Prioritization of the Watershed for GWPZ, Through Remote Sensing, GIS and Integrated Weighted Sum Approach: A Case Study of the Dhodana River Basin, Central India

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Abstract: The Dhodana miniwatershed is a part of Deccan Volcanic Province (DVP) of central India. The basalt lava flows of the area are of simple aa' type and forms a multi-layered aquifer system due to alternate hard massive and vesicular units, which creates heterogeneity of groundwater occurrence. The hydrogeological field data acquired during field operations was taken into account to create an accurate picture of groundwater availability. The results indicate that static water levels range between 4.58 mbgl to 18.6 mbgl in pre-monsoon season and between 0.1 to 15.5 meter bgl in post-monsoon season. The seasonal water level fluctuation ranges between 2 to 7.93 mbgl. Similarly yield of the dug wells ranges between 4500 litre/day to 1,97,100 litre/day in pre-monsoon season and ranges between 36,000 litre/day to 5,40,000 litre/day in the post-monsoon season. Thematic maps like lithology, geomorphology, slope, land use-land cover, lineaments and soil were taking into account with appropriate weightages, according to their contribution for groundwater occurrence. The remote sensing technique and GIS softwares were utilized for this purpose. The watershed was divided into five categories, based on their respective weightages as: very good, good, moderate to good, poor to moderate and poor groundwater prospective zones. The result shows that the area of very good and good groundwater potential covers 6% and 24% watershed area, which is mostly under storage zone; moderate to good and poor to moderate groundwater prospect zone covers 33% and 23% area of the watershed in the runoff and recharge zones. The area of poor groundwater potential covers 14 % of the watershed in the runoff zone. It is also observed that groundwater potential is almost same along the river banks and also along the small drainage banks.

Keywords: Watershed Prioritization, Geology, Geomorphology, Hydrogeology, Remote Sensing and GIS, Groundwater Potential Zones (GWPZ).

1. Introduction

Watersheds are best units for managing and planning land and water resources (Moore et al., 1991; Gajbhiye et al., 2014; Pande, 2022). In order to mitigate the current challenges of groundwater, it is significant to implement sustainable soil and water conservation techniques which can be achieved by dividing drainage basins into smaller hydrological units (sub-basins/watersheds). To create an efficient management plan, however, realistic evaluations of a hydrological characteristics is necessary (Sharma et al., 2014; Sharmaetal, 2014) and an understanding of the connections between soil, slope, uplands, lowlands, land use and geomorphology are crucial (Arefin et al., 2020; Jothimani et al., 2020; Kandpal et al., 2017; Sebastian et al., 1995; Kumar et al., 2021). The crucial factors for interpreting lithology, soil, geomorphology are drainage characteristics (Bharathkumar, 2016). The quantity and quality of water resources are declining to the lowest point as a result of increased development activities including encroachment and urbanization (Jayakumar, et al., 2013). Integrating remote sensing data with GIS technologies has shown to be a useful tool for projects involving the development and management of water resources, as well as the prioritization and characterization of watersheds (Ali et al., 2002; Pandey et al., 2011; Pandey et al., 2010; Pandey et al., 2009).

Groundwater potential refers to the amount of groundwater that is available in a certain location and is determined by hydrogeological parameters (Jha, 2010). The topography, lithology, lineaments, geomorphology, drainage pattern and land use and land cover pattern influence groundwater prospective. Remote Sensing data and integration of a geographic information system (GIS) are commonly employed in well monitoring and data analysis. The technology of remote sensing is commonly used to define groundwater prospective zones (Obi Reddy et al., 2000; Sarkar, et al., 2001; Rao 2001). Aim of the present study was to identify Groundwater potential zones (GWPZ), using the watershed development, water resource management, RS and GIS technique, along with the Integrated Weighted Sum Approach method.

2. Study Area and Geological Setup

Study Area (Dhodana watershed, Chargarh river basin) is a portion of rich orange orchid growing belt of Central India and popularly known as California of India due to similarity with California oranges of United States of America. The watershed extended from 21°16' to 21°24' N latitudes and 77°51' to 77°57'E longitude and included in Survey of India topographical maps 55 G/15, 55G/16, 55K/3 and 55K/4 (Figure 1), with an area of approximately 25 km^2. The research area experiences sub-tropical temperatures, with maximums between 42^0 C to 46^0 C and minimums between 10^0 C and 20^0 C. Along with the perennial crops like orange orchid, the area is also covered by sporadic seasonal crops like cotton, pulses etc. The area is a part of an assured rainfall zone, which receives about 900 to 1000 mm rainfall/year.

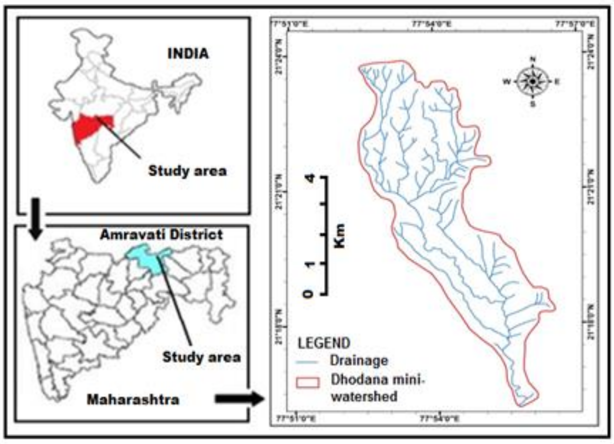

Figure 1. Location map of the Dhodna watershed.

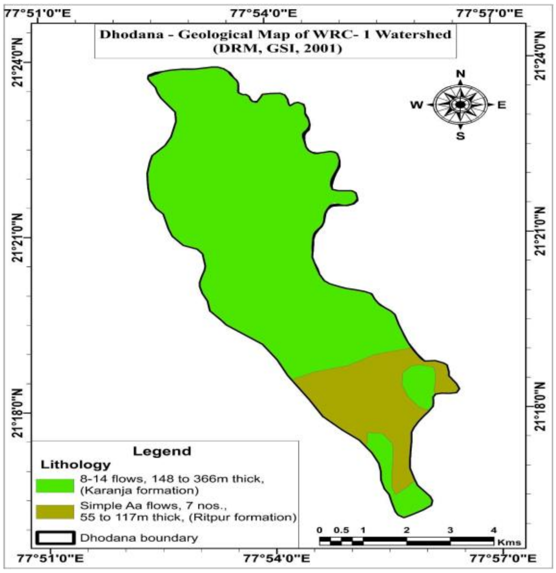

Figure 2. Geological map of the Dhodana watershed

The Dhodana watershed is covered by the Deccan basaltic lava flows which belong to the Upper Cretaceous to Lower Eocene age (DRM, GSI, 2001). Stratigraphically, the basaltic lava flows of the area are included in Sahyadri Group and categorised as Karanja and Ritpur Formations (GSI, 2001) (Figure 2).

3. Materials and Methods

The present investigation technique includes consideration of the satellite data, which was geo-referenced using Survey of India topographical map 55G/16. The topographical and geological maps were geo-rectified using spatial analysis techniques of GIS. Utilizing satellite data, rapid and helpful baseline information on drainage, geomorphology, geology and land use-land cover, along with the other features of terrain evolution controls the groundwater occurrence, distribution and movement. This enhances the ability to identify groundwater potential zones and creates space for the construction of artificial recharge facilities. The Survey of India topographical maps of 55G/15, 55G/16, 55K/3 and 55K/4 on the 1:50,000 scale were utilized to generate a base map of the study area.

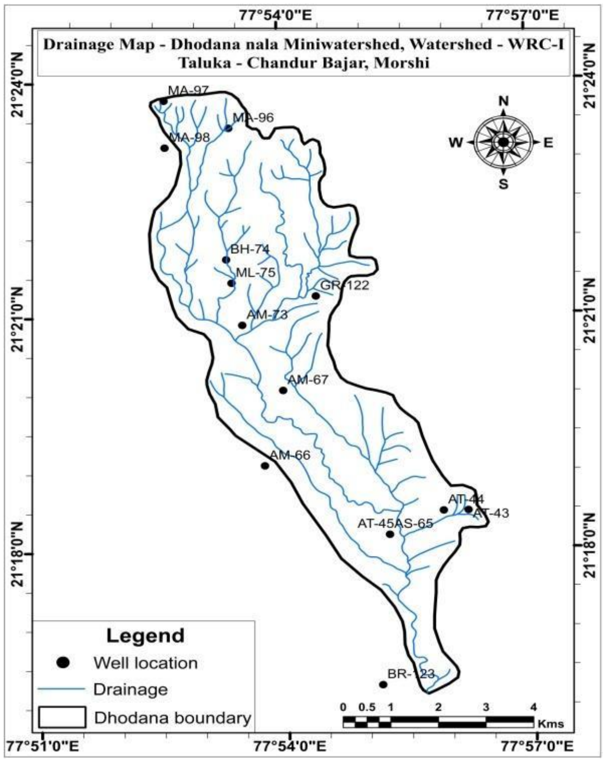

Figure 3. Location of Dug wells in Dhodana watershed

The WGS-1984 UTM Zone-43N projection system was used to extract geomorphological units from a digital elevation model (DEM), using Arc map 10.2 software. LISS-III false colour composite (FCC) satellite imageries, IRS-Resource Sat-II (Tile No. F43R15, F43R16, F43M03 and F44M04) have been diploid for the accurate results. The images were obtained from Resource Sat-II (November 2017) with spatial resolution of 23.5 metre and three spectral bands viz. green, red and near-infrared (NIR) were used to create the False Colour Composite (FCC) imageries (Figure 5). Prioritizing the watershed was done using the weighted sum approach method (Malik et al., 2019). This approach consists of generating a correlation matrix, estimating compound factors, weighting calculations and preliminary priority ranking. (Jothimani et al., 2020; Shelar et al., 2022; Godif and Manjunatha, 2022). Weighted overlay integration of all spatial layers allowed for the evaluation of the groundwater potential zones. Prior to the overlaying procedure, each geographical layer was classed to a uniform rating of 15, with 1 denoting a very high groundwater potential and 5 a low groundwater potential. Weights have been allocated using an analytical hierarchical procedure and a pairwise matrix comparison. Taking into account the data from the field survey, the ranks were allocated to the appropriate parameters. (Krishnamurthy et al., 1996; Saraf and Choudhury 1998; Waikar and Nilawar 2014). The two most important factors were lithology and geomorphology (Figure 6), whereas slope, soil and drainage density was given a relatively small weighting in terms of land use and land cover (Figure 7, Table 1), lineament density received a low weight. Sub-variables were ranked individually after the corresponding parameters were assigned weights (Butler et al. 2002; Yammani 2007; Asadi et al. 2007). The highest groundwater potentiality was characterized by the maximum value, and vice versa.

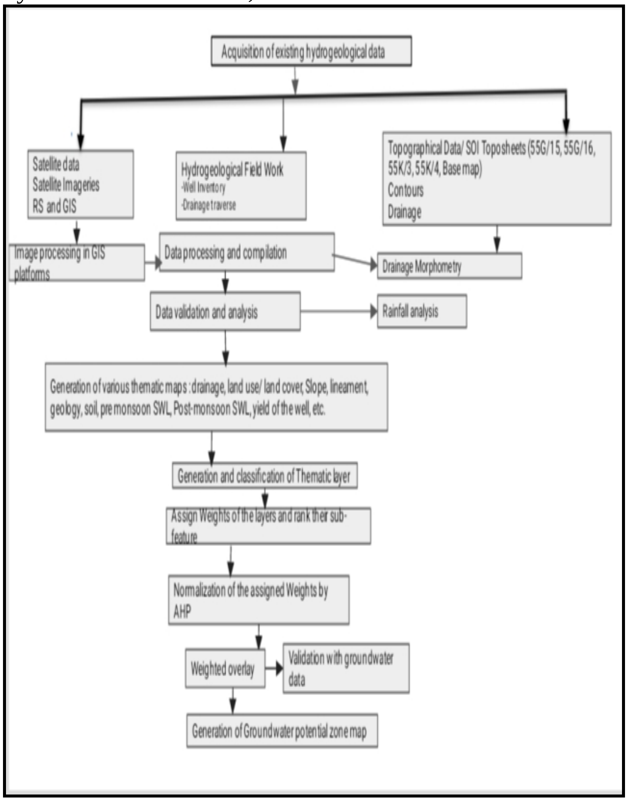

Figure 4. Flow chart of the methodology adopted for the hydro-geological investigations of the dhodana mini-watershed.

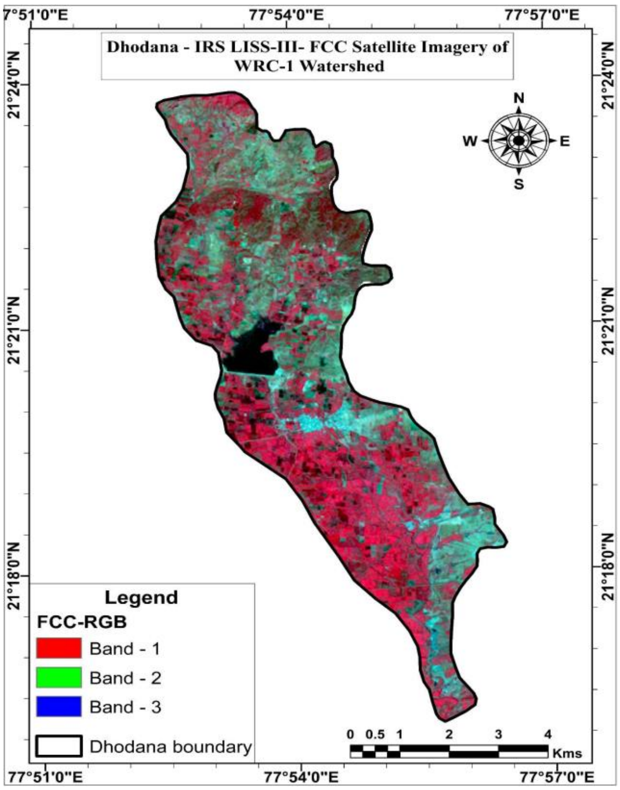

Figure 5. IRS LISS- III, FCC satellite imagery of Dhodana watershed.

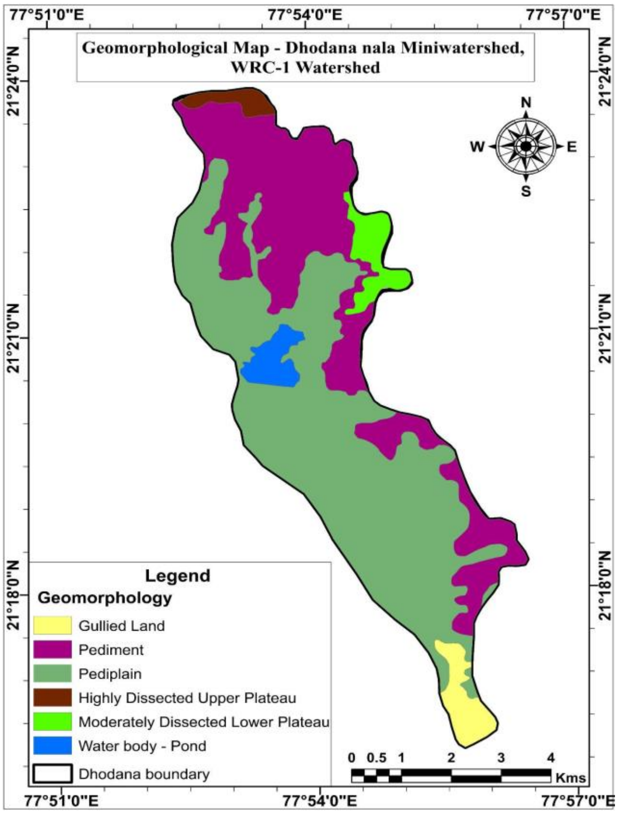

Figure 6. Geomorphological map of the Dhodana watershed.

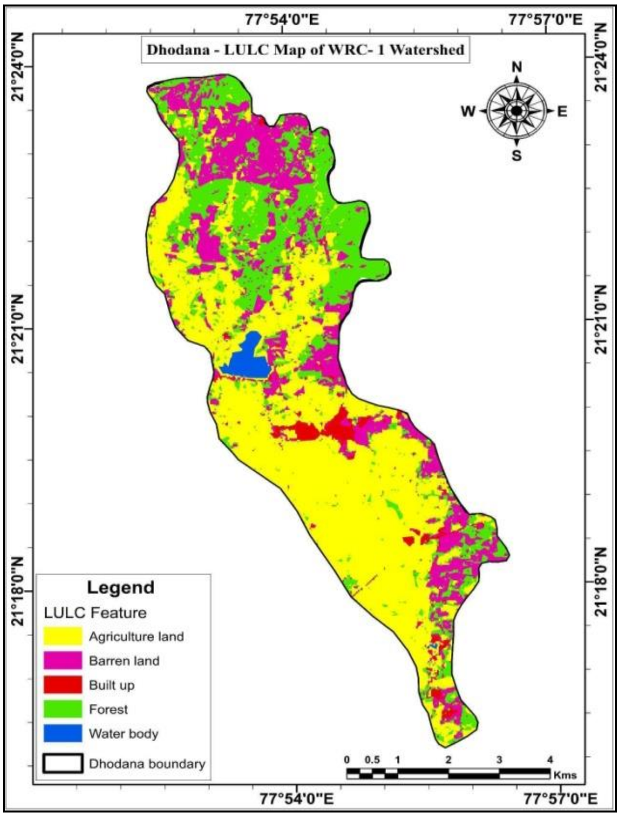

Figure 7. LU/LC map of the Dhodana watershed.

Table 1. Area covered by different LU/LC patterns.

Sr. No.	LU/LC class	Area (in sq. km.)	Area (%)
1	Agricultural land	19.60	49.96
2	Barren land	8.17	20.83
3	Builtup	1.00	2.55
4	Forest	9.91	25.27
5	Water bodies	0.55	1.39
	Total	39.22	100

4. Result and Discussion

4.1. Hydrogeodynamics and Weightages

The multi-layered aquifer system of basalt offers limited amounts of groundwater, where groundwater is especially stored in weathered, vesicular and jointed/fractured zones. The majority of the groundwater in the Deccan Trap Basalt often lies in the higher, fractured, reaching a depth of 15-20 meters. The hydrogeological units of Deccan Traps, encountered in the well sections include highly weathered basalt, moderately weathered basalt, vesicular basalt and compact massive basalt. This complicated geological structure has a great impact on water percolation beneath the ground surface and lateral movement. Potential zones can occasionally be found at deeper levels as inter-flow zones and fractures. Groundwater exists under water table (unconfined) conditions, with the top worn and cracked portions, forming the phreatic aquifer. Groundwater occurs in semi-confined situations at deeper depths. Static water levels during the pre-monsoon season range between 4.58 mbgl to 18.6 mbgl (Figure 8). The dug wells yield in pre-monsoon season varies between 4500 litre/day to 1,97,100 litre/day (Figure 9) and the post-monsoon yield, ranges between 36,000 litre/day to 5,40,000 litre/day (Figure 10).

In the western part of the watershed, shallow groundwater levels are observed due to the hard rock (Deccan Traps). In the central part of the basin groundwater levels are between 6.1 to 12 meters (Figure 8 and 11, Table 2) and in the north-western part, post-monsoon static water level is >9 meters bgl. Similarly, in the central, north- western and north-eastern part, 3.1 to 6 mbgl SWL is observed. Shallow SWL occurs in the southern part of the basin (Figure 8 and 11). Yields of the dug wells are obtained on the basis of capacity of the pump and pumping hours. Accordingly, the pre-monsoon yield obtained from the wells are between 4500 to 1,97,100 lph in fractured, weathered, vesicular and amygdaloidal basalt. On the other hand, the post-monsoon yields ranges between 36,000 to 5,40,000 lph in fractured, weathered, vesicular, and amygdaloidal basalt. This indicates that basalt is more productive in the weathered, vesicular and highly fractured zones.

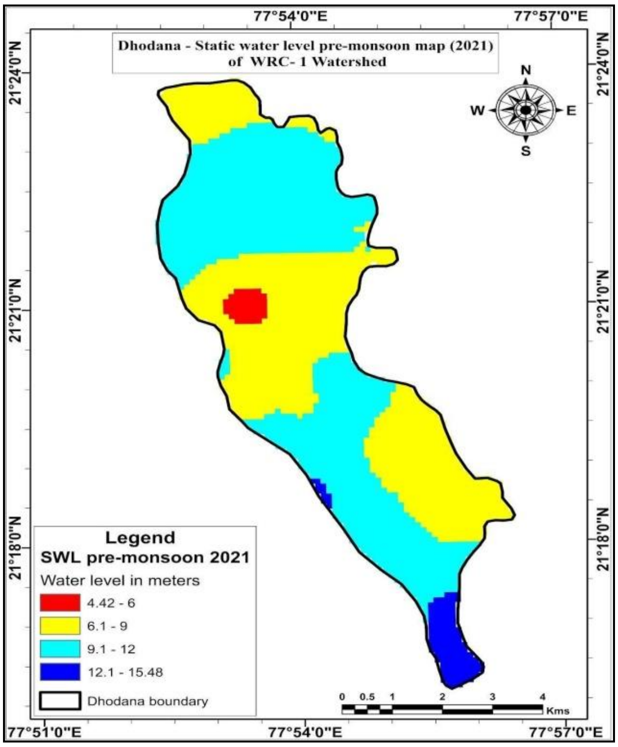

Figure 8. Pre-monsoon static water levels in the Dhodana watershed.

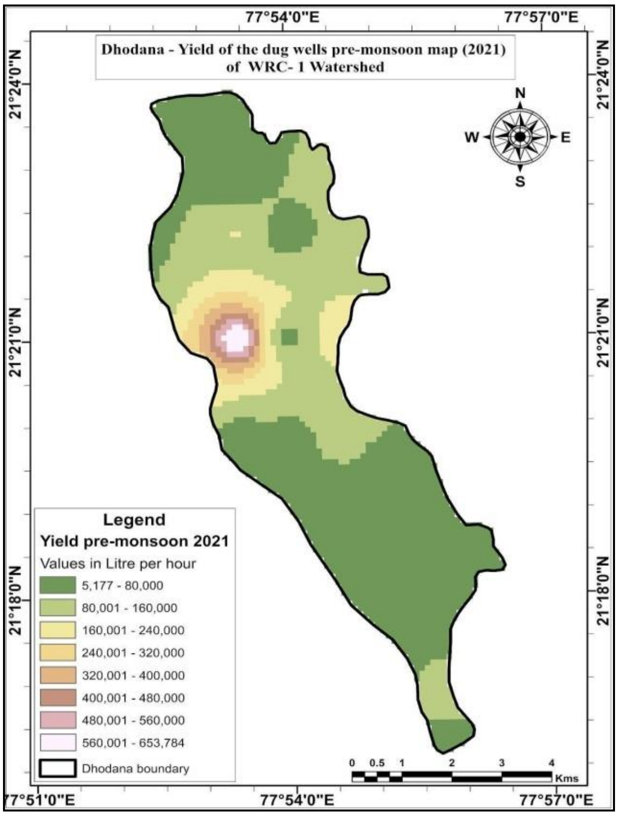

Figure 9. Yield of the dug wells in pre-monsoon season.

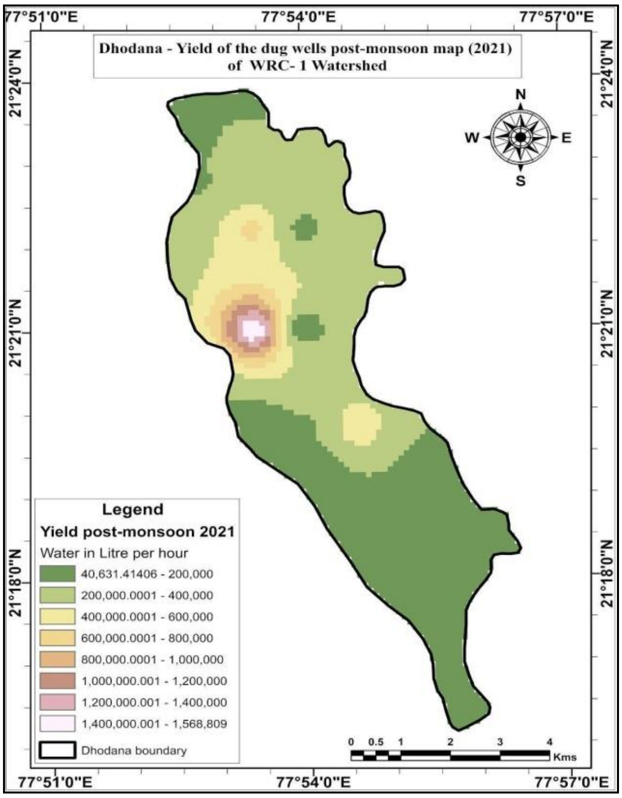

Figure 10. Yield of the dug wells in the post-monsoon season.

The groundwater potential zones are defined on the basis of integrated examination of geological elements such as slope lithology, geomorphology, soil, drainage, lineament and land use-land-cover pattern (Table 1, 2, 3 and 4). In addition to this, field data acquired during hydrogeological field operations was considered to decipher groundwater availability. Additionally, a variety of thematic maps are taken into account and given the proper weights according to how they affect the occurrence and transmissivity of groundwater.

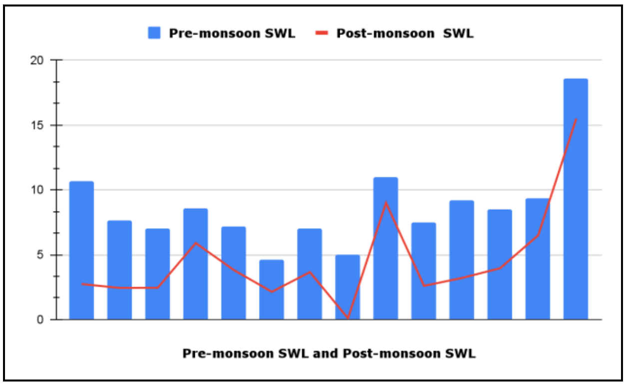

Figure 11. Static water levels (SWL) of the dug wells (mbgl) in pre-monsoon and post-monsoon season.

Finally, all of the thematic layers are methodically combined one after another. During the weightage overlay analysis, each individual parameter of the thematic maps has been ranked based on their contributing factors (Figure 12; Table 3 and 4). An integrated map of the watershed has been divided into three zones, based on their respective weightages as: very good, good, moderate to good, poor to moderate and poor groundwater potential. The results indicate that very good and good groundwater potential covers an area of 6% and 24% respectively which is mostly under the storage zone of the watershed. Moderate to good and poor to moderate groundwater potential covers 33% and 23% of the area of the watershed, especially in the runoff and recharge zone. The poor groundwater potential covers 14 % of the area of the runoff zone (Figure 12). It is also observed that groundwater potential is almost same near river courses and drainages. Some of the lineaments in the storage zone also contribute to groundwater potential (Figure 12).

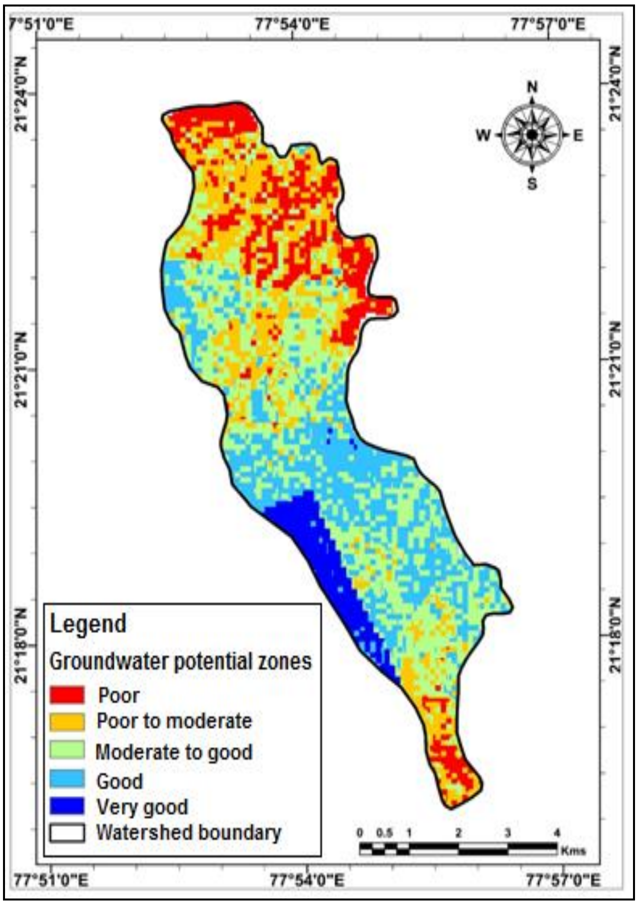

Figure 12. Groundwater potential zone map of the Dhodana watershed.

Table 2. The static water levels, seasonal water table fluctuations and yield of the open wells in the Dhodana watershed.

Well ID	Village/ Locality	Altitude (meter, amsl)	Pre-monsoon SWL (meter bgl)	Post-monsoon SWL (meter bgl)	Water table fluctuation (in meters)	Pre-monsoon (Lit/day)	Yield (Lit/day)
MA-96	Maniardi	449	10.67	2.74	7.93	36,000	2,16,000
MA-97	Maniardi	449	7.62	2.44	5.18	36,000	1,08,000
MA-98	Maniardi	440	7.02	2.45	4.57	36,000	1,08,000
GR-122	Charor	394	8.6	5.9	2.7	1,97,100	2,62,800
AT-43	Ashtagaon	378	7.17	3.82	3.35	4500	36,000
AT-44	Ashtagaon	380	4.58	2.14	2.44	6000	40,500
AT-45	Ashtegaov	381	7.01	3.66	3.35	54,000	1,44,000
BH-74	Bhangara, Malkapur	416	5	0.10	4.90	45,000	1,57,500
ML-75	Bhangara, Malkapur	410	11	9	2	1,35,000	5,40,000
AS-65	Ashtagaon	383	7.48	2.6	4.88	36,000	1,08,000
AM-66	Ambada	392.8	9.2	3.21	5.99	54,000	2,16,000
AM-67	Ambada	393	8.53	3.96	4.57	54,000	90,000
AM-73	Ambada	403	9.35	6.5	2.85	54,000	1,80,000
BR-123	Borana / khopra	362	18.6	15.5	3.1	1,26,000	1,89,000

Table 3. Area of groundwater prospectus in different GWPZs in the Dhodana watershed.

Sr. No.	GWPZ	Area of Groundwater Prospectus	Area in sq.km.	Area (%)
1	Very low	Area of Poor Groundwater Prospectus	5.43	14%
2	Low	Area of Poor to Moderate Groundwater Prospectus	8.75	23%
3	Medium	Area of Moderate to Good Groundwater Prospectus	12.87	33%
4	High	Area of Good Groundwater Prospectus	9.33	24%
5	Very high	Area of Very Good Groundwater Prospectus	2.34	6%
		Total	**38.73**	**100%**

Table 4. Weightages assigned to various geological units influencing groundwater potential in Dhodanamini-watershed.

Sr. No.	Geological Parameter in Dhodana basin	Geological Units	Category	Weightage/ Class Rank	Weightage
1	Lithology	8-14 flows, 148 to 366m thick, (Karanja Formation)	Moderate To Good	3	38.5%
		8-14 flows, 148 to 366m thick, (Karanja Formation)	Moderate To Good	3	
		Simple Aa flows, 7 nos., 55 to 117m thick, (Ritpur Formation)	Moderate To Good	3	
		8-14 flows, 148 to 366m thick, (Karanja formation)	Moderate To Good	3	
2	Geomorphic Unit	Gullied Land	Moderate To Good	3	19.20%
		Pediplain	Very Good	5	
		Highly Dissected Upper Plateau	Moderate To Good	3	
		Moderately Dissected Lower Plateau	Moderate To Good	3	
		Water body - Pond	Good	4	
		Pediment	Very Good	5	
3	Slope (degree)	Very Gentle slope ($0-5^0$)	Very High	4	12.8 %
		Gentle slope (5^0-15^0)	High	3	
		Moderately Steep Slope (15^0-30^0)	Moderate	2	
		Steep Slope (30^0-45^0)	Low	1	
4.	LULC	Agricultural land	High	4	6.4%
		Barren land	High	4	
		Built up	Moderate	3	
		Forest	Low	1	
		Water bodies	High	5	
5.	Soil	Clayey soil on gently sloping area (3.14)	Low	1	7.7%
		Fine calcareous soil on very gently sloping area (29.84)	Low	2	
		Loamy soil on gently sloping lower plateau (9.11)	High	3	

		Loamy soil on gently sloping rolling lands (17.94)	Very High	5	
6.	Drainage Density	Very high	Very Low (Poor GWPZ)	1	9.6%
		High	Low	2	
		Moderate	Moderate	3	
		Low	High	4	
		Very low	Very High (High GWPZ)	5	
7.	Lineament Density	Minor	High	3	5.5%
		Intermediate	Moderate	2	

Conclusion

The geologic, geomorphological and remote sensing techniques were effectively used to identify groundwater potential zones within the Dhodana mini-watershed, which is dominantly covered by the Deccan basaltic lava flows which otherwise considered as groundwater scarce zones. This watershed, in particular, was always considered for agricultural productivity of orange orchid and thereby over-exploited for a long time due to excessive withdrawal of groundwater. The findings will aid in understanding the groundwater regime which also has environmental consequences. The response of an area is heavily influenced by its geomorphological units. The groundwater behavior can be easily understood by linking the geomorphological context with the hydrological parameters of a region. In comparison to a low slope region, more runoff is caused by a steeply sloped area and less infiltration, resulting in poor groundwater prospects. The characteristics of surface and sub-surface formations are reflected in the drainages. Greater the drainage density, greater is the runoff. The field studies as well as GIS analysis shows that the rock type (geology), landforms (geomorphology) and slope affects the occurrence of groundwater in the sub-basin. By considering the hydrological conditions and available run-off, the suitable artificial groundwater recharge structures can be recommended for the Dhodanamini-watershed like cement plug, gabion structure etc. The overall findings show that remote sensing and GIS technique is most effective for groundwater resources and planning with an acceptable groundwater exploitation limit. This provides more accurate groundwater information of the area, which can be utilized for further groundwater development or management plans.

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