GROUND WATER LEVEL ANALYSIS IN MULA-MUTHA WATERSHED, MAHARASHTRA, INDIA, WITH RESPECT TO RAINFALL AND TOPOGRAPHIC PARAMETERS

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ABSTRACT: In the present study, Ground Water Level (GWL) variations are studied in Mula-Mutha watershed with respect to urban-rural areas, rainfall and topographic parameters. Digital Elevation Model (DEM) data is processed on GIS platform to delineate the study area and to estimate slope in the region. Urban and rural areas are delineated from Landsat Operational Land Imager (OLI) satellite image of October 2014. Rainfall surface is generated using Krigging spatial interpolation method. Further, monthly GWL dataset of two seasons pre-monsoon season (May) and post-monsoon season (October) of 1992 to 2011 are analyzed using multiple regression analysis. Other than climatic and topographic factors, urbanization also affects GWL. Therefore, GWL variations are studied based on four different scenarios in the region: (i) GWL variations are first studied separately for urban and rural areas; (ii) GWL variations are then analyzed with respect to rainfall, elevation and slope for the complete study area; (iii) Since, rainfall, elevation and slope do not show significant relationship in urban areas, these areas are excluded from the analysis in the next step. All this analysis is done considering the GWL and other parameters individually at each well location and also by averaging these parameters over the significant zones. From the results, it is observed that GWL varied in space and time in the study area based on rainfall, elevation, slope and existing land forms in both pre-monsoon and post-monsoon seasons. GWL analysis with all the parameters of individual wells offered better results. It took into account local variations in rainfall, elevation and slope. In urban areas GWL showed a weak (r) with respect to rainfall, elevation and slope in both the seasons. Whereas in rural areas GWL showed a moderate (r) with respect to rainfall but weak (r) with respect to elevation and slope in both the seasons.

1. INTRODUCTION

Watershed of Mula-Mutha River is a part of Maharashtra district of India which falls under semi-arid climatic zone. Due to dissimilarities in the geological, topographical, climatological and hydro-chemical conditions across the watershed, the ground water behaviour in this region is highly complex. Majority of the region is a part of Deccan Trap where occurrence of ground water is controlled by geological structures, soil, lithology, Land Use Land Cover (LULC), rainfall and recharge conditions (Patki et al., 2012). This region is facing a chronic water shortage for the last few decades. There is always uncertainty and variability in the occurrence of rainfall in space and time (Sivapragasam et al., 2013). With an uneven distribution of rainfall across the watershed, majority of its population is dependent on ground water resources for its domestic and agricultural demands (Gartley et al., 2009 ; Nandargi, 2014). If abstraction of ground water is not controlled, soon the ground water in the study area may exceed safe exploitation levels. With uncertainties in future climatic changes, achieving developmental targets along with sustainable ground water management is extremely challenging. Hence, ground water management is an important factor in conserving sustainable conditions in semi-arid regions (Surinaidu et al., 2013 ; Ahmadi and Sedghamiz, 2007). The GWL data obtained from Piezometers are often used to understand the GWL fluctuations in a region. GWL in a region is affected due to LULC and distinct seasonality in ground water recharge. The ground water abstraction is higher in the agricultural areas. Therefore, the spatial variation in the GWL the agricultural area is very site specific (Anuraga et al., 2006 ; Healy and Cook, 2002). Hence, in this study ground water level analysis is done for both pre-monsoon and post-monsoon seasons of distinct rainfall zones as well as spatial zones as urban and rural areas. The main objective of this study is to analyze and understand the GWL variations in the study area with respect to urban-rural areas, rainfall and topographic parameters. Geographical Information System (GIS) platform is used to analyze and present the results of spatial and non-spatial datasets.

2. STUDY AREA

Mula-Mutha watershed of Upper Bhima river basin is the study area (Figure 1). This watershed extends from Western Ghats in the west to Deccan Plateau in the east. It falls in semi-arid region of Maharashtra state, India. It covers an area of 2,918.20 km^2. It has latitudinal extent of 18^0 17' to 18^0 44' and longitudinal extent of 73^0 20' to 74^0

20'. Major rivers contributing this watershed are: Mula, Mutha, Pauna, Ambi, Walki, Ram and Mose. Mula river meets Mutha river in the heart of the Pune city. Mega city Pune falls in this watershed along with Pimpri-Chinchwad industrial zone. The altitude in the study area ranges from 495 m to 1327 m (Figure 2). Slope varies from 0 to 68.05^0 (Figure 3). Geology mainly comprises of basaltic lava flows (100-300 m). Major soil group in the study area is: medium black soil. The study area is suffering from the water scarcity due to high water demands from urban and agricultural regions.

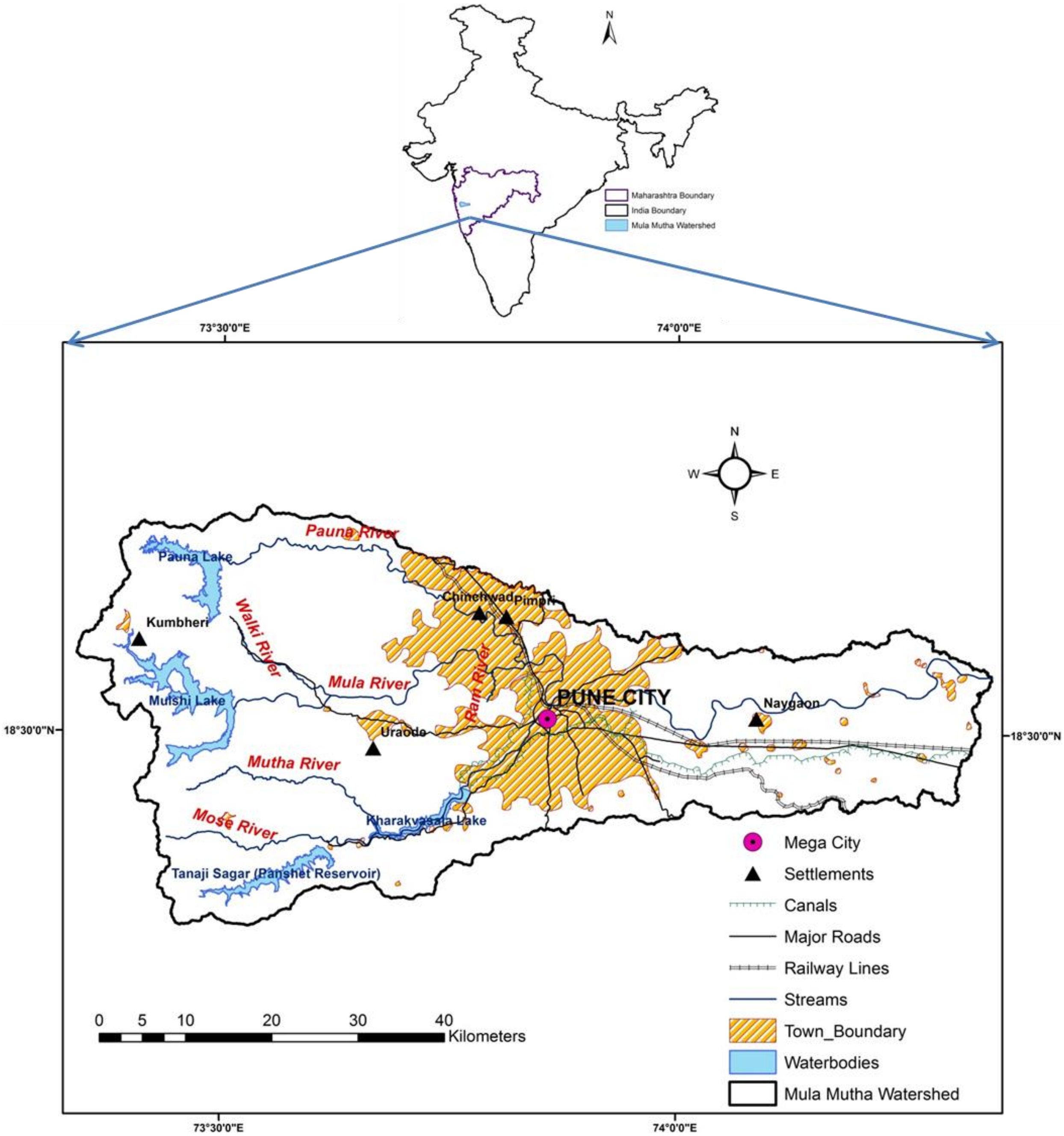


Figure 1: Location Map of the Study Area

This study area is characterized by semi-arid climate and it has primarily three agricultural seasons viz. monsoon (Kharif), post-monsoon (Rabi) and summer (Zaid). Main crops grown in the region are Bajara, Rice, Sugarcane, Groundnut, Cotton, Gram, Wheat, etc. Horticulture is also practiced in the region. The study area receives most of the precipitation (~85%) from South-West monsoon (June to mid-October). The rainfall pattern in this study area is highly un-even. Western part of the study area experiences much higher rainfall than the eastern parts. The average annual rainfall is about 741 mm and it often comes with heavy storms causing runoff and soil erosion. The un-even precipitation coupled with basaltic rock structure leaves about 60% of the study area area drought prone. The hottest months in the are April and May whereas December and January are the coolest months. Mean annual temperature is about 24.88^{0}C, with mean minimum and maximum temperatures 17.76^{0}C and 31.59^{0}C, respectively. Extensive changes in the LULC are observed in the past four decades due to increasing urbanization, industrialization and agricultural activities (NIC, 2009).

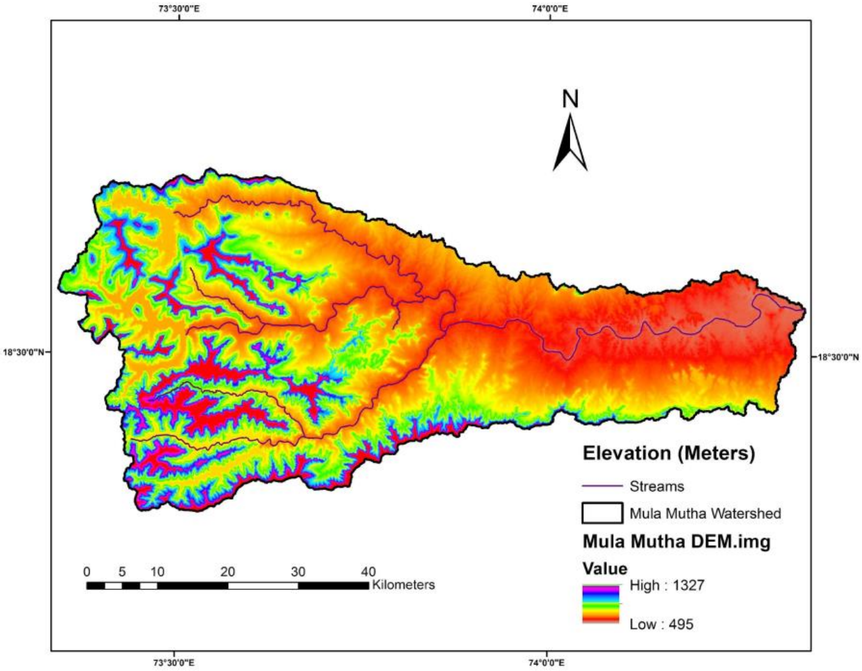


Figure 2: DEM of the Study Area with Major Stream Network

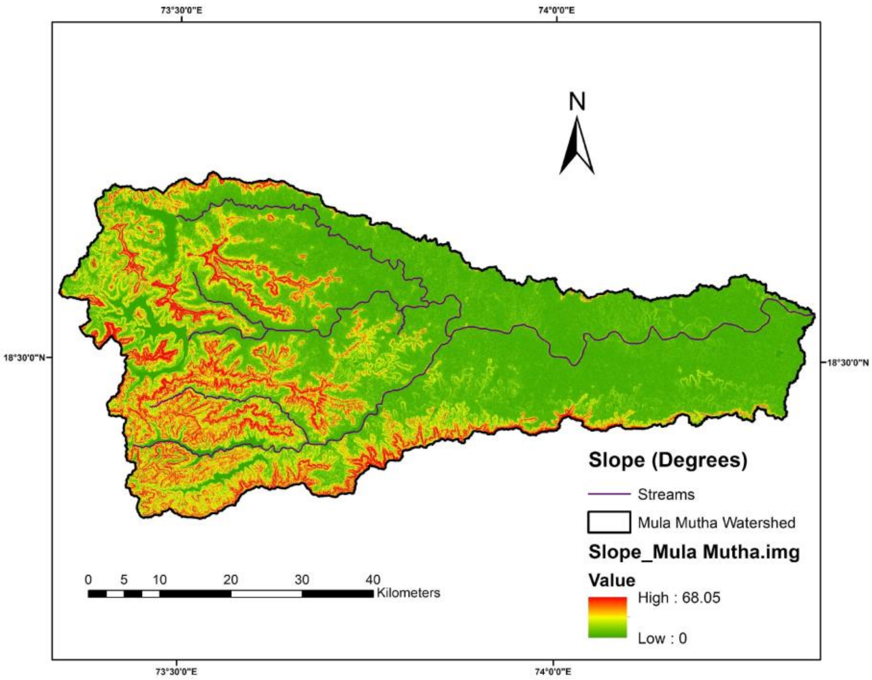


Figure 3: Slope Map of the Study Area with Major Stream Network

3. MATERAILS AND METHOD

This study is an attempt to understand the GWL variations in the study area with respect to urban-rural areas, rainfall and topographic parameters. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data and Landsat Operational Land Imager (OLI) satellite image (October 2014) of 30 m spatial resolution are derived from United States Geological Survey (USGS) website. SRTM DEM data is processed on GIS platform to delineate the watershed of Mula-Mutha rivers and to estimate the slope in the region. Landsat OLI satellite image is used to make False Colour Composite (FCC) of October 2014 (Figure 5). Monthly GWL dataset of 20 years i.e. from 1992 to 2011 is acquired from Ground water Survey and Development Agency (GSDA), Pune, Government of Maharashtra, India. Daily rainfall dataset from 1992 to 2011 is acquired from Hydrology Project (H. P.) office, Nasik, Pune, Government of Maharashtra, India.

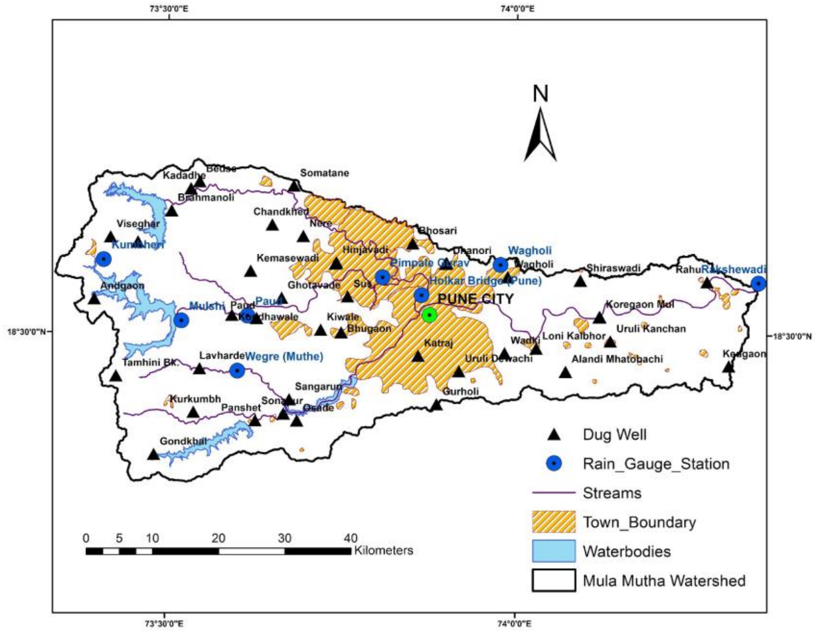


Figure 4: Map Showing Rainfall Gauge Stations and Dug Wells in the Study Area

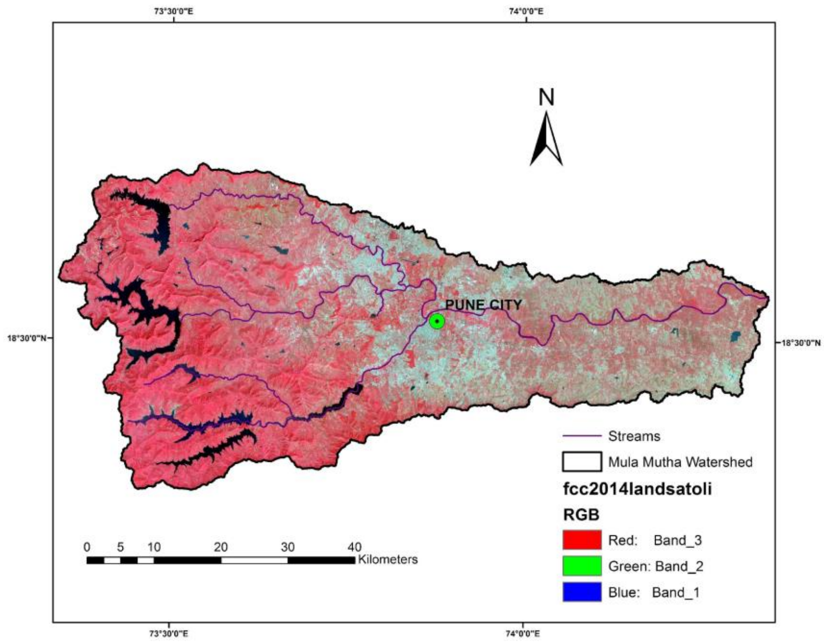


Figure 5: FCC of the Study Area (Landsat OLI Image of October 2014)

For rainfall analysis total 8 rainfall stations are selected across the study area. For ground water level analysis, 39 ground water monitoring wells (Dug wells) are chosen across the study area (Figure 4). Rainfall data is a point data, hence Krigging spatial interpolation method is used to create a spatial rainfall surface with three zones (Figure 6).

3.1 Rainfall variations in the study area

High topographic variations in the study area result in a highly un-even distribution of rainfall in space and time.

Higher elevation zones in western part of the watershed experience a very high rainfall whereas comparatively flat eastern part remains dry with low rainfall. Annual average rainfall in the region ranged between 482.19 mm to 3298.40 mm from the year 1992 to 2011. Annual average rainfall data of 8 rainfall stations across the study area are interpolated on GIS platform using Krigging spatial interpolation method. In this way, a spatial surface of annual average rainfall is created for complete study area. Based on the elevation, slope and rainfall analysis, following three distinct rainfall zones are identified in the study area: (a) Rainfall zone A or low rainfall zone (482.19 mm – 1200.05 mm); (b) Rainfall zone B or medium rainfall zone (1200.05 mm – 2171.92 mm) and (c) Rainfall zone C or high rainfall zone (2171.92 mm – 3298.40 mm) (Figure 6). It is noticed that urban areas where the water demand is already high are mainly located in low rainfall zone A of the study area.

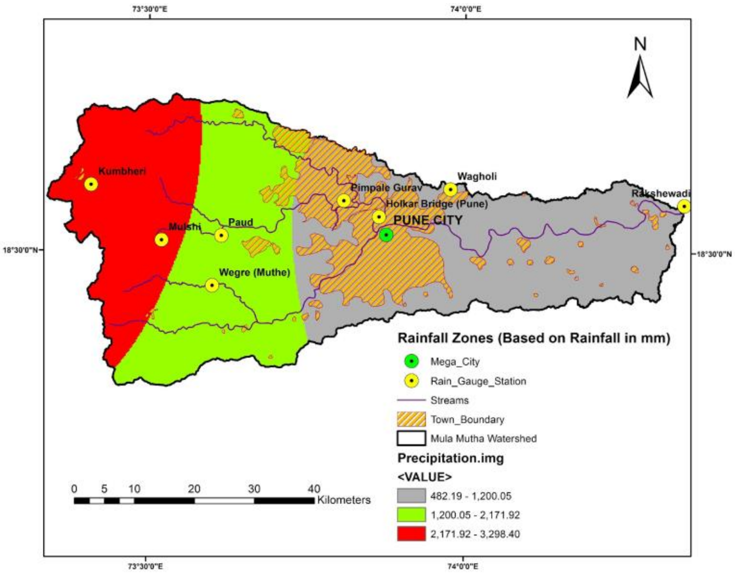


Figure 6: Rainfall Zones in the Study Area

GWL dataset of two seasons pre-monsoon season (May) and post-monsoon season (October) of the year 1992 to 2011 are analyzed using multiple regression analysis. Other than rainfall and topography, urbanization also affects GWL. Therefore, the GWL variations are studied based on four different scenarios in the region: (i) First GWL variations are studied separately for urban and rural areas; (ii) GWL variations are then analyzed with respect to rainfall, elevation and slope for the complete study area; (iii) Since, rainfall, elevation and slope do not show significant relationship in urban areas, they are excluded from the analysis in the next step; (iv) All this analysis is done considering the GWL and other parameters individually at each well location and also by averaging these parameters over the significant rainfall zones.

4. RESULTS AND DISCUSSION

The results and discussion about the GWL variations for the above mentioned four scenarios are presented below:

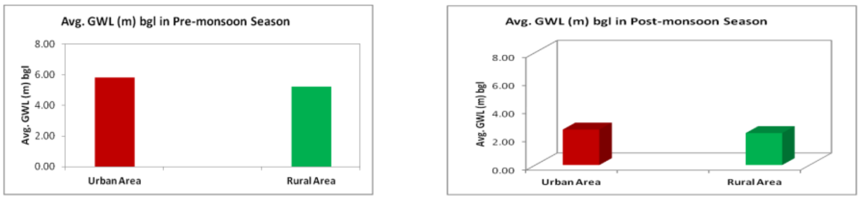
4.1 GWL variations in urban and rural areas

To understand the ground water variations in the study area, different scenarios are studied. Ground water in a region is affected by the land use type in the region. Therefore in the first scenario, average GWL variations are studied for urban and rural areas of the watershed separately.

Table 1: Ground Water Level in Pre-monsoon and Post-monsoon Seasons of Urban and Rural Areas

Dug Well (Urban Areas)				Dug Well (Rural Areas)			
Pre-monsoon Season (May) 1992-2011		Post-monsoon Season (October) 1992-2011		Pre-monsoon Season (May) 1992-2011		Post-monsoon Season (October) 1992-2011	
Average GWL (m) bgl	GWL Range in m (min-max) bgl	Average GWL (m) bgl	GWL Range in m bgl (min-max)	Average GWL (m) bgl	GWL Range in m bgl (min-max)	Average GWL (m) bgl	GWL Range in m bgl (min-max)
5.81	0.8 – 14.24	2.52	0.01 – 11.2	5.22	0.2 – 15.8	2.27	0.01 – 17

From the results, it is observed that in urban areas GWL observed are in the range of 0.01 m to 14.24 m bgl. In rural areas for same period it is in the range of 0.01 m to 17 m bgl (Table 1).



(a) (b)

Figure 7: Average GWL Variation in Urban and Rural Areas (a) Pre-monsoon Season, and (b) Post-monsoon

The average GWL in urban areas is deeper than rural areas in both the seasons (Figure 7). In the urban areas ground water level is actually affected mainly due to reduced infiltration from impervious land surfaces and draining the rain water through storm water drains. Whereas, in rural areas the ground water recharging is more due to availability of extensive pervious surfaces. And so, the GWL in urban areas should be much deeper than in the rural areas. However it is observed that the GWL at some well locations in the rural areas are deeper than in the urban areas (Table 1). This is because the well water is extensively used for domestic and agricultural purposes in the rural areas whereas in urban areas the water demand is mainly met with the municipal water supply. The rural areas are present on both eastern flat areas of low rainfall zones and also on the western hilly areas of high rainfall zones. The eastern part of the study area experiences more agricultural activities and lower rainfall. Conversely, western part of the watershed experiences very high rainfall and very less agricultural activities. Depending upon the rainfall, geomorphology, soil type and LULC, the ground water availability in the region varies highly from place to place.

4.2 GWL variations in complete study area with respect to rainfall, elevation and slope

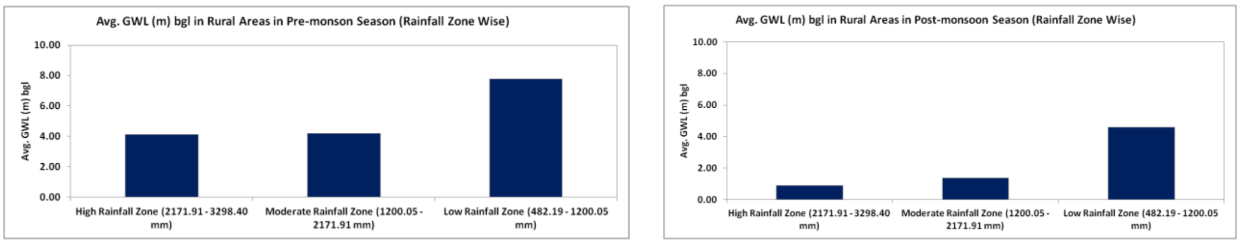
For complete study area, the average GWL from 1992-2011 in pre-monsoon and post-monsoon seasons are 5.39 m bgl and 2.34 m bgl respectively. Due to increased infiltration of ground water during monsoon period the GWL rises in the post-monsoon season. Other than land use type, availability of ground water in a region depends on factors such as rainfall, elevation and slope. Therefore, in the second scenario the complete study area is divided into three zones based on rainfall, which also indirectly reflect approximate zones of elevation and slope. Further, GWL variations are studied for all these three zones viz. (a) Rainfall zone A or low rainfall zone with rainfall in the range of 482.19 mm to 1200.05 mm, with elevations in the overall range of about 495 m to 645 m above Mean Sea Level (MSL) and slopes in the overall range of about 0^0 to 8^0; (b) Rainfall zone B or medium rainfall zone with rainfall in the range of 1200.05 mm to 2171.92 mm, with elevations in the overall range of about 645 m to 770 m above MSL and slopes in the overall range of about 8^0 to 20^0; and (c) Rainfall zone C or high rainfall zone with rainfall in the range of 2171.92 mm to 3298.40 mm, with elevations in the overall range of about 770 m to 1327 m above MSL and slopes in the overall range of about 20^0 to 68.05^0 (Figure 6). Correlation coefficient (*r*) is the correlation between the predicted values and the observed values. In the pre-monsoon season, GWL in the three zones showed a strong correlation coefficient (*r*) with respect to elevation (*r*=0.99), slope (*r*=0.99) and rainfall (*r*=0.91) respectively. In post-monsoon season also the three zones showed a strong correlation coefficient (*r*) with respect to elevation (*r*=0. 99), slope (*r*=0.99) and rainfall (*r*=0.95) respectively. In the pre-monsoon season from 1992-2011, the average GWL of low rainfall zone, medium rainfall zone and high rainfall zone are 6.63 m bgl, 4.35 m bgl and 4.11 m bgl respectively. Whereas, in the post-monsoon season from 1992-2011, the average GWL of low rainfall zone, medium rainfall zone and high rainfall zone are 3.44 m bgl, 1.47 m bgl and 0.89 m bgl respectively. The eastern part of the study area is comparatively flat and experiences low rainfall. It is a highly intense agricultural zone using well water for irrigation. The middle part of the study area mainly consists of urban areas whereas western part of the study area consists of hilly Western Ghats, small villages and forests (Figure 5). Due to intense agricultural activities in low rainfall zone there is over abstraction of ground water in this region. Therefore, the GWL of this zone is deeper than medium and high rainfall zones in both pre-monsoon and post monsoon seasons. Medium rainfall zone consists of urban areas therefore, ground water of this zone is mainly affected by reduced infiltration from impervious urban land surfaces. High rainfall zone consists of mainly hilly areas, small villages and forests. The ground water of this zone is comparatively less affected by anthropogenic activities. This zone experiences heavy rainfall. Even though this region has steep slope but during heavy rainfall the runoff generated in this region is reduced by the presence of dense forests. Therefore, GWL of this zone is higher than the other two zones.

4.3 GWL variations in rural areas with respect to rainfall, elevation and slope

Since, rainfall, elevation and slope do not show significant relationship in urban areas, these areas are excluded from the analysis in the third scenario. Therefore, GWL variations are studied for three rainfall zones of rural areas viz. (a) Rainfall zone A or low rainfall zone (b) Rainfall zone B or medium rainfall zone and (c) Rainfall zone C or high rainfall zone (Figure 6). In the pre-monsoon season, GWL in the three zones showed a strong correlation coefficient (r) with respect to elevation (*r*=0.99), slope (*r*=0.99) and rainfall (*r*=0.90) respectively. In post-monsoon season also the three zones showed a strong correlation coefficient (r) with respect to elevation (*r*=0.99), slope (*r*=0.99) and rainfall (*r*=0.93) respectively. In the pre-monsoon season from 1992-2011, the average GWL of low rainfall zone, medium rainfall zone and high rainfall zone are 7.76 m bgl, 4.18 m bgl and 4.11 m bgl respectively. Whereas, in the post-monsoon season from 1992-2011, the average GWL of low rainfall zone, medium rainfall zone and high rainfall zone are 4.59 m bgl, 1.37 m bgl and 0.89 m bgl respectively (Table 2).

Table 2: Seasonal Ground Water Level in Three Rainfall Zones of Rural Areas

Zone Name	Rainfall Range (mm)	Pre-monsoon (1992-2011)			Post-monsoon (1992-2011)		
		Avg. GWL (m) bgl	Min GWL (m) bgl	Max GWL (m) bgl	Avg. GWL (m) bgl	Min GWL (m) bgl	Max GWL (m) bgl
High Rainfall Zone C	2171.91 - 3298.40	4.11	0.2	8.8	0.89	0.01	6.35
Medium Rainfall Zone B	1200.05 - 2171.91	4.18	0.8	10.2	1.37	0.01	17
Low Rainfall Zone A	482.19 - 1200.05	7.76	2	15.8	4.59	1	10.5



(a) (b)

Figure 8: Variations in Average GWL in Three Rainfall Zones of Rural Areas (a) Pre-monsoon Season, and (b) Post-monsoon

Due to low rainfall and large scale agricultural activities in low rainfall region the ground water depletion is higher than ground water recharge especially in pre-monsoon season. Medium rainfall zone consists of rural areas surrounding urban agglomeration in the middle of the study area. It has moderate level of average GWL. This region experiences medium rainfall. Hence, the GWL in medium rainfall zone of rural areas is higher than low rainfall zone. High rainfall zone experiences very high rainfall, steep slope and lower ground water abstraction than other two zones. Therefore, the GWL in this region is higher than both medium rainfall and low rainfall zones (Figure 8).

4.4 GWL analysis carried out considering rainfall, elevation and slope at each well location individually.

All the analysis is carried out for the study area considering the GWL and other parameters individually at each well location and also by averaging these parameters over the significant rainfall zones. First the regression analysis is carried out between GWL, rainfall, elevation and slope at individual ground water wells of urban and rural areas separately for both pre-monsoon and post-monsoon seasons. Correlation coefficient (*r*) is the correlation between the predicted values and the observed values.

GWL analysis for all parameters at individual observation wells in urban and rural areas separately: It is observed that in the pre-monsoon season, GWL in urban areas showed a weak correlation coefficient (*r*) with respect to elevation (*r*=0.33), slope (*r*=0.02) and rainfall (*r*=0.35). In post-monsoon season, GWL in urban areas showed a weak (*r*) with respect to elevation (*r*=0.44), slope (*r*=0.13) and rainfall (*r*=0.33). In urban areas, rainfall, elevation and slope do not show very significant relationship with GWL in both the seasons. In the pre-monsoon season, GWL in rural areas showed a moderate relationship with respect to rainfall (*r*=0.65) but weak relationship with respect to elevation (*r*=0.11) and slope (*r*=0.01). In post-monsoon season, GWL in rural areas showed a moderate relationship with respect to rainfall (*r*=0.62) but weak relationship with respect to elevation (*r*=0.23) and slope (*r*=0.09). In rural areas, GWL showed a moderately significant relationship with rainfall but showed non-significant relationship with elevation and slope in both the seasons. Rural areas in this watershed fall in all rainfall zones with varying topographic parameter. Hence, the availability of ground water in this region is highly variable with time and space.

GWL analysis for all parameters at individual observation wells in the complete study area: This analysis for complete study area without urban/rural separation, is also carried out for three rainfall zones viz. (a) Rainfall zone A or low rainfall zone (b) Rainfall zone B or medium rainfall zone and (c) Rainfall zone C or high rainfall zone (Figure 6). In the pre-monsoon season, GWL in the low rainfall zone A showed a moderate relationship with respect to rainfall (*r*=0.60) but very weak relationship with respect to elevation (*r*=0.09) and slope (*r*=0.09). GWL in the medium rainfall zone B showed a weak relationship with respect to all parameters, rainfall (*r*=0.01), elevation (*r*=0.06) and slope (*r*=0.23). In high rainfall zone C, GWL showed a weak relationship with respect to rainfall (*r*=0.32) and elevation (*r*=0.49) but moderate relationship with respect to slope (*r*=0.60). In the post-monsoon season, GWL in the low rainfall zone A, showed a moderate relationship with respect to rainfall (*r*=0.61) but weak relationship with respect to elevation (*r*=0.23) and slope (*r*=0.03). GWL in the medium rainfall zone B showed a weak (*r*) with respect to rainfall (*r*=0.27), elevation (*r*=0.06) and slope (*r*=0.14). In high rainfall zone C, GWL showed a weak (*r*) with respect to rainfall (*r*=0.04) but moderate relationship with respect to elevation (*r*=0.55) and strong relationship with respect to slope (*r*=0.87). It is observed that due to high variability in rainfall and other parameters across the complete study area, the GWL also varied in time and space in both pre-monsoon and post-monsoon seasons. Ground water availability in the study area is highly dependent on the amount of rainfall, elevation, slope and land use at a particular location. GWL is not following a regular trend across the watershed, especially in and around the urban areas. Rainfall, elevation and slope have not shown significant relationship in medium rainfall zone which mainly consists of urban areas. Therefore in the next step, the GWL analysis is done again for three rainfall zones but excluding urban areas (Figure 6).

GWL analysis for all parameters at individual observation wells in rural areas: In this analysis the urban areas are excluded. In rural areas, during the pre-monsoon season, GWL in the low rainfall zone A showed a weak relationship with respect to rainfall (*r*=0.35), elevation (*r*=0.14) and slope (*r*=0.05). GWL in the medium rainfall zone B showed a weak relationship with respect to rainfall (*r*=0.04), elevation (*r*=0.01) and slope (*r*=0.40). In high rainfall zone C, GWL showed a weak relationship with respect to rainfall (*r*=0.32) and elevation (*r*=0.49) but moderate relationship with respect to slope (*r*=0.60). In the post-monsoon season, GWL in the low rainfall zone A showed a weak (*r*) with respect to all the parameters, rainfall (*r*=0.43), elevation (*r*=0.32) and slope (*r*=0.24). GWL in the medium rainfall zone B showed a weak relationship with respect to rainfall (*r*=0.35), elevation (*r*=0.02) and slope (*r*=0.33). In high rainfall zone C, GWL showed a weak relationship with respect to rainfall (*r*=0.04) but moderate relationship with respect to elevation (*r*=0.55) and strong relationship with respect to slope (*r*=0.87). A high variability in the rainfall and slope is observed across the study area. Therefore, the GWL also varied in time and space in both pre-monsoon and post-monsoon seasons. GWL is influenced by amount of rainfall, elevation, slope and land use at a particular location.

5. CONCLUSIONS

It is observed that in this study area, both pre-monsoon and post-monsoon seasons follow similar strength of (*r*) with respect to different scenarios but with difference in the magnitudes. GWL analysis considering rainfall, elevation and slope at each well location individually gave better results than just considering average GWL of different scenarios. It took into account local variations in rainfall, elevation and slope. The following conclusions are drawn from the study: (i) In urban areas GWL showed a weak relationship (*r*) with respect to rainfall, elevation and slope in both the seasons. Whereas in rural areas GWL showed a moderate relationship (*r*) with respect to rainfall but weak (*r*) with respect to elevation and slope in both the seasons. (ii) In low rainfall zone, GWL analysis for complete study area showed moderate relationship (*r*) with respect to rainfall but weak relationship (*r*) with respect to elevation and slope in both the seasons. However, GWL analysis for rural areas excluding urban areas showed weak (*r*) with respect to rainfall, elevation and slope in both the seasons. (iii) In medium rainfall zone, GWL analysis for both complete study area and for rural areas excluding urban areas showed weak (*r*) with respect to rainfall, elevation and slope in both the seasons. (iv) In high rainfall zone, GWL analysis for complete study area and for rural areas excluding urban areas showed weak (*r*) with respect to rainfall, moderate (*r*) with respect to elevation and strong (*r*) with respect to slope in both the seasons. The study area has a very uneven distribution of rainfall in space and time. It is evident from the results that GWL is dependent on local parameters viz. rainfall, elevation, slope and LULC at individual well locations. A high variability is observed in these parameters across the study area. Therefore, the GWL also varied highly in time and space in both pre-monsoon and post-monsoon seasons. No regular trend is observed in the GWL of the region.

6. ACKNOWLEDGEMENT

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