Hydrogeomorphological Assessment of Kanakapura Watershed Using Geo-Spatial Technology

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Abstract

The study aimed to explore the hydro geomorphological aspects of the Kanakapura watershed using a range of geospatial data sources and tools. Specifically, the study integrated the data on geology, geomorphology, and lineament information derived from a sentinel satellite image and digital elevation models (DEM) using Arc GIS software to analyse and visualize these layers. The objective attained to delineate the groundwater prospects zone by identifying areas with higher groundwater potential. In the study area lineaments were classified into minor, intermediate, and major based on their length. Lineaments were further divided into various portions based on lineament density, fluctuating between extremely low to extremely high. The study found that the very low and low lineament density zones were the most common throughout the watershed. The results suggest that the north western and south eastern regions of the research area had higher lineament concentrations and superior groundwater potential compared to the upper middle basin and north-northeast region. The integrated subsurface water potential zone map revealed that the valley fills and discreetly disintegrated pediplains were the most promising zones for groundwater potential. On the other hand, shallowly weathered pediplains, Pediment Inselberg complex, Pediments, Denudational, residual hills, and Inselberg were identified as zones with modest to very poor groundwater potential.

Keywords: Hydro geomorphological units, Lithounits, Lineaments

1. Introduction

Ground water is a subterranean phenomena, its location and identification depends on an indirect investigation of some readily visible terrain characteristics, for example lithology, geological formations, topological features, and associated hydrologic characteristics [1-2]. Therefore, interrelationships between these factors are necessary. Satellite data is becoming more commonly used in the investigation of ground water due to its ability to recognize and state various terrain characteristics that can act as prominent indicators of the existence of subsurface water. The presence of groundwater in rocky terrain is constrained, and its existence is mostly restricted to deformational and altered zones, despite being a dynamic and repressible natural resource [3]. Consequently, it is vital to integrate the terrain landscapes, with an aid of geospatial techniques. As a result, hydro-geomorphological characteristics are effectively studied to recognize the ground water potential zones in the Kanakapura watershed [1, 3-4].

Geologically the Kanakapura watershed is in a hard rock region. While the groundwater resources are well investigated, the subaerial water resources in this area are insufficient to suit the demands of the locals [5]. Geospatial data is widely used to delineate the terrain features as structural, geomorphic and hydrologic features in order to recognize the ground water prospective zones. Understanding the origins, presence, and flow patterns of subterranean water which are either straightly or circuitously influenced by the features of the terrain is necessary for both its exploration and consumption [6]. Effective potential zones are identified by analyzing remotely sensed data of the various terrain characteristics in an integrated manner. Similar efforts have been made to create a variety of thematic maps for delineating the subterranean water prospective zones around the nation [7-9]. The Study of water resources has been given new directions with the application of geospatial technologies. User-specific administration and integration of several thematic data are made possible by geographic information systems [10-11].

The recent advancement in the geospatial field has given new dimension to understand the potentials of hydrological, hydrogeological and ecological studies [11]. The detailed prospecting and mapping of different hydro geomorphic units are recorded and effectively presented. The different hydro geomorphic units are Channel Island, Denudational hills, Inselberg, moderately weathered pediplains, Pediment Inselberg complex, Pediments, Residual hills, Shallow weathered pediplains, Structural hills and Valley fills mapped using satellite imagery data based on standard visual interpretation techniques as prescribed by Lillesand and Kiefer, 2002 [12]. The elementary interpretation keys of hydro geomorphic units are recognized using sentinel II satellite data. The Slope derived from DEM data interpreted for each sub watershed. There were different ground water prospects zone like very good to good, good to moderate, moderate to poor and poor to very poor had been evaluated. Fig. 1 depicting the methodology used for evaluation of ground water prospect zones [13-14].

2. Material and Method

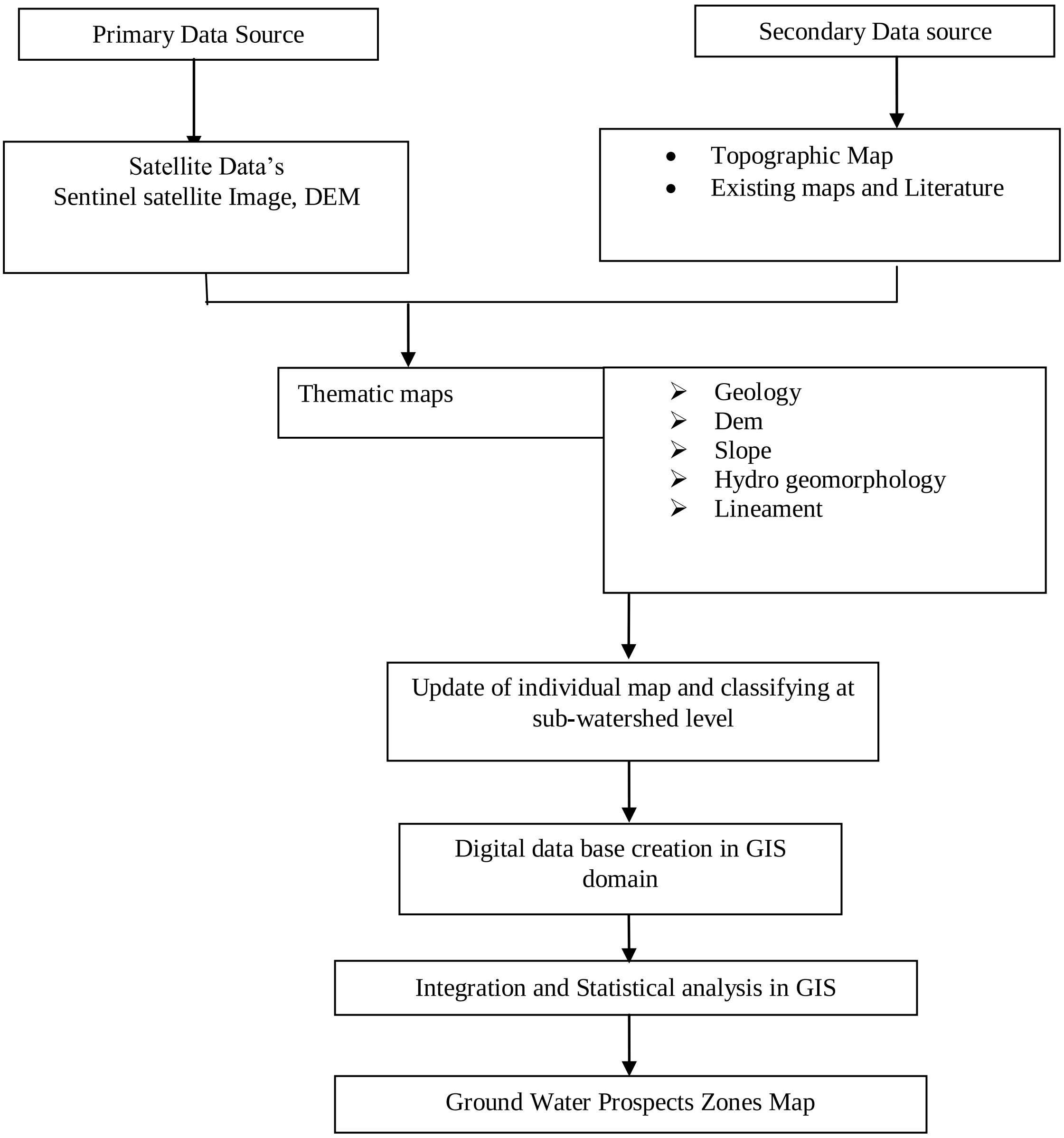

Fig.1: Flow chart portraying the methodology used for evaluation of ground water prospect zones

3. Objective

The objective of the hydrogeomorphological study of the Kanakapura watershed with the aid of Geo-Spatial Platform was to investigate and delineate the ground water prospects zone in the study area. The study aimed to identify the hydrogeomorphological characteristics of the Kanakapura watershed using spatial analyst tools on sentinel 2 satellite image. Classifying lineaments in the study area based on their length and density, and integrate them with other thematic layers to produce a groundwater potential zone map. Suggested valuable insights into the hydrogeomorphological characteristics of the study area and highlight the importance of using Geo-Spatial platforms in such investigations to facilitate the development of sustainable groundwater management strategies.

4. Geology

Kanakapura watershed forms a part of the Archean high grade gneiss terrain of Karnataka and is located just north of the main Biligirirangana hill Charnokite massif (79.38 Sq.km). The area lies immediately to east of the eastern margin of the Clospet granite. The area lies in transition zone between granulites and amphibolite facies rocks [15-16]. The eastern part consists largely of amphibolite facies Peninsular gneisses. Western part of the study area comprises principally of Closepet granite (549.93 Sq.km) with Peninsular gneisses (185.26 Sq. km) and quartzite bands (1.577 Sq.km).

5. Hydrogeomorphological Analysis

Hydrogeomorphology deals with the morphological characteristics of the earth, rocks, and water. Geomorphological factors and hydrological traits have a significant inverse relationship. Surface and groundwater regimes are also susceptible to this interaction. The hydrogeomorphological behavior can be easily understood by connecting geomorphological factors with basin-level hydrological features.

Hydrogeomorphology has been applied in a numerous way with reference to GIS and additional methodologies in recent years, and it has shown to be a effective tool for analyzing and ranking potential natural resource management strategies. Due to the spatial character of natural resource management issues, GIS technology offers a tool for determining the scope of the issue and makes it easier to plan and implement various management solutions. The hydrogeomorphological characteristics of the watershed are estimated using the GIS, and these results may be utilized for sub-watershed planning and management. The study's findings may be used to extrapolate the region's hydrological aspects, such as infiltration, ground water recharge, and runoff potential.

In the current study, ground water potential zones were marked off by the definition of hydrogeomorphic units. In this study field, hydrogeomorphic units are combined with geological data, which is thought to be a highly helpful strategy for creating unified hydrogeomorphological plots that target subsurface water. By breaking down the watershed into different hydrogeomorphic components, such as hills, valleys, ridges, and floodplains, the map can help to inform land-use planning, water resource management, and other applications. The research area's distinct geomorphic units' image features are shown. The different hydrogeomorphic units are represented in Table-1 (area statistics in Sq Km) and Table-2 (area statistics with % wise) respectively. The hydrogeomorphic map of Kanakapura watershed is represented in the Fig.2. All the hydrogeomorphic units are graphically represented with respect to an area in Fig.10.

Results and Discussion:

Channel Island: In the study area the channel island covers an area 0.129 sq.km found closed to the present course of Cauvery River in the form of channel bars and sand bars with respect to the Bannimukudlu, Bennagodu, and Madarahalli sub-watersheds.

Denudational hills: Denudation rate and kind are greatly influenced by tectonic movements. The absolute and relative heights steadily decrease, and the relief is generally levelled down, as the processes of fragmentation and denudation outweigh the influence of a structural high. The long-term dominance of denudation processes can cause whole peaks to become undulating denuded lowlands [17].

Due to the buildup of weathered material seen in Fig.2, denudational mounts consist of extensively broken Closepet granites enclosed with large boulders and scant flora. These mounts are distinguished by solitary terrain masses with abrupt to blunt antiformal lines, craggy tops, and olive green colour upright on undulating topography. The likelihood of subsurface water occurrence is low since the lithological compositions of charnockite are found as an incessant range of varied heights that serve as runoff zones. Here joints, fractures and shear zones act as recharge zone. Denudation hills are presents in all sub-watersheds. The Kodihalli Sub-Watershed has the most area, 69.71 sq km, and the Maralebbekupe Sub-Watershed covers the least, 6.88 sq km.

Residual hills: The revelations of Closepet granite occurs as enduring hills restrained to seven sub-watersheds ranging maximum of 5.12 sq.km in Kodihalli sub-watershed (Fig.3) and minimum 0.36 sq.km in Horalagallu sub-watershed. Due to differential erosion, this results in solitary hillocks with steep slopes ranging from moderate to extremely steep. However, they are still there as small mounds [5,18-19].

Structural hills: Structural hills are rectilinear or arched unveiling trend lines of mountain ranges They are mechanically regulated by intricate folding, faulting, and a network of joints and cracks that primarily serve as run-off regions and allow for some penetration. Only the Bannimukudlu sub-watershed hosts this unit, which has a 19.65 sq. km. coverage area. (Fig.4) [5].

Inselbergs: Only the Kodihalli, Horalagallu, Maralebbekupe, Madarahalli, and Mudagod subwatersheds have these geomorphic units, which range in size from 0.10 sq.km to 0.36 sq.km. They appear as small, rounded, smooth, or rocky hills

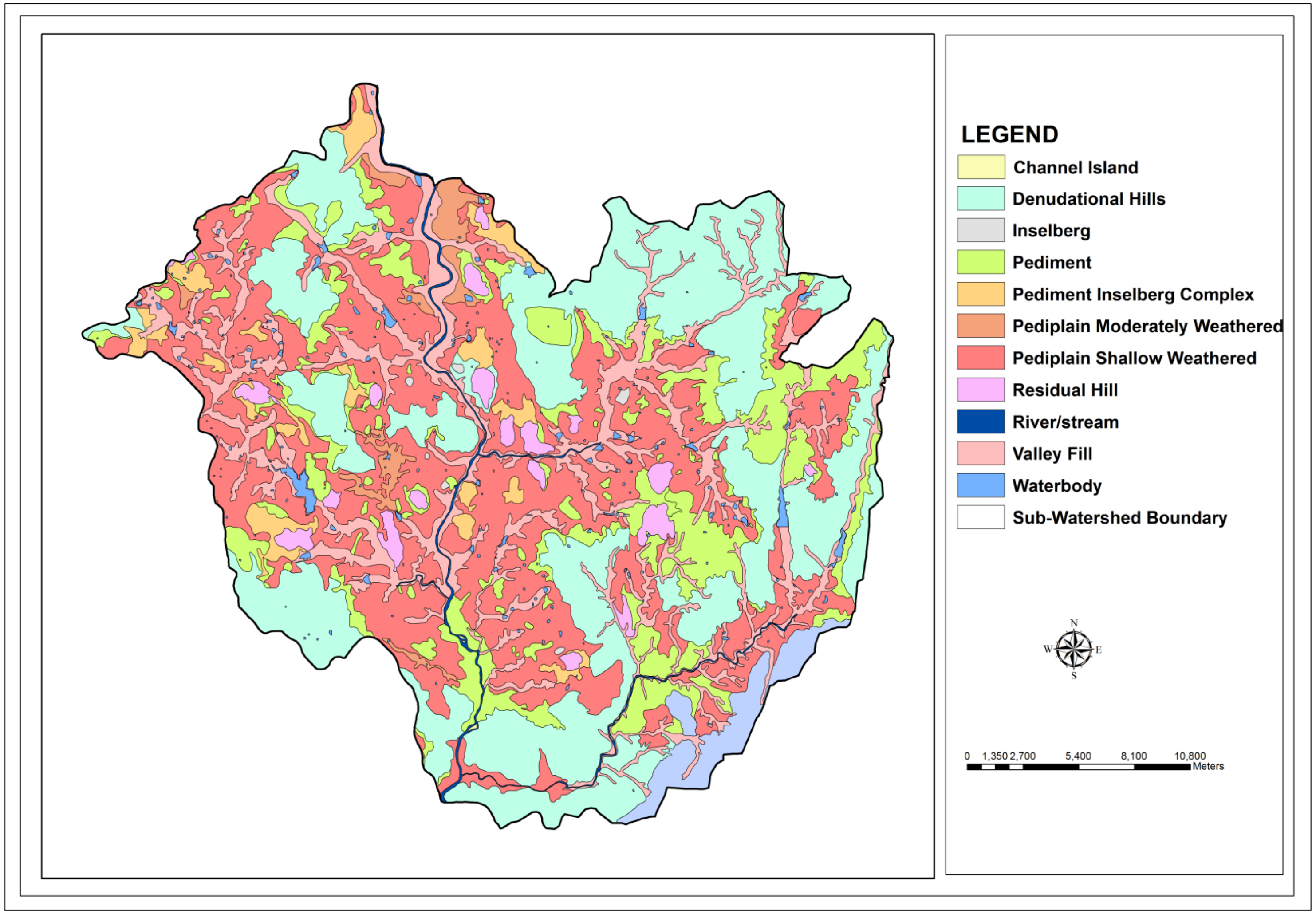

Fig.2: Hydrogeomorphic map of the Kanakapura Subwatersheds

that are elevated above the surrounding pediplains (Fig. 5). From the ground water point of view, this unit is treated as aquifuge in nature neither contains nor transmits ground water [3,8,20].

Pediment: They display dark to intermediate grey tone and coarse to medium texture in the satellite imagery. A characteristic Pediment landscape is created by the river and watercourses that have carved gorges and terraced across the undulating and low plateau like drift deposits [21-22]. On FCC, this unit exhibits dotted outcrops and exhibit light brown tone over Charnockite and gneissic rocks. It is predicted that the sort of underlying folded structures, the fracture system, and the degree of weathering would all affect the subsurface water condition in this unit [7]. Groundwater exploration can be prospected for in Pediments since there is potential for groundwater movement there. Pediment covers an area 104.98 sq.km and noticed in the all subwatersheds (Fig.6) except in Gadasahalli sub-watershed. The area ranges varies between 2.42 sq.km in Maralebbekupe) to 36.64 sq.km in Bannimukudlu.

Pediment Inselberg Complex: The Pediment is an inaccessible hilltop that emerged near Dodda Alahalli through denudation and weathering of the Closepet granite. Field photograph Fig.7 showing the Pediment Inselberg complex. They are composed of rocky terrain with hills and sheet rock [5]. aquifer possibilities in this unit are restricted to the fissures of the Pediment section and operate as run-off regions in this unit. This is observed only in the six subwatersheds except Bannimukudlu and Bennagodu. Maximum units observed in Dodda Alahalli is about 10.98 sq.km and minimum observed in Horalagallu is about 0.73 sq.km. Ground water prospects are poor in this unit [11,14,23].

Pediplains: Generally speaking, this region is made up of pediplains, which are broad, gently undulating plains that are frequently interspersed with inselbergs created by the coalescence of numerous pediments. The research region is classified as hard rock terrain, therefore pediplains make excellent recharge and storage zones. This also depends on the composition, environments for recharging, and thickness of the collected resources due to weathering and accretion [20, 24].

Moderately Weathered Pediplains: The unit's ground water possibilities range from fair to excellent. When coupled with fractures/lineaments in this geomorphic unit, excellent yields are anticipated [23]. These geomorphic units are often located in the topographically lowland regions and related with the torrent courses, hence good recharging of subsurface water is anticipated in these geomorphic parts. This type is observed in five sub-watershed highest 5.85 sq.km in Mudagod and least 0.54 sq.km in Dodda Alahalli and completely absent in Bannimukudlu, Kodihalli and Maralebbekupe (Fig 8).

Shallow Weathered Pediplains: This layer, which has a thickness that ranges from 5 to 20 metres and is highly worn, was originally found as large stretches of sparsely vegetated highland terrain. This is the furthermost prevalent geomorphic unit, covering a sizable portion of the studied region. These often reside in relatively high areas and are sporadically connected to fractures or lineaments. Groundwater yields in these strata are predicted to be poor to modest. (Vijay Kumar et al., 2009). On a standard FCC picture, it shows a light yellow to greenish tone and is exposed in all sub-watersheds, ranging in size from 59.62 to 1.17 sq. km, with the highest and least areas being found in Dodda Alahalli and Gadasahalli, respectively [5].

Valley Fills: These areas have the lowest elevations and a fairly flat slope (Fig. 9). Ground water can be recharged and discharged in this location. A significant infiltration rate is produced by the valley fills, which are found along stream channels and vary in thickness and composition between colluvial and alluvial sediments. On standard satellite image it appears as reddish tone or some time dark greenish blue tone. The Bannimukudlu subwatershed has the largest size, measuring 25.99 sq km, and the Bennagodu subwatershed has the smallest area, at 0.6 sq km. (Table-1) [7,25].

6. Lineament Analysis

According to their length, lineaments in the current study are divided into three categories: minor, moderate, and large lineaments. Minor lineaments represents if the length less than or equal to 1.5 km are smaller and Intermediate lineaments various between the range of length >1.5 <4 km and major lineaments are greater than 4km respectively (Table-3).

Fig.3: Field photograph showing Denudational hill with Closepet granite and dense vegetation noticed near western side of Dodda Alahalli sub-watershed.

Fig-4: Field photograph showing Residual hill with Closepet granite , big boulders and sparse vegetation noticed near eastern side of Kodihalli sub-watershed.

Fig-5: Field photograph showing Structural hill consisting of hill ranges with highly Fractured Closepet granite with big boulders and sparse vegetation noticed near eastern side of Bannimukudlu sub-watershed.

Fig.6: Field photograph showing inselberg having moderate to steep slope formed due to differential erosion in Madarahalli sub-watershed.

Fig.7: Field photograph showing pediment consisting of granitic rocks with gentle slopes noticed near Mudagod Sub-watershed.

Fig-8: Field photograph showing pediment Inselberg complex developed in Closepet granitic rocks near Dodda Alahalli Sub-watershed.

Fig-9: Field photograph showing moderately weathered pediplains with thickness of more than 20 meters located Gadasahalli sub-watershed.

Fig.10: Field photograph showing shallow weathered pediplains with nearly level to gentle slope representing the weathered zones underlain by gneisses / granites located Madarahalli sub-watershed.

Bannimukudlu subwatershed consists of 116 lineaments having the sum length of 116 km of minor lineaments are about 71 % and intermediates are about 29%, with total length of 134.85 km. Two major lineaments are observed in the Dodda Alahalli subwatershed, total lineaments present in this subwatershed is 75 with the length of 157.35 Km and. Kodihalli subwatershed consists 108 lineaments with total length of 123.97 km. Mudagod subwatershed consists of 1 major lineament and 24 minor and 5 intermediate lineaments. The entire study area sub-watersheds showed that the good pathways for groundwater movement and storage. Bennagodu, Gadasahalli, Horalagallu, Madarahalli and Maralebbekupe consist of total no of lineaments are 20, 19, 46, 23, 21, 30 respectively. Integrated map of hydrogeomorphic units, lineaments and bore well's location of Kanakapura watershed are well represented.

Table-1: Subwatershed wise area statistics in (sq.km) for each hydrogeomorphic units

Sub-watershed	GEOMORPHIC UNITS IN SQ.KMS									
	Channel Island	Denudational hill	Inselberg	Pediment	Pediment Inselberg Complex	Moderately weathered pediplain	Shallow weathered pediplain	Residual hill	Structural hill	Valley fill
Bannimukudlu	0.08	84.81	0	36.64	0	0	42.45	2.65	19.65	25.99
Bennagodu	0.01	7.28	0	4.56	0	0.9	11.63	0	0	0.6
Dodda Alahalli	0	24.87	0.1	13.11	10.98	0.54	59.62	4.6	0	24.56
Gadasahalli	0	8.65	0	4.33	3.11	1.17	6.57	0	0	5.86
Horalagallu	0	18.32	0.13	8.66	0.73	0.833	29.74	0.36	0	13.06
Kodihalli	0	69.71	0.36	26.68	1.02	0	44.76	5.12	0	24.53
Madarahalli	0.02	8.66	0.123	8.95	3.43	35.52	35.52	0.68	0	9.1
Maralebbekupe	0	6.88	0.173	2.42	0.24	4.07	15.45	1.72	0	3.59
Mudagod	0	10.87	0.2	3.93	6.03	5.85	14.35	3.65	0	6.45

Table-2: Subwatershed wise area statistics in (%) for each hydrogeomorphic units

Sub-watershed	GEOMORPHIC UNITS IN %									
	Channel Island	Denudational hill	Inselberg	Pediment	Pediment Inselberg Complex	Moderately weathered pediplain	Shallow weathered pediplain	Residual hill	Structural hill	Valley fill
Bannimukudlu	0.04	39.95	0	17.26	0	0	20	1.25	9.26	12.24
Bennagodu	0.04	29.14	0	18.25	0	3.6	46.56	0	0	2.4
Dodda Alahalli	0	17.97	0.07	9.47	7.93	0.39	43.08	3.32	0	17.75
Gadasahalli	0	29.13	0	14.58	10.47	3.94	22.13	0	0	19.74
Horalagallu	0	25.5	0.18	12.06	1.02	1.16	41.4	0.5	0	18.18
Kodihalli	0	40.49	0.21	15.5	0.59	0	26	2.97	0	14.25
Madarahalli	0.02	8.49	0.12	8.77	3.36	34.82	34.82	0.67	0	8.92
Maralebbekupe	0	19.92	0.5	7.01	0.69	11.78	44.73	4.98	0	10.39
Mudagod	0	21.18	0.39	7.66	11.75	11.4	27.96	7.11	0	12.57

6.1 Lineament Density:

The overall length of the lineaments per unit area was used to compute the lineament density for the studied region. (Edet et al., 1998) represented in Fig. 11 and area statistics shown in the Table-3. Lineament density for this investigation was divided into three equal interval classes: low (<0.833 km/km2), medium (0.833-1.666 km/km^2), and high (>1.666 km/km2). The Northeastern and Southeastern sides of the basin have the uppermost lineament density (>1.666 km/km2), whereas the bulk of the basin has the lowermost lineament density (0.833 km/km2) [26-27]**.**

For this investigation, lineament density was divided into five equal interval groups. Lineament densities of Very low (42.19%), Low (26.52%), Moderate (18.88%), High (9.2%), and Very High (3.11%) were assigned to the identified lineaments. Over the whole basin, the Very low and Low zone is most frequently observed [18].

Due to lineament concentrations being higher in the research area's northwest and southeast, high levels of lineament density were observed, suggesting considerable groundwater potential (Fig. 11) [28-30].

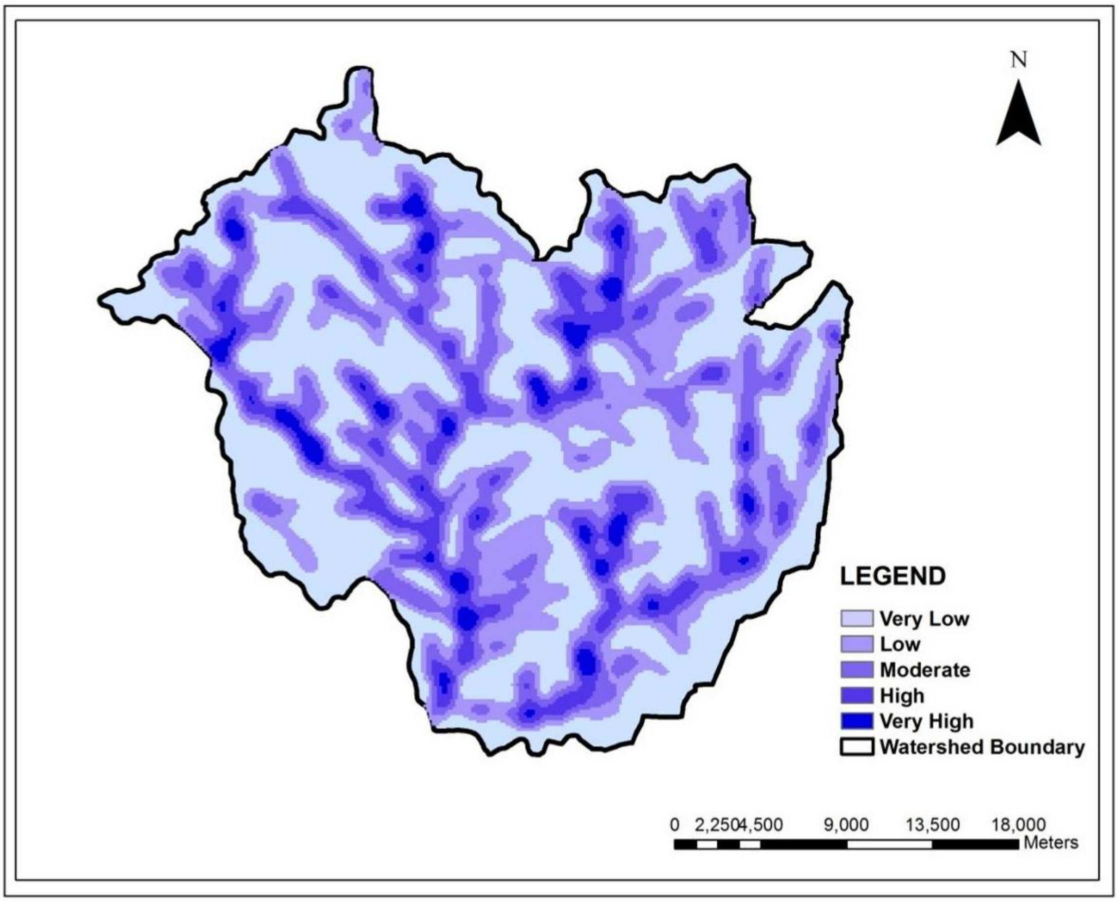

Fig. 11: Lineament density map of the Kanakapura watershed

Table 3 Lineament density area statistics of the subwatershed of Kanakapura watershed

Sub-watershed	Lineaments density km/km2		
	Low	Medium	High
Bannimukudlu	132.69	65.18	17.53
Bennagodu	14.03	8.35	3.25
Dodda Alahalli	80.67	52.94	7.67
Gadasahalli	22.34	6.24	1.60
Horalagallu	44.53	24.90	4.01
Kodihalli	95.96	63.95	14.08
Madarahalli	33.10	30.92	3.86
Maralebbekupe	21.60	10.82	2.70
Mudagod	32.07	19.45	1.16

7. Conclusion

Objective of the present study is the integration of numerous thematic layers for example geology, geomorphology, and lineament was carried out with an aid of geospatial techniques for the evaluation of ground water prospect zones for the research region. From the obtained results, southern half of the study area are highly efficient for subsurface water resources compared to the upper middle basin and the north-northeast portion of the basin, which was evident from Fig.12. These findings were further verified through field observations. The data obtained from the analysis is noteworthy for the advanced study of groundwater resources in the research area.

It is broadly divided into four categories, namely extremely poor to poor, poor to modest, modest to decent, and decent to excellent, and marked for each sub-watershed. Based on the unified groundwater potential zone map, valley fills and subtly weathered pediplains in the Kanakapura watershed are classified as excellent groundwater prospect zones, while shallowly weathered pediplains are categorized as fair to modest. The Pediment Inselberg complex and Pediments are classified as modest to meagre, and Denudational, residual hills, and Inselberg are considered to be extremely deprived regions.

From the above study, the largest area of excellent groundwater potential zone is observed in Bannimukudlu sub-watershed (26.07 sq.km) and the least one is in Bennagodu sub-watershed (0.61 sq.km). The area and percentage of each groundwater prospect zone for all sub-watersheds are systematically presented in Tables 4 and 5. Table 6 summarizes the combined results of lithounits and hydrogeomorphic units, with regard to groundwater prospects.

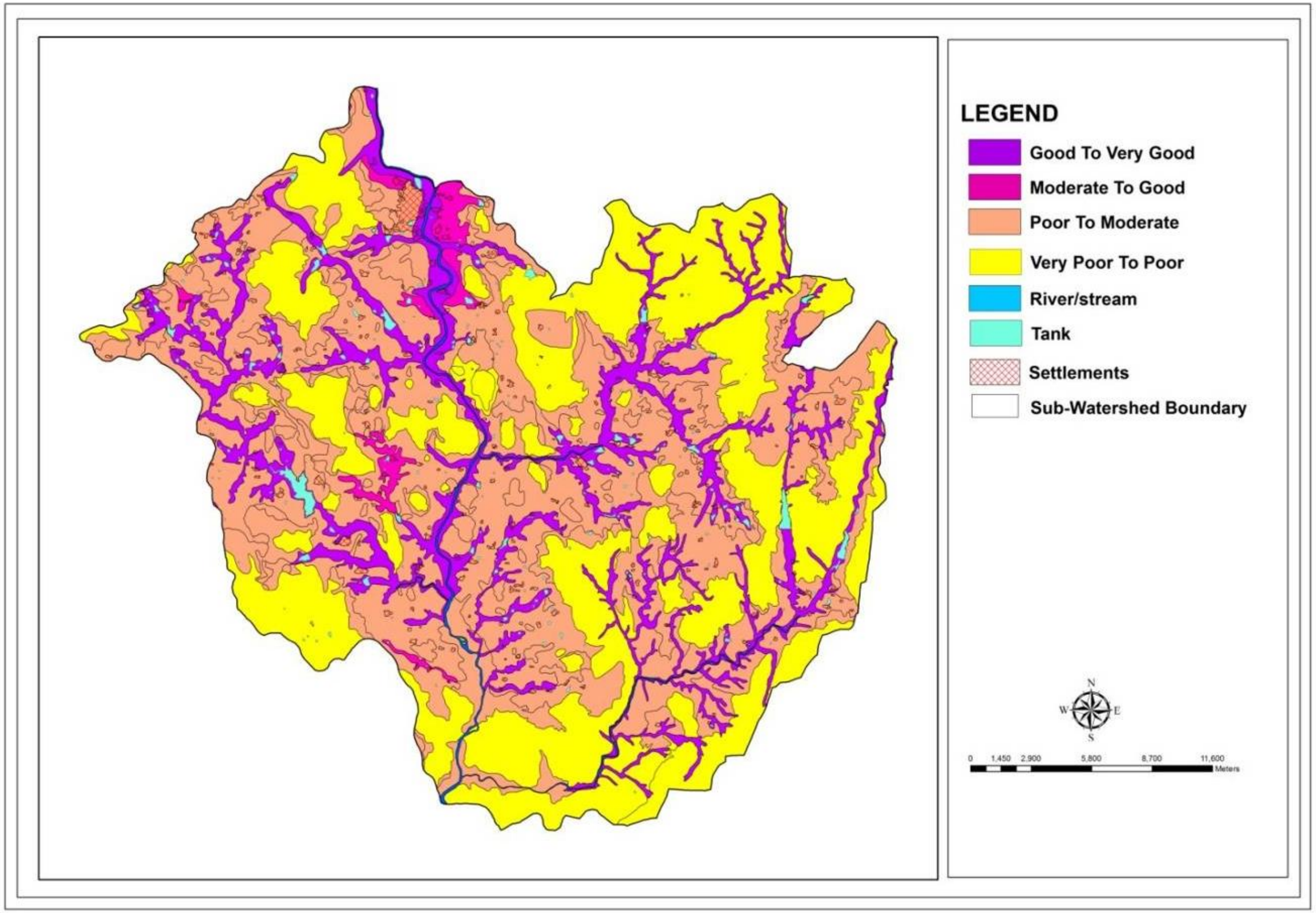

Fig.12: Ground water prospects map of the Kanakapura subwatershed

Table-4: Subwatershed wise area of ground water prospect zones in sq.kms

Sub-watershed	AREA OF GROUND WATER PROSPECT ZONES IN SQ.KMS			
	Good to Very Good	Moderate to Good	Poor to Moderate	Very poor to Poor
Bannimukudlu	26.07	0	79.09	107.12
Bennagodu	0.61	0.9	16.2	7.28
Dodda Alahalli	24.56	0.54	83.71	29.58
Gadasahalli	5.86	1.17	14.02	8.65
Horalagallu	13.06	0.83	39.14	18.82
Kodihalli	24.53	0	72.48	75.2
Madarahalli	9.12	0	47.91	9.47
Maralebbekupe	3.59	4.07	18.12	8.77
Mudagod	6.454	5.85	24.32	13.72

Table-5: Subwatershed wise area of ground water prospect zones in sq.kms

Sub-watershed	AREA OF GROUND WATER PROSPECT ZONES IN %			
	Good to Very Good	Moderate to Good	Poor to Moderate	Very poor to Poor
Bannimukudlu	12.28	0.00	37.26	50.46
Bennagodu	2.44	3.60	64.83	29.13
Dodda Alahalli	17.75	0.39	60.49	21.37
Gadasahalli	19.73	3.94	47.21	29.12
Horalagallu	18.18	1.16	54.47	26.19
Kodihalli	14.24	0.00	42.09	43.67
Madarahalli	13.71	0.00	72.05	14.24
Maralebbekupe	10.39	11.78	52.45	25.38
Mudagod	12.82	11.62	48.31	27.25

Table - 6: Integrated result of lithounits and hydrogeomorphic units of the study area [31]

Geological Sequence/ Rock types	Geomorphological Unit	Ground Water Prospects	Remarks
Dyke rigde	-		Act as a ground water barrier.
Closepet Granite	Valley Fill	Excellent	Good Prospects further development of ground water is recommended..
	Pediplain shallow weathered	Moderate	Success rate of wells are moderate at contact of weathering and massive rock . Good at the fractures/Lineaments
	Pediplain moderately weathered	Good	Weathering not uniform, generally casing is required. Prospects are inferred.
	Pediment	Limited	Act as run off zone
	Inselberg	-	Run off zone not suitable for ground water development
	Pediment Inselberg Complex	-	Prospects limited to fracture zone in the pediment area
	Denudation Hill	-	Mainly act as run off zone, Prospects limited to valley portions only
	Residual hill	-	Mainly act as run off zone
	Structural hill	-	Mainly act as run off zone
Peninsular Gneisses	Valley Fill	Excellent	Good Prospects further development of ground water is recommended.
	Pediplain shallow weathered	Moderate	Better prospects along fracture zone
	Pediplain moderately weathered	Good	Weathering not uniform, generally casing is required. Prospects are inferred.
	Pediment	Limited	Act as run off zone
	Denudation Hill	-	Mainly act as run off zone, Prospects limited to valley portions only
	Structural hill	-	Mainly act as run off zone
Charnokite	Valley Fill	Excellent	Good scope for ground water development and recharge
	Pediplain moderately weathered	-	Weathering not uniform, generally casing is required. Prospects are inferred
	Pediplain shallow weathered	-	Better prospects along fracture zone
	Pediment	-	Act as run off zone
	Pediment Inselberg Complex	-	Prospects limited to fracture zone in the pediment area
	Residual hill	-	Mainly act as run off zone

References

1. Kamaleshwar Pratap, Groundwater prospect zoning using remote sensing and geographical Information System: Case study in Dala-Renukoot area, Sonbhadra district, Uttar pradesh, India J. Geol. Soc. India, v.28 No 4 pp. 250. (2000)
2. Anji Reddy Mareddy. "Baseline data and environmental setting" , Elsevier BV. (2017)
3. Kamal Raj et. al., and Targeti, N.G. Ground water in tribal dominated bonai Area of Drought- Prone sundargarh district, Orissa, India- A combined Geophysical and Remote Sensing Approach.J.Hum.Ecol.,v.20(2), pp.109-115. (2006)
4. Debajani Basumatary, Madan Kumar Shankar, Kullaiah Byrappa, Kandarpa Kumar Saikia et al. "Polymorph of transdichlorotetrakis(pyridine-N)ruthenium(II) influenced by a dihydrazone: crystal structure, spectral, Hirshfeld surfaces, antimicrobial, toxicity andin silicodocking studies" , Journal of Chemical Sciences. (2020)
5. Sankar, K. Evaluation of groundwater potential zones using remote sensing data in upper Vaigai river basin, Tamil Nadu, India J. Geol. Soc India v. 30, pp. 119. (2002)
6. M A Khan, P C Moharana. Use of remote sensing and geographical information system in the delination and charaterization of ground water prospect zones J. Geol. Soc India, v. 30 No 3, pp. 165. (2002)
7. Girish Gopinath, and Seralathan, P. Identification of groundwater prospective zones using LISS III and pumping test methods. Photonirvachak, J. Indian Soc. Remote Sensing, v. 32 (4) pp. 329-342. (2004)
8. Sethupathi, A.S., Lakshmi Narasimhan, C., and Vasanthamohan, V. Evaluation of hydrogeomorphological landforms and lineaments using GIS and Remote Sensing techniques in Bargur – Mathur subwatersheds, Ponnaiyar River basin, India. International Journal of Geomatics and Geosciences, v. 3, No 1. (2012)
9. Selvarani, A. Geetha, G. Maheswaran, and K. Elangovan. "Evaluation of groundwater potential zones using GIS and remote sensing in Noyyal Basin, Tamil Nadu, India" , International Journal of Environmental Technology and Management. (2014)
10. S Das, S C Behera, A Kar, P Narendra, S Guha. "Hydrogeomorphological mapping in ground water exploration using remotely sensed data — a case study in keonjhar district, orissa" , Journal of the Indian Society of Remote Sensing. (1997)
11. Murthy, K.R.S., Amminedu, E., and Venkateshwara Rao, V. Integration of thematic maps through GIS for identification of ground water potential zones J. Geol. Soc. India, v. 31 No 3, pp. 197. (2003)
12. Hossam H. Elewa, Ahmad M. Nosair, Elsayed M. Ramadan. "Chapter 9 Sustainable Development of Mega Drainage Basins of the Eastern Desert of Egypt; Halaib–Shalatin as a Case Study Area" , Springer Science and Business Media LLC. (2020)
13. Lillesand, T.M., and Kiefer, R.W. Remote Sensing and Image Interpretation. John Wiley & Sons (ASIA) Pte Ltd, Singapore. (2002)
14. Srinivasa Vittala, S. Integrated hydrogeological, remote sensing and GIS studies of watersheds around Pavagada Tumkur district, Karnataka, South India" Ph.D Thesis, University of Mysore. (2005)
15. Srinivasa Vittala, S., Govindaiah, S., and Honnegowda, H. Evaluation of groundwater potential zones in the sub-watersheds of North Pennar river basin around Pavagada, Karnataka, India using Remote sensing and GIS techniques. Jour. Ind. Soc. Remote Sensing, v. 33(4), pp.483-493. (2006)
16. Condie, K.C., Allen, P., and Eason, J. Geochemistry of the Archaean low to high grade transition zone, southern India. Chem. Geol. v.11, pp. 223-229. (1982)
17. Radhakrishna, B.P. Archaean granite-greenstone terrain of south India Sheild. In: S.M.Naqvi and J.J.W.Rogers(Eds.). Precambrian of south India, Mem. Gelo.soc. India, no.4, pp. 1-46. (1983)
18. Narendra, K., Nageswara Rao, K., Swarna Latha, P. Integrating Remote Sensing and GIS for Identification of Groundwater Prospective Zones in the Narava Basin, Visakhapatnam Region, Andhra Pradesh, Journal Geological Society Of India , v.81, pp.248-260. (2013)
19. Thornbury.W.D. Principle of Geomorphology. Wiley Eastern Limited, New Delhi, pp. 594. (1990)
20. Pushpavathi, K.N., and Basavarajappa, H.T. Mapping of geological and geomorphological land forms of Chamrajnagara taluk, Karnataka,India by remotesensing and GIS techniques, Environmental Geochemistry, v.12, No.1&2, pp.13-18. (2009)
21. Mukhpadhya, S.C. Basinal characteristics of the middle Torsa basin. Indian J. Landscape System and Ecol. Studies, v.2(2), pp.105-120. (1994)
22. M M Jana. "Application of remote sensing in the study of geomorphic processes and lanforms in piedmont zone of Darjeeling SubHimalaya", Journal of the Indian Society of Remote Sensing. (03/2002)

23. Vijay Kumar, J., Suresh, M., and Venkat Reddy, D. Application of Remote sensing Data for Delineation of Groundwater Potential Zones in Solipur Vagu Sub-Basin of Kongal River Nalgonda District, Andhra Pradesh, India. International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Vol. 02(02), pp. 120-124. (2009)
24. Hema H. C., Govindaiah S, Lakshmi Srikanth, HJ Surendra. "Prioritization of sub-watersheds of the Kanakapura Watershed in the Arkavathi River Basin, Karnataka, India- using Remote sensing and GIS" , Geology, Ecology, and Landscapes. (2020)
25. Agarwal, and Garg. Textbook on Remote Sensing In Natural Resources Monitoring and Management. Wheeler Publishing, pp.213. (2000)
26. Mohamad Abd Manap, Wan Nor Azmin Sulaiman, Mohammad Firuz Ramli, Biswajeet Pradhan, Noraini Surip. "A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia" , Arabian Journal of Geosciences. (2011)
27. Indrani Mukherjee, Umesh Kumar Singh. "Delineation of groundwater potential zones in a drought-prone semi-arid region of east India using GIS and analytical hierarchical process techniques" , CATENA. (2020)
28. Pradeep K Jain. "Remote sensing techniques to locate ground water potential zones in upper Urmil River Basin, district Chhatarpur — Central India" , Journal of the Indian Society of Remote Sensing. (1998)
29. N. Lokesha. "Hydrogeomorphological studies in kallambella watershed, Tumkur District, Karnataka State, India Using Remote Sensing and GIS" , Journal of the Indian Society of Remote Sensing. (03/2007)
30. Shashank Shekhar, Arvind Chandra Pandey. "Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques", Geocarto International (2014).
31. Sitangshu Chatterjee, Archisman Dutta, Ramesh Kumar Gupta, U.K. Sinha. "Genesis, evolution, speciation and fluid-mineral equilibrium study of an unexplored geothermal area in Northeast Himalaya, India" , Geothermics.(2022)