Exploring groundwater dynamics through change point detection in static water level in the alluvial plain of Purba Bardhaman district, West Bengal, India

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Abstract

Static water level dynamics is an integral process of a complex hydrological system. However, the concern arises if the static water level goes beyond the long-term average level and the groundwater abstraction rate recurrently exceeds the recharge rate. The present study attempts to uncover the hydraulic head dynamics in the Purba Bardhhaman district based on the past 25 years of static water level data (1996-2020) retrieved from a web-based Water Resource Information System (WRIS) maintained by the Central Groundwater Board. Change year detection in static water level is an effective way to determine whether any monotonic increasing or decreasing trend persists in the static water level of the Purba Bardhhaman district. Multiple change year detection methods such as Pettit's test, SNH homogeneity test and Buishand rang tests have been applied to determine the exact change year from which abrupt change in SWL was started. Descriptive statistics like average, standard deviation, change rate and coefficient of variation (CV) in SWL were performed before and after the change point. Variability in SWL has been determined using a graphical analysis and groundwater level index. The trend in SWL for both pre and post-change points has been identified using a simple linear regression model for selective wells in this area. The results revealed that most of the wells found a declining SWL in both the pre and post change point conditions. This study has considered and used a network of groundwater monitoring wells consisting of 47 wells. Additionally, a substantial negative trend was noted in the annual groundwater level.

Keywords: Groundwater level, Sen's innovative trend, Multilayer perceptron, Machine learning

1. Introduction

Groundwater depletion is becoming a major challenge due to factors such as population density, growing urbanisation, variability in precipitation patterns, and extensive agricultural reliance on groundwater resources (Alam et al., 2003). The depletion of groundwater storage at the regional level is primarily influenced by the temporal reactions of both natural and anthropogenic factors. The evidence suggests that groundwater is susceptible to stress in terms of quantity and quality. Numerous aquifers are currently experiencing over-exploitation, particularly in locations characterised by semi-arid and dry climates. Groundwater recharge is a crucial determinant that impacts groundwater withdrawal (Basu et al., 2001). However, estimating groundwater availability poses challenges for scientists, mainly attributed to a scarcity of data resulting from a limited number of hydrological monitoring field stations, a restricted number of aquifer monitoring wells, and infrequent collection of field data (Basu et al., 2001; Halder et al., 2020; Hsin-Fu Yeh & Chang, 2019; Pathak & Dodamani, 2019). Aquifer systems of an area respond to hydraulic stressors, such as recharge and outflow, by exhibiting changes in groundwater level through time and/or season and spatial variations. The fluctuation in water level elevation is a time-dependent stochastic process influenced by multiple inflow and outflow components within the system. Therefore, the groundwater level indicates groundwater availability, flow and physical features of the hydrogeologic system within a specific area. The fluctuation in groundwater level over time is applied to estimate changes in aquifer storage. Simultaneously, heterogeneity in aquifer features, such as transmissivity and storativity, results in diverse responses within the aquifer. Consequently, this heterogeneity gives rise to variations in trends, jumps, periodicities, and other related attributes of groundwater level (Patle et al., 2015; Praveen et al., 2020; Sakiur Rahman et al., 2016). The introduction of seasonality in hydrologic time series data in India is significantly influenced by the variability in monsoon, as stated by (Shekhar et al., 2020). The distribution of groundwater resources in the Indian subcontinent has a high degree of heterogeneity, with notable variations observed across distinct geological and geomorphological terrains. Research indicates that the hypothesised intensification of the problem is attributed to the recent alterations in weather patterns. According to (Asoka et al., 2017; Small & Rimal, 1996), it has been approximated that in India, an annual hydrological influx of around 4000 billion m^3 of water occurs within the hydrologic system. Approximately 50% of the water budget comprises unaccounted water losses, including outflow to oceans, evapotranspiration, seepage to deep levels, and pipeline leakages. According to (Mukherjee, 2020), approximately 60% of the remaining water resource, which amounts to 2000 billion cubic meters, is located within the expansive alluvial plains of the Indus-Ganges-Brahmaputra river basins in northern India. The modelling of natural hydrologic systems using time series observations is subject to uncertainties, which can be attributed to the geology and/or hydrogeologic factors of the systems in question. Numerous investigations have been undertaken in this direction. However, the studies conducted thus far vary in magnitude and technique compared to the current research. The majority of the prior studies have focused on examining comparable issues related to understanding the impact of elements such as climatic variability and anthropogenic interventions. The Purba Bardhaman plain in West Bengal is characterised by the alluvial aquifers, which have become notorious for groundwater depletion and arsenic poisoning. Simultaneously, it serves as a significant agricultural epicentre for the surrounding area. In general, it is not well recognised as a water-scare region. The primary purpose of this study is to provide a scientific technique for assessing the sub-soil water resource situation. The static water level elevation data within the hydrogeologic framework of Purba Bardhaman Plain has been analysed to examine the current trends in this field. The findings of this study have been analysed in sync with the hydrological attributes of the Bengal basin in its entirety. The application of novel techniques for analysing groundwater stress has led to significant advancements in our comprehension of the availability of groundwater resources in meeting present water requirements (Amarasinghe et al., 2007; Mukherjee, 2020). The existing literature suggests that in the context of climate uncertainty, the scope of establishing a comprehensive assessment of groundwater resources for guiding future groundwater planning at the C.D. block level. Hence, this study aims to explore the dynamics of static water level at the block level by utilising historical time-series data from 1996-2020. Several scientific methodologies are widely available to explore and analyse the dynamics and changing behaviour of the groundwater landscape of an area. The Mann-Kendall (MK) test and Sen's slope estimator are widely employed non-parametric tests in the field of hydrology for analysing time series data. Similarly, Buishand's range test, Standard Normal Homogeneity test and Pettit's test exhibit high sensitivity in detecting changes in time series. However, these methods are particularly well-suited for finding changes in the central period of a series. However, the approaches employed by previous authors fail to account for the possibility of inhomogeneities, which are characterised by considerable variations in static water level over time. (Samal & Gedam, 2021) demonstrated that variations in hydrological data can be attributed to three main factors: rapid changes or jumps, regular trends, or jumps superimposed over a trend. Furthermore, inhomogeneities might result in systematic deviations or significant disruptions in the data series. Hence, thoroughly assessing the long-term static water level trend, including the rate of change and homogeneity, is imperative.

2. Materials and methods

2.1. Study Area

The Purba Bardhhaman plain is located in the bountiful alluvial plain of the Bengal Basin. Its western segment, the Ausgram plain, contains older alluvial deposits than its eastern part, known as the Kusumgram plain. This region belongs to the GBM deltaic plain, a significant tract of the Bengal basin's western section. Latitudes ranging from 22° 15' 08" to 23° 15' 17" north and longitudes ranging from 87° 13' 17 to 88° 7' 22" east define the region under study, as depicted in Figure 1. The immense expanse of the plain is bisected by four notable rivers: the Hugly, Ajay, Damodar and Darkeswar. In addition, an extensive network of waterways, distributaries, and stagnant surface water bodies such as tanks, ponds, and bills significantly endowed the region's abundant water supply. Five thousand seven hundred sixty square kilometres comprise the region's entire land area under consideration. This region has a humid climate, with annual precipitation averaging 1250 mm and average temperatures from 8° to 27°C. The predominant economic activity is agriculture, with three principal growth seasons: Aus (Zaid), Aman (Kharif), and Boro (Summer). Rice is the most important staple crop in the region, surpassing all other cereals and vegetables. The cultivation intensity in this area is 177%, which is substantially higher than the state's average cropping intensity.

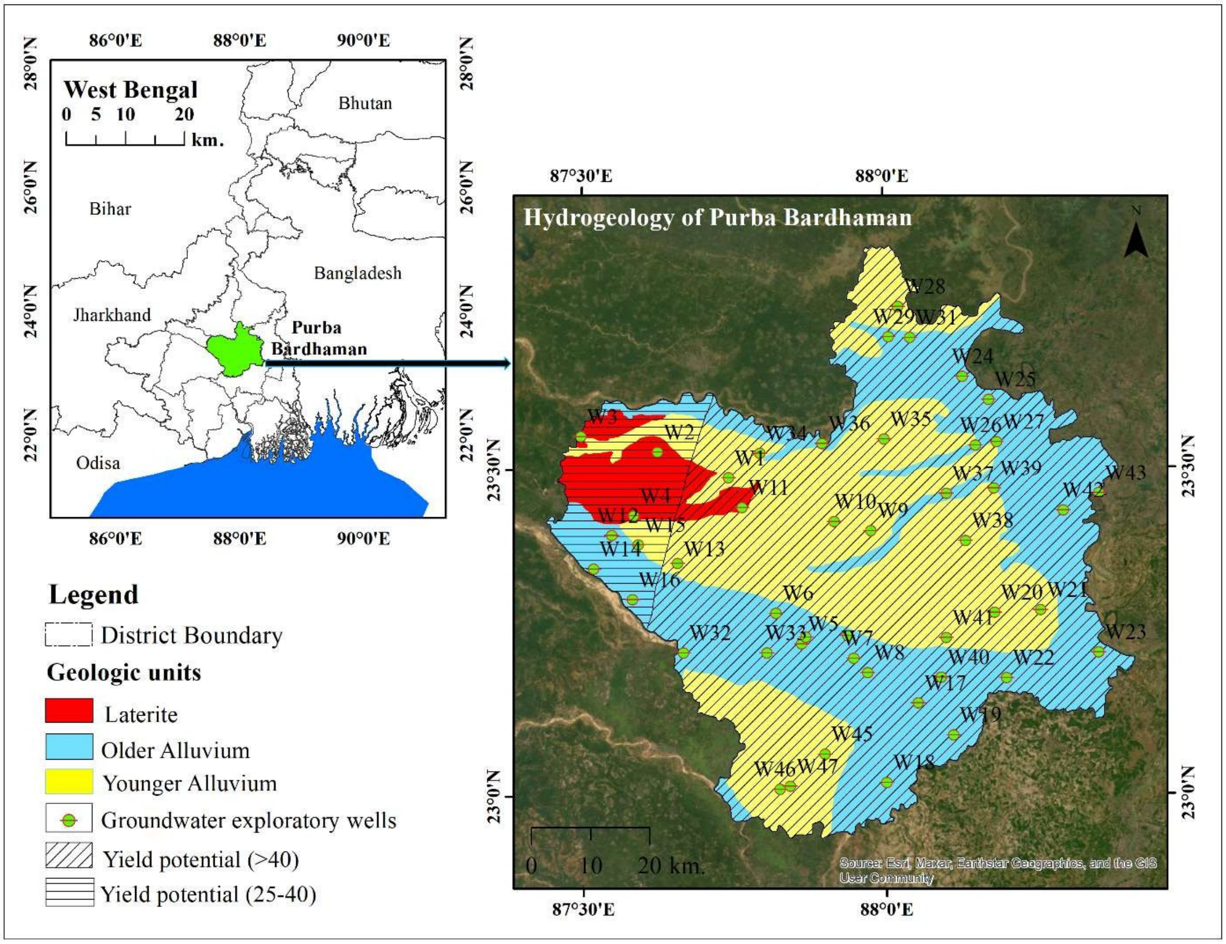

Fig. 1 Location map of the study area: The map on the right represents the hydro-geologic units of the Purba Bardhaman plain (district), with 47 groundwater exploratory wells distributed on the map.

2.2. The hydro-geological architecture of Purba Bardhaman plain

The majority of the Purba Bardhaman district is situated on the alluvial fan delta of the Damodar Basin, located on the southwestern shelf of the Bengal Basin. During the arid months, the flow in the Damodar river and its associated tributaries and distributaries experiences a significant reduction. According to the State of Environment Report (2016), the monsoon flows tend to overflow the channels and cause severe floods in the riparian areas. The delta-building processes in the Bardhaman region have been extensively documented in the publications of the Geological Survey of India (GSI). These reports have documented and classified three distinct terraces in this area: the Orgram Terrace, the Kusumgram Terrace, and the Kalna Terrace. The Lower Damodar Basin is characterised by a hydrological division with the Ajay River to the north, while Peninsular shield rocks demarcate its western boundary and Gangetic sediments define its eastern edge. The eastern segment of the region is traversed through the lower Damodar Basin, which is predominantly overlain by Quaternary alluvial deposits. The primary geological units encountered in the study region are depicted in Figure 1, as reported by GSI. The area in question is primarily characterised by the presence of older alluvium, laterite, tertiary, and quaternary deposits. Groundwater is found in unconfined conditions at depths of up to

70 meters below ground level. Access to this groundwater is facilitated through a network of open-dug wells and shallow tube wells. The shallow aquifers inside tertiary strata consist predominantly of coarse sand and gravel.

In contrast, the quaternary formation is characterised by fine to medium sand layers, occasionally interspersed with gravel and pebble deposits. The sand and gravel deposits are occasionally interspersed with relatively narrow clay layers, resulting in their occurrence within semi-restricted to confined hydro-geological settings (Central Groundwater Board, 2019). The Purba Bardhaman plain comprises two primary physiographical divisions: the flood plain, characterised by a cyclic arrangement of sand, silt, and clay layers. Figure 1 displays the upper mature deltaic plain and para deltaic flood surface. The overall topographical gradient of the district has a directional trend from the Northwest to the southeast. The Purba Bardhaman district is characterised by a predominantly flat alluvial plain terrain, which can be further classified into distinct geomorphic sections. The Ketugram Plain is situated to the north, adjacent to the Ajay River, which afterwards converges with the Bhagirathi River in Katwa. The core region of the district is occupied by the Bardhaman Plain, which the Damodar River flanks to the south and southeast. The Khandaghosh Plain is located in the southern region. The Bhagirathi River traverses the eastern periphery of the district, while the Bhagirathi Basin encompasses the eastern margin of the plain. The chotonagpur plateau exhibits undulating laterite topography, which extends up to the westernmost region of this district.

2.3. Collection of static water level data

The Central Groundwater Board (CGWB), a water agency of the Ministry of Jalshakti, employs a network of groundwater observation wells to systematically measure the static water level at different observation points on a seasonal basis. The data taken during April and November are commonly referred to as pre-monsoon and post-monsoon depth to static water level data. The data pertaining to the 23 C.D. blocks in the Purba Bardhhaman district, spanning 1996 to 2020, has been obtained from the Central Ground Water Board (CGWB). The site information about the monitoring wells, such as their geographical coordinates, was documented using a portable GPS survey. Within this geographical region, sixty-nine wells are designated explicitly for monitoring groundwater. However, the study only included 47 wells due to missing data seen at several years in the remaining wells. The study collected the static water levels (SWL) from three types of monitoring wells: hand pump, conventional piezometer, and digital piezometer. During the primary field survey, the identification and recording of all monitoring wells utilised in this study were conducted.

2.4. Change point detection methods

Pettit’s test, Alexandersson and Moberg’s Standard Normal Homogeneity Test (SNHT) and Buishand Rang test have been used to determine the presence of abrupt change points in the annual and seasonal static water level in the Purba Bardhhaman district from 1996-2020.

2.4.1. Pettit Test

The Pettitt test is a rank-based distribution-free test used to detect significant changes in the mean of a time series. It is more beneficial when no hypothesis testing on the location of a change point is required. This test has been widely used to denote observed variations in meteorological and hydrological data series. When the duration of a time series is marked by t and the shift occurs after m years, the resulting test statistics are given in Eq. (1). The statistic is comparable to the Mann-Whitney statistic, which uses two samples, such as k1, k2…, km and km+1, k2…, kn:

$$U_{\mathrm{t,m}} = \sum_{\mathrm{j=1}}^{\mathrm{m}} \sum_{\mathrm{j=t+1}}^{\mathrm{t}} \mathrm{sgn}\,(K_{\mathrm{i}} - K_{\mathrm{j}}) \tag{1}$$

Where sgn in Eq. 1 is defined by Eq. 2:

$$\mathrm{sgn}\,(K_{\mathrm{t}} - K_{\mathrm{j}}) = \begin{pmatrix} 1 & ff(K_{\mathrm{t}} - K_{\mathrm{j}}) &)1 \\ 0 & 1f(K_{\mathrm{t}} - K_{\mathrm{j}}) & = 0 \\ -1 & f(K_{\mathrm{t}} - K_{\mathrm{j}}) & \langle 1 \end{pmatrix} \tag{2}$$

The test statistic Ut,m is computed with all arbitrary variables ranging from 1 to n. The bulk of distinct change points are identified where the magnitude of the test statistic |Ut,m | is greatest (Eq. 3)

$$Z_{\mathrm{T}} = \mathrm{Max}_{1\leq \mathrm{t|m}} |U_{\mathrm{t.m}}| \tag{3}$$

The probability of shifting year is estimated when |*Ut,m* | is maximum following Eq. 4:

$$P = 1 - \exp\,\left(\frac{\overset{2}{\mathrm{T}}}{\mathrm{K}^2+\mathrm{K}^3}\right) \tag{4}$$

2.4.2. Standard Normal Homogeneity Test (SNHT)

The Alexanderson test is another name for the basic normal homogeneity test. This test detects an abrupt shift or the presence of a transition point in climatic and hydrologic time series datasets. Following Eq. 5, the change point has been identified:

$$T_{\mathrm{s}} = maxT_{\mathrm{m}}, 1 \leq m < n \tag{5}$$

The change point is when Ts attains the maximum value in the data series. The Tm is derived using Eq. 6:

$$T_{\mathrm{m}} = mz_1 + (n-m)\Sigma_{\mathrm{p}}, m = 1,2, \dots, n \tag{6}$$

Where,

$$\bar{z}_1 = \frac{1}{m}\sum_{i=1}^{n}\frac{(M_F-\bar{M})}{s} \quad (7)$$

Where *m* represents the mean and *s* represents the standard deviation of the sample data.

2.4.3. Buishand Range Test:

The Buishand range test, alternatively called the Cumulative Deviation test, is calculated using corrected biased sums or cumulative deviation from the mean. The change point is determined using Eqs. 8 and 9:

$$R^{*}_{0} = 0 \text{ and } R^{*}_{m} = \sum_{t=1}^{m} (P_t - P_{mean}) \quad (8)$$

$$m = 1,2 \ldots \ldots \ldots, n$$

$$R^{**}_{m} = R^{*}_{m}/\sigma$$

$$S = \text{Max}\,|R^{**}_{m}| - Min|R^{**}_{m}|, 0 \le m \le n \quad (9)$$

The *S*/ *n* is then estimated using the critical values proposed by Buishand.

2.5. Simple linear regression trend in SWL

Regression analysis is the most useful parametric model used to develop functional relationships between dependent and independent variables, known as the “simple regression” model. A linear equation y= a + bx, defined for SWL value y and t as time in year, a (least square estimates of the intercept) and the trend b (slope), can be fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provides the rate of rise/fall in the variable. It is reasonable to interpret if the slope is statistically significantly different from zero. The positive sign of the slope indicates an increasing trend, and its negative value shows a decreasing trend.

2.6. Statistical measures of variability and dynamics in SWL

Descriptive statistics such as mean, standard deviation, coefficient of variation and percentage change rate have been computed to understand the spatio-temporal variation in SWL. All these statistical measures were executed before and after the change point in SWL of the pre-monsoon and post-monsoon conditions. Static water level fluctuation is another critical indicator used to analyse the behaviour of SWL. Seasonal and annual fluctuation for the entire study period provides a good estimate of variability and subsequent decaying of SWL. Important results were mapped to identify the spatio-temporal variability, dynamics and an overall falling trend in SWL.

2.7. The Standard Groundwater Level Index (SGWI)

The Standard Groundwater Level Index bears a resemblance to the Standard Precipitation Index. This quantitative methodology assesses the shortfall in groundwater levels throughout different periods, indicating the stress on the groundwater resource situation. The groundwater condition for each station and its spatio-temporal variation can be inferred from this SGWI. This study calculated SGWI (Standard Groundwater Level Index) for 47 wells from 1996 to 2020 with an interval of five years for pre- and post-monsoon seasons. The calculation of SGWI has been derived using the following equation: K represents the value of the specific year, M denotes the mean value over the study period, and σ represents the standard deviation.

3. Results and Discussion

Analysis of the static water level time series can be done in multiple ways based on the purpose and objective of the study. The scale of the assessment unit is also an important parameter that decides the broader direction and scope of the study. The present study has been conducted at the C.D. block level, which is considered to be a small geographical unit with an areal extent of several hundred sq. mt. to a few hundred sq. km. This study considers two monitoring wells from each assessment unit and computes the relative differences in static water level among different assessment units in the Purba Bardhaman plain.

3.1. Analysis of change-point in static water level

Change-point detection is vital to identify drastic changes and variability in any hydro-meteorological time series. It seeks to check the homogeneity in the historical time series based on abrupt data values and divides it into two unequal time frames. The first set includes datasets from the origin of the time series up to the change year, while the second set comprises the rest of the data. Three distinct statistical methods, the Pettit test, Buisand Range test and Standard Normal Homogeneity test, have been employed to detect the change year in the SWL time series of 47 monitoring wells over 1996-2020 for pre-monsoon and post-monsoon seasons. The results of change year detection have been tabulated in Table 1. It is evident from the result that all three methods produce different change years for the same time series. However, it is persistently observed that all three methods capture the same change year in the SWL time series for multiple wells. In case different change years for a particular well have been detected, the most likely year was taken based on the significance value (p-value) at 95% confidence level. The most frequent pre-monsoon change year is 2009, while it is 2010 for post-monsoon season. In the majority of the wells, the change year lies between 2008-2012, while the extreme change year varies between 2002-2018. The dramatic changes in SWL were precisely observed between the years 2007-2008 to 2014-15. This period is marked by the large-scale transformation of privately owned diesel-operated irrigation pumps into the cooperative-owned electric submersible. This period is also significant from the viewpoint of the massive land use and land cover changes in terms of expansion of cropping land and reduction in vegetation area. In addition, the subsidised electricity rate led to the revolution in groundwater-based irrigation in this area and the resulting decline in SWL.

Table. 1. Change point detection in SWL using different methods for pre-monsoon and post-monsoon seasons from 1996-2020

	Pre-monsoon			**Post-monsoon**		
Name of the site	Pttitt test change point and year	Buisand range test change point and year	SNHT Change point detection and year	Pettitt test change point and year	Buisand range test change point and year	SNHT Change point detection and year
Ajhapur	16 (2011)	16 (2011)	21 (2016)	21 (2016)	21 (2016)	21 (2016)
Amirpur	17 (2012)	17 (2012)	21 (2016)	17 (2012)	17 (2012)	17 (2012)
Amra	11 (2006)	11 (2006)	11 (2006)	12 (2007)	20 (2015)	22 (2017)
Amragarh Pz	23 (2018)	23 (2018)	23 (2018)	12 (2007)	17 (2012)	20 (2015)
Bamunpara-I	18 (2013)	18 (2013)	19 (2014)	10 (2005)	10 (2005)	10 (2005)
Bannabagram-I	14 (2009)	14 (2009)	14(2009)	12 (2007)	13 (2008)	13 (2008)
Bara Dhamas	15 (2010)	15 (2010)	15 (2010)	15 (2010)	15 (2010)	15 (2010)
Barabelun	14 (2009)	15 (2010)	22 (2017)	15 (2010)	15 (2010)	15 (2010)
Barddhaman	10 (2005)	21 (2016)	24 (2019)	19 (2014)	20 (2015)	23 (2018)
Barsul Pz	15 (2010)	15 (2010)	19 (2014)	13 (2008)	13 (2008)	22 (2017)
Bhatar Pz	12 (2007)	14 (2009)	14 (2009)	15 (2010)	15 (2010)	15 (2010)
Bud Bud Pz-I	16 (2011)	16 (2011)	16 (2011)	3 (1999)	13 (2008)	3 (1999)
Chak Banangoria	14 (2009)	14 (2009)	14 (2009)	17 (2012)	17 (2012)	17 (2012)
Chakdigi	7 (2002)	7 (2002)	7 (2002)	9 (2004)	9 (2004)	22 (2017)
Charnak Pz	14 (2009)	14 (2009)	14 (2009)	13 (2008)	17 (2012)	17 (2012)
Chupi	8 (2003)	11 (2006)	11 (2006)	14 (2009)	14 (2009)	14 (2009)
Dainhat-I	13 (2008)	4 (2000)	1 (1997)	7 (2002)	6 (2001)	2 (1998)
Dakshin Radhakantapur	7 (2002)	17 (2012)	17 (2012)	20 (2015)	13 (2008)	16 (2011)
Dommara Pz	11 (2006)	7 (2002)	7 (2002)	9 (2004)	13 (2008)	9 (2004)
Galigram	8 (2003)	8 (2003)	8 (2003)	20 (2015)	20 (2015)	20 (20150
Guskara Pz	12 (2007)	25 (2020)	9 (2004)	12 (2007)	13 (2008)	18 (2013)
Hat Murgram	17 (2012)	17 (2012)	17 (2012)	16 (2011)	16 (2011)	16 (2011)
Jamra	13 (2008)	13 (2008)	23 (2018)	13 (2008)	15 (2010)	15 (2010)
Jhinguti	13 (2008)	13 (2008)	13 (2008)	11 (2006)	11 (2006)	18 (2013)
Kaity	13 (2008)	14 (2009)	22 (2017)	15 (2010)	15 (2010)	23 (2018)
Kalna	9 (2004)	14 (2009)	14 (2009)	9 (2004)	13 (2008)	13 (2008)
Kasba	7 (2002)	8 (2003)	3 (1999)	20 (2015)	20 (2015)	24 (2019)
Katwa Town-I	19 (2014)	19 (2014)	19 (2014)	21 (2016)	21 (2016)	21 (2016)
Ketugram	16 (2011)	16 (2011)	16 (2011)	12 (2007)	16 (2011)	16 (2011)
Khalipur PZ	14 (2009)	14 (2009)	21 (2016)	15 (2010)	15 (2010)	21 (2016)
Koichor	14 (2009)	14 (2009)	21 (2016)	15 (2010)	15 (2010)	15 (2010)
Kusumgram Pz	13 (2008)	13 (2008)	13 (2008)	15 (2010)	15 (2010)	15 (200)
Madhyamgram Pz	11 (2006)	11 (2006)	23 (2018)	13 (2008)	13 (2008)	13 (2008)
Metedanga	15 (2010)	15 (2010)	15 (2010)	20 (2010)	20 (2015)	20 (2015)
Metedanga	9 (2004)	8 (2003)	8 (2003)	14 (2009)	16 (2011)	20 (2015)
Nandigram	13 (2008)	13 (2008)	13 (2008)	15 (2010)	15 (2010)	15 (2010)
Natunhat-I	20 (2015)	15 (2010)	15 (2010)	16 (2011)	16 (2011)	19 (2014)
Orgram	10 (2005)	15 (2010)	15 (2010)	12 (2007)	12 (2007)	19 (2014)
Paharhati	15 (2010)	15 (2010)	15 (2010)	15 (2010)	15 (2010)	15 (2010)
Raghunathpur-I	17 (2014)	18 (2013)	24 (2019)	9 (2004)	23 (2018)	23 (2018)
Raina	14 (2009)	14 (2009)	14 (2009)	13 (2008)	13 (2008)	10 (2005)
Rakona Pz	15 (2010)	15 (2010)	20 (2015)	19 (2014)	19 (2014)	23 (2018)
Ramgopalpur	20 (2015)	20 (2015)	20 (2015)	20 (2015)	20 (2015)	20 (2015)
Ramjibanpur	12 (2007)	14 (2009)	15 (2010)	13 (2008)	15 (2010)	15 (2010)

Simlon-I	8 (2003)	23 (2018)	23 (2018)	14 (2009)	21 (2016)	22 (2017)
Singhi Pz SWID	13 (2008)	14 (2009)	14 (2009)	13 (2008)	15 (2010)	4 (2000)
Tildanga	14 (2009)	14 (2009)	14 (2009)	13 (2008)	10 (2005)	10 (2005)

3.2. Simple Linear trend in static water level

The present study employed the ordinary least squares method to examine the linear trend in the time series of SWL in the Purba Bardhaman plain. The objective of this study was to ascertain the presence of linear patterns in the static water level (SWL) throughout the pre-monsoon and post-monsoon periods, both before and after a designated year of alteration. The substantial number of groundwater monitoring wells hinders the feasibility of creating graphical representations to depict the trend of Static Water Level (SWL) for individual wells. Therefore, a selection of wells was made by random sampling to serve as a representative sample for analysing static water levels (SWL) before and after the change year, as illustrated in Figures 2 and 3. The OLS regression technique was insufficient in accounting for the whole variance in the supplied dataset due to the univariate structure of the SWL time series. Hence, it has been determined that the linear trend observed in the data from all 47 monitoring wells lacks statistical significance.

Nevertheless, the overall pattern seen in the majority of wells exhibited a downward trajectory, with just a limited number of deviations, suggesting an increasing trend in the static water level. Before the change year, the static water level displayed a slight downward trend. However, a drastic downward trend was observed after the change year for pre and post-monsoon conditions. The observed decrease in SWL for both seasons suggests a deficiency in monsoonal replenishment and the resulting anomaly in recharge and discharge volumes within this region.

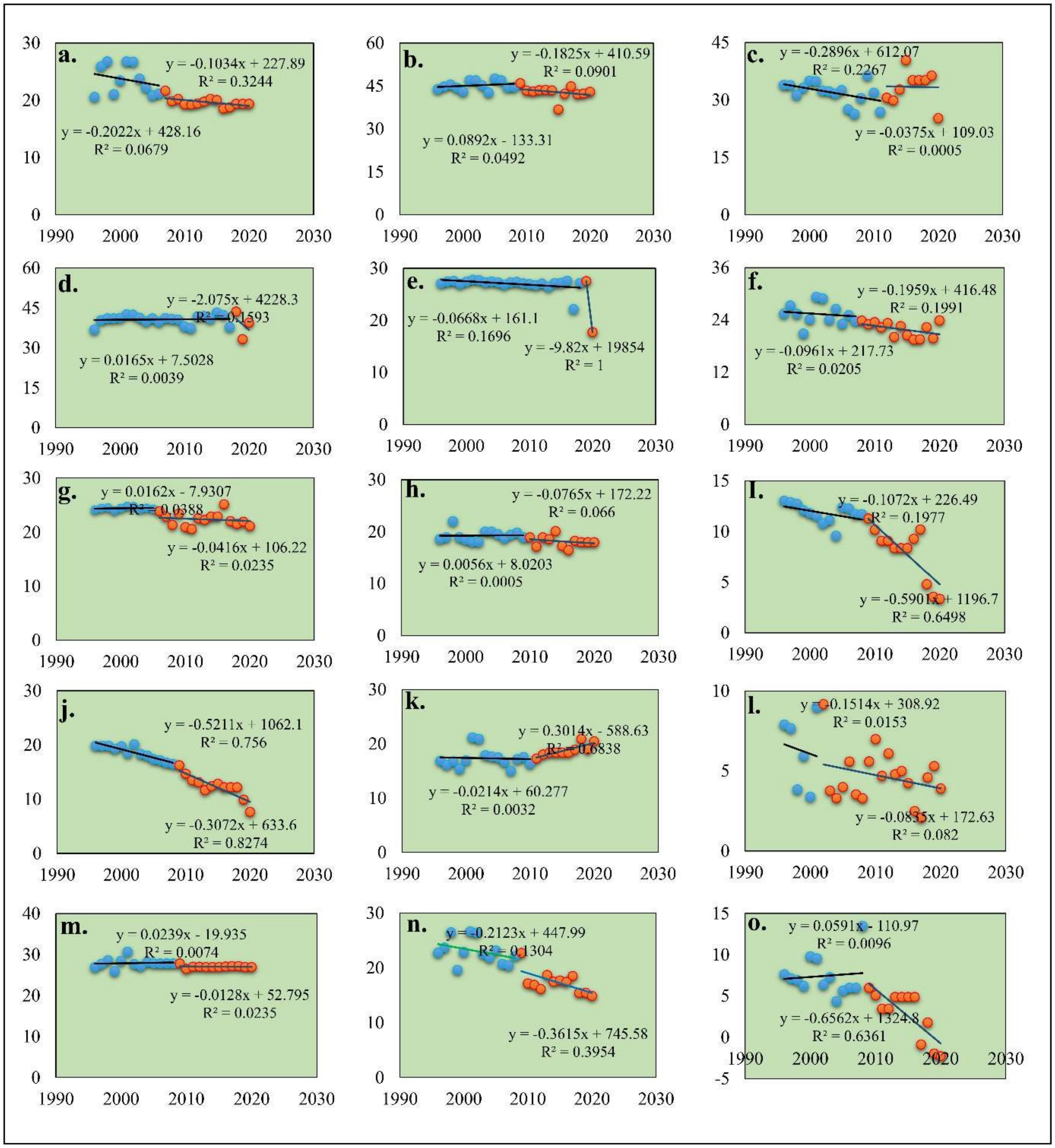

Fig. 2 Linear trend before and after the change year in SWL for pre-monsoon season

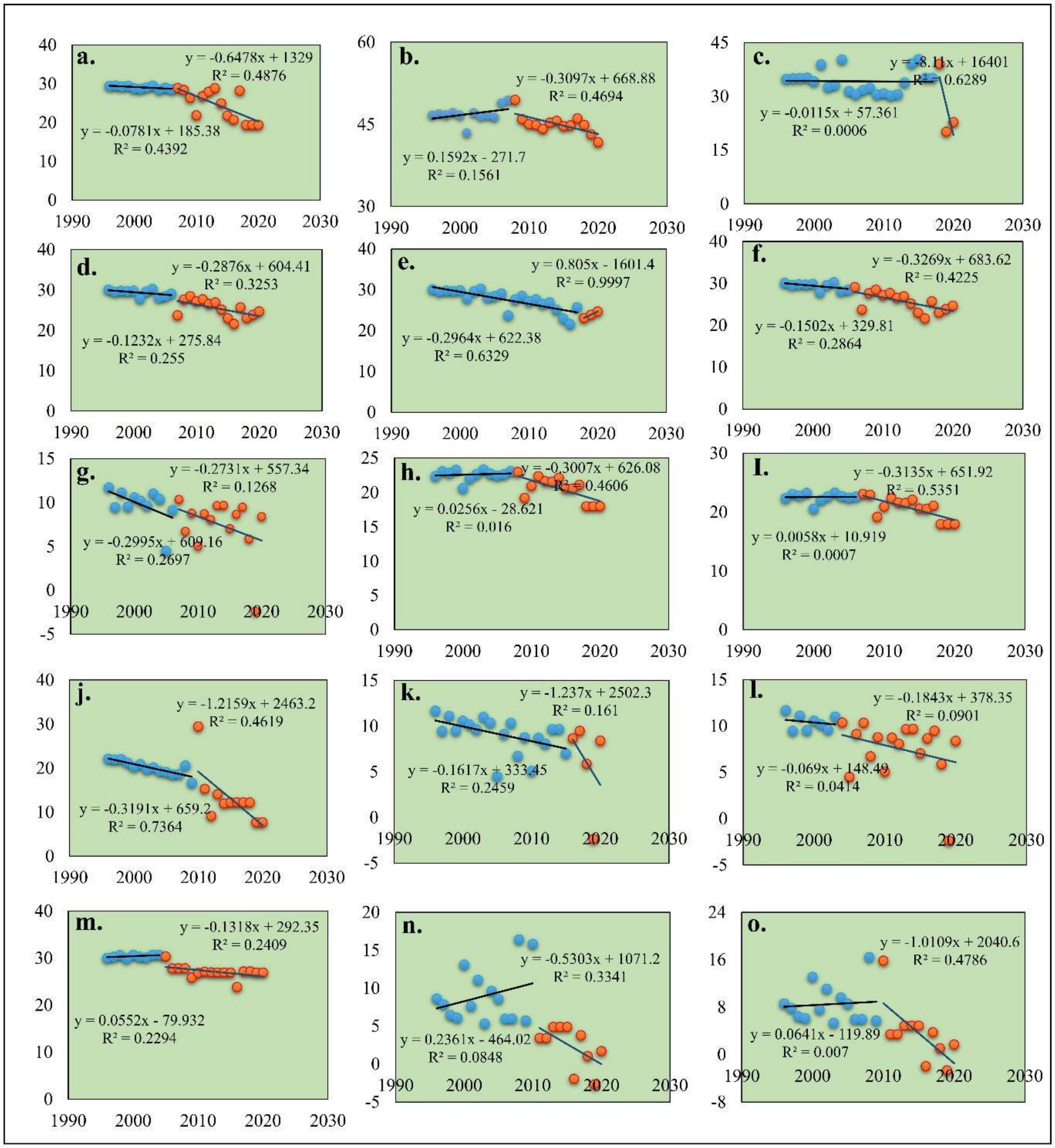

Fig. 3 Linear trend before and after the change year in SWL for post-monsoon season

3.3. Spatial variation in static water level

The decrease in the static water level is directly associated with reducing aquifer storage, indicating that extraction rates surpass natural recharge (Kumar et al., 2005; Sen, 2021; Singh, 2016). In the study area, it has been seen that the SWL elevations are shallower in the extreme western section as compared to the alluvial deposits of the Bhagirathi-Ajay interfluvial zone in the eastern segment. During investigation, a notable decrease in the static water level was detected in the Kusumgram Plain, exhibiting a significant downward tendency. The evaluation of the interpolated maps for the pre-monsoon and post-monsoon periods reveals that both seasons exhibit notable declines in static water level within the same zones. However, there is more variability observed during the post-monsoon period. This observation illustrates the consistent difference between recharge and discharge in this area. Groundwater depletion typically arises from a combination of climatic influences and human activities that disrupt the natural hydrological cycle, primarily through excessive groundwater pumping without adequate consideration for water availability to refill the depleted reserves. Therefore, it is probable that locations characterised by aridity are more susceptible to experiencing this crisis. According to (Kumar et al., 2005; MISTRI, 2017; Prabhakar & Tiwari, 2015; Sen, 2021; Singh, 2016), groundwater depletion is prevalent globally in semi-arid and humid locations. They argue that the over-extraction of groundwater is the primary factor contributing to this phenomenon, surpassing the influence of climatic conditions that regulate natural recharge. Therefore, the evidence derived from these observations indicates that alterations in recharge rates caused by climate change have the potential to impact the pace at which groundwater is depleted. Nevertheless, according to the surveys conducted on global literature, it is anticipated that the impacts of these alterations on aquifers have been relatively minor compared to non-climatic factors (Feng et al., 2013; Mahammad & Islam, 2021). How groundwater systems react to changes in climate is contingent upon the specific geological characteristics of the area (Saha et al., 2014). Additionally, factors such as land use and land cover (LULC) and other variables that influence the rates of infiltration and recharge also contribute to this variability (Kalbus et al., 2006). The study by (Farahmand et al., 2021) demonstrates a correlation between alterations in groundwater levels and specific patterns of global climatic variability and annual precipitation. Based on the findings, rivers' base flow and ecosystems' functioning are sustained by shallow groundwater at a depth of 30 meters. Additionally, (Roy & Chakravarty, 2021) have indicated that the influence of climatic conditions on the static water levels of these unconfined aquifers is minimal, occurring only at sub-annual to annual periods. The water level fluctuations in deep restricted aquifers are influenced mainly by climatic conditions over extended periods, owing to physical limitations such as the time it takes for the recharge to travel and reach the aquifer. The significant extraction from underground storage has a direct and localised effect on alterations in groundwater mass, especially in deep aquifers (Bandyopadhyay et al., 2014; Halder et al., 2020). Based on these principles, it is essential to highlight that within the scope of the current study, the influence of irrigation pumping on the monitored aquifers within a depth range of 30-150 meters is more pronounced.

3.4. Temporal dynamics in static water level

The simple linear regression analysis indicates a significant decrease in the static water level elevation for most of the wells in both seasons, as depicted in Figures 2 and 3. During the pre-monsoon season, the extreme western tract comprising wells at Guskara, Bannabagram, and Raghunathpur in Ausgram-I and II C.D. blocks exhibit no noticeable trend. However, a decline in the SWL trend has been seen in blocks composed of older alluvium. In the post-monsoon period, static water levels have decreased in most wells except a few located in different corners of the district. This suggests that the influence of climatic factors, such as monsoonal rainfall, has minimal impact on the fluctuations of water levels in this area. The current study's spatial extent restricts its ability to determine the broader impact of climate change, especially the influence of meteorological factors. However, this study pointed out that, like other parts of the Bengal Basin (BB), human intervention in the hydrologic regime through pumping can be attributed to the observed decline in static water levels in this area. (Central Groundwater Board, 2010) found that excessive groundwater use for irrigating Boro crops in different areas of Purba Bardhaman plain, along with little replenishment from rainfall, has led to a continuous decline in the static water levels well below the mean sea level (MSL) in this region. As (Mukherjee, 2020) stated, the primary origin of arsenic in this specific region of the lower Gangetic delta can be attributed to arsenic sulphide minerals deposited alongside clay within a reducing environment. The excessive use of groundwater for Boro cultivation during the summer season results in a significant decline in groundwater levels above sustainable thresholds and contributes to the aeration and oxidation of arsenic sulphides. Consequently, this phenomenon finally results in the process of arsenic leaching into groundwater. The excessive pumping of groundwater beyond sustainable levels since the 1990s has caused significant disturbances to the regional flow pattern of groundwater in the entire Gangetic West Bengal (GWB) region, including Purba Bardhaman district. This has been observed through the formation of multiple local to intermediate-scale flow systems, as documented by (Hsiao et al., 2007; Konar & Dey, 2015; Mukherjee et al., 2018; Perrone & Jasechko, 2019). The pumping centres and aquifer architecture influenced the regional hydraulic gradients in the study area. Coincidentally, the alluvial Purba Bardahaman plain is a prominent agricultural hub and a significant groundwater depletion hotspot in the state. The present analysis reveals that there has been a tremendous drop in the storage capacity and static water level elevation of aquifers in this region, which can be attributed to the significant increase in irrigated land. Indeed, although situated in a fluvio-deltaic environment with abundant water resources, the observed decrease in static water level elevations appears to be similar to that recognised for their water scarcity in the country. This can be mainly attributed to the limited replenishment of water through precipitation. The average SWL before change year for all 47 wells was much less than the after-change year in pre- and post-monsoon seasons, as depicted in Figures 4 and 5. The maximum decline in average SWL (equal to or more than 5 meters) before and after change years has been recorded at wells Paharhati, followed by Ketugram, Ramjibanpur, Nandigram, Bhatar, Orgram and Koichar. In contrast, the minimum decline in SWL has been found at the wells of Dakshin Radhakantapur, Dainhat, Katwa town and Budbud.

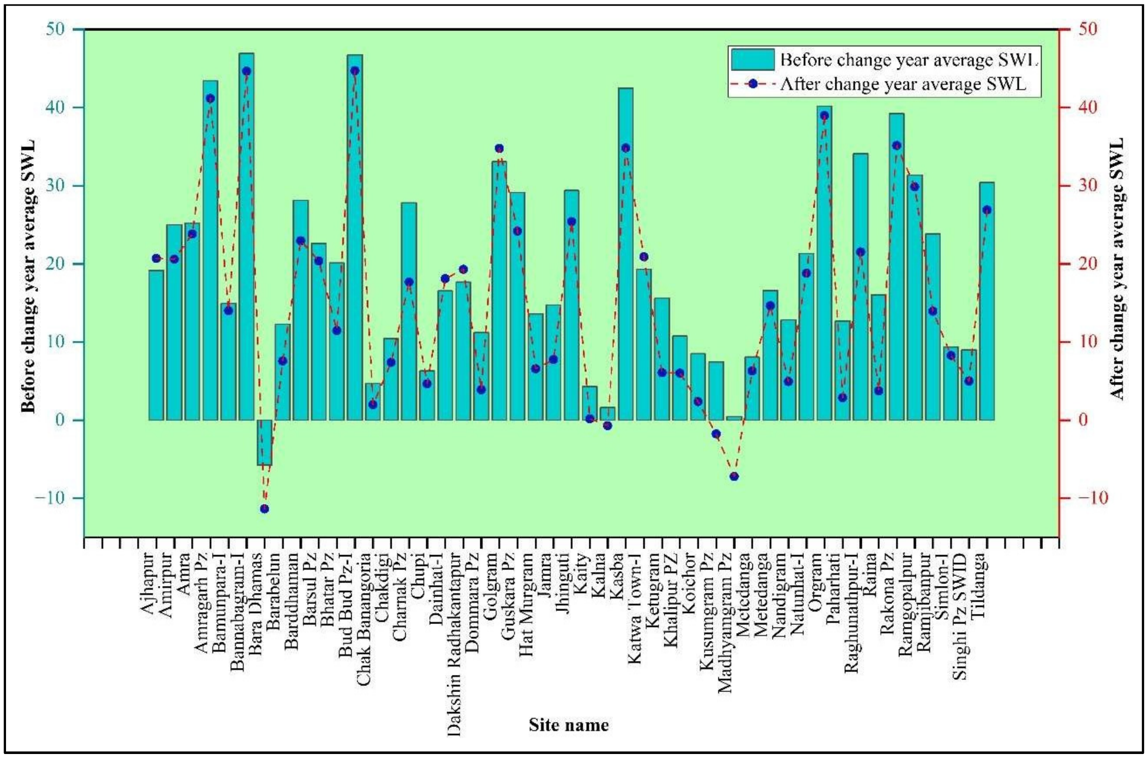

Fig. 4 Average SWL before and after the change year for pre-monsoon season

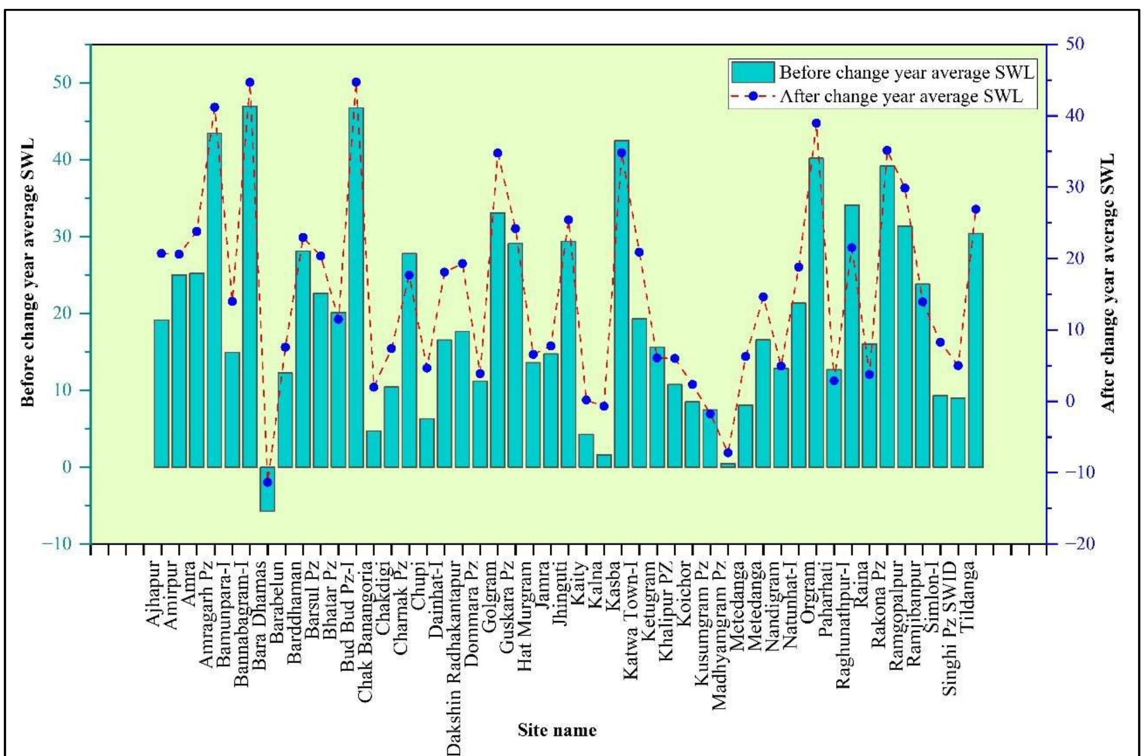

Fig. 5 Average SWL before and after the change year for post-monsoon season

3.5. Standard groundwater level index

The depletion of groundwater has the potential to manifest as a natural calamity, leading to the loss of human lives and causing significant economic devastation. In the contemporary era, the issue of groundwater stress has emerged as a pervasive global concern. The urgency of addressing water stress caused by irresponsible groundwater development is paramount, given that groundwater represents the most extensive reservoir of fresh water on our planet. The phenomenon of climate change can lead to a deficiency in precipitation, which in turn can result in water stress, particularly in groundwater resources. Using groundwater level data to assess hydrological stress contributes to the preservation and stability of various ecosystem services. In this study, an analysis of groundwater stress has been conducted utilising the Standard Groundwater Level Index (SGWI). The calculation of SGWI has been performed for a period spanning from 1996 to 2020, encompassing both seasons, for all wells under consideration. The calculation of the Standard Groundwater Level Index (SWGI), in conjunction with trend analysis, can contribute to the effective design of management units and the conservation of groundwater systems. In 2020, the wells in the lower middle part experienced a state of groundwater stress characterised by a decline in static water levels. The geographical region under consideration exhibits significant fluctuations in evapotranspiration and an irregular precipitation pattern throughout the year. (Ghosh, 2019) asserts that the likelihood of substantial groundwater exploitation is particularly heightened in the eastern plain, accounting for several wells distributed across the C.D. blocks of Manteswar, Bhatar, Memari-I, Memari-II, and Burdwan-I, Burdwan-II, Katwa-I, Katwa-II, Ketugam and Mongalkote within the Purba Bardahaman plain. In addition to the observed climate abnormalities, most of these monitoring wells are predominantly situated in close proximity to the settlement area. In a geographical area characterised by swift agricultural expansion and limited availability of surface water, it is imperative to conduct a comprehensive examination of the impacts of land use and land cover on the process of groundwater recharge. A limited number of studies have been undertaken on the regional and local characterisation of groundwater stress and its ongoing monitoring. A noticeable change in groundwater stress areas was portrayed in Figures 6 and 7. Here, negative values of SGWI indicate groundwater stress areas, while a positive groundwater level index manifests comparatively low groundwater exploitation and development areas.

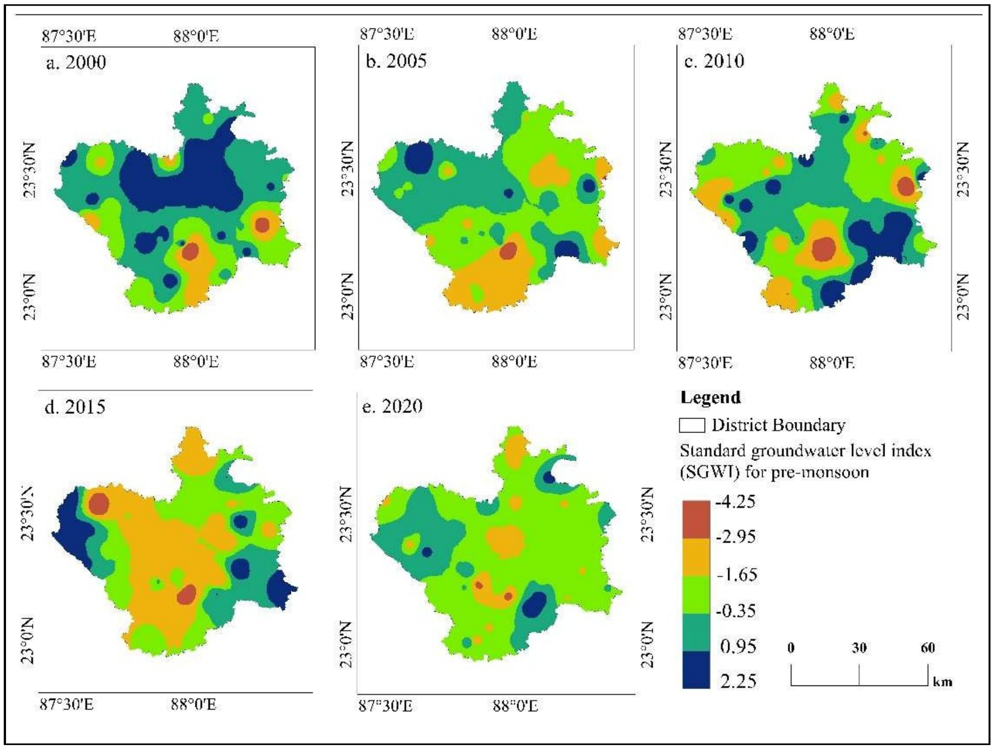

Fig. 6 Pre-monsoon Standard Groundwater Level Index (SGWI) for different years

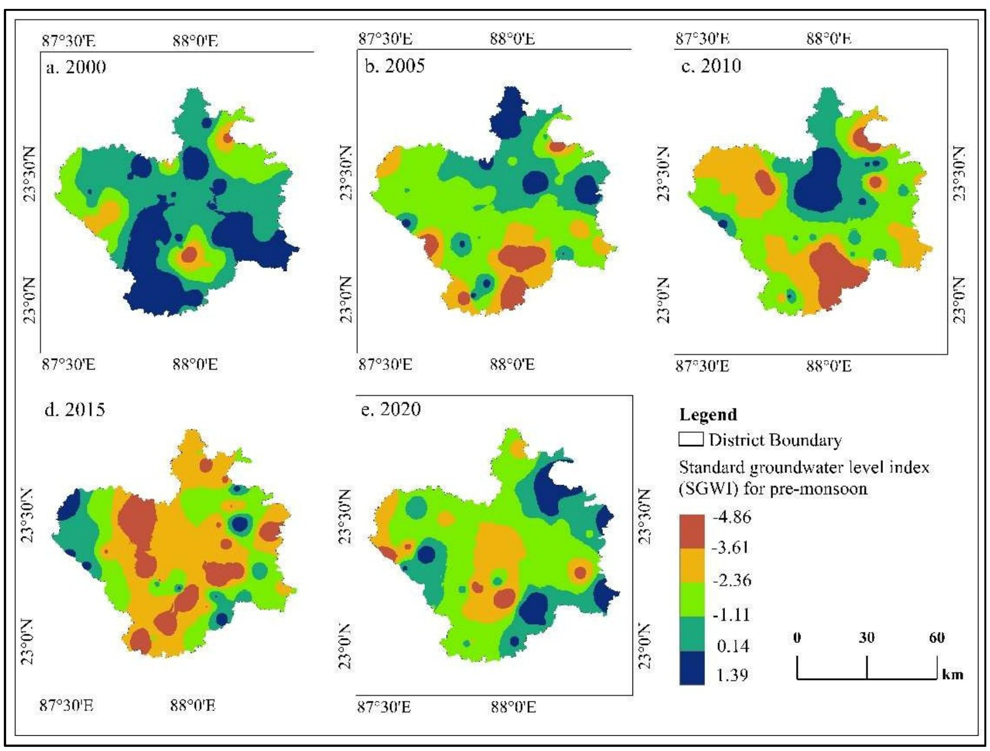

Fig. 7 Post-monsoon Standard Groundwater Level Index (SGWI) for different years

4. Conclusion

In order to effectively manage and plan for groundwater resources, it is essential to investigate the spatio-temporal dynamics and evolving groundwater landscape within a specific region. From this vantage point, the current study aims to examine the linear trend and variability of pre-monsoon and post-monsoon static water levels (SWL) before and after the change year in forty-seven monitoring wells located within the Purba Bardhaman plain areas. The findings of the study validate that the eastern segment of the study area comprising C.D. blocks of Manteswar, Bhatar, Mongalkote, Ketugram-I, Ketugram-II, Memari-I and Memari-II exhibited the maximum seasonal variability in SWL, whereas Ausgram I, Ausgram II, Jamalpur and Khandaghosh demonstrated the lowest SWL variability. This comprehensive study may help water planners curtail the vulnerable groundwater depletion conditions in this region. To develop a management plan for the sustainable development of groundwater resources, researchers worldwide are increasingly emphasizing the need for comprehensive investigations of SWL. Ensuring thorough research on a broad spatial scale requires considering several local aspects, including the pace at which groundwater is extracted and the hydro-geomorphic diversity of the area that influences the dynamics of SWL. This study becomes more significant for practitioners who wish to adopt a source-to-sink approach. Therefore, determining the SWL trend and its associated dimensions can aid in developing strategies and policies to manage groundwater resources within the designated study area.

Statements and Declarations

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Competing Interest

The authors have no relevant financial or non-financial interests to disclose

Authors Contributions

Mr. Islam has primarily conceived the idea and designed the entire study, from data collection to interpretation and discussion of the results. While, Dr. Majumder has helped to review the methods used in this study and finalise the findings of the work.

Data Availability

The dataset used in the current study is available in the Water Resource Information System Repository of Central Groundwater Board, Ministry of Jalshakti (https://indiawris.gov.in/.)

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Ethical Approval

Research ethics has been maintained at every stage of this study, from conceptualising the research idea to data collection, analyses and interpretation. Research ethics has also been prioritised for ranking the authors.

Consent to Participate

Not Applicable

Consent to Publish

All authors have agreed to publish the study in this journal.

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