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*Full Length Research Paper*

# Influence of various factors on the fluctuation of groundwater level in hard rock terrain and its importance in the assessment of groundwater

**Bhagyashri C. Maggirwar[1] and Bhavana N. Umrikar [2]***

[1]Groundwater Surveys and Development Agency, Pune, India.
[2]Department of Geology, University of Pune, India.

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**A vast terrain, nearly 65% of the total area of India is occupied by hard rocks, more predominantly in the area of peninsular shield covering southern part of India. The peninsular shield is mostly constituted of granites, gneisses, basaltic rocks of volcanic origin and metamorphic complexes. In basaltic rock, the main aquifer horizons are in vesicular, fractured and weathered zone. These basaltic rocks are devoid of primary porosity. The groundwater occurs largely in the secondary porosity of weathered mantle and developed at a shallow depth. These aquifers are mostly phreatic, occurring up to the depth of 10 to 15 m. This weathered mantle is underlain by massive rocks which form the bottom of the phreatic aquifer, limiting its downward extent. The groundwater in the shallow aquifers gets replenished annually, and therefore, the status of water levels and its fluctuation play a key role in the assessment of groundwater. The pre-monsoon and post-monsoon groundwater levels indicate the degree of saturation and extent of recharge in the hard rock aquifers. A network of 3920 hydrograph stations (observation wells) has been established in Maharashtra by Groundwater Surveys and Development Agency (GSDA) and water levels are monitored since last three decades. On the basis of analysis of these water level data, it has been observed that the decline in water levels has influences of various factors. The instances of lowering of water level have been noticed in many of the less exploited watersheds also, due to various reasons. The present paper discusses various factors controlling water levels and probes that manifestation of decline in water levels can not be conclusive of overexploitation.**

**Key words:** Maharashtra, secondary porosity, groundwater level fluctuation, hard rock terrain, assessment, dynamic recharge, shallow unconfined aquifer.

## INTRODUCTION

India is a country with a total geographical area of about $3.28 \times 10^6$ km$^2$. A vast terrain nearly about 65% of the total area of the country is occupied by 'hard rocks' more predominantly in the peninsular shield of southern India. The peninsular shield is mostly constituted of granites, basaltic rocks, gneisses and metamorphic complexes. A major part of the hard rock terrain in the peninsular states is drought prone and hence groundwater is in intensive use. Maharashtra too is occupied by hard rocks (Figure 1) whose receptiveness of precipitation is restricted to the degree of weathering and secondary porosity, so also its capacity to store and transmit the water. As a result, even in high rainfall areas of the state, water scarcity is experienced in summer months (GSDA, 2004). Hard rocks derive its status as an aquifer on the basis of secondary porosity that gets developed due to decomposive and weathering processes over a period of time (Radhakrishna, 1971; Powar, 1981). Consequently, groundwater occurs largely in the secondary porosity of weathered mantle limited to a shallow depth (Singhal, 1973, 1986). Main source of groundwater is from the

*Corresponding author. E-mail: bnumrikar@gmail.com. Tel: 0091-9225527407.

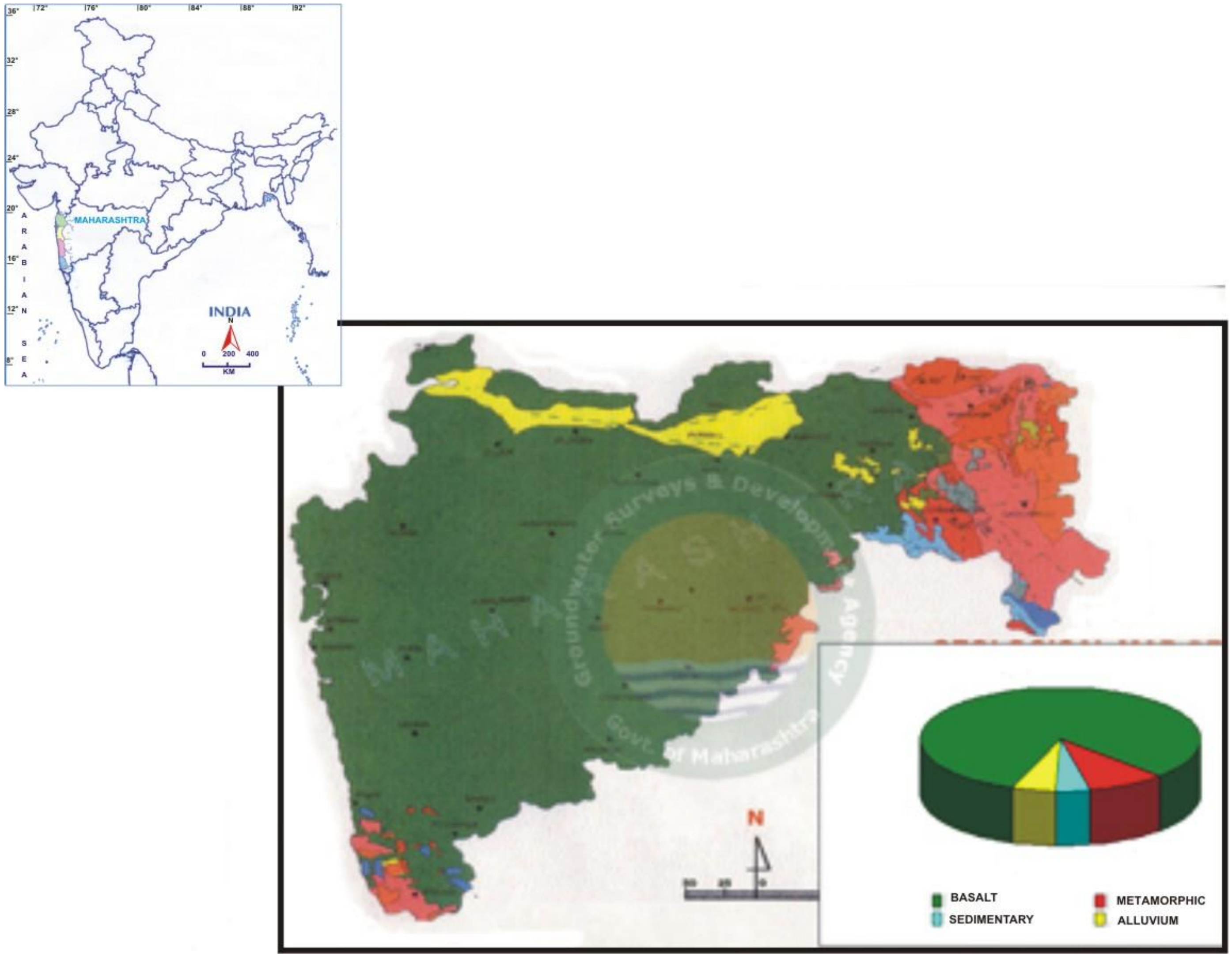


**Figure 1.** Location and geological map of Maharashtra. Source: Geological Survey of India.

the fractured, weathered and vesicular horizons. Hard rock aquifers are by nature limited in their potentials and heterogeneous in occurrence. It is confined mostly to the weathered residuum, fracture and fissure section generally up to the depth of 60 m.

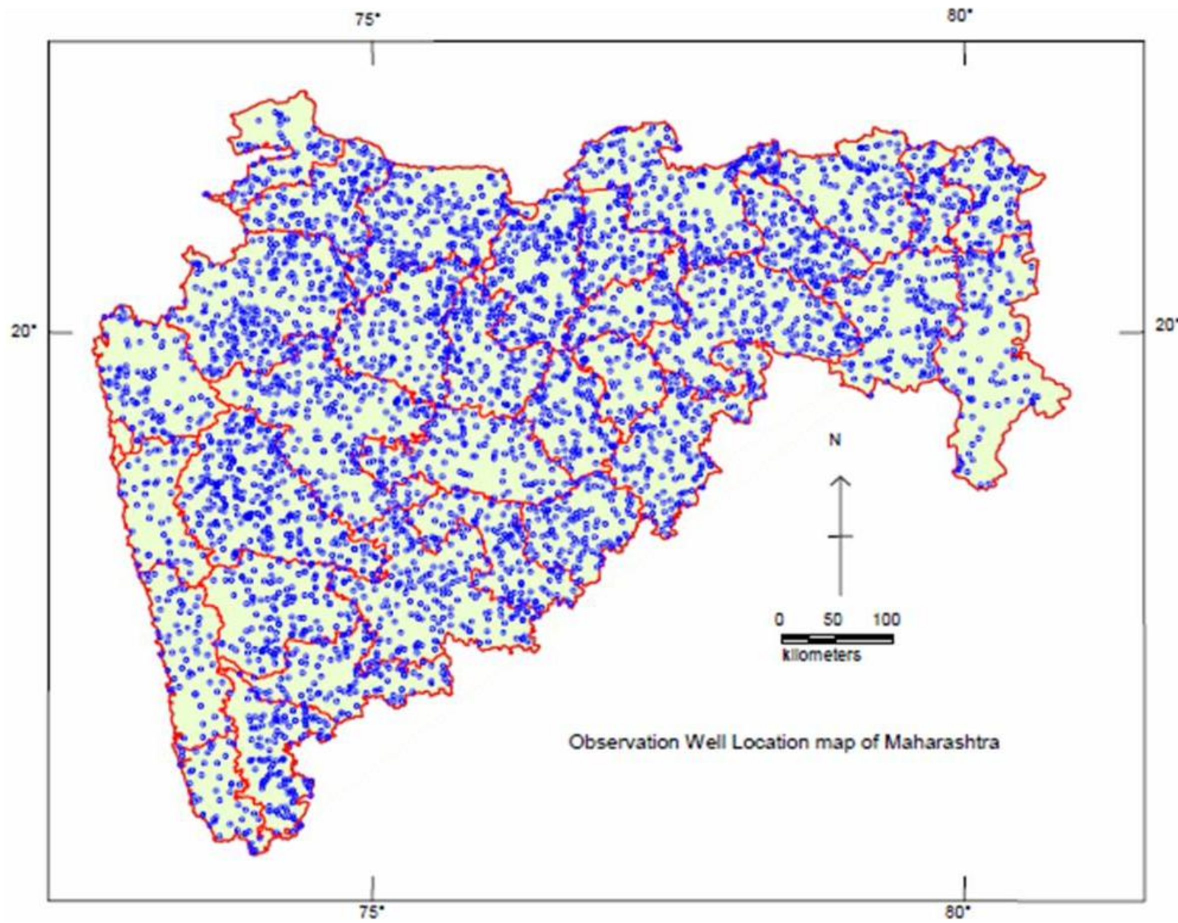


**Figure 2.** Location of hydrograph stations within Maharashtra.

The aquifers in hard- rock are unconfined and their water table generally follows the surface topography. Therefore, there is a good match between the surface drainage (watershed) and groundwater system (aquifer geometry). Thus, it becomes imperative to understand the hard rock physiography, its characteristics vis-à-vis availability of groundwater. The shallow aquifers are phreatic and found to be occurring up to the depth of 10 to 15 m underlain by massive rocks which forms the bottom of phreatic aquifer. The groundwater in shallow aquifers gets replenished annually as the monsoon rainfall occurs only within a four-month period (June to September). This recharge in unconfined shallow aquifer is dynamic and groundwater continues to flow according to the surface gradient towards lower reaches. Eventually, it gets discharged to the streams and rivers as a base flow. This flow movement causes desaturation and water level fluctuation in the aquifers. The pre and post monsoon water levels indicate the degree of saturation in the hard rock aquifers.

A network of 3920 hydrograph stations (observation wells) and 1136 piezometers has been established in Maharashtra and water levels are recorded since last three decades (Figure 2). An analysis of water level data from these hydrograph stations has indicated that declining of water level trends could occur even in the underdeveloped watersheds indicating that there are various factors influencing in declining of water level. The authors have attempted to analyse the various reasons and field evidences to corroborate the various factors which influence the decline in water levels in hard rock aquifers.

## HARD ROCK PHYSIOGRAPHY

Physiographically, the State has been divided into three units:

1) The Sahyadri Range (Western Ghats) extends north to south and form the main drainage division and have elevations ranging between 600 and 1600 m above msl,
2) The Western Coastal Tract (Konkan) runs almost 500 km north to south and the elevation ranging up to 350 m above mean sea level, and;
3) The Eastern Plateau (Deccan Plateau). The plateau typically depicts highly dissected, moderately dissected

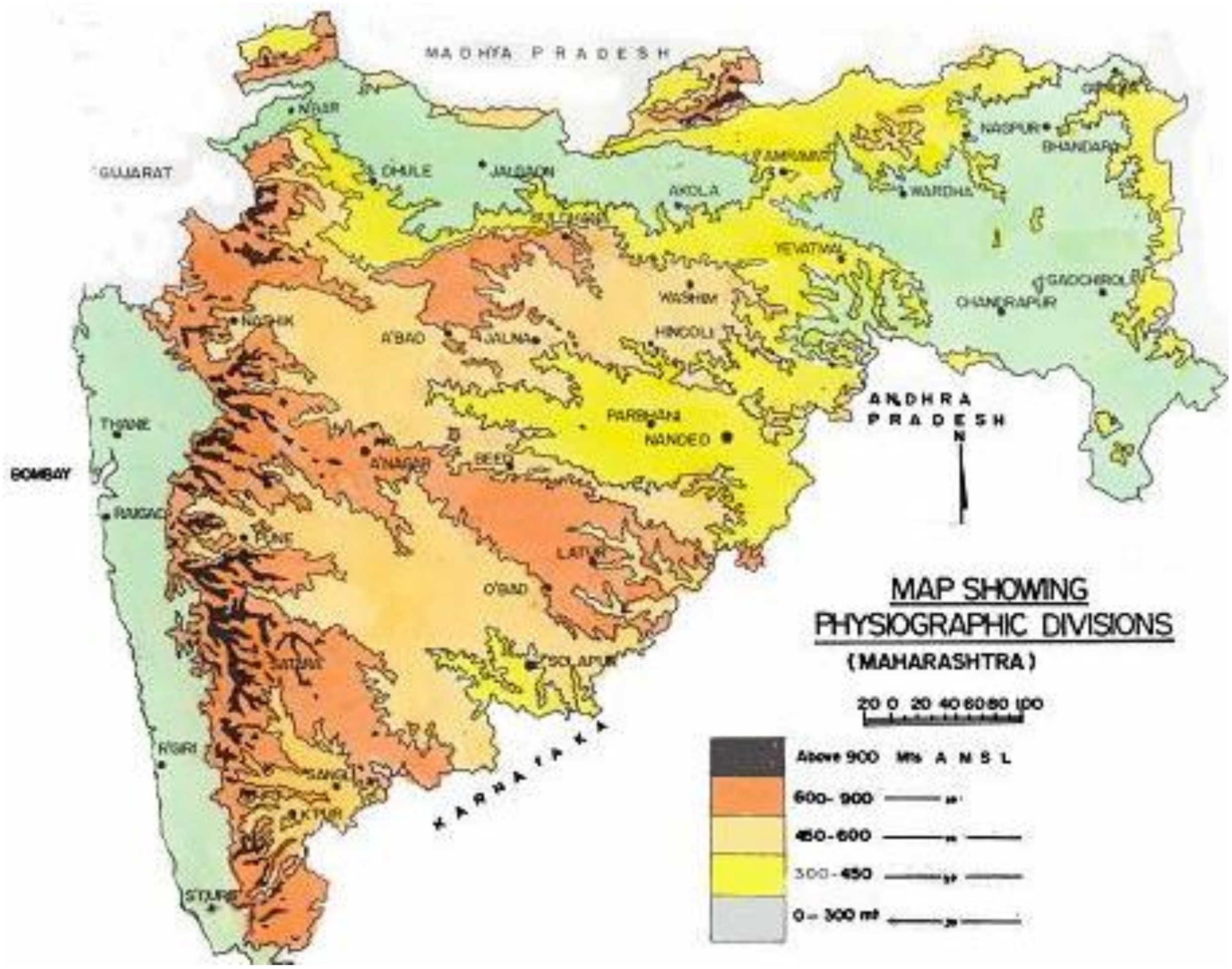


**Figure 3.** Physiographic Map of Maharashtra.

and un-dissected segments (Figure 3). Further these segments are classified on morphological basis in a given watershed namely: runoff-, recharge- and storage zone (Figure 4). This ridge to valley topography brings dynamism to groundwater and makes the system more complex.

This correlation highlights topographic control over the dimensions of an aquifer. The physiography, rainfall pattern, geological details, aquifer details, availability of groundwater and degree of fracturing and jointing are contributing factors in hard rock area to make it a potential aquifer (Maggirwar, 1990; Thigale, 2004). This brings up the prima-facie groundwater scenario of Deccan Trap. This dynamic groundwater system gets annually replenished and thus pre- and post-monsoon water levels assure the availability of groundwater for its usage in domestic-, agriculture- and industrial purpose. It is apparent that under such peculiar set-up, there are multiple factors controlling the water levels in hard rock terrain.

**The nature of occurrence of groundwater, its hydrodynamics and role of water levels in groundwater regime of hard rocks**

The groundwater occurs in the secondary porosity developed by weathering and disintegration of hard rocks. The extent of secondary porosity depends on the degree of weathering, jointing and fracturing due to various natural processes acting on these hard rocks. These conditions are reflected in the built up of topography. The highly dissected plateau (HDP)/mountainous areas have less weathered zone which develops poor secondary porosity in the rock. The similar situation is reflected in the moderately dissected plateau (MDP) areas with moderately weathered mantle. This process is observed to its maximum in the undissected plateau (UDP)/valley terrain or peneplains where the weathered mantle is considerably high. As a result of this varying secondary porosity, the groundwater storage and occurrence also gets limited in these three situations as poor, moderate and good respectively.

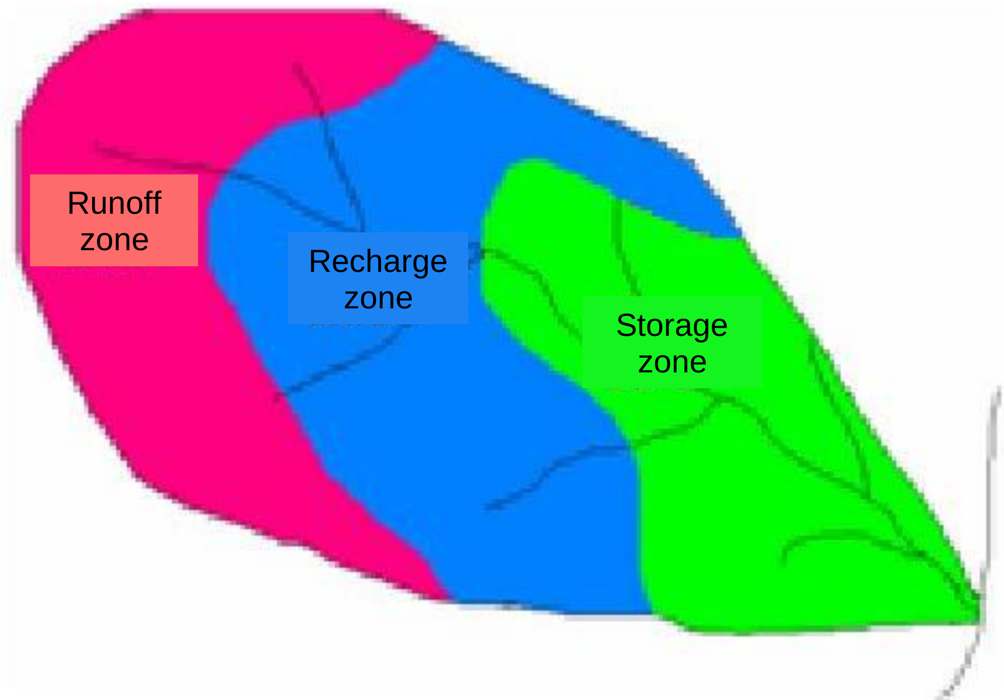


**Figure 4.** A typical morphological classification of watershed.

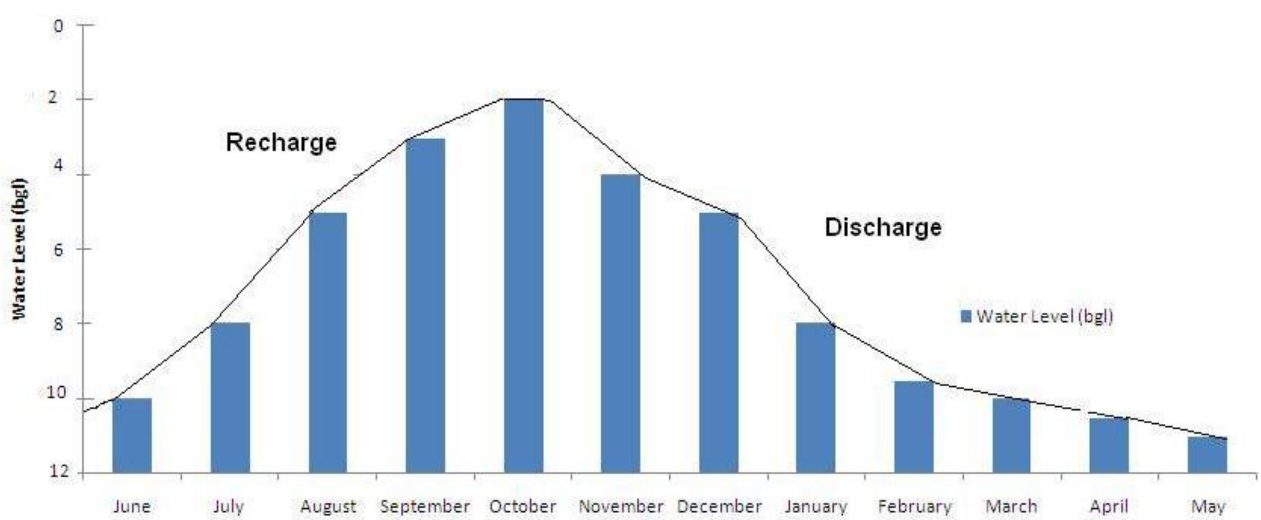


**Figure 5.** A representative hydrograph showing recharge and discharge condition in hard rock.

Rainfall is the main source of recharge and the aquifers get saturated by infiltration process. The recharging conditions also vary according to the topography. The HDP areas are predominantly runoff due to steep gradients, MDP as recharge areas and UDP areas are storage zones. According to the storage conditions, the groundwater recharge also takes place with different time duration. Aquifer gets fully saturated in short duration, by the end of July in HDP as well as high rainfall areas; whereas it takes longer in UDP/valley terrain from June to October. Variation in rainfall is reflecting in the full saturation of the aquifer in high and assured rainfall zone and partial saturation in the low rainfall zone/drought prone area. Figure 5 shows a representative hydrograph depicting recharge and discharge conditions in hard rock aquifer. The extent of saturation in the aquifers is reflected in the status of static water levels. Unlike groundwater in alluvial areas, which is static and remains

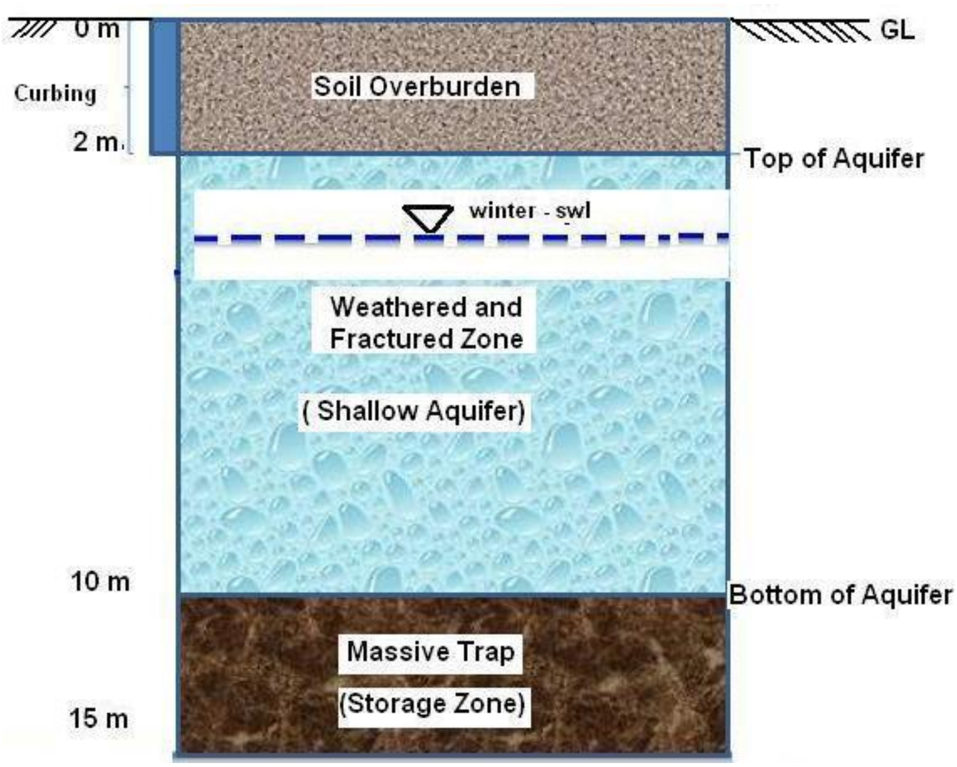


**Figure 6.** A dug well section showing shallow aquifer in hard rock.

confined to porous zone, the groundwater in hard rock is dynamic and gets its movement towards the direction of slope from high hydraulic head to low hydraulic head. This provides a linear movement to groundwater parallel to the surface topography and the water level contours remain parallel to the surface elevation contours. This dynamism of the groundwater in shallow unconfined aquifers provide a continuous decrease in saturation level as its movement towards lower reaches where it gets discharged in streams and rivers in the form of a base flow. This dynamism is very significant in the development and utilization of groundwater in the hard rock.

The saturation of the aquifer starts depleting after monsoon and reaches to its minimum during summer months which could be termed as residual recharge in the aquifer zone. This residual level observed in the summer months is the combine effect of total withdrawal/abstraction and discharge to the streams. Whether it is utilized or not, the groundwater does not remain static and the storage get emptied in the streams/lower reaches due to the movement of groundwater.

## Importance and establishment of observation wells

The proper construction and site selection of the observation wells in various watersheds and accurate recording of static water level is very important. The observation wells in the hard rock terrain in unconfined aquifer need to be more representative of the homogenous regional conditions. The open dug wells are selected which are preferably non-pumping and representative of the regional conditions. A characteristic observation well has 3 distinct zones (Figure 6):

1) Overburden/soil/curbing zones (1 to 2 m).
2) Aquifer zone of weathered mantle/murmic (weathered basalt)/gritty material (2 to 10 m).
3) Storage zone/massive hard rock/bottom (10 to 15 m).

These observation wells are monitored for pre and post monsoon water level to understand the degree of saturation due to rainfall recharge. The measurement of water levels in observation wells therefore plays a vital role in the understanding of groundwater recharge and discharge phenomenon. It may be stated that like the pulse in the human body, the behavior of water levels forms a valuable diagnostic tool in the hands of the Hydrogeologist to understand the health of groundwater both on the regional and micro (watershed) levels. The periodic monitoring of static water level in observation wells provides an important tool for the assessment of groundwater recharge and potential in the hard rock areas. However, this water level could be closely

**Table 1.** Category wise details of 7th groundwater assessment.

| Category | No of WS | Assessment area | Area (%) | Net recharge (Ham) | Draft (Ham) | Average stage of dev. (%) |
|---|---|---|---|---|---|---|
| Safe | 1331 | 21896707 | 85.12 | 2898912.02 | 1203670.02 | 40.78 |
| Semi critical | 127 | 2428414 | 9.44 | 305677.10 | 269406.62 | 86.99 |
| Critical | 3 | 60632 | 0.24 | 9607.49 | 8969.06 | 94.87 |
| Over exploited | 66 | 1268849 | 4.93 | 177069.52 | 217655.27 | 124.27 |

Note: WS- Watershed, Ham- Hectameter

monitored on monthly as well as shorter periods of time to understand the variation in recharge conditions and scope of utilization of groundwater for irrigation and other purposes. Any misreporting of these static water levels can cause erroneous assessment. The water level measurements therefore need to be carefully recorded only within the saturation zone that is the top and bottom of the aquifer. Any extra measurements of the water level, either in storage zone (below the bottom of aquifer) or in capillary fringe zone may lead to miscalculations of the potential as well as projecting the status of groundwater development.

## Phenomenon of safe withdrawal and overexploitation

The situation of extraction of groundwater and the extent of utilization for various purposes could be allowed to the extent of groundwater saturation levels in the aquifer that is annual recharge. This situation is reflected in majority of the dug wells which are fully pierced till the bottom of the aquifer and becomes dry during summer months and there is no residual saturation for pumping or use of water for any other purpose. Whatever recharge is available in basaltic terrain only form the current hydrological cycle and there is no static storage availability for additional extraction. In such environment it needs to have a careful observation and detail ground data collection with physical recording of extraction and recharge before assessing the areas as overexploited. The areas of over extraction in the hard rock have to be fully supported with the field evidences of the observed data and conclusive effects supporting such level of extraction. The Maharashtra, observations in watershed wise assessment recently done by GSDA (2007 to 2008) indicated 85% areas as underdeveloped (safe) where semi critical and critical areas limited to 10% and overexploited area to 5% (Table 1). In the event of such a situation, the condition of depleting water level in underdeveloped watersheds are required to be analyzed very scientifically with proper documentation of data explaining the behavior of such situation. The depletion in water level in the underdeveloped watersheds is a natural phenomenon. The poor extraction of groundwater from the underdeveloped watersheds bring in a limited fluctuation of pre and post monsoon water levels, which is largely created by groundwater movement leaving a significant residual saturation in summer months. With periodic increase in extraction by digging of new wells, the additional extraction causes more desaturation which is reflected in reduction in residual saturation (lowering of pre monsoon level). Similarly, in the drought prone areas, the annual recharge to groundwater is poor resulting in the partial recharge of aquifers. In this environment, the annual increase in extraction will be reflected in the depletion of both pre monsoon and post monsoon levels, keeping the annual fluctuation constant due to annual recharge factor. All these aspects have clearly indicated that as long as the depletion of water levels are within the annual saturation limits of aquifer that is top and bottom of aquifer, the watershed does not get overdeveloped.

In view of this, it could be conclusively expressed that merely depletion of water levels in the hard rock cannot reflect the overexploitation situation. The water level fluctuation therefore has various controlling factors in their behavior and expression as next.

## Multiple reasons for declining groundwater levels

Most of the aquifers get replenished annually and get depleted largely to full saturation thickness before the onset of monsoon leaving no groundwater available for extraction. This phenomenon is more predominantly and effectively observed in ‘basaltic rocks’. Further, aquifer is mostly unconfined and limits to the depth up to 20 m restricted to moderate to high weathered zone. The degree of weathering and topography are the influential factors in governing yield of wells. These are the main natural hydrogeological parameters along with groundwater dynamics for the crisis period in the state. Multiple reasons can be cited for the falling groundwater levels in unconfined aquifers as:

1) Rainfall variation.
2) Groundwater withdrawal during rainy season for irrigating khariff (rain-fed) crops.
3) Increase in the withdrawals due to development.
4) Extraction from the deeper confined aquifers through bore wells.
5) The groundwater in hard rock in shallow aquifers is dynamic and hence joins the surface water as base flow.

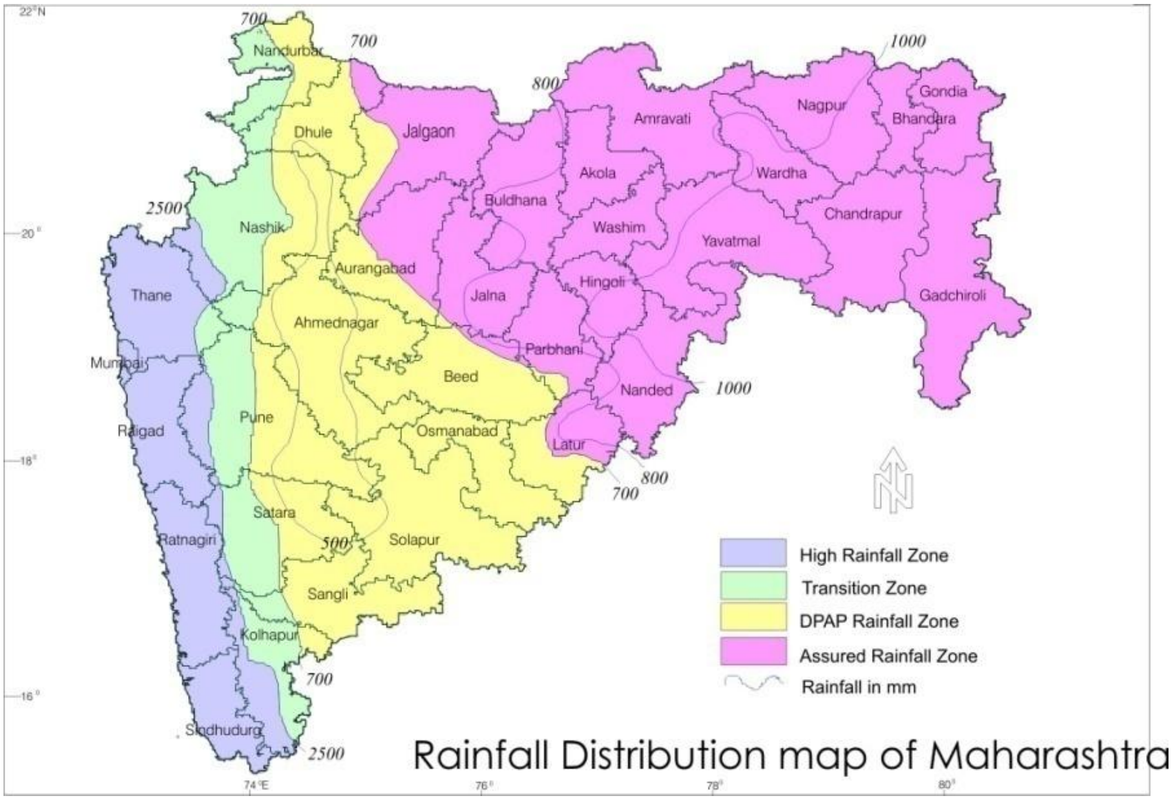


**Figure 7.** Rainfall distribution map of Maharashtra.

***Rainfall variation***

The rainfall is the main recharge of groundwater reservoirs. Any changes in the rainfall quantity and storm pattern can affect the recharge quantity since it has direct impact on the rate of infiltration. In the event of decrease in rainfall, the recharge also reduces which is seen in the depletion of post monsoon levels in the observation wells. In case of normal rainfall or excess rainfall, there can be a situation where post monsoon levels are depleted; this could be attributed to the variation in the rainfall pattern. Heavy intensity rainfall causes more runoff and less infiltration reducing the recharge quantity and depletion in post monsoon levels. This has been observed in various observation well data. This effect of rainfall on water levels needs to be monitored closely by automatic water level recorders established on the observation wells. The state receives rainfall from southwest monsoonal winds in the months of June to September (GSDA, 1990). Due to its peculiar physiography, the state has been divided into four major zones from west to east (Figure 7). The Konkan area receives high rainfall up to 3000 mm. In transition zone, there is an increase in rainfall from the coast up to the crest line from 2000 to over 5000 mm, the drought prone area receives less than 500 mm and assured rainfall zone up to 1200 mm (IMD, 1972). This huge variation in rainfall in the entire state is a leading factor in controlling the water levels in annually replenishing groundwater system. Deficit rainfall and inadequate recharge from time to time causes drying up of existing sources. As aquifers are not getting recharged to its full capacity, the post monsoon water levels are recorded initially at lowered depths. Moreover, if recurring situation stands true for few consecutive years, a declining trend is noticed in the analysis of hydrographs (Figure 8). Patterns of rise and fall of water levels is directly related to the intensity, amount and duration of rainfall, seasonal fluctuation and water abstraction for different causes as there exists a variable time lag between two rainfall sessions or due to vagaries of monsoon.

In contrast, though the western coastal districts have assured rains, due to steep gradient and hard rock formation, the groundwater recharge in the area is meager. Obviously, the fluctuation of water is higher and water levels are recorded at lower depths causing drought since early summer months. Secondary porosity is very poor in hilly terrain that leads to meager availability of groundwater even for drinking water purposes and become severe in the summer months.

***Groundwater withdrawal during Rainy season for irrigating khariff (rain-fed) crops***

Conditions of uncertain rainfall and land gradient creates

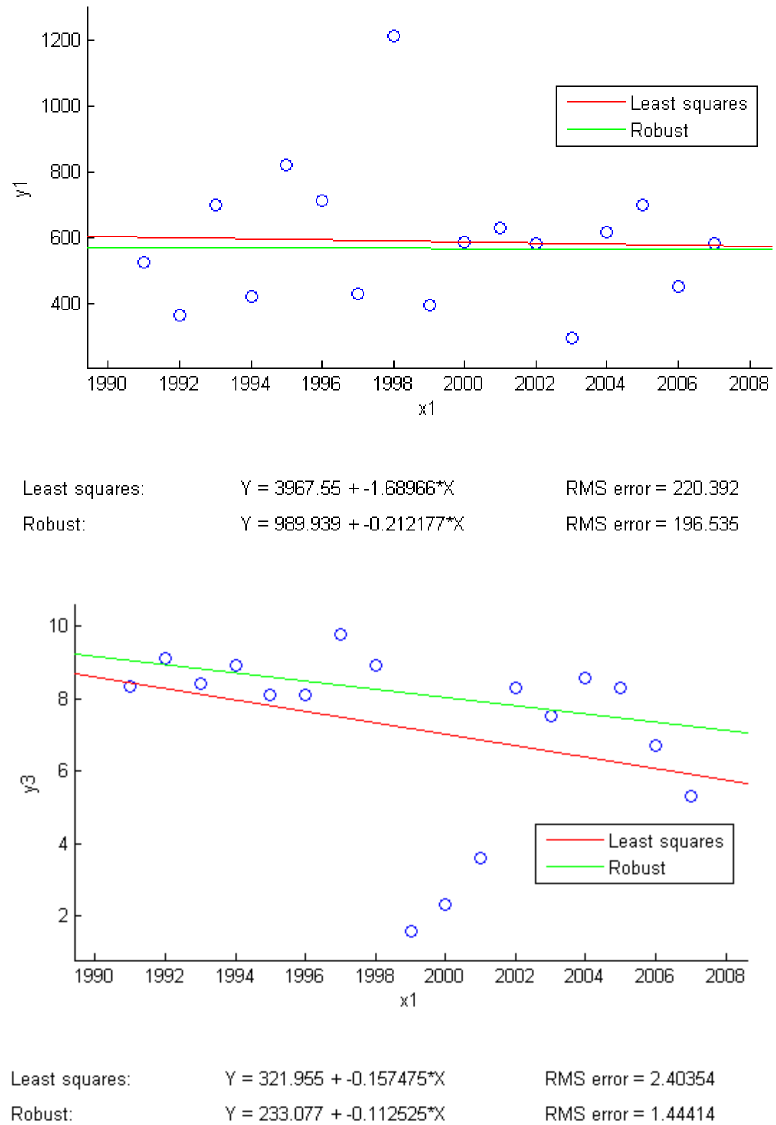


**Figure 8.** Declining trend observed in rainfall and groundwater levels.

problem of water availability both for irrigation and drinking purpose. Therefore, groundwater assumes a great importance in meeting the irrigation and drinking water demands of the rural population and especially during the long dry spell condition. If the two consecutive rainfall episodes have longer dry spell period, then immediate requirement for irrigating the 'khariff' crops is met by withdrawing groundwater. This deficit in the saturation reflects on declined post monsoon water levels. It is particularly observed in the drought prone area of the state where the area constantly faces drought due to deficit rainfall. The cropping in this area is predominantly irrigated from groundwater. Therefore, the hydrographs of this area shows subsequent decline in the water levels during two rainfall episodes. This phenomenon of lowering of water level due to extraction for protective irrigation cannot be categorized as overexploitation as fluctuation is within the limit of annual recharge saturation and stage of development is underdeveloped and holds enough recharge for future development.

### *Increase in the withdrawals due to development causing increase in extraction*

Overexploitation occurs when groundwater draft exceeds its annual recharge and dents into the static reserve occurring below the zone of dynamic fluctuation. Various workers have defined overexploitation by referring to

**Table 2.** The number of bore wells in watershed and trend of groundwater level.

| River basin | WS | Pre - monsoon WL trend | Post - monsoon WL trend | No. of bore wells |
|---|---|---|---|---|
| Manjra | 19 | Falling | Rising | 1480 |
| Godavari | 20 | Falling | Rising | 2500 |
| Godavari | 21 | Falling | Rising | 5456 |
| Manjra | 16B | Falling | Rising | 1420 |

various physical manifestation of prolonged unbalanced groundwater regime: continuous fall in water level, and possible effects on stream flows and quality of water. In view of the growing demand for domestic, irrigation and industrial purpose, the groundwater abstraction structures are found to be increasing every year. The number of dug wells has been increased from 7 to 15.6 lakhs and the draft from 11 to 15 lakh Ham from 1974 to 2004 (GWA, 2004). The increasing number of dug wells causes lowering of water level at faster rate. The dynamic assessment of groundwater resources of state revealed that there is an increase in the density of wells in a given watershed. The extraction of groundwater for various purposes from these abstraction structures contributes to lowering of water level. Groundwater resources estimation committee (1997) has prescribed areas as critical, if the stage of groundwater development is 90 to 100% with significant long term decline of pre- or post–monsoon groundwater level or both, whereas, areas are categorized as overexploited if the stage of groundwater development is more than 100% with significant long term decline in post – or pre – monsoon water level. In short it is the long term declining trend indicative of unbalanced groundwater regime which defines overexploitation. Therefore, the decline in water levels is attributed to increase in the withdrawals due to development causing increase in extraction. Further, it may be emphasized that the hard rock in Maharashtra does not hold recharge storativity which could be overexploited.

Most of the aquifer reaches to its minimum saturation level during summer months and wells become non-pumping and no irrigation takes place for summer crops. In such event, there is no availability of recharge excess than annual recharge.

### *Extraction from the deeper confined aquifers through bore wells*

The extraction from the deeper confined aquifers leads to assess the cause for fluctuation in shallow aquifers. Once groundwater has been extracted from a deeper aquifer, its replenishment depends upon the inflow from the shallow system. Moreover, the rate and depth of extraction from these deeper aquifers renders the fluctuation intensity in the shallow aquifers. The deeper aquifer in hard rock below weathered mantle are infested with joints and fractures and receive recharge from shallow aquifer by vertical infiltration due to hydraulic connectivity between them. Table 2 includes the total number of bore wells present in particular watershed falling in respective basin. Because of the high density of bore wells the pre-monsoon groundwater levels in dug wells shows falling trend compared with post-monsoon rising level. The rising post-monsoon water levels depict the recharge from rainfall during monsoon.

### *The base flow in hard rock*

The outflow of groundwater affects the water levels. Periodically monitoring of observation wells reveals that a large no. of dug wells gets completely dried during summer months. As such, the shallow aquifer does not hold any saturation worth exploitable or minable storages. The water level studies and its analysis have indicated that the storativity of groundwater is largely confined to weathered mantle. The extraction is only limited and controlled for seasonal irrigation for 'khariff' (rain fed crops) and 'rabbi' (winter) crops and the saturation gets depleted and the residual saturation during summer months is minimum rendering the wells not exploitable. The groundwater in hard rock from shallow aquifers is dynamic and hence joins surface as base flow rendering the aquifers to its minimum saturation levels particularly in the pre-monsoon months (Figure 9).

### Analysis of multiple factors controlling groundwater levels

The occurrence of groundwater in hard rock is confined to the shallow weathered zone (Karanth, 1987). The saturation in the zone gets depleted due to extraction and also due to outflow of groundwater which ultimately leaks out with the streams and drainages as a base flow. The system is dynamic and has hydraulic gradient parallel to surface contours. This indicates that the groundwater, whether extracted or not, it does not remain static and gets depleted and de-saturated and reaches its minimum saturation during summer months. This situation compels the optimum utilization of groundwater in hard rock by its

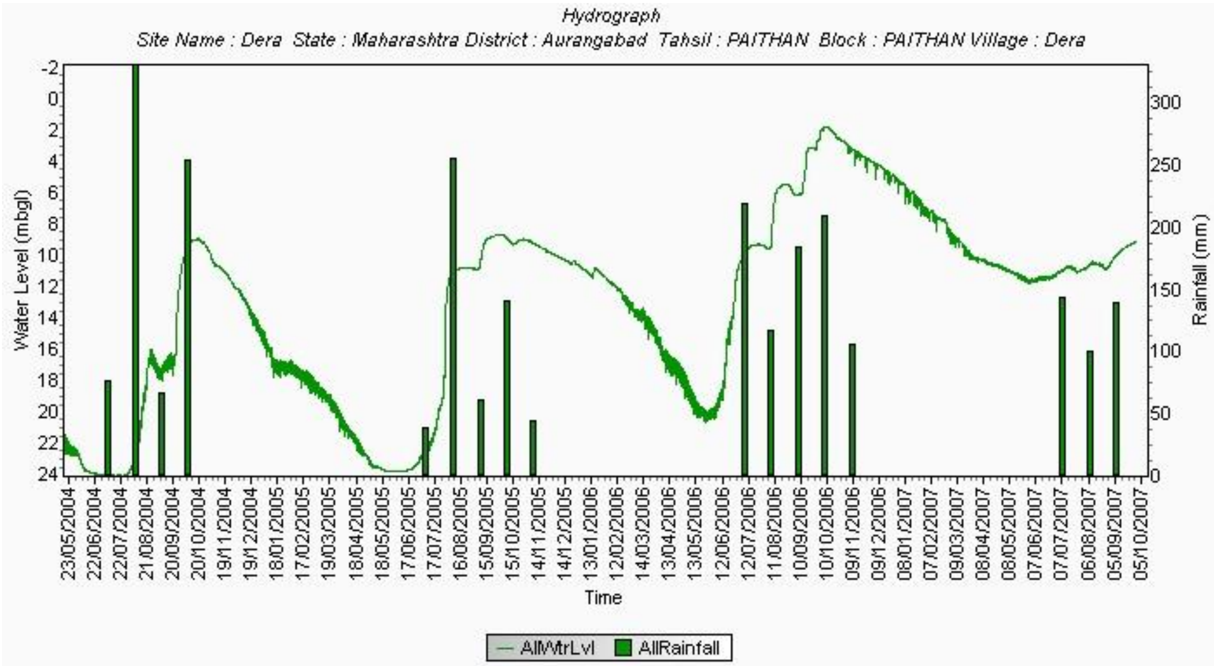


**Figure 9.** Hydrograph showing minimum saturation level in pre-monsoon period.

extraction during khariff and rabbi cropping seasons. If not extracted and utilized, if flows out to the river and streams. In this peculiar situation, the basic strategy for groundwater extraction is to utilize the groundwater to its storage and make the aquifer fully emptied so as to get ready for replenishment during monsoon season. The exploitation of deeper aquifer from bore wells provides additional well capacity for obtaining more recharge during monsoon season. In fact, this helps in optimizing the groundwater storage. It has been observed in many of the cases that with poor utilization, the aquifers in hard rock get fully saturated during 1st two months of monsoon (July to August) and there is no scope for further infiltration or recharge and the rejected recharge results in increase in run-off. The nature has already controlled the extraction in hard rock as the pumping of water is limited to overnight recuperation and no well owner can extract than the capacity of well. The decrease in saturation over the period of time reduces the overnight recuperation capacity of the dug well and renders the well non utilizable for pumping during the summer months where the residual saturation is to its minimum and no one can extract water for summer crops. This limitation has reduced the groundwater utility as a source of protective irrigation during the water stress period of ‘khariff’ season and ‘rabbi’ crops.

Most of the wells in Maharashtra have the capacity of irrigating 1 to 2 ha of cropped areas in basaltic terrain. Only a few pockets of UDP areas in canal command areas, the aquifers are better yielding and possess a good saturation in summer months to provide support to perennial crops. In view of the limitations of dynamics of unconfined aquifer, existence of secondary porosity up to shallow depth and non – feasibility of techno economic factors of deepening the dug wells in the fracture porosity, there is no level of overexploitation or mining of groundwater in basaltic rock terrain of Maharashtra which is reflected in the assessment studies wherein only 2 to 5% area has shown withdrawal more than recharge (Figure 10). However, it may be mentioned here that micro level studies of groundwater assessment needs to be obtained in support of declining of groundwater in hard rocks to go through the reality of their being overexploited.

## CONCLUSION

The analytical studies of water level fluctuation in the hard rock particularly basaltic terrain of Maharashtra has brought out a conclusive evidence that the water level in the shallow aquifers have effects of various influencing factors. The depletion of water levels within the saturated horizon of the aquifer recharge is not an indication of overexploitation. The depletion of water levels in the underdeveloped watersheds shows the ground truth and evidence that these falling water levels are not due to overextraction but they are the effect of increase in development and the quantity of abstraction. Any situation of overextraction in the hard rock areas in the shallow unconfined aquifer therefore need to be carefully assessed and supported by micro level field data.

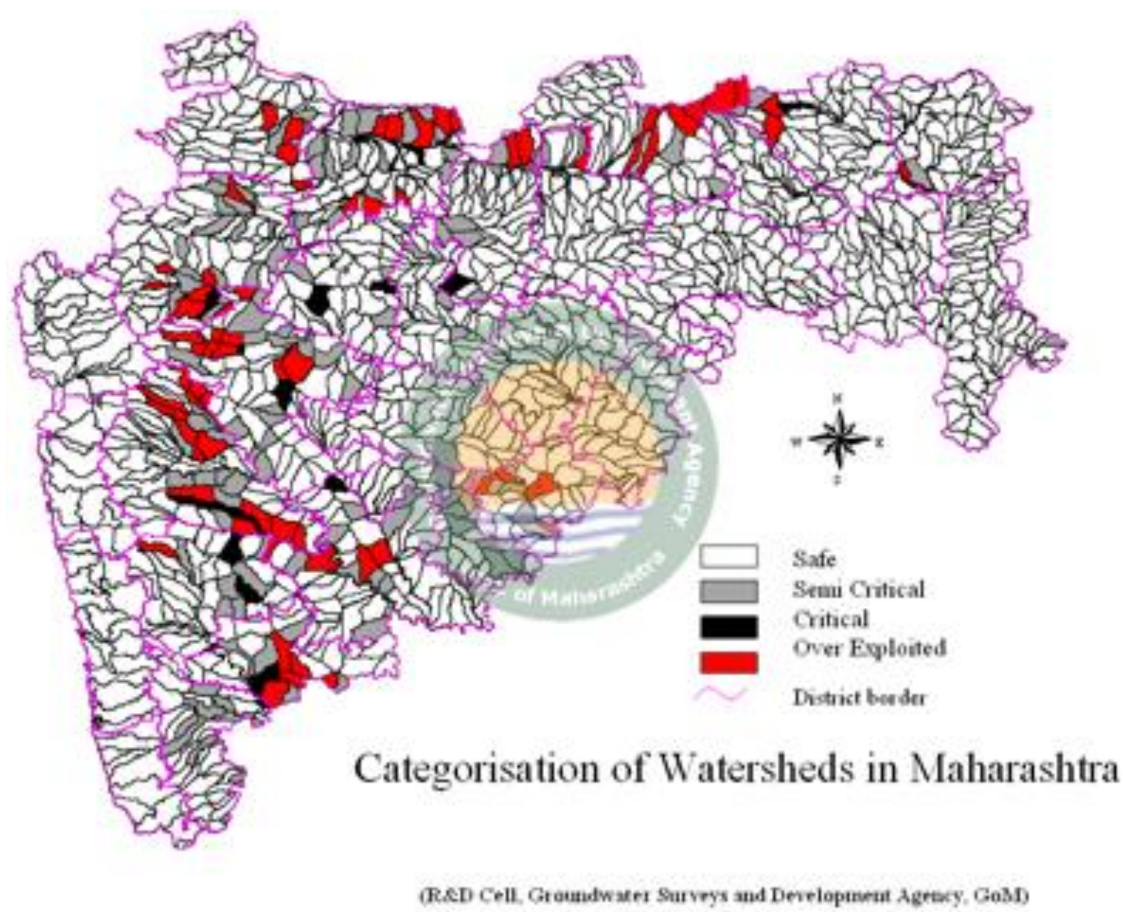


**Figure 10.** Categorization of watersheds in Maharashtra.

## SCOPE FOR FURTHER STUDIES

The groundwater potential in the hard rock in the shallow unconfined aquifer is a heterogeneous and complex phenomenon. The utilization of these resources is confined to seasonal abstraction for 'khariff' and 'rabbi' crops. The aquifers in these rocks have a very limited transmissivity and storativity providing a natural control over the extraction of groundwater. The extraction is mostly from the large diameter open dug wells which provide storage from overnight recuperation for pumping in the day hours. A large scope exists for demarcating the micro level areas which provide an extra recharge from the zone below annual recharge from the static storages. Any situation of overextraction in the canal command areas also need a careful examination by monitoring the annual extraction from irrigation wells. High well density areas (> 10 wells per sq.km) also need a detailed micro level data of recharge and withdrawal for water level situations. These studies reflect the water level situations and the assessment of groundwater availability. Further, due to the ever increasing number of dug wells and deep bore wells, the emphasis has shifted from development to sustainable management. While managing the groundwater resources, the further scope of this study is in identification of deficient recharge areas immediately after monsoon. These maps superimposed with deficit rainfall areas provides to plan out the tackling of situation of groundwater levels and undertake recharging measures to safeguard the drinking water sources.

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