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Research Article

Estimation of Groundwater recharge studies in Gundal Watershed, Gundlupet Taluk, Chamarajanagar District, Karnataka, India using Remote Sensing and GIS

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Abstract

Water resources in Gundal watershed are unevenly distributed in spatial and temporal domains. Effectively utilizing the water resources is an imperative task due to climate change. At present, groundwater contributes 34% of the total annual water supply and is an important freshwater resource. However, over-exploitation has decreased groundwater availability and has led to land subsidence. Assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. this paper enlighten regarding the assessment of groundwater and groundwater potential Zones in the gundal watershed. Remote sensing and the Geographical Information System (GIS) are used to integrate five contributing factors: lithology, land cover/land use, lineaments, drainage, and slope. The weightage of factors contributing to the groundwater recharge are derived using aerial photos, geology maps, a land use database, and field verification. The resultant map of the groundwater potential zone demonstrates that the highest recharge potential area is located towards the downstream regions in the basin because of the high infiltration rates caused by gravelly sand and agricultural land use in these regions. In contrast, the least effective recharge potential area is in upstream regions due to the low infiltration of the area. In this study Groundwater Resource Estimation Committee's methodology - 1997 as followed for evaluating the groundwater recharge estimation. Rainfall infiltration method (RF) and Water table fluctuation method (WTF) based on crop duty and unit draft methods are used for groundwater recharge assessment. The study reveals that the Gundal watershed is Categorize as a critical to overexploited area.

Keywords: *Geographical Information system, Groundwater recharge, infiltration, Groundwater recharge estimation, Potential Zones.*

Introduction

Groundwater recharge refers to the entry of water from the unsaturated zone into the saturated zone below the water table surface, together with the associated flow away from the water table within the saturated zone (Freeze and Cherry 1979). Recharge occurs when water flows past the groundwater level and infiltrates into the saturated zone. Occurrence and movement of groundwater in a region including topography, lithology, geological structures, and depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use / land cover, and climate (Mukherjee 1996; Jaiswal*et al*. 2003).

Study Area

Gundal watershed falls in Gundlupet taluk of Chamarajanagara district, Karnataka state with an geographical extent of 790 sq. km covering parts or whole of 120 revenue villages. It's located between the latitude 11^{0}41'00 to 11^{0}51'15 N and longitude 76^{0}30'45 to 76^{0}51'15 E falls in Survey of India (SOI) toposheetsnos 58A/9, 58A/10, 58A/13 and 58A/14 on a 1:50,000 scale **(Fig 1.)**.

The climate of the area is semi-arid, mean maximum temperature is 34.6^{0}C in the month of April is the hottest month in the year and mean minimum temperature is 19^{0}C to 19.5 ^{0}C recorded in the month of January and December. The average annual rainfall is 716 mm. Gundlupettaluk is a tri-junction point, connected between Karnataka, Tamilnadu and Kerala state by very good state high way. All the revenue villages in the study area have a good network of roads with good communication facilities. Relative humidity ranges from 53.20 to 78.53 % in the morning and in the evening it ranges from 47.80% to 69.30%. The wind speed ranges from 8.4 to 19.5 kmph. The potential evopo-transpiration in Gundal watershed is ranged from 106 mm to 165 mm/year.

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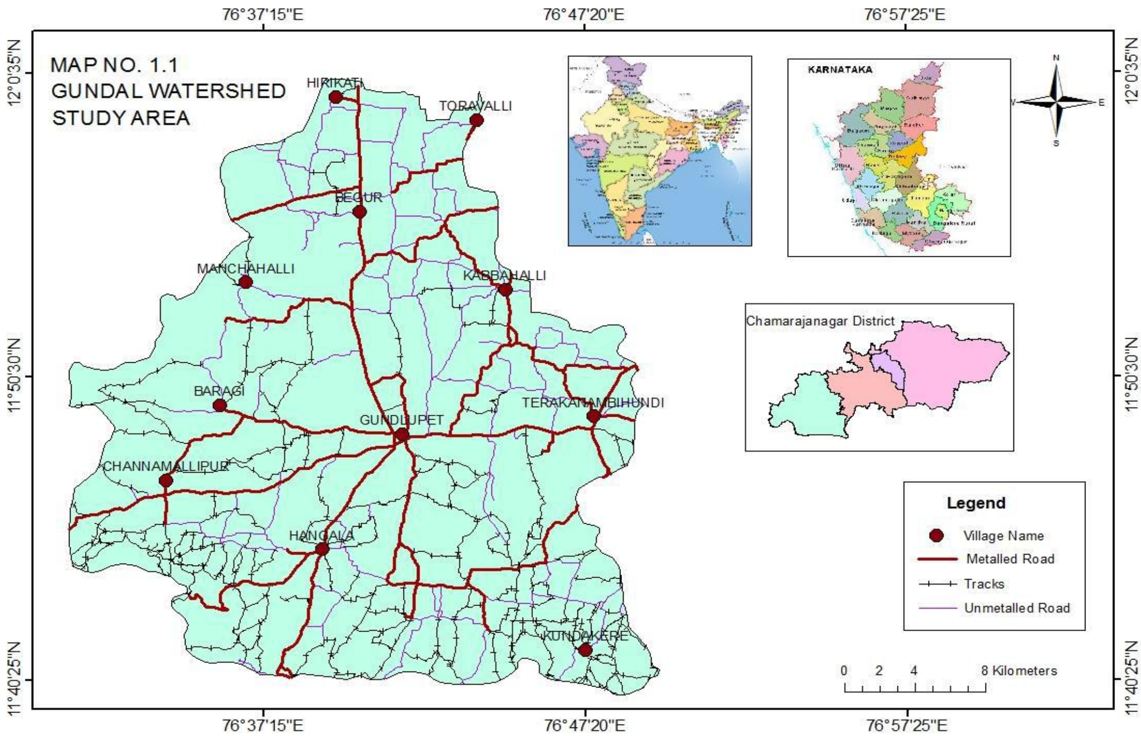

Fig.1 Location of the study area

Methodology

Remote Sensing technology, such as aerial photos and satellite imageries used in the present study to identify the geological features, topography, distribution of drainage system with lineament. Additionally, the Land Utilization Survey Database, geologic maps, and on-site investigation were adopted to quantitatively and qualitatively describe the hydro-geological conditions of the area. The different polygons in the thematic maps were labeled separately. The influence of the factors of groundwater recharge and the interaction between the factors were examined. Weighting values were assigned according to the on-site situation. The distribution of the groundwater recharge potential zone was determined by coordinating it with the space integrating function of the Geographical information system. **(Fig 7)**

Factors Influencing on Groundwater Recharge

Factor basis of categorization, lithology, land use/cover, lineaments, drainage, and slope as the five significant factors affecting groundwater recharge. The factors influencing groundwater recharge potential**.** GIS technology was used to digitize the hydrologic and geographic information, and a fundamental database was constructed. Appropriate scores were set for different factors. Therefore, the spatial analysis function was used to demonstrate the groundwater recharge potential zone of the research area. Establishment of groundwater recharge potential-related factors **(Fig.7)**

Lithology

Lithology affects the groundwater recharge by controlling the percolation of water flow (El-Baz and Himida 1995) **(Fig.2**) Although some investigations have ignored this factor by regarding the lineaments and drainage characters as a function of primary and secondary porosity, this paper includes lithology to reduce uncertainty in determining lineaments and drainage. The study area mainly comprise with granitic gneiss with enclaves of sargur group of rocks and charnakites.

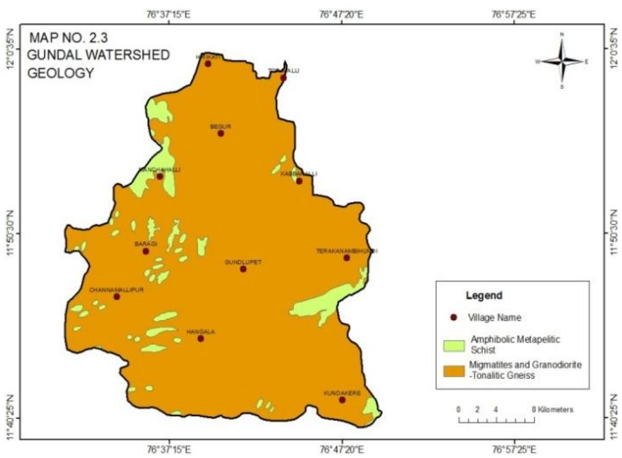

Fig.2 Lithology of the study area

Slope

Rainfall is the main source of groundwater recharge in tropic and subtopic regions. The slope gradient directly influences the infiltration of rainfall. Larger slopes produce a smaller recharge because water runs rapidly off the surface of a steep slope during rainfall, not having sufficient time to infiltrate the surface and recharge the saturated zone. Interrelationships between the factors of the groundwater recharge potential there might be interactions between the factors of groundwater recharge. This study used five factors of groundwater recharge potential, namely lithology, land use/cover, lineaments, drainage, and slope. A plot of the interrelationship between these factors is shown in **Fig. 3** and illustrates the primary and secondary interrelationships among the factors. Each relationship is weighted according to its strength. The representative weight of a factor of the recharge potential is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact on groundwater recharge. Spatial integration and analysis was performed using GIS technology to demonstrate the groundwater recharge potential zone as depicted in **(Fig.7)**

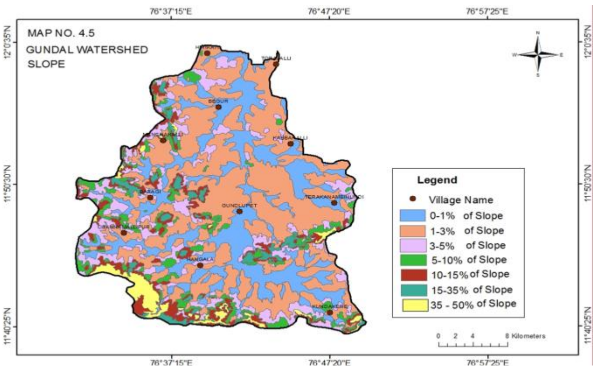

Fig.3 Slope of the study area

Drainage

The structural analysis of a drainage network helps assess the characteristics of the groundwater recharge zone **(Fig.4).**

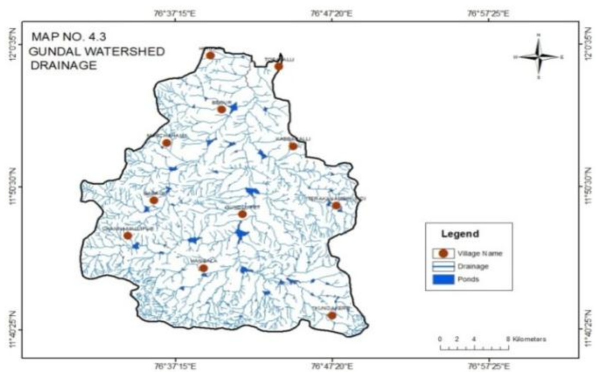

Fig.4 Drainage of the study area

The quality of a drainage network depends on lithology, which provides an important index of the percolation rate. The drainage-length density (Dd, L-1), as defined by Greenbaum (1985), indicates the total drainage-length in a unit area, and is determined by: Dd ¼ P i¼n i¼1 Si A where P i¼n i¼1 Si denotes the total length of drainage (L) and A denotes the unit area (L2). The drainage-length density is significantly correlated with the groundwater recharge; a zone with a high drainage-length density has a high level of groundwater recharge. Many studies have integrated lineaments and drainage maps to infer the groundwater recharge potential zone (Edet*et al*. 1998; Shaban*et al*.2006).

Lineaments

The analysis of lineaments has been applied extensively to explain geological status since geological images were first utilized in the 1930s (**Fig 5**).

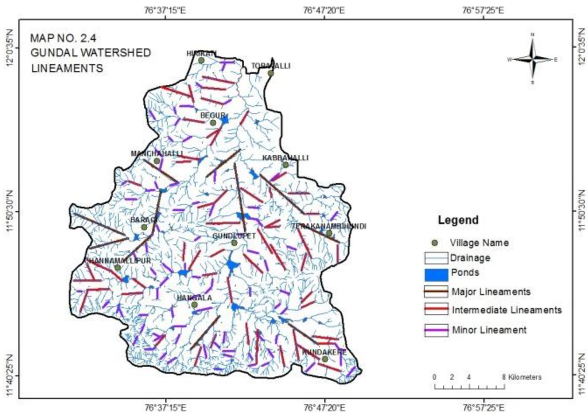

Fig.5 Lineament of the study area.

Lineaments are generally referred to in the analysis of remote sensing of fractures or structures. Lineament photos from satellites and aerial photos have similar characteristics but the results of the explanation in on-site may be different. Lineaments are currently not fully defined. O'Leary *et al*. (1976) has defined lineaments as the simple and complex linear properties of geological structures such as faults, cleavages, fractures, and various surfaces of discontinuity, that are arranged in a straight line or a slight curve, as detected by remote sensing. Many non-geological structures, such as roads and channels, cause errors in the analysis of lineaments. Therefore, geologic maps and on-site investigations must be used to eliminate possible errors. Lineaments may be used to infer groundwater movement and storage. Lattman and Parizek (1964) were the first to adopt a lineaments map to exploit groundwater. Thereafter, many scholars have applied this approach in complicated geological regions (Solomon and Quiel 2006). The present study used lineament-length density(Ld, L-1) (Greenbaum 1985), which represents the total length of lineaments in a unit area, as:

Ld ¼ P i¼n i¼1 Li A where P i¼n i¼1

Li denotes the total length of lineaments (L) and A denotes the unit area (L2). A high lineament-length density infers high secondary potential. In the study area 12 major lineament, 52 intermediate and 169 Minor lineaments are identified.

Land use/land cover

Land use /land cover is an important factor in groundwater recharge **(Fig 6)**. It includes the type of soil deposits, the distribution of residential areas, and vegetation cover. Shaban*et al*. (2006) concluded that vegetation cover benefits groundwater recharge as follows biological decomposition of the roots helps loosen the rock and soil, so that water can percolate to the surface of the earth easily, Vegetation prevents direct evaporation of water from soil, The roots of a plant can absorb water, thus preventing water loss. Leduc *et al*. (2001) estimated the difference for recharge due to changes of land utilization and vegetation from changes in the groundwater level. Land use/land cover was included in this paper, as an important factor affecting the groundwater **(Fig.7)** Methodology flowchart for the groundwater potential zone recharge process.

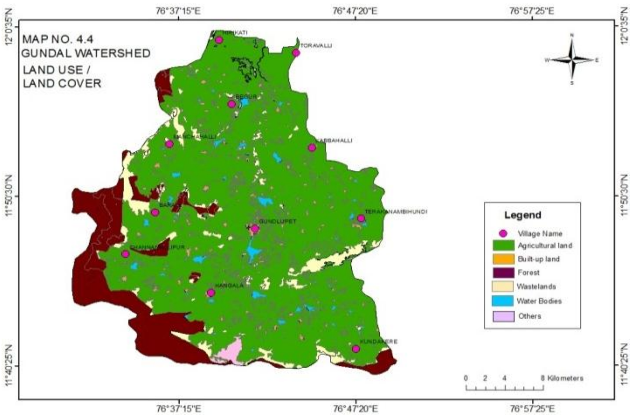

Fig.6 Land Use/ Land Cover of the study area

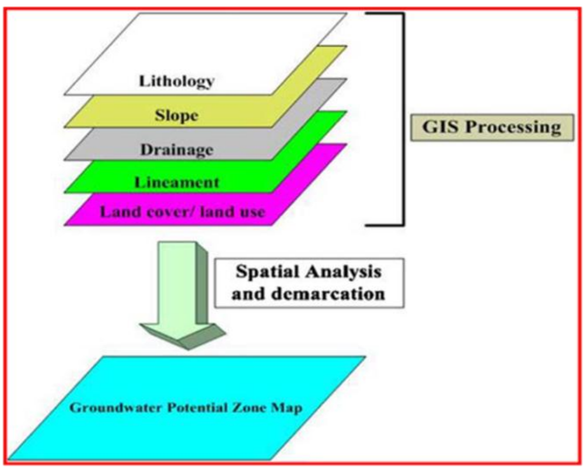

Fig.7 Methodology- flow chart for the groundwater potential zone recharge process

Results and Discussions

Groundwater recharge estimation can be based on various models which are designed to represent the actual physical processes. Methods which are currently in use include Zero flux plane method; Soil water balance method (soil moisture budget);Inverse modelling for estimation of recharge (two-dimensional groundwater flow model); Saturated volume fluctuation method (ground water balance); One-dimensional soil water flow model; and (vi) isotope techniques and solute profile techniques. Quantification of natural groundwater recharge is a basic pre-requisite for groundwater resource management. The techniques are used to assessment of groundwater recharge rates are 1. Darcian approach, 2.Soil water balance approach, 3. Water level fluctuation,4. Rainfall infiltration factor,5. Tracer techniques, 6.Chloride mass-balance, 7.Isotope dating, 8. Water budgeting, Information about these methods is given in Gee and Hillel (1988); Simmers (1988, 1997); Sharma (1989); Lerner *et al.*(1990); Allison *et al* (1994); Stephens (1994, 1996); Bredenkamp*et al.* (1995); Lerner (1997); De Vries and Simmers (2002); and Scanlon *et al.* (2002).In this paper , Groundwater Resource Estimation Committee's methodology -1997 as followed for evaluating the groundwater recharge estimation. Rainfall infiltration method (RF) and Water table fluctuation method (WTF) based on crop duty and unit draft methods are used for groundwater recharge assessment.

Groundwater Recharge estimation of Gundal Watershed

Groundwater is an important variable in regional scale hydraulic models and aquifer system analysis (Gehrels*et al.*, 2001) when water flow passes groundwater level and infiltrates into the saturated zone it is called groundwater recharge. In the Gundal watershed, there is no surface water. The river Gundal is completely dried up and there is no flow for the past 20-25 years as per the local enquiry and satellite image data. There is no major tank in this area. Hence, the area is totally depending upon the groundwater for all purpose. The total geographical area of Gundal watershed is 79,000 hectares out of which, rocky area (76 hectares), forest land (16,357 hectares) and area with more than 20% slope (274 hectares), accounts to 16707 hectares and the remaining 62293 hectares are considered as non-command aquifer area (Item No.6 of **Table 7).** The groundwater level observation wells data, of 14 years (2001 to 2014) were collected from the Department of Mines and Geology, Government of Karnataka. Water table fluctuation is calculated as 2.36 m **(Table 4).** The specific yield is considered as 3% for water table fluctuation method as per GWREC 1997 report page No.52 item No. 5.9.1. The groundwater recharge from rainfall by rainfall infiltration factor is also adopted. In this method, the rainfall infiltration factor is considered as 11% as per GWREC 1997 report page No.53 item No. 5.9.2.

Table: 1 Average Annual and Monthly Rainfall Data of Gundal Watershed from the ear 1980-2014 in mm

S No	Name of the Rain gauge Station	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Rainfall
			Pre- monsoon					SW-monsoon				NE- Monsoon			
1	**Gundlupet**	1980-2014	4.1	6.21	21.66	81.8	118.1	55.17	49.66	95.7	93.7	151	80.77	24.1	**782.03**
2	**Begur**	1980-2014	4.7	5.67	19.94	69.86	100.4	67.66	59.6	54.4	81.68	126.2	65.77	15.2	**671.12**
3	**Kundakere**	1980-2014	1.5	7.45	19.05	74.54	118	49.88	44.52	59.97	109.6	159.7	103.2	28.9	**776.22**
4	**Terakanambi**	1980-2014	5.4	6.53	13.3	51.52	96.37	39.64	51.93	66.43	112.9	159.5	84.97	18.8	**707.26**
5	**Mookahalli**	1980-2014	10.9	13.45	20.92	68.5	75.5	85.3	81.8	33.9	99.77	113.6	57.7	10.2	**671.54**
6	**Hangala**	1980-2014	2.53	2.2	7.84	78.77	114.7	38.04	52.91	56.41	83.73	150.2	80.09	22	**689.4**
Total			203.57					270.72				**241.98**			**716**

Table: 2 Average Monsoon Rainfall of Gundal watershed from 1980 to 2014 in mm

Raingauge Station	May	Jun	Jul	Aug	Sep	Oct	Monsoon
Gundlupet	118.14	55.17	49.66	95.7	93.7	151.2	563.57
Begur	100.4	67.66	59.6	54.4	81.68	126.23	489.97
Kundakere	118	49.88	44.52	59.97	109.6	159.66	541.63
Terakanambi	96.37	39.64	51.93	66.43	112.94	159.51	526.82
Mookahalli	75.5	85.3	81.8	33.9	99.77	113.6	489.87
Hangala	114.65	38.04	52.91	56.41	83.73	150.23	495.97
Average Monsoon =**518mm**							
Source: District Statistical Department. Government of Karnataka							

Table: 3 Average Non monsoon Rainfall of Gundalwatershed from 1980 to 2014 in mm

RaingaugeStation	Jan	Feb	Mar	Apr	Nov	Dec	Non monsoon
Gundlupet	4.11	6.21	21.66	81.8	80.77	24.11	218.66
Begur	4.68	5.67	19.94	69.86	65.71	15.23	181.09
Kundakere	1.45	7.45	19.05	74.54	103.1	28.9	234.49
Terakanambi	5.37	6.53	13.3	51.52	84.91	18.75	180.38
Mookahalli	10.9	13.45	20.92	68.5	57.7	10.2	181.67
Hangala	2.53	2.2	7.84	78.77	80.09	22	193.43
Average non-monsoon =**198 mm**							
Source: District Statistical Department, Govt. of Karnataka							

Table: 4 Water table Fluctuation in Gundal Watershed from 2001 to 2014 in mts

Name of the village	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Min	Max	Flx
Gundlupet	31.2	31.77	32.1	31.93	34.7	31.17	31.76	34.78	30.58	34.02	33.15	30.4	30.4	34.8	4.38
Terakanambi	26.5	27.19	28	27.81	27.8	28.93	29.91	28.13	29.95	28.23	26.73	28.75	26.53	30	3.42
Hasaguli	26	26.82	27.5	27.47	28.3	29.41	30.32	30.32	29.64	28.68	26.46	27.12	26.01	30.3	4.31
Bommalapura	22.6	23.17	23.4	23.76	23.1	23.43	23.53	23.75	23.19	22.9	22.55	23.21	22.55	23.8	1.21
Siddaianapura	36.4	36.86	37	36.71	36.2	35.87	37.59	38.4	38.46	37.23	36.37	33.5	33.5	38.5	4.96
Kaggalahundi	9.85	10.47	9.52	10.31	8.7	8.94	10.41	10.05	8.51	8.81	8.35	9.56	8.35	10.5	2.12
Begur	3.51	4.11	4.02	4.68	3.91	4	3.63	3.59	3.41	2.57	2.26	2.82	2.26	4.68	2.42
Averge water level fltuctuation =**3.26**															
Source: Dept. of Mines and Geology, Govt. of Karnataka															

Table: 5 Crop duty and Groundwater Recharge

SNo.	Name	Paddy Monsoon	Paddy Non-Monsoon	Vegetables, Fruits and Flowers			Perennial			
				Khariff Season	Rabi Season	Summer Season	Sugarcane	Banana	Turmeric	Coconut
1	**Extent in Acres**	Nil	Nil	6378.66	4967.39	2137.56	3704.59	3823	4900	3082.09
2	**Extent in Hectares**	Nil	Nil	2581.41	2010.27	865.05	1499	1547.14	1983	1247.3
3	**Water requriment in mts(per Hectare)**	Nil	Nil	0.21	0.29	0.56	1.2	1.2	1.2	0.56
4	**Total water requriment n mts (per Hectare)**	Nil	Nil	542.09	582.97	484.43	1798.8	1856.57	2379.6	698.488
5	**%of recharge considered**	20%	20%	5%	5%	5%	20%	20%	20%	5%
6	**Ground water recharge in hectare meter**	Nil	Nil	27.1	29.145	24.22	359.76	371.514	475.92	34.92

Table: 6 Groundwater categorization

S.No	Category	Percentage
1	**Safe**	<70%
2	**Semi Critical**	70%-90%
3	**Critical**	90%-100%
4	**Over exploited**	>100%

Table: 7 Summary report in respect of Gundal watershed for groundwater recharge estimation

1	**Watershed Assessment year 2013-14**	
2	State	Karnataka
	District	Chamarajanagara
	Taluk	Gundlupet
3	Type of groundwater assessment unit	Watershed
4	Name	Gundal
5	Type of rock formation	Granitic Gneiss, Amphibolite schist Charnockite&metaphelite
6	Areal extent in hectares	
	(a) Total geographical area (ha)	79000
	(b) Area with more than 20% slope, rocky and forest	16707
	(c) Poor groundwater quality area	Nil
	(d) Groundwater assessment area (a-b-c) (ha)	**62293**
	(e) Command area	Nil
	(f) Non-command area (ha)	**62293**
7	Specific yield in % (as per norms) Page no. 52 of G.W.R.E.C 1997 report.	**3%**
8	Water Table Fluctuation in mts.	3.26
9	Rainfall considered (mm)	
	(a) Average annual rainfall (mm)	716.3
	(b) Average monsoon rainfall	518
	(c) Average non-monsoon rainfall	*198*
10	Infiltration percentage (as per norms)	11%
	(Page no. 53 of GWREC. 1997 report item no 5.9.2.)	
11	Population as on 2011	2,32,456
12	Population as on 2014	2,46,403
13	Population by 2025	2,97,543
14	Number of irrigation wells as on 2013	
	(a) Bore wells	6577
	(b) Dug wells	232
	(c) Dug cum bore wells	214
	Total	**7023**
15	Unit draft considered (ham/well) as per the field conditions.	
	(a) Bore wells	1
	(b) Dug wells	0.6
	(c) Dug cum bore wells	0.8
16	Groundwater draft in ham (as per unit Draft method)	

	(a) Annual groundwater draft	6887
	(b) G.W.draft during monsoon season (30% of annual groundwater draft)	2066
	(c) G.W.draft during non- monsoon season (70% of annual groundwater draft)	4821
17	Cultivable area in hectares	
	(a) Paddy –Monsoon	Nil
	(b) Paddy-Non-monsoon	Nil
	(c) Non-paddy- monsoon	8805
	(d) Non-paddy-Non monsoon	5320
	(e) Perennial crops	1499
	1. Sugarcane	1547
	2. Banana	1983
	3. Turmeric	1247
	4. Coconut	Nil
18	Water requirement in ham (based on crop pattern)	
	a) paddy-Monsoon	Nil
	(b) Paddy-Non monsoon	1125.06
	(c) Non-paddy –monsoon	484.43
	(d) Non-paddy –non monsoon	1798.8
	(e) Perennial crops	1856.57
	1. Sugarcane (1.20)	2379.6
	2. Banana (1.20)	698.49
	3. Turmeric (1.20)	
	4. Coconut (0.56)	**6733.46**
	Perennial crops Total	
	30% Monsoon	2020.04
	70% Nonmonsoon	4713.42
19	Groundwater draft in ham (as per crop duty method)	
	(a) Annual groundwater draft	8342.95
	(b) G.W.draft during monsoon season	3145.1
	(c) G.W.draft during non- monsoon season	5197.85
20	Groundwater recharge from the cultivable area through irrigation wells in ham	
	a) Paddy Monsoon	Nil
	(b) Paddy-Non monsoon	Nil
	(c) Non paddy –monsoon	52.245
	(d) Non paddy –non monsoon	24.22
	(e) Perennial crops - Monsoon(30%)	372.57
	Non monsoon(70%)	869.34
	Annual	**1241.91**
	Groundwater recharge during monsoon season	428.82
	Groundwater recharge during non monsoon season	893.56
	Annual groundwater recharge	**1322.38**
	Water conservation structures	5
21	(A) Check Dams	1
	(a) Width in mtrs.	15
	(b) Height in mtrs.P	0.5
	(c) Water spread area length in mtrs.	178
	(d) Depth of water column in mtrs.	6
	(e) No. of CDs existed as on 2013	Nil
	(f) No. of fillings during monsoon period only	0.00093
	(g) No. of fillings during non-monsoon period	0.00093
	(h) Unit storage per ARS in ham	0.0056
	(i) Recharge from one filling per CD in ham	0.99
	(j) Recharge from 6 fillings (ham)	Nil
	(k) Recharge for all the CD s (ham) monsoon	0.99
	(l) Recharge for all the CDs(ham)non monsoon	
21B	(B) Infiltration Wells	
	(a) Width in mtrs.	2.5
	(b)Height in mtrs.	3
	(c)Depth	5

	(D) Volume	37.5
	(E) Voids %	30%
	(F) Water holding capacity mt^3	11.25
	(G) Recharge for one filling ham	0.001125
	(H) Recharge for 8 fillings ham	0.007
	(I) Total number of Infiltration Wells	356
	(J) Total Recharge during monsoon ham	2.49
	(K) Recharge during non-monsoon ham	Nil
22	Recharge from tanks (Rt)	
	(a) Total number of tanks	13
	(b) Area of the tanks in ham	616.33
	(c) Average water spread area in ham	225.13
	(d) Unit seepage per day in mm	30
	(e) Number of days of storage during monsoon period	Nil
23	Recharge from tanks command	
	(1) Area of the tank command	9.46
	(2) Paddy monsoon	Nil
	(3) Paddy non monsoon	Nil
	(4) Non Paddy monsoon	Nil
	(5) Non Paddy non monsoon	Nil
	(6) Water requirement for Paddy during monsoon	Nil
	(7) Recharge from tank command	Nil
	(8) The Net recharge from tanks and tank command (Rt+Rtc)	9.46+0=9.46

Table: 8 Groundwater recharge estimation in Gundal watershed

S.No	Calculations	Crop duty method		Unit draft method	
		WTF	*RF*	*WTF*	*RF*
1	Recharge from the rain fall during monsoon season in hems (a) Water table fluctuation Method: Rrf = (h x Sy x A) + Dg – Rgw – Rwc – Rt =(3.26x0.03x62293)+3145.10-428.82-3.48-9.46) (CD) 3.26x0.03x62293+2066-320.24-3.48-9.46 (UD) (b) Rainfall infiltration method Rrf = A x RF in mts x infiltration factor in % =62293x518/1000x11/100 (CD)	8795.56	3549.45	7825.08	3549.45
2	Recharge from other sources during monsoon in ha (a) Rgw=Recharge from the groundwater irrigation =428.82 (b) Rwc = Recharge from water conservation structures =3.48 (c) Rt - Recharge from tanks =9.46 Recharge from the other sources during monsoon season = Rgw +Rwc +Rt =428.82+3.48+9.46 320.24+3.48+9.46	441.76	441.76	333.18	333.18
3	Recharge from rainfall during non monsoon season in ham (a) Water table fluctuation method - (b) RF – rainfall infiltration method Area X RF in mtr. X Infil.factor in % 62293x198/1000x11/100	Nil	1356.74	Nil	1356.74
4	Recharge from other sources during non monsoon season (a) Rgw = Recharge from the ground water irrigation **(893.56-CD), (747.31-UD)** (b)Rwc =Recharge from water conservation structures **(0-CD), (0-UD)** (c) Rt = recharge from tanks **(0-CD), (0-UD)** – Recharge from other sources during non monsoon season = Rgw+Rwc+Rt (893.56+0+0)	893.56	893.56	747.31	747.31

5	Total annual groundwater recharge in ham (CD method) (a) 1a+2+3a+4=8795.50+441.76+0+893.56 (b) 1b+2+3b+4=3549.45+441.76+1356.74+ 893.53 UD method 7825.08+333.18+0+747.31 3549.45+333.18+1356.74+747.31	10130.88	6241.51	8905.57	5986.68
6	Natural discharge during non monsoon in ham –10 % of annual GW recharge as per 5-10-1 of GWECR.1997	1013.09	624.15	890.56	598.67
7	Net groundwater availability (5 – 6) in ham 1. 11242.91-1124.29=10118.62-CD 2. 7240.43-724.04=6516.39-CD 3. 9346.38-934.64=8411.74-UD 4. 6731.27-673.13=6058.14-UD	9117.79	5617.36	8615.01	5188.01
8	Existing groundwater draft for irrigation in ham a) unit draft method 1) Bore wells 2) Dug cum bore wells 3) Dug wells l 4) crop pattern method	5095 134.4 14.4 8342.95	5095 134.4 14.4 8342.95	6887	6887
9	Existing groundwater draft for domestic use at 60 Lpd per head as on 2011 in ham 246403x60/1000x365/10000	540	540	540	540
10	Existing groundwater draft as on 2014 - (8 + 9) in ham 8343+540=8883	8883	8883	7427	7427
11	Allocation for domestic use at the year 2025 at 60 Lpd in ham 297543x60/1000x365/10000	652	652	652	652
12	Net groundwater availability for future irrigation development in ham - (7-8-11) in ham 9117.792-8342.95-652=122.84 5617.36-8342.95-652=-3378 8015.01-6887-652=476.01 5388.01-6887-652=2151	122.84	-3378	476.01	-2151
13	Method adopted for computing recharge during monsoon - WATER TABLE FLUCTUATION & RF both methods is shown.	WTF	RF	WTF	RF
14	Existing stage of groundwater development in % 8883x100/9117.792=97.42%-CD 8883x100/5617.36=158.13% CD (5244+540)x100/8015.01=92.66%-UD (5784+540)x100/5388.01=137.84-UD	97.42%	158.13%	92.66	137.84
15	Is there a significant decline of pre monsoon water table level	Yes	Yes	Yes	Yes
16	Is there a significant decline of post monsoon water level				
17	Categorization for further ground water development as (a) Safe (< 70%) (c) Critical (90% - 100%) (b) Semi Critical (70% - 90%). (d) Over exploited (> 100%)	Critical	Overexploited	Critical	Overexploited

The average rainfall for a period of 35 years i.e. from 1980 to 2014 is considered for 6 raingauge stations which are located in the Gundal watershed and monitored daily by statistical department, Government of Karnataka. The average annual rainfall is 716 mm (**Table 1),** of which, average monsoon rainfall account to 518mm (**Table 2)**& average non monsoon rainfall accounts to 198 mm **(Table 3).** The groundwater recharge from rainfall by rainfall infiltration factor method is assessed for both monsoon & non monsoon periods, because the average non monsoon rain fall is more than 10% of the average annual rainfall as per GWREC 1997 report page No.50 item No. 5.7.2. As per the field enquiry and data collected from various Government departments, there are 6577 bore wells, dug wells 232 and dug com bore wells 214 are present in this area (dried wells 1568 in this area are excluded). As per the norms and field enquiry the unit draft considered for bore wells is 1, dug wells is 0.6 and dug com bore wells is 0.80 and total groundwater draft by this method is 6887Ham,of which 2066 Ham is considered as monsoon draft and 4821 Ham is considered as non-monsoon draft. The groundwater draft is also estimated based on the crop patterns. The annual groundwater draft by this method is estimated as 8342.95 Ham. Of which, 3145.10 Ham is considered as monsoon draft and remaining 5197.85 Ham is considered as non-monsoon draft. As per the 2011 census, Gundal watershed included 120 revenue villages with 2, 32,456 population. By the year 2014 it is estimated as 2, 46,403 population and by the year 2025, it is estimated as 2, 97,543. For catering domestic water supply for a population of 2, 46,403 is estimated as 540 Ham at the rate of 60 LPD per person. By the year 2025, the groundwater draft for domestic needs is accounted as 652 Ham. The net groundwater draft for domestic needs & for agricultural purposes as on 2014 and by unit draft method is 8883 and by crop duty is 7427 Ham. Recharge from groundwater irrigation during monsoon period is 428.82 Ham and non-monsoon period is 893.56 Ham. The recharge from water conservation structures is 3.48 ham and recharge from tanks is estimated as 9.46 Ham during monsoon season. The total recharge from other sources during monsoon season is assessed as 441.76 Ham and during non-monsoon season is estimated as 1356.74 Ham. The recharge from rainfall by water table fluctuation method is estimated as 7825.08 Ham by unit draft consideration and 8795.56 Ham as based on the crop duty. The total annual ground water recharge by WTF method is estimated as 9346.38 Ham by the unit draft consideration and 11242.91 Ham as based on crop duty. The natural discharge during non monsoon season is 10% of the annual groundwater recharge as per GWREC 1997 report page No.56 item No. 5.10.1. The net groundwater availability is estimated as 8411.74 Ham by unit draft consideration and 10118.62 Ham as based on crop duty **(Table-7and 8).** The net groundwater availability for future irrigation development by WTF method is 2516 by the unit draft consideration and 1123.62 Ham based on crop duty. The existing stage of groundwater development is accounted as 97.42% the unit draft consideration categorizes as *critical* and the existing stage of groundwater development is estimated as 92.66 based on the crop duty categorizes as *critical*. The groundwater recharge from rainfall by rainfall infiltration factor method during monsoon is estimated as 3549.45 Ham and during non monsoon is estimated as 1356.74 Ham. **(Table-8)**.The total annual groundwater recharge is accounted as 8883 Ham. The natural discharge during non monsoon season is 10% of the annual groundwater recharge is considered as per GWREC 1997 report, page No.50, item No. 5.10.1. Therefore, the net groundwater availability as on 2014 is estimated as 5617.36 Ham. The net groundwater availability for future irrigation development is estimated as -3378 Ham (deficient) by unit draft consideration and 2151 Ham based on crop duty. The existing stage of groundwater development as on 2014 is accounted as 158.13% by unit draft consideration categorizes as *overexploited* and as 137.84% based on crop duty categorizes as *overexploited* **(Table 6).**

Conclusion

Remote sensing technique is a powerful source of spatial data as input for GIS through which a lithology, drainages, lineament, slope, Land use/land cover are interconnected for groundwater potential zones recharge process. Slope, land use/ land cover, lineaments, drainage, lithology were generated with the help of other collateral data derived from several other sources. (IRS ID PAN+ LISS III geocoded standard FCC satellite data was used to groundwater potential zone recharge process) Groundwater recharge assessment is a complex function of meteorological conditions drainage, landuse/land cover, soil,vegetation, physiographic characteristics and lithological condition of the area. In this paper, groundwater recharge estimation committee- 1997 recommendations are water table fluctuation method, the existing stage of groundwater development is accounted as 97.42% (unit draft method) and 92.66 (crop duty method) the Gundal watershed is categorized as *critical.* Rainfall infiltration method, annual groundwater recharge is accounted 8883 Ham,/ existing stage of groundwater development as on 2014 Ham is accounted as 158.13% (Unit draft method) and 127.84 ((crop duty) the area is categories as *over exploited*. As per groundwater recharge estimation committee 1997 recommendations, the Gundal watershed area is catogarised as critical to over exploited. Hence groundwater potential zone recharge process is an important aspect of the study area.

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