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GIS for analyzing Pumping Tests and Wells Data for Assessing Groundwater Prospects of Pedda Kedari Reserve Forest, Srikakulam, AP

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Abstract

Groundwater resources of an area depend on aquifer hydraulic parameters such as storage coefficient, transmissivity permeability and meteorological conditions. The Remote Sensing, GIS and GPS techniques were used to prepare various thematic maps which include Land use/Land cover, Lineaments, Well locations, Storage coefficient (S), Permeability (K), Transmissivity (T), Groundwater level and Integration Map of S, T and K. Water levels were measured in pre-monsoon for three consecutive three years from 23 dug wells which are spatially distributed in entire study area of the pedda kedari. The Groundwater level (GWL) map was generated by using mean depth of water columns in dug wells. The 12 dug wells are selected, which are spatially distributed in the entire study area of the pedda kedari reserve forest, for conducting pumping tests. The hydraulic parameters which include Transmissivity, Permeability and Storage coefficient were found through pumping test analysis there by thematic maps were generated for each hydraulic parameter. By integrating the three layers Groundwater Prospects (GWP) map was generated. The Integrated map was validated with GWL map so that 75% of common area is got in the regions of moderate to good prospect zones. The suitable locations for artificial recharge structures are suggested by using Lineaments map, existing wells and a map which was generated by integrating both the Integrated and GWL maps.

Keywords: Remote sensing, GIS, GPS, Transmissivity, Permeability, Storage coefficient

INTRODUCTION

Groundwater is a dynamic and replenishable natural resource. On the planet earth, fresh water constitutes about 3% of surface water resource and only 0.6% from groundwater resource. Groundwater is a very important source of freshwater for human beings. It fulfills most of the requirements for a wide range of uses, and so demand for groundwater has increased manifold. Given the increased demand, it is necessary to understand the groundwater resources so as to be able to supply present and future generations. But, in hard rock terrain availability of groundwater is very limited. In such terrains groundwater is essentially confined to fractured and weathered zones. Therefore, exploration and exploitation of groundwater resources require the knowledge of the nature of structural disposition, land use/land cover etc. Integration of various data and thematic maps such as aquifer hydraulic parameters, depth to groundwater table data helps in generation of groundwater prospects zone maps.

With the rapid advances in remote sensing and GIS, modern satellite imagery has become accessible with rich multi-resolution and scales, as a data source for monitoring natural processes. It is technically feasible to integrate large quantities of data for further spatial analysis related to urban development by using GIS. Remote sensing and GIS have proved an effective means for extracting and processing varied resolutions of spatial information for monitoring natural resources (Masser, 2001). In case of inaccessible region, this technique is perhaps the only method of obtaining the required data on a cost and time-effective basis. Several remote sensing satellites were launched for various purposes and of various resolutions, which provides a new dimension to the remote sensing technology. Now, most common remote sensing systems operates in one and/or several of the visible, infrared, or microwave portions of the electromagnetic spectrum (Jensen, 2007). Digital elevation models (DEM) are among the remote sensing techniques that have been used to measure landscape surface roughness properties over large areas. These are used for visual and mathematical analysis of topography, landscapes and landforms; and also modeling of surface processes (Millaresis and Argialas, 2000; Tucker et al.

2001). Prudhvi Raju and Vaidyanathan (1981) analyzed the fracture patterns of Eastern Ghats region, Andhra Pradesh, which was taken from Landsat imagery using standard visual interpretation techniques. Chetty and Murthy (1993) have mapped the structural and various lithological features of east coast of India using remote sensing data. They adopted different remote sensing techniques for identification of lineaments and other structural features followed by ground check in the field.

Land use and land cover changes are important elements of the global environmental change processes (Dickinson, 1995; Hall et al. 1995). The classification and change detection of land cover has a great potential in remote sensing applications. Due to limitations such as the temporal resolution of the satellite data and image classification techniques (Liu and Lathrop, 2002), visual image interpretation is an efficient method to classify complex and heterogeneous landscapes (Antrop and Van Eetvelde, 2000). Traditional approaches to automated land cover mapping using remotely sensed data have employed pattern recognition techniques including supervised and unsupervised approaches (Jensen, 1986; Benediktsson et al. 1990; Fried and Brodley, 1997; Ward et al. 2000; Rashed et al. 2001; Shamsudheen et al. 2005). Murthy and Venketeswara Rao (1997) have carried out temporal studies of land use/land cover in Varaha river basin, Andhra Pradesh, India using Landsat and IRS LISS data. According to Rajeshwari (2006), proper planning and management of urban environment requires huge amount of information regarding all aspects of natural and man-made features of the area.

More efficient tools are needed for groundwater exploration, so as to meet the increased demand for water supply, and to protect the water resource. In arid regions, vegetation characteristics are good indicators of groundwater depth and quality. Recharge and discharge areas in drainage basins can be detected from soils, vegetation and shallow/perched groundwater (Todd, 1980). Nevertheless, a study of aquifer properties will provide more relevant information on the aquifer characteristics of the terrain that controls the groundwater storage and movement. Theis (1935) first proposed a method to evaluate aquifer parameters from pumping tests in confined aquifers. The hydraulic study of the aquifer performance test is normally done in large-diameter wells in hard rock terrain, as they generally have more exposed fractures and fracture planes. This test allows hydro-geologists to quantify the groundwater and the hydraulic conductivity, which mainly depend on secondary porosity in the hard rock aquifer (Jain, 1977).

Surface water bodies like rivers, ponds, etc. can act as recharge zones enhancing the groundwater potential in the vicinity (Jensen, 1986). Digital image processing techniques are used to integrate various datasets to delineate not only groundwater prospective zones but also solve other problems related surface and subsurface studies. Kamaraju et al. (1995) delineated the groundwater potential zones in West Godavari district of Andhra Pradesh using remote sensing and GIS. Krishnamurthy et al. (1996) used remote sensing data for demarcating groundwater potential areas in the Marudaiyar basin of Tamil Nadu. The utility and suitability of integrated studies in delineating groundwater potential zones and identifying recharge sites in a hard rock terrain like the Deccan Volcanic province (DVC) of India is demonstrated by Saraf and Choudhury (1998). Goyal et al. (1999) used a multi-criteria evaluation technique to evaluate the inter-class and inter-map dependencies for groundwater evaluation in the Rawasen and Pili watersheds of Uttar Pradesh state, India. Musa et al. (2000) used an integrated remote sensing and GIS system to produce various thematic maps for classifying groundwater potential zones in Langat Basin, Malaysia.

Satellite imagery are increasingly used in groundwater exploration because of their utility in identifying and outlining various ground features, which may serve as either direct or indirect indicators for the presence of groundwater. Subba Rao et al. (2001) and Singh et al. (2002) have used remote sensing and GIS techniques to demarcate groundwater potential zones in the hard rock region of India. They prepared lineament maps from IRS LISS-III data by using visual interpretation. Jaiswal et al. (2003) have used the GIS technique for generation of groundwater prospect zones towards rural development. Hadithi et al. (2003) evaluated the groundwater potential in the Ratmau-Pathri Rao watershed in Haridwar district, India using geo-electrical, remote sensing and GIS techniques. Appropriate weights were assigned for various thematic layers to evaluate groundwater potential in each segment of their study area. Murthy et al. (2003) has generated various thematic maps to identify the groundwater potential zones in Bhamini mandal, Srikakulum district, A.P.

In recent years, extensive use of remote sensing satellite data along with SOI topo maps, collateral information and limited field checks has made it easier to establish the base line information for groundwater prospective zones. In contrast, geoinformatics technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources (Harinarayana et al. 2000; Jha et al. 2007). An important aspect of GIS and remote sensing applications in hydrology and water management have been presented by several researchers (Zhang et al. 1990; Ross and Tara, 1995; Deckers and Te Stroet, 1996; Tsihrintzis et al. 1996; Lachassagne et al. 2001; Pinder, 2002; Sikdar et al. 2004; Navalgund et al., 2007).

In hard rock terrains, groundwater is limited and is essentially confined to fractured and weathered horizons. Groundwater is a form of water occupying all the voids with in a geological stratum. Water bearing formations of the earth’s crust act as conduits for transmission and as reservoirs for storing water. The groundwater occurrence in a geological formation and the scope for it exploitation primarily depends on the formation of porosity. High relief and steep slopes impart higher runoff, while topographical depressions increase infiltration. An area of high drainage density also increases surface runoff compared to allow drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones (Murugesan et al. 2012).

Pandian et al. (2013) have attempted to identify the groundwater potential zones analyzing thematic data such as lineaments, land use/land cover in GIS. Biswas et al. (2012) opined that remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of multi-disciplinary data and decision making for groundwater studies. Water flows in the form of rivers, streams, lakes, channels and play an important role in balancing the natural ecosystems. Groundwater targeting in hard rock terrain is a very difficult task due to very typical hydrological properties of unconfined and fractured aquifers (Basavarajappa et al. 2014). Yousef et al. (2015) have attempted to delineate groundwater potential zones in deep midland aquifers along the Bharathapuzha river basin, Kerala, India. VES data collected from different locations were interpreted qualitatively and quantitatively to obtain layered resistivity parameters and potential fractured zones in the deep aquifer.

Geospatial data on land use/land cover and groundwater potential zones are not available for Pedda Kedari Reserve Forest area. The topic of the present project work has highest importance and relevance, as the rapid drawing of water resources have enormous impact on the environment of the study area. The focus of the project work is to identify the various factors affecting the water and land environments using well inventory and pumping tests information in Pedda Kedari Reserve Forest area of Srikakulam district, Andhra Pradesh, India.

STUDY AREA

The study area, Pedda Kedari Reserve Forest, is an integral part of Srikakulam district of Andhra Pradesh State. The district is located in the north-eastern part of the State. The district has a coastline of 192 km, and is situated in between the Eastern Ghats and the Bay of Bengal. It is one of the less populated and low literacy district of the State. The district is endowed by good rainfall, forest wealth, mineral and surface water resources. The aerial extent is 5,837 km2. The district is bounded by the Bay of Bengal on the east, Vizianagaram district on west and south, and Odisha state on north and northwest. Howrah–Chennai broad gauge railway line and NH-5 are passing through the district almost parallel to the coastline. The district is divided into three revenue divisions viz. Srikakulam, Palakonda and Tekkali. Further these revenue divisions are subdivided into 38 revenue mandals consisting of six towns and 1,763 villages with a population of 25, 37,593 as per Census 2011. The urban population is 4, 36,347 whereas rural population constitutes 22, 63,124 (District Census Handbook, 2011). The density of population of the district is 462 persons per km^2. The important rivers flowing in the district are Vamsadhara, Nagavali, Suvarnamukhi, Vegavati, Mahendratanaya and Bahuda. Among the rivers Vamsadhara, Nagavali and Suvarnamukhi are perennial (Figure 1.0). The general drainage pattern is dendritic to sub-dendritic and occasionally parallel at places.

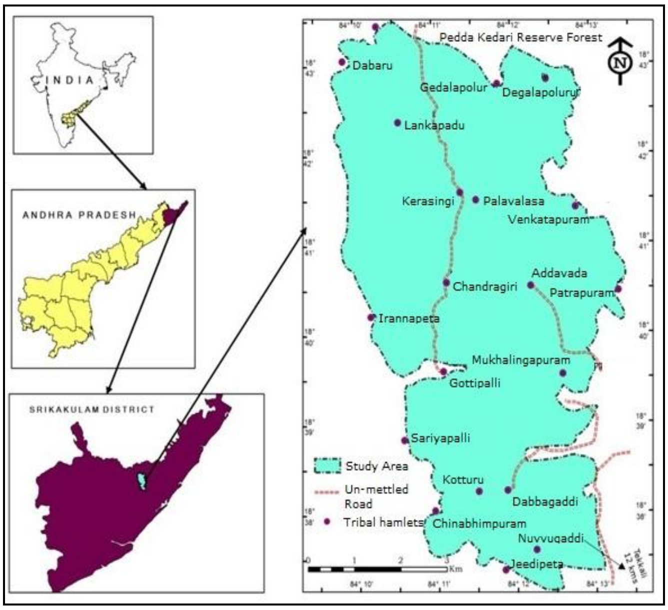
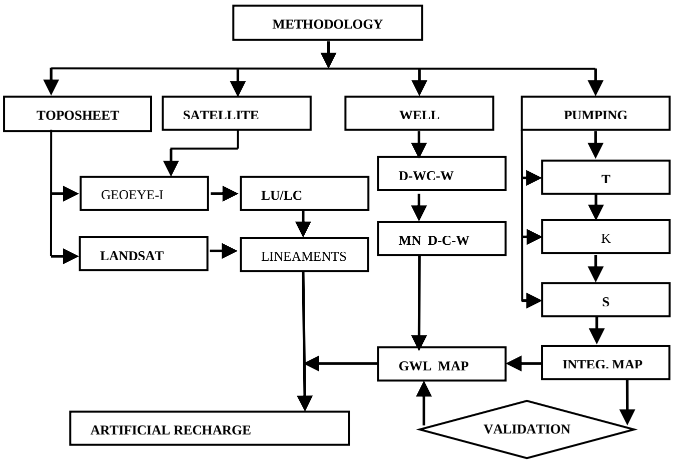


Figure 1.0 Location map of the study area

DATA USED AND METHODOLOGY

The survey of India (SOI) toposheet No. 74 B/2 of 1:50,000 along with GeoEye-I imagery of 1.65 m resolution and Landsat ETM+ imagery of 30 m resolution were used to generate the different maps. Land Use/Land Cover was mapped using the GeoEye-I imagery by visual interpretation. Lineaments map was mapped using the Landsat imagery by applying sobel filter techniques. The depth of water columns were collected from 23 dug wells in pre-monsoon season for three years and mapped a Groundwater Level (GWL) map using mean depth of water columns. The 12 wells were chosen to do pumping tests for doing hydraulic analysis which are suggested by Cooper and Jacob (1946). From the analysis three hydraulic parameters were extracted for each dug well. From the hydraulic parameters three thematic maps were generated which include Transmissivity, Permeability and Storage coefficient. The three layers were then integrated to get Groundwater Prospects (GWP) Map. The GWP map was validated with GWL map so that 75% of common area is got in the regions of moderate to good prospects zones. The suitable locations for artificial recharge structures are suggested by using Lineaments map, existing wells and a map which was generated by integrating both the GWP and GWL maps



D-WC-W----DEPTH OF WATER COLUMNS OF WELLS
MN D-WC-W----MEAN DEPTH OF WATER COLUMNS OF WELLS
T--TRANSMISSIVITY, K--PERMEABILITY, S—STORAGE COEFFICIENT

Figure 2: Flow Chart

RESULTS AND DISCUSSIONS

The occurrence and movement of groundwater in a hard rock terrain is mainly controlled by secondary porosity caused by fracturing of the underlying rocks. GeoEye-1 with 1.65 m spatial resolution and Landsat ETM+ with 30 m spatial resolution datasets were used in the present study for the creation of thematic maps on land use/land cover and lineaments map. A total of three thematic maps such as Transmissivity (T), Permeability (K) and Storage coefficient (S) are analyzed through modeling for identification of groundwater prospects zones in the study area.

Land Use/Land Cover (LU/LC) Studies

Satellite remote sensing and GIS techniques coupled with conventional filed investigations were used for mapping of land use/land cover (LU/LC) features of the study area towards estimating the runoff of the area. The knowledge of land use and land cover is important for many planning and management activities as it is considered as an essential element for modeling and understanding the earth feature system. Land use defines as any human activity or economical related function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of earth (Lillesand and Kiefer, 2003). The Land use/Land cover features (Figure 3.0) were extracted from GeoEye-I imagery (Figure 2.0) by using visual interpretation techniques

Table 1.0. Land use/land cover changes from satellite data observed in the study area

Land use/Land cover		GeoEye-I Imagery	
Category	Sub-category	Area	
		Km^2	%
Built-up land	Rural	0.03	0.07
Agricultural land	Crop land	3.25	7.07
Forest land	Deciduous forest	0.96	2.09
	Dense Scrub	35.73	77.67
	Open Scrub	4.56	9.91
Wastelands	Barren land	1.47	3.20
	Grand total	46	100

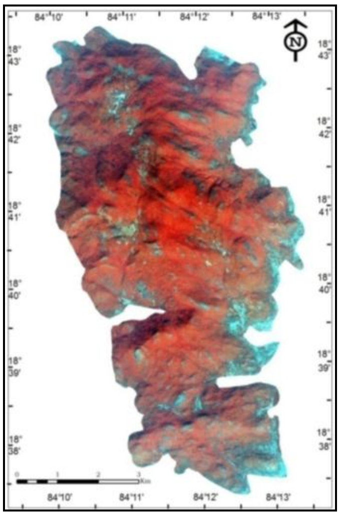


Figure 2: GeoEye-I Imagery -2011

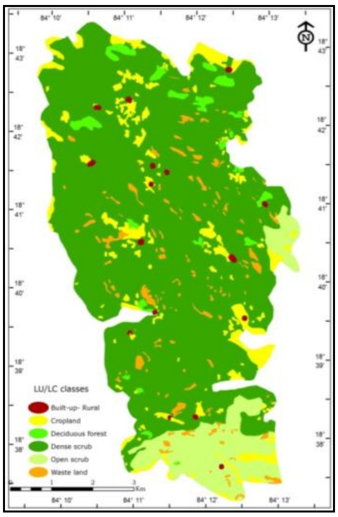


Figure 3: Land use/Land cover Map

Structural Geological Studies

Remote sensing techniques have found extensive application in structural geological studies to supplement and integrate field data. The basis for deriving structural information from remote sensing data emanates from the fact that the rocks acted upon by erosional processes result in landforms (Raviprakash Gupta, 1991). Lineament map has been generated from Landsat 7 ETM+ of Band 1, Band 2 and Band 3 using Sobel directional filter. A number of major and minor lineaments traverse the study area. Lineaments appear on the FCC imagery as straight, curvilinear, parallel and discontinuity features. The pattern of lineament is important on the image. Lineaments with straighter alignments indicating moderate to steeply dipping surfaces in the study area. The length and direction of lineaments present in this area vary considerably. The study areas is characterized by major NS, NE-SW and NNE trending lineaments (Figure 4.0) and are varying in length between 0.17 and 1.25 km.

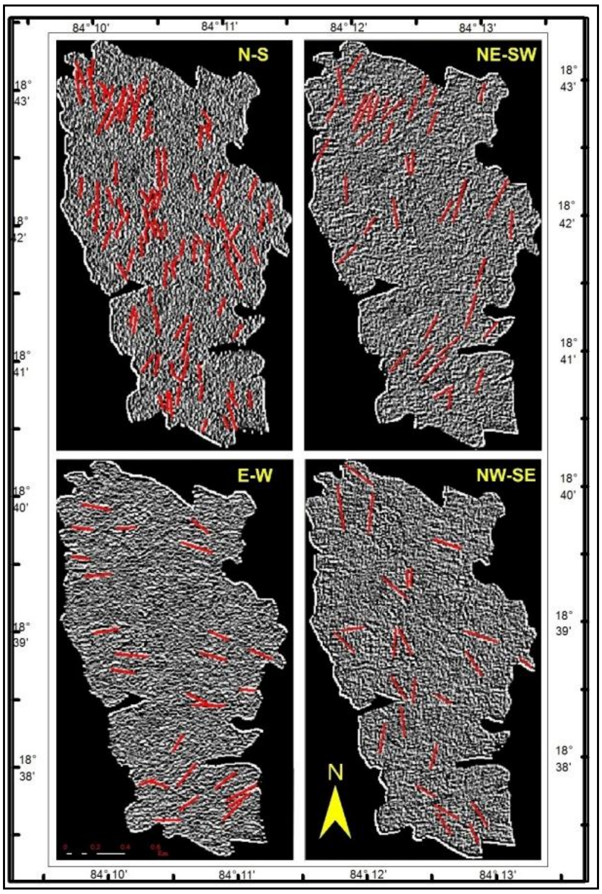


Figure 4.0. Lineaments Map of Study Area

Well Inventory

Twenty three dug wells were inventoried in the entire study area (Figure 5.0). Water levels were measured in May, representing the pre-monsoon season during the years 2014, 2015 and 2016. The field work was conducted in the early morning i.e. before commencement of pumping of wells to ensure the measurement of seasonal static water levels. It was observed from the data, the mean depth of water column during pre-monsoon season in the study area varies between 0.72 to 6 m. Since the wells are spatially distributed throughout the Pedda kedari reserve forest, the groundwater level map (Figure 4.2) is generated using GIS. The groundwater level (GWL) map is categorized into three zones. The Poor zone is having mean depth water columns are less than 2 meters, where as the Moderate zone is having mean depth values in between 2 meters to 4 meters. The Good zone is having mean depth water columns greater than 4 meters. The details of GWL map are given below.

The Good zone area is 36.66% of the total area, where as the Moderate zone area is 36.75% of the total area and of course the remaining poor zone area is 26.59% of the total area.

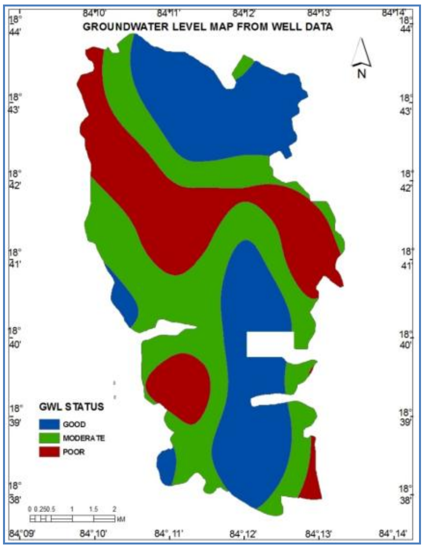


Figure 4.0. GWL Map of Study Area

S.Noo..No	Status	Range	Area (Sq Km)
1	Good	>94 m	16.87
2	Moderate	2 – 4 m	16.91
3	Poor	< 2 m	12.23

The Aquifer System

Formations of the Eastern Ghats group include khondalites, charnockites, granite gneisses, and younger intrusives. Alluvium of recent age occurs as thin discontinuous patches associated with stream courses. The rocks of the Eastern Ghats group have undergone intense structural and metamorphic deformations. Groundwater occurs mostly under unconfined to semi-confined conditions in these hard rock formations. Study of aquifer system is an important tool which provides the information related to potential influences on local wells and helps to understand the local aquifer characteristics. Knowledge of hydraulic properties of aquifer and associated rock properties of formations is essential in any design of groundwater resource assessment. Pumping tests are an accepted means of acquiring data on hydraulic properties. In hard rock regions, the development of porosity and permeability is due to fracturing and weathering. Weathering and fracturing are denser near the surface and hence the permeability of hard rock generally decreases with depth. Thorough understanding of the hydrogeological regime helps in interpreting the pumping test data obtained from bore, tube, and dug wells.

The discharge through porous media is proportional to the product of the hydraulic gradient, the cross-sectional area normal to the flow and the coefficient of permeability of the material (Darcy, 1856). Historically, large diameter wells have drawn attention of many early workers contributed towards the estimation of well yields (Slichter, 1906; Muscat, 1937; Hvorslev, 1951). Estimation of aquifer parameters from dug wells was attempted for the first time by Papadopulos and Cooper (1967) and followed by several modifications from time to time by Kumaraswamy, 1973; Mishra and Chachadi, 1985; Sinha et al. (1986); Singhal, 1991; Singh and Gupta, 1991; Pantelis, 2007; Tizro et al, 2014; Venkat Rao et al. 2015). Low permeability and high storage capacity of the porous rock intersected by fractures is having high permeability and low storage capacity in which flow to the well primarily through fractures (Warren and Root, 1963). In case of discretely fractured granitic aquifers, flow is confined to conductive fractures and the rock matrix is essentially impermeable (Cohen et al. 1996). In heterogeneous aquifer, the drawdown curve may have different slopes at different times, and therefore the drawdown behavior is partly dependent on the duration of pumping (Streltsova, 1988). The slope of semi-log drawdown curve during the initial period of pumping is a function of the transmissivity of the fractures intersected by the borehole. The area of influence increases and the slope may increase or decrease depending on the nature of change in hydraulic properties of the fracture networks in the surrounding area when the continuation of pumping. This may result in a multiple slope curve depending on the heterogeneities present. Analysis of late-time data from a well in a crystalline rock fracture aquifer may give only some average parameters for the area influenced by the test. Early-time data is likely to be more representative of the conditions near the observed well. Therefore, comparison of water level responses to theoretical models has certain limitations since no response is unique to any particular type of aquifer (Kukillaya, 1992).

Aquifer Characteristics

The research area is covered by Archaean granitic gneisses. Groundwater occurs under water table conditions mainly in weathered mantle, fractured zone of hard rock and narrow zone of unconsolidated sediments along the stream courses and valley fill zones. The phreatic aquifer does not yield much in summer, except in valleys and foot hill regions. In order to suggest suitable harvesting structures for improving the groundwater levels, it is imperative to understand fully the aquifer characteristics. Based on the type of well, depth, diameter, radius, steady and un-steady state conditions of the flow from the aquifers, different methods of analysis are available to determine the aquifer characteristics.

According to non-equilibrium theory, introduced by Theis (1935), the time factor and the co-efficient of storage; it made possible the computation of future pumping levels when the flow of groundwater due to pumping did not approach an equilibrium condition. However, the use of Theis formula in determining the coefficients of transmissibility and storage, the formation constants of an aquifer, presented much difficulty because of mathematical complexities in applying the formula, which contains an exponential integral.

Cooper and Jacob (1946) have introduced an approximation into the non-equilibrium method which is convenient to use. Both the equilibrium and the non-equilibrium methods assume that the water-bearing material is homogeneous and isotropic. This assumption is probably never true in a natural aquifer. However, these methods give reliable results in actual cases when there is no hydrologic boundary existing within the effective area of pumping. Cooper and Jacob (1946) have shown that when plotted on semi-logarithmic paper, the theoretical drawdown curve approaches a straight line when sufficient time has elapsed after pumping started. In many instances plotting of the data while the test is in progress reveals whether the straight line regime is being attained. However, the gentle transition into the straight line is sometimes hard to see without precise plotting and analysis, and may be confused with effects of other forces such as barometric effects, non-homogeneity, variations in pumping rate, etc. The transition into the straight line may always be expected to occur but it may be hard to recognize because it sometimes passes very quickly and other times endures for an extended period. The principle of using the derivative of drawdown with respect to the logarithm of time is a generalization of the Cooper-Jacob (1946), straight line method. This method can be applied to the infinite, acting, radial, flow case (i.e., the zone of influence delivering most of the well's flow is radial in an apparent homogeneous aquifer).

In the present study, Cooper and Jacob (1946) method was used for the analysis of data in unsteady state condition. The method of analysis is based on the following assumptions:

- the aquifer is homogenous and isotropic
- the aquifer is of an infinite areal extent
- the discharge well penetrates the entire thickness of the aquifer
- the transmissivity is constant at all times and at all places
- water removed from storage is discharged instantaneously with a decline in the head

Following this method, pumping tests were carried out at twelve selected dug wells and a graph is drawn for the measurements of the observation well, drawdown versus time of pumping and recovery levels in the well; and the time of observation while water level recuperating. The points on the plot form a straight line, except an early time data of pumping and recuperating. The constant discharge of each test well is calculated from the time and residual recuperation. Aquifer constant, the slope of the time-draw down and time-recuperation curves are computed from the discharge rate. The following equations are used for calculating the aquifer parameters:

$$T = \frac{2.303 \times Q}{4\pi\Delta_s} \ldots\ldots\ldots\ldots\ldots\ldots . eq.5.1$$

$$S = \frac{2.25 \times T \times t_0}{r^2} \ldots\ldots\ldots\ldots\ldots eq.5.2$$

$$K = \frac{T}{D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. eq.5.3$$

Where,

Q = constant rate of discharge (m^3/day)

r = radius of the well (m)

Δ_s = drawdown in m for one log cycle of time

t_0 = time since pumping is started

S = storage coefficient

T = transmissivity (m^2/day)

K = permeability (m/day)

D = thickness of aquifer or water column pumped (m)

Aquifer Parameters

Transmissivity (T)

Transmissivity is the product of the average hydraulic conductivity (K) and the saturated thickness of the aquifer (H). Consequently, the transmissivity is the rate of flow under a hydraulic gradient equal to unity through a cross-section of unit width over the whole saturated thickness of the water bearing layer. It is expressed in m^2/day. Its range can be derived from those of K and H.

Storage Coefficient or Storativity (S)

Storage co-efficient or storativity is a dimensionless coefficient defined as the volume of water that a permeable unit will release from storage per unit surface area per unit change in head. In an unconfined unit, the level of saturation rises or falls with changes in the amount of water in storage due to specific yield.

Permeability or Hydraulic Conductivity (K)

Permeability or hydraulic conductivity is a measure of the capacity of a porous medium to transmit water. It is defined as the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The dimensions of hydraulic conductivity are length per time or velocity. Hydraulic conductivity is governed by the size and the shape of the pores, the effectiveness of the interconnection between pores, roughness of mineral particles, degree of soil saturation, and the physical properties of the fluid.

Hydraulic parameters of aquifers namely transmissivity (T), coefficient of storage (S), and permeability (K) were studied based on pumping test data of twelve dug wells. Out of 12 dug wells, 5 in valley fills, 2 in buried pediment and 5 are tapping from fracture zones within granitic gneiss. The pumping well locations are shown in Figure 5.0. Pumping tests were carried out using 5 horse power (hp) centrifugal pumps. The pumping rate is fixed for all the test wells at 200 lit/25 sec. All these dug wells are located in granite gneiss terrain. The pumping capacity is around 28 m^3/hr drained the entire water from each test well within an hour. Average pump discharge is measured by measuring the out let at least 3 times while pumping. Water levels are observed during pumping and as well as the recovery of water table after pumping is stopped. It is observed from the analysis that the aquifer is a weathered rock aquifer and unconfined. In practice the flow is considered to be in an unsteady state as long as the water level in the well is measurable or, in other ways as long as the hydraulic gradient is changing in a measurable way while pumping is continued. Aquifer material is a highly weathered rock consisting of kailonised (weathered) granite gneiss formations and the material is white murrum. The total depth of pumping test wells is varying between 2.1 at Chinna Kedari to 7.6 m at Eguvabndapalli . Diameter of the wells ranges from 1.69 to 7.14 m and radius of the wells vary between 0.84 to 3.07 m. All well waters are being utilized only for domestic purposes. During the pumping test water levels were rise up to 3.4 m. The well discharge ranges from 13.7 to 303.2 for m^3/day draw downs varying from 1.4 m at Nelabonthu to 6.1 m at Jakkarapeta. Transmissivity (T) varies widely in the area from 0.75 to 25.43m^2/day (Table 4.2 and Figure 6.0). Transmissivity depends on permeability and thickness of the aquifer (Todd, 1995). Storage coefficient (S) values range from 0.15 to 0.24 indicating semi-confined to confined nature of the aquifer (Table 4.2 and Figure 7.0). The lowest permeability observed at Guda with 0.26 m/day whereas the highest K value was 16.95 m/day at Mukhalingapuram (Table 4.2 and Figure 8.0).The pumping time of wells varies widely between 18 to 550 minutes in a day mainly depending upon the potentiality of the aquifer. The porosity responses observed in pumping wells mainly due to presence of major conduits in a network of minor fractures. Many of the responses explain similarity to responses of a homogeneous and anisotropic aquifer. The study indicates that fracture aquifers in the area have limited groundwater potential and hence should be developed with care so as to avoid over exploitation.

Table 2.0. Summarized data of pumping test in dug wells

Well	Location	Latitude (N)	Longitude (E)	T	S	K
PW1	Jakkarapeta	18^{0}38’09.82’’	84^{0}11’18.08’’	2.81	0.19	0.59
PW2	Chinna kedari	18^{0}38’53.46’’	84^{0}12’53.46’’	10.93	0.18	5.52
PW3	Dabbaguddi	18^{0}38’49.68’’	84^{0}11’48.02’’	13.24	0.18	3.57
PW4	Gottipalli	18^{0}40’10.71’’	84^{0}10’59.67’’	8.87	0.15	2.86
PW5	Mukhalingapuram	18^{0}40’10.57’’	84^{0}12’28.69’’	25.43	0.17	16.95
PW6	Naraharipuram	18^{0}40’38.06’’	84^{0}13’10.31’’	7.66	0.17	1.74
PW7	Chandanagiri	18^{0}41’11.67’’	84^{0}11’11.06’’	6.57	0.16	4.38
PW8	Nelabonthu	18^{0}41’43.26”	84^{0}09’53.45”	6.42	0.24	2.73
PW9	Eguvabandapalli	18^{0}42’10.55’’	84^{0}12’23.18’’	10.17	0.20	2.42
PW10	Guda	18^{0}42’54.74’’	84^{0}10’55.09’’	0.75	0.20	0.26
PW11	Gedalapoluru	18^{0}43’35.67’’	84^{0} 1’52.90”	2.95	0.20	1.09
PW12	S Mukundapuram	18^{0} 3’52.82’’	84^{0} 0’10.23’’	0.86	0.21	0.29

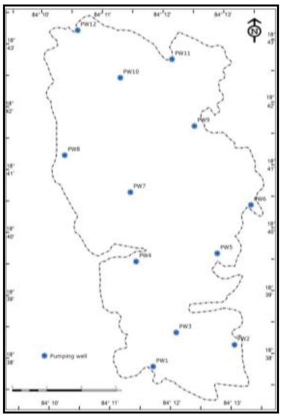


Figure 5.0. Well locations to conduct Pumping tests

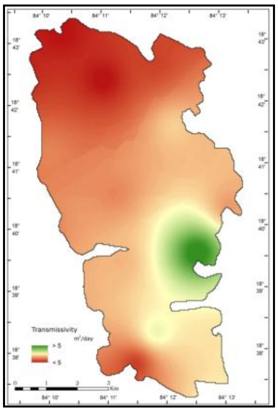


Figure 6.0. Variations of Transmissivity values

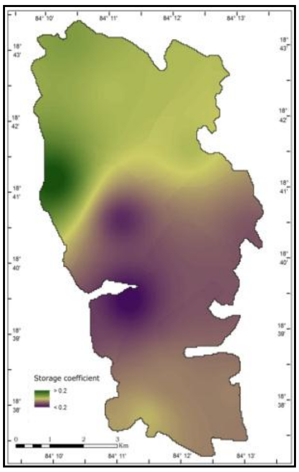


Figure 7.0. Variations of Storage Coefficient values

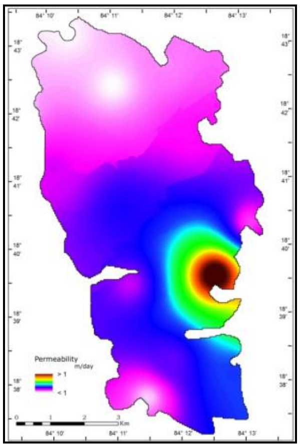


Figure 8.0. Variations of Transmissivity values

Groundwater Prospects From Integrated Map

Integration of aquifer parameters data in the GIS environment is very useful in delineating various groundwater potential zones in a meaningful way. Several studies on groundwater potential zoning using remote sensing and GIS technologies have been conducted both in India and abroad (Chi and Lee, 1994; Reddy et al. 1996; Sreedevi et al. 2005; Agarwal et al. 2004; Sener et al. 2005; Solomon and Quiel, 2006). Thus, the potential of GIS in various applications related to water resources is well established: hence, it is necessary to use this technology not only for targeting of groundwater potential zones, but also for identifying location specific activities such as percolation tanks, check dams, farm ponds, recharge well etc. Applications of GIS in groundwater management such as artificial recharge have been reported by various researchers (Akram and Mushtaq, 2009; Mukherjee et al. 2012; Murali and Paul, 2013; Nag and Ray, 2015). The objective of this study is to demarcate the groundwater prospective zones and to identify sustainable locations for recharge wells in the Pedda Kedari reserve forest area.

The three thematic layers were re-sampled to match the same resolution. The thematic layers are integrated in GIS. The thematic layers are categorized into good, moderate and poor zones of groundwater prospects. Thematic map categories and status are shown in Table 3.0

Table 3.0. The Thematic layers showing categories and Status

S.No	Thematic layers	Category	Status
1	Transmissivity (T)	< 5 m^2/day	Poor
		5-104 m^2/day	Moderate
2	Permeability (K)	< 1 m/day	Poor
		1-864 m/day	Moderate
3	Storage coefficient (S)	0.1 - 0.2	Moderate
		> 0.2	Good

The Transmissivity, Permeability and Storage coefficient maps are integrated in GIS. In the integrated layer out of three statuses (Good or Moderate or Poor), if two statuses are having Good and Good or Good and Moderate then the region corresponding is categorized as Good. Again out of three statuses, if two statuses are having Moderate and Moderate the region corresponding is categorized as Moderate and the remaining region as Poor. The groundwater potential map generated for the study area is shown in Figure 9.0. The classified map shows different groundwater prospect zones based on the decision as good, moderate and poor. The good groundwater prospective zone occupies 5.32 km^2 in the study area. The moderate groundwater prospective zone occupies 30.41 km^2 in the study area. The maximum area is characterized by poor potential zone occupying about 10.28 km^2 of the total geographical area. It is observed that nearly 77.65 % of the study area has moderate to good potential for groundwater prospecting.

Validation Of Integrated Map & Gwl Maps

Both GWP and GWL maps are validated so that 75% of common area is got in the regions Moderate to Good potential zones. The resulting validation map (Figure 10.0) which is generated by integrating both the maps, is categorized into Good (12.93 sq km, 28.11 %), Moderate (12.26 sq km, 26.64%) and Poor (20.82 sq km, 45.25%). It is observed that nearly 49.18 % of the study area has moderate to good potential for groundwater prospecting.

Suitable Locations For Artificial Recharge

The exploration of prospective groundwater zones has been suggested through hand pump well, dug well and dug-cum-bore wells (existed) based on the lineaments and Final (validated) Groundwater potential map. Out of twenty six suggested wells, a total of nineteen specific locations were proposed for construction of hand pump well and dug wells (Figure 11.0). Suitable zones were identified for hand pump wells where Lineament intersections meet Good Groundwater potential region (Figure 11.0). Dug wells are suggested where lineament intersections meet with moderate potential zones. Lineament and fracture zones are important for decision making in delineation of the zones. Dug cum Bore wells were suggested where the existing wells meet the good and moderate zones of the

groundwater potentials. In hard rock areas, the underlying lithological units do not have sufficient primary porosity and permeability. Thus, additional recharge by location specific activities becomes necessary to augment the ground water in regions where it is insufficient. The suggested locational recharge wells involve the application of set of criteria resulting from GIS analysis coupled with field data of scientific factors, which needs to be integrated with social factors also. This associational analysis not only helps in better understanding of the cause and effect related to problems/limitations but also helps in assessing the potential that exists in the study area for its betterment

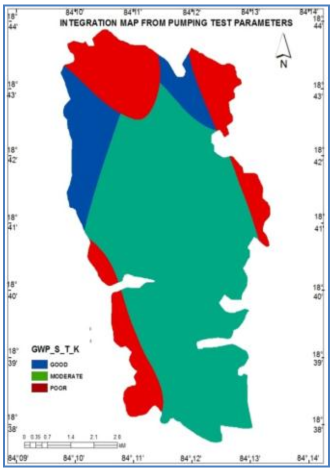


Figure 9.0. Integration Map of T, S and K

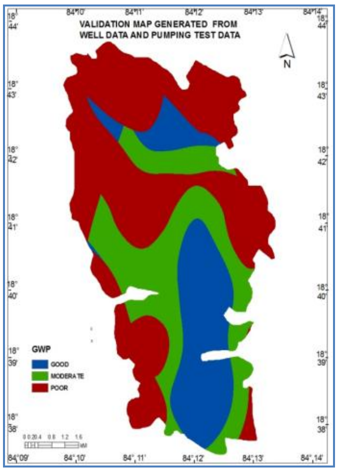


Figure 10.0. Validation Map

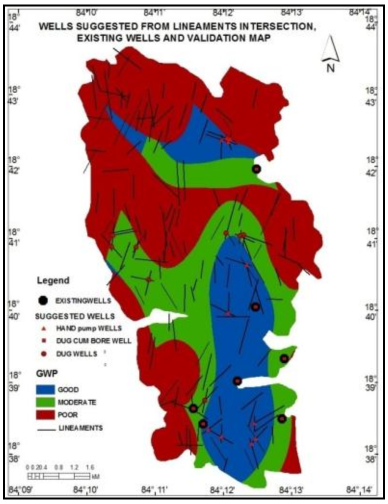


Figure 11: Suggested Wells Map

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