International Research Journal of Environment Sciences ISSN 2319–1414
Vol. **1(4),** 24-31, November **(2012)** *Int. Res. J. Environment Sci.*

Groundwater Level and Rainfall Variability Trend Analysis using GIS in parts of Jharkhand state (India) for Sustainable Management of Water Resources

Tirkey Anamika Shalini[1], Pandey A.C.[1] and Nathawat M.S.[2]
[1]Department of Remote Sensing, Birla Institute of Technology, Mesra, Ranchi-835215, Jharkhand, INDIA
[2]School of Sciences, Indira Gandhi National Open University (IGNOU), New Delhi, INDIA

Available online at: www.isca.in
Received 11th October 2012, revised 19th October 2012, accepted 25th October 2012

Abstract

The present study entails groundwater level variability analysis and its relationship with rainfall for the drought affected Palamu District of Jharkhand State. The sum of least squares method was adopted to analyse the relationship of groundwater level variability with the rainfall trends. The analysis revealed that this region during the post-monsoon season exhibit shallow depth of water level (2-3m) which declines upto 8-10m during pre-monsoon in the month of May. The declining trend of water level is more conspicuous at those places which are located relatively at lower elevation. Although the south-eastern region exhibits an increase in the rainfall over the years, yet the average water level is very deep indicating large water losses due to runoff. On the contrary, the southern region shows an increase in the amount of rainfall over the years with concomitant increase in the water level indicating a positive relationship between rainfall and depth of water level. The spatio-temporal rainfall trend analysis performed using interpolation in GIS provided conceptual understanding for developing large water harvesting structures in those regions which exhibit an increase in rainfall and the need for developing a number of small water harvesting structures to recharge the groundwater in rainfall declining zones.

Keywords: Groundwater level, rainfall, trend analysis, spatial interpolation, GIS.

Introduction

Groundwater is the most important water resource on earth[1]. It comprises of the major and the preferred source of drinking water in rural as well as urban areas and caters to 80% of the total drinking water requirement and 50% of the agricultural requirement in rural India[2, 3]. The groundwater is a dynamic and replenishable natural resource, but in hard rock terrains its availability is of limited extent and is essentially confined to the fractured and weathered horizons, which points towards efficient management of groundwater in these areas[4]. The behaviour of groundwater in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations[5].

To prepare a sustainable management strategy for groundwater development, it is important to understand the fluctuation of groundwater levels with reference to natural or artificial recharge in space and time domain. The rainfall comprises an important component of the water cycle and is the prime source of groundwater recharge. In India, the distribution of rainfall however, varies from place to place owing to different physiographic and climatic setting. Although some parts of the country receive abundant rainfall, there are regions which face a meteorological drought like condition. India is leading towards a fresh water crisis mainly due to improper management of water resources and environmental degradation, which has lead to a lack of access of safe water to millions of people[6]. In drought hit Palamu district of Jharkhand although the average rainfall is adequate, the erratic nature of rainfall distribution within monsoon months from June-September make the region suffer from meteorological drought and water scarcity. In recent decades, the exploitation of groundwater has increased greatly particularly for agricultural purpose, because large parts of the country have little access to rainfall due to frequent failures of monsoon[7]. Thus the increasing population and their dependence on groundwater for irrigation are further inducing heavy stress on groundwater resources, leading to the decline of groundwater levels in this region. The recurrent drought and concomitant decline in the groundwater levels over the years in parts of the Palamu district necessitate a detailed study to elucidate the behaviour of groundwater level fluctuations in both, spatial and temporal scales.

A very useful tool for analysing groundwater level fluctuations is the use of geostatistics[8]. Geostatistical methods are good tools for water resources management and can be effectively used to derive the long-term trends of the groundwater[9]. Statistical methods for trend analysis vary from simple linear regression to more advanced parametric and non parametric methods[10]. Linear regression and a seasonal- trend decomposition procedure was applied to a groundwater level database in Bangladesh to resolve trends in shallow groundwater levels within the Ganges-Brahamaputra-Meghna Delta[11]. In a similar study[12] the water level data of Dhaka city for 17 years (1988-2004) was analysed for assessing the water level fluctuation and predicting its trend using the MAKESENS computer model. Linear regression method was used to analyse the water level fluctuation in

Kutahya – Cavdarhisar plain in Turkey[13]. The Geographic Information System (GIS) presents an important tool in the effective management of groundwater resources, as it helps in preparing a scientific geodatabase of the resource and also facilitates for updating the data[14]. GIS has been put to effective use in many earlier groundwater studies and found to be extremely successful[15-18, 4].

In the present study, the sum of least squares method under the time series regression analysis was used to access the groundwater level trend and the rainfall trend along with the response of groundwater with reference to rainfall during the pre and the post monsoon seasons. To analyse the spatio-temopral variability of rainfall vis-a-vis groundwater level, the spline interpolation technique using GIS was used. The study demonstrated the potential of GIS in evaluating the spatial relationship of rainfall and groundwater for sustainable utilisation of water resources in drought prone regions.

Study Area: The study area, Palamu district, lies between 23˚ 20' to 24˚ 40' N latitude and 83˚ 50' to 84˚ 55' E longitude covering an area of 8714 sq. km. Climatically, the district comes under monsoonal sub-tropical zone characterised by mean annual precipitation of 1000 mm and a mean annual temperature of 25.1°C. The location map of the study area is shown in figure-1.

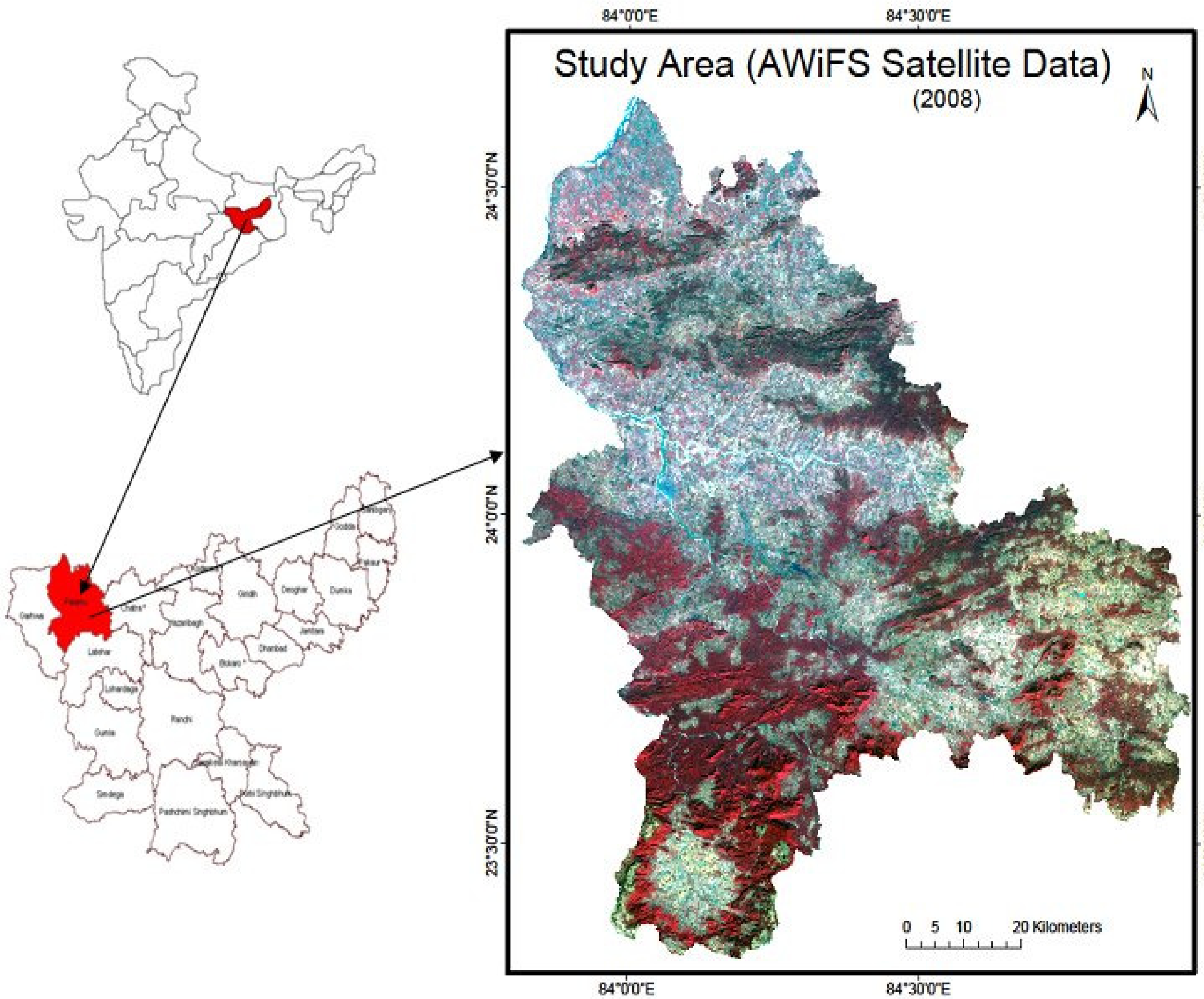


Figure-1
AWiFS satellite data of the study area with red colour (dark tone) depicting undulating mountainous terrain with forest cover and bluish white colour (grey tone) showing flat terrain with agricultural lands.

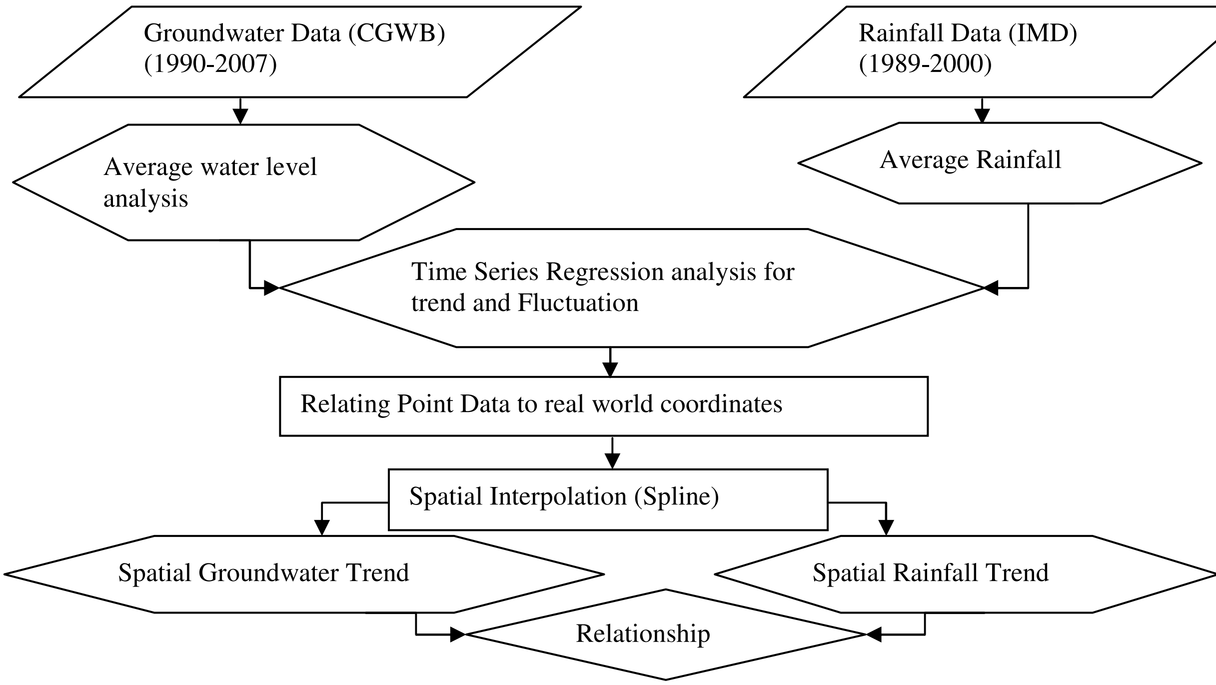


Figure-2
Methodology flow chart

Material and Methods

For analysing the average depth to water level, and its variability in the study area, the water level (WL) data of 18 years (1990-2007) recorded at 14 hydrological stations was procured from the Central Ground Water Board (CGWB). To calculate the average rainfall and the increase or decrease in rainfall amount, the rainfall data of 12 years (1989-2000) for the same places was procured from the Indian Meteorological Department (IMD). The water level fluctuation was analysed for the month of January, May, August, and November. Curve fitting using the regression equation $y = mx+c$ was done for the required places to fill in for the missing data. The methodology flow chart is shown in figure-2.

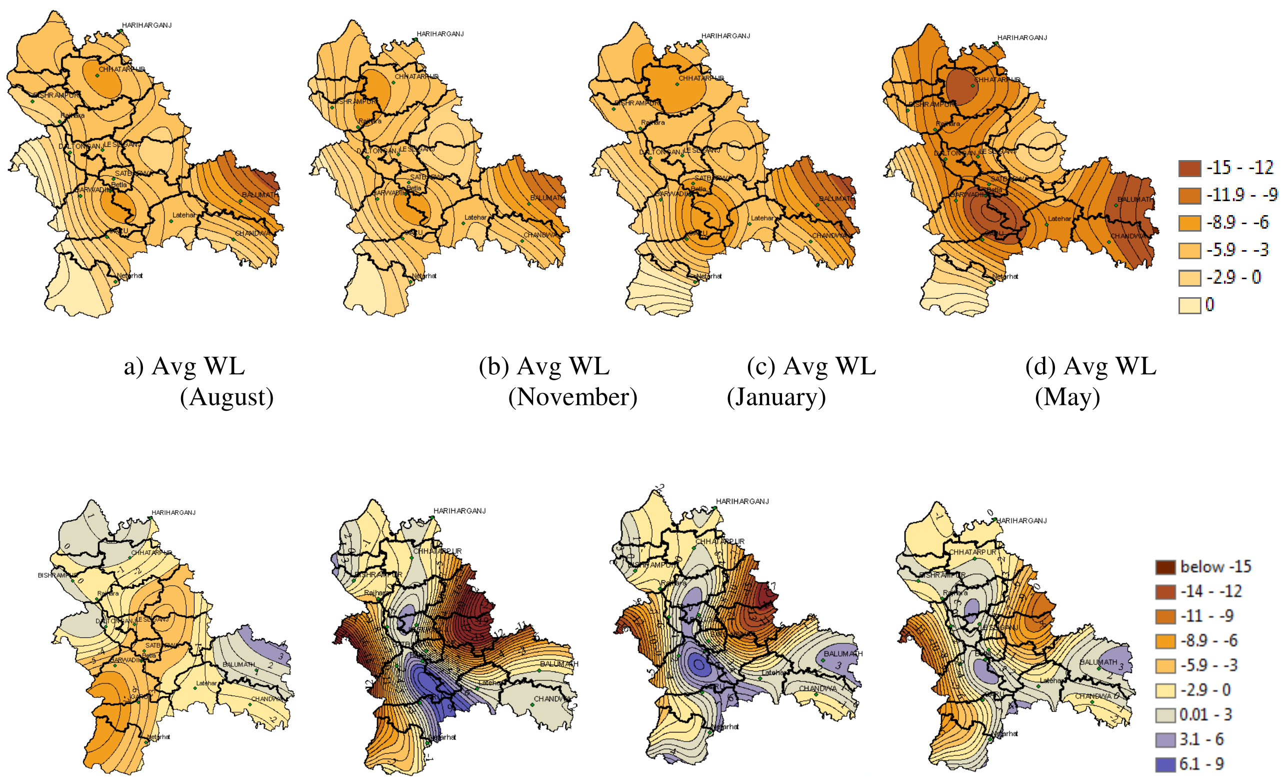
The groundwater data and the rainfall data assorted on monthly basis were analysed for their long - term pattern, and were interpreted graphically to understand the dynamics of the groundwater level and rainfall. The average water level depths and average rainfall recorded for 18 and 12 years respectively were used to indicate the long-term trend. The results were used to make the spatial variation maps of average depth to water level and water level fluctuation from the groundwater data. Similarly, the spatial variation maps of average rainfall and increase or decrease in rainfall was also depicted.

When a series of observations are arranged with reference to their occurrences in a systematic order, the resulting series is called time series and conversely, a steady increase or decrease of the time series characteristics is known as trend[19]. In Time Series Models the past behaviour of time series data set is examined in order to infer something about its future behaviour and the sum of least squares method is most widely used to calculate the trend[20]. In the present study the Sum of the Least Squares Method under the Time Series Regression analysis was adopted for estimating the trend of groundwater level and thereafter the water level fluctuation and similarly the trend and the increase or decrease in rainfall from the trend of the rainfall data was calculated using average values of water level and rainfall, using Microsoft office Excel 2007.

After computing the average depth to water level, water level fluctuation, average rainfall and the increase or decrease in rainfall, the spatial variation maps of the same were generated using spline interpolation technique in ArcGIS software. The correlation between rainfall and depth to water level was plotted and analysed for the pre and post monsoon periods for places at elevation below 300m (undulating plains) and between 300-600m (mountainous terrain).

Results and Discussion

The maps generated for average depth to water level, water level fluctuation, average rainfall and increase/ decrease in rainfall were analysed. The spatial variation maps of average depth to water level and water level fluctuation is shown in figure-3(a-d) and figure-3(e-h) respectively, and the spatial variation maps of average rainfall and increase/ decrease in rainfall is shown in figure-4(a) and figure-4(b) respectively.



a) Avg WL (August) (b) Avg WL (November) (c) Avg WL (January) (d) Avg WL (May)

(e) RISE/FALL (August) (f) RISE/FALL (November) (g) RISE/FALL (January) (h) RISE /FALL (May)

Figure-3
Map showing average water level at different places for different months (a-d) and water level fluctuation at different places for different months for a period of 18 years (e-h)

Average water level and its fluctuation in different months: Post Monsoon Season: The average depth to water level for the month of August lies between 3-6 m for most parts of the study area and below 6m in parts of northern, southern, and eastern regions (figure-3a). The study on water level fluctuation however shows that there is deepening in water level by 3-5 m and shallowing by 1-2 m in the central region (figure-3e). During November, the average depth to water level is similar to its situation in August (figure-3b) although from the water level fluctuation study, it is observed that the central region which showed a rise of 1-2m during August now shows a rise of upto 6m. However, in the other parts of eastern, western and northern regions the water level deepens below 3m (figure-3f).

Pre Monsoon Season: In the month of January, the average depth to water level lies below 6m in the northern, southern and SE regions (figure-3c). It is however observed that inspite of the average water level being lower than 6m, there is a rise in parts of central, southern, and SE regions of upto 4m and deepening below 3m in eastern, western and northern regions (figure-3g). Although the water level fluctuation study shows a rise in water level in the northern, southern and SE regions, these regions are still characterized by a deep average water level depth which further exhibits a much deeper average water level depth (below 10m), during the month of May (figure-3d). Thus, it can be inferred that these regions are more prone to drought due to a constant decline in the water level during summer season when water requirement is more which points to the need for water resource planning for its effective use particularly during the pre monsoon period. The other parts of the region also show a deep average depth to water level, ranging between 3-9 m, although the water level has fluctuated upto a 3m rise (figure-3h).

Average rainfall and its increase or decrease over the years: The study on average rainfall shows that the average rainfall is above 1000mm in western, NW, SW, and SE parts of the region whereas the central, north- eastern (NE) and only a part of the southern region has an average rainfall below 700mm (figure-4a). On the other hand, the study on increase or decrease in the amount of rainfall showed that the south-west (SW), north-west (NW) and parts of northern and central region exhibits a decrease (between 300-600mm), whereas the southern region shows an increase in the amount of rainfall (50- 300mm) over the years (figure-4b).

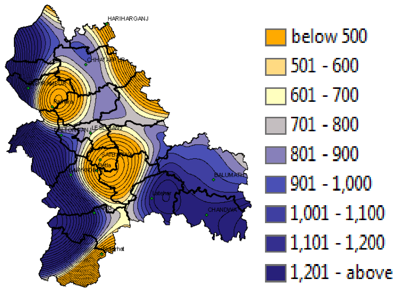


Figure-4 (a)
Average Rainfall

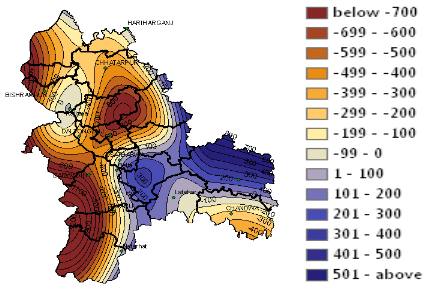


Figure-4 (b)
Rainfall Increase/ Decrease
Map showing average rainfall (a) and increase/decrease in rainfall at different places for a period of 12 years (b) Places at elevation upto 300 m Places at elevation 300-600 m

Although the SW and the NW regions, receive an average rainfall of above 1000mm, from figure-4(b) it is observed that these regions exhibit a gradual decrease in rainfall over the study period. In contrast the central region which has an average rainfall below 700mm, exhibits an increase in the rainfall during the same period. Thus, it can be said that the increase in water level during the month of November in this region is due to an increase in the rainfall in this region. Also, since the western, SW, and the NW regions receive an average rainfall of above 1000mm the average groundwater level also remains at shallow depths in these regions. In contrary, towards SE, even though there has been an increase in the amount of rainfall over the years and the region having an average rainfall of 1000mm the average depth to water level still lies very deep which indicates that a large portion of the rainfall goes waste as runoff owing to the large intensity of rainfall. A small rainfall intensity with a long duration can induce a greater groundwater level variation than a large rainfall intensity with a short duration[21]. Therefore, there is a need of developing large water harvesting structures in this region due to possibility of getting high rainfall. The captured runoff would augment the recharge of groundwater to sustain the water requirements even during the peak summer season. In comparison, the northern and western region which exhibit a decreasing trend in rainfall points to the development of number of water harvesting structure of small size to recharge the groundwater. The pattern of long-term variation of groundwater level can thus be explained by variations in precipitation[22]. From this it can be inferred that groundwater does get recharged during rainfall, as it shows a rise in the water level during the subsequent months, following rainfall, it declines substantially during pre monsoon periods (January- May), and thus results in deeper average depth to water level. This may be due to the presence of metamorphic rocks which does not have joints and fractures and therefore does not allow the rain water to recharge the deeper aquifer zones. A declining trend in the groundwater levels is generally observed in complex geological terrains of Ganges-Brahamaputra- Meghna delta[11]. A similar pattern is observed in the present study and hence it may be accounted to the presence of hard rock terrain in the region which does not allow water to infiltrate into the deeper aquifer zones, and hence most of the water escapes as runoff and partially gets absorbed into the ground to sustain shallow aquifers, and thus during post monsoon, the groundwater level exhibits fast decline by the month of November and January. Adequate water however infiltrates into the subsoil in the vicinity of recharge structures like reservoirs, which captures the runoff and thereby help in recharging the groundwater during rainfall. The recharged water however is still not sufficient to sustain the water yield from the aquifer throughout the year, and hence the average depth to water level remains quite deep. It is also noticeable that in the central and parts of NW regions where the average rainfall is less, the average depth to water level is also deep which further declines substantially by the month of May at a number of places. It is also evident that the regions where there has been a decrease in rainfall over the years, particularly in the central and SW regions, the water level fluctuation study shows a rise in the water level during the subsequent months after November following rainfall which however does not sustain much and the average depth of water level lies deep which further deepens by the month of May in the central region. The SW region however shows a constant declining trend in water level over the years, when there is a decrease in rainfall. From table-2 it is observed that during the study period there is a decrease in rainfall for most of the places and only Latehar, Balumath and Hariharganj show an increase, although these places still have deeper average water levels throughout the year which suggests more runoff and less recharge, due to hard rock in these regions.

Table-2
Average Rainfall and the Increase/Decrease in Rainfall at Different Places for a Period of 12 Years (1989-2000)

Place	Rise (mm)	Fall (mm)	Average rainfall (mm)
Daltonganj		312.05	1003.14
Lesliganj		637.77	722.80
Bishrampur		453.33	1296.28
Chandwa		234.87	1253.13
Latehar	43.33		1260.64
Balumath	286.86		1044.25
Barwadih		676.50	1092.35
Garu		352.90	1234.88
Chhatarpur		389.95	877.14
Hariharganj	347.75		896.03

From the graph plotted between rainfall and average depth to water level (figure-5), for the pre and post monsoon periods for different places, there exists a weak correlation statistically, however, a positive correlation is apparent viz. when rainfall increases, the average depth to water level also decreases and vice-versa.

The antecedent rainfall has a continuous influence on the groundwater level variation despite the influence decaying with time. As the rainfall ceases the residual groundwater levels gradually decreases owing to the trend recession[17]. In present study also, for the places at elevation upto 300 m, (during the post monsoon period), the water level occurs between 2-5m at a number of places irrespective of rainfall in the region. During the month of November the average depth to water level remains stagnant when there is no change in rainfall, but for the month of May, the average depth to water level changes with reference to the corresponding increase and decrease in rainfall in the previous monsoon months. Thus looking into the scenario of groundwater during November, it suggests that rainfall is not the only driving factor for groundwater level trends as the contribution from higher elevation through runoff and subsurface flow and can affect it and besides, the overdraft of groundwater for agricultural and domestic purposes also play an important role in water level fluctuation. From table-1 also it is clear that most of the places have very deep (upto 9m) average depth to water level during May. Although the water level lies at shallow depth (2-3m) during the month of August the water level fluctuation shows a more declining trend over the years.

On contrary, it is observed that the pre-monsoon water level exhibits a dependence on rainfall received by these regions during the previous monsoon season as higher rainfall areas have shallow water levels. Also, it is observed from table-1, that most of the places have deeper water levels, and the decline in the water level is more prominent particularly, in the places like Balumath, Betla, Chandwa, Chhatarpurr, and Garu, where the groundwater level decline is upto 10 m during the month of May. These places which are at a lower to moderate elevation, where decline in the water level is prominent are prone to drought conditions if monsoon failure occurs during the subsequent south west monsoon period starting during the second week of June. The groundwater levels fluctuate naturally in response to a sequence of climatic events and to constraints imposed by the hydrogeologic and topographic characteristics[9]. In the present study also, the study area has a plateau terrain and an undulating topography, and the water levels are found to be deep in the plain regions (at elevation below 300m). At these low lying regions agriculture is practiced more and hence the water requirement is also more but however due to less infiltration of the water during post monsoon, where the water replenishes the shallow aquifers for shorter period of time, (until November/December), and groundwater recharge is largest as during winter, and spring months, when plants are dormant and evaporation rates are small[9]. The water levels remains stable only upto November but during the month of January to May, the water level declines gradually due to water extraction for irrigation during Rabi season and domestic requirement. Thus the water level deepens in summers before the onset of monsoon as during summer the evapotranspiration rates exceeds the available moisture from precipitation and so the recharge to the water table becomes negligible. A number of small water harvesting structures should therefore be developed in these regions to augment the groundwater recharge.

Table-1
Average depth to water level and water level Fluctuation at Different places for a period of 18 years for Different Months (1990-2007)

Place	elev.[a] (m)	January		May		August		November	
		avg. WL[b] (m)	WL fluct.[c] (m)	avg. WL (m)	WL fluct.(m)	avg. WL (m)	WL fluct.(m)	avg. WL (m)	WL fluct.(m)
Balumath	560	9.31	3.34	9.72	2.86	8.39	1.74	7.87	0.0
Barwadih	280	3.81	3.17	7.99	-0.40	3.4	-5.39	4.28	-0.36
Betla	320	7.22	4.13	10.2	2.72	6.22	-4.18	6.4	4.73
Satbarwa	280	6.44	-0.52	8.31	-0.03	5.21	-4.17	5.37	-0.82
Bishrampur	200	4.55	0.39	5.23	-0.62	2.55	-0.14	3.56	-0.35
Rajhara	200	5.18	-2.17	7.66	0.09	2.46	-0.35	5.8	-2.80
Chandwa	520	5.47	-0.36	8.58	-0.76	2.95	-1.41	3.59	1.62
Chhatarpur	280	6.73	-0.01	9.2	-2.02	6.36	-4.10	5.78	0.36
Hariharganj	160	4.63	-1.17	5.86	0.62	2.83	-0.29	2.96	-0.11
Daltonganj	240	5.19	-1.91	7.33	-1.89	2.65	-3.98	4.07	-2.06
Garu	400	6.57	2.48	8.26	-0.62	3.93	-5.15	4.05	3.85
Latehar	400	4.74	1.62	7.0	0.54	3.6	-1.37	3.31	1.62
Lesliganj	240	5.23	2.58	6.49	2.12	4.42	-3.80	3.71	1.78
Netarhat	1080	0.75	2.13	2.11	1.29	1.7	-3.23	2.12	1.44

([a] Elevation, [b] Average water level, [c] Water level fluctuation)

Conclusion

The present study showed that although the average rainfall in the south eastern region is above 1000m, yet the average depth to water level in this region is very deep particularly during pre-monsoon in May, where the water level lies below 10m at various places. In August although the average depth to water level lies at 6m in parts of northern, southern, and eastern regions there is deepening in water level by 3-5 m in the central region and shallowing by 1-2 m in parts of northern and eastern region. It is observed that by the month of January the water level starts lowering and by the month of May, the water level declined to 10m. Although there is substantial amount of rainfall in the south eastern region where the water level is near surface conditions during August, the average depth to water level also deepens by the month of May. This may be due to the hard rock terrain in the region which does not allow water to infiltrate into the deeper aquifer zones, and hence most of the water escapes as runoff and partially gets absorbed into the ground to sustain shallow aquifers. It is also observed that although the water level in the northern, southern and SE regions has risen, these regions are still characterized by deep average water level depth. Thus it can be inferred that these regions are more prone to drought like conditions due to a constant decline in the water level particularly the places which are at elevation below 300m where small water harvesting structures should be made to augment the ground water.

The study shows the potential of employing GIS based interpolation techniques for geospatial analysis of ground water trend for deciphering areas for groundwater development in accordance with the temporal rainfall pattern over the region.

Acknowledgement

Authors are thankful to the Central Ground Water Board for providing the water level data and also to Indian Meteorological Department for providing the rainfall data for the study area. Author (AST) acknowledges the financial assistance under Rajiv Gandhi National Fellowship.

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