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A Spatio-temporal study on fluctuation in pre-monsoon and post-monsoon groundwater level in Tripura, North-east India

Jimmi Debbarma[1] and Nibedita Das (Pan)[2]

[1,2] Department of Geography and Disaster Management, Tripura University, Suryamaninagar-799022, Tripura, India

Abstract

Spatially and temporally groundwater provides the necessary security in absence of available fresh water resource. In the present study area, the groundwater level is highly subjected to the occurrence of spatial and temporal variability in precipitation. Seasonal fluctuation in groundwater table was observed in many parts of the study area resulting to groundwater stress during the dry season, particularly in the hilly and the foothill zones. A significant fluctuation in groundwater depth was found to vary from 0.23 to 29.78 mbgl during the period 1987-2016. The spatio-temporal change in pre and postmonsoon groundwater level in Tripura has been analysed and represented with the help of charts and maps using ArcGIS 10.3 software. The results show that on an average a marginal decline was taken place during the period 1987 to 2016 with exceptions to some areas where the level is below 10 mbgl. The maximum decline was observed in the northern, southern and western parts of Tripura (adjacent to Bangladesh). The correlation study between the decadal actual rainfall and average groundwater level strongly suggests that an increase in rainfall leads to a decrease in groundwater depth in the study area. Therefore, the knowledge about the seasonal groundwater depth may provide a vital element with regard to usage and management of groundwater.

Keywords: *Groundwater level; pre-monsoon; post-monsoon; spatial; temporal; rainfall*

1. Introduction

Groundwater is the sub-surface water resource found beneath the surface of the earth in the pores of soils and rocks. This resource is dynamic in the water table fluctuation zone which reflects seasonal recharge and discharge of aquifers; and becomes static below this zone which remains perennially saturated [1,2,3]. A direct correspondence between rainfall and ground water level was observed, although the spatial and seasonal differences were more pronounced [4]. The fluctuations in ground water level correspond in relation to the pre-monsoon and post-monsoon rainfall [5,6] and exhibited multi-peak and multi-valley curves and the fluctuation cycle of groundwater is synchronized with precipitation events. [7].The variation in seasonal soil moisture and withdrawal of groundwater influence the fluctuation in groundwater level [8]. An estimated 40% of the world's food is produced by irrigated farming [9.] Today, groundwater is the world's most extracted raw material with agriculture being the largest user accounting to about 70% of the total water withdrawals [10,11,12]. It also plays a significant role in maintaining surface water systems through flows into the lakes and base flow to the rivers [13]. The groundwater is interlinked with topography, geology, climate, rainfall pattern, land use and land holding patterns, socio-economic and human interferences [14,15,3].

The groundwater resource, being dynamic in nature, is subjected to change with seasons and thus needs to be exploited judiciously [16]. A recent study based on the analysis of GRACE (Gravity Recovery and Climate Experiment) satellite data revealed that the groundwater resources in the states of Rajasthan, Punjab and Haryana are being depleted at a mean rate of 4.0+1 cm yr^{-1} [17,18,4,6]. The fluctuation in groundwater level (gwl) is controlled by recharge and discharge and overall draft of groundwater [14,15,19,20,21]. The seasonal fluctuation in gwl greatly determines the availability and accessibility of water for a variety of uses, particularly in the hilly and the foothill regions. Water table follows a marked seasonal disparity involving a drying-down period of the water table from the end of spring and a wet period during winter and spring. The water table fluctuation also varies substantially among locations [22]. Therefore, the time series of the gwl is the principal source of information concerning the effects of hydrological and anthropogenic stresses on groundwater systems [23,24]. Knowledge on the depth of water table and its response to rainfall is a crucial element in many hydrological investigations for judicious management of ground water resource for various purposes [19,25].

The ground water level is a key parameter for evaluating the spatial and the temporal changes in groundwater environment [7]. Climatic variability in terms of precipitation greatly influences the recharge of aquifers [26], thus base flow to the channels and the gwl in shallow dug wells [27]. With the development in the number of groundwater structures, there has been a change in the cropping pattern from single to double crop in some of the areas of Tripura. [17] attributed that the depletion of groundwater may be due to unsustainable consumption of groundwater for irrigation (i.e. anthropogenic factors only). In India, the decline in ground water level from 0.1-0.5 mbglyr^{-1} indicates reduction in aquifer storage for unsustainable water abstraction for both irrigation and urban water supplies [26]. In Tripura, a significant variation of groundwater depth has been found within a range from 0.23 to 29.78 mbgl from the year 1987 to 2016. Seasonal fluctuation in water table results to stress, particularly in the hilly and the foothill zones. Adding to this stress is the increasing population leading to a demand for more water for domestic and agricultural purposes.
The availability of groundwater is of immense importance in response to safe drinking water, particularly in the hills, and irrigation for the lowlands in the study area. Thus, the objective of this study is to investigate the temporal change in pre and postmonsoon ground water level and to assess the spatial variability in the same. Therefore, knowledge about the seasonal groundwater depth may provide a vital element with regard to the groundwater usage and its management.

2. Materials and Methods

In order to study the spatio-temporal changes in the seasonal groundwater level ofTripura, the data for pre and postmonsoon periods have been obtained from the Central Ground Water Board (CGWB), Guwahati, Assam. The data for four decades, from 1987 to 2016, pertained to 132 groundwater stations monitored by the CGWB have been taken into account for the present study. However, the total number of groundwater stations is not uniform in all the years. At the same time, the rainfall data have been acquired from the Department of Agriculture, Government of Tripura for four decades to correlate the influence of rainfall on the fluctuation of groundwater level.

For the present purpose the groundwater level (gwl) data have been analysed using Microsoft Excel and represented through charts to study the temporal change in its depth. ArcGIS 10.3 software has been used to prepare location map of the study area. On the basis of the available gwl data, interpolation has been carried out using the same software and the spatial distribution maps of the pre and the post-monsoon gwl for the years 1987, 1997, 2007 and 2016 have been prepared using the isopleth technique. The groundwater level has been categorized into four classes ranging from <2, 2-4, 4-6 and >6 mbgl.

3. Study Area

Tripura is a landlocked state covering an area of 10,491 km². It is one of the smallest states in the North-East region of India. It is located between 22°56' N to 24°32' N latitude and 91°10' E to 92°21' E longitude. The State shares 84% (839 km) of its international border with Bangladesh in the north, west, south and south-east (Fig.1). In the east it has common national boundary with Karimganj District of Assam (53 km) and the state of Mizoram (109 km).
Physiographically, the study area is characterised by anticlinal hill ranges, intermontane synclinal troughs, piedmont slopes and upland, flood plains and terraces or hillocks. Out of the total geographical area approximately 60% is covered by low hills and forested tracts and only 27% is available for agriculture. The maximum and minimum elevations of about 930m and 4m are observed in the in the anticlines and the synclinal troughs respectively. The slope ranges from very gentle (<5°) to very steep (>25°) slope. Groundwater occurs under unconfined conditions in Recent, Dupitila and Tipam formations. Tipam formation, characterised by medium to fine grained, semi-consolidated and friable sandstone, form the major aquifer system of the state and groundwater occurs under confined to semi-confined conditions. The state records an annual average precipitation of about 1200mm. According to the 2011 Census, the state's population is 36,73,917 with a density of 350 persons/km^2.

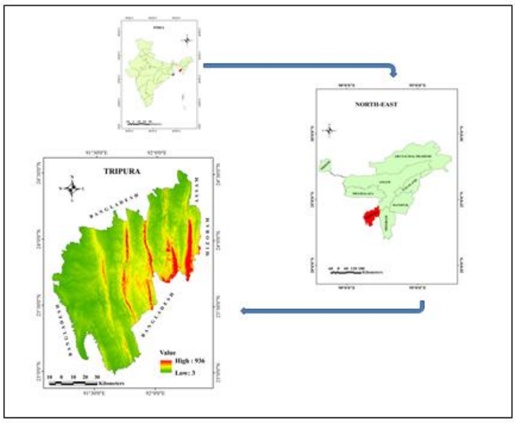

Fig. 1 Location Map of Tripura

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4. Results and Discussion

Temporal change in pre-monsoon groundwater level (1987-2016)

The minimum and maximum depth of gwl observed during the years 1987 and 2016 were 1.83 & 6.23 mbgl and 1.66 & 5.82 mbgl respectively (Fig.2) whereas the average depths were 3.8 and 3.6 mbgl respectively. Ambassa and Kanchanpur recorded the minimum depth during the period 1987 and 2016 whereas, Sabroom and Kenania showed the maximum depth during the same periods respectively (Fig.3).The average gwl during the period 1987 to 2016 was found to be 3.70 mbgl during the pre-monsoon season (Fig.2). Maximum deviation from mean is observed in the stations of Amarpur, Kanchanpur and Udaipur. The analysis of the decadal study reveals that the pre-monsoon groundwater depth has a marginal decline with the lowest depth being 3.57 mbgl and the highest being 5.28 mbgl (Fig.4). A declining trend in average gwl with rise and fall is observed in most of the years. Such an erratic nature of gwl is likely to have its impact on the availability of water in future.

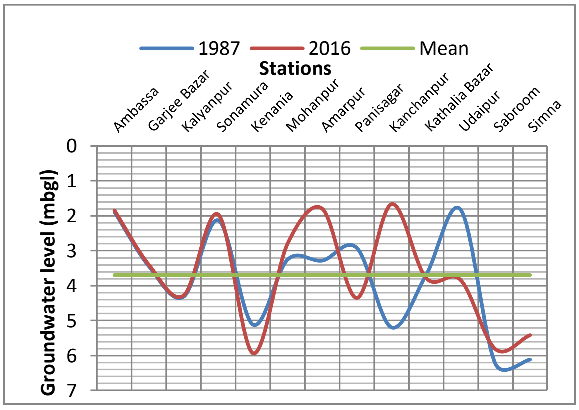

Fig. 2 Deviation of groundwater level from the mean during pre-monsoon period

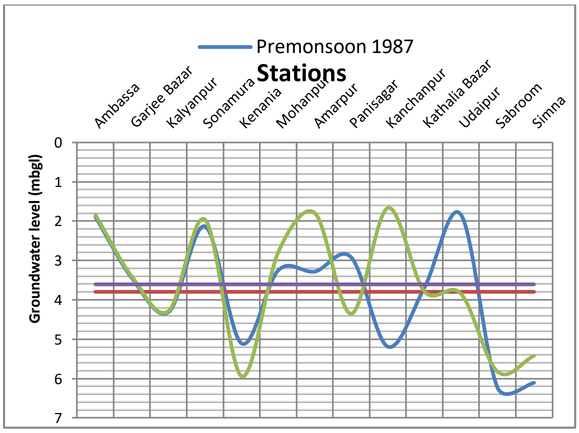

Fig. 3 Variation from mean in groundwater level during pre-monsoon season in the years 1987 and 2016

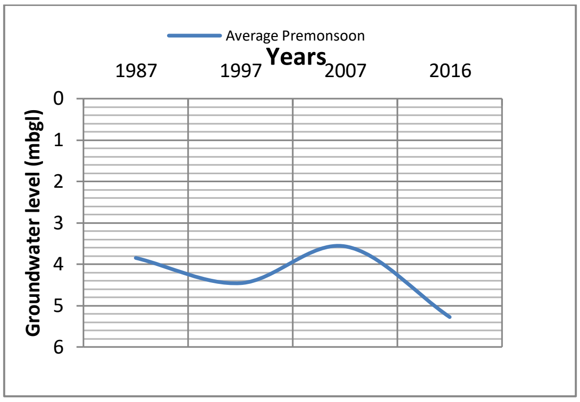

Fig. 4 Temporal variation in average pre-monsoon groundwater level

Temporal change in Post-monsoon groundwater level (1987-2016)

The minimum and maximum depth of gwl were found to be 1.4 and 4.41 mbgl in the year 1987 and 0.65 & 5.31 mbgl respectively in the year 2016 (Fig.5). A perusal of the study reveals that the mean depth of ground water in the years 1987 and 2016 were 2.9 and 2.6 mbgl respectively (Fig.6) which does not show marked variation for the two periods. The graph in (Fig.7) reveals a fluctuating trend with rise and fall in gwl. A declining trend in average groundwater level can be noticed in the year 1997 and 2016. Udaipur and Ambassa recorded the minimum depth during the period 1987 and 2016 whereas Kanchanpur and Kenania showed the maximum depth during the same period (Fig.5). The result of the post-monsoon decadal study indicates no major decline in groundwater depth of all the stations except that of Kenania. During the period 1987 to 2016 the average gwl observed was 2.73 mbgl (Fig.5). The stations showing the maximum deviation from the mean are Kenania, Kanchanpur and to certain extent Ambassa.

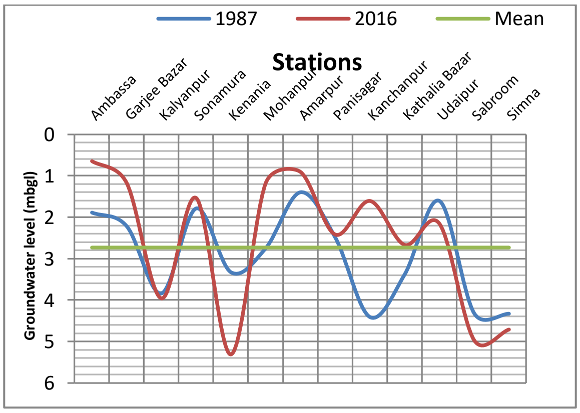

Fig. 5 Deviation of groundwater level from the mean during post-monsoon period

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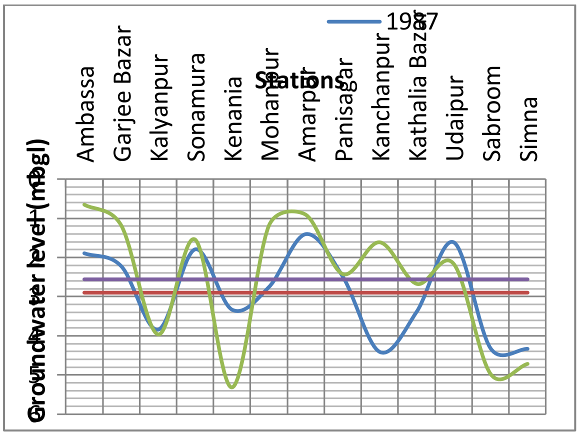


Fig. 6 Variation from mean in groundwater level during post-monsoon season in the years 1987 and 2016

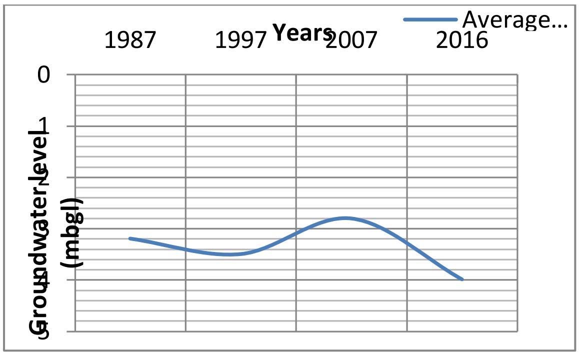
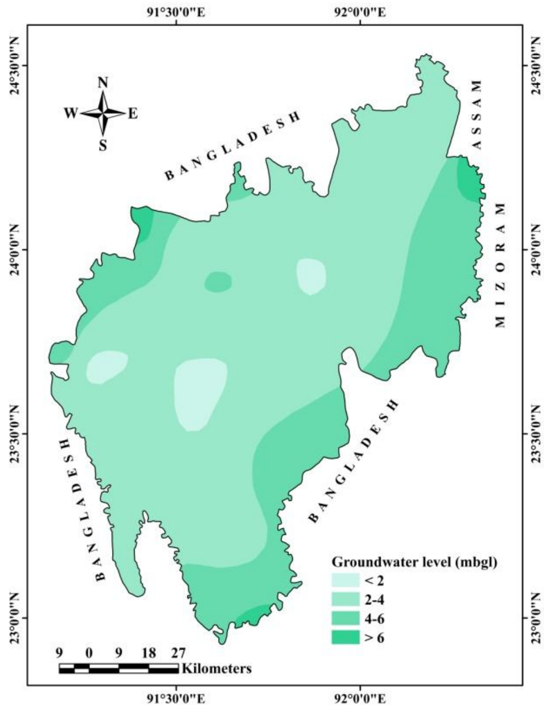


Fig. 7 Temporal variation in average post-monsoon groundwater level

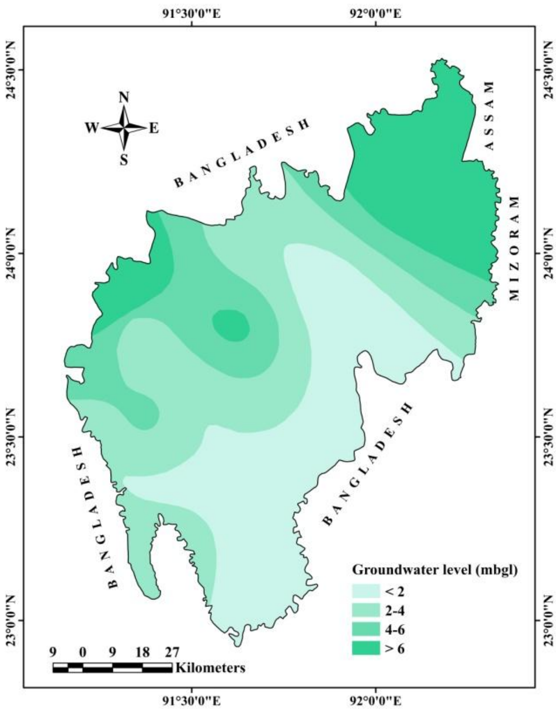
Spatial change in Pre-monsoon groundwater level (1987-2016)

A spatial study on the groundwater depth in Tripura indicates a declining trend. It varies from place to place as influenced by topography and precipitation. A sporadic decline in many parts of the state is revealed in the level of groundwater from 1987-2016 (Fig.8). The year 1987 witnessed maximum decline (>6 mbgl) in small pockets in the north-eastern and the north-western parts of the state (Fig.8a) followed by its areal increase in the northern and north-western parts in the year 1997 (Fig.8b). Similarly in 2007 and 2016 this declining trend increased and expanded to the southern part, pockets of south-western and north-western parts of the state (Fig.8c and 8d). The maximum decline was observed in the northern, southern and western parts of Tripura.

The decline in groundwater level during the pre-monsoon is more pronounced as compared to the post-monsoon. Fig.8 clearly depicts that this decline in depth exceeds 6mbgl during the period 1987-2016. It was also noticed that there are some pockets where the groundwater level has declined even below 10 mbgl, such as at Kakraban and Bodhjung Nagar in Gomati and West Tripura District respectively. Both of these areas have high concentration of settlement as well as the dominance of agriculture. Such an unprecedented decline in groundwater level may also be attributed to the forest cover condition as seen in Fig. 13.



(a) 1987



(b) 1997

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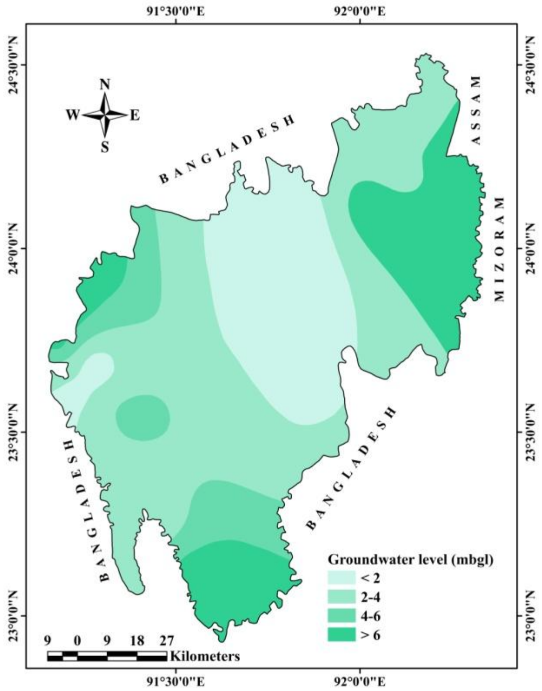
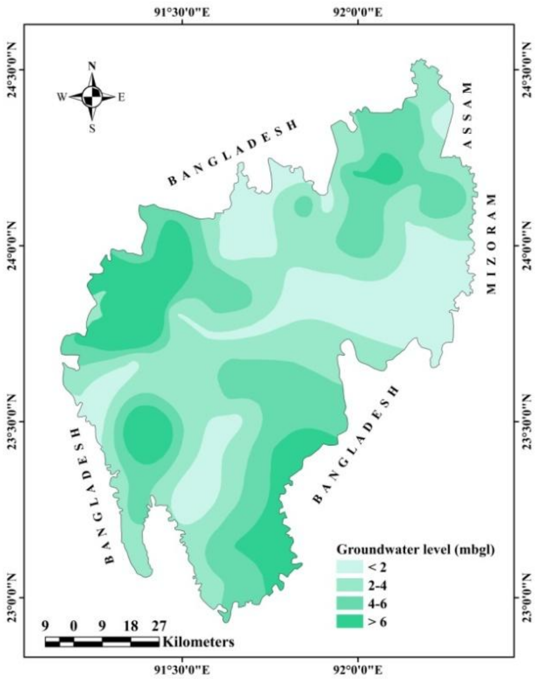


(c) 2007



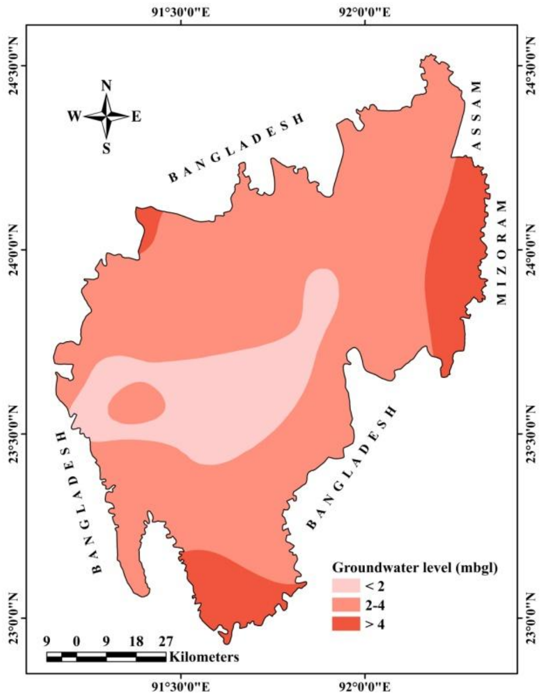
(d) 2016

Fig. 9 Spatial distribution of post-monsoon groundwater level in
(a) 1987, (b) 1997, (c) 2007 and (d) 2016

The groundwater monitoring stations were few in number upto the year 2007, but their number has been doubled by the year 2016 due to which the spatial distribution maps in (Fig. 8 and 9) reveal a lot of variation for the four decades.

Spatial change in Post-monsoon groundwater level (1987-2016)

A perusal on the post-monsoon groundwater level also reflects a declining trend spatially. Much of the spatial variation during the period 1987-2016 may be attributed to the availability of data as stated earlier. The maximum decline in gwl during 1987 and 2007 was above 4 mbgl and restricted to the north-eastern, southern and in a small patch in western part of the state (Fig.9a and 9c). In the year 1997 the gwl was below 6 mbgl as observed in the areas of the northern and a small pocket in the western part of the state (Fig.9b). In contrast to all the previous decades, the groundwater level in 2016 reveals its decline in the western part and a small pocket in the south-western part (Fig.9d). An exceptional decline of below 10 mbgl was observed at Kakraban and Bodhjung Nagar areas of Gomati and West Tripura District respectively just as the case of the pre-monsoon level. High concentration of habitation, agricultural practice, dominance of wasteland and forest cover condition may be attributed to the unusual decline in the groundwater level (Fig.13).



(a) 2007

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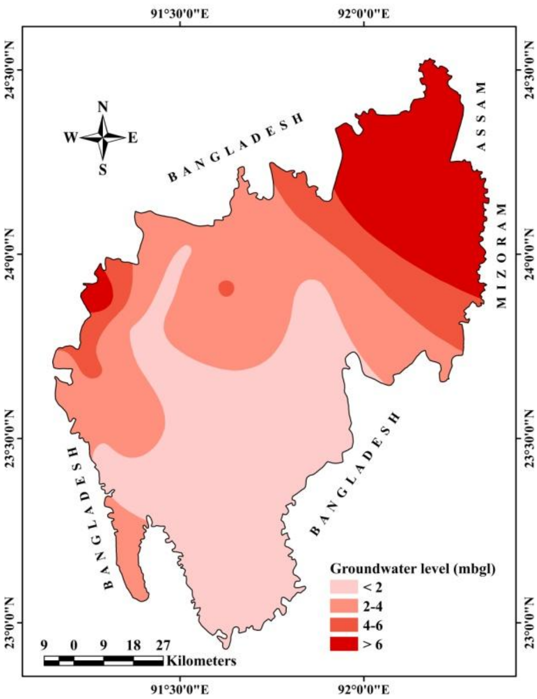
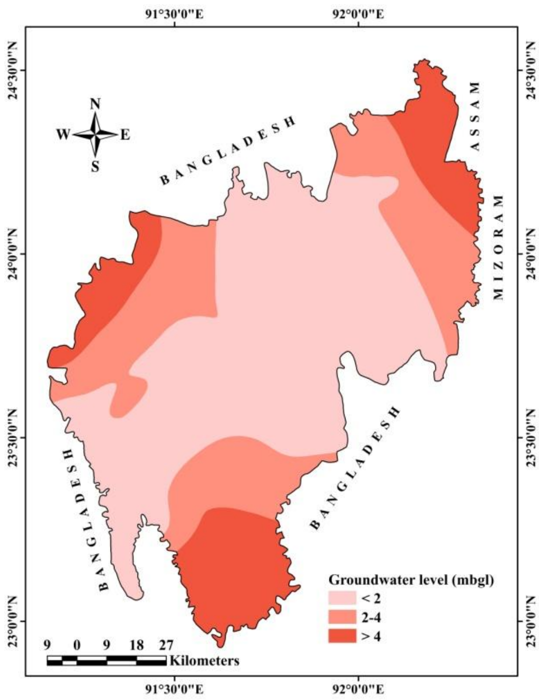
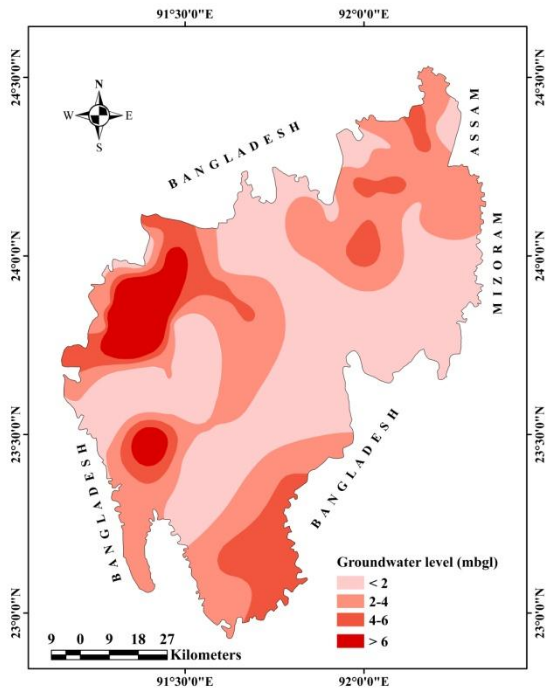


(b) 2016



(c) 2007



(d) 2016

Fig. 9 Spatial distribution of post-monsoon groundwater level in
(a) 1987, (b) 1997, (c) 2007 and (d) 2016

Correlation between Rainfall and Groundwater level

The effects of spatial and temporal precipitation pattern on fluctuation of ground water are significant though groundwater responds gradually to the meteorological conditions [27]. Groundwater level varies with variability in the intensity, recharge, draft and runoff of rain water. Other factors that greatly influence the groundwater level are anthropogenic in nature. The Pearson’s Correlation or Correlation coefficient is a parametric statistics used to show the quantitative measurement of the degree and direction of linear relation between two variables. The value of Correlation Coefficient indicates the strength and magnitude of relationship between variables. Here a strong correlation is observed between rainfall and groundwater level. The r value was -0.73 and -0.82 for pre-monsoon and post-monsoon respectively indicating a strong correlation (Fig.11 and 12). The strong negative correlations indicate that as rainfall increases the depth of groundwater decreases both in pre and post-monsoon periods as seen in fig.11 and 12. The analysis indicates 53% dependency of gwl on rainfall during pre-monsoon and 67% in post-monsoon which indicates the natural recharge of groundwater.

The cropping pattern in the state has switched over from double to triple crop reflecting an increase in cropping intensity from 155% in 1975 to 197% in 2016-2017 period (Table.1). It may be one of the

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reasons beside other factors which determine the decline in groundwater level. As per the Economic Review, Govt. of Tripura as mentioned in table.2 assured irrigated area has increased from 521.97 km^2 in 1999-2000 to 1158.45 km^2 in 2016-2017 indicating an increase of 120.02%. The change in cropping pattern as well as increasing trend of assured irrigation is suggestive of the fact that more water will be required for irrigation in near future. Such a situation may lead to depletion in the groundwater level.

Table 1: Proportion of area sown more than once and cropping intensity

Year	Area sown more than once (km^2)	Cropping Intensity (%)
1995-96	1970	171
1996-97	1940	170
1997-98	2050	173
1998-99	2070	174
1999-00	2008.8	172
2000-01	N.A	N.A
2001-02	N.A	N.A
2002-03	N.A	N.A
2003-04	N.A	N.A
2004-05	N.A	N.A
2005-06	N.A	N.A
2006-07	1938.58	176
2007-08	1341.5	176
2008-09	1341.5	176
2009-10	1451.22	175
2010-11	N.A	N.A
2011-12	2150	185
2012-13	2191.65	186
2013-14	2194.28	186
2014-15	2281.28	189
2015-16	2302.27	190
2016-17	2350.5	192

N.A. Not available.Data source: Economic Review, Govt. of Tripura, 1995-2017

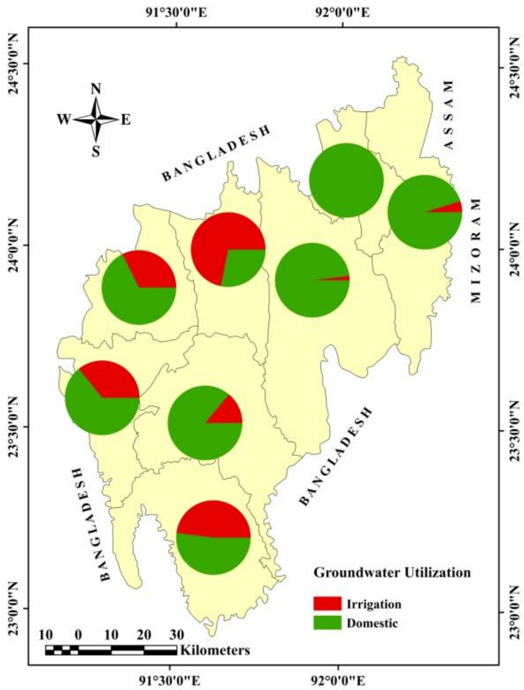

Fig. 10 District-wise utilization of groundwater in Tripura

Table 2: Proportion of area under assured irrigation

Year	Area under assured irrigation (km^2)
2009-10	1049.95
2010-11	1084.49
2011-12	1105.24
2012-13	1117.44
2013-14	1128.06
2014-15	1135.97
2015-16	1148.42
2016-17	1158.45

Data source: Economic Review, Govt. of Tripura, 2009-2017

Sustainable manner of groundwater extraction is the means to prevent and minimize the consequences of groundwater depletion. Since the state receives sufficient amount of precipitation, management of groundwater can be carried by means of recharge through several structural measures like construction of farm pond, check dams and diversion, pits or shafts, recharge wells etc. This will not only prevent loss of water through surface runoff but also result in the overall management of watershed.

but with reduced vegetation cover, even in the plains, the lesser percolation of surface water leads to decline in gwl. Groundwater decline may result into several consequences like lowering of groundwater table, deterioration in the quality of water, drying up of wells etc.

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As per Report of the Directorate of Agriculture, Govt. of Tripura (2013-2014), out of the total cultivable land of 2,74,354 km^2, single cropped accounted for about 31%, double cropped for about 43.74% and triple cropped to about 18.12%. It can be observed that maximum utilization of groundwater in the state is for the purpose of domestic use (Fig.10). As evident in fig.13 almost 70% of the state has hilly terrain. Therefore, utilization of groundwater for irrigation is negligible as compared to domestic use. However, in the southern and the western part, the presence of plain land favours paddy cultivation which supports the use of ground water for irrigation because paddy cultivation requires assured means of water supply. Groundwater accounts for more than 50% of the use for agriculture in the plains. In the present scenario, irrigation may not be a dominating control on the spatial and temporal change in groundwater level. However, looking at the present trend of copping pattern and rising trend of assured irrigation (Table.1 and 2) it is expected that groundwater level may decline in due course of time if no proper measures are undertaken.

From fig.13 it may be assumed that land use/land cover (LULC) has played a vital role in the recharge of groundwater as it is clearly correlated with the spatial change in groundwater level. The analysis of LULC reveals that high groundwater level is found where the settlement concentration is dense. Further, the presence of scrub land, scrub forest, and agriculture highly determine the increase or decrease in gwl as these factors strongly influence the natural recharge. Deforestation is one the causes for LULC change. It has led to encroachment in the fringe zone of the hills. These activities might have resulted in an increase of barren land as the soil got exposed partially or wholly in many parts of the hill slopes. Consequently, the rapid surface runoff impedes the infiltration capacity of soil in the hills and remains high in the plains. As such, the level of groundwater varies topographically,

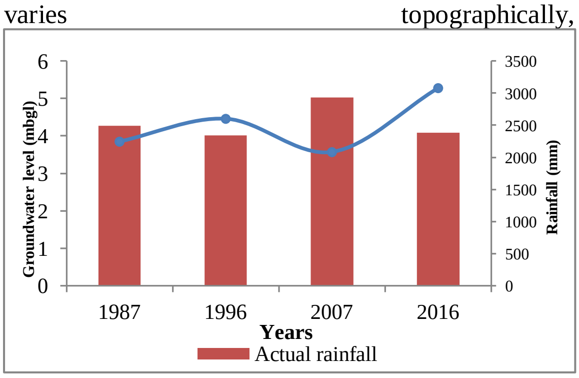

Fig. 11 Correlation between decadal rainfall and average Pre-monsoon groundwater level

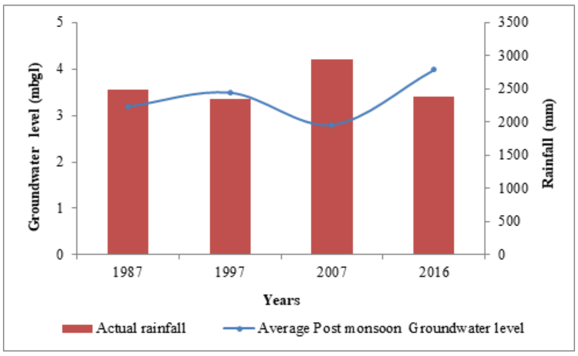

Fig. 12 Correlation between decadal rainfall and average Post-monsoon groundwater level

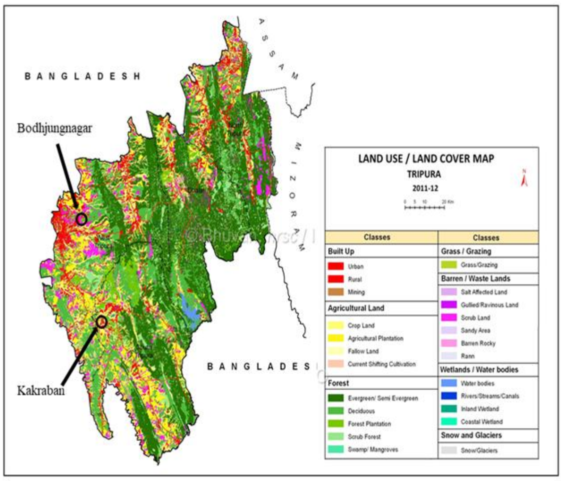

Fig. 13 Land use/Land cover Map of Tripura
Source: National Remote Sensing Centre, Hyderabad, 2011-2012

5. Conclusion

The results of the study indicate a sporadic decline in the level of groundwater throughout the state. Quantification of the spatio-temporal change in pre-monsoon and post-monsoon groundwater level for four decades during the period 1987-2016 reveals declining trend. An insight into the study of spatial change in groundwater level also reflects a declining trend, particularly during the pre-monsoon season. These fluctuations in the pre and the post-monsoon groundwater level are strongly influenced by the variability in rainfall. The correlation study between the decadal actual rainfall and average groundwater level strongly suggests that an increase in rainfall leads to a decrease in groundwater depth. It has also been observed that deforestation induced land use/ land cover change may be a contributing factor in decline of groundwater level in the state. A temporal study on pre-monsoon groundwater level signifies a declining trend followed by marginal decline in post-monsoon season. It is also observed that there are some pockets of excessive withdrawal leading to decline of the groundwater depth even below 10 mbgl. Therefore, groundwater extraction needs to be managed in a sustainable manner so as to prevent the depletion as well as minimise its consequences. Tripura receives sufficient amount of rainfall and in order to prevent loss of water from surface runoff better management of groundwater can be carried by means of recharge through several structural measures like construction of farm pond, check dams and diversion, pits or shafts, recharge wells etc. Such measures will not only help in assuring regular supply of water but are of importance in maintaining the balance of the groundwater cycle.

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