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Prioritizing Groundwater Potential Zones Using Morphometric Analysis: A Case Study of Gulbarga Watershed

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Abstract: *Prioritization of watershed is an important step in conserving and managing water resource. Morphometry is the measurement and mathematical analysis of configuration of the earth's surface, shape and dimensions of its landforms. Drainage characteristics are important analysis to study the prevailing Lithology, Soil, Geomorphology and Slope of an area. An attempt had been made to prioritize the subwatersheds into Groundwater prospect zones as very good, good, moderate, poor and very poor groundwater prospect zones. Drainage networks are extracted from Cartosat DEM data. Watershed is delineated using hydrological tools in ArcGIS 10.1. Based on third order contact subwatersheds are classified to analyze the micro level planning and management. 10 linear parameters such as Stream order, Stream length, Bifurcation ratio, Drainage density, Dranage texture, Stream frequency, Elongation ratio, Form factor and Constant of channel maintenance were calculated by morphometric analysis using ArcGIS 10.1. Weightage were assigned based on the infiltration and holding capacity of groundwater. Groundwater potential prioritization map has been prepared by assigning each subwatershed weightage. The results can be used to allocate proper budget to watershed planning and in recharge structure prioritization. Hence management and proper utilization can be carried out to sustain the Groundwater resource.*

Keywords: *DEM, Morphometric analysis, Thematic layer integration, Groundwater Prospect Zone*

I. Introduction

Drainage basin analysis is one of the important criteria for hydrological investigations (N. S. Magesh et al., 2012). Drainage characteristics are the important criteria to decipher Lithology, Soil, Geomorphology and other scenarios. Groundwater is recharged mainly by surface water body and drainage. Remote sensing and GIS were used for extraction of drainage networks using Cartosat DEM to evaluate the morphometric analysis (Surabhi et,al., 2014). Due to increased developmental activities like urbanization and encroachment, water resource is depleting to its lower limit in terms of quality and quantity (Jaykumar et.al.,2013). Hydrogeological properties are mapped to investigate Groundwater Potential Zones. Remote sensing and GIS techniques provide an effective platform to analyze stream network, basin geometry, watershed management and development and prioritization studies. Physiographic elements like relief and slope can be derived from calculating amount of infiltration and surface runoff analysis (Kumar et.al,2014). The research focuses on integrated approach of Remote Sensing and GIS to study Gulbarga Watershed and to demarcate the favorable zones for groundwater through morphometric analysis. The watershed is quantitatively computed for selected 10 parameters using morphometric variables. Sub watershed prioritization was executed to determine the deficit and surplus zones of groundwater based on the weightage of morphometric parameters.

Study Area

The study area Gulbarga watershed falls in Gulbarga taluk of Karnataka as shown in figure 1. The study area covers 225.54 sq kms. Surface Water and Groundwater conditions are in safe zone and the area needs proper management to sustainably utilize the resource. The study area is drained by 5th order stream as shown by figure 2 and lastly pouring water to Saradagi Dam.

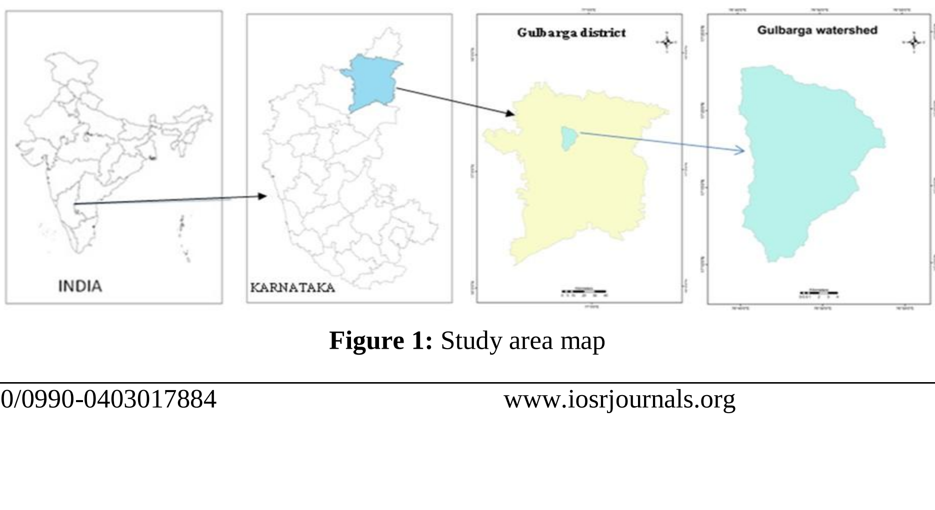

Figure 1: Study area map

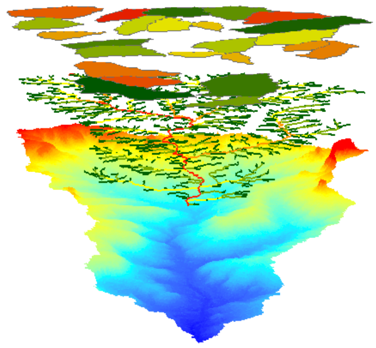

Figure 2: 3 Dimensional Representation of Hydrological Scenario in Gulbarga Watershed

II. Methodology

Cartosat DEM is downloaded from Bhuvan portal and processed in ArcGIS 10.1 to extract the hydrological networks. Drainage features of the study area were extracted from the DEM using hydrology tools in ArcGIS. Using automatic watershed extraction, watershed boundary is extracted for the area based on Saradagi Dam catchment. Subwatersheds are extracted based on the third order divide. Selected 10 morphometric parameters were analyzed for each 24 Subwatersheds. Maps were created by Interpolation tool in ArcGIS 10.1 for all parameters. Weightage were assigned to each thematic layer to get the Integrated Groundwater Potential map.

III. Results and discussions

Drainage network analysis

The extraction of drainage networks has done by using hydrology tools under spatial analyst extension in ArcGIS 10.1. Cartosat DEM data is used for the analysis (figure 3). The data can be freely downloadable from the website (bhuvan.nrsc.gov.in). Stream features were manually selected and post processed to get strahler stream order as shown in figure 4. The following formulae were used to calculate various morphometric parameters based on Strahler stream order as shown in table 1.

Sl.no.	Parameters	Formulae
1	Stream order (U)	Hierarchical rank
2	Stream length (Lu)	Length of the stream
3	Bifurcation ratio (Rb)	Rb=Nu/(Nu-1)
4	Drainage density (Dd)	Dd=Lu/A
5	Dranage texture (T)	T=Dd*Fd
6	Stream frequency (Fs)	Fd= SNu/A
7	Elongation ratio (Re)	Re=D/L
9	Form factor (Ff)	$Ff=A/L^2$
10	Constant of channel maintenance (C)	$C=km^2/km$

Table 1: Formulae for Morphometric Linear parameters

Sub-basins	Basin Length(L in kms)	Stream Orders(U)	Total stream no.	Stream length(Lu in kms)	Total stream length	Bifurcation ratio(Rb)	Mean Rb
		1 2 3 4 5 6		1 2 3 4 5 6		Rb1 Rb2 Rb3 Rb4 Rb5	
1	3.7712	39 8 2 1	50	12.6271 2.0660 0.6962 0.7764	16.4950	4.875 4 2	3.625
2	3.8432	25 6 3	32	6.6764 2.0773 0.1648	8.9186	4.1666 2	2.0833
3	2.9949	24 5 2 1	32	9.8223 1.7807 1.6377 0.3191	13.5600	4.8 2.5 2	3.1
4	4.0300	24 3 1	28	12.9994 1.3229 0.5602	14.8826	8 3	5.5
5	2.8500	21 4 2 1	28	8.4151 0.9371 1.5743 0.2454	11.1720	5.25 2 2	3.0833
6	4.8641	18 4 1	23	7.7684 1.0988 0.6890	9.5563	4.5 4	4.25
7	3.4132	25 7 2 1	35	7.4493 0.9860 0.8413 0.3422	9.6189	3.5714 3.5 2	3.035
8	2.6048	5 2 1 1	9	2.6736 1.3132 0.7524 0.3191	5.0584	2.5 2 1	1.83
9	2.5849	12 2 1	15	4.2170 0.2256 0.3690	4.8117	6 2	4
10	4.1759	24 4 1	29	11.1596 1.3525 0.5625	13.0746	6 4	5
11	6.5663	47 9 1	57	17.3000 5.3046 0.4373	23.0419	5.22 9	7.11
12	3.4026	14 4 1	19	6.3833 1.7963 0.0680	8.2477	3.5 4	3.75
13	3.5921	19 5 1	25	8.8 1.2382 0.3291	10.3673	3.8	3.8

14	2.8996	19 3 1	25	8.4321 0.3193 0.7564	9.5079	6.33 3	4.66
15	4.0139	31 6 2 1	40	11.2799 2.9008 0.5928 0.0304	14.8041	5.1666 3 2	3.3886
16	1.9407	7 2 1	10	3.5220 0.5116 0.1925	4.2262	3.5 2	2.75
17	1.9647	6 2 1	9	2.4958 0.9027 0.7378	4.1363	3 2	2.5
18	2.1868	10 2 1	13	3.4947 1.0476 0.1291	4.6714	5 2	3.5
19	3.2103	12 2 1	15	5.8944 0.9745 0.2116	7.0805	6 2	4
20	4.2761	24 5 1	30	8.7082 2.4481 0.0861	11.2425	4.8 5	4.9
21	2.6844	12 3 1	16	5.7646 1.3230 0.2253	7.3130	4 3	3.5
22	5.0229	19 3 1	23	9.8043 1.3046 0.1097	11.2188	6.33 3	
23	3.7966	25 5 1	31	7.9967 2.5749 0.0304	10.6021	5 5	5
24	2.3798	6 2 1	9	1.7660 1.5477 0.8003	4.1141	3 2	2.5
Gulbarga watershed	22.3899	727 148 29 5 1	910	297.5680 54.8789 12.4203 1.7136 0.3291	366.9100	4.9121 5.1034 5.8 5	5.2038

Table 2: Results showing Basic Linear parameters

1	Area(A)	Drainage density(Dd) km/km2	Drainage texture (T)	Stream frequency (Fs)	Elongation ratio(Re)	Form factor(Ff)	Constant of channel maintainance©
1	11.4375	1.4421	6.3041	4.3715	1.011568	0.804215	0.693433
2	5.4505	1.6362	9.6061	5.8710	0.685227	0.36902	0.611172
3	7.2409	1.8726	8.2756	4.4193	1.013498	0.807287	0.534017
4	8.4813	1.7547	5.7928	3.3013	0.815146	0.522219	0.569898
5	6.6248	1.6863	7.1271	4.2265	1.01871	0.815611	0.593014
6	5.9807	1.5978	6.1447	3.8457	0.56713	0.252783	0.625861
7	5.7020	1.6869	10.3544	6.1381	0.789153	0.489445	0.592803
8	2.2514	2.2467	8.9812	3.9975	0.649772	0.331821	0.445097
9	3.7535	1.2819	5.1225	3.996	0.845442	0.561758	0.780092
10	8.9196	1.4658	4.7656	3.2512	0.806736	0.511499	0.682221
11	14.5991	1.5783	6.1617	3.904	0.656374	0.338598	0.633593
12	4.2553	1.9382	8.6541	4.4650	0.683854	0.367543	0.515943
13	6.3203	1.6403	6.4882	3.9555	0.789459	0.489825	0.609645
14	5.7488	1.6538	7.1919	4.3487	0.932738	0.683756	0.604668
15	8.872	1.6686	7.5229	4.5085	0.837054	0.550666	0.599305
16	1.8796	2.2484	11.9619	5.3202	0.796863	0.499055	0.444761
17	1.6812	2.4603	13.1707	5.3533	0.744428	0.435539	0.406454
18	2.7489	1.6993	8.0362	4.7291	0.855223	0.574832	0.588478
19	4.4115	1.6050	5.4573	3.4002	0.738	0.428051	0.623053
20	6.3925	1.7587	8.2536	4.693	0.666955	0.349603	0.568602
21	3.4352	2.1288	9.9151	4.6576	0.778821	0.476714	0.469748
22	6.5944	1.7012	5.9334	3.4878	0.57669	0.261376	0.58782
23	8.0792	1.3122	5.0349	3.8370	0.844498	0.560504	0.762079
24	2.0486	2.0082	8.8224	4.3932	0.678418	0.361723	0.497958
Total area	225.5497	1.6267	6.5629	4.0345	0.75662	0.449923	0.614742

Table 3: Results showing Linear parameters

Drainage density

Drainage density is the total length of all streams in a basin to the total area of the basin. It measures the richness or poorness of a watershed to drain by streams. Drainage density depends on factors like soil permeability, lithological porosity. Areas of High drainage density indicate low water potentiality as the runoff will be more in such a regions. It indicates mountainous reliefs with sparse vegetation. The areas of high drainage density are not suitable for groundwater development. Drainage density values of the Gulbarga Subwatersheds ranges from 1.28 to 2.46 km/km^2 as shown in figure 6.

Drainage frequency

Drainage frequency mainly depends on the lithological conditions prevailing in the area. It reflects the texture of drainage network and is related to permeability, infiltration capacity and relief of litho units. High frequency value indicates greater surface runoff, steep slope, impermeable subsurface material and sparse vegetation. The frequency values of the Subwatersheds ranges from 3.25 to 6.13 as shown in figure 5.

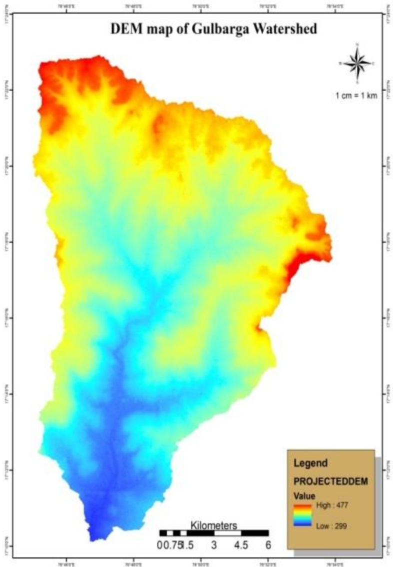

Figure 3: DEM map of Gulbarga Watershed

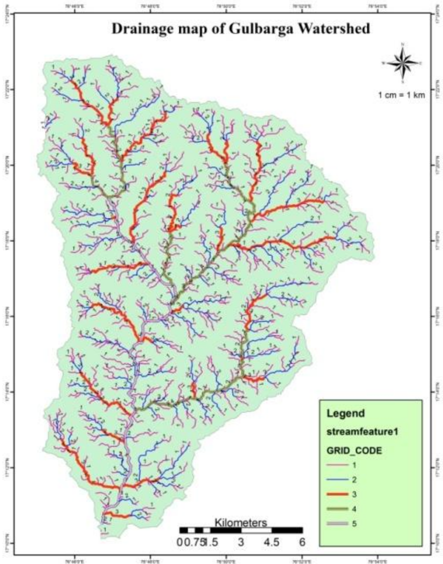

Figure 4: Drainage map of Gulbarga Watershed

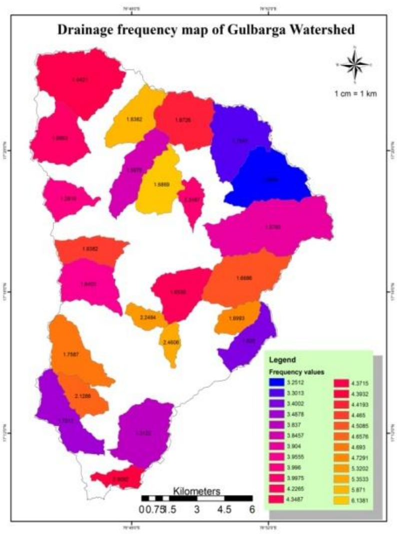

Figure 5: Drainage frequency map of Gulbarga Watershed

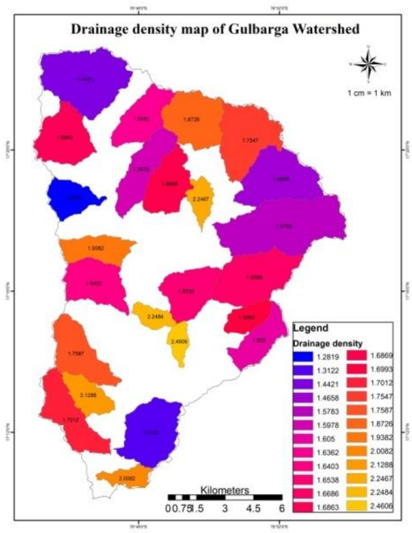

Figure 6: Drainage density map of Gulbarga Watershed

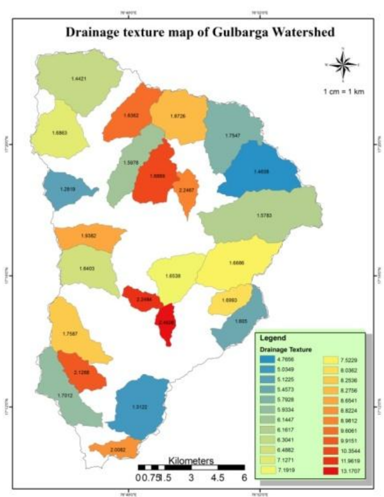

Figure 7: Drainage texture map of Gulbarga Watershed

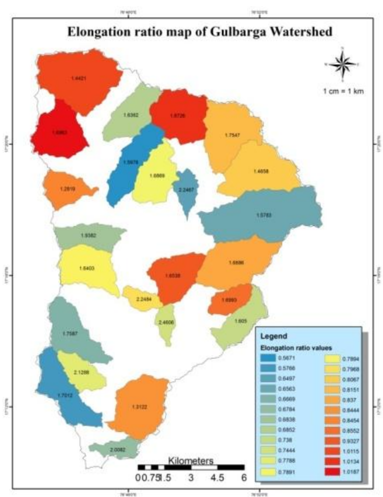

Figure 8: Elongation ratio map of Gulbarga Watershed

Drainage texture

Drainage texture is defined as the relative spacing between drainage per unit length in a square grid. Soft or weak rocks by sparse vegetation characterize fine texture, while massive and resistant rocks represent a course texture. The drainage texture of the streams ranges from 4.76 to 13.17 (Figure 7).

Elongation Ratio

The elongation ratio is a significant index in the analysis of basin shape. It can provide an idea of hydrological character of a drainage basin. The elongation ratio of the subbasins varies from 0.56 to 1.01 (Figure 8).

Form factor

Form factor is defined as the ratio of basin area to the square of the watershed length. Low Ft value indicates less side flow for shorter duration and high main flow for longer duration. The form factor ranges from 0.25 to 0.81 (Figure 10).

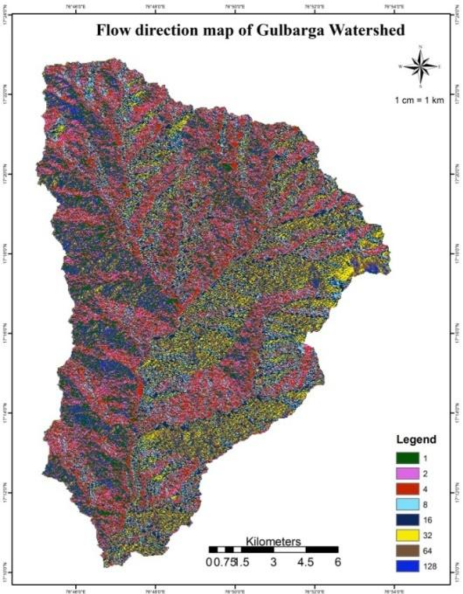

Figure 9: Flow direction map of Gulbarga Watershed

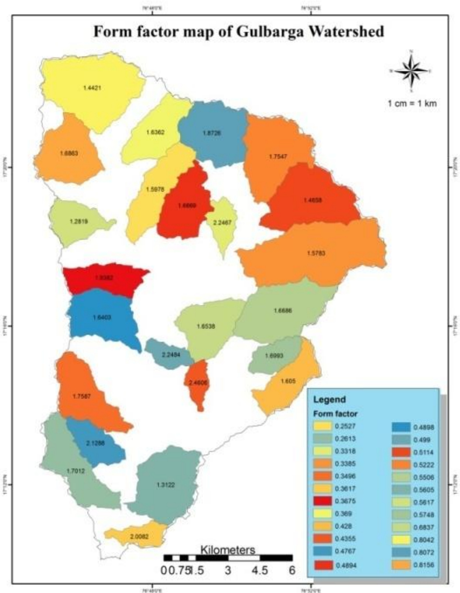

Figure 10: Form factor map of Gulbarga Watershed

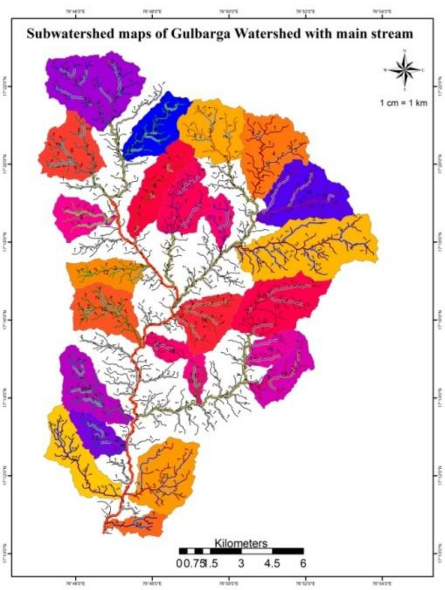

Figure 11: Subwatershed map of Gulbarga Watershed

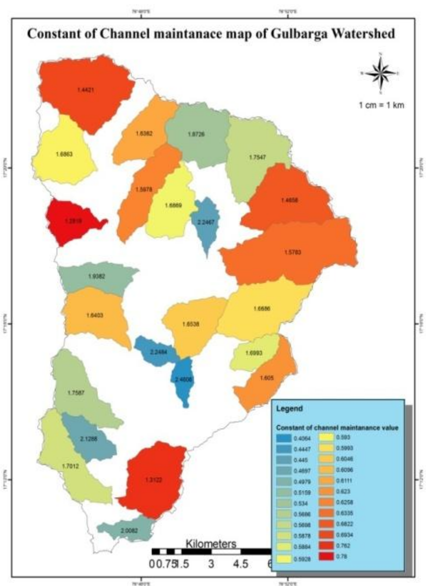

Figure 12: Constant of Channel maintenance map of Gulbarga Watershed

Constant of channel maintenance

Constant of channel maintenance is defined as the inverse of drainage density. Constant of channel maintenance decreases with decrease in erodability. Higher value of C represents more area is required to produce surface flow. Lower value of C represents less chances of percolation or infiltration and allows more surface runoff. The constant of channel maintenance varies from 0.40 to 0.78 (Figure 12).

GWP	Very good	Good	Moderate	Poor	Very poor
Drainage density	1.281 to 1.51692	1.51693 to 1.75284	1.75284 to 1.98876	1.98877 to 2.22468	2.22469 to 2.4606
Drainage frequency	3.2512 to 3.82858	3.82859 to 4.40596	4.40597 to 4.9833	4.9834 to 5.56072	5.56072 to 6.1381
Drainage texture	4.7656 to 6.4466	6.4467 to 8.1276	8.1276 to 9.8086	9.8086 to 11.4896	11.4896 to 13.1707
Elongation ratio	0.5671 to 0.65742	0.65743 to 0.74774	0.74775 to 0.83806	0.83807 to 0.92838	0.92839 to 1.0187
Form factor	0.2527 to 0.36528	0.36529 to 0.47786	0.47787 to 0.59044	0.59045 to 0.70302	0.70303 to 0.8156
Constant of channel maintenance	0.4064 to 0.48112	0.48113 to 0.55584	0.55585 to 0.63056	0.63057 to 0.70528	0.70529 to 0.78

Table 4: Criteria table to prioritize subwatersheds to Groundwater prospect zones

Based on the weightage assigned to each thematic layer (Table 4), Groundwater potential prioritization map is prepared to suggest an action plan in Gulbarga watershed as shown in figure 13. Accordingly Subwatersheds 11, 19 and 20 belong to very good groundwater potential zones. Subwatersheds 8 and 10 belong to good groundwater potential zones. Subwatersheds 4, 9, 12, 13, 15, 20, 23 and 24 belong to moderate groundwater potential zone category. Subwatersheds 1, 2, 3, 5, 6, 7, 14, 16, 17, 18, 21 and 22 belong to poor and very poor groundwater potential zones. Immediate action is required to poor and very poor groundwater potential zones to improve the groundwater development and in the study area.

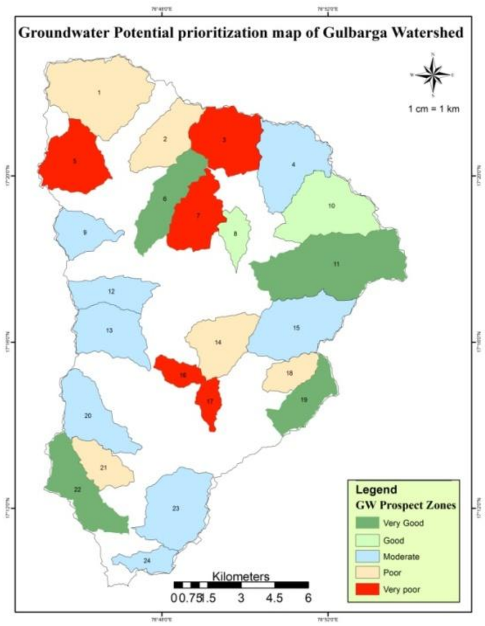

Figure 13: Groundwater potential prioritization map of Gulbarga Watershed

IV. Conclusion

The research aims at prioritizing subwatershed on groundwater prospects zones. Groundwater gets often recharged by surface water and stream networks. The methodology illustrates morphometric analysis to prioritize sub watersheds. According to result Kusnur, Kanagnur, Naganahalli and a southern part of Khandel villages are in safe zone. Pallapur, Zaferabad, Sindagi, Hirapur, Sirnur villages are noticed as very low groundwater prospect zones. Immediate action is required for the above listed villages. Community participation is important in order to achieve watershed developmental activities. Proper agricultural and irrigational techniques for water conservation, Rainwater harvesting structure construction, Avoid misuse of water resource play an important role in sustainable development of water resource.

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