ELSEVIER Scopus doi

Journal of Vibration Engineering

ISSN:1004-4523

Registered

- SCOPUS
- DIGITAL OBJECT IDENTIFIER (DOI)
- GOOGLE SCHOLAR
- IMPACT FACTOR 6.1

Our Website
www.jove.science

Exploring groundwater dynamics through change point detection in static water level in the alluvial plain ofPurbaBardhaman district,WestBengal, India

Mr.MainulIslam[1],(correspondingauthor),SeniorResearchFellow,DepartmentofGeography,JadavpurUniversity,Kolkata-32, WestBengal,India,
Dr.ArijitMajumder[2],AssistantProfessor,DepartmentofGeography,JadavpurUniversity,Kolkata-32,WestBengal,India,

Abstract

Static water level dynamics is an integral process of a complex hydrological system. However, the concern arises ifthe static waterlevel goes beyondthe long-term average level andthe groundwaterabstractionrate recurrently exceedsthe recharge rate. The present study attempts to uncover the hydraulic head dynamics in the Purba Bardhhaman districtbased on the past 25 years of static water level data (1996-2020) retrieved from a web-based Water ResourceInformation System (WRIS) maintained by the Central Groundwater Board. Change year detection in static waterlevelisaneffectivewaytodeterminewhetheranymonotonicincreasingordecreasingtrendpersistsinthestaticwaterlevelofthePurbaBardhhamandistrict.MultiplechangeyeardetectionmethodssuchasPettit's test,SNHhomogeneity test and Buishand rang tests have been applied to determine the exact change year from which abruptchange in SWL was started. Descriptive statistics like average, standard deviation, change rate and coefficient ofvariation (CV) in SWL were performed before and after the change point. Variability in SWL has been determinedusing a graphical analysis and groundwater level index. The trend in SWL for both pre and post-change points hasbeen identified using a simple linear regression model for selective wells in this area. The results revealed that mostof the wells found a declining SWL in both the pre and post change point conditions. This study has considered andusedanetworkofgroundwatermonitoringwellsconsistingof47wells.Additionally,asubstantialnegativetrendwasnoted inthe annualgroundwaterlevel.

Keywords: Groundwaterlevel,Sen'sinnovativetrend,Multilayerperceptron,Machinelearning

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 bothnaturalandanthropogenicfactors.Theevidencesuggeststhatgroundwaterissusceptibletostressintermsofquantityand quality. Numerous aquifers are currently experiencing over-exploitation, particularly in locations characterisedby semi-arid and dry climates. Groundwater recharge is a crucial determinant that impacts groundwater withdrawal(Basuetal.,2001).However,estimatinggroundwateravailabilityposeschallengesforscientists,mainlyattributedtoa scarcity of data resulting from a limited number of hydrological monitoring field stations, a restricted number ofaquifer 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 asrecharge 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 andoutflowcomponentswithinthesystem.Therefore,thegroundwaterlevelindicatesgroundwateravailability,flowandphysical features of the hydrogeologic system within a specific area. The fluctuation in groundwater level over timeisappliedtoestimatechangesinaquiferstorage.Simultaneously,heterogeneityinaquiferfeatures,suchastransmissivity and storativity, results in diverse responses within the aquifer. Consequently, this heterogeneity givesrise 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 inIndia is significantly influenced by the variability in monsoon, as stated by (Shekhar et al., 2020). The distribution ofgroundwaterresourcesintheIndiansubcontinenthasahighdegreeofheterogeneity,withnotablevariationsobservedacross distinct geological and geomorphological terrains. Research indicates that the hypothesised intensification ofthe problem is attributed to the recent alterations in weather patterns. According to (Asoka et al., 2017; Small &Rimal,1996),ithasbeenapproximatedthatinIndia,anannualhydrologicalinfluxofaround4000billionm^3ofwateroccurswithinthehydrologicsystem.Approximately50%ofthewaterbudgetcomprisesunaccountedwaterlosses,includingoutflowtooceans,evapotranspiration,seepagetodeeplevels,andpipelineleakages.Accordingto(Mukherjee,2020),approximately 60% of the remaining water resource, which amounts to 2000 billion cubic meters, is located withinthe expansive alluvial plains of the Indus-Ganges-Brahmaputra river basins in northern India. The modelling of naturalhydrologic systems using time series observations is subject to uncertainties, which can be attributed to the geologyand/or hydrogeologic factors of the systems in question. Numerous investigations have been undertaken in thisdirection.However,thestudiesconductedthusfarvaryinmagnitudeandtechniquecomparedtothecurrentresearch.The majority of the prior studies have focused on examining comparable issues related to understanding the impactofelementssuchasclimaticvariabilityandanthropogenicinterventions.ThePurbaBardhamanplaininWestBengalis characterised by the alluvial aquifers, which have become notorious for groundwater depletion and arsenicpoisoning. Simultaneously, it serves as a significant agricultural epicentre for the surrounding area. In general, it isnot well recognised as a water-scare region. The primary purpose of this study is to provide a scientific technique forassessingthesub-soilwaterresourcesituation.Thestaticwaterlevelelevationdatawithinthehydrogeologic framework of PurbaBardhaman Plain has been analysed to examine the current trends in this field. The findings ofthis study have been analysed in sync with the hydrological attributes of the Bengal basin in its entirety. Theapplicationofnoveltechniquesforanalysinggroundwaterstresshasledtosignificantadvancementsinourcomprehension of the availability of groundwater resources in meeting present water requirements (Amarasinghe etal., 2007; Mukherjee, 2020). The existing literature suggests that in the context of climate uncertainty, the scope ofestablishingacomprehensiveassessmentofgroundwaterresourcesforguidingfuturegroundwaterplanningatthe C.D. block level. Hence, this study aims to explore the dynamics of static water level at the block level by utilisinghistorical time-series data from 1996-2020. Several scientific methodologies are widely available to explore andanalysethedynamicsandchangingbehaviourofthegroundwaterlandscapeofanarea.TheMann-Kendall(MK)testandSen's slopeestimatorarewidelyemployednon-parametrictestsinthefieldofhydrologyforanalysingtimeseriesdata. Similarly, Buishand's range test, Standard Normal Homogeneity test and Pettit's testexhibit high sensitivity indetecting changes in time series. However, these methods are particularly well-suited for finding changes in the centralperiod of a series. However, the approaches employed by previous authors fail to account for the possibility ofinhomogeneities,whicharecharacterisedbyconsiderablevariationsinstaticwaterlevelovertime.(Samal&Gedam,2021) demonstrated that variations in hydrological data can be attributed to three main factors: rapid changes or jumps,regulartrends,orjumps superimposedovera trend.Furthermore, inhomogeneities mightresultinsystematicdeviations or significant disruptions in the data series. Hence, thoroughly assessing the long-term static water leveltrend, includingthe rateofchangeandhomogeneity,isimperative.

2. Materialsandmethods

2.1. StudyArea

The Purba Bardhhaman plain is located in the bountiful alluvial plain of the Bengal Basin. Its western segment, theAusgram plain, contains older alluvial deposits than its eastern part, known as the Kusumgram plain. This regionbelongstotheGBMdeltaicplain,asignificanttractoftheBengalbasin'swesternsection.Latitudesrangingfrom22°15' 08"to23°15'17"northandlongitudesrangingfrom87°13'17to88°7'22"eastdefinetheregionunder study,as depicted in Figure 1. The immense expanse of the plain is bisected by four notable rivers: the Hugly, Ajay, DamodarandDarkeswar.Inaddition,anextensivenetworkofwaterways,distributaries,andstagnantsurfacewaterbodiessuchas tanks, ponds, and bills significantly endowed the region's abundant water supply. Five thousand seven hundredsixty square kilometres comprise the region's entire land area under consideration. This region has a humid climate,withannualprecipitationaveraging1250mmandaveragetemperaturesfrom8°to27°C.Thepredominanteconomicactivity is agriculture, with three principal growth seasons: Aus (Zaid), Aman (Kharif), and Boro (Summer). Rice isthe most important staple crop in the region, surpassing all other cereals and vegetables. The cultivation intensity inthisareais177%,whichissubstantially higherthan thestate'saveragecroppingintensity.

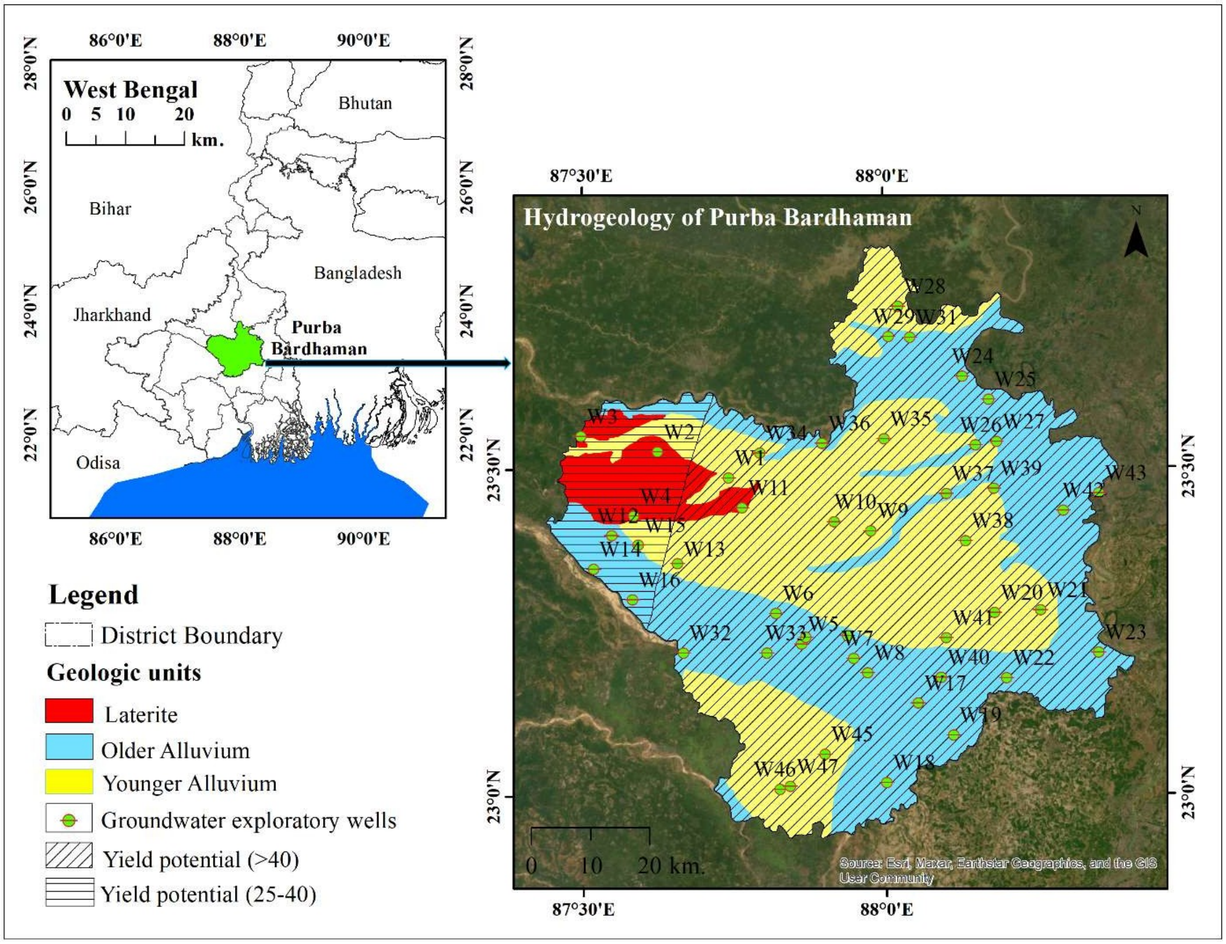

Fig. 1 Location map of the study area: The map on the right represents the hydro-geologic units of the PurbaBardhaman plain(district),with 47 groundwaterexploratorywellsdistributed on the map.

2.2. Thehydro-geologicalarchitectureofPurbaBardhamanplain

The majority of the PurbaBardhaman district is situated on the alluvial fan delta of the Damodar Basin, located onthe southwestern shelf of the Bengal Basin. During the arid months, the flow in the Damodarriver and its associatedtributaries and distributaries experiences a significant reduction.Accordingto the State of EnvironmentReport(2016),the monsoon flows tend to overflow the channels and cause severe floods in the riparian areas. The delta-buildingprocesses in the Bardhaman region have been extensively documented in the publications of the Geological Surveyof 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 divisionwith the Ajay River to the north, while Peninsular shield rocks demarcate its western boundary and Gangetic sedimentsdefine its eastern edge. The eastern segment of the region is traversed through the lower Damodar Basin, which ispredominantlyoverlainbyQuaternaryalluvialdeposits.Theprimarygeologicalunitsencounteredinthestudyregionare depicted in Figure 1, as reported by GSI. The area in question is primarily characterised by the presence of olderalluvium,laterite,tertiary,andquaternarydeposits.Groundwaterisfoundinunconfinedconditionsatdepthsofupto

70 meters below ground level. Access to this groundwater is facilitated through a network of open-dug wells andshallowtubewells.Theshallowaquifersinsidetertiarystrataconsistpredominantly ofcoarsesandandgravel.

In contrast, the quaternary formation is characterised by fine to medium sand layers, occasionally interspersed withgravel and pebble deposits. The sand and gravel deposits are occasionally interspersed with relatively narrow claylayers, resulting in their occurrence within semi-restricted to confined hydro-geological settings (Central GroundwaterBoard, 2019).The PurbaBardhaman plaincomprises two primary physiographical divisions: theflood plain,characterised by a cyclic arrangement of sand, silt, and clay layers. Figure 1 displays the upper mature deltaic plainand para deltaic flood surface. The overall topographical gradient of the district has a directional trend from theNorthwest to the southeast. The PurbaBardhaman district is characterised by a predominantly flat alluvial plainterrain,whichcanbefurtherclassifiedintodistinctgeomorphicsections.TheKetugramPlainissituatedtothenorth,adjacent to the Ajay River, which afterwards converges with the Bhagirathi River in Katwa. The core region of thedistrict is occupied by the Bardhaman Plain, which the Damodar River flanks to the south and southeast. TheKhandaghosh Plain is located in the southern region. The Bhagirathi River traverses the eastern periphery of thedistrict, while the Bhagirathi Basin encompasses the eastern margin of the plain. The chotonagpur plateau exhibitsundulatinglateritetopography,which extendsuptothewesternmostregion ofthisdistrict.

2.3. Collectionofstaticwaterleveldata

The Central Groundwater Board (CGWB), a water agency of the Ministry of Jalshakti, employs a network ofgroundwater observation wells to systematically measure the static water level at different observation points on aseasonal basis. The data taken during April and November are commonly referred to as pre-monsoon and post-monsoondepthtostaticwaterleveldata.Thedatapertainingtothe23C.D.blocksinthePurbaBardhhamandistrict,spanning1996to2020,hasbeenobtainedfromtheCentralGroundWaterBoard(CGWB).Thesiteinformationaboutthe monitoring wells, such as their geographical coordinates, was documented using a portable GPS survey. Withinthis geographical region, sixty-nine wells are designated explicitly for monitoring groundwater. However, the studyonlyincluded47wellsduetomissingdataseenatseveralyearsintheremainingwells.Thestudycollectedthestaticwaterlevels(SWL)fromthreetypesofmonitoringwells:handpump,conventionalpiezometer,anddigitalpiezometer. During the primary field survey, the identification and recording of all monitoring wells utilised in thisstudy wereconducted.

2.4. Changepointdetectionmethods

Pettit'stest,AlexanderssonandMoberg'sStandardNormalHomogeneityTest(SNHT)andBuishandRangtesthavebeenusedtodeterminethepresenceofabruptchangepointsintheannualandseasonalstaticwaterlevelinthePurbaBardhhamandistrict from 1996-2020.

2.4.1. PettitTest

The Pettitt test is a rank-based distribution-free test used to detect significant changes in the mean of a time series. Itis more beneficial when no hypothesis testing on the location of a change point is required. This test has been widelyusedtodenoteobservedvariationsinmeteorologicalandhydrologicaldataseries.Whenthedurationof atimeseriesis marked by t and the shift occurs after m years, the resulting test statistics are given in Eq. (1). The statistic iscomparableto theMann-Whitney statistic,which usestwo samples, suchask1,k2…,kmand km+1,k2…,kn:

$$U_{t,m} = \sum_{j=1}^{m} \sum_{1}^{tj=t+} \mathrm{sgn}(K_i - K_j) \quad (1)$$

Wheresgn inEq.1isdefinedby Eq.2:

$$\mathrm{sgn}(K_t - K_j) = (0 \begin{matrix} 1 & ff(K_t - K_j) &)1 \\ & 1f(K_t - K_j) & = 0) \\ -1 & f(K_t - K_j) & \langle 1 \end{matrix} \quad (2)$$

TheteststatisticUt,miscomputedwith allarbitraryvariablesrangingfrom1ton.Thebulkofdistinctchangepointsareidentifiedwherethemagnitudeoftheteststatistic|Ut,m| isgreatest(Eq.3)

$$Z_T = \mathrm{Max}_{1 \le t|m} |U_{t.m}| \quad (3)$$

Theprobabilityofshiftingyearisestimatedwhen|*Ut,m*|ismaximum followingEq.4:

$$P = 1 - \exp\left(\frac{Z_T^2}{K^2 + K^3} \right) \quad (4)$$

2.4.2. StandardNormalHomogeneityTest(SNHT)

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

$$T_s = max T_m, 1 \le m < n \quad (5)$$

ThechangepointiswhenTsattainsthemaximumvalueinthedataseries.TheTmisderivedusingEq.6:

$$T_m = m z_1 + (n - m) \Sigma_p, m = 1, 2, ..., n \quad (6)$$

Where,

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

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:

$$R_0^* = 0 \text{ and } R_m^* = \sum_{t=1}^{m}(P_t - P_{mean}) \tag{8}$$

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

$$R_m^{**} = R_m^* / \sigma$$

$$S = \text{Max}|R_m^{**}| - Min|R_m^{**}|, 0 \le m \le n \tag{9}$$

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 derivedusing the following equation: K represents the value of the specific year, M denotes the mean value over the studyperiod, andσrepresentsthe standarddeviation.

3. ResultsandDiscussion

Analysis of the static water level time series can be done in multiple ways based on the purpose and objective of thestudy. The scale of the assessment unit is also an important parameter that decides the broader direction and scope ofthe study. The present study has been conducted at the C.D. block level, which is considered to be a small geographicalunit with an areal extent of several hundred sq. mt. to a few hundred sq. km. This study considers two monitoringwellsfromeachassessmentunitandcomputestherelativedifferencesinstaticwaterlevelamongdifferentassessm entunitsinthePurbaBardhamanplain.

3.1. Analysisofchange-pointinstaticwaterlevel

Change-point detection is vital to identify drastic changes and variability in any hydro-meteorological time series. Itseekstocheckthehomogeneityinthehistoricaltimeseriesbasedonabruptdatavaluesanddividesitintotwounequaltime frames. The first set includes datasets from the origin of the time series up to the change year, while the secondset comprises the rest of the data. Three distinct statistical methods, the Pettit test, Buisand Range test and StandardNormal Homogeneity test, have been employed to detect the change year in the SWL time series of 47 monitoringwells over 1996-2020 for pre-monsoon and post-monsoon seasons. The results of change year detection have beentabulated in Table 1. It is evident from the result that all three methods produce different change years for the sametimeseries.However,itispersistentlyobservedthatallthreemethodscapturethesamechangeyearintheSWLtimeseries for multiple wells. In case different change years for a particular well have been detected, the most likely yearwastakenbasedonthesignificancevalue(p-value)at95%confidencelevel.Themostfrequentpre-monsoonchangeyear is 2009, while it is 2010 for post-monsoon season. In the majority of the wells, the change year lies between2008-2012, while the extreme change year varies between 2002-2018. The dramatic changes in SWL were preciselyobserved between the years 2007-2008 to 2014-15. This period is marked by the large-scale transformation of privatelyowneddiesel-operatedirrigationpumpsintothecooperative-ownedelectricsubmersible.Thisperiodisalsosignificantfromtheviewpointofthemassivelanduseandlandcoverchangesint ermsofexpansionofcroppinglandandreductioninvegetationarea.Inaddition,thesubsidisedelectricityrateledtotherevoluti oningroundwater-basedirrigation inthisareaandtheresultingdeclineinSWL.

Table.1. ChangepointdetectioninSWLusingdifferentmethodsforpre-monsoonandpost-monsoonseasonsfrom1996-2020

	Pre-monsoon			Post-monsoon		
Nameof thesite	Pttitt testchangepoint and year	Buisand rangetestchange pointand year	SNHT Changepointdetection and year	Pettitt testchangepoint and year	Buisand rangetestchange pointand year	SNHT Changepointdetection 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)
AmragarhPz	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)
BaraDhamas	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)
BarsulPz	15(2010)	15(2010)	19(2014)	13(2008)	13(2008)	22(2017)
BhatarPz	12(2007)	14(2009)	14(2009)	15(2010)	15(2010)	15(2010)
BudBudPz-I	16(2011)	16(2011)	16(2011)	3 (1999)	13(2008)	3 (1999)
ChakBanangoria	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)
CharnakPz	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)
DakshinRadhakantapur	7 (2002)	17(2012)	17(2012)	20(2015)	13(2008)	16(2011)
DommaraPz	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
GuskaraPz	12(2007)	25(2020)	9(2004)	12(2007)	13(2008)	18(2013)
HatMurgram	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)
KatwaTown-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)
KhalipurPZ	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)
KusumgramPz	13(2008)	13(2008)	13(2008)	15(2010)	15(2010)	15 (200)
MadhyamgramPz	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)
RakonaPz	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)
SinghiPzSWID	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. SimpleLineartrendinstaticwaterlevel

The present study employed the ordinary least squares method to examine the linear trend in the time series of SWLinthePurbaBardhamanplain.Theobjectiveofthisstudywastoascertainthepresenceoflinearpatternsinthestaticwaterl evel(SWL)throughoutthepre-monsoonandpost-monsoonperiods,bothbeforeandafteradesignatedyearofalteration. The substantial number of groundwater monitoring wells hinders the feasibility of creating graphicalrepresentations to depict the trend of Static Water Level (SWL) for individual wells. Therefore, a selection of wellswasmadebyrandomsamplingtoserveasarepresentativesampleforanalysingstaticwaterlevels(SWL)beforeandafter the change year, as illustrated in Figures 2 and 3. The OLS regression technique was insufficient in accountingfor the whole variance in the supplied dataset due to the univariate structure of the SWL time series. Hence, it hasbeendeterminedthatthelineartrendobservedinthedatafromall47monitoringwellslacksstatisticalsignificance.

Nevertheless, the overall pattern seen in the majority of wells exhibited a downward trajectory, with just a limitednumberofdeviations,suggestinganincreasingtrendinthestaticwaterlevel.Beforethechangeyear,thestaticwaterlev el displayed a slight downward trend. However, a drastic downward trend was observed after the change year forpreandpost-monsoonconditions.TheobserveddecreaseinSWLforbothseasonssuggestsadeficiencyinmonsoonalreplenishment and theresultinganomaly in rechargeanddischargevolumeswithin thisregion.

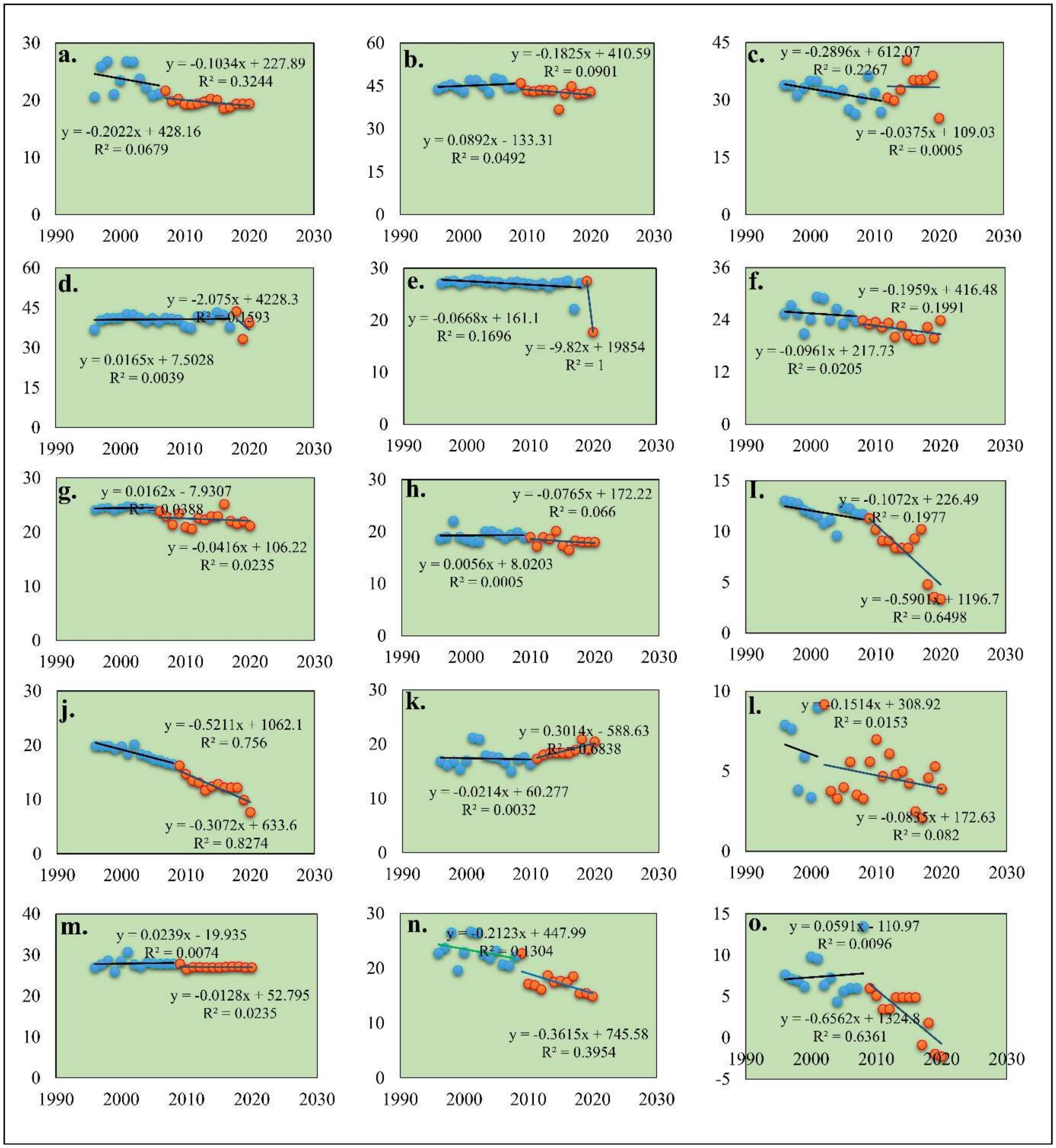

Fig.2 LineartrendbeforeandafterthechangeyearinSWL for pre-monsoonseason

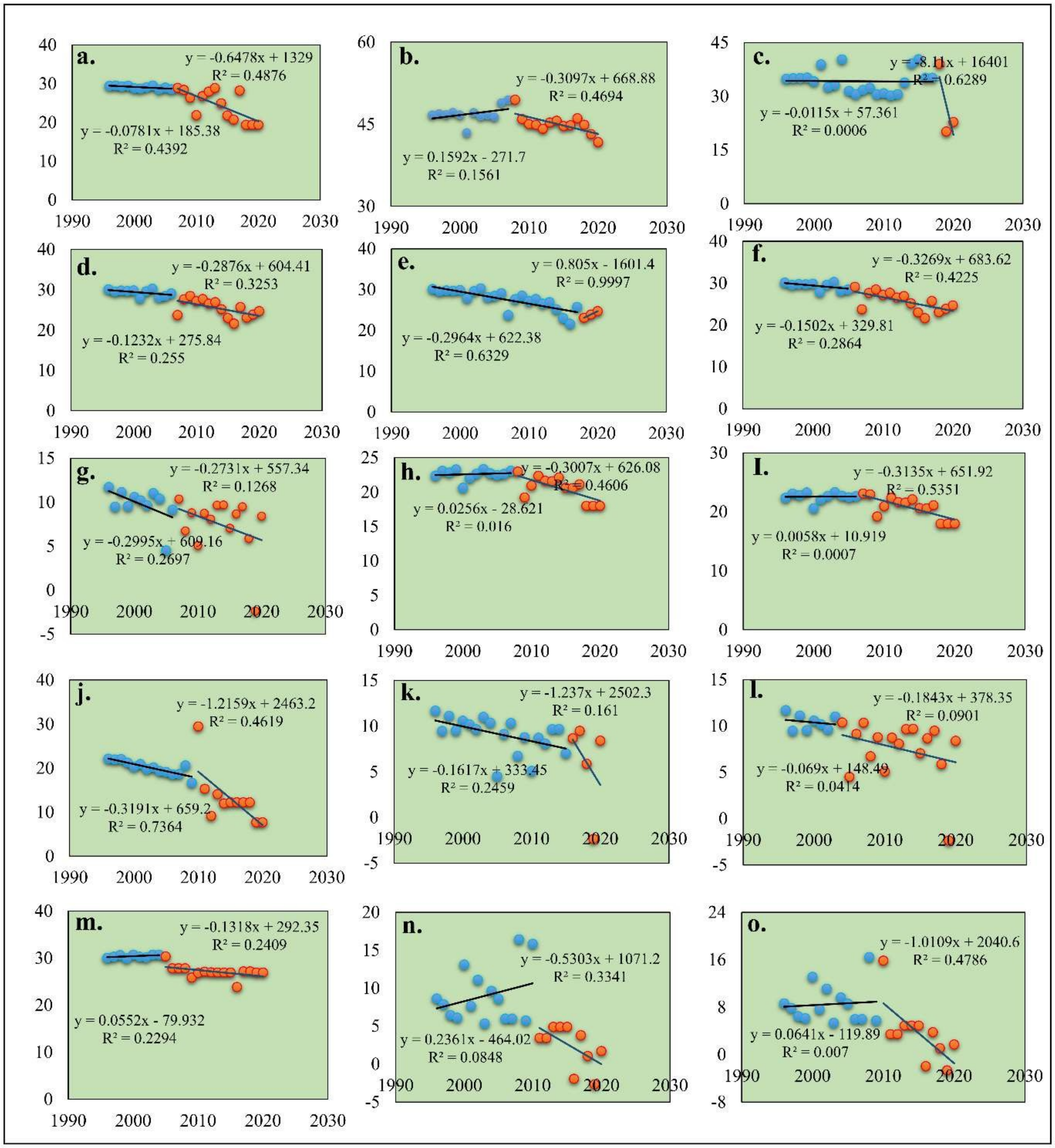

Fig.3 LineartrendbeforeandafterthechangeyearinSWLforpost-monsoonseason

3.3. Spatialvariationinstaticwaterlevel

The decrease in the static water level is directly associated with reducing aquifer storage, indicating that extractionratessurpassnaturalrecharge(Kumaretal.,2005;Sen,2021;Singh,2016).Inthestudyarea,ithasbeenseenthattheSWL 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 wasdetected in the Kusumgram Plain, exhibiting a significant downward tendency. The evaluation of the interpolatedmapsforthepre-monsoonandpost-monsoonperiodsrevealsthatbothseasonsexhibitnotabledeclinesinstaticwaterlevel within the same zones. However, there is more variability observed during the post-monsoon period. Thisobservation illustrates the consistent difference between recharge and discharge in this area. Groundwater depletiontypically arises from a combination of climatic influences and human activities that disrupt the natural hydrologicalcycle, primarilythrough excessive groundwater pumping withoutadequate consideration forwateravailabilityto refillthe depleted reserves. Therefore, it is probable that locations characterised by aridity are more susceptible toexperiencing this crisis. According to (Kumar et al., 2005; MISTRI, 2017; Prabhakar& Tiwari, 2015; Sen, 2021;Singh,2016),groundwaterdepletionisprevalentgloballyinsemi-aridandhumidlocations.Theyarguethattheover-extraction of groundwater is the primary factor contributing to this phenomenon, surpassing the influence of climaticconditions that regulate natural recharge. Therefore, the evidence derived from these observations indicates thatalterations in recharge rates caused by climate change have the potential to impact the pace at which groundwater isdepleted. Nevertheless, according to the surveys conducted on global literature, it is anticipated that the impacts ofthesealterations onaquifers have been relativelyminor compared tonon-climatic factors(Fenget al.,2013;Mahammad& Islam, 2021). How groundwater systems react to changes in climate is contingent upon the specificgeologicalcharacteristicsofthearea(Sahaetal.,2014).Additionally,factorssuchaslanduseandlandcover(LULC)andothervariablesthatinfluencetheratesofinfiltrationandrechargealsocontributetothisvariability(Kalbusetal.,2006). The study by (Farahmand et al., 2021) demonstrates a correlation between alterations in groundwater levelsand specific patterns of global climatic variability and annual precipitation. Based on the findings, rivers' base flowand 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 theseunconfined aquifers is minimal, occurring only at sub-annual to annual periods. The water level fluctuations in deeprestricted aquifers are influenced mainly by climatic conditions over extended periods, owing to physical limitationssuch as the time it takes for the recharge to travel and reach the aquifer. The significant extraction from undergroundstoragehasadirectandlocalisedeffectonalterationsingroundwatermass,especiallyindeepaquifers(Bandyopadhyayetal.,2014;Halderetal.,2020).Basedontheseprinciples,itisessentialtohighlightthatwithinthescope of the current study, the influence of irrigation pumping on the monitored aquifers within a depth range of 30-150 metersismorepronounced.

3.4. Temporaldynamicsinstaticwaterlevel

Thesimplelinearregressionanalysisindicatesasignificantdecreaseinthestaticwaterlevelelevationformostofthewells in both seasons, as depicted in Figures 2 and 3. During the pre-monsoon season, the extreme western tractcomprisingwellsatGuskara,Bannabagram,andRaghunathpurinAusgram-IandIIC.D.blocksexhibitnonoticeabletrend.However,adeclineintheSWLtrendhasbeenseeninblockscomposedofolderal luvium.Inthepost-monsoonperiod, static water levels have decreased in most wells except a few located in different corners of the district. Thissuggests that the influence of climatic factors, such as monsoonal rainfall, has minimal impact on the fluctuations ofwater levels in this area. The current study's spatial extent restricts its ability to determine the broader impact ofclimate change, especially the influence of meteorological factors. However, this study pointed out that, like otherparts of the Bengal Basin (BB), human intervention in the hydrologic regime through pumping can be attributed tothe observed decline in static water levels in this area. (Central Groundwater Board, 2010) found that excessivegroundwateruseforirrigatingBorocropsindifferentareasofPurbaBardhamanplain,alongwithlittlereplenishmen tfrom rainfall, has led to a continuous decline in the static water levels well below the mean sea level (MSL) in thisregion. As (Mukherjee, 2020) stated, the primary origin of arsenic in this specific region of the lower Gangetic deltacanbeattributedtoarsenicsulphidemineralsdepositedalongsideclaywithinareducingenvironment.Theexcessiveuse of groundwater for Boro cultivation during the summer season results in a significant decline in groundwaterlevels 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 ofgroundwaterbeyondsustainablelevelssincethe1990shascausedsignificantdisturbancestotheregionalflowpatternofgro undwaterintheentireGangeticWestBengal(GWB)region,includingPurbaBardhamandistrict.Thishasbeenobserved 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 aquiferarchitectureinfluencedtheregionalhydraulicgradientsinthestudyarea.Coincidentally,thealluvialPurbaBardaham an plain is a prominent agricultural hub and a significant groundwater depletion hotspot in the state. Thepresent analysis reveals that there has been a tremendous drop in the storage capacity and static water level elevationofaquifersinthisregion,whichcanbeattributedtothesignificantincreaseinirrigatedland.Indeed,althoughsituated in a fluvio-deltaic environment with abundant water resources, the observed decrease in static water level elevationsappears to be similar to that recognised for their water scarcity in the country. This can be mainly attributed to thelimitedreplenishmentofwaterthroughprecipitation.TheaverageSWLbeforechangeyearforall47wellswasmuchless than the after-change year in pre- and post-monsoon seasons, as depicted in Figures 4 and 5. The maximumdecline in average SWL (equal to or more than 5 meters) before and after change years has been recorded at wellsPaharhati, followed by Ketugram, Ramjibanpur, Nandigram, Bhatar, Orgram and Koichar. In contrast, the minimumdeclinein SWL hasbeenfound atthewellsofDakshinRadhakantapur, Dainhat,Katwatown and Budbud.

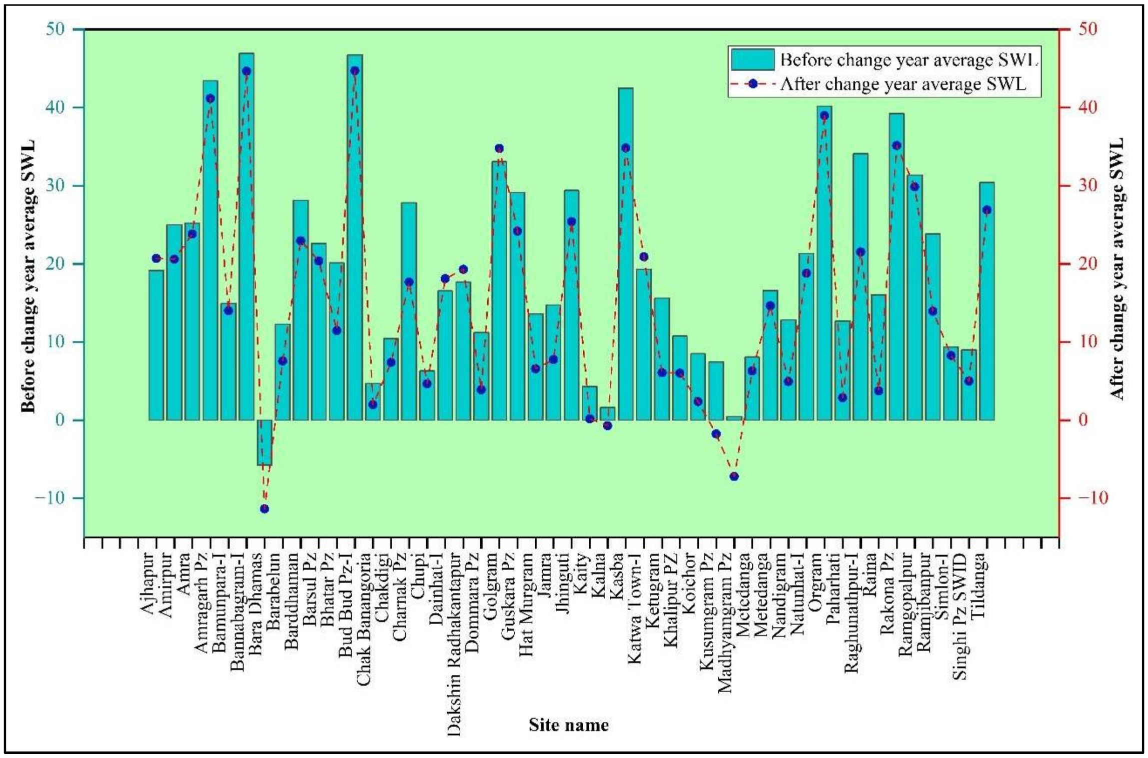

Fig.4 AverageSWLbeforeandafterthechangeyearforpre-monsoonseason

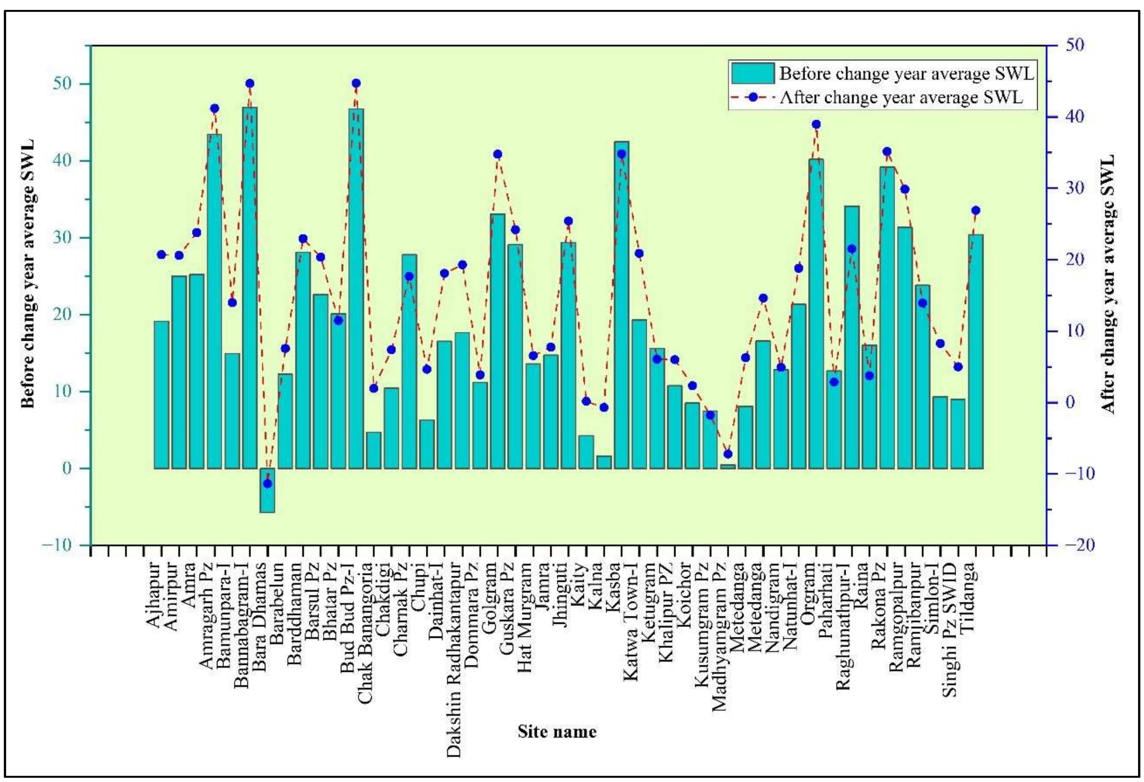

Fig.5 AverageSWLbeforeandafterthechangeyearforpost-monsoonseason

3.5. Standardgroundwaterlevelindex

The depletion of groundwater has the potential to manifest as a natural calamity, leading to the loss of human livesand causing significant economic devastation. In the contemporary era, the issue of groundwater stress has emergedasapervasiveglobalconcern.Theurgencyofaddressingwaterstresscausedbyirresponsiblegroundwaterdevelopm ent 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 thepreservation and stability of various ecosystem services. In this study, an analysis of groundwater stress has beenconductedutilisingtheStandardGroundwaterLevelIndex(SGWI).ThecalculationofSGWIhasbeenperformedfora period spanning from 1996 to 2020, encompassing both seasons, for all wells under consideration. The calculationof the Standard Groundwater Level Index (SWGI), in conjunction with trend analysis, can contribute to the effectivedesignofmanagementunitsandtheconservationofgroundwatersystems.In2020,thewellsinthelowermiddleparte xperienced a state of groundwater stress characterised by a decline in static water levels. The geographical regionunder consideration exhibits significant fluctuations in evapotranspiration and an irregular precipitation patternthroughout the year. (Ghosh, 2019) asserts that the likelihood of substantial groundwater exploitation is particularlyheightenedintheeasternplain,accountingforseveralwellsdistributedacrosstheC.D.blocksofManteswar,Bhat ar,Memari-I, Memari-II, and Burdwan-I, Burdwan-II, Katwa-I, Katwa-II, Ketugam and Mongalkote within the PurbaBardahamanplain.Inadditiontotheobservedclimateabnormalities,mostofthesemonitoringwellsarepredominantly situated in close proximity to the settlement area. In a geographical area characterised by swiftagriculturalexpansionandlimitedavailabilityofsurfacewater,itisimperativetoconductacomprehensiveexamination of the impacts of land use and land cover on the process of groundwater recharge. A limited number ofstudies have been undertaken on the regional and local characterisation of groundwater stress and its ongoingmonitoring. A noticeable change in groundwater stress areas was portrayed in Figures 6 and 7. Here, negative valuesof SGWI indicate groundwater stress areas, while a positive groundwater level index manifests comparatively lowgroundwaterexploitationanddevelopmentareas.

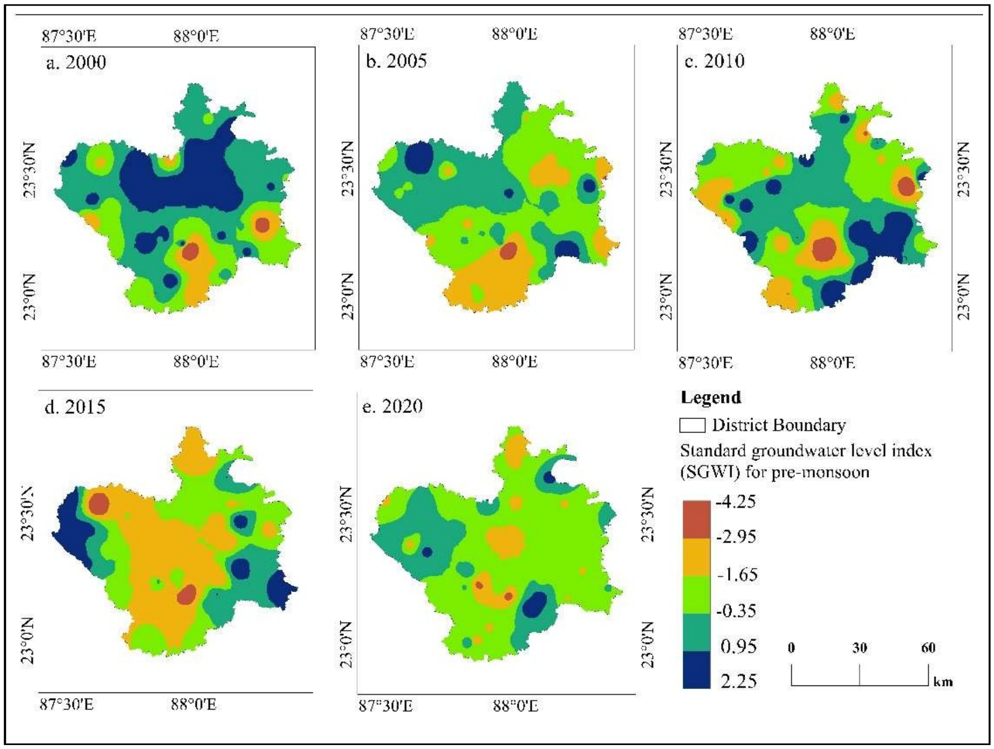

Fig.6 Pre-monsoonStandardGroundwaterLevelIndex(SGWI)fordifferentyears

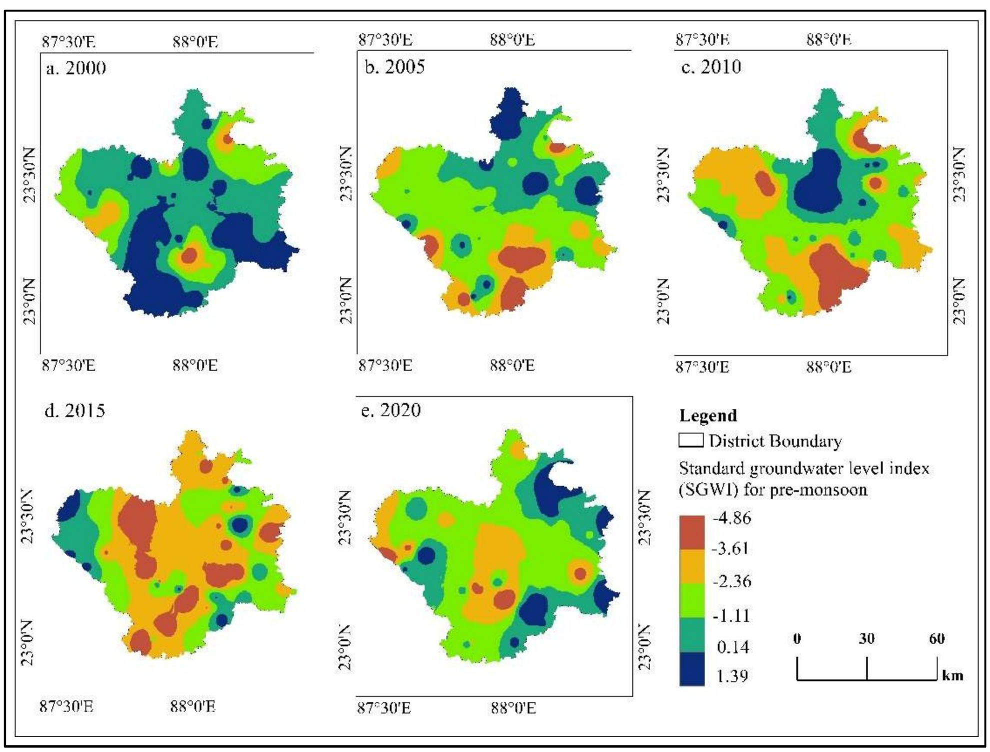

Fig.7 Post-monsoon StandardGroundwaterLevelIndex(SGWI)fordifferentyears

4. Conclusion

In order to effectively manage and plan for groundwater resources, it is essential to investigate the spatio-temporaldynamics and evolving groundwater landscape within a specific region. From this vantage point, the current studyaims to examine the linear trend and variability of pre-monsoon and post-monsoon static water levels (SWL) beforeand after the change year in forty-seven monitoring wells located within the PurbaBardhaman plain areas.

Thefindingsofthestudyvalidatethattheeasternsegmentofthestudyareacomprising C.D.blocksofManteswar,Bhatar,Mongalkote, Ketugram-I, Ketugram-II, Memari-I and Memari-II exhibited the maximum seasonal variability in SWL,whereasAusgramI,AusgramII,JamalpurandKhandaghoshdemonstratedthelowestSWLvariability.Thiscomprehensive study may help water planners curtail the vulnerable groundwater depletion conditions in this region.Todevelopamanagementplanforthesustainabledevelopmentofgroundwaterresources,researchersworldwideareincreasingly emphasizing the need for comprehensive investigations of SWL. Ensuring thorough research on a broadspatial scale requires considering several local aspects, including the pace at which groundwater is extracted and thehydro-geomorphic diversity of the area that influences the dynamics of SWL. This study becomes more significantfor practitioners who wish to adopt a source-to-sink approach. Therefore, determining the SWL trend and its associateddimensionscanaidindevelopingstrategiesandpoliciestomanagegroundwaterresourceswithinthedesignatedstudyarea.

Statements and DeclarationsFunding

Theauthorsdeclarethatnofunds,grants,or othersupportwerereceivedduringthepreparationofthismanuscript.

CompetingInterest

Theauthorshavenorelevantfinancialornon-financialintereststodisclose

AuthorsContributions

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

DataAvailability

ThedatasetusedinthecurrentstudyisavailableintheWaterResourceInformationSystemRepositoryofCentralGroundwater Board,Ministryof Jalshakti(https://indiawris.gov.in/.)

Acknowledgements

Theauthorswouldliketoacknowledge theCentralGroundwaterBoard,MinistryofJalshakti,GovernmentofIndia,for makingstaticwaterlevelsdataavailableforallthe23C.DBlocksofPurbaBardhhamandistrictinthewebsiteof https://indiawris.gov.in/.Additionally,theauthorswishtothanktheDepartmentofGeographyatJadavpurUniversityinKolkata,WestBengal,forprovidinglaboratoryspaceandotherresourcesnecessaryforconductingtheresearch.

EthicalApproval

Researchethicshasbeenmaintainedateverystageofthisstudy,fromconceptualisingtheresearchideatodatacollection,analysesand interpretation. Research ethicshasalso been prioritised forranking theauthors.

ConsenttoParticipate

NotApplicable

ConsenttoPublish

Allauthorshaveagreedtopublish thestudyin thisjournal.

References:

Alam,M.,Alam,M.M.,Curray,J.R.,Chowdhury,M.L.R.,&Gani,M.R.(2003).Anoverviewofthesedimentarygeology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. *SedimentaryGeology*, *155*(3–4),179–208.https://doi.org/10.1016/S0037-0738(02)00180-X

Amarasinghe, U., Shah, T., & Singh, O. P. (2007). *Changing consumption patterns: implications on food and waterdemand inIndia*.

Asoka,A.,Gleeson,T.,Wada,Y.,&Mishra,V.(2017).Relativecontributionofmonsoonprecipitationandpumpingtochange singroundwaterstorageinIndia.*NatureGeoscience*,*10*(2),109–117.https://doi.org/10.1038/ngeo2869

Bandyopadhyay, S., SekharKar, N., Das, S., &Sen, J. (2014). River Systems and Water Resources of West Bengal:AReview. In*GEOLOGICALSOCIETYOFINDIASPECIALPUBLICATION*(Issue3).

Basu,A.R.,Jacobsen,S.B.,Poreda,R.J.,Dowling,C.B.,&Aggarwal,P.K.(2001).LargeGroundwaterStrontiumFluxtotheO ceansfromtheBengalBasinandtheMarineStrontiumIsotopeRecord.*Science*,*293*(5534),1470–1473.http://www.jstor.org/stable/3084433

Central Ground Water Board. (2019). Central Ground Water Board. *Government of India*, *GROUND WAT*(June).http://cgwb.gov.in/faq.html

Central Groundwater Board. (2010). *Ground Water Quality in Shallow Aquifers of India. CENTRAL GROUNDWATERBOARD(CGWB) MINISTRYOF WATER RESOURCESGOVERNMENTOFINDIA*. 107.

Farahmand, A., Hussaini, M. S., Zaryab, A., &Aqili, S. W. (2021). Evaluation of Hydrogeoethics approach forsustainable management of groundwater resources in the upper Kabul sub-basin, Afghanistan. *SustainableWaterResourcesManagement*,*7*(3),1–7. https://doi.org/10.1007/s40899-021-00525-9

Feng,W.,Zhong,M.,Lemoine,J.M.,Biancale,R.,Hsu,H.T.,&Xia,J.(2013).EvaluationofgroundwaterdepletioninNorthC hinausingtheGravityRecoveryandClimateExperiment(GRACE)dataandground-basedmeasurements.*WaterResourcesResearch*, *49*(4),2110–2118. https://doi.org/10.1002/wrcr.20192

Ghosh,K.G.(2019).SpatialandtemporalappraisalofdroughtjeopardyovertheGangeticWestBengal,easternIndia. *GeoenvironmentalDisasters*,*6*(1).https://doi.org/10.1186/s40677-018-0117-1

Halder, S., Roy, M. B., & Roy, P. K. (2020). Analysis of groundwater level trend and groundwater drought usingStandard Groundwater Level Index: a case study of an eastern river basin of West Bengal, India. *SN AppliedSciences*, *2*(3).https://doi.org/10.1007/s42452-020-2302-6

Hsiao,T.C.,Steduto,P.,&Fereres,E.(2007).Asystematicandquantitativeapproachtoimprovewateruseefficiencyinagriculture. *Irrigation Science*, *25*(3),209–231. https://doi.org/10.1007/s00271-007-0063-2

Hsin-Fu Yeh, H. F., & Chang, C. F. (2019). Using Standardized Groundwater Index and Standardized PrecipitationIndex to Assess Drought Characteristics of the Kaoping River Basin, Taiwan. *Water Resources*, *46*(5), 670–678.https://doi.org/10.1134/S0097807819050105

Kalbus, E., Reinstorf, F., &Schirmer, M. (2006). Hydrology and Earth System Sciences Measuring methods forgroundwater-surfacewaterinteractions:areview.*Hydrol.EarthSyst.Sci*,*10*,873–887.www.hydrol-earth-systsci.net/10/873/2006/

Konar,A.,&Dey,G.(2015).Astudyongrowthofirrigatedareaundergroundwaterinsomedistrictsof WestBengalin India.*InternationalJournalofEcosystem*,*5*(3A),5.https://doi.org/10.5923/c.ije.201501.18

Kumar, R., Singh, R. D., & Sharma, K. D. (2005). Water resources of India. *Current Science*, *89*(5), 794–811.https://doi.org/10.1002/047147844x.wr243

Mahammad, S., & Islam, A. (2021). Identification of palaeochannels using optical images and radar data: A study ofthe Damodar Fan Delta, India. *Arabian Journal of Geosciences*, *14*(17). https://doi.org/10.1007/s12517-021-07818-5

MISTRI, K. C. & B. (2017). Irrigation System and Pattern of Crop Combination , Concentration and Diversificationin BarddhamanDistrict ,WestBengal.*TheNEHUJournal*,*XV*(2),45–65.

Mukherjee, A. (2020). Groundwater flow and hydrogeochemical evolution in the Western Bengal Basin. In *JournalofGeohydrology*(Vol.1,Issue 1).

Mukherjee, A., Bhanja, S. N., & Wada, Y. (2018). Groundwater depletion causing reduction of baseflow triggeringGangesriversummerdrying. *ScientificReports*,*8*(1),1–9. https://doi.org/10.1038/s41598-018-30246-7

Pathak, A. A., &Dodamani, B. M. (2019). Trend Analysis of Groundwater Levels and Assessment of RegionalGroundwaterDrought:GhataprabhaRiverBasin,India.*NaturalResourcesResearch*,*28*(3),631–643.https://doi.org/10.1007/s11053-018-9417-0

Patle, G. T., Singh, D. K., Sarangi, A., Rai, A., Khanna, M., &Sahoo, R. N. (2015). *Time Series Analysis ofGroundwaterLevelsandProjectionofFutureTrend*(Vol.85).

Perrone, D., &Jasechko, S. (2019). Deeper well drilling an unsustainable stopgap to groundwater depletion. *NatureSustainability*, *2*(8),773–782.https://doi.org/10.1038/s41893-019-0325-z

Prabhakar,A.,& Tiwari,H.(2015).Landuseandlandcovereffectongroundwaterstorage.*ModelingEarthSystemsand Environment*,*1*(4),1–10.https://doi.org/10.1007/s40808-015-0053-y

Praveen, B., Talukdar, S., Shahfahad, Mahato, S., Mondal, J., Sharma, P., Islam, A. R. M. T., & Rahman, A. (2020).Analyzing trend and forecasting of rainfall changes in India using non-parametrical and machine learningapproaches.*ScientificReports*,*10*(1).https://doi.org/10.1038/s41598-020-67228-7

Roy, S., &Chakravarty, N. (2021). *Rainfall analysis by using Mann-Kendall trend, Sen's slope and variability at sixStationsofAndaman&Nicobarislands*.

Saha, D., Ground, C., Board, W., Dwivedi, S., Ground, C., Board, W., & Mukherjee, R. (2014). *Concept Note OnGEOGENICCONTAMINATIONConceptNoteOn GEOGENICCONTAMINATIONOF*.*February*.

Sakiur Rahman, A., SarwarJahan, C., &HasanMazumder, Q. (2016). Long-Term Trend Analysis of Water Tableusing"MAKESENS"ModelandSustainabilityofGroundwaterResourcesinDroughtProneBarindArea,NWBangladesh. In*JOURNALGEOLOGICALSOCIETYOFINDIA*(Vol.87).

Samal,D.R.,&Gedam,S.(2021).AssessingtheimpactsoflanduseandlandcoverchangeonwaterresourcesintheUpperBhimariverbasin,India.*EnvironmentalChallenges*,*5*(August),100251.https://doi.org/10.1016/j.envc.2021.100251

Sen,S. P.(2021).*IntegratedBasinDevelopmentofDamodarValley–DVCandLowerDamodar*. *March*,1–8.

Shekhar,S.,Kumar,S.,Densmore,A.L.,vanDijk,W.M.,Sinha,R.,Kumar,M.,Joshi,S.K.,Rai,S.P.,&Kumar, D.(2020).ModellingwaterlevelsofnorthwesternIndiainresponsetoimprovedirrigationuseefficiency. *ScientificReports*,*10*(1).https://doi.org/10.1038/s41598-020-70416-0

Singh,A.(2016).Managingthewaterresourcesproblemsofirrigatedagriculturethrough geospatialtechniques:Anoverview. *AgriculturalWaterManagement*,*174*,2–10.https://doi.org/10.1016/j.agwat.2016.04.021

Small,L.E.,&Rimal,A.(1996).Effectsofalternativewaterdistributionrules onirrigationsystemperformance: Asimulationanalysis.*IrrigationandDrainageSystems*,*10*(1),25–45.https://doi.org/10.1007/BF01102763

Weekly,P.,&Weekly,P.(2016).*ModemAgricultureandtheEcologicallyHandicappedFadingGloyoryofBorPaddyCultivationi nWestBe*.*42*(26),2534–2542.