annually, seasonally and monthly using the Mann– Kendall test and the Sen's slope estimator and obtained that the stronger increasing trends were recognized in the groundwater level time series in summer and spring than those in autumn and winter. Bui (2012) carried analysis of recent groundwater-level trends at spatio-temporal level and found that the levels of groundwater of confined-aquifer were at downward trend in almost all locations. Daneshvar (2012) analyzed the trends in groundwater level and fifteen hydro-geochemical elements using non-parametric modified Mann-Kendall test with pre-whitening. It was found that negative trends which were significant ($\alpha < 0.1$) in level of groundwater were predicted. Panda (2012) investigated the trends in level of groundwater, temperature extremes and rainfall. It was obtained from the results that a huge number of decreasing trends in levels of groundwater [Panda (2012)].

Lee (2013) studied on relationship between groundwater and climate change using Mann-Kendall and Sen's slope tests with levels and temperatures of groundwater. It was found that more plentiful rainfall in the wet season does not add considerably to groundwater recharge while a lesser amount of rainfall in the dry season can reason for a reduction in the groundwater level [Lee (2013)].

Patle (2015) carried time series analysis of groundwater levels and prediction of trend using Mann- Kendall test and Sen's slope estimator. It was got from the results that pre and post monsoon levels of groundwater would reduce [Patle (2015)]. Singh (2015) carried spatio–temporal analysis of resources of groundwater using Mann–Kendall test, Sen's slope estimator and linear regression method and got the results that typically declining trend in the time series of the groundwater. Amini (2015) analyzed variability of fluoride concentrations in spatial and temporal perspective in resources of groundwater using Mann–Kendall trend test and got the results that monotonic trend was observed in the time series of fluoride concentrations of groundwater. Abdullahi (2015) analyzed trends of

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groundwater level using Mann-Kendall trend test and obtained that a negative increase in trends for the level of groundwater.

Minea (2017) studied groundwater response to changes in precipitations using trend test Mann-Kendall test and Sen's slope estimator and the correlation between groundwater and precipitation was determined based on Bravais-Pearson correlation. It was found that the increasing trends are governing both for annual and seasonal precipitation and correlation between hydrostatic level and precipitation is stronger and more recurrent for summer and autumn [Minea (2017)]. Thapa (2017) carried delineation of groundwater potential zones using a geospatial multi-influencing factor technique and got the results as a declining trend of levels of groundwater. Bhanja (2018) estimated groundwater storage and its controlling factors in long-term and found that the precipitation has a vital role to affect groundwater storage [Bhanja (2018)]. Biswas (2018) studied to recognize the trends in pre- and post-monsoon groundwater levels using statistical trend tests like Mann-Kendall, Sen's slope estimator, and linear regression model. It was obtained that the groundwater levels were reduced significantly [Biswas (2018)]. Kumar (2018) evaluated trends of groundwater with the use of modified Mann-Kendall (MMK) trend test and Sen's slope estimator. It was obtained that the water level trends variation in two diverse seasons may be due to the recharge from rainfall in season of post-monsoon [Kumar (2018)]. Pathak and Dodamani (2018) assessed regional characteristics of groundwater drought using SGI [Standardized Groundwater level Index] and carried trend analysis of groundwater levels using Mann–Kendall test. It was obtained that significant declining trends were detected in more number of the wells which was due to reducing precipitation and over-abstraction of resources of groundwater [Pathak and Dodamani (2018)].

Ouhamdouch (2019) found a decreasing trend of water resources from the piezometric study to evaluate the impact of climate change on groundwater. Also, groundwater quality degradation was observed with salinity increase from the hydrogeochemical approach [Ouhamdouch (2019)]. Anand (2019) examined trends of groundwater levels in long-term using GIS [Geographical Information System]. The statistical trend tests, Mann–Kendall test and Sen's slope estimator performed had shown that the average annual groundwater level lowered beyond 15 m (below ground level) during all the monsoon seasons as infiltration was less and groundwater exploited more [Anand (2019)]. Farid (2019) assessed seasonal and long-term changes in groundwater quality due to over exploitation using trend tests such as Mann–Kendall and Sen's slope estimator tests**.** Groundwater EC [electrical conductivity] and SAR [sodium adsorption ratio] values were increased during the pre-monsoon season and were decreased during the post-monsoon season which was due to more use of groundwater [Farid (2019)]. Bhanja (2019) estimated variations in groundwater recharge in major river basins across India. It was found that the precipitation rates do not considerably impact groundwater recharge in the majority of the river basins across India, demonstrating anthropogenic activities affect existing groundwater recharge rates [Bhanja (2019)]**.** Verma (2019) found the impacts of long-term variations in land use/land cover (LULC) on surface and groundwater resources of quaternary aquifers. It was obtained that the large-scale variations in groundwater reservoirs were occurred as LULC changes, features of hydro-geomorphic characteristics and wide exploration of groundwater practices taken place [Verma (2019)]. Jame (2020) analyzed trends of groundwater and found that irrigated area and groundwater withdrawals were increased during the last 30 years in humid and temperate regions and area of irrigation area reduced in semi-arid regions. Ducci (2020) evaluated the trends of nitrate concentrations in groundwater using Mann-Kendall test and Sen's slope estimator and found variations in groundwater quality at different stations and trends were resulting from environmental factors. Hamidov (2020) studied climate change impact on groundwater management and the depths of water table in the region usually reduce based on Mann-Kendall trend test.

Oiro (2020) assessed groundwater resources status under rapid urbanization using numerical modelling. The modelled study recommended that anthropogenically-driven reduction trend can be partially mitigated through conjunctive use of water [Oiro (2020)].

However, there are no studies carried out using numerous modified versions of Mann-Kendall test and R programming to assess trends of groundwater level and quality for a proposed city.

Novel Aspects and Objectives of the present study

As discussed in the review of available literature, there are no much studies performed to assess trends of groundwater using number of versions of Mann-Kendall test and R programming of a proposed city. To build on existing knowledge and to fill gaps as described, the present study aimed at assessment of trends of groundwater level and quality of proposed Amaravati city, Andhra Pradesh state, India.

STUDY AREA

Amaravati city of bifurcated new state of Andhra Pradesh, India has been chosen as a study area in the present study. Amaravati city is located on the bank of Krishna river in Guntur district. Proposed Amaravati city area is 217.50 km^2 and is located at 16.51^0 N latitude and 80.52^0 E longitude. This city area is proposed to make up from agricultural lands and 29 number of existing villages belong to various mandals of Guntur district.

Study area map [Fig. 1] i.e. detailed master plan of Amaravati city is being considered for this research study as provided / available from AP CRDA/AMRDA web portal. This study area master plan map is presented below for ready reference.

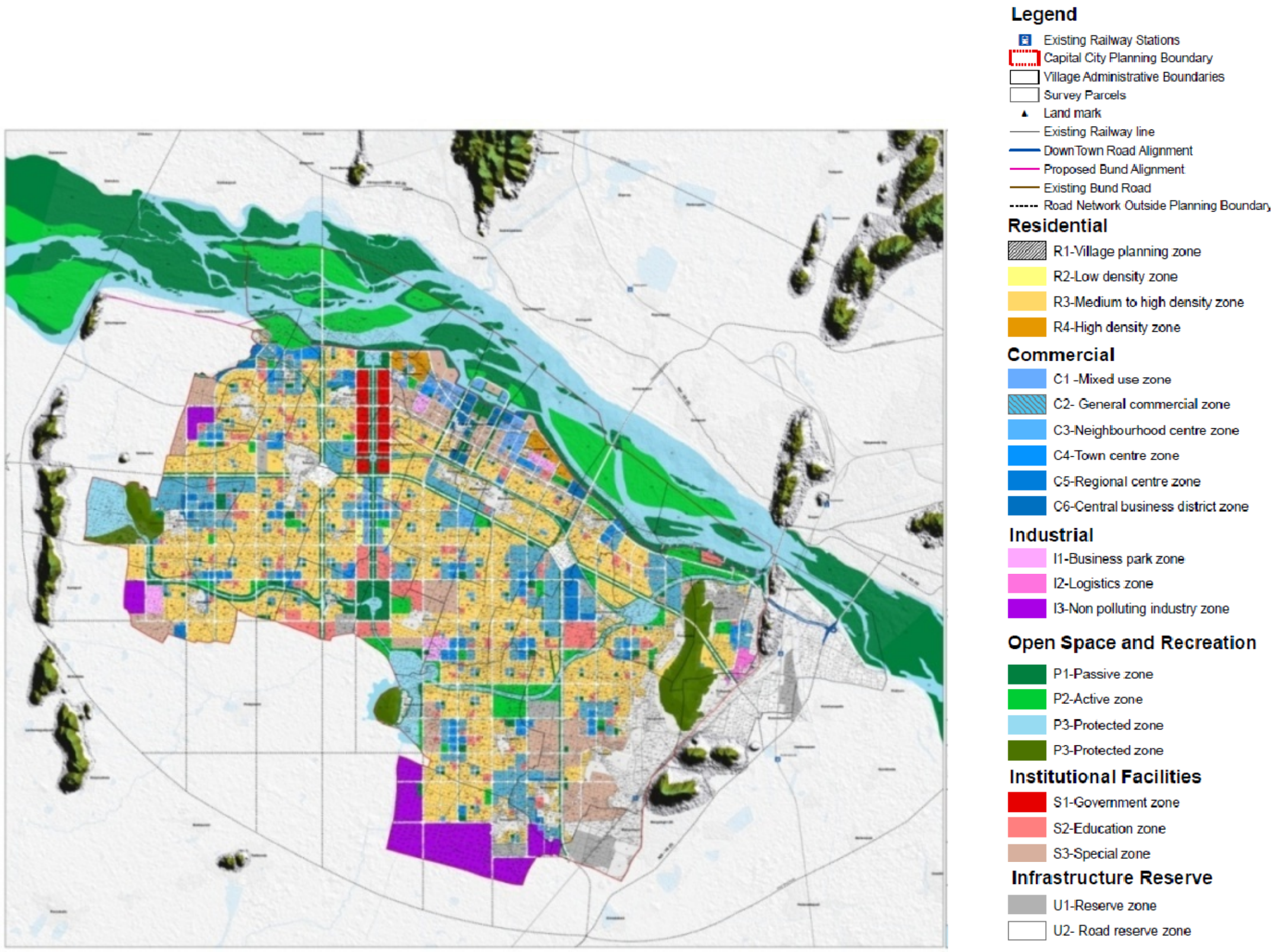

Fig. 1 Detailed master plan of Amaravati city
(Source: AP CRDA/AMRDA)

Hydrogeology of the study area

(Source: Hydrogeological and Hydrological Atlas of A.P. CGWB 1983)

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

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

where, x_1, x_2 ……x_n represent n data points,

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

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} -1 \text{ if } (x_j - x_i) < 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ 1 \text{ if } (x_j - x_i) > 0 \end{cases} \qquad (2)$$

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18} \qquad (3)$$

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

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S < 0 \end{cases} \qquad (4)$$

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]

$$p = 0.5 - \varphi|Z| \tag{5}$$

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, 1968]

Sen's slope method is a nonparametric method of finding the scale of trend in terms of slope of trend. For a given time series $x_i = x_1, x_2 \ldots\ldots x_n$, with data of N pairs, the slope is computed as

$$\beta_i = \frac{x_j - x_k}{j - k}, \forall\ k \leq j \text{ and } i = 1,2 \ \ldots\ldots N \tag{6}$$

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

$$\beta = \begin{cases} \beta_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2}\left[\beta_{\frac{N}{2}} + \beta_{\frac{N+2}{2}}\right] & \text{if N is even} \end{cases} \tag{7}$$

Autocorrelation

When a time series related to hydrology such as precipitation is significantly auto-correlated or serially correlated, modified version(s) of Mann-Kendall trend test need to be applied.

For any time series $x_i = x_1, x_2 \ldots. x_n$, lag-1 autocorrelation or serial correlation coefficient (r_1) is determined as [Kendall and Stuart, 1968; Salas, 1980]

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - E(x_i)).(x_{i+1} - E(x_i))}{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x_i))^2} \tag{8}$$

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

$$E(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{9}$$

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

$$r_1 = \begin{cases} \frac{-1 \pm 1.645\sqrt{n-2}}{n-1} & \text{for the one – tailed test} \\ = \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} & \text{for the two – tailed test} \end{cases} \tag{10}$$

When the lag-1 autocorrelation coefficient is within the interval, then the time series is not having a significant autocorrelation. If the lag-1 autocorrelation coefficient is beyond the interval, then the time series shows a significant autocorrelation at the 5% level of significance.

When time series data of precipitation is significantly auto-correlated or serially correlated, modified Mann-Kendall test needs to be considered for trend analysis. Numbers of versions are made available for modified version of Mann-Kendall test.

Bootstrapped Mann-Kendall trend test with optional bias corrected pre-whitening

Out of various modified Mann-Kendall trend tests, *bootstrapped Mann-Kendall trend test with optional bias corrected pre-whitening* has all the latest methods to remove and resample significant autocorrelation in time series data such as bootstrapping, bias correction and pre-whitening.

In the bootstrapped Mann-Kendall trend test with optional bias corrected pre-whitening, the empirical distribution of the Mann-Kendall test statistic is determined by bootstrapped re-sampling. The Hamed (2009) bias correction pre-whitening technique can be used as a choice to the default to pre-whitening prior to the bootstrapped Mann-Kendall test is utilised [Lacombe, 2012].

Bootstrapped samples are estimated with re-sampling one value at a time of the time series with replacement. The p-value (p_s) of the re-sampled data is calculated by [Yue and Pilon, 2004]:

$$p_s = m_s/M \tag{11}$$

The Mann-Kendall test statistics (S) is computed for every re-sampled data. The resultant vector of re-sampled S statistics is subsequently arranged in ascending ordering, where m_s the rank related to the largest bootstrapped value of S is being less than the test statistic value determined from the actual data. M is the total number of bootstrapped re-samples. The default value of M is 1000, however, Yue and Pilon (2004) recommend values between 1000 and 2000.

R Programming

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

DATA CONSIDERED

Groundwater data i.e. level below ground level and various quality parameters data related to the study area is adapted as available from WRIS [Water Resources Information

System] portal and groundwater and water audit department, Government of Andhra Pradesh state. Groundwater level data is considered for the period 1996 - 2021. Groundwater quality data of various parameters is considered for the period 2000 - 2020. However, as data is not available for few parameters, F, K, Na, NO_3, Residual Sodium Carbonate, SAR and total alkalinity, period of trend analysis is considered for the period 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

Table 4 : Trend Results of Modified versions of Mann-Kendall Test for Total Alkalinity

Trend Test	Z	Sen's Slope
Nonparametric Block Bootstrapped Spearman's Rank Correlation [Spearman (1904)]	1.7321	
Modified Mann-Kendall Test for Serially Correlated Data using the Hamed and Rao (1998) Variance Correction Approach	1.6984	58.19
Modified Mann-Kendall test for serially correlated data using the Yue and Wang (2004) Variance Correction Approach	2.8728	58.19
Modified Mann-Kendall test for serially correlated data using the Yue and Wang (2004) Variance Correction Approach using the Lag-1 Correlation Coefficient Only	2.1092	58.19
Mann-Kendall test of prewhitened time series data in presence of serial correlation using the von Storch(1995) approach	1.0445	58.19
Spearman's Rank Correlation Test [Spearman (1904)]	1.7321	
Mann-Kendall trend test applied to trend-free prewhitened time series data in presence of serial correlation using Yue (2002) approach	0.0000	58.19

RESULTS AND DISCUSSION

Tables 1 to 4 present checks for significant serial or autocorrelation in groundwater data, trend results, and characteristics of trends of various parameters.

Trend results [Table 4] of total alkalinity reveal that it is having an insignificant increasing trend with an increase of 3.23 mg/l per year.

Trend analysis [Tables 1 to 3] shows there is no serial or significant autocorrelation exits for any groundwater parameters except for total alkalinity. The trend analysis for all parameters including water level is carried at a significance level of 5%. For any trend, if it is resulting as ***insignificant increasing or decreasing trend***, it means there is ***No Trend*** [Table 3]. However, *groundwater level is having an insignificant decreasing trend at 5% significance level with a decline of 0.152 mm per year.* Ca is with an insignificant decreasing trend with a decrease of 0.21 mg/l per year. Cl is having an insignificant decreasing trend with a decrease of 1.86 mg/l per year. CO_3 is having an insignificant increasing trend with a decrease of 0.01 mg/l per year. *F is with a significant increasing trend with an increase of 0.01 mg/l per year.* HCO_3 is having an insignificant increasing trend with an increase of 0.5 mg/l per year. K is having an insignificant decreasing trend with a decrease of 0.72 mg/l per year. Mg is with an insignificant increasing trend with an increase of 0.002 mg/l per year. Na is with an insignificant increasing trend with an increase of 1.28 mg/l per year. NO_3 is with an insignificant decreasing trend with a decrease of 1.07 mg/l per year. pH is having an insignificant decreasing trend with a decrease of 0.001 per year. Residual Sodium Carbonate is with an insignificant increasing trend with an increase of 0.08 mg/l per year. SAR is having an insignificant increasing trend with an increase of 0.02 % per year. SO_4 is having an insignificant decreasing trend with a decrease of 0.63 mg/l per year. Total alkalinity is having an insignificant increasing trend with an increase of 3.06 mg/l per year. Total hardness is with an insignificant decreasing trend with a decrease of 0.9 mg/l per year.

Changes in land use/land cover patterns, removal of vegetation and agriculture practice following lands are modified at few areas are affecting groundwater levels and quality parameters as urbanization is onset within the study area. Also, exploitation of ground water resources is the key driver for trends in various groundwater parameters including water level. As urbanization is commenced from the year 2014 for proposed city, existing ground surface is becoming more impervious which is resulted in more surface runoff, less infiltration and further less groundwater availability.

The present groundwater trend analysis of levels and quality is useful to assess trends in groundwater parameters for any existing or proposed city using Mann-Kendall trend test, Sen's slope estimator, and various modified versions of Mann-Kendall test and R programming.

CONCLUSIONS

In the present study, trend analysis of groundwater is carried for the city area using Mann-Kendall test, Sen's slope estimator and R programming. It is obtained that most of the trends of various quality parameters including groundwater level below ground level are insignificant and decreasing. The declining trends are might be due to less precipitation, more exploitation of groundwater resources, commencement of urbanization for the proposed city, climate change, and land use/land cover patterns. However, parameter wise study may give more insight on drivers for trends. *Groundwater level is having an insignificant decreasing trend at 5% significance level with a decline of 0.152 mm per year. F is with a significant increasing trend with an increase of 0.01 mg/l per year.*Ca is with an insignificant decreasing trend with a decrease of 0.21 mg/l per year. Cl is having an insignificant decreasing trend with a decrease of 1.86 mg/l per year. CO_3 is having an insignificant increasing trend with a decrease of 0.01 mg/l per year. Total alkalinity is having an insignificant increasing trend with an increase of 3.06 mg/l per year. Total hardness is with an insignificant decreasing trend with a decrease of 0.9 mg/l per year. The findings of the present study can help to evaluate trends of groundwater of any existing or proposed city. Further, parameter-wise studies during various stages of urbanization of proposed Amaravati city may add more insights on the groundwater quality due to urbanization.

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