Trend Analysis of Groundwater via RS & GIS

Zafar BEG[1] Dr. Jyoti Sarup[2]
[1]PG Student [2]Associate Professor
[1,2]Department of Civil Engineering
[1,2]MANIT, India

Abstract— “This work deals with the long term of groundwater level, water level irregularity study and its correlation with rainwater for enhancement of ground water via remote sensing (RS) and geographical information systems (GIS) based technology. For the groundwater situation well inventory and rainwater data required, so for this study water samples were collected from 52 observation open wells and bore wells for the period of 12 years and rainfall data that was used for the period of 14 years. The geophysical data in the study area extract from the IRS-LISS-IV and with the help of land use land cover (LULC), Digital elevation models (DEM) and Topographical map on 1:50,000 scales trend was analyze. For the trend of ground water spatio- temporal variations map of the entire study area have been prepared using GIS spatial data also used for analyzing ground water trend information using spline interpolation in GIS. At last, by integrating the geophysical data, and the groundwater conditions data, the trend of groundwater of the study area has been found by means of tool in ArcGIS10.2, This integrated study facilitates to propose an appropriate groundwater management map for a study area.” This work also showed that though the mean precipitation in the study area is above 1100 mm, however the mean ground water level in this region is very shallow for the most part in the study area for the duration of pre monsoon in May. That is possibly because of the urbanisation and hilly terrain in the study area which do not permit water to penetrate into the sub-surface, and consequently the water gets away as runoff and somewhat finds infiltrate into the ground to sustain shallow WT, hence the result shows study areas are subjected to drought caused by a steady decline in the ground water level.

Key words: Remote Sensing, Indian Remote Sensing (IRS), Geographic Information System Linear Imaging Self Scanner (LISS), Land use Land cover

I. INTRODUCTION

Remote Sensing (RS) is the accumulation of information regarding an object and observable fact of the Earth's surface by a device that is to say not in physical contact with it. This is done by sensing by a remote platform or vehicle and recording reflected or emitted energy and processing, analyzing, and applying that information. Usually this technique used reflected or radiated electromagnetic energy, such as radiometry, photometry, spectrometry, and photographic and radar techniques (NASA Thesaurus).

The term “remote sensing” was initially introduced in 1960. New methods and technologies for sensing of the Earth’s surface were moving beyond the traditional black and white aerial photograph, requiring a new, more comprehensive term be established. Today, many satellites, with various remote sensing instruments, monitor the Earth’s surface (e.g. IRS, GOES etc). Earth observation satellites have been used for many decades in a wide field of applications. With the advancements in sensor technology remote sensing can directly contribute to water resource management and enables the opportunity to provide unique solutions to meet the information requirements of water resource managers.

One of the critical components of our natural resources is groundwater. It serves as a priceless resource in regions lacking access to surface water (Leake and Alley, 2004). Ground water is the underground water that takes place in saturated zone of inconsistent thickness and depth beneath the earth’s surface. The water resources of the basins remain almost constant while the demand for water continues to increase. It consists of the major and the ideal resource 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 requisite in rural India (Maheshwari, 2006 and Murhekar, 2012). The utilizable water resources of India are estimated to be 112 mham out of which 69 mham is surface water resources and 43 mham is groundwater resources.

Groundwater is a mobile and replenish able natural resource, at present there are lots of areas in the country facing scarce the quantity of water, fall of water levels, failure of wells, in areas is for the reason that the unintended groundwater development. This has lead to accentuate on planned and best probable development of water resources. An appropriate strategy will be to build for groundwater resources with planning based on amalgamation use of groundwater and surface water.

Groundwater management entails an appropriate perceptive of the long-term trends of the groundwater body for any province, the long-term trend replicates the steady transformation that are going on in the system over time by naturally or induced by man. Time series analysis can be a supportive tool since it yields the long-term trends of water table fluctuations. The appropriate management of both surface and groundwater resources from beginning to end are organized record, preservation and appropriate development is essential for economic and social growth of any country. Hence, in the present scenario, it has turn out to be important to know the trend in ground water over a period of time. For determining trend of groundwater the RS and GIS techniques have found to be very successful and trustworthy tools to scrutinize spatial and nonspatial data on drainage, LULC slope parameters to recognize their interrelationship for determining trend of groundwater as it helps in preparing a scientific geodatabase of the resource and also facilitates for updating the data (Sankar, 2009).

It long been acknowledged that remote sensing applications can contribute to the studies of the spatial and temporal variations of hydrological characteristics. Thus a major aim of remote sensing applications in water resources management is to develop techniques for estimating plant physiology and growth, soil moisture, groundwater, snow, surface water or static basin characteristics such as topography or land use. Temporal pattern refer to Change Detection.

II. STUDY AREA

The study area encompasses southern region of Bhopal district at Bhopal, capital of M.P. which is situated in the central part of India on the Malwa plateau with Chambal and Betwa drainage basin. The southern region of Bhopal district has been preferred for this thesis based on the data accessibility of groundwater level (GWL) records. The study area in Bhopal, lies between 23°7' to 23°22'N latitude and 77°14' to 77°31'E longitude and is covered under the Survey of India(SOI) toposheet no. 55E/07 and 55E/08 on 1:50,000 scale covering an area of 850 sq. km.(approx.)

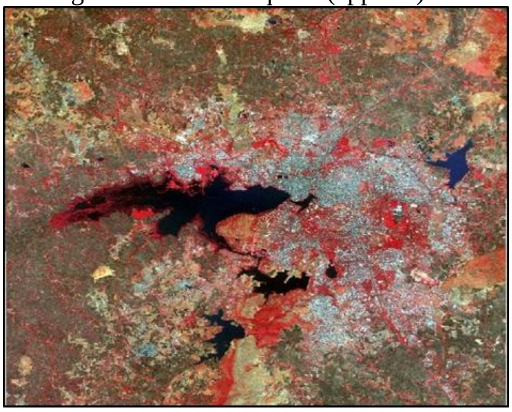


Fig. 1: Location Map of the Study Area

III. METHODOLOGY

The ground water level was considered for the pre-monsoon and post-monsoon month of January, May, August, and November. The data were cautiously investigate for homogeneity and for omitted data records in the data sets are not taken on regularly basis due to this data sets have some non-recorded values which are calculated by linear regression. Regression equation "y=mx+c" under curve fitting technique was applying on data to fill the omitted value into the datasets, and also some time in some gauges non recorded data can reach 5-6 years, so availability of very less data, slope of regression equation become negative, due to this averaging of data can be done, averaging is done because in the study area there is no sudden climatic changes. The water level fluctuation can be imagine and understand from the water level data of monitoring wells. The methodology flow chart is shown below.

The precipitation data and the groundwater level data were converted to seasonal and annual averages for each station. Separate on the basis of month wise and were examine for their time series analysis, and also understand graphically to identify the long term pattern of the rainfall and groundwater. The mean of rainfall and mean of depth to ground water recorded for 14 and 12 years respectively were utilized to know the trend of ground water procured from MPWRD and CGWD. Data attributes of 52 monitoring wells and Bhopal rain gauge stations is presented in Table 1.The results were creating the spatial variation maps of the groundwater data i.e. mean ground water level depth and water level fluctuation. Similarly, the graphs of mean rainwater and rise or fall in precipitation were also illustrated.

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 (Patra, 2001).

A time series of observations is influenced by four components such as (i) Long term component (ii) Cyclicity component (iii) Seasonality component and (iv) Irregularity component.

Several techniques are available for separating the trend component Time Series Decomposition Analysis by Multiplicative Model method was adopted for smoothing a time series. In Time Series study the past nature of time series data set is observed in order to conclude something about its future i.e. forecasting and the investigative analysis of wells and precipitation of time series datasets offers an initial idea of seasonality and trends in the groundwater levels and rainfall. The Time Series Decomposition Analysis by Multiplicative Model is a good to determine the trend was adopted using Microsoft Excel 2007 and applied to time series data at each monitoring wells for direct assessment of outcome. In this method for estimating the trend of groundwater level and water level fluctuation and the rise or fall in precipitation data was calculated using mean of water level and rainfall data, from the time series datasets.

Once calculating the mean depth to water level, water level fluctuation, mean rainfall and the rise or fall in rainfall, the spatial variation maps are generated using spline interpolation technique in ArcGIS 10.2 software. The relationship between precipitation and depth to water level was analyzed for the pre monsoon and post monsoon era for the study area.

A. *Time Series Decomposition Method*

Y = Cyclical X Trend X Seasonal X Irregular

Where,
Trend = trend at any time t
Seasonality = seasonality at any time t
Cyclicity = cyclicity at any time t
Irregularity = irregularity at any time t

IV. FLOW CHART OF METHODOLOGY

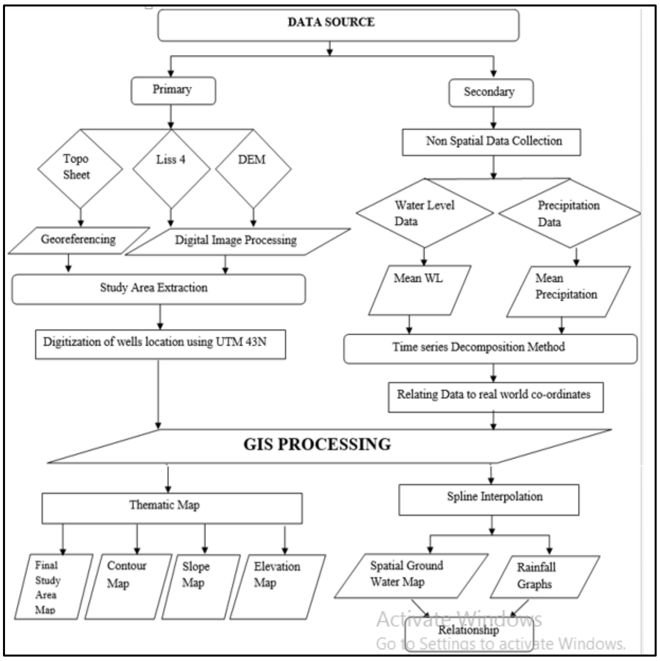
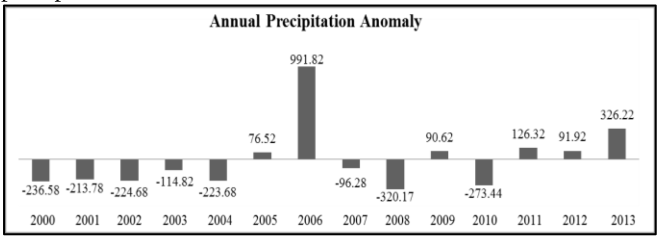


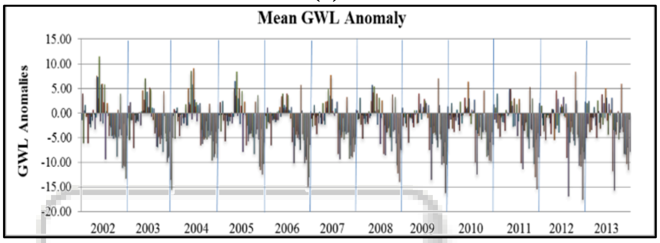
Fig. 2: Flowchart of methodology

V. RESULT & ANALYSIS

A greater part of examined wells in the dataset explain declines trend in groundwater into the study period. The correlation among water level, water level fluctuation and precipitation is complex and spatially changeable. In this thesis, we analyze various patterns and probable link amongst them (Lall and Russo, 2014). This connection is confine in the mean underground water trends, when similitude against to the mean precipitation over the study area Figure 2. Additional correlation involving underground water and precipitation are converse in Section 4.2.



(a)



(b)

Fig. 2: (a) Annual Precipitation Anomaly. (b) Calculated Trend Anomalies of Groundwater Level of 52 wells change for study area, negative indicates greater decline than average

Though the precipitation trend within study period is negative, the allocations of gradient variance are comparatively small except in the year 2006, with a leg on each side of both depressing and rising observations shown in Figure 2(A).On the other hand almost all of the study area encompass both growing and depression water level in various observation wells. The above graph of WL fluctuation of 52 wells shows significant long-term declining trends in most of the wells shown in Figure 2(B).

In this work GWL, of the pre-monsoon and post-monsoon groundwater depth data of 52 observation wells for the 2002-2013 periods were collected from the CGWB and MPWRD Bhopal, Government of M.P. for spatial analysis. (Sahoo, 2014) as shown in Table 1

Sr. No.	Site Name	Pre-Monsoon	Post-Monsoon	Topo sheet No.
		Mean WL(m)	Mean WL(m)	
1	Arera Colony	7.02	7.51	55 E/8
2	Bhainsa Khedi	8.11	7.05	55 E/4
3	Bairagarh	10.07	8.43	55 E/8
4	Jahangirabad	6.54	6.15	55 E/7
5	Chhola	7.57	7.95	55 E/7
6	Anna Nagar	6.10	3.58	55 E/8
7	Jhangirabad	4.27	3.89	55 E/8
8	Ayodhya Nagar	8.05	3.03	55 E/7
9	Barkhera	6.33	5.64	55 E/8
10	Piplani	7.20	5.74	55 E/8
11	Shahjahanabad	3.92	2.96	55 E/7
12	Shahpura	3.85	3.17	55 E/8
13	South T T Nagar	8.37	6.44	55 E/8
14	Bagmugaliya	10.84	8.50	55 E/8
15	Ratibad	9.39	10.52	55 E/8
16	Jhitniya	11.80	10.65	55 E/3
17	Kala	11.14	10.24	55 E/8
18	Berkhedi Kala	10.37	11.66	55 E/8
19	Bairagarh Chichli	9.88	11.67	55 E/8
20	Shahpura	10.40	13.52	55 E/7
21	Navi Bagh	9.69	13.14	55 E/7
22	Rasla Khedi	8.90	9.63	55 E/7
23	Koh-e-Fiza	11.98	12.88	55 E/8
24	Dharampuri	8.38	12.64	55 E/8
25	Shahpura	9.97	10.61	55 E/8
26	Narela Sankari	15.45	16.57	55 E/7
27	Mungalia hat	12.08	13.93	55 E/7
28	Chopra Kala	14.40	12.89	55 E/7
29	Neelbad	10.97	10.90	55 E/8
30	Kolu Khedi	11.13	11.76	55 E/8
31	Aish Bagh	8.76	9.72	55 E/7
32	Govind Pura	16.87	9.49	55 E/7
33	Kalisot	10.06	7.15	55 E/8
34	Rasla Khedi	20.30	9.83	55 E/7
35	Semra Kalan	12.29	8.29	55 E/7
36	DIG Bangla	11.37	7.05	55 E/7
37	E- 2 Nursery	10.71	7.65	55 E/8
38	Gandhi Nagar	13.73	10.98	55 E/7
39	Lal Ghati	10.20	5.40	55 E/7
40	Walmi	16.58	11.86	55 E/8
41	Bairagarh	16.80	10.52	55 E/7
42	Arwaliya	15.30	19.72	55 E/7
43	Piplani Market	19.03	16.74	55 E/8
44	Bairagarh	18.46	14.75	55 E/7
45	Misrod	24.84	20.35	55 E/8
46	Navibagh	21.87	14.68	55 E/7
47	Patel Nagar	23.52	14.21	55 E/8
48	Islamnagar	31.01	20.86	55 E/7
49	Nishatpura	32.91	28.21	55 E/7
50	Khajoori Sadak	34.25	22.59	55 E/7
51	Intkhedi	33.14	25.11	55 E/7
52	Gitanjali Girls Collage	32.65	26.25	55 E/7

Table 1: List of Wells with Mean WL of Pre and Post Monsoon at different places in the Study Area procured by CGWD and MPWRD.

The trend on the whole of GWL fluctuations build up through time which represent a downward trend. The explanation is that the water extraction is large during the dry season, hence seems into the circumstances of groundwater through December, it propose that precipitation is not the only forceful aspect for water level trends all the way through overflow and subsurface flow be able to influence it and water used for farming and domestic purpose also take part an significant role in ground water level fluctuation. The water level fluctuation shows a more declining trend over the years, Figure 3 shows the WL trend per 3 year via graph.

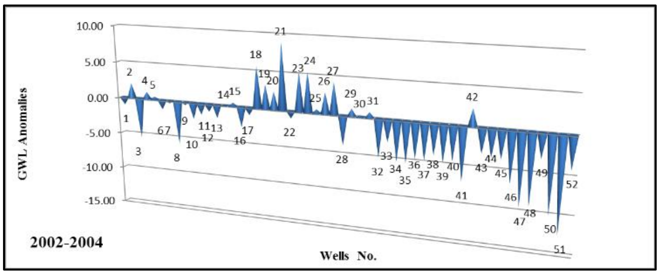


Fig. 3: (a)

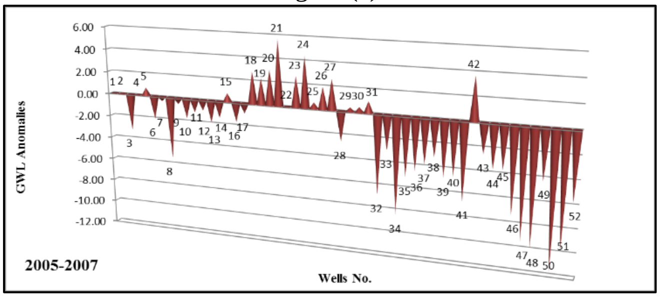


Fig. 3: (b)

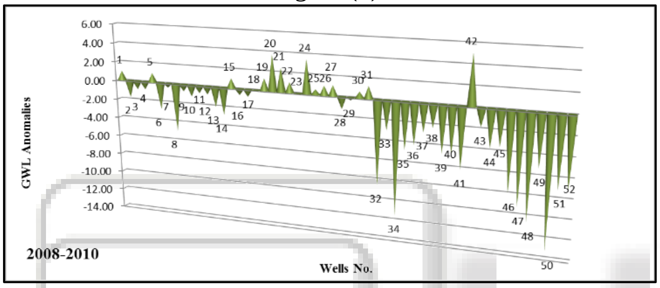


Fig. 3: (c)

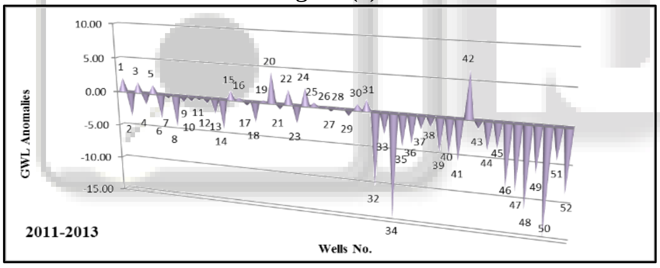


Fig. 3: (d)

Fig. 3: Three-year Mean GWL Trends Anomalies for wells with long-term declining records.

Above Figure 3 consists of four graphs showing Mean GWL Anomalies per three year trend. From the analysis it revealed that Figure3 (A) show the trend of ground water of mean of 2002 to 2004 i.e. 3 years, most of the wells show fall in WL but out of 52 wells, 18 wells shows rise in WL. Figure 3 (B) show the trend of ground water of mean of 2005 to 2007 i.e. 3 years, in this 19 wells shows rise in WL but the ground water elevation are less than the previous case. However Figure 3 (C) show the trend of ground water of mean of 2008 to 2010 i.e. 3 years, from the analysis there is decreasing in no. wells of wells .i.e. 16 shows positive results and the remaining wells shows not only show negative results but also more fall in WL. At last Figure 3 (D) show the trend of ground water of mean of 2011 to 2013 i.e. 3 years, only 15 wells shows rise in WL with less ground water elevation also shows more falls in WL as compare to all previous cases. Hence according to the graphs and analysis it is very clear that the study shows declining trend i.e. gradual decrease of WL in wells showing positive result and also WL go down and down gradually in wells showing fall in ground water significantly.

The rise/fall of the water level is the collective effect of various factors; the main amongst these is precipitation. To eliminate the cyclic and seasonal and irregular effects on groundwater level and rain water, Time Series Decomposition Analysis by Multiplicative Model is applied.

The Time Series Decomposition Analysis by Multiplicative Model analyses have been made for the hydrological stations which are in study area and have a 14 year of data between the years 2000–2013 and the mean water level for pre-monsoon and post-monsoon of 12 years (2002-2013). This is done to recognize any increase/decrease in rainfall and WL has occurred in study area throughout the time span. In precipitation all the values are small (either positive or negative) and can be deem as unimportant except in the year 2006 in this year seasonal mean rise in precipitation reach 207 mm which is more than the mean monsoon rainfall of some years in the study period. The negligible increase/decrease of total monsoon rainfall at a study area over the period cannot be the only cause for the monitored rise/fall of the water table. Table 2 shows the results of the time series analysis of observation of the average monsoon rainfall and its rise and fall in the study area.

Year	Mean Monsoon Precipitation	Monsoon RISE	Monsoon FALL
2000	228.84		-53.2
2001	164.75		-55.85
2002	207.51		-41.27
2003	254.8		-19.56
2004	182.76		-57.15
2005	229.39	37.05	
2006	280.77	207.38	
2007	200.77		-10
2008	251.28		-67.62
2009	306.73		-19.02
2010	218.78		-93.81
2011	273.16	53	
2012	332.69	43.48	
2013	236.79	76.55	

Table 2: Time Series decomposition analysis of Mean monsoon precipitation and Rise/Fall in monsoon period for a period of 14 years (2000-2013)

In the study area usually municipal corporation, farmers, industries and public abstract water, and they depend chiefly on wells for water. Usually there are 52 wells (mainly open wells) in study area as talk about earlier, all monitoring wells goes through only the shallow water table comprise both rising trend and declining trend in water levels in different wells. Infiltration from irrigation constitutes one of the major components of groundwater recharge at many locations (Karanth, 1985), even though it have well-known that the to be expected problems in temporal and spline of data because of their relationship and reliance, a lot of integrated temporal and spatial study have been tale even in recent.

Among the integrated temporal and spline study, the good enough outcome attain from integrated temporal and spline study.

A. Average WL and its Fluctuation

All the monitoring water wells in the study area of ground water records ranges 2002 to 2013 are assemble into four clusters, which are divided in term of mean water level.

1) Post Monsoon Season

The mean ground water level in post monsoon for the clusters 1 wells lies between 1.5 to 4.25 m, clusters 2 wells lies between 3 to 6 m except Narela sankari which shows very high mean WL upto 8.3 m clusters 3 wells lies between 7 to 10 m clusters 4 wells lies between 10 to 14m for most parts of the study area (Figure 4)

The detailed analysis on ground water level fluctuation in post monsoon season shows that mean ground water level fluctuation in clusters 1 well range -1.5 to +1 m except south TT nagar well shows large variation in the fluctuation i.e. -2.3 m generally in cluster 1 all the wells shows random trend in fluctuation, clusters 2 wells ranges -2.7 to +2.5 m except Aishbagh and Rasla Khedi and DIG wells which shows large deviation in fluctuation in falling WL i.e. -5.28, -3.95 and -3.27 m whereas Jhitniya shows rise in WL about 3.4 m ,whereas other wells shows random trend in WL fluctuation. In clusters 3 wells, range -3 to +1 except Patel nagar well shows large variation in the fluctuation i.e. -8.0 m analysis shows that all the observing wells showing declining trend in mean WL fluctuation, and clusters 4 wells ranges -2 to +1m WL fluctuation on an average in the study area (Figure 4).

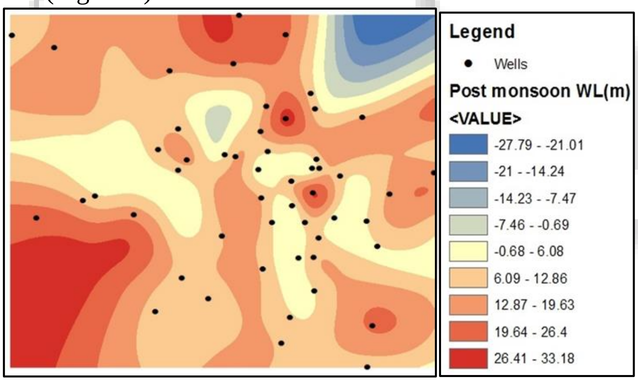


Fig. 4: Map showing Post-Monsoon Mean WL at different places using Spline Interpolation for a period of 12 years.

2) Pre Monsoon Season

In the pre monsoon, the mean depth to water level for the cluster 1 wells lies between 2 to 4 m, cluster 2 wells lies between 4 to 6 m except Narela sankari and Rasla Khedi wells these wells shows high mean WL i.e. 8 m and 7.5 m cluster 3 wells lies around 9 m cluster 4 wells lies around 14 m for most parts of the study area. (Figure 5).

Although the water level fluctuation study shows that ground water level fluctuation in cluster 1 wells values ranges are very small i.e. near to 1 (either positive or negative} and shows declining trend, cluster 2 wells ranges -2.5 to +2 except Govindpura Rasla Khedi and Gandhi nagar shows very large fall in WL in pre monsoon i.e. -5.9, -4, -4.3 analysis shows that all the observing wells showing decreasing in mean WL trend. In cluster 3 wells, ranges -3 to +3, and cluster 4 wells ranges around -3 m on an average in the study area analysis shows that all the observing wells showing decreasing in mean WL. (Figure 5).

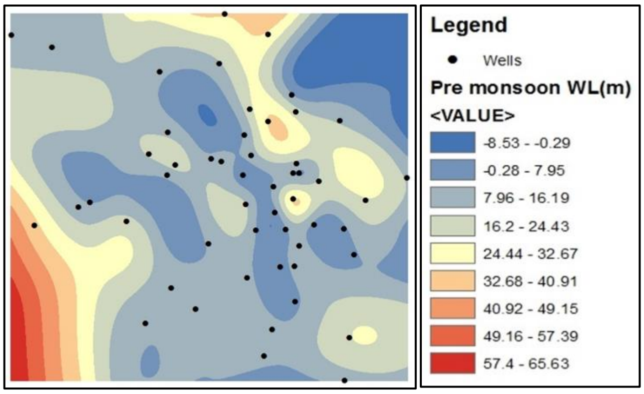


Fig. 5: Map showing Pre-Monsoon Mean WL at different places using Spline Interpolation for a period of 12 years

Thus, it can be deduced that the study area are more engaged to drought due to a fall in the ground water level in summer season when need of water necessity is much which requests for water Resource development for its efficient use mainly for the period of the pre monsoon.

B. Correlation of Water Level

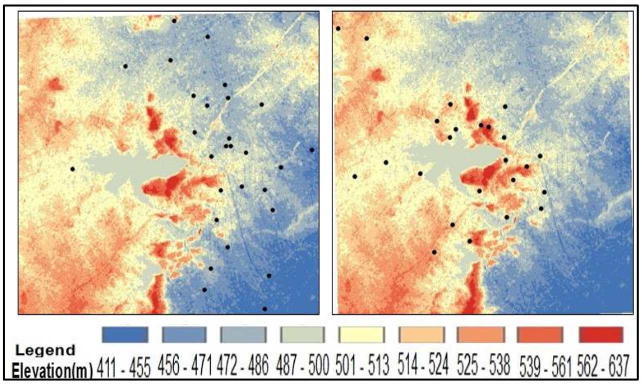
1) Correlation of WL with Precipitation and Elevation

In this analysis, for the places at altitude below 500 m, (during the post monsoon period), the mean water level take place between 2-4 m at a number of locations in cluster 1 during the month of August however Shahpura and Ayodhya nagar well shows very low average depth to WL i.e. around 1, water level comes about moderate depth between 3.5-8 m at a most of the space in cluster 2, irrespective of precipitation in the area during the month of August. Water level lies between 7-10 m at in cluster 3 during the month of August however Patel nagar well shows very less WL elevation i.e. around 3, water levels occurs above 10 m at a locality in cluster 4 during the month of August.

Again, for the places at elevation above 500 m, (during the post monsoon period), the mean water level occurs between 2-5 m at a locations in cluster 1, water level come about between 4-8.5 m at a wells in cluster 2, irrespective of precipitation in the area. Water level lies between around 9.5 m wells in cluster 3 water level occurs above 16 m at a number of locations in cluster 4.

Similarly, for the locations at altitude below 500 m, (during the pre-monsoon period), the mean water level lies between 2.5-4 m at a number of locations in cluster 1 during May, water level occurs between 4.5-7m at a wells in cluster 2, irrespective of rainfall in the region during May however Govindpura, Rasla Khedi and well shows very high WL elevation i.e. around 10. Water level occurs between 10-12 m at a number of spaces in cluster 3 most of the places have very deep up to 9m average depth to water level during May, water level take place above 15 m at a wells in cluster 4 most of the places have very deep up to 17m average depth to water level during May.

Again, for the places at elevation above 500 m, (during the pre-monsoon period), the mean water level occurs between 2-5 m at a number of places in cluster 1, water level occurs between 4-7 m at a number of places in cluster 2 during May irrespective of rainfall in the region Gandhinagar well shows very high WL elevation i.e. around 10. Water level occurs between around 9.5 m at a number of places in cluster 3, water level occurs above 15 m at a number of places in cluster 4.



a) (b)

Fig. 6: (a) DEM with wells having Elevation below 500 m (b) DEM with wells having Elevation above 500 m in the Study Area.

VI. Conclusion

The sub-surface water existing in the water bearing structures have collected over long period of time. Analysis of Well inventory records point out water levels declined trend between 2002 and 2013 throughout the study area. This work also showed that though the mean precipitation in the study area is above 1100 mm, however the mean ground water level in this region is very shallow for the most part in the study area for the duration of pre monsoon in May. That is possibly because of the urbanisation and hilly terrain in the study area which do not permit water to penetrate into the sub-surface, and consequently the water gets away as runoff and somewhat finds infiltrate into the ground to sustain shallow WT. Hence the result shows study areas are subjected to drought caused by a steady decline in the ground water level.

Therefore, appropriate steps must be commenced as early as possible to support the sustainable use of the groundwater resources. Suitable attentiveness agenda have to be carried out. Where small water harvesting scheme should be prepared to enhance the ground water. This is mostly vital in terms of the sustainable improvement of the study area.

This work shows the potential of utilization of GIS based spline interpolation techniques for analysis trend of ground water for make sense of areas for groundwater management in accordance with the temporal precipitation pattern over the study area.

VII. Future requirements

Auxiliary information is essential to determine a few of the deviations in the analysis of the trend of ground water, more precisely is related to sub-surface feature. The main problems are associated with data, e.g. Soil Data, Geological Data, and Losses etc. in the time series.

Trend of ground water will be commenced in the Planning, Management and Development cycle; Trend of ground water will also be carried out to evaluate ground water potential zones as this information was not available during this work.

Future research supposed to be focused on the improvement of user-friendly procedure to enumerate sub-surface water storage and imagine fluid flow and transportation technique in the sub-surface surroundings.

References

[1] Williams Mary, Wen Hui, Russo Tess, and Lall Upmanu, “Assessment of trends in groundwater levels across the United States”,Columbia Water Center White Paper Earth Institute Columbia University, (2014).

[2] Sedghamiz Abbas and Ahmadi Seyed Hamid, “Geostatistical Analysis of Spatial and Temporal Variations of Groundwater Level”, Environmental Monitoring and Assessment, Volume129, (2007).

[3] Robert C. Reedy, Kevin F. Dennehy, Scanlon, Bridget R., David a. Stonestrom,, and David E. Prudic., “Impact of Land Use and Land Cover Change on Groundwater Recharge and Quality in the South-western US.”, Global Change Biology ,Volume11(10), (2005).

[4] Pandey A.C., Nathawat M.S. and Tirkey Anamika Shalini, “Groundwater Level and Rainfall Variability Trend Analysis using GIS in parts of Jharkhand state (India) for Sustainable Management of Water Resources.” , International Research Journal of Environment Sciences Volume 1(4), (2012)

[5] Murthy T. R. Sreedhar, Raghavan B. R. and Reghunath Rajesh, “Time Series Analysis to monitor and assess water resources: A moving average approach.”, Environmental Monitoring and Assessment, Volume 109(1-3), (2005).

[6] Lamas M.R. and Martinez-Santos P., “Intensive groundwater use: Silent revolution and potential source of social conflicts.” , Journal Water Resources Planning and Management, 337-342 (2005).

[7] Lahiri Anindita and Nag.S.K “Integrated approach using Remote Sensing and GIS techniques for delineating groundwater potential zones in Dwarakeswar watershed, Bankura district, West Bengal”, International Journal of Geomatics and Geosciences, Volume 2(2), (2011).

[8] Karanth, K. R, “Groundwater Recharge Evaluation in Hard Rocks, in: Seminar volume on Research and Development Programme for Water Resources in Karnataka”, KSCST – IISc, Bangalore, (1985).

[9] G Mohan and M N Ravi Shankar, “A GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province”, Journal. Earth Syst. Sci., Volume 114(5), (2005).

[10] Leake SA and Alley WM., “The Journey from Safe Yield to Sustainability.”, Ground Water, Volume 42(1), (2004). http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2004.tb02446.x/full.pdf.

[11] Rao B.S.P., Rao Ch.V., and Sankar M.R., “Spatial distribution of ground water quality information at Rajahmundry and its surrounding areas – GIS approach.”, Seminar on Spatial Information Retrieval, Analysis, Reasoning and Modelling ,(2009).