ASSESSMENT OF GROUNDWATER RESOURCES: A CASE STUDY

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ABSTRACT

Assessment of groundwater resources by whatever method is normally subject to large uncertainties and errors. The methodology recommended by Groundwater Estimation Committee (GEC) is being adopted to compute the groundwater resources in India. The proposed methodology follows the recommendations of Groundwater Estimation Committee, and it uses the water level changes in two specific seasons i.e. one monsoon period and other one is non-monsoon period. The methodology requires water level changes for specified seasons at number of well locations. In this methodology, specific yield is estimated using the non-monsoon water level changes. But there are different approaches are used for estimation of rainfall recharge factor and for the sake of convenience these are referred as Model 1, Model 2 and Model 3 respectively. The study area considered entire Kurnool district, in Andhra Pradesh state (India).Among the three models Model 2 is better model because values are nearly matched with earlier investigations by inverse modeling for other parts of India.

KEYWORDS: *Specific yield, Rainfall recharge factor, Groundwater assessment, Aquifer parameter, Kurnool*

I. INTRODUCTION

Groundwater resource estimation is an important issue and should be viewed in more comprehensive manner. In order to estimate groundwater resource accurately, the aquifer parameter values such as transmissivity, specific yield and rainfall recharge factor have to be known precisely. Assessment of recharge by whatever method is normally subject to large uncertainties and errors. Recharge and discharge components have been quantified based on inflows, outflows and changes in the aquifer groundwater storage. Inflow to the system includes groundwater recharge from precipitation lateral groundwater inflow, irrigation infiltration, influent seepage from rivers. Discharge from the system includes effluent seepage to rivers, evaporation losses, groundwater lateral outflow, and groundwater extraction. Regional groundwater models used for analyzing groundwater systems (infiltration–discharge relations) are often steady state.

1.1. Numerical model

Somanath et al (1991) developed a numerical model for assessing the ground water regime in the Gurpur river basin of Dakshina Kannada district in Karnataka. The model is based on finite difference approach and uses backward difference method with successive over-relaxation (SOR) technique.

1.2. Ground water level fluctuation

Johanson (1987) studied the ground water recharge in moraine area in southeastern Sweden by using two methods both based on ground water level fluctuations. The first method utilizes a one dimensional soil water model, which was tested against observed ground water levels. The second method directly transforms the ground water level fluctuations to equivalent amounts of water from a constructed recession curve and the specific yields.

1.3. Electric analog groundwater model

William et al (1986) predicted water level declines and stream flow depletions that were made in 1965 using an electric analog groundwater model, of the Blue river basin in South Eastern Nebraska.

1.4. Hydrologic equilibrium

Azawi (1983) studied the ground water development for the rapid increase of inhabitation in the Republic of Zaire region. Recharge is estimated by considering the basic hydrologic equilibrium.

1.5. Rainfall recharge model

A rainfall recharge model by non-linear regression technique to determine groundwater recharge using only annual rainfall data based upon groundwater balance study.

1.6. Remote Sensing and GIS techniques

The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. For effective groundwater exploration and exploitation it is important to study the different parameters in an integrated approach. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to 'safer' decisions (Sander 1996). The Geographic information system offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data (Burrough 1986). Remote sensing data provide accurate spatial information and can be economically utilized over conventional methods of hydrogeological surveys. Digital enhancement of satellite data results in extraction of maximum in formation and an increased interpretability. GIS techniques facilitate integration and analysis of large volumes of data.

1.7. Chloride mass balance (CMB) techniques

Chloride is perhaps the most informative ion from a hydrochemical perspective. Due to the conservative nature of chloride, chloride mass balance (CMB) techniques are the most widely utilized approach for estimating recharge in unsaturated and saturated zones. Scanlon et al summarized ~70 studies of groundwater recharge which have applied of CMB methods in watersheds located across the globe.

1.8. WETSPASS methodology

WETSPASS is a physical-based methodology for estimation of the average ground water recharge capability that includes spatially varying, water balance components, surface runoff, and actual evapotranspiration. The model is especially suitable for studying effects of land-use changes on the water regime. The computer model was integrated in the GIS ArcView. The estimated distributed recharge can, therefore, be used in regional steady-state groundwater models and hence decrease the uncertainty in simulated heads.

1.9. MODFLOW model

MODFLOW model is derived from a combination of topology, soil type, land use, well location using geographic information systems (GIS). The model was calibrated and validated and then used to predict groundwater recharge.

1.10. SWAT method

SWAT method used the water balance components from soil and water assessment tool model.

1.11. Inverse modeling

Aquifer parameter values such as transmissivity, specific yield and rainfall recharge factor can be estimated by using inverse modeling. In inverse problem the convergence, uniqueness, stability and identifiability are the key issues to be considered. Gauss Newton algorithm is used for minimization and this method requires computation of first derivatives.

1.12. Ground Penetrating Radar (GPR)

Estimation of groundwater table by hydrogeologists over the past decades has proven to be difficult due to the dearth of data on piezometric heads from the very few boreholes. Ground Penetrating Radar (GPR) has been successfully used to delineate water table depths and possible ground water flow directions. GPR is an electromagnetic method which has advantage over the conventional methods by being more affordable, fast and non-invasive. When the transmitting wave impinges on an object with varying electrical properties, part of the travelling wave gets reflected while part passes through the material. Some of the transmitted waves get absorbed by the material through which it travels. Due to attenuation caused by the materials electrical properties coupled with geometrical spreading, the wave finally dies off at a depth where the energy of the wave is not strong enough to be reflected. The depth of penetration and the strength of the reflected wave are mainly influenced by the electrical properties of the material such as the electrical conductivity and dielectric permittivity. The basic principle behind the GPR is the principle of scattering of electromagnetic waves.

1.13. Regional regression recharge (RRR) model

A regional regression model is to estimate the spatial distribution of ground water recharge in sub humid regions. The regional regression recharge (RRR) model was based on a regression of basin-wide estimates of recharge from surface water drainage basins, precipitation, growing degree days (GDD), and average basin specific yield (SY). Decadal average recharge, precipitation, and GDD were used in RRR model. The RRR estimates were derived from analysis of stream base flow using a computer program that was based on the Rorabaugh method. Tritium and bromide were used as applied tracers to determine groundwater recharge in Hebei Plain, North China, to evaluate the impacts of different soil types, land use, irrigation, and crop cultivation practice on recharge

1.14. Tritium Injection Technique

In Tritium Injection Technique, the moisture at certain depth in the soil profile is tagged with tritiated water. The racer moves downward along with the infiltrating moisture due to subsequent precipitation or irrigation. Moisture content of the soil column, between injection depth and depth of sample collection (after a time interval)is the measure of recharge to groundwater over the time interval for the distance travelled by the tracer. Through the application of Tritium Injection technique in West Survarnamukhi sub-basin, Vedavati basin, Karnataka, the arithmetic mean of the recharge values was estimated as 39.2 mm which amounts to 8.5% of the seasonal precipitation in the region. Studies have been carried out by National Geophysical Research Institute, National Institute of Hydrology and other Research Institutes to estimate recharge from rainfall by tracer techniques at a number of sites all over the country in different agro climatic and hydro geological regions.

II. GROUNDWATER ESTIMATION COMMITTEE (GEC) METHODOLOGY

Groundwater resource estimation must be seen as an interactive procedure. Initial estimators are revised and refined by comparing these with results of other methods and ultimately with field manifestation. The methodology recommended by Groundwater Estimation Committee is being adopted to compute the groundwater resources of the country in volumetric terms. There are two phases to groundwater development. First one is estimation of groundwater recharge from rainfall and other sources, second is from pumping/draft. These require an estimate of present groundwater draft. Groundwater draft necessarily estimated by well census, electricity consumption and area irrigated. There can be considerable uncertainties in these estimates unless a careful review is made for consistency from different approaches. The aquifer parameters are computed as below:

$$\text{Specific yield} = \text{Draft} / \text{water level changes} \tag{1}$$

$$\text{Recharge} = (\text{specific yield} * \text{water level changes}) + \text{Draft} \tag{2}$$

$$\text{Rainfall Recharge Factor} = \text{Recharge} / \text{Rainfall} \tag{3}$$

III. RECOMMENDATIONS OF GEC

GEC recommended ground water fluctuation and specific yield method, rainfall infiltration method for estimation of groundwater resources.

3.1. Groundwater fluctuation and specific yield method

The utilizable recharge is estimated based on pre-monsoon (April – May) to post monsoon (November) water level fluctuation for the areas receiving south west monsoon. Similarly for the areas receiving north-east monsoon water level fluctuation of pre monsoon (November) and post monsoon (March) have been taken in to consideration. The monitoring of water level network stations needs to be adequate space and time analysis of data carried out keeping in view of the hydro-geological situation. The specific yield values of the geological formations in the zone of water table fluctuation

3.2. Rainfall infiltration method

In areas where groundwater level monitoring is not adequate in space and time this method may be adopted. The norms for rainfall infiltration contributing to groundwater recharge are evolved, based on studies undertaken in various water balance projects in India. GEC recommended the norms for recharge from rainfall under various hydro geological situations. The normal rainfall

IV. LIMITATIONS OF GEC METHODOLOGY

4.1. Unit for ground water recharge assessment

Watershed has been proposed as a more desirable option, and in fact, some states are presently using watershed as the unit for ground water assessment. However, it is to be recognized that in alluvial areas, there may be ground water flow across watershed boundary also, as surface and subsurface water divides may not coincide. It has also been suggested that the unit for ground water assessment should be based on geo-morphological and hydro-geological characteristics.

4.2. Delineation of areas within a unit

The estimation of ground water recharge as per the basically three components: (a) recharge from rainfall (b) recharge from return flow from irrigation and other sources (c) potential recharge in waterlogged and shallow water table areas. Among these, the recharge from rainfall is the only component which is available in a distributed way over the entire block or taluka. Recharge from return flow from surface water irrigation, is mainly relevant only to canal command areas. In alluvial areas, some component of return flow from canal irrigation may be available downstream of the command area, but even here, the availability is spatially restricted. The potential recharge from waterlogged and shallow water table areas can also distort the estimate of available ground water, since this recharge can be realized only under special circumstances, and even then this water may be available only locally. Separate assessment may also be required for areas where ground water is saline. Hence, there is a necessity for delineation of different sub-areas within a unit for ground water assessment.

4.3. Season-wise assessment of ground water resource

There is a clear need expressed for season-wise assessment of the ground water resource for Kharif/ Rabi and summer seasons or for monsoon and non-monsoon seasons. It is felt that this approach may explain the paradox of water not being available in summer even for drinking purposes in hard rock areas.

4.4. Ground water resource estimate in confined aquifer

The GEC has made a brief mention regarding ground water resource estimation in confined aquifers, based on Darcy’s law. Questions have been raised on this aspect on three grounds: (a) practical utility of this estimate (b) reliability of the estimate, in view of the difficulty of delineating the confined and unconfined parts, or the recharge and discharge parts (c) possibility of duplication of resource estimation as the flow which enters the confined aquifer is already estimated under unconfined aquifer part due to their inter-relationship. However, there may be situations in alluvial areas where ground water estimate in confined aquifer may be an important aspect.

4.5. Estimation of specific yield

The ground water level fluctuation method requires the use of specific yield value as a key input for assessment of ground water recharge. The GEC suggests that for semi-critical and critical areas, pumping tests may be used for the estimation of specific yield. Regarding regional ground water assessment in hard rock areas, determination of specific yield through pumping tests has several limitations. First, there is an inherent bias in the location of test wells in terms of potential yield of the well for future utilization. Thus the local value may not be an average representation of the region. Secondly, pumping tests are more useful for estimating transmissivity value than specific yield value. Small duration pumping tests on dug wells are not suitable for the estimation of specific yield. Third, a proper estimation of parameters (including specific yield) from long duration pumping tests in hard rock areas, requires the use of fairly sophisticated modeling techniques, and simplistic estimates based on Theis curve (or some other simple models) may result in wrong assessment of specific yield. In alluvial areas, pumping tests may yield more representative values of specific yield, but here also, the tests should be of sufficiently long duration.

4.6. Ground water draft estimation

Ground water draft refers to the quantity of ground water that is being withdrawn from the aquifer. Ground water draft is a key input in ground water resource estimation. Hence, accurate estimation of ground water draft is highly essential to calculate the actual ground water balance available. The following three methods are normally used in the country for ground water draft estimation. (a) Based on well census data : In this method, the ground water draft is estimated by multiplying the number of wells of different types available in the area with the unit draft fixed for each type of well in that area. This method is being widely practiced in the country. (b) Based on electrical power consumed: In this method, the ground water draft estimation is done by multiplying the number of units of power consumed for agricultural pump sets with that of the quantity of water pumped for unit power. (c) Based on the ground water irrigated area statistics: In this method, the ground water draft is estimated by multiplying the acreage of different irrigated crops (cultivated using ground water) with that of the crop water requirement for each crop. In the recent years, studies conducted by NRSA have shown that remote sensing data collected from earth orbiting satellites provide information on ground water irrigated crops and their acreage. This can form an additional or alternate method for draft estimation in non-command area.

4.7. Ground water flow

The ground water level fluctuation method as per the GEC does not account for ground water inflow/outflow from the region and also base flow from the region, as part of the water balance. This means that the recharge estimate obtained provides an assessment of net ground water availability in the unit, subject to the natural loss or gain of water in the monsoon season due to base flow and inflow/outflow.

4.8. Return flow from ground water draft

The GEC recommends that 30% of gross ground water draft used for non-paddy areas may be taken as return flow recharge, and this is raised to 35% for paddy areas. It is generally felt that with respect to ground water irrigation, these estimates of recharge from return flow are high, particularly for non-paddy areas. It is even felt that when the water table is relatively deep and the intensity of ground water application is relatively low, return flow recharge may be practically negligible. On the other hand, some data available from Punjab, Haryana and Western UP suggests, that the return flow from paddy areas may be higher than 35%.

V. REVIEW OF PARAMETER ESTIMATION OF REGIONAL GROUNDWATER SYSTEM

Evaluation of properties of aquifers is an important aspect of any scheme of groundwater resource assessment. Aquifer parameters such as transmissivity, specific yield and rainfall recharge factor have to be estimated correctly in order to get proper assessment of groundwater. These parameters on regional scale are also useful in planning model of groundwater basin, conjunctive use models and river basin development models. These parameters on regional scale are not directly measurable. The information of the aquifer parameters obtained by conducting pumping tests at local levels. In all these studies two different flow conditions are assumed. First one is a steady state condition, i.e. when the flow is steady and water levels are ceased to decline. Second one is a non-steady state condition, i.e. when the aquifer is changing and water levels are declining: water is taken from storage within aquifer water level is gradually reduced.

5.1 Specific yield

The specific yield of the soil in the zone of water table fluctuation must be determined in order to estimate the available of water supply due to increment of water table during the period of recharge, as well as the water supply is obtainable for each incremental lowering of the water table.

5.2 Rainfall recharge factor

It is the ratio between recharge and rain fall, and expressed as percentage. For non-monsoon periods, generally there is no recharge. For monsoon equation (2) is used for estimating rainfall recharge factor estimated by using equation (3).

VI. PROPOSED METHODOLOGY

The proposed methodology follows the recommendations of Groundwater Estimation Committee, and it uses the water level changes in two specific seasons i.e. one monsoon period and other one is non-monsoon period. The methodology requires water level changes for specified seasons at number of well locations. In this methodology, specific yield is estimated using the non-monsoon water level changes by using equation (1).But there are different approaches are used for estimation of rainfall recharge factor and for the sake of convenience these are referred as Model 1, Model 2 and Model 3 respectively.

6.1. Model 1

By using non-monsoon water level changes and equation (1) the specific yield estimated for all the wells. The average specific yield value is used in equation (2) along with individual water level changes of wells during monsoon season and recharge values are obtained for each well location. The rainfall recharge factor values are obtained by using equation (3).

6.2. Model 2

In this the average specific yield of the region is estimated using equation (1) by considering average water level change in the region during non-monsoon period and the average specific yield value is used in equation (3) along with individual water level changes during monsoon period for estimation of rainfall recharge factor.

6.3. Model 3

In this average specific yield is not considered for the estimation of recharge. Individual specific yield values at each well location are obtains as explained in Model 1 and these individual specific yield values are used in equation (2) along with associated individual well water level fluctuations of monsoon period and recharge values are obtains for each well location. The rainfall recharge values are estimated by using equation (3).

VII. STUDY AREA CONSIDERED

The unit considered Kurnool district, which is in Andhra Pradesh state (India) lies between a latitude of 140 35' 35" - 160 09' 36"N and longitude of 750 58' 42" - 780 56' 06" of E occupying an area of 17600 sq.km. The study area receives an average rainfall of 665 mm per annum. The geological formation consists of shales, lime stones, granite gneisses and quartzites. Major rivers in this location are Krishna, Tungabhadra, Vedavati, Middle Pennar and soils are red earths, black cotton. Source of irrigation such as canals, tanks, dug wells, bore / tube wells. Gross area irrigated 2,98,842Ha.m.Major irrigation projects are Tungabhadra low level canal, Tungabhadra high level canal, K.C. canal, Gajuladinne project, Telugu Ganga Project. The aquifers contains water level in pre-monsoon 2.20 to 12.67 mbgl (meters below ground level) and post monsoon0.47 to 22.0 mbgl. Net annual ground water availability is 1,20,856 Ha.m and net annual draft 41,185Ha.m.The mandals in Kurnool district are shown in Fig.1 and Table.1. The revenue division in Kurnool district are shown in Fig.2. The details of water level changes are calculated by taking data of water level depths in wells of respective mandals of Kurnool district recorded by CGWB. In this study parameters estimation worked for entire district and also for three revenue divisions in this district. The data of water level changes shown inTable.2.

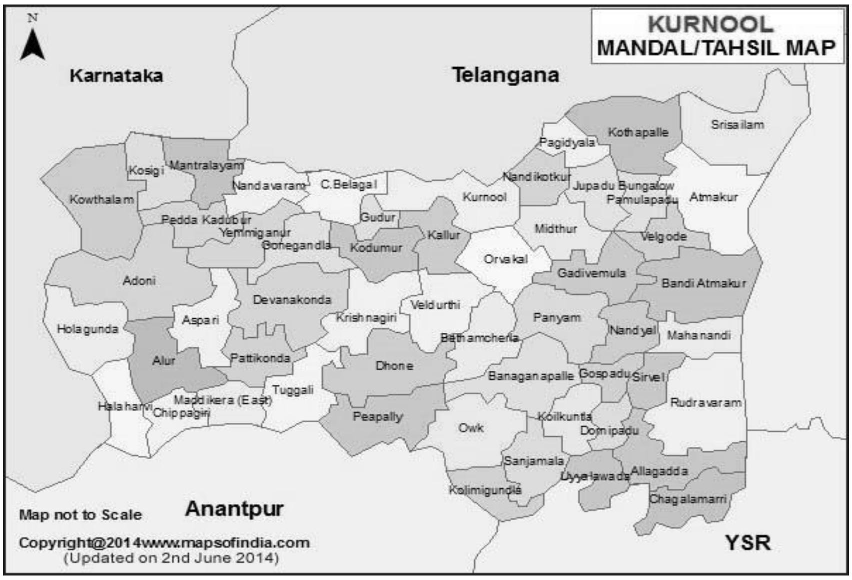

Fig 1.Mandals in Kurnool district, Andhra Pradesh (India)

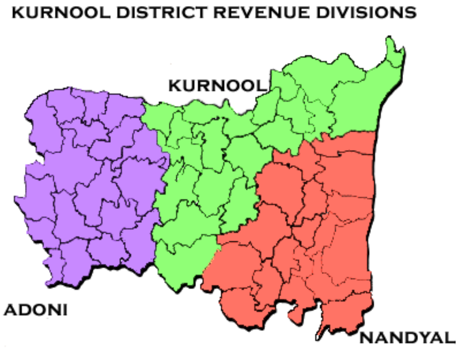

Fig 2. Revenue divisions of Kurnool dt district, Andhra Pradesh (India)

Table 1.Mandals in Kurnool district, Andhra Pradesh (India)

SL No.	Mandals in Kurnool district, Andhra Pradesh (India)	SL No.	Mandals in Kurnool district, Andhra Pradesh (India)
1	Kurnool	28	C. Belagal
2	Nandikotkur	29	Gudur
3	Pagidala	30	Kallur
4	Kothapalle	31	Orvakal
5	Srisailam	32	Midtur
6	Atmakur	33	JupaduBangalow
7	Velgodu	34	Pamulapadu
8	Bandiatmakur	35	Gadivemula
9	Mahanandi	36	Nandyal

10	Rudravaram	37	Gospad
11	Allagadda	38	Siruvel
12	Chagalamarri	39	Dornipadu
13	Uyyalawada	40	Koilkuntla
14	Sanjamala	41	Ba naganapalli
15	Kolimigundla	42	Bethamcherla
16	Owk	43	Dhone
17	Peapaly	44	Krislmagiri
18	Tuggali	45	Devenakonda
19	Maddikera	46	Pattikonda
20	Chippagiri	47	Alur
21	Halaharvi	48	Arpari
22	Holagunda	49	Peddakadbur
23	Adoni	50	Yemmiganur
24	Kowtllalam	51	Gonegandla
25	Kosigi	52	Kodumur
26	Manthralayam	53	Veldurthy
27	Nandavaram	54	Panyam

Table 2. Monthly water levels changes from wells located respective mandals for entire district

Sl. No.	**Mandal (well location)**	**Water levels changes (m)**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	Chagalamarri	7.75	9.52	12.70		14.20	14.00	13.90	12.10	10.50	8.63	4.94	
2	Kolimigundla	14.00	14.70	15.60		17.80	17.30	17.20		3.08	1.85		
3	Uyyalawada	3.92	3.98	12.50		4.11	4.22	4.35	4.45	4.13	3.57		
4	Allagadda	2.41	3.29	5.52		8.25	16.90	14.80	10.50	2.72	0.01		
5	Owk	3.80	3.64	3.68		3.61	3.88	3.69	3.62	2.85	2.60		
6	Chippagiri	4.10	4.23	4.40		4.65	4.76	4.55	4.49	3.70	2.55		
7	Koilkuntla	17.2	17.30	17.60		17.5	17.00	17.50	18.20	17.40	16.70		
8	Peapally	12.00				12.00			12.80			9.05	
9	Maddikera	11.60	11.80	12.00		12.40	12.50	12.30	12.30	11.10	8.50		
10	Banaganapalli	2.96	3.85			9.82	8.68	5.06	4.42	1.79	0.99		
11	Tuggali	12.10				13.00			7.75			8.05	
12	Pathikonda	12.20	12.70	13.30		14.30	14.60	8.52	7.80	5.47	3.75		
13	Aluru	9.83				12.40			8.78			7.05	
14	Dhone	8.61	8.80	9.13		9.25	9.35	8.70	8.20	5.88	4.94		
15	Bethamcherla	19.30	20.90	21.60		21.60	22.40	18.50	18.20	12.00	12.20		
16	Nandyal	5.51	5.74	6.36		6.89	7.18	7.45	7.11	5.69	4.82		
17	Aspari	8.42				12.90			6.72			5.70	
18	Holagonda	5.81				7.78			7.14	5.68	4.58	4.53	4.90
19	Panyam	11.30	11.80	13.90		16.90	17.60	18.80	16.10		11.70		
20	Veldurti	3.68				5.50			2.75			0.90	
21	Krishnagiri	6.58	8.57	16.10		15.60	15.40	9.17	16.10	7.30	5.72		
22	Devanakonda	15.3	15.30	16.50		16.90	17.00	16.90	16.80	15.90	15.90		

23	Bandiatmakur	2.30	2.50	2.75		3.76	4.21	4.61	3.74	2.75	1.43		
24	Kodumuru	6.67				7.10			4.46			5.90	
25	Gadivemula	7.85	7.78	8.02		8.15	8.22	8.34	8.15	7.81	7.21		
26	Orvakallu	5.14				4.30			2.96	1.80	1.03	1.60	2.60
27	Gonegandla	4.85				8.20			6.38			3.30	
28	Velugodu	3.20	3.30	3.56		4.47	4.72	3.88	2.05	1.94	1.74		
29	Gudur	19.00				10.70			14.60			10.80	
30	Yemiganur	7.65				7.50			11.00			4.15	
31	Kurnool	2.77	3.56	4.10		5.84	3.73	0.99	1.34	1.18	0.94		
32	Nandikotkur	19.20	19.50	20.10		19.60	18.50	18.00	15.50	13.60	12.60		
33	Kosigi	23.40	23.40	23.80		9.32	8.57	7.73	7.25	25.70	23.60		
34	Rudravaram	1.42				4.75			0.43			0.60	
35	JupaduBunglow	21.60	22.80	23.60		24.90	31.50	7.04	5.18	2.89	2.33		
36	Atmakur	10.60	11.30	12.00		15.40	16.10	13.00	4.82	1.60	1.53		
37	HariHalvi	6.93											
38	Mantralayam	7.77				8.67			10.80			4.47	

Table 3. Specific yield and rainfall recharge factor values for total district

Sl No.	Mandal (well location)	Specific yield	Rainfall recharge factor (%)		
			Model 1	Model 2	Model 3
1	Chagalamarri	0.025	4.25	3.88	3.54
2	Kolimigundla	0.009	5.62	4.54	3.57
3	Uyyalawada	0.253	3.59	3.55	3.52
4	Allagadda	0.017	4.61	4.05	3.55
5	Owk	0.135	3.65	3.58	3.52
6	Chippagiri	0.065	3.80	3.65	3.53
7	Koilkuntla	0.171	3.62	3.57	3.52
8	Peapally	0.011	5.10	4.29	3.56
9	Maddikera	0.035	4.03	3.77	3.53
10	Banaganapalli	0.015	4.68	4.09	3.55
11	Tuggali	0.011	5.24	4.35	3.56
12	Pathikonda	0.013	4.91	4.20	3.55
13	Aluru	0.011	5.16	4.32	3.56
14	Dhone	0.032	4.09	3.80	3.53
15	Bethamcherla	0.015	4.76	4.12	3.55
16	Nandyal	0.066	3.79	3.65	3.53
17	Aspari	0.011	5.22	4.35	3.56
18	Holagonda	0.043	3.94	3.72	3.53
19	Panyam	0.026	4.21	3.85	3.54
20	Veldurti	0.025	4.24	3.87	3.54
21	Krishnagiri	0.014	4.82	4.15	3.55
22	Devanakonda	0.137	3.65	3.58	3.52
23	Bandiatmakur	0.059	3.83	3.67	3.53
24	Kodumuru	0.019	4.46	3.98	3.54
25	Gadivemula	0.145	3.64	3.58	3.52
26	Orvakallu	0.042	3.95	3.73	3.53
27	Gonegandla	0.017	4.60	4.05	3.55

28	Velugodu	0.050	3.88	3.69	3.53
29	Gudur	0.013	4.93	4.21	3.56
30	Yemiganur	0.018	4.51	4.00	3.54
31	Kurnool	0.028	4.17	3.83	3.54
32	Nandikotkur	0.020	4.44	3.97	3.54
33	Kosigi	-0.010	1.63	2.60	3.47
34	Rudravaram	0.029	4.15	3.82	3.54
35	JupaduBunglow	0.006	6.50	4.97	3.60
36	Atmakur	0.010	5.35	4.41	3.57

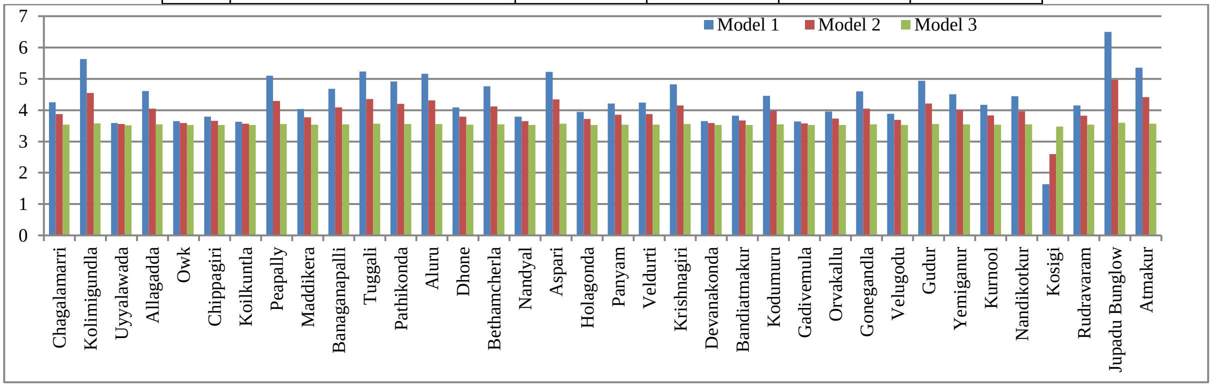

Fig3. Rainfall recharge factor values for entire Kurnool district

Table 4. Specific yield and rainfall recharge factor values for Kurnool revenue division

Sl No.	**Mandal (well location)**	**Specific yield**	**Rainfall recharge factor (%)**		
			Model 1	**Model 2**	**Model 3**
1	Peapally	0.011	4.22003	4.06015	3.73512
2	Dhone	0.032	3.77066	3.71323	3.59649
3	Bethamcherla	0.015	4.06810	3.94286	3.68825
4	Veldurti	0.025	3.84020	3.76692	3.61795
5	Krishnagiri	0.014	4.09615	3.96451	3.69690
6	Kodumuru	0.019	3.93369	3.83910	3.64679
7	Orvakallu	0.042	3.70988	3.66632	3.57775
8	Gudur	0.013	4.14406	4.00150	3.71169
9	Kurnool	0.028	3.80513	3.73985	3.60713
10	Nandikotkur	0.020	3.92785	3.83459	3.64499
11	JupaduBunglow	0.006	4.83770	4.53699	3.92567
12	Atmakur	0.010	4.32931	4.14451	3.76883

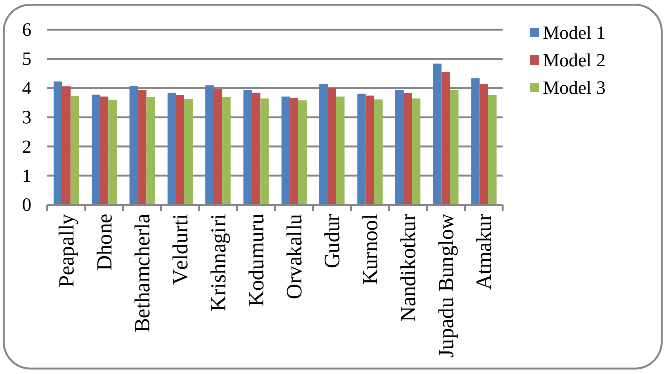

Fig 4. Rainfal recharge factor values for Kurnool revenue

Table 5. Specific yield and rainfall recharge factor values for Nandyal revenue division revenue division

Sl No.	Mandal (well location)	Specific yield	Rainfall recharge factor (%)		
			Model 1	Model 2	Model 3
1	Chagalamarri	0.025	6.29774	4.02135	3.81497
2	Kolimigundla	0.032	4.51690	4.95789	4.36691
3	Uyyalawada	0.015	5.69564	3.56752	3.54751
4	Allagadda	0.025	4.79248	4.26226	3.95694
5	Owk	0.014	5.80680	3.60992	3.57250
6	Koilkuntla	0.019	5.16301	3.59098	3.56134
7	Banaganapalli	0.042	4.27606	4.31549	3.98831
8	Nandyal	0.013	5.99669	3.70556	3.62886
9	Panyam	0.028	4.65353	3.98797	3.79530
10	Bandiatmakur	0.020	5.13985	3.72902	3.64269
11	Gadivemula	0.006	8.74553	3.60361	3.56878
12	Velugodu	0.010	6.73080	3.76511	3.66396
13	Rudravaram	0.015	3.51880	3.94737	3.77137

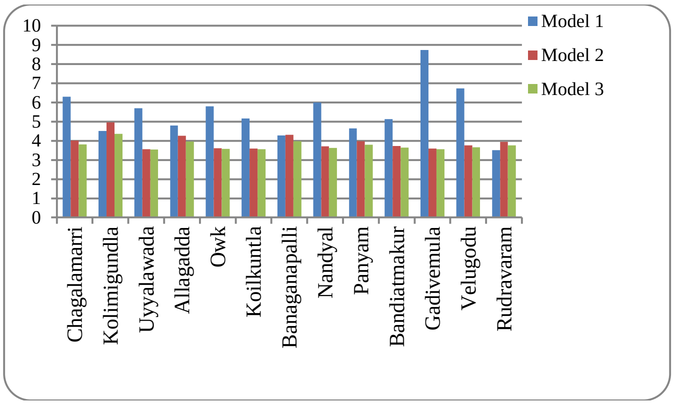

Fig 5.,Rainfall recharge factor values for Nandyal revenue division

Table 6. Specific yield and rainfall recharge factor values for Adoni revenue division

Sl No.	Mandal (well location)	Specific yield	Rainfall recharge factor (%)		
			Model 1	Model 2	Model 3
1	Chippagiri	0.065	3.72090	3.67669	3.54200
2	Maddikera	0.035	3.89414	3.81203	3.56188
3	Tuggali	0.011	4.76992	4.49624	3.66241
4	Pathikonda	0.013	4.53414	4.31203	3.63535
5	Aluru	0.011	4.71218	4.45113	3.65579
6	Aspari	0.011	4.76030	4.48872	3.66131
7	Holagonda	0.043	3.82677	3.75940	3.55415
8	Devanakonda	0.137	3.61504	3.59398	3.52984
9	Gonegandla	0.017	4.30797	4.13534	3.60939
10	Yemiganur	0.018	4.24060	4.08271	3.60165
11	Kosigi	-0.010	2.14448	2.44511	3.36104

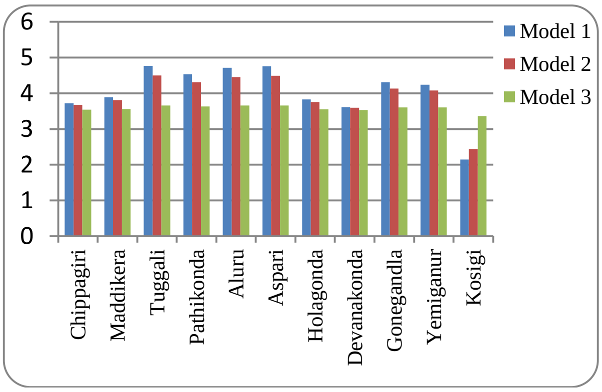

Fig 6.,Rainfall recharge factor values for Adoni revenue division

VIII. RESULTS AND DISCUSSIONS

The present methodology requires only water level changes and does not require any computational tools, and hence works out to be very economical. But it must be noted that specific yield and rainfall recharge factor are estimated using non-monsoon and monsoon data respectively.

8.1 Estimation of parameters for entire district

The Table.3 shows that the parameter specific yield values obtained for entire district. From the Table.3 it is observed that the well of Uyyalawada mandal shows the highest value of 0.253 while the well of kosigi mandal shows the lowest value of 0.000.The Fig.3 shows that the parameter rainfall recharge factor values obtained for entire district. From the Fig.3 it is observed that the well of Jupadu Bunglow mandal shows the highest value of 6.50% which is from Model 1 while the well of kosigi mandal shows the lowest value of 1.63% which is from Model 1.

8.2 Estimation of parameters for Kurnool revenue division

The Table.4 shows that the parameter specific yield values obtained for Kurnool revenue division. From the Table.4 it is observed that the well of Orvakal mandal shows the highest value of 0.042

while the well of Jupadu Bunglow mandal shows the lowest value of 0.006.The Fig.4 shows that the parameter rainfall recharge factor values obtained for Kurnool revenue division. From the Fig.4 it is observed that the well of dJupadu Bunglow mandal shows the highest value of 4.83% which is from Model 1 while the well of Kurnool mandal shows lowest value of 3.60% which is from Model 3.

8.3 Estimation of parameters for Nandyal revenue division

The Table.5 shows that the parameter specific yield values obtained for Nandyal revenue division. From the Table.5 it is observed that the well of Banaganapalli mandal shows the highest value of 0.042 while the well of Gadivemula mandal shows the lowest value of 0.006.The Fig.5 shows that the parameter rainfall recharge factor values obtained for Nandyal revenue division. From the Fig.5 it is observed that the well of Gadivemula mandal shows the highest value of 8.74% which is from Model 1 while the well of Rudravaram mandal shows the lowest value of 3.51% which is from Model 1.

8.4 Estimation of parameters for Adoni revenue division

The Table.6 shows that the parameter specific yield values obtained for Adoni revenue division. From the Table.6 it is observed that the well of Devanakonda mandal shows the highest value of 0.137 while the well of kosigi mandal shows the lowest value of 0.000.The Fig.6 shows that the parameter rainfall recharge factor values obtained for Adoni revenue division. From the Fig.6 it is observed that the well of Tuggali mandal shows the highest value of 4.76% which is from Model 1 while the well of Kosigi mandal shows the lowest value of 2.14% which is from Model 1.

IX. CONCLUSIONS

The present methodology requires only water level changes and does not require any computational tools, and hence works out to be very economical. But it must be noted that specific yield and rainfall recharge factor are estimated using non-monsoon and monsoon data respectively. In this monthly measurements are used. Among the three models which are used for estimation of rainfall recharge factor, Model 2 is better model because values are nearly matched with earlier investigations by inverse modelling for other parts of India. In this study aquifer parameters specific yield and rainfall recharge factor are estimated only.

Draft data as per monthly is used on roughly estimates. Assessment of parameters is worked out for both regional wise and zonal wise. Region taken as entire district and zones taken as revenue divisions. Sensitivity analysis is not carried for this study.

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