CHAPTER V

Groundwater

Introduction

Groundwater may be defined as the subsurface water in soils and rocks that fully saturated. It is one of the most widely distributed and important natural resources of the earth. Excluding ice sheets and glaciers it has been estimated to account for 94% of all fresh water, half of which is held within 800m of the ground surface (Wikipedia).

The saturated permeable geologic formations that can transmit significant quantities of water under ordinary hydraulic gradient are known as aquifers. However, in the hard rock areas like peninsular India, groundwater is mostly confined to fractured zones as well as master joint systems. The occurrence of groundwater in semi-arid areas is governed by climate, geology, structure and geomorphology.

In the study area (Mulehole, Maddur and Terakanambi), aquifers are distributed in weathered and fractured metamorphic rocks. These crystalline rocks are devoid of initial or primary inter-granular porosity (Todd, 1980) and permeability. However, they have rendered secondary porosity and permeability due to the weathering, disintegration, and also be development of joints, fractures and fissures caused by polyphase structural disturbances. In crystalline rocks the degree of weathering depends on structural, topographical and climatic conditions and may extended up to a depth of 30m with an average of 5 to 15m, from the surface as observed in road cuttings, nallas and also in well sections which are not lined. Weathering is concentrated along joints and fractures at depths and becomes less effective with increasing depth. The weathered zone is under laid by comparatively unaltered rocks which are traversed by numerous cracks and joints extending to considerable depth of 140 to 190m. The joints are comparatively open near the surface and get closer within the zone extending up to 45to75m. Drilling wells beyond that depth is therefore generally not warranted (Radhakrishna, 1974).

Development programmes concerning optimum utilization of natural resources are now increasingly oriented with watershed as an integral unit. A watershed is a natural entity conforming to the increasing homogeneity of geomorphic sculpturing process. Watershed implies rational utilization of land and water resources for optimal and
sustained production with the minimum hazard to natural resources and environment. It requires collection and analysis of great deal of information on physical relationship of hydrogeology, meteorology, vegetation-soil-water to land management to ensure economic and social progress of a watershed or a river basin. Therefore, accurate and reliable data base generation and management are extremely important for devising ways for optimal planning and management of watershed.

5.1. General concepts of drainage basin

Drainage basin can be treated as an open system within which hydrological processes can be studied; an open system is a set of interrelated elements and processes that exchanges energy with its surroundings, and the materials flow. The drainage characteristics can be measured and analysed quantitatively, a process is called as drainage basin morphometry (Kumar, 2012). The basin represents the basic unit used in hydrology. Basins are major features of the landscape and over most of the world’s continents and landscape-forming processes are dominated by fluvial erosion, transport, and deposition. For these reasons, the basin also constitutes the fundamental unit of physical geography. Basins exist over a vast range of scales, from the ocean basins that define the largest drainage units on Earth to field-sized areas feeding small streams. Many basins are formed by geological processes involving deformation of the Earth’s crust through extension, down warping, faulting, folding, or volcanic activity. Others are the result of erosion of the land surface by wind, water or ice. The structure of the underlying rocks influences the distribution of erosion with low and high areas developing on erodible and erosion-resistant rocks respectively. Because rocks stretched upwards in an anticline are weaker than those compressed downwards in a syncline, erosion often leads to inverted relief with high areas becoming basins and formerly low areas forming watershed. Where the rocks underlying a basin are permeable it is possible for water moving through the ground or groundwater to “leak / migrate” from one basin to another. Hence, the boundaries of a groundwater basin do not always coincide with the watersheds of the drainage basin.
5.1.2 Basin hydrology

Water in the basin arrives in the form of precipitation as part of the water cycle (hydrological cycle). Some precipitation returns to the atmosphere, having been intercepted by vegetation and evaporated from the surfaces of leaves and branches. More is lost to evaporation from the ground surface and transpiration by plants. In arid and semi-arid climates all of the precipitation may be consumed in this way for most of the time; basin run-off occurs only occasionally, following intense storms. Where precipitation exceeds losses to evapo-transpiration, the excess water makes its way through the drainage system. Its rate of progress is not uniform; however, water may be stored in lakes, soils, and as groundwater for considerable periods before it eventually arrives at the outlet or basin channel, as basin run-off. Water which infiltrates to the permanently saturated groundwater or phreatic zone below the water table moves as base flow; in the partially saturated aerated or vadose, zone above, it moves as interflow and through flow. Water that is unable to infiltrate the soil becomes overland flow. The proportion of run-off following the different pathways depends on a variety of factors, some of which are fixed properties of the basin (geology, structure and relief). Other factors can vary with time and in response to human activities (climate, soils and vegetation), and some depend on the recent weather experienced by the basin (antecedent conditions). Subsurface drainage by interflow and groundwater seepage occurs much more slowly than surface drainage by overland flow, a characteristic that is important in maintaining base flow in the river system between precipitation inputs.

5.1.3 Water-Table Fluctuations

Groundwater levels rise and fall in response to many different phenomena. Fluctuations are not always indicative of groundwater recharge or discharge. Changes in water levels occur over different time scales. Long-term fluctuations over periods of decades, can be attributed to naturally occurring changes in climate and to anthropogenic activities (e.g., changes in land usage, pumping, irrigation and induced infiltration). Seasonal fluctuations in groundwater levels are common in many areas due to the seasonality of evapotranspiration, precipitation and irrigation. Short-term water-table fluctuations occur in response to rainfall, pumping, barometric-pressure fluctuations or other phenomena.
5.1.4 Quantification of ground water recharge by Water-Table Fluctuations method

Groundwater recharge is quantified by employing surface water, unsaturated, and saturated zone techniques. Identification of an appropriate technique in a given location partly depends on the recharge rate (Scanlon et al. 2002). However, limitations and uncertainties associated with each of these methods sometimes warrants application of multiple methods to authenticate the estimation. Regional recharge estimation for water resources evaluation has relied mostly on groundwater based approaches, which integrate over large spatial scales and generally cannot be used to estimate local variability in the recharge.

To quantify the Recharge water budget approach is developed here to jointly estimate specific yield and natural recharge in this saprolite - fractured rock formations existing in unconfined conditions with significant seasonal water table fluctuations. Water budget approach provides a potential recharge without considering hydrogeological conditions. Separation of the hydrologic year into two extended seasons of recharge and no recharge (dry season) and second, to estimate recharge from the water table rise during the wet season, after considering all other water budget components explicitly (Marechal et al. 2008) are the main aims of this conjunctive approach.

Water table fluctuations are due to distinct seasonality in the groundwater recharge. Water table fluctuations method (WTF) is based on the principle that increases in groundwater levels is due to recharge water arriving at the water table. This method is most applicable over short time periods in regions having shallow water tables that display sharp raises and declines following rainfall events (Coes et al. 2007). Analysis of water level fluctuations can, however, also be useful for determining the magnitude of long term changes in recharge caused by climate or land use changes. The advantage of the method is that specific yield and recharge, both are estimated at the scale of interest to basin hydrologic studies and that the method requires no extensive in situ instrumentation network (Marechal et al. 2008).

Difficulties in applying the method are related to determining a representative value for specific yield and ensuring that fluctuations in water levels are due to recharge and are not the results of changes in atmospheric pressure, the presence of entrapped air, or due to pumping. WTF method generally estimates higher recharge rates, representing
the total recharge over a local to regional area on an annual basis. High fluctuations in deep wells and in pumping areas yield high recharge rates especially in semi-arid and arid regions. Further, uncertainty in specific yield estimates causes an over-estimate/ under-estimate of the recharge. In addition, this method requires a large number of water level measurements throughout the unconfined aquifer before and after the monsoon. Hence, a methodology of using WTF approach in conjunction with groundwater basin water budget method is employed here to estimate both specific yield and recharge rates (Laurent, 2009).

5.2. PRINCIPLE

A water budget approach is developed to jointly estimate specific yield and natural recharge in an unconfined aquifer with significant seasonal water table fluctuation. This method is first used to estimate specific yield from the water table drop during the dry season (no recharge) and then, to estimate recharge from the water table rise during the wet season, after considering all other water budget components explicitly. Total Recharge (TR) to the groundwater system can be written as a function of groundwater inflow – outflow, evaporation from groundwater, pumping and the changes in groundwater storage (Scanlon et al. 2002; Marechal et al. 2008; Sharada et al. 2006) as:

\[
TR_{WTF} + Q_{in} = E + Q_{out} + Q_{bf} + Q_{pumping} + \Delta S \quad (5.1)
\]

where \(TR_{WTF}\) is the total groundwater recharge estimated using WTF method (mm), \(P\) is precipitation (mm), \(E\) is the evaporation from groundwater since transpiration from groundwater is negligible, \(Q_{in}\) and \(Q_{out}\) are groundwater flows into and off the basin (mm), \(Q_{bf}\) is the baseflow (groundwater discharges to streams) (mm), \(Q_{pumping}\) is the abstraction of groundwater by pumping (mm) and \(\Delta S\) is the change in groundwater storage.

Unknown term, the groundwater storage (\(\Delta S\)) is obtained by incorporating WTF method to this groundwater budget model which links the change in groundwater storage (\(\Delta S\)) with water table fluctuations (\(\Delta h\)) (Marechal et al. 2008):

\[
\Delta S = S_y \times \Delta h = TR_{WTF} \pm Q_{net} - E - Q_{bf} - Q_{pumping} \quad (5.2)
\]

where \(Q_{net}\) is the net flow into/from the watershed computed from \(Q_{in} - Q_{out}\) (sign of the value indicates the net inflow/outflow into/from the watershed), \(S_y\) is the specific yield (storage) and \(\Delta h\) is water table fluctuation. This fluctuation is given as \(\Delta h = GW_t - GW_{t-1}\), where GW denotes the depth to groundwater and is estimated during the time period at which other components of Eq. (5.1) are measured.
It was necessitated to account for the sudden change in water table due to instantaneous recharge. At any given location, storativity ($S_v$) of the formation remains essentially constant with time, but the volume of water in storage and all the aquifer parameters vary with the changes in saturated thickness. The negative water table change is attributed to the feeder zones from the previous recharge instances.

### 5.2.1 Hydrological Monitoring and Assessment Mulchole, Maddur and Terakanambi watersheds

**Mulchole watershed:**

In Mulchole watershed thirteen monitoring wells, were installed (Fig. 5.1) in the watershed for sample and monitor the water level namely P1 to P13 (20 to 60 m deep). A few of them have been monitored continuously (Fig. 5.3) (Thalimedes (OTT), Orphemedes (OTT), DL/N 70(STS), Diver (Schlumberger)). P4 were abandoned after the initial drilling and P11 collapsed after more than two years of monitoring. In this National Park hosting protected wildlife, authorization was sanctioned only for drilling along the existing tracks. Hence a representative distribution of wells was not possible. Three wells (P3, P5 and P6) have been drilled at the boundaries of the watershed, along the ridge in order to obtain the background characteristics of the aquifer far away from the main stream network. The last ten wells (including abandoned well P4) have been drilled along a straight line crossing the stream axis in order to monitor the effects of water seepage from the stream. Samples from monitoring wells and storm collected through the automatic sampler at the stream gauging station have been analyzed in the laboratory.

At the experimental site crossing the stream axis, water table fluctuates according to the monsoon regime. The water levels are located at an average depth of 8 m below the stream bed during the dry season. During the monsoon, the water levels rise close to the stream (at monitoring wells P1 and P7) up to a level of about 1 m below the stream bed.

The water table fluctuations (Dh) between pre- and post-monsoon seasons are highly variable in space. The influence of the distance to the stream network on the water table level is analyzed in Fig- 5.2 where three groups of wells can be identified.
Group 1 (wells P3, P5 and P6) is characterized by small water table fluctuations ($Dh < 2.5\ m$) observed at wells far away (>200 m) from the nearest stream. Wells of group 2 (P8, P9, P10, P12 and P13), located in the vicinity of the watershed flowing streams (distance comprised between 40 and 200 m), show medium water level fluctuations ($3 < Dh < 5\ m$). Group 3 (P1, P7, P11) is constituted by wells located in the close vicinity of surface stream (<40 m) and characterized by high ($Dh > 7\ m$) water level fluctuations.

This relationship between water level fluctuations and distance to the surface stream confirms the existence of heterogeneity in the recharge process mainly caused by the losing stream.

The analysis of water level fluctuations in wells from group 3 provides information on the dynamics of indirect recharge from the stream. For instance, the response of this group (wells P1 and P7) to the first rain events of April–June 2005 is very sharp (Fig. 5.4). During the first event identified (57 mm rainfall on 10th April), the water levels rose by 3.7 m in 46 h at P1 and by 2.2 m in 56 h at P7. At the same time, the water level rose gently by 0.61 m in 17 days at P13 (group 2). Wells P3 (group 1) and P10 (group 2) do not show any response to these events. During the second event (17 mm rainfall on 27th April), the water levels rose by 3.37 m in 63 h at P1 and by 2.9 m in 68 h at P7 while the rise is only 0.56 m in 11 days at P13. After, despite several rainy events (i.e., 38 mm on 25th May and 29 mm on 20th June) the water levels in all the wells decrease in the absence of any runoff in the stream.

Both large water level fluctuations are correlated with runoff occurrence in the stream. During the whole observation period, the water levels are higher below the stream axis than elsewhere which results in a groundwater mound. The resulting hydraulic gradient potentially induces groundwater flows from the stream axis towards North and South. The water table fluctuations in wells P1 and P7 close to the stream are linked to direct recharge from rainfall and indirect recharge from the stream. The relationships between rainfall and stream head as input function and water levels below the stream as output have been evaluated using a cross-correlation analysis in order to estimate the relative importance of both processes. Despite it is low in both cases; the correlation co-efficient is clearly higher for the stream/aquifer relationship than for rainfall/aquifer relationship (Fig. 5.5). The influence of the seepage from the stream is
preponderant for the water level signal at wells P1 and P7 from group 3. In other words, the water table fluctuations at wells P1 and P7 are more dependent on the stream head than on rainfall.

The low average correlation co-efficient is induced by the difference in the duration of input and output events: short rainfall and storm events are not well correlated to long duration water table fluctuations.

Long term monitoring of the piezo’s indicated increased water table in all the wells in forested non anthropogenic environment due to that (i) deciduous trees can uptake a significant amount of water from the deep regolith, (ii) this uptake, combined with the spatial variability of regolith depth, can account for the variable lag time between drainage events and groundwater rise observed for the different piezometers and (iii) water table response to recharge is buffered due to the long vertical travel time through the deep vodose zone, which constitutes a major water reservoir (Laurent et. al. 2010).

Fig. 5.1 Location of the Piezometers in Mulehole

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Fig. 5.2 The influence of the distance to the stream network on the water table level of Mulehole

Fig. 5.3 Hydrograph of Mulehole watershed
Fig. 5.4. Hourly water levels in the stream and observation wells; April–June.

Fig. 5.5 Cross-correlation of rainfall data and water levels in the stream with water levels in monitoring wells P1 and P7 (group3), monitored at hourly time set. (Marechal. et al. 2008)
Maddur watershed

Groundwater levels

Groundwater levels are monitored monthly in more than 50 points of the Maddur watershed and samples are collected to understand the ground water chemistry from all available sources which are (is shown in fig. 5.6), 16 hand-pumps, 9 open wells, 6 dugwells, 40 borewells, 5 water tanks, 4 ponds among them four piezometers are monitored continuously.

Maddur watershed is located in a gneissic rock formation which has been weathered and an important fractures network put in place, in these conditions, water can circulate and be stored. More in surface, the chemical alteration of the bedrock formed more or less deep layer of saprolite (Fig. 5.7).

To follow the evolution of the Maddur aquifer, dispose of 4 data-logger coupling with manual measurements in piezometers, dugwells and tanks in order to know the influence of the different environmental factors on the aquifer recharge.

The data-logger (STS, Diver or Thalimédies) enables us to observe precisely the evolution of the aquifer levels. Four points are continuously monitored in Maddur watershed since 2007 which are Vellapaly farm, Maddur Hotel, CMpura 1 and CMpura 2. A pumping well (PW) is located between CMpura 1 and CMpura 2.

Groundwater fluctuation at Channamallipuram (CMpura 1 – CMpura 2):

CMpura 1 and CMpura 2 have the specificity to be located at a very low distance from a pumping two different signals in the piezometers CMpura 1 and CMpura 2 (Fig. 5.8 and 5.9.), the first in low-frequency and the second in high-frequency. Pumping causes the last one. The low-frequency signal is a consequence of the evolution of the climatic conditions; find again the quick aquifer recharge caused by the monsoon.

The amplitudes of these two piezometers are more important than the amplitudes of the others. In 2007 water level as bigger amplitude with a difference of levels reaching 25 meters. In 2008 the amplitudes for CMpura 1 and CMpura 2 are of 10 meters.

In fact, the evolution of the water depth observed at a short time scale is typical of a pumped aquifer (Fig. 5.10). It can be used to estimate the evolution of the
physical parameters of the aquifer at different depths (pumping test at different depths). Most of the pumping lasts 4 hours (from 8am to 12am) or 8 hours (from 11pm to 7am).

Vellapaly farm is an open well equipped by a pump. The figure 5.11 shows that the water level in the aquifer evolves cyclically. Indeed the levels are low during the winter and summer, from January to June and increase during the monsoon from June to October. Next the levels progressively decrease from September to December. The level amplitude fluctuates between 6 m in 2007 and 4 m in 2008. We can observe that the more important anthropogenic solicitation in 2007 caused a big decrease of the levels in the aquifer. However, we observe a very high increase of the water levels during the monsoon. Levels are also at least than 2 meters from the surface.

The aquifer is more or less pumped during the dry period. When precipitations increase, villagers stop the pumping and water is sometimes injected. So, the difficulty to understand the natural dynamic of the aquifer is bigger. For this reason, the survey of Vellapally piezometer has been stopped.

**Dug well near Maddur hotel:**

The same gross dynamic in the Maddur Hotel piezometer (Fig. 5.12). However, the amplitudes are different. A difference between the level in winter and during the monsoon of 4.5 m in 2007 and almost 3 m in 2008. In 2009, the levels have decreased more and the amplitude is at least of 5 m and about 7 m during 2010 and 5.5 m during 2011. The trend of the water level decreasing gradually every year, the observation shows about 4 meters decrease in water level in 4 years and the water level fluctuation also from 3 m to 7 m due to the high level of pumping.

When compare the evolution of the water levels of the monitored piezometers (Fig 5.13), we observe that there is a more important variability on the piezometer close to a pumping. Indeed, CMpura 1, which is the more affected by pumping presents amplitude almost four time bigger than Vellapaly or Maddur Hotel.

Consequently the climatic conditions have a light influence on the water levels evolution compared to the importance of the pumping effect on the aquifer levels. Indeed, the anthropogenic factors can have big consequence on the availability of the resource. In June 2006, the water depth in CMpura 1 was of 25 m. In this condition, the
pressure on the groundwater resource is important and the shallow wells of the poorest farmer in proximity of the pumping are empty.

But we observe that the south-west monsoon permit a good recharge of the aquifer from July to September. So, we can try to observe, at a global spatial scale, the evolution of the availability of the water for aquifer recharge to make a water budget of the Maddur aquifer.

![Map of Maddur watershed with monitoring wells](image)

**Fig. 5.6 Density of monitoring wells in Maddur watershed**
Fig. 5.7. Maddur aquifer section

Fig. 5.8. Water depths in CMpura 1
Fig. 5.9: water depths in CMpura 2

Fig. 5.10. High frequency signal in CM pura 2
Vellapaly farm:

Fig. 5.11 water depths in Vellapaly farm

Fig. 5.12. Groundwater fluctuation near Maddur Hotel
Fig. 5.13 Shows water table fluctuation in pre monsoon (a) and post-monsoon (b) in Maddur watershed
Terakanambi

Terakanambi watershed is nested in the Gundal sub-basin and has an area of 92.9 Sq.km. The ground level at the lowest point at the outlet of watershed is 760 m above mean sea level with about 860 m above mean sea level in the upland regions. This provides gentle topographical slopes in the watershed influencing the groundwater movement. This watershed is characterized by higher level of pumping, which is used for growing crops both in the monsoon and non-monsoon seasons. Fig. 5.14 shows the average growth of wells in the Terakanambi watershed and Terakanambi town. It is observed that the growth of the wells in Terakanambi watershed is 4.3 times in a period of 8 years and in the Terakanambi village the growth is 2.3 times in the same period. In some areas of this watershed, crops that have a crop period stretching over one year such as sugar cane and also plantations (e.g. coconut and banana) are cultivated through irrigation from groundwater. The land use and land cover in this watershed is shown using the satellite map in Fig. 5.15, which shows the presence of multi-season crops in this watershed.

The groundwater table fluctuation of Terakanambi watershed is monitored by manually (Fig. 5.17 and 5.18) and there is also one station is equipped which recorded the monthly groundwater levels from 1973 onwards from CGWB. A station recording daily precipitation is also located close to the groundwater monitoring station, which has since 1976 shown in the Fig. 5.16. The groundwater hydrograph and the cumulative rainfall departure curve at the station are shown in Fig 5.16. It is observed from this figure that the groundwater levels in this watershed show decadal variations apart from the intra-annual fluctuations due to monsoon recharge.
Fig. 5.14: Growth of wells in the Terakanambi watershed (sum of all the villages)

Fig. 5.15: land use and land cover map of Terakanambi watershed
Fig. 5.16: Plot of groundwater hydrograph and Cumulative rainfall departure at Terakanambi station.
Fig. 5.17 Well location of Terakanambi watershed
Fig. 5.18: Depth to groundwater map of Terakanambi watershed.