Journal of Climate Change, Vol. 4, No. 2 (2018), pp. 77–86.
DOI 10.3233/JCC-1800015

Short-term Periodic Observation of the Relationship of Climate Variables to Groundwater Quality along the KT Boundary

C. Thivya[1], S. Chidambaram[2,3]*, R. Thilagavathi[2], Venkatraman[4], N. Ganesh[2], Banajarani Panda[2,5] and M.V. Prasanna[6]

[1]School of Earth and Atmospheric Sciences, University of Madras, Chennai, India
[2]Department of Earth Sciences, Annamalai University, Cuddalore, Tamilnadu – 608002, India
[3]Presently at Water Research Centre, Kuwait Institute for Scientific Research, Safat, Kuwait
[4]Department for Management of Science and Technology, Faculty of Applied Sciences
Ton Duc Thang University, Ho Chi Minh City, Vietnam
[5]Presently at University of Nebraska-Lincoln, Lincoln, USA
[6]Faculty of Engineering and Science, Department of Applied Geology, Curtin University Malaysia,
CDT 250, 98009 Miri, Sarawak, Malaysia
✉ sabarathinam.chidambaram@gmail.com

Received May 24, 2018; revised and accepted July 12, 2018

Abstract: Ground water is the most important resource in the region where it meets with water shortage. Climate change and shifts in precipitation intensity will affect groundwater continuity, thus altering groundwater level. In the present study groundwater level, rainfall and geochemistry of groundwater data have been collected for six years from 2011-2016. The deeper water level is noted in sedimentary terrain and the shallow water level is noted in hard rock regions. The higher intensity of rainfall is observed in the year of 2015 and the higher electrical conductivity is noted in 2013. The results illustrate the importance of precipitation intensity in relation to groundwater level and provide further insights for groundwater management in non-renewable groundwater systems and in a changing climate.

Keywords: Groundwater level; Rainfall; Climate change; Electrical conductivity.

Introduction

Rainfall is a significant climatic parameter, it varies from year to year and over decades, and changes in amount, intensity, frequency, and type which affect the hydrological system (Trenberth, 2011). The groundwater quality/quantity depends on the source of recharge water mainly from precipitation, inland surface water and by subsurface geochemical processes (Prasanna et al., 2010; Chidambaram et al., 2011). There are several factors which affects the occurrence and movement of groundwater in a region, including topography, lithology, geological structures and depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use/land cover, and climate (Mukherjee, 1996; Jaiswal et al., 2003; Jha et al., 2007). The hydrological cycle is an integral part of the climate system and climate change is expected to have negative effects on water resources such as a shorter precipitation season and an increase

*Corresponding Author

in hydrological extremes such as floods and droughts (Middelkoop et al., 2001; Xu, 2000).

Increase of population, demand for water resources together with the influence of climate change, has intensely altered the water cycle and has degraded water conditions (Froend and Sommer, 2010). The rainfall is the important component of the water cycle and is the prime source of groundwater recharge in India. The distribution of rainfall varies from place to place due to different physiographic and climatic setting. Although some parts of the country receive abundant rainfall, there are regions which face a meteorological drought condition. India is leading towards a freshwater crisis mainly due to improper management of water resources and environmental degradation, which has led to a lack of access of safe water to millions of people. The sustainable groundwater management requires an understanding of groundwater system fluctuations as it depends mainly on the amount of atmospheric precipitation, air temperature, lithological composition of rocks and degree of the drainage capacity of the area (Levina et al., 1998). The relationship between groundwater level and rainfall by variability trend analysis using Geographical information system in Palamu district of Jharkhand has been studied by Tirkey Anamika Shalini et al. (2012). An attempt has been made to understand the impact of rainfall variability on groundwater resources and suggested the artificial recharge structure in fresh groundwater zones of Haryana (Bhaskar Narjary et al., 2014). The spatial and temporal changes of groundwater with seasonal rainfall in alluvial aquifer of Hoshangabad District of Madhya Pradesh has been studied by Sourabh Nema et al. (2017). The bi-decadal groundwater level changes and their causes in semi-arid regions of south Indian region is attempted by Rajendra P. Sishodia et al. (2016).

Geochemical changes in aquifers depend on chemical, physical, and biological properties of country rocks. In general, mineral weathering and anthropogenic processes are the two major processes that control the hydrogeochemical characteristics of groundwater. Several studies have highlighted the role of weathering in groundwater chemistry, regulating the concentration of dissolved ions in groundwater (Cloutier et al., 2008; Yidana et al., 2008; Banoeng-Yakubo et al., 2009); various groundwater contaminants have been carried out in different parts of the world (Min et al., 2003; Perez del Villar et al., 2003; Chae et al., 2004). The Tamil Nadu state is underlain by diverse hydrogeological formations, nearly 73% of the state is occupied by hard rocks. The study area falls in KT (Cretaceous-Tertiary) boundary which covers both hard rock and sedimentary terrain. The vagaries in monsoon changes in rainfall periods and insufficient surface water flow conditions have led to an increase of agricultural and domestic extraction (Aravindhan et al., 2004). One of the most severe consequences of climate change will be the alteration of the hydrological cycle, which will impact on the quantity and quality of regional water resources (Xu, 2000). The hydrogeochemical behaviour of groundwater in KT (Cretaceous tertiary) region of Tamilnadu has been studied by Devaraj et al. (2016 a, b). The preliminary study has been carried out to understand the role of rainfall, water level fluctuation with geochemistry of groundwater.

Study Area

The proposed study area is the KT boundary which covers parts of four districts (Perambalur, Ariyalur, Tiruchirapalli and Thanjore) with an area of 2845 km^2. Geological formations of the study area range from Archean to Recent. The study area is covered by both hard rocks and sedimentary terrains (Figure 1). Fissile hornblende-biotite gneiss is the major rock type of the region and Charnockite rocks occur as patches. Argillaceous sandstone and fossiliferous limestones are noted in the Ariyalur region. The region enjoys a semi-arid and tropical climate with hot summers from April to June (CGWB, 2008, 2009). Coleroon river flows along the southern part of the study area. The weather is pleasant during the period from November to January. During summer, the maximum temperature often exceeds 40°C. The relative humidity ranges between 50 and 92%. In most of the regions ground water occurs in phreatic condition ranges to semi confined conditions in the inter-granular pore spaces in sands and sandstones (CGWB, 2008). The yield of large diameter wells taps the weathered mantle of crystalline rocks or the unconsolidated formations ranging from 200 to 900 lpm for drawdowns ranging from 0.4 to 2.5 m. The transmissivity of Cretaceous formation of the aquifer is 234 m^2/day and storativity is in the order of 3.527×10^{-4} (CGWB, 2009). The Specific Capacity in the Tertiary formations ranges from 40 to 1627 lpm/m/d. More potential specific capacity is noted in Cretaceous formation ranges from 18.77 to 90.66 lpm. The normal rainfall for the period (1901-70) ranges from 843.5 to 1123.3 mm. The major soil types encountered in the district are black cotton soils, red sandy to loamy soils and alluvial soils. The red soil is found in the hard rock

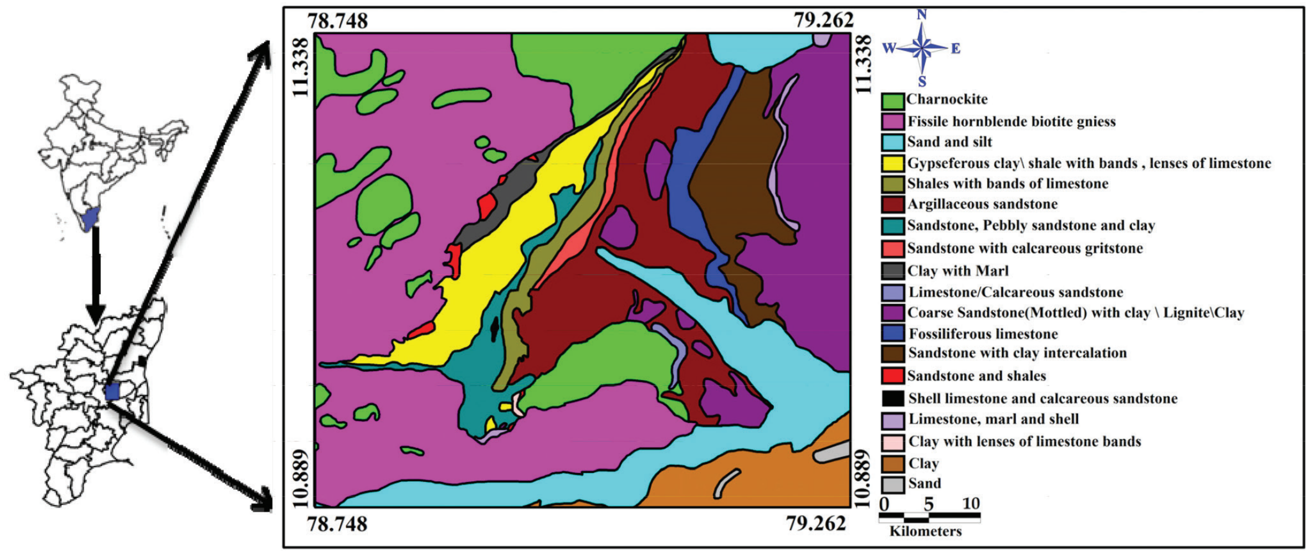

Figure 1: Location map of the study area with lithology (after GSI, 1995).

terrains and the black soil in the limestone regions and the alluvial nature in the sandstone regions.

Methodology

Rainfall, water level and groundwater chemistry data have been collected from CGWB (Central Groundwater Board) for the year from 2011 to 2016. The water level data is collected in four months interval for each year from 15 locations distributed spatially throughout the study area. The rainfall data has been collected monthly from major seven rainfall stations namely Ariyalur, Thirumanoor, Senthurai, Perambalur, Chettikulam, Pullambadi and Kallakudi. Groundwater data (pH, EC, Ca, Mg, Na, K, Cl, HCO_3, NO_3, SO_4, F) from 2011 to 2016 has been collected for six locations spatially representing the entire region (Figure 2). The data has been processed using Map Info professional (8.5) software. In order to achieve the accurate estimation of the spatial distribution of rainfall and water level, interpolation method has been used. Piper diagram has been plotted using Aquachem software.

Water Level

Groundwater level measurements and their fluctuations are the major sources for the identification of recharge mechanism, hydrologic stresses impressed on aquifer and the quantity and quality of water in storage mechanism and discharge (Solomon et al., 2007). Groundwater level is a significant parameter for assessing the spatial and temporal changes in groundwater environments. It is governed by various factors such as climate change, as it has been reflected in precipitation and evaporation rates that mainly influences the groundwater level fluctuation (Vijith et al., 2007). Decrease in rainfall causes the depletion of groundwater level, due to greater extraction of groundwater level for irrigating crops.

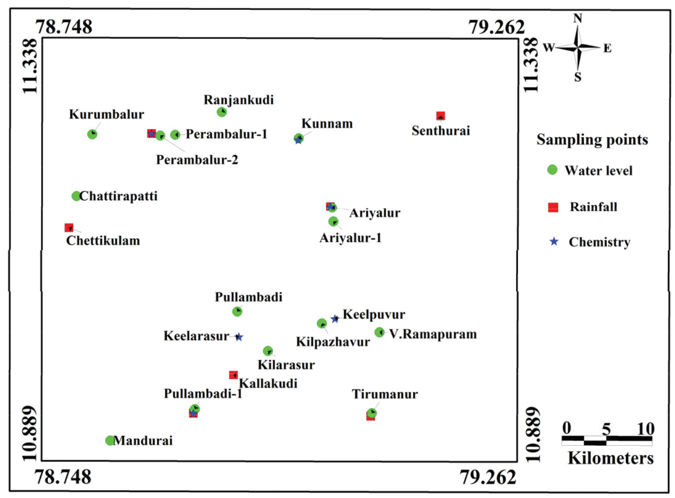

Figure 2: Sampling location points of the study area.

A total of fifteen monitored wells were considered for the study. The deepest water level is noted in V. Ramapuram and Tirumanur stations whereas shallow water level is observed in Chattirapatti and Kurumbalur stations (Figure 3). In comparing the years from 2011-2016, the higher shallow water level fluctuations are noted in 2012 in the hard rock regions whereas the deeper water level fluctuations are noted in 2015 of sedimentary terrains. Declining of surface-water availability ultimately declines the recharge rates, especially in the most water-stressed regions

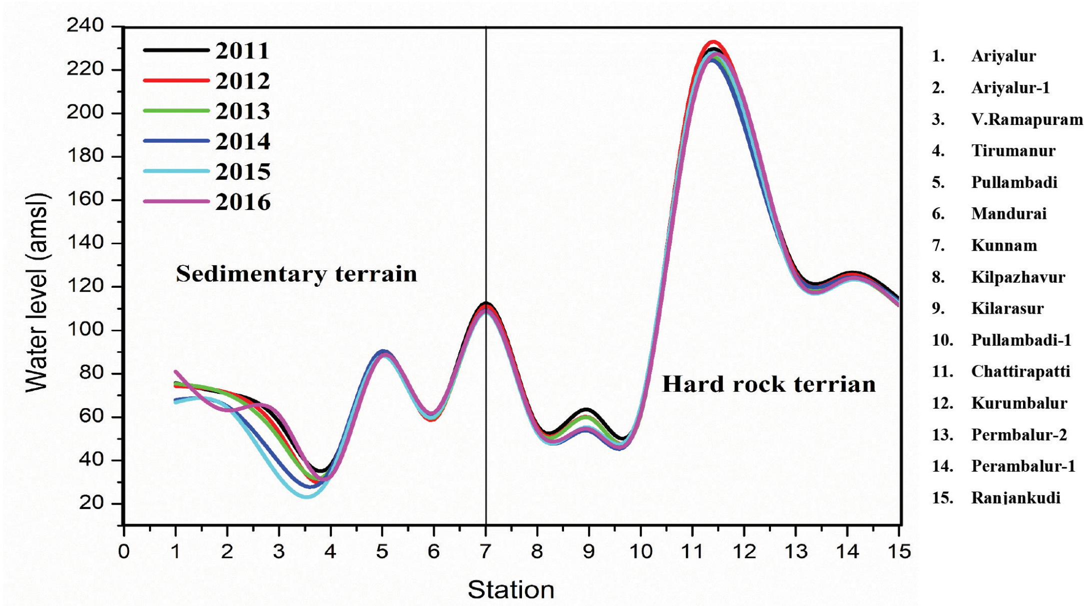

Figure 3: Water level variations from 2011-2016.

(Kundzewicz et al., 2007). The water level fluctuations reflect the change in groundwater storage. The deeper water level monitoring stations are in Ariyalur region which lies in sedimentary terrains. According to the Central groundwater board (CGWB, 2016) report for the year 2006-2015 the fall in water level is in the range of 2-4 m in these regions. The groundwater estimation based on report of Government of India on the Mine area is found to be falling in semi-critical category (Summary Environmental impact assessment report 2010).

Spatial Distribution of Water Level and Its Fluctuation

The level of the water table is the upper surface or top of the saturated portion of the soil or bedrock layer that indicates the uppermost extent of groundwater. It can be expressed as a height above a datum, such as sea level, or depth from the surface. The ground water level in this region varies according to the formation of rocks. The average depth of water level in sedimentary terrains for the year of 2011 is 72.03 m, 2012 is 70.38 m, 2013 is 70.18 m, 2014 is 66.97 m, 2015 is 64.85 m and 2016 is 71.05 m whereas in hard rock region it varies from 120.56 m, 119.96 m, 117.49 m, 116.88 m, 117.62 m, 117.52 m irrespective of years (Figure 4). The study on water level fluctuations shows that there is deepening of water level for the year from 2011 to 2015 in sedimentary terrains. 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.

The spatial distribution of water level shows that the shallow water level is observed in north-west region and the deepest water level is noted in southern part. It also indirectly indicates that the ground water moves towards the southern part of the study area. River Marudaiyar flows in south west to south eastern region and the deeper water level is noticed in the region as observed in Vaigai river of Madurai district (Thivya et al., 2013 a, b). The shallow water level is noted in hard rock regions which implies the thick weathering mantle in the study area. Geomorphologically the north western part of the study area is surrounded by hills and the water level varies from NW to southern region.

Rainfall

The amount of rainfall depends on several meteorological and topographic factors. It is also to be noted that distribution of rainfall varies in both time and space. The precipitated water reaches the surface ground and most of them are distributed as runoff or partially infiltrates to the subsurface. It depends upon the geomorphology, lithology and geology of the region.

The lowest rainfall is noted in Chettikulam for the year 2012 and the higher rainfall is observed in Ariyalur stations for the year 2015 (Figure 5). In comparing the six years, 2015 received higher intensity of rainfall in the north east monsoon (from the month of September-November). It is observed that these regions exhibit a

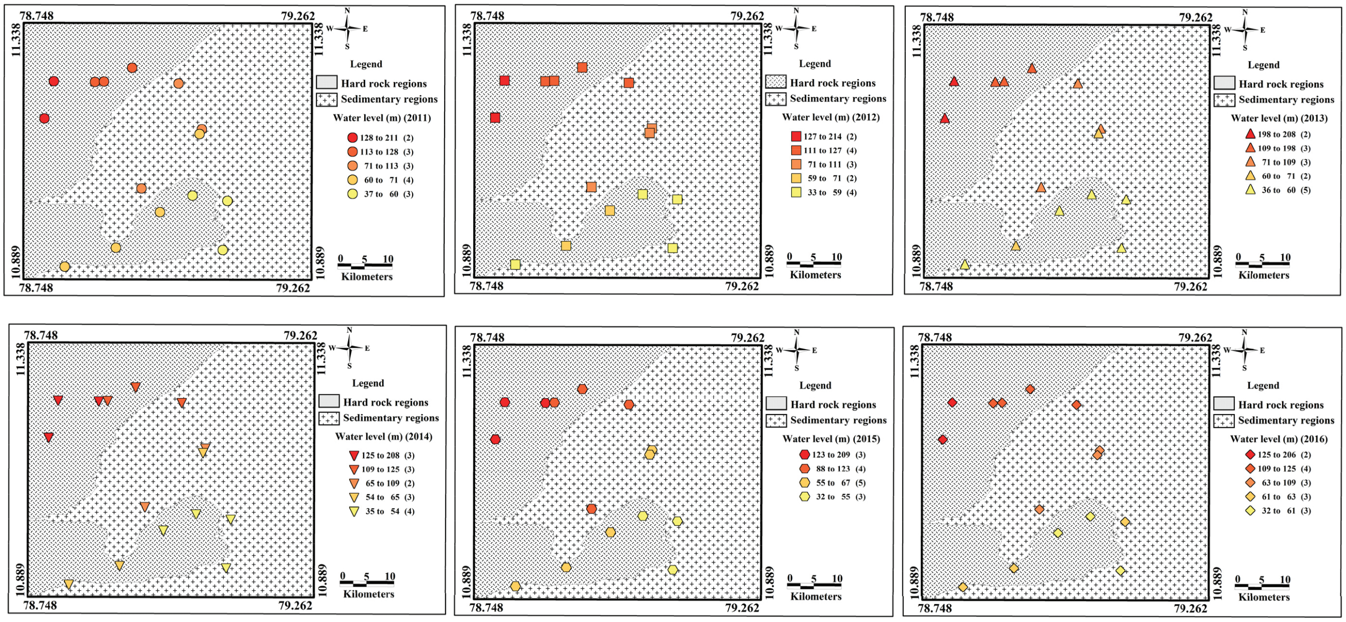

Figure 4: Spatial distribution of water level (amsl) overlaid with lithology map.

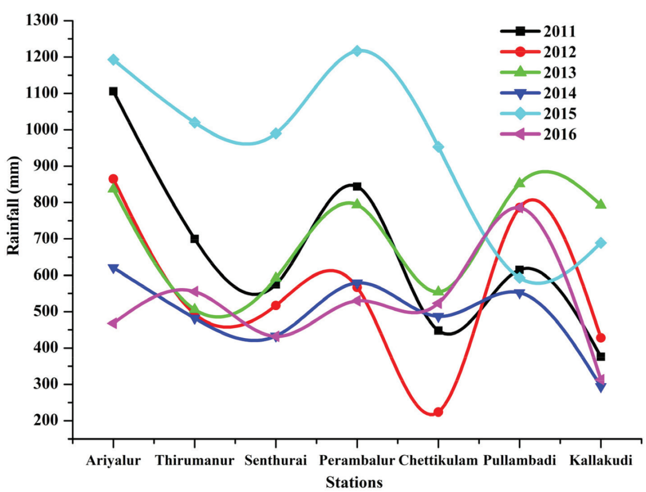

Figure 5: Variations of annual rainfall from 2011-2016.

gradual decrease in rainfall over the study area from 2011-2014 period. Several studies on rainfall variation in India suggests that yearly rainfall has not clearly shown the increasing and decreasing trend (Lal, 2001). Numerous case studies all over the world have proved that the frequency of more intense rainfall events in most parts of Asia have increased, whereas the amount of rainy days and total number of yearly precipitation has decreased (Khan et al., 2000; Mirza, 2002; Lal, 2003; Goswami et al., 2006; Dash et al., 2007).

Spatial Distribution of Rainfall (mm)

The spatial distribution of total annual rainfall from the year 2011-2016 has been presented in Figure 6. The average rainfall received for the year 2011 is 666 mm, 2012 is 554 mm, 2013 is 704 mm, 2014 is 493, 2015 is 951 mm and that of 2016 is 515 mm. The highest rainfall is observed in the year 2015 (Figure 6). In the year 2011, 2012 and 2014 the higher intensity of rainfall is noted in lower elevation (>29 m) i.e. central part of the study area and lower intensity is noted in southern region. These regions are covered by flat terrains and the water levels are found to be deep in the plain regions. At these low-lying areas the mining activities are more which is rich in limestone resources. In addition to that agriculture is also practiced in these regions, hence the water requirement is also more. However, due to less infiltration of the water, the water replenishes the shallow aquifers for shorter period of time. The groundwater levels fluctuate naturally in response to a sequence of climatic events and to constraints imposed by the hydrogeologic and topographic characteristics (Reghunath et al., 2002). 2013 and 2016 showed the higher rainfall in low elevated region in southern part. In 2015 the higher rainfall is noted in higher elevated region (90-148 m) of north western part of the study area. A small rainfall intensity with a long duration can induce a greater groundwater level variation than a large rainfall intensity with a short duration (Jan et al., 2007).

When rainfall increases, the average depth to water level also increases in 2015 and vice-versa. The rainfall has a continuous influence on the groundwater level variation despite its influences with time. As the rainfall ceases the residual groundwater levels gradually decreases owing to the trend recession (Ravindran,

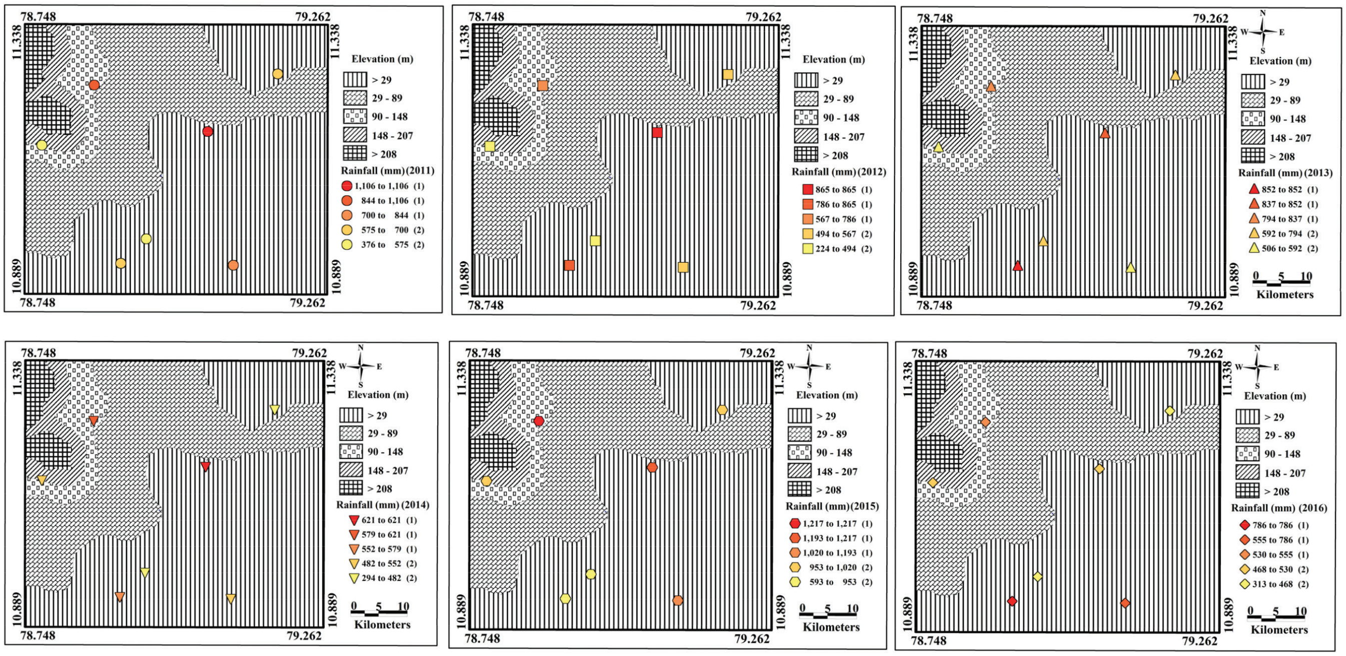

Figure 6: Spatial distribution of rainfall (mm) overlaid with elevation (m) map.

1997). 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 can also affect it and besides, the overdraft of groundwater for agricultural and domestic purposes also play an important role in water level fluctuation.

Geochemistry of Groundwater

The study of the chemical concentration of the groundwater provides the information about the hydrogeochemical status of an aquifer. Totally six samples (three from sedimentary and three from hard rock terrains) were considered for the study and the average concentration of major ions are given in Table 1. pH varies from 7.28 to 7.75 irrespective of years. In the average concentration, the higher EC is noted in the year 2011. Lower EC is observed in the year of 2015 where the higher rainfall is observed, the dissolution of ions due to weathering is the major source for the lesser concentration of ions. Higher EC is noted in sedimentary regions irrespective of all years. The samples of these regions are affected by the anthropogenic processes like sewage infiltration, mining activities and also inferred that the rainfall recharge is very limited, and that groundwater flushing is incomplete (Tyagi et al., 2008).

The concentrations of major ions in the study area varies both regionally and seasonally. Na is the dominant cation and Cl is the dominant anion in the

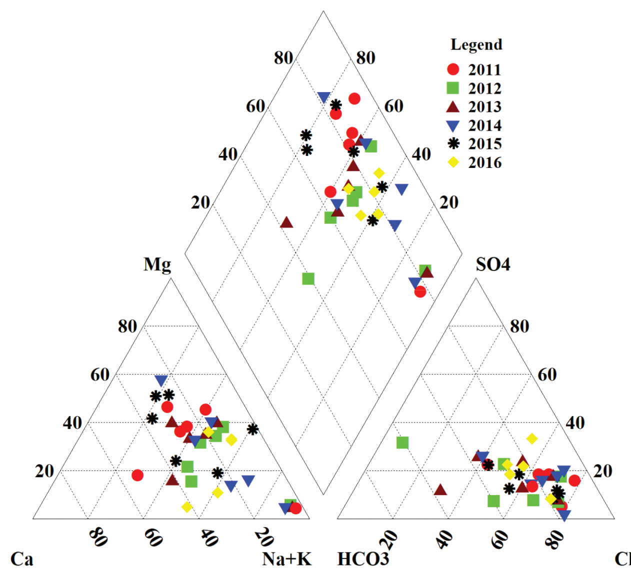

Figure 7: Piper plot deciphering the geochemistry during the time period from 2011-2016.

study area. The order of dominance is Na > Ca > Mg > K = Cl > HCO_3 > SO_4 > NO_3 > F for all sedimentary regions except in the year 2015, in that Mg is the second dominant cation. In hard rock regions the order of dominance is Na > Mg > Ca > K = Cl > HCO_3 > SO_4 > NO_3 > F except in the year 2015, where Ca is the secondary dominant ion. Mg in hard rock regions are mainly derived from the mica, pyriboles, ion exchange dissolution of magnesium calcite, gypsum, Mg hyper-

Table 1: Average chemical concentrations of groundwater from 2011-2016 (All values are in mg/l except EC in µs/cm and pH)

	pH	*EC*	*Ca*	*Mg*	*Na*	*K*	*HCO_3*	*Cl*	*SO_4*	*NO_3*	*F*
2011											
Sedimentary rock	7.42	5606.67	242.80	99.87	627.73	71.33	398.79	1048.39	316.67	102.84	1.06
Hard rock	7.75	2326.67	128.93	141.11	199.43	7.73	331.87	570.43	171.20	36.24	1.49
2012											
Sedimentary rock	7.38	5416.67	279.67	122.96	1138.23	65.83	433.61	1099.47	237.33	94.50	1.37
Hard rock	7.75	1670.00	118.20	147.18	385.23	19.49	483.78	344.70	149.20	34.37	1.21
2013											
Sedimentary rock	7.39	5523.33	455.77	170.72	1661.55	116.75	478.40	1157.30	327.00	175.72	0.78
Hard rock	7.28	2179.33	247.13	288.29	584.67	27.22	522.32	494.63	210.20	39.06	0.86
2014											
Sedimentary rock	7.68	4290.00	144.92	83.01	681.76	24.36	345.92	886.97	302.69	79.29	1.05
Hard rock	7.71	3248.33	127.13	151.49	340.19	19.51	395.66	781.94	172.65	48.98	0.94
2015											
Sedimentary rock	7.55	2718.00	109.33	124.67	303.00	32.33	301.00	656.67	171.00	91.33	0.74
Hard rock	7.33	1747.33	113.33	69.56	102.33	19.70	236.67	358.67	87.33	65.07	0.33
2016											
Sedimentary rock	7.33	4943.33	274.67	45.33	563.33	13.67	494.33	811.67	496.33	166.67	1.44
Hard rock	7.39	2534.33	64.00	97.33	290.00	8.67	340.00	526.33	158.33	44.33	1.55

sthene in charnockite and dolomite from source rock (Garrels and Christ, 1965; Hostetler, 1964; Thivya et al., 2013a). Sodium is introduced in groundwater due to the weathering of plagioclase feldspar and clay minerals and due to ion exchange process and the higher average concentration is noted in the year 2013. Lesser rainfall in 2013 helps in releasing the more Na in groundwater by ion exchange processes. Chloride is the major anion in groundwater due to the various sources like dissolution of halite and other related minerals, marine water entrapped in sediments, but the higher concentration is also attributed to the sewage effluents and the various types of industrial wastes (Hem, 1985; Thivya et al., 2013b) and the average higher concentration of ions is observed in the year 2013.

Mechanism Controlling the Hydrogeochemical Processes

The geochemical nature of groundwater can be understood by plotting the concentrations of major cations and anions in the piper trilinear diagram. The trilinear diagram of Piper (1953) is very useful in bringing out the chemical relationship in groundwater. Three samples of 2011 fall in Ca-Cl type, two samples fall in mixed region (Na- Mg- Ca- Cl-HCO_3) and one sample falls in Na-Cl type (Figure 7). In 2012 and 2013 four samples fall in mixed type, whereas one sample falls in Ca-HCO_3 type and one sample falls in Na-Cl type. Three samples fall in Na-Cl type, two samples fall in mixed region and one sample falls in Ca-Cl type in the year of 2014. In 2015 two samples fall in mixed region, Ca-Cl type and Na-Cl type respectively. In 2016 all the samples fall in Na-Cl type except one sample which falls in mixed region.

Na-Cl type indicates the saline nature in the groundwater (Prasanna et al., 2010) and the samples represented in Ca-Cl type indicates the predominance of the anthropogenic impacts such as industries and mining activities. Ion exchange reactions of Ca and Mg lead to the release of Na and K into the groundwater. Only one sample of 2013 and 2012 falls in Ca-HCO_3 type indicating that both ion exchange process/weathering exists. This type may be due to the influence of monsoons (Thivya, 2014) and facies indicating the dominance of freshwater recharge into the aquifers (Chidambaram et al., 2012; Thivya et al., 2016). The rainfall recharge, ion exchange processes and irrigation return flow contribute to the ionic concentration in the groundwater (Rajmohan and Elango, 2004).

Relation between Water Level Fluctuation, Rainfall and EC

The relationship of Electrical conductivity, rainfall and water level fluctuations are plotted in Figure 8. The increase of rainfall and decrease of EC and water level is observed in the year of 2015 due to the dilution processes in groundwater (Figure 8). The study area is comprised by both hard and sedimentary regions where the higher EC is noted in sedimentary terrains. The recharge of groundwater by precipitation is the major source for the variations in groundwater chemistry (Scheytt, 1997). The decrease of rainfall and the deepening of water level are observed from 2011 to 2015 whereas the higher fluctuation of water level is noted in 2014 with increase of EC due to ion exchange processes. The rainfall has a strong influence on the groundwater level variations and as the rainfall ends the residual groundwater levels gradually decreases (Ravindran, 1997). From this it can be inferred that groundwater does not get recharged during the higher intensity of rainfall; as it shows a fall in the water level during the subsequent years, it declines and results in deeper average depth to water level.

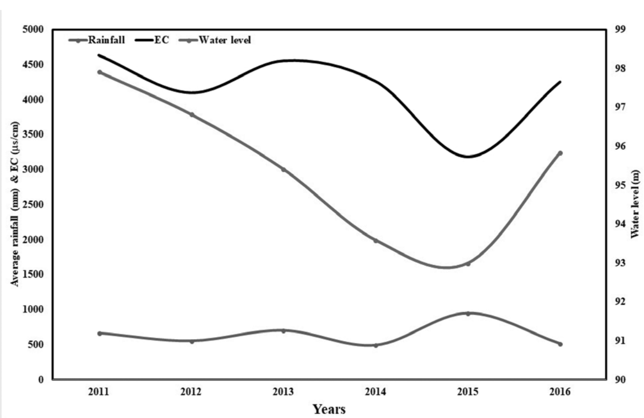

Figure 8: Relationship of water level fluctuations with rainfall and EC of groundwater.

Conclusions

The study on water level fluctuations shows that deeper water level is observed in sedimentary terrain whereas shallow water level is noted in hard rock regions and the deepening of water level is noted during the period from 2011 to 2015 in sedimentary terrains. The higher intensity of rainfall observed within a short duration has not significantly influenced the groundwater level in the region, but the lowering of EC noted in the study area, indicating the dissolution of ions. Further, it is interesting to note that the rainfall at higher elevation have greater influence on the water table than that at lower elevations. But, the deepening of water level is noted in the year 2015 suggesting that there is lesser infiltration due to short duration, higher intensity of rainfall. This phenomenon may also be because of the time lag in the process of recharge as the rainfall was at a higher elevation. Lowering of water levels is reflected by variation of ionic concentration. The hydrogeochemistry of the groundwater in the study area suggests that it is governed by both mineral dissolution and anthropogenic activities, especially mining. Groundwater recharge through artificial recharge structures in low-lying region is one of the feasible solutions for increase of groundwater level.

Acknowledgement

The authors express their sincere thanks to University Grants Commission (UGC), India, for providing the necessary financial support to this research project through post-doctoral fellowship for women wide reference to 201516-PDFWM-2015-17-TAM-37809.

References

Aravindan, S., Manivel, M. and Chandrasekar, N., 2004. Groundwater quality in the hard rock area of the Gadilam River Basin, Tamilnadu. *Journal of the Geological Society of India*, **63(6):** 625–635.

Banoeng-Yakubo, B., Yidana, S.M. and Nti, E., 2009. Hydrochemical modeling of groundwater using multivariate statistical methods—the Volta Region, Ghana. *KSCE J Civ Eng*, **13(1):** 55–63.

Bhaskar Narjary, Satyendra Kumar, Kamra, S.K., Bundela, D.S. and Sharma, D.K., 2014. Impact of rainfall variability on groundwater resources and opportunities of artificial recharge structure to reduce its exploitation in fresh groundwater zones of Haryana. *Current Science*, **107(8):** 25.

CGWB, 2008. Ground water resources and development prospects in Perambalur region, Technical Report Series. Government of India, Ministry of Water Resources, Central Ground Water Board, South Eastern Coastal Region, Chennai.

CGWB, 2009. Ground water resources and development prospects in Tiruchirapalli region, Technical Report

Series. Government of India, Ministry of Water Resources, Central Ground Water Board, South Eastern Coastal Region, Chennai.

CGWB, 2016. Groundwater year book of Tamil Nadu and U.T. of Puducherry (2015-2016), Technical Report Series, SECR/GWYB/TN/15-16, Government of India, Ministry of Water Resources, Central Ground Water Board, South Eastern Coastal Region, Chennai.

Chae, G.T., Kim, K., Yun, S.T., Kim, K.H., Kim, S.O., Choi, B.Y., Kim, H.S. and Rhee, C.W., 2004. Hydrogeochemistry of alluvial groundwaters in an agricultural area: An implication for groundwater contamination susceptibility. *Chemosphere*, **55:** 369–378.

Chidambaram, S., Bala Krishna Prasad, M., Manivannan, R., Karmegam, U., Singaraja, C., and Anandhan, P., 2012. Environmental hydrogeochemistry and genesis of fluoride in groundwaters of Dindigul district, Tamilnadu (India). *Environmental Earth Science*, **68(2):** 333–342.

Chidambaram, S., Karmegam, U., Prasanna, M.V., Sasidhar, P. and Vasanthavigar, M., 2011. A study on hydrochemical elucidation of coastal groundwater in and around Kalpakkam region, Southern India. *Environmental Earth Sciences*, **64:** 1419-1431, ISSN 1866-6280.

Cloutier, V., Lefebvre, R., Therrien, R. and Savard, M.M., 2008. Multivariate statistical analysis of geochemical data as indicative of the hydrogeochemical evolution of groundwater in a sedimentary rock aquifer system. *J. Hydrol*., **353:** 294–313.

Dash, S.K., Jenamani, R.K., Kalsi, S.R. and Panda, S.K., 2007. Some evidence of climate change in twentieth-century India. *Climatic Change*, **85:** 299–321.

Devaraj, N., Chidambaram, S. and Thivya, C., 2016a. Evaluation of groundwater quality in and around Ariyalur of Tamilnadu using Geographical Information System. *IOSR Journal of Applied Geology and Geophysics*, **4:** 15-20.

Devaraj, N., Thivya, C., Thilagavathi, R., Adithya, V.S. and Chidambaram, S., 2016b. A study on hydrogeochemical processes and groundwater quality of Ariyalur region, Tamilnadu. *International Journal of Current Research and Development*, **4(1):** 1–13.

Froend, R. and B. Sommer. 2010. Phreatophytic vegetation response to climatic and abstraction-induced groundwater drawdown: Examples of long-term spatial and temporal variability in community response. *Ecological Engineering*, **36:** 1191–1200.

Garrels, R.M. and Christ, C.L., 1965. Solutions Minerals and Equilibria (p. 450). New York: Harper and Row.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanam, M.S. and Xavier, P.K., 2006. Increasing trends of extreme rain events over India in a warming environment. *Science*, **314:** 1442–1445.

GSI (Geological Survey of India) (1995). Geological and mineral map of Tamil Nadu and Pondicherry, 1:500,000.

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural water. *USGS Water Supply Paper*, **2254:** 117–120.

Hostetler, P.B., 1964. The degree of saturation of magnesium and calcium carbonate minerals in natural waters pairs: International Association of Scientific Hydrology Commission of Subterranean. *Waters Publication*, **64:** 34–49.

Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J. and Saxena, R., 2003. Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development – An approach. *Int. J. Remote Sens.*, **24:** 993–1008.

Jan, C., Chen, T. and Lo, W., 2007. Effect of rainfall intensity and distribution on groundwater level fluctuations. *J. of Hydrology*, **332:** 348–360.

Jha, M.K., Chowdhury, A., Chowdary, V.M. and Peiffer, S., 2007. Groundwater management and development by integrated remote sensing and geographic information systems: Prospects and constraints. *Water Resour. Manag.*, **21:** 427–467.

Khan, T.M.A., Singh, O.P. and Sazedur Rahman, M.D., 2000. Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones. *Marine Geodesy*, **23:** 103–116.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Doll, P., Kabat, P., Jimenez, B., Miller, K.A., Oki, T., Sen, Z. and Shiklomanov, I.A., 2007. Freshwater resources and their management. *In:* Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds), Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.

Lal, M., 2001. Climatic change – Implications for India's water resources. *J. Ind. Water Resour. Soc.*, **21:** 101–119.

Lal, M., 2003. Global climate change: India's monsoon and its variability. *J. Environ. Studies & Policy*, **6:** 1–34.

Levina, N., Levins, I., Gavena, I., Latvijas pazemes ūdeņu resursi and Dzilna, I., 1998. Valsts Ģeoloģijas Dienests, Rīga, 24 pp.

Middelkoop, H., Daamen, K., Gellens, D., Grabs, W., Kwadijk, J.C.J., Lang, H., Parmet, B.W.A.H., Schadler, B., Schulla, J. and Wilke, K., 2001. Impact of climate change on hydrological regimes and water resources management in the Rhine basin. *Climatic Change*, **49:** 105–128.

Min, J.H., Yun, S.T., Kim, K., Kim, H.S. and Kim, D.J., 2003. Geologic controls on the chemical behavior of nitrate in river side alluvial aquifers, Korea. *Hydrol Process*, **17:** 1197–1211.

Mirza, M.Q., 2002. Global Warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Global Environ. Chang.*, **12:** 127–138.

Mukherjee, S., 1996. Targeting saline aquifer by remote sensing and geophysical methods in a part of Hamirpur – Kanpur, India. *Hydrogeol. J.*, **19:** 53–64.

Nema, Sourabh, Awasthi, M.K. and Nema, R.K., 2017. Spatial and temporal ground water responses to seasonal rainfall replenishment in an alluvial aquifer, *Biosci. Biotech. Res. Comm.*, **10(3):** 431–437.

Perez del Villar, L., Reyes, E., Delgado, A., Nunez, R., Pelayo, M. and Cozar, J.S., 2003. Argillization processes at the El Berrocal analogue granitic system (Spain): Mineralogy, isotopic study and implications for the performance assessment of radwaste geological disposal. *Chem Geol*, **193(3–4):** 273–293.

Piper, A.M., 1953. A Graphic Procedure in the Chemical Interpretation of Water Analysis. US Geological Survey Groundwater Note, 12.

Prasanna, M.V., Chidambaram, S., Shahul Hameed, A. and Srinivasamoorthy, K., 2010. Study of evaluation of groundwater in Gadilam basin using hydrogeochemical and isotope data. *Environ Monit Assess*, **168:** 63–90.

Rajmohan, N. and Elango, L., 2004. Identifcation and evolution of hydrogeochemical processes in the groundwater environment in an area of the Palar and Cheyyar River Basins, Southern India. *Environmental Geology*, **46(1):** 47–61.

Ravindran, K.V., 1997. Drainage Morphometry Analysis and Its Correlation with Geology, Geomorphology and Groundwater Prospects in Zuvari Basin, South Goa, Using Remote Sensing and GIS. Proc. Nal Sym-remote sensing for natural resource with special emphasis on water management, held at Pune during Dec. 4–6, 1996.

Reghunath, R., Murthy, T.R.S. and Raghavan, B.R., 2002. The utility of multivariate statistical techniques in hydrogeochemical studies: An example from Karnataka, India. *Water Res*, **36:** 2437–2442.

Scheytt, T., 1997. Seasonal variations in groundwater chemistry near Lake Belau, Schleswig-Holstein, Northern Germany. *Hydrogeol. J.*, **5:** 86–95.

Sishodiaa, Rajendra P., Shuklaa, Sanjay, Grahamb, Wendy D., Wani, Suhas P. and Garg, Kaushal K., 2016. Bi-decadal groundwater level trends in a semi-arid south Indian region: Declines, causes and management, *Journal of Hydrology: Regional Studies*, **8:** 43–58.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M. and Averyt, K., 2007. Climate Change 2007: The Physical Science Basis. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Summary Environmental Impact Assessment Report, 2010. Environmental clearance under EIA notification. Environmental system consultants, Ensyscon environmental laboratory.

Tirkey, Anamika Shalini, Pandey, A.C. and Nathawat, M.S., 2012. 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*, **1(4):** 24–31.

Thivya, C., Chidambaram, S., Rao, M.S., Gopalakrishnan, M., Thilagavathi, R., Prasanna, M.V. and Nepolian, M., 2016. Identification of recharge processes in groundwater in hard rock aquifers of Madurai district using stable isotopes. *Environmental Processes*, doi.10.1007/s40710-016-0137-3.

Thivya, C., 2014. Study on Uranium in groundwater of Madurai district, Tamilnadu. Unpublished Ph.D. thesis, Department of Earth Sciences. Annamalai University.

Thivya, C., Chidambaram, S., Singaraja, C., Thilagavathi, R., Prasanna, M.V., Anandan, P. and Jainab, I., 2013a. A study on the significance of lithology in groundwater quality of Madurai district, Tamil Nadu (India). *Environmental Development and Sustainability*, **15(5):** 1365–1387.

Thivya, C., Chidambaram, S., Thilagavathi, R., Prasanna, M.V., Singaraja, C., Nepolian, M. and Sundarrajan, M., 2013b. Identification of the geochemical processes in groundwater by factor analysis in hard rock aquifers of Madurai district South India. *Arabian Journal of Geosciences*, doi:10.1007/s12517-013-1065-4.

Trenberth, K.E., 2011. Changes in precipitation with climate change. *Clim Res*, **47:** 123–138. doi:10.3354/cr00953.

Tyagi, S.K., Datta, P.S., Kulshreshtha, S. and Sharma, R.K., 2008. Isotopic and Hydrochemical Signatures in Characterizing Pollutants Movement in Overexploited Groundwater Aquifers of Delhi State. 3rd WEPA International Forum on Water Environmental Governance in Asia.

Vijith, H., 2007. Groundwater Potential in the Hard Rock Terrain of Western Ghats: A Case Study from Kottayam District, Kerala using Resources at (IRS-P6) data and GIS Techniques. *Journal of the Indian Society of Remote Sensing*, **35(2):** 163–171.

Xu, C.Y., 2000. Modeling the effects of climate change on water resources in central Sweden. *Water Resour. Manage.*, **14:** 177–189.

Yidana, S.M., Ophori, D. and Banoeng-Yakubo, B., 2008. A multivariate statistical analysis of surface water chemistry – The Ankobra Basin, Ghana. *Environ. Manag.*, **86:** 80–87.